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Tsuko Nakamura
Wayne Orchiston *Editors*

The Emergence of Astrophysics in Asia

Opening a New Window on the Universe

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Preface

You can see on the Internet an organization on the history of astronomy in Asia called the *International Conference on Oriental Astronomy* (ICOA). The concept of this organization was initially proposed by Professor Nha Il-Seong from Yonsei University in Korea, and the first meeting (ICOA-1) was held in Seoul in 1993 and was organized by Professor Nha and Professor Richard Stephenson from Durham University in Britain. Since 1993, ICOA conferences have been held about every 3 years, and thus far there have been nine successful meetings, and proceedings have been published (or are in the process of being published) for each one.

At the ICOA-6 meeting, which was held in July 2008 at James Cook University in Townsville, northern Australia, one of the editors of this book (T.N.) presented a paper on "The Emergence of Modern Astronomy and Astrophysics in Japan". Soon after returning home from the conference, the idea came to him that the theme of his talk was not specific to his country but also was equally relevant to the history of astronomy in other nations in Asia. He noted that the introduction of modern science and technology only took place in many Asian countries after WWII. Previously they had been colonized by European or Japanese powers, so it seemed to him that the emergence of astrophysics in Asia would be worth pursuing from an international perspective since it was very different to that experienced in many European and North American countries. After discussing the concept with the second editor (W.O.) and gaining his wholehearted support, the two editors invited ICOA-related people to contribute papers describing the development of astronomy and emergence of astrophysics in different Asian countries. As a result, this book eventually took shape.

Although the central concept of this book was reasonably straightforward, the editorial processes proved challenging, and it took years before all of the national overview chapters were written. One of the reasons for the delay in publication related to the differences in the process of 'modernization' that existed in the West and in the East. During the eighteenth and nineteenth centuries, the development of science and technology in central Europe and the USA proceeded roughly in parallel with the formation of modern states and nationalism, so the transition from the so-called 'classical astronomy' to the 'new astronomy' (astrophysics) in these countries proceeded relatively smoothly and at about the same time, perhaps because of shared knowledge and regular communication between astronomers.

However, the situation in Asia was quite different, and varied from country to country. In the case of Japan, for example, the process of modernization was similar to that experienced in the West. Consequently, the emergence of astrophysics in Japan also occurred gradually and similarly, but with a delay of one century relative to European nations, following the early introduction of Western classical astronomy. On the other hand, some other Asian countries walked very different historical paths. In the past they had only their own traditional indigenous astronomical systems, and/or the old calendrical astronomy inherited from ancient China or India. Then after WWII, advanced astronomical instruments and astrophysical knowledge developed in Europe and the USA suddenly flooded into these countries. Therefore, some astronomers found it hard to accept that the emergence of astrophysics had made any meaningful impact on the history of astronomy in these countries.

Consequently, as editors we spent a lot of time and effort requesting rewrites of some chapters or substantially revising them ourselves. Despite this, some readers still may feel that there is an inhomogeneity of descriptions in comparison to similar books about the history of astronomy in the Western world. Readers should understand that this mainly reflects the different historical paths that Asian countries have followed.

Itabashi, Tokyo, Japan Tsuko Nakamura
Chiang Mai, Thailand Wayne Orchiston

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Chapter 1
Introduction

Tsuko Nakamura and Wayne Orchiston

1.1 The International Emergence of Astrophysics

1.1.1 The Emergence of the Term 'Astrophysics'

During the last four decades of the nineteenth century astronomy underwent an observational, experimental and theoretical revolution as the long-entrenched classical (positional) astronomy was replaced by the 'new astronomy' known as astrophysics (e.g., see Clerke 1903; Herrmann 1984; Meadows 1984a, b, c). The Oxford English Dictionary (2000 edition) mentions that the first use of the term 'astrophysics' appears in the book *Midnight Sky*…, which was published in 1869 by the Royal Observatory Greenwich astronomer Edwin Dunkin (1821–1898; W.G.T. 1899).[1] In reality, however, this book does not use 'astrophysics' as a single word, but instead adopts 'astronomical physics' at least twice, in the preface and in the sixth chapter. Hence it seems that the term 'astrophysics' evolved from 'new astronomy' → 'astronomical physics' → 'astrophysics' during the second half of the nineteenth century (Nakamura and Okamura 2011: Chapter 9).

Astrophysics involved a marriage of spectroscopy, photography and photometry. Gone was that notoriously unreliable photon-counter, the human eye. Gone, too,

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[1] Hereafter unless explicitly mentioned, the birth and death years of historical individuals are taken from Hockey et al. (2014).

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was that preoccupation with celestial mechanics. Instead, astrophysics was concerned with

> … the physical characteristics of celestial bodies, that is, their luminosity and spectroscopic peculiarities, their temperature and radiation, the nature and condition of their atmosphere, surface, and interior, their qualitative and quantitative composition, and finally all the phenomena arising from these physical conditions. (Abetti 1954: 181).

Thus, astrophysics focused on patterns, processes and mechanisms; on changes through time; and on interrelations. It was largely non-descriptive, and emphasized the dynamic rather than the static. In the following subsections, we outline briefly the early history of the basic components that comprise astrophysics, as an introductory background and context for the subsequent chapters in this book.

1.1.2 Photometry and Star Brightness

The ancient Greek astronomer Hipparchus (of Nicaea, ca. 190 BC–ca. 120 BC) classified for the first time the brightness of stars in his systematic observations of 128 BC, and his results were included in the star catalogue in the *Almagest* by Claudius Ptolemy (ca. 100 AD–ca. 170), with the brightness scale having six rankings (magnitudes) (Graßhoff 1990). This magnitude system was then used for nearly two millennia without any substantial change (Pannekoek 1961).

In the first half of the nineteenth century, Friedrich Wilhelm Argelander (1799–1875; Markkanen 2007) of Bonn University Observatory introduced a stepping method of stellar brightness to monitor visually light variations of variable stars, thereby calling astronomers' attention to quantitative measurements of star brightness. Then, astronomical instruments were invented to compare the brightness of stars with that of an artificial light source (Hearnshaw 1996). The German astronomer Johann Karl Friedrich Zöllner (1834–1882; Fig. 1.1; Habashi 2007) is known

Fig. 1.1 A sketch of J.K.F. Zöllner published prior to 1882 (https://en.wikipedia.org)

to have developed various types of astronomical photometers (see Sterken and Staubermann 2000), and an example of one of those is shown in Fig. 1.2. Use of such a photometer in astronomical observations without having to rely on naked-eye estimates greatly enhanced the measurement accuracy of stellar magnitudes, although further developments in photometry had to await the introduction of photography in astronomy.

As a result, it was understood that stellar magnitudes perceived by the human eye were proportional to the logarithm of light intensity emitted from stars, which was later recognized as a typical example of the Weber-Fechner's Law in psychology. In 1856 the British astronomer Norman Robert Pogson (1829–1891; Fig. 1.3; Reddy et al. 2007) formulated the relationship between brightness and magnitude by defining that a five-magnitude difference precisely corresponded to a factor of

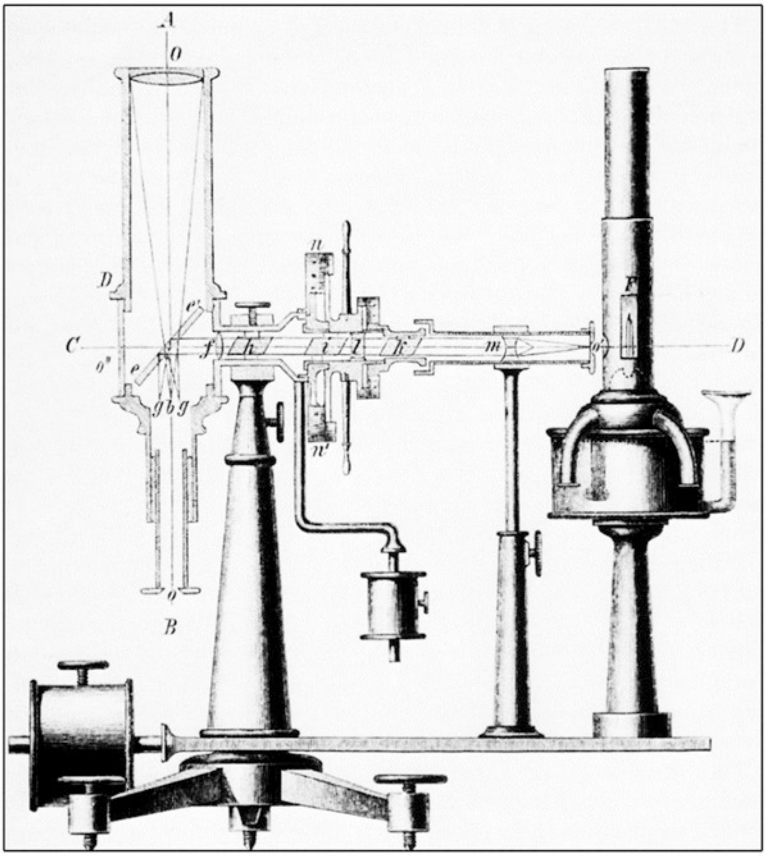

Fig. 1.2 Zöllner's astronomical photometer used a kerosine lamp as a standard light source. The light from the lamp (right-hand side) was introduced through the inside of the rotation axis to the telescope (left-hand side), and an observer could see the image of the artificial star through a half mirror at the eye-piece lens along with that of a star (after Herrmann 1984: 74)

Fig. 1.3 An undated photograph of N. Pogson (adapted from www.dhinakarrajaram.blogspot.com)

100 in brightness (Pogson 1856; c.f. Jones 1967). His proposal had been accepted internationally by the beginning of the twentieth century. This formulation eventually led to the adoption at the 1922 General Assembly of the International Astronomical Union of the 'absolute magnitude'—a fundamental concept in astrophysics—instead of the 'apparent (visual) magnitude' of stars (Hughes 2006).

1.1.3 The Discovery of Infrared and Ultraviolet Light

In 1671 Isaac Newton (1642–1727; Christianson 1984) found that a ray of white sunlight upon passing through a glass prism was dispersed into a rainbow-colored band, and he named it a spectrum (Newton 1704). Around 1800, William Herschel (1738–1822; Hoskin 2011) performed experiments to examine the temperature effects of lights. He placed small thermometers at several locations on a projected band of the solar spectrum to see how the temperature changed. Utterly unexpectedly, a maximum temperature rise occurred at colourless locations with wavelengths longer than that of red light. This was the discovery of infrared light (see Lequeux 2009).

In the following year, 1801, stimulated by the discovery of infrared radiation, the German physicist Johann Wilhelm Ritter (1776–1810; Porter 1994) investigated the sunlight photosensitivity of slips of paper dipped in a solution of silver chloride. Strangely enough, he discovered that a part of the paper corresponding to wavelengths shorter than that of violet light turned black, showing that this part of the paper was most photosensitive (Frercksa et al. 2009).

These two experiments demonstrated that sunlight included colour components invisible to the human eye at both longer and shorter wavelengths.

Fig. 1.4 An undated woodcut of Joseph Fraunhofer (https://www.wikipedia.org)

1.1.4 *Fraunhofer Lines in the Solar Spectrum*

When he was eleven years of age the orphan Joseph von Fraunhofer (1787–1826; Fig. 1.4; DeKosky 2007b) was working as an apprentice in a glass factory in Bavaria and was badly injured when the building collapsed. This gave him a chance, thanks to the Bavarian Prince-elector, to be educated at schools and later to enter the Bavarian Institute of Optics.

As an optical engineer at the Institute, Fraunhofer had been looking for monochromatic light sources appropriate to study the chromatic aberration of lenses. For that purpose he managed to invent a spectrometer equipped with a telescope that had a thin slit for incident light (see Fig. 1.5).

Fraunhofer directed this instrument to the Sun and noticed numerous thin black lines perpendicularly overlapped on a continuous rainbow-colour solar spectrum. He measured exact positions of some 300 lines, gave alphabetical symbol names to the main lines starting at the longest wavelength, and published the result as diagrams of the solar spectra in 1817 (Jackson 2000). He discovered similar black lines also in the spectra of the Moon, Venus and several bright stars. These black lines were called the Fraunhofer lines, which would later play a vital role in the identification of the chemical composition of the solar and stellar atmospheres.

1.1.5 *The Application of Laboratory Spectroscopy to Stars*

Astrophysics saw its birth with the pioneering spectroscopic work of Robert Wilhelm Eberhard Bunsen (1811–1899; Fig. 1.6; DeKosky 2007a) and Gustav Robert Kirchhoff (1824–1887; Fig. 1.6; Charbonneau 2007) during the 1850s. In

Fig. 1.5 Joseph von Fraunhofer demonstrating his spectroscope to colleagues (Wikipedia Commons)

particular, Kirchhoff used a laboratory spectroscope (Fig. 1.7) to establish the fundamental principles in spectroscopy, now known as Kirchhoff's three laws of spectroscopy, and regarding to the creation of continuous, emission and absorption spectra.

Between 1859 and 1862 Bunsen and Kirchhoff applied their laboratory findings to astronomy, and came up with a model for the Sun (Meadows 1970).

As Meadows (1970) has documented, during the late 1860s and throughout the 1870s major breakthroughs in solar physics took place, largely as a result of research by the American astronomers William Harkness (1837–1903; Fig. 1.8; Dick et al. 1998) and Charles Augustus Young (1834–1908; Fig. 1.9; Frost 1910), the pioneering French astrophysicist Pierre Jules César Janssen (1824–1907; Fig. 1.10; Launay 2012), Britain's Joseph Norman Lockyer (1836–1920; Fig. 1.11; Meadows 1972) and the Italian Jesuit astronomer Angelo Secchi (1818–1878; Fig. 1.12; Rigge 1918).

This initial interest in the Sun was prompted by its proximity, relative brilliance and solar-terrestrial relations, but the spectroscope was soon turned to the stars, gaseous nebulae and comets (Hearnshaw 2009). The earliest 'key players' in these new areas were Sir William Huggins (1824–1910; Fig. 1.13; Becker 2011) and Secchi, during the period 1864–1885. Secchi developed the first stellar classification of stars in 1866, and in the same year Huggins was able to examine the composition of a nova for the first time. Two years earlier, he had established the gaseous nature of a planetary nebula, and by 1868 had examined 70 different galactic and

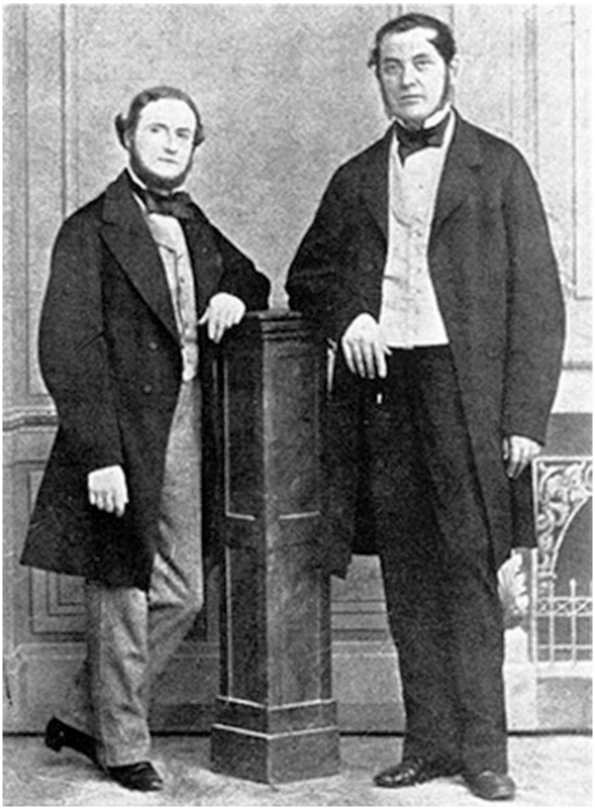

Fig. 1.6 A photograph dated about 1850 showing G.R. Kirchhoff (*left*) and R.W.E. Bunsen (*right*) (*Courtesy* Edgar Fahs Smith Memorial Collection, Department of Special Collections, University of Pennsylvania Library)

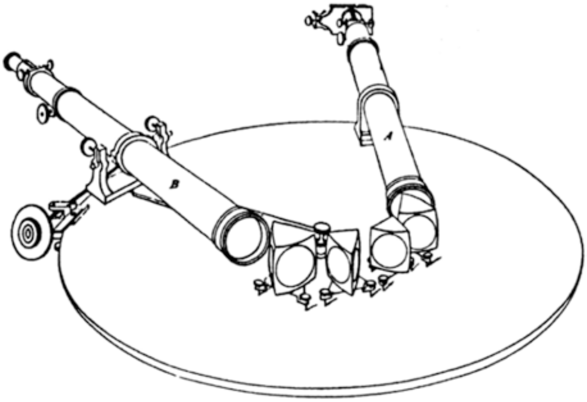

Fig. 1.7 Kirchhoff's laboratory spectrometer. The tube **(A)** is the collimeter and the left-hand tube **(B)** is the telescope that was used for measuring the spectral lines. The spectrometer was manufactured by the Steinheil Co. of München (after Herrmann 1984: 178)

Fig. 1.8 W. Harkness (after *Popular Science Monthly* 1903: 86)

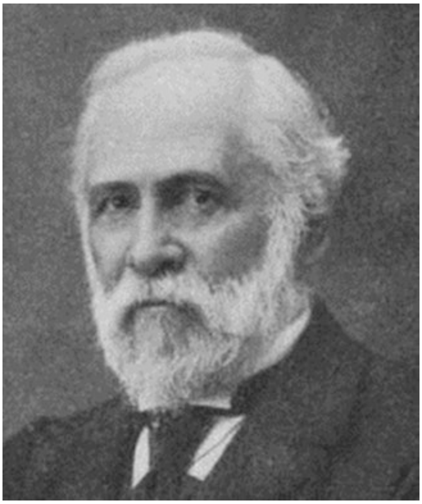

Fig. 1.9 Professor C.A. Young (https://en.wikipedia.org)

extra-galactic nebulae (although at that time no one realised that some of these were extragalactic). In 1864 Giovanni Battista Donati (1826–1873; Olivier 1930) had carried out pioneering spectroscopic observations of Comet C/1864 N1 (Tempel) (see Fig. 1.14), and this was followed up in 1881 with the advent of the Great Comet of that year (Orchiston 2017: Chapter 9).

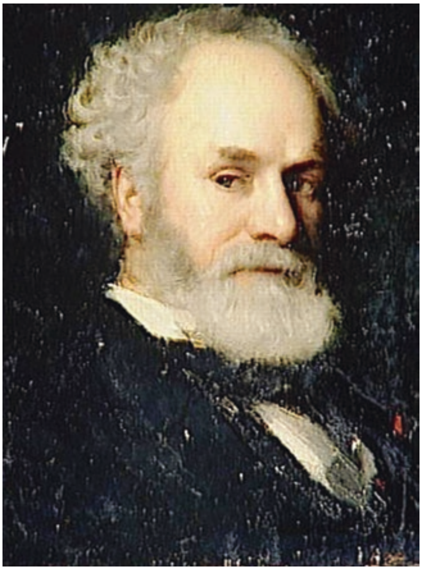

Fig. 1.10 An oil painting of Jules Janssen by Jean-Jacques Henner, that is now in the Musee d'Orsay in Paris (https://en.wikipedia.org)

Fig. 1.11 Sir Norman Lockyer in 1909 (https://en.wikipedia.org)

1.1.6 The Doppler Effect and Its Significance in Astronomy

While he was teaching at Prague Polytechnic, the Austrian physicist Christian Andreas Doppler (1803–1853; Fig. 1.15; Eden 1992) published a paper titled "On the coloured light of the binary stars and some other stars of the heavens" (Doppler 1842). This paper treated his postulated principle that the observed frequency of a wave would change depending on the relative speed between the wave source and

Fig. 1.12 Father Angelo Secchi (https://en.wikipedia.org)

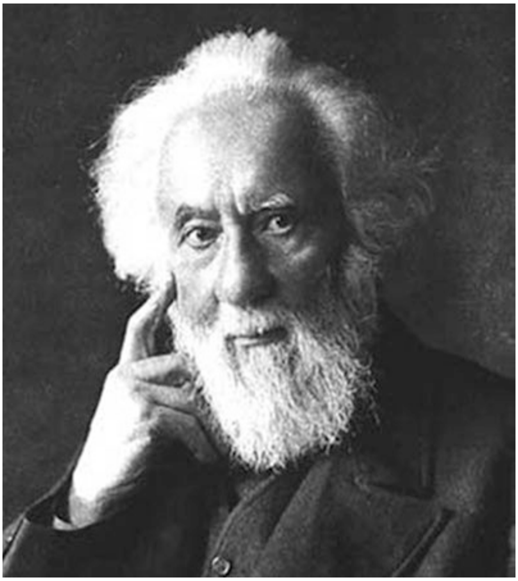

Fig. 1.13 Sir William Huggins in 1910 (https://en.wikipedia.org)

the observer. He intended to apply this concept (later called the 'Doppler Effect') when interpreting the colours of binary stars. Actually, Doppler misunderstood that each star in a binary system acquired its own colour owing to the relative motions of the two components, while the intrinsic colour of each single star was white.

In the case of a sound wave, the correctness of the Doppler Effect was soon ascertained experimentally in Holland, by listening to the sound of musical instruments played on a wagon running at high speed. But observational detection of the

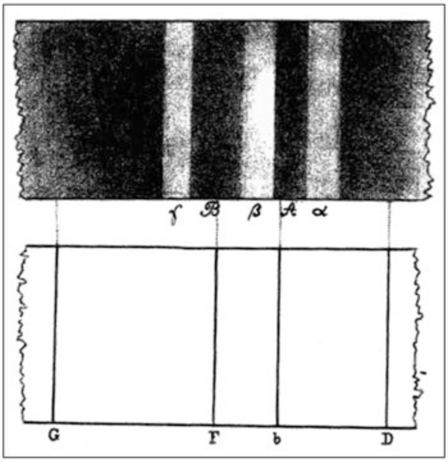

Fig. 1.14 At the top is Donati's drawing of the spectrum of Comet C/1864 N1 (Tempel), with three broad emission bands (α, β and γ). These were unrelated to the principal Fraunhofer lines in the solar spectrum, shown below (*Courtesy* James Lequeux)

Fig. 1.15 The plaque on the house in Prague where Christian Doppler lived from 1843 to 1847 (https://en.wikipedia.org)

effect in stellar spectra took about half a century after the publication of Doppler's paper (see Hearnshaw 2009). Success in measuring the Doppler Effect of stars was of revolutionary importance in the development of astrophysics because it could provide the radial velocities of stars along the line-of-sight (that had previously been impossible to observe). When these radial velocities were taken in conjunction with measured proper motions, astronomers were able to determine the three-dimensional motions of celestial bodies in space for the first time.

1.1.7 The Introduction of Photography to Astronomy

The development of the photographic dry plate in 1870 quickly led to the spectrogram which eliminated the uncertainty of naked eye examination and interpretation of spectra. In 1888, following an earlier attempt by Huggins, Hermann Carl Vogel (1841–1907; Fig. 1.16; Frost 1908) was able to publish the first reliable radial velocity observations of stars. By this time, the ability to determine the rotational velocity of stars from line-broadening in their spectra had been established by William de Wiveleslie Abney (1843–1920; H.P.H. 1921), and Vogel had offered an alternative stellar classification model. Then in 1889 Edward Charles Pickering (1846–1919; Bailey 1932) discovered the first spectroscopic binary. Spectroscopy was well and truly established as an essential analytical tool of the modern astronomer.

The same could be said of the photographic plate (Hughes 2013; Lankford 1984). Indeed, Waterfield (1938: 63) would go so far as to claim that

> … the photographic plate ranks second only to the telescope as a weapon of astronomical research. Even the spectroscope… could not have carried us very far without the assistance of the camera.

While the earliest successful applications of photography to astronomy were demonstrated in the 1840s, the first meaningful research developments did not occur until the late 1850s. At this time, Harvard Observatory's William Cranch Bond (1789–1859) and his son George Phillips Bond (1825–1865) obtained the first useful stellar photographs (Hughes 2013), and in England Warren De la Rue (1815–1889;

Fig. 1.16 H.C. Vogel (after Macpherson 1905: facing 129)

Fig. 1.17 W. De la Rue (https://en.wikipedia.org)

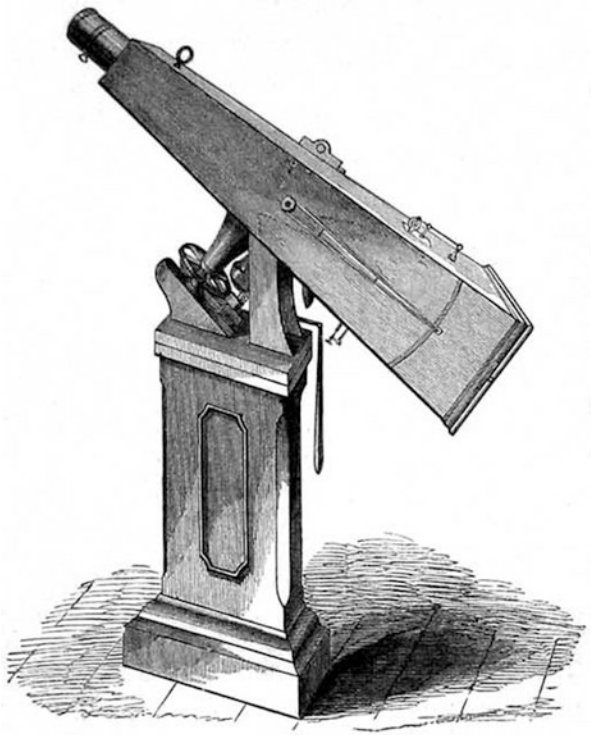

Fig. 1.18 An engraving of the ‘Kew Photoheliograph’ (after *The Engineer* 1866: 137)

Fig. 1.17; Hirshfield 2014) captured some excellent lunar images. In 1858 De la Rue also completed a photoheliograph for Kew Observatory (Fig. 1.18), and this was used to obtain daily solar photographs.

Fig. 1.19 Henry Draper (after *Popular Science Monthly* 1883)

Fig. 1.20 L. Rutherfurd (https://en.wikipedia.org)

During the early 1860s two American astronomers, Draper (1837–1882; Fig. 1.19; Barker 1888) and Lewis Rutherfurd (1816–1892; Fig. 1.20; Gould 1895), were experimenting successfully with solar and lunar photography, but major developments only took place after the invention of the silver bromide plate in 1870. In France during the 1870s Janssen obtained some of the best photographs of sunspots and solar granulation ever taken from the surface of the Earth. During the 1880s and early 1890s the British astronomers Andrew Ainslie Common (1841–1903; Fig. 1.21; Baum 2014) and Isaac Roberts (1829–1904; Abbey 2007) used large reflecting telescopes and Lick Observatory's Edward Emerson Barnard (1857–1923; Sheehan 1995) and Heidelberg Observatory's Maximillian Franz Joseph Cornelius (Max) Wolf (1863–1932; MacPherson 1932) specially constructed astrographs to show the superiority of the photographic plate over the human eye in

Fig. 1.21 A.A. Common (https://www.wikipedia.org)

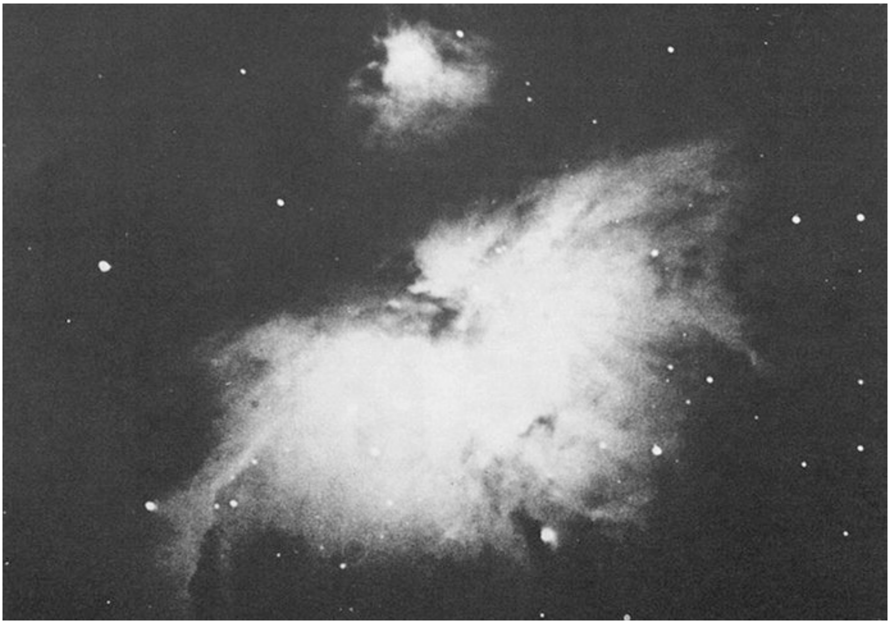

Fig. 1.22 A photograph of the Orion Nebula taken by Andrew Common in 1883 (https://en.wikipedia.org)

documenting the intricacies of gaseous nebulae (e.g. see Fig. 1.22). Meanwhile, the Cape Observatory's David Gill (1843–1914; Forbes 1916) and Paris Observatory's Henry brothers, Pierre Paul (1848–1905; Barthalot 2014) and Prosper-Mathieu (1849–1903; ibid.), were busy with photographic sky surveys of specific star fields (see Fig. 1.23).

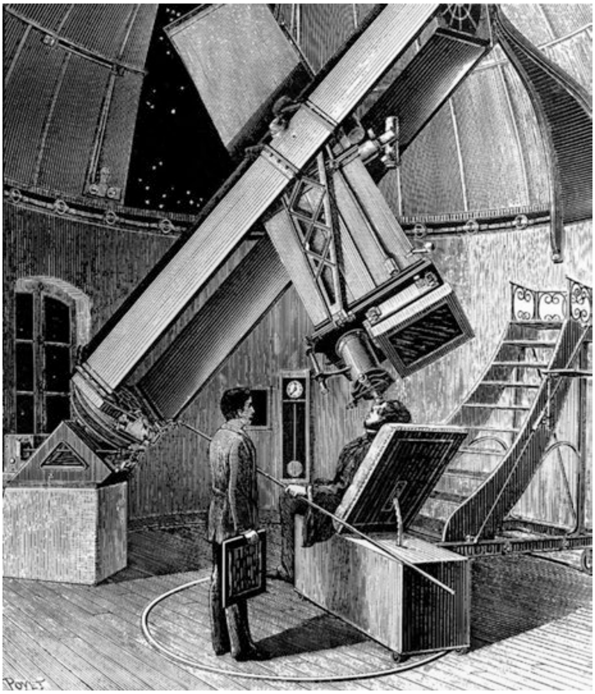

Fig. 1.23 An engraving of the 34-cm astrograph and associated 25-cm guide scope made in 1885 and used by the Henry Brothers to photograph star fields (http://www.astro.oma.be)

The 1880s stand as a watershed in the history of astronomy as the research merits of astronomical photography, reflecting telescopes and astrographs were debated internationally by professional astronomers. In the end they were swayed by the results already obtained, and the photographic plate took its rightful place in the arsenal of the modern astronomer, alongside the spectroscope.

The three decades from 1860 were formative ones in the evolution of astrophysics when the 'principal players'

> … lived in a fever of exciting discoveries, revolutionary ideas, magnificent conceptions – all of which were only a foreshadowing and prelude of what was to come. (Thiel 1957: 286).

However, this characterization should not blind us to the considerable controversy that surrounded astrophysics at this time.

1.1.8 The Role of the Amateur Astronomer in the Development of Astrophysics

One of the reasons for the controversy surrounding the early development of astrophysics was the important role played by amateur astronomers, such as Common, De la Rue, Draper, Huggins, Roberts and Rutherfurd. While most professional astronomers saw serious amateur astronomers as colleagues at this time, their duty was to perpetuate the craft of traditional astronomy not pioneer new fields (Lankford 1981a). Far too many amateurs neglected their rightful duty!

Another reason why some professional astronomers viewed astrophysics with suspicion was the faith placed in reflecting telescopes and astrographs by many of the pioneering astrophysicists. Every positional astronomer knew that the research instrument *par excellence* was the equatorially-mounted clock-driven refractor. The less said about the reflector the better: if it must be used in astronomy then it was simply a 'plaything' of the amateur and was not suitable for serious research!

Despite earlier publicity given to 'the new astronomy' by Langley (1884) and the pioneering efforts of professional astronomers like Janssen, Lockyer, Secchi, Vogel, Young and Zöllner, it was only when other professionals of international repute—such as E.E. Barnard, George Ellery Hale (1868–1938; Adams 1939), James Edward Keeler (1857–1900; Osterbrock 1984), E.C. Pickering and Max Wolf—espoused astrophysics that their professional colleagues began to take this new branch of astronomy seriously.

1.1.9 Publication of the Astrophysical Journal

By 1895 the *Astrophysical Journal* had been floated, to provide a venue for the publication of research in the 'new astronomy' (Meadows 1984a), and in 1897 the First Conference of Astronomers and Astrophysicists was held in conjunction with the dedication of the Yerkes Observatory, thereby initiating what was to become an annual event. By the end of the nineteenth century astrophysics was a major force to be reckoned with in United States and to a lesser extent world astronomy, bringing with it an accelerated divergence of the perceived role and status of the amateur and professional astronomer (see Hetherington 1976; Lankford 1979, 1981a, 1981b; Orchiston 1999, 2015; Rothenberg 1981).

1.2 The Emergence of Astrophysics in Asia

This book is titled *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. What do we regard as 'Asia'? It is easily understood that Asia cannot be defined unanimously, as it has long been used in many different contexts by many different people, depending upon geographical, racial, ethnographic, historical, cultural, political or economic viewpoints. For the purposes of this book, though, we decided to include all of those countries labelled in red in Fig. 1.24.

It is now known that the earliest astronomy, which became the basis of classical or traditional indigenous astronomy, was born almost independently in ancient civilizations near large rivers in Egypt, Mesopotamia, India and China between 4000 and 5000 years ago (e.g., see Dekker 2013; North 2008). It has been hypothesized

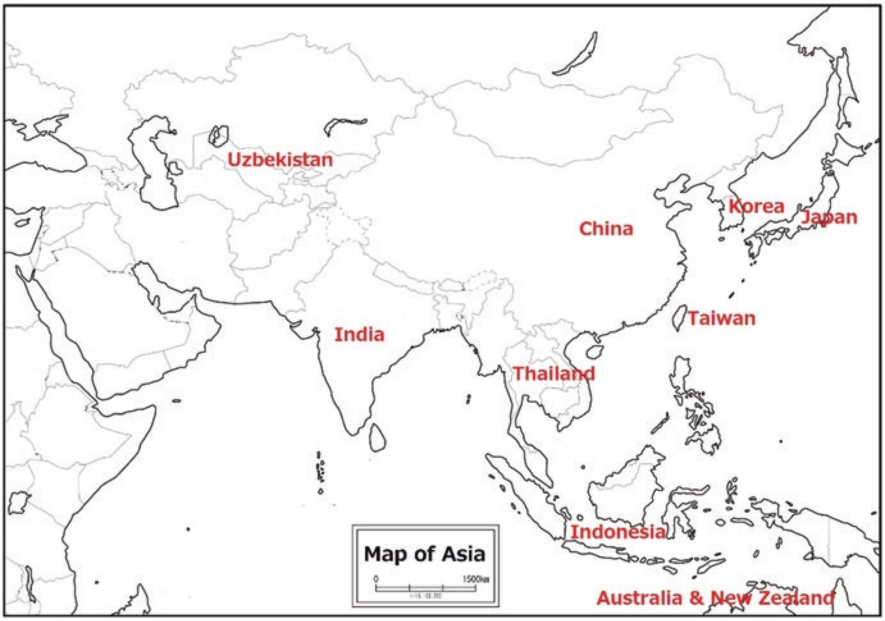

Fig. 1.24 A map showing those 'Asian' nations included in this book (*Map modifications* Tsuko Nakamura)

that this nearly simultaneous emergence of astronomy in antiquity in remote regions widely separated from each other was not accidental, but can be attributed to the abrupt global changes that took place in climate and sky visibility conditions soon after the Holocene climate optimum, during the interval 9000–5000 years BP (Nakamura and Okamura 2011: Chapter 2).

When we examine the astronomical legacy found in various nations included in the expansive area shown in Fig. 1.24 we note that astrophysics came comparatively early to some nations, but until very recently it bypassed other nations altogether. As a result we chose to focus only on those nations shown in red print on this map, namely Japan, South Korea, China, Taiwan, Thailand, Indonesia, Australia, New Zealand, India and Uzbekistan. Some of these nations made valuable contributions to solar physics (and occasionally astrophysics) in the nineteenth and/or early twentieth centuries, while astronomers in other nations only began to conduct astrophysical research in the second half of the twentieth century.

Our focus in this book is on the *emergence* (=early development) of astrophysics and solar physics in each of the above-mentioned nations, so we make no attempt to review the recent development of astrophysics (which for some countries has already been nicely presented in books and papers, or on the web sites of key observatories and/or universities).

In planning this book, we decided to divide it into national sections, and each section contains an overview chapter on the development of astronomy and emergence of astrophysics that shows how astronomy in that particular nation evolved up to the point when gradual—or sometimes sudden—changes occurred when astrophysics was introduced.

Then, if there were important early studies in either solar physics or astrophysics in any of these nations that preceded the widespread emergence of astrophysics, we introduce some of these as illustrative case studies immediately following the relevant national overviews. Thus, there are three such Japanese case studies, two of which deal with early asteroid research; two Thailand case studies, both relating to nineteenth century solar eclipses; two Indonesian case studies, both also relating to historic solar eclipse; two New Zealand case studies, one being about the 1885 total solar eclipse; and two Indian case studies, both of which relate to nineteenth century solar eclipses.

Finally, when nations such as Australia, China, India, Japan and New Zealand began early pioneering research in radio astronomy, we also devote one chapter (or, in Australia's case, two chapters) to this type of 'new astronomy' that really did "Open a New Window in the Universe" worldwide, and not just for Asian nations (hence the subtitle of this book).

Sometimes it was hard to know what to include or omit, but if an Asian astronomer moved overseas and only conducted important astrophysical research while there we chose not to include him in the book. But if overseas astronomers came to Asia (as on solar eclipse expeditions) and carried out research there that contributed to international solar physics, then some of these projects have been included as national case studies.

Many of the chapters in this book represent new research, but some are revised versions of previously-published research paper (and where this occurs the original publication is clearly identified).

This is the first book ever written that attempts to overview the emergence of astrophysics in Asia, and we hope it will inspire those with an interest in astronomical history to carry out new research and publish it. Then if we later have a chance to publish a Second Edition, it will be our pleasure to include some of these new studies, which will illustrate even better the important role that Asian nations played in the early development of astrophysics.

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References

Abbey, L.B. (2007). Roberts, Isaac. In Hockey et al., pp. 976–978.

Abetti, G. (1954). *The History of Astronomy*. London: Sidgwick and Jackson.

Adams, W.S. (1939). Biographical Memoir of George Ellery Hale, 1869–1938. *Biographical Memoirs of the National Academy of Sciences,* 21, 181–241.

Bailey, S.I. (1932). Biographical Memoir of Charles Pickering 1846–1919. *Biographical Memoirs of the National Academy of Sciences,* 15, 169–189.

Barker, G.F. (1888). Biographical Memoir of Henry Draper 1837–1882. *Biographical Memoirs of the National Academy of Sciences,* 81–139.

Barthalot, R. (2014). Henry, Paul Pierre and Prosper-Mathieu. In Hockey et al., pp. 483–485.

Baum, R. (2014). Common, Andrew Ainsley. In Hockey et al., pp. 447–449.

Becker, B. (2011). *Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy*. Cambridge: Cambridge University Press.

Charbonneau, P. (2007). Kirchhoff, Gustav Robert. In Hockey et al., pp. 641–643.

Christianson, G. (1984). *In the Presence of the Creator: Isaac Newton and His Times*. New York: Free Press.

Clerke, A.M. (1903). *Problems in Astrophysics*. London: Adam & Charles Black.

DeKosky, R.K. (2007a). Bunsen, Robert Wilhelm Eberhard. In Hockey et al., pp. 181–182.

DeKosky, R.K. (2007b). Fraunhofer, Joseph von. In Hockey et al., pp. 388–389.

Dekker, E. (2013). *Illustrating the Phenomena: Celestial Cartography in Antiquity and the Middle Age*. New York: Oxford University Press.

Dick, S.J., Orchiston, W., & Love, T. (1998). Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy,* 29, 221–255.

Doppler, C. (1842). *On the Coloured Light of the Binary Stars and Some other Stars of the Heavens*. Prague: printed for the author. (in German).

Dunkin, E. (1869). *Midnight Sky: Familiar Notes on the Stars and Planets*. London: The Religious Tract Society Co.

Eden, A. (1992). *The Search for Christian Doppler*. Wien: Springer.

Forbes, G. (Ed.), (1916). *Sir David Gill. Man and Astronomer* … London: John Murray.

Frercksa, J., Weberb, H., & Wiesenfeldt, G. (2009). Reception and discovery: the nature of Johann Wilhelm Ritter's invisible rays. *Studies in History and Philosophy of Science Part A*, 40, 143–156.

Frost, E.B. (1908). Hermann Carl Vogel. *The Astrophysical Journal*, 27, 1–11.

Frost, E.B. (1910). Biographical Memoir of Charles Augustus Young. *Biographical Memoirs of the National Academy of Sciences,* 7, 91–114.

Gingerich, O. (Ed.), (1984). *The General History of Astronomy. Volume 4: Astrophysics and Twentieth-Century Astronomy to 1950: Part A*. Cambridge: Cambridge University Press.

Gould, B.A. (1895). Biographical Memoir of Lewis Morris Rutherfurd 1816–1892. *Biographical Memoirs of the National Academy of Sciences,* 415–441.

Graßhoff, G. (1990). *The History of Ptolemy's Star Catalogue*. New York: Springer.

Habashi, F. (2007). Zöllner, Johann Kark Friedrich. In Hockey et al., pp. 1266–1267.

Hearnshaw, J. (1996). *The Measurement of Starlight: Two Centuries of Astronomical Photometry*. Cambridge: Cambridge University Press.

Hearnshaw, J. (2009). *The Analysis of Starlight: One Hundred and Fifty Years of Astronomical Spectroscopy. 2nd Edition*. Cambridge: Cambridge University Press.

Herrmann, D.B. (1984). *The History of Astronomy from Herschel to Hertzsprung*. London: Cambridge University Press.

Hetherington, N.S. (1976). Amateur versus professional. The British Astronomical Association and the controversy over canals on Mars. *Journal of the British Astronomical Association,* 86, 303–308.

Hirshfield, A.W. (2014). De la Rue, Warren. In Hockey et al., pp. 546–547.

Hockey, T., et al. (Eds.), (2007). *The Biographical Encyclopedia of Astronomers. 1st Edition*. New York: Springer.

Hockey, T., et al. (Eds.), (2014). *The Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hoskin, M. (2011). *Discoverers of the Universe: William and Caroline Herschel.* Princeton: Princeton University Press

H.P.H. (1921). Obituary. Sir William de Wiveleslie Abney. *Monthly Notices of the Royal Astronomical Society,* 81, 250–254.

Hughes, D.W. (2006). The introduction of absolute magnitude (1902–1922). *Journal of Astronomical History and Heritage,* 9, 173–179.

Hughes, S. (2013). *Catchers of the Light. The Forgotten Lives of the Men and Women who First Photographed the Heavens. Their True Tales of Adventure, Adversity & Triumph* (2 Vols). Paphos: ArtDeCiel Publishing.

Jackson, M.W. (2000). *Spectrum of Belief: Joseph von Fraunhofer and the Craft of Precision Optics.* Cambridge (Mass.): MIT Press.

Jones, N. (1967). Norman Pogson and the definition of stellar magnitude. *Astronomical Society of the Pacific Leaflet,* 469, 145–152.

Langley, S.P. (1884). *The New Astronomy*. New York: Houghton Mifflin.

Lankford, J. (1979). Amateur versus professional: the transatlantic debate over the measurement of Jovian longitude. *Journal of the British Astronomical Association*, 89, 574–582.

Lankford, J. (1981a). Amateurs and astrophysics: a neglected aspect in the development of a scientific speciality. *Social Studies in Science,* 11, 275–303.

Lankford, J. (1981b). Amateurs versus professionals: the controversy over telescope size in late Victorian science. *Isis,* 72, 11–28.

Lankford, J. (1984). The impact of photography on astronomy. In O. Gingerich, pp. 16–39.

Launay, F. (2012). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. New York: Springer.

Lequeux, J. (2009). Early infrared astronomy. *Journal of Astronomical History and Heritage*, 12, 125–140.

Macpherson, H. (1905). *Astronomers of Today and Their Work*. London: Gall & Inglis.

Macpherson, H. (1932). Obituary: Max Wolf. *The Observatory,* 55, 355–359.

Markkanen T. (2007). Argelander, Friedrich Wilhelm August. In Hockey et al., p. 58

Meadows, J. (1970). *Early Solar Physics*. Oxford: Pergamon Press.

Meadows, J. (1972). *Science and Controversy. A Biography of Sir Norman Lockyer.* Cambridge (Mass.), MIT Press.

Meadows, A.J. (1984a). The origins of astrophysics. *American Scientist,* 72, 269–274.

Meadows, A.J. (1984b). The origins of astrophysics. In O. Gingerich, pp. 3–15.

Meadows, A.J. (1984c). The New Astronomy. In O. Gingerich pp. 59–72.

Nakamura, T., & Okamura, S. (2011). *Five Thousand Years of Cosmic Visions: How Human Beings have Viewed the Universe.* Tokyo: University of Tokyo Press. (in Japanese).

Newton, I. (1704). *Opticks*. London: Sam. Smith & Benj. Walford.

North, J. (2008). *Cosmos: An Illustrated History of Astronomy and Cosmology*. Chicago: University of Chicago Press.

Olivier, C.P. (1930). *Comets*. Baltimore: Williams and Wilkins.

Orchiston, W. (1999). Comets and communication: amateur-professional tension in Australian astronomy. *Publications of the Astronomical Society of Australia,* 16, 212–221.

Orchiston, W. (2015). The amateur-turned-professional syndrome: two Australian case studies. In W. Orchiston, D.A. Green, & R. Strom (Eds.), *New Insights from Recent Studies in Historical Astronomy: Following in the Footsteps of F. Richard Stephenson. A Meeting to Honor F. Richard Stephenson on His 70th Birthday* (pp. 259–350). Cham: Springer.

Orchiston, W. (2017). *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy*. Cham: Springer.

Osterbrock, D. (1984). *James E. Keeler, Pioneer American Astrophysicist, and the Early Development of American Astrophysics*. Cambridge: Cambridge University Press. *Oxford English Dictionary*

Pannekoek, A. (1961). *A History of Astronomy*. London: Allen and Unwin.

Pogson, N. (1856). Magnitudes of thirty-six of the minor planets for the first day of each month of the year 1857. *Monthly Notices of the Royal Astronomical Society,* 17, 12–15.

Popular Science Monthly, 22 January (1883).

Popular Science Monthly, 63, 86 (1903).

Porter, R. (Ed.), (1994). Ritter. In *The Biographical Dictionary of Scientists*. 2nd edition (p. 583). New York: Oxford University Press.

Reddy, V., Snedegar, K., & Balasubramanian, R.K. (2007). Scaling the magnitude: the rise and fall of N.R. Pogson. *Journal of the British Astronomical Association,* 117, 237–245.

Rigge, W.F. (1918). Father Angelo Secchi. *Popular Astronomy,* 26, 589–598.

Rothenberg M. (1981). Organsation and control: professionals and amateurs in American astronomy, 1899–1918. *Social Studies in Science*, 11, 305–325.

Sheehan, W. (1995). *The Immortal Fire Within: The Life and Work of Edward Emerson Barnard*. Cambridge: Cambridge University Press.

Sterken, C., & Staubermann, K.B. (Eds.), (2000). *Karl Friedrich Zollner and the Historical Dimension of Astronomical Photometry: A Collection of Papers on the History of Photometry*. Brussels: VUB University Press.

The Engineer, 23 February, 137 (1866).

Thiel, R. (1957). *And there was Light: The Discovery of the Universe*. New York: Alfred A. Knopf.

Waterfield, R.L. (1938). *A Hundred Years of Astronomy*. London: Duckworth.

W.G.T. (1899). Obituary: Dunking, Edwin. *Monthly Notices of the Royal Astronomical Society,* 59, 221–225.

Part I
Japan

Chapter 2
The Development of Astronomy and Emergence of Astrophysics in Japan

Tsuko Nakamura

2.1 Introduction

The year 2008 was a very memorable one in the history of astronomy, and especially for Japanese astronomers. The reason is that 2008 was the 400th anniversary of the invention of the telescope in the Netherlands, and also the centenary of the foundation of the Astronomical Society of Japan. Hence, in taking advantage of this timely opportunity (these words are the ones used in Nakamura 2008), I would like to attempt to overview the emergence of modern astronomy and astrophysics in Japan, mainly before WWII. It is commonly recognized that the rise of the so-called 'New Astronomy' (astrophysics) is a major topic in the history of astronomy.

In order to clarify astronomical developments in Japan leading to the emergence of astrophysics, we describe in this chapter the history of Japanese astronomy by dividing it into four chronological stages as follows. The first stage was in the ruling era of the Tokugawa Shogunal Government, before the Meiji Restoration (1868),[1] during which the Japanese first learned about Western astronomy through books translated into Chinese, and then through books written in Dutch. The second stage was marked by the direct introduction of *modern* Western astronomy after 1868 through students who were educated in Europe or in the US. At the third stage, astrophysics emerged in the Japanese astronomical community for the first time. Thereafter, astrophysical research finally rivalled that of classical astronomy.

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[1] The Meiji Restoration (1868) was a sort of revolution, in which, after small-scale civil wars, political power moved from the Samurai's hands to modern citizens. In Japanese history, the Meiji Restoration is generally regarded as the turning point from a feudal world to a modern society.

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The Japanese version of this chapter can be found in Chaps. 1 and 2 of the book *One Hundred Years of Astronomy in Japan* (Nakamura 2008), although some new considerations and insight have been added here.

2.2 Encounters with Western Astronomy

2.2.1 Western Astronomy Learnt from Chinese Books

In ancient times from the seventh century through to the sixteenth century, the astronomy of Japan was under the exclusive influence of Chinese astronomy, and there was almost nothing original from a scientific viewpoint, except for very primitive and indigenous recognition of the heavens relating to animism. What the Japanese learned from China during that period was technical aspects of calendar-making, the institution of the court astronomical bureau (*Onmyo-ryo* in Japanese) and astrology (or celestial divination).

Japan's first encounter with Western astronomy took place through Chinese translations of astronomical books written or brought into China by Jesuit missionary priests[2] who served during the Ming or Qing Dynasties as court astronomers. Some of these books on astronomy began to be imported into Japan after 1720, when the eighth Shogun Tokugawa Yoshimune[3] relaxed the import ban on Chinese books authored by Jesuit missionaries. As a result, the books on Western astronomy listed below arrived in Japan.

The first one that affected Japanese astronomy was *Lixiang kaocheng* (*Compendium of Calendrical Astronomy*, 1723). This book was compiled by the German Jesuit Ignatius Kögler (Dai Jinxian; 1680–1746) in collaboration with Chinese astronomers, and described the Tychonic planetary system, which was a compromise between the Copernican (heliocentric) and Ptolemaic (geocentric) systems. In the book, planetary motions were calculated using the epicycle-deferent technique.

The second book, *Lixiang kaocheng houbian* (*Revised Compendium of Calendrical Astronomy*, 1742) was the first one in Chinese that calculated motions of the Sun and Moon using Kepler's theory of elliptic orbits, so with this book Japanese astronomers learned about elliptic motion for the first time. Another influ-

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[2] Actually in Japan, Christian evangelism had already begun soon after the landing of St. Francis Xavier in Japan in 1549. The Jesuit priests made full use of astronomy to demonstrate to the Japanese people the superiority of Christianity and the Western culture. They (mainly the Portuguese and Spanish) even attempted to build a few colleges in Japan to introduce the Christian doctrine to Japanese students, and elementary Western astronomy also was taught in these colleges—see Nakayama (1969), for the details.

[3] In case of Japanese names, in the text of this chapter the first name indicates the surname, and the second name is the person's given name. Also, to distinguish persons with the same surname or to be in accordance with Japanese tradition, their given names are sometimes cited in the text and in references.

ential book, *Lingtai lixiangzhi* (*Astronomical Instruments*, 1674), compiled by Ferdinand Verbiest, (Nan Huairen; 1623–1688; Coyne 2014), mainly discussed astronomical instruments that were based on Western astronomy, originally attributable to Tycho Brahe's instruments that were developed and used at his observatory on the island of Hven in Denmark.

From 1780s, civil astronomers such as Takahashi Yoshitoki and Hazama Shigetomi, led by Asada Goryu, the pioneer in this field who had taught astronomy at Osaka, started to learn from those three Chinese books. At a later date, because of their conspicuous ability, Takahashi and Hazama were ordered to become official astronomers by the Shogunal Government, so that they could be involved in calendar reform.

In addition to those three books—which were for professional astronomers—the book *Tienjing huowen* (*Queries on the Classics of Heaven*, 1681), written by You ziliu, also was imported and was popular with a wide cross-section of Japanese society, from the general public to professional astronomers. This book was repeatedly translated into Japanese with a variety of annotations, and contributed very much to help the Japanese understand elementary Western astronomy, meteorology and geography. Note that the Japanese had already been taught 'the sphericity of the Earth' by the Portuguese priests who had engaged in propagating Christianity in Japan during the period from the 1580s through to the 1630s when Japan introduced a strict ban on Christianity and the Christian priests were expelled.

2.2.2 Western Astronomy Learnt from Dutch Books

In 1803, Takahashi was required by the Shogunate to examine a Dutch translation of the French book on astronomy, *Astronomia of Sterrekunde* in five volumes (Fig. 2.1). The title of the original book was *Astronomie*, written by Joseph Jérôme Lalande (1773–1780; Boistel et al. 2010) who was once the Director of Paris Observatory (Lalande 1771).

When he examined this book Takahashi was deeply impressed by the elaborate contents, and he had never seen such high-level and exact astronomy presented in Chinese books. Therefore, without a dictionary or a book of Dutch grammar, and with only a poor knowledge of this language, Takahashi challenged himself to understand the book. After half a year of painstaking attempts to translate the book he died of pulmonary disease and overwork midway through this project, leaving eight notebooks that record his efforts. Although Takahashi could not grasp some of the concepts introduced, such as 'aberration of light', he was able to correctly understand most other parts of the book. His efforts then were continued by his two sons Takahashi Kageyasu and Shibukawa Kagesuke. This was the first Japanese encounter with a professional astronomical book written in a European language. As a Shogunal astronomer, Kagesuke later incorporated some results from his translation into a new calendar (the *Tenpo* calendar). It is worth noting, however, that the

Fig. 2.1 *Astronomia of Sterrekunde* (Second Edition, 1773–1780) by J.J.F. Lalande (*Courtesy* National Astronomical Observatory of Japan). These four books were all purchased at a later time of the Edo Era, since the original copies used by Takahashi et al. were lost in a fire in 1813. Note that for some unknown reason the first volume of the books preserved in the NAOJ Library is missing (*Courtesy* National Astronomical Observatory of Japan)

primary interest of the Shogunal astronomers was to apply knowledge of Western astronomy within the traditional framework of Chinese calendrical astronomy, and they had little interest in theoretical aspects of Western astronomy.

In June 2007, a 200th-year memorial symposium after the death of Lalande was held at Paris Observatory, and it was reported there that Lalande's *Astronomie* had been translated into German, Italian, Russian, Turkish and Arabic, in addition to Dutch and Japanese, clearly showing that this book was widely welcomed by the international astronomical community.

2.3 The Introduction of Western Modern Astronomy

2.3.1 Foreign Teachers

In 1868, the Shogun Government surrendered to the new political power, and Japan finally abandoned its seclusion policy which had continued for 230 years and opened its gates to the world. On this occasion, many historical matters and traditions belonging to the 'ancien régime' were regarded as useless and were discarded. On the other hand, the new Meiji Government set the immediate introduction of Western science and technology as a top priority policy, in order to strengthen the country and catch up with European powers. Education was no exception either. In every field, foreign professors and teachers were invited to come and give lectures at newly-established universities and colleges. The first teacher of astronomy, Émile-Jean Lépissier came from Paris Observatory in 1872 and taught at an astronomical school. However, since there were neither appropriate astronomy textbooks there nor instruments for astronomical education at the University of Tokyo, Lépissier's invitation was premature and not very fruitful (Nakamura 2016).

The next foreign astronomer to come to Japan was Thomas Corwin Mendenhall (1841–1924; Rubinger and Mendenhall 1989), the Professor of Physics at Ohio State University in the USA, who arrived in 1878. Since Mendenhall's autobiographical notes written during his 3-year stay in Japan were published by his grandson in 1989, we have a good idea of his educational experience in Japan. At the University of Tokyo he made precise measurements of the Fraunhofer lines in the solar spectrum, and he carried out meteorological observations. With assistance from some of his Japanese students, he also measured gravity at the top of Mt. Fuji, and from this he derived a figure for the mean density of the Earth. At the time, his value was believed to be the best one available.

Figure 2.2 is a photograph of Mendenhall taken together with his students and young staff at the University of Tokyo in 1881, just before he returned to the USA. Mendenhall had an enduring influence on Japanese society and on his students, some of whom later were promoted to important positions (including the President and the Dean of the University of Tokyo).

Fig. 2.2 T.C. Mendenhall (center, seated) with his students and the staff of University of Tokyo in 1881 (*Courtesy* University of Hawaii Press, 1989)

Fig. 2.3 The French expedition team for the transit of Venus (1874) to Japan. Seated are J. Janssen and F.F. Tisserand. To the left of Tisserand's shoulder is Janssen's 'Revolver camera' (after Launay and Hingley 2005; *Courtesy* Anne Guigan-Léauté)

The third foreign teacher, Henry M. Paul came from the US Naval Observatory and taught his students the fundamentals of positional astronomy using basic astronomical instruments.

However, it is worth emphasizing that the Japanese first learned professional techniques of astronomical observations *not* from those foreign teachers *but* from a spectacular cosmic event that also took place in the 1870s. This was the transit of Venus, which occurred on 9 December 1874 (Saito 1974). France (Débarbat and Launay 2006), the USA (Dick et al. 1998) and Mexico (Allen 2005) dispatched expeditions to Nagasaki, Kobe and Yokohama, respectively, on this occasion.

Figure 2.3 shows the French team photographed in France, probably at Marseille, before their embarkation (after Launay and Hingley 2005). The leader of the expedition, Jules Janssen (1824–1907; Launay 2012), is the person with the white hair seated in the center. He later became well known as the founder of modern astrophysics in France and Director of Meudon Observatory. The other seated man is François-Félix Tisserand (1845–1896; Débarbat 2014), who was then at Toulouse Observatory but later was appointed Director of Paris Observatory. He also is famous of his four-volume standard textbook on celestial mechanics, *Traité de Mécanique Céleste* (1889–1896). The short man standing immediately behind Janssen is Shimizu Makoto

Fig. 2.4 Portrait of Shimizu Makoto. After coming back from France, he devoted his life to the initiation and development of the domestic safety-matches industry (http://www.match.or.jp/column/column02.html)

(Fig. 2.4; 1845–1899), a Japanese who was then in France studying the French shipbuilding industry; he joined the French expedition as a photographic technician.

Through these overseas transit of Venus teams Japanese astronomers learned some of the professional techniques of Western astronomers for the first time, including (1) the use of geodesic and astronomical measurements to determine latitude and longitude; (2) how to establish time synchronization of clocks between remore sites using the telegraphic transfer of time signals; and (3) the application of photography to astronomy (Saito and Shinozawa 1972, 1973).

2.3.2 *The First Japanese Modern Astronomer*

The first Japanese modern astronomer was Terao Hisashi. He graduated from University of Tokyo in 1878, and went to Paris in 1879 to learn modern European astronomy, under the supervision of Professor Tisserand (Bartholomew 1989) and Jules Henri Poincaré (1854–1912; Trachet 2014). It is important to note that before going to Paris he had no knowledge of modern astronomy. Figure 2.5 shows a portrait of Terao painted by the famous Japanese artist Kuroda Seiki, who is now recognized as 'the Father of Modern Oil-Painting in Japan'.

Terao was fortunate, because he could attend the Montsouris Astronomical School, which just happened to open in 1879, the year that Terao arrived in Paris. This school was established by Admiral Ernest Amédée Barthélémy Mouchez (1821–1892; Grillot 2014), the Director of Paris Observatory, with the purpose of training young astronomers in fundamental techniques of astronomical observa-

Fig. 2.5 An oil portrait of Terao Hisashi, the first Director of Tokyo Astronomical Observatory, painted by Kuroda Seiki in 1909. Terao, who had just returned from Paris, taught 18-year old Kuroda French conversation, as he was about to leave for France (*Courtesy* National Research Institute for Cultural Properties, Tokyo)

tions (Paris Observatory 1890); this indicated that French astronomers previously had a strong tendency towards theoretical astronomy rather than observations.

Figure 2.6 is a photograph of a small dome that was used by the Astronomical School and is now located in Montsouris Park in southern Paris. According to Mouchez (1890), in addition to Terao, students from China, Greece and Romania learnt modern astronomy at this School.

After finishing his 4-year study of astronomy in France, Terao joined the 1882 French transit of Venus expedition to Martinique Islands, off the shores of Venezuela, and he returned home via the USA in 1883 (Terao 1890). Then he was nominated as the successor to Paul's position, and promoted to a Chair in the Department of Astronomy at the University of Tokyo where he taught students astronomy and astrometric observations using meridian circles and the 15-cm equatorial refractor at the observatory that had been built on the University campus in 1878.

2.3.3 *The Foundation of Tokyo Astronomical Observatory*

In 1888 Tokyo Astronomical Observatory (TAO) was founded as an institute of the University of Tokyo in the central part of Tokyo (Fig. 2.7), with Terao as the Director. Since Terao's supervisor at Paris Observatory was Tisserand, who was a celestial

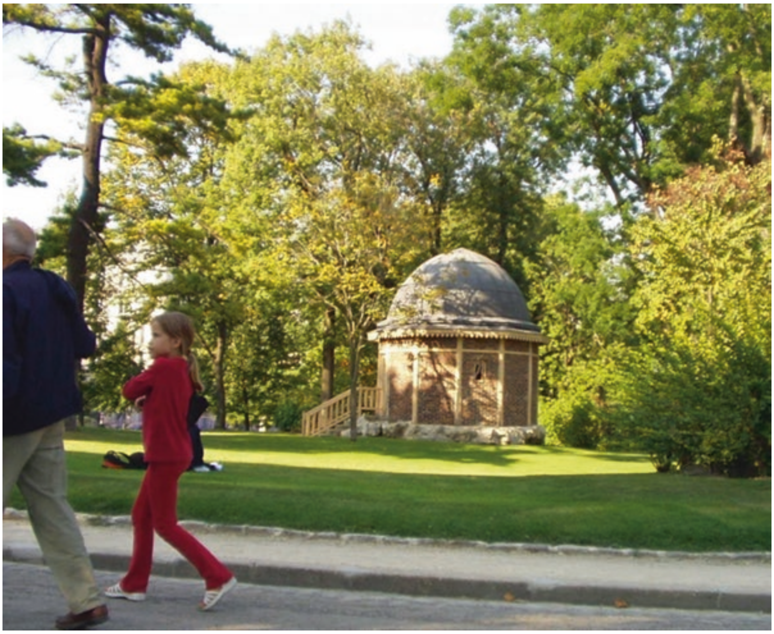

Fig. 2.6 The dome of the Montsouris Astronomical School established by Admiral Mouchez in 1879. Currently the dome is empty, and it seems to merely serve as a decorative pavilion in Montsouris Park (*Photograph* Tsuko Nakamura)

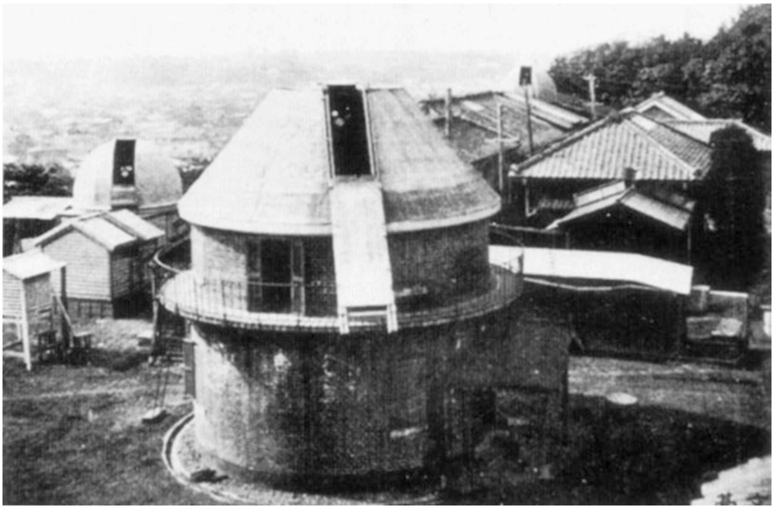

Fig. 2.7 Tokyo Astronomical Observatory, which was established at Azabu in downtown Tokyo in 1888 (*Courtesy* National Astronomical Observatory of Japan)

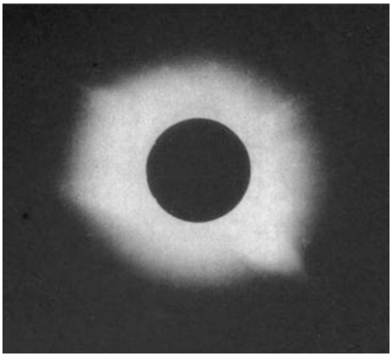

Fig. 2.8 A 20 s exposure of the 22 January 1898 total solar eclipse taken at Jeur, India, and clearly showing the corona (after Terao and Hirayama 1910: 4)

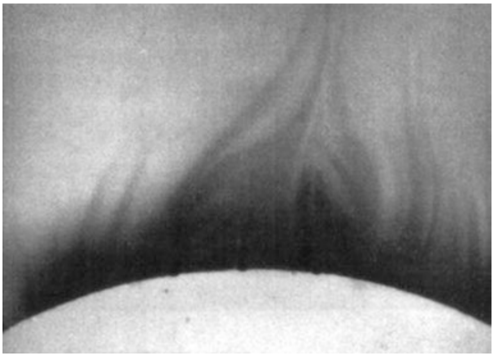

Fig. 2.9 A magnified image of prominences observed on the solar limb (after Terao and Hirayama 1910: 7)

mechanician, the astronomy that Terao mastered and taught his students was so-called 'classical astronomy'. And for an extended period of time this characterized the type of astronomy studied at TAO. For almost two decades Terao had to contend with meager staff, poor instrumentation and a bad financial situation, and he also had to carry a laborious administrative load.

In 1898, the Japan Government for the first time dispatched a solar eclipse expedition to Jeur, near Bombay (now Mumbai), in India, where an American team also was based—see Chap. 26 in this book (Orchiston and Pearson 2017). The team was headed by Terao (see Terao and Hirayama 1910). Figure 2.8 is a copy of the first photograph of the solar corona taken by a Japanese astronomer outside of Japan, and Fig. 2.9 shows a magnified image of solar prominences on the limb of the solar disk. One can see the fine structure of prominences along the solar magnetic lines.

Figure 2.10 shows the prismatic camera that was used during the second Japanese solar eclipse expedition, to Padang (Sumatra) in 1901 (Hirayama et al. 1910; once again, a US Lick Observatory expedition also was sited in Padang—see Chap. 16 (Pearson and Orchiston 2017) in this book). On this occasion the solar spectra at

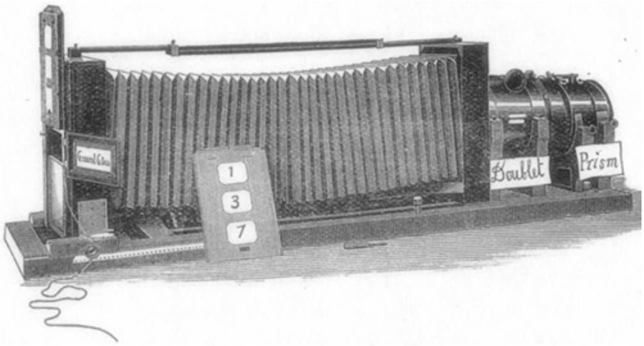

Fig. 2.10 Prismatic camera used to take flash spectra of the solar eclipse on 18 May 1901 at Padang, Sumatra (after Hirayama et al. 1910: 10)

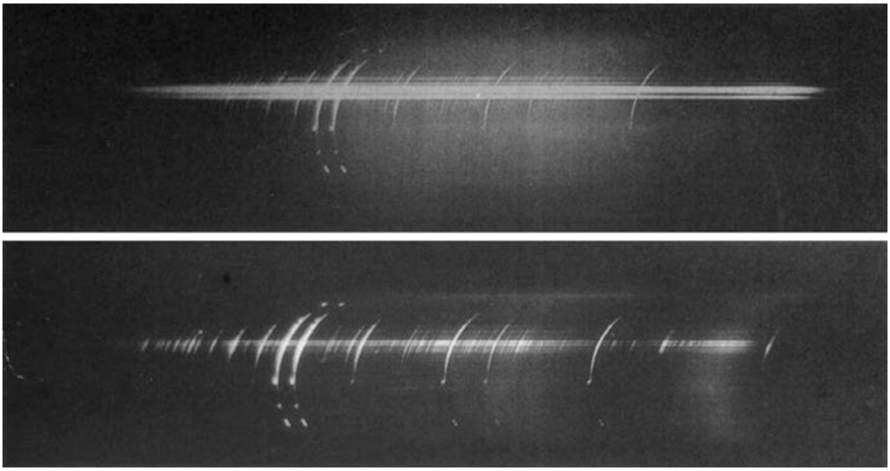

Fig. 2.11 Flash spectra photographed with the camera shown in Fig. 2.10 (Hirayama et al. 1910: 16)

totality were successfully observed by the Japanese astronomers for the first time, and Fig. 2.11 shows two flash spectra that they recorded. The wavelengths of emission lines associated with hydrogen (the Balmer series), helium, ionized metals, etc., were measured with a comparator. It was thought that the flash spectrum was caused by the chromosphere, a narrow atmospheric layer sandwiched between the photosphere and the corona.

Further overseas solar eclipse expeditions were mounted by Japan almost until the outbreak of WWII, but they did not produce any particularly important findings. Rather, they merely provided follow-up confirmation of new results obtained by Western solar physicists.

2.3.4 The First Internationally Recognized Japanese Studies in Astronomy

In a latter section, I shall show that the rise of astrophysics took place in Japan as late as in 1920s. This may be attributed at least partially to the nature of the 'modern astronomy' introduced by Terao. In particular, I would dare to say that discoveries made by Kimura Hisashi and Hirayama Kiyotsugu, which I will describe in the following subsections, would fail to stimulate young Japanese astronomers to be interested in astrophysics, rather than in classical astronomy. The works of Kimura and Hirayama were the first internationally recognized achievements in the field of classical astronomy since the Japanese had started to learn about Western modern astronomy.

2.3.4.1 Kimura Hisashi and the Z-Term in the Polar Motion of the Earth

Kimura Hisashi (1870–1943; Fukushima 2014) was one of Terao's early students. Kimura (Fig. 2.12) graduated from the University of Tokyo in 1892. In 1888 a new phenomenon called 'polar motion' in the rotation of the Earth, which varied with latitude, was discovered by a German astronomer Karl Friedrich Küstner

Fig. 2.12 Kimura Hisashi at the Mizusawa Latitude Observatory. This photograph seems to have been taken soon after he was awarded the Gold Medal by the British Royal Astronomical Society. It is interesting to see in the background of his photograph the formula of Talcott's method, the standard reduction technique of latitude observations (*Courtesy* Mizusawa VLBI Observatory, National Astronomical Observatory of Japan)

(1856–1936; Brosche 2000; Luzum 2014). Polar motion is a quasi-periodic motion of the instantaneous spin axis of the Earth, relative to the shape axis of the Earth as an ellipsoid. Such a type of rotation, like polar motion, had been theoretically predicted for the rigid-body Earth by the Swiss mathematician Leonhard Euler (1707–1783; Verdun 2014) more than 100 years prior to the actual discovery of polar motion.

In order to study the newly-discovered polar motion in more detail the international astronomical community proposed to establish a special series of astronomical stations along a nearly-equal-latitude circle of the Earth, so that the latitude change could simultaneously and systematically be observed at different places. Accordingly, a latitude observatory was built at Mizusawa, a village in the northern part of Japan, and Kimura was appointed as the Director. Although Kimura and his international colleagues continued careful and persistent latitude observations for several years, the Central Bureau of Latitude Variation in Germany judged that only Mizusawa's data deviated markedly from those obtained at other stations and were far from reliable. Shocked by this unexpected judgment, Kimura and his colleagues again and again rechecked both their meridian transit instruments and the data reduction method, but they could not pin-point any mistakes or problems. As a result, Kimura gradually became confident that he had detected something new in the polar motion.

The relationship between latitude variation ($\Delta\varphi$) and the coordinates (x, y) of the instantaneous spin axis with respect to a certain origin on the surface of the Earth near the north pole is given by the equation:

$$\Delta\varphi = \mathrm{x}\cos\lambda - \mathrm{y}\sin\lambda \tag{2.1}$$

where λ is the longitude of an observing station.

Kimura demonstrated that, if the third term, the 'Z-term', which is independent of longitude, is introduced anew in the right-hand side of the above equation, all the observed latitude data, including Mizusawa's values, could satisfactorily be fitted without mutual contradiction. Kimura published his discovery in 1902 (Kimura 1902).

The discovery of the Z-term was reasonably quickly approved and was welcomed by the world-wide astronomical community. As a result, Kimura was awarded the Gold Medal of the British Royal Astronomical Society, in addition to some domestic prizes.

Currently, we know that the Z-term was eventually no more than a result of an incomplete nutation correction of star positions used in the reduction of the latitude data (Wako 1970). And this correction has recently been shown to have been caused by the motion of the liquid core of the Earth. However, it still deserves to be appreciated that Kimura's finding motivated geophysicists to pursue physical connections of the latitude variation with the inner core motion of the Earth. In a sense then, the Z-term could be regarded as a tracer to sound the interior of the Earth.

2.3.4.2 Hirayama Kiyotsugu and Asteroid Families

Another internationally recognized project carried out by one of Terao's former students was the discovery of 'asteroid families' by Hirayama Kiyotsugu (1874–1943; Fig. 2.13; Kozai 2014b), and this subject is discussed in detail by Yoshida and Nakamura (2017) in Chap. 3 in this book. Hirayama graduated from the University of Tokyo 5 years after Kimura did, also majoring in classical astronomy. Before going to the USA, he was involved in studies of the latitude observations. He also surveyed accounts of ancient eclipses and comets that appeared in the historical records of Japan and China, and therefore should be regarded as a pioneer in this field.

In 1915 Hirayama went to the USA where he studied there celestial mechanics under Professor Ernest William Brown of Yale University (1866–1938; Baum 2014), an authority on the lunar motion. Brown suggested that Hirayama study the dynamics of the asteroids, and upon following this advice Hirayama began statistical and dynamical research on asteroids. However, Hirayama seems to have been interested in the behavior of asteroids as a group, not in the dynamics of individual asteroids.

By applying secular perturbation theory of planets to the motions of asteroids, Hirayama calculated so-called 'proper eccentricity and inclinations' of those objects that were free from the gravitational effects of Jupiter, the dominant disturber of asteroidal orbits. In his analysis, Hirayama recognized several groups of asteroids, each of which shared common values of proper elements. This fact suggested that asteroids belonging to a group were produced from a single parent body. Hence Hirayama called those groupings 'families', and each one was identified by the name of a particular asteroid belonging to that family, such as the Koronis Family. Hirayama (1918) published his discovery in 1918.

After WWII, Dirk Brouwer (1902–1966; Fosmire 2014), another US highly-regarded celestial mechanician, recognized the importance of Hirayama's discovery, and Brouwer soon added several new families. It is now understood that asteroid

Fig. 2.13 A portrait of Hirayama Kiyotsugu (*Courtesy* National Astronomical Observatory of Japan)

families are dynamical evidence of mutual collisions between asteroids. In addition, impact events between celestial objects are now regarded one of the basic processes in the evolutionary history of the Solar System. However, Hirayama himself was reluctant to admit that asteroid families were collisional products, and he adhered to the idea that they resulted from autonomous explosions of individual asteroids.

The following are some relatively recent developments relating to asteroid families:

1. In 1993 there was an international symposium in Tokyo that celebrated the 75th anniversary of Hirayama's discovery of asteroid families (Kozai et al. 1993).
2. In 2001 a large conference was held in Palermo, Sicily, to memorialize the 200th Anniversary of the discovery of the first asteroid, Ceres, by Giuzeppe Piazzi. Out of 228 papers presented at that conference, 74 (~30%) discussed asteroid families.
3. In 2004 the Karin asteroid family was dynamically identified using a theory of family-formation (Nesvorny et al. 2002), and it also was shown that the spectroscopic nature of each of the member asteroids is consistent with the idea that this group has a common origin. This is a very young family, with an age of only 5.8 My.
4. Families have recently been detected among Trojan asteroids (e.g. see Beaugé and Roig 2001) and among Kuiper-belt objects orbiting the Sun beyond Pluto's orbit (Ragozzine and Brown 2007).

In the near future, therefore, it is very likely that the concept of asteroid families will become even more important in Solar System studies.

2.3.5 Studies of Variable Stars

As explained above, during the late nineteenth and early twentieth century the Japanese astronomical community of Japan was almost totally committed to research in classical astronomy. However, there was a unique individual who chose instead to explore astrophysics (Nakayama 1989). His name was Ichinohe Naozo (1872–1920; Sakuma 2002).

After studying (classical) astronomy at the University of Tokyo Ichinohe (Fig. 2.14) joined the staff of TAO, and then spent 1905–1907 in the USA, where the recent construction or refurbishing of large reflecting telescopes had led to a rapid rise in the popularity of astrophysics. Thus, Ichinohe was the first Japanese astronomer to make observations with these large telescopes, and his favorite targets were variable stars. Between 1906 and 1911 he published 25 research papers in the *Astronomical Journal,* the *Astrophysical Journal* and in *Astronomische Nachrichten*.

Table 2.1 provides a chronological list of the different variable stars that Ichinohe studied. As we can see, the first object that he observed was RY Cassiopeiae in 1906, while in the USA, and the last one was 27.1911 Cygni, in 1911, several years after he had returned to Japan.

The majority of Ichinohe's papers are reports on light curve measurements and period determination of these variable stars, but some papers that he wrote while in the USA included spectroscopic observations, and the discovery of a few new vari-

Fig. 2.14 A portrait of Ichinohe Naozo (after Nakayama 1989)

Table 2.1 Variable stars studied by Ichinohe

Year	Names of variable stars
1906	RY Cassiopeiae
1907	κ Cancri, μ Sagittarii, η Virginis, 120.1906 Persei, 24.1907 Monocerotis, RZ Draconis, 87.1906 Draconis, o Ceti (Mira)
1908	122.1906 Ceti, RU Camelopardalis
1909	S Sextantis, 43.1906 Crateris, μ Herculis
1910	26.1910 Scuti, 62.1907 Scuti, SZ Aquilae, Y Scuti
1911	TT Aquilae, 27.1911 Cygni

able stars. Back in Japan, he noticed that RT Scuti was variable in 1909, and this object was regarded as the first variable star discovered by a Japanese astronomer (although later confirmation negated Ichinohe's discovery).

After returning to Japan Ichinohe eagerly promoted the importance of astrophysical studies among his TAO colleagues. Around that time, there was active discussion about moving TAO outside central Tokyo, because of the increasingly-intolerable light pollution. Most TAO staff followed Terao's lead and supported the movement of the Observatory to Mitaka in the suburbs of Tokyo as a realistic plan, whereas Ichinohe vehemently believed that TAO should transfer to a remote high mountain site in northern Japan. After continuing conflict, Ichinohe eventually was forced to leave TAO and the astrophysical research activities that he had initiated ceased. This clearly indicates that the inertia of the times was so strong that Ichinohe's enthusiasm and research efforts were unable to affect any change in direction.

2.4 The Move to Mitaka and the Dawn of Astrophysical Studies

In 1923 the Tokyo district experienced the Great Kanto Earthquake and more than 100,000 people were killed or disappeared. TAO located in the central part of Tokyo also was heavily damaged, but for several years prior this earthquake the move of TAO to the Mitaka campus—about 20 km from central Tokyo—had been under way. The destruction of TAO facilities in central Tokyo by the earthquake accelerated the move to Mitaka.

2.4.1 The Introduction of Large Instruments

The movement to Mitaka had been almost completed by the end of 1924.[4] At this new site, the land area was widened by as much as 50 times than at the old TAO, and the sky was dark enough to observe faint celestial objects. Because of those reasons, two large telescopes were installed for the first time; such instruments would have been of no use at the light-polluted old campus.

2.4.1.1 The 65-cm Equatorial Refractor

One of these telescopes was a 65-cm equatorial refractor made by the famous Carl Zeiss Co. of Jena (Fig. 2.15), which was completed in 1929. It has generally been believed that Japan acquired this telescope from Germany as ‘reparations’ following WWI.

Scientific ‘first-light’ of this telescope was dedicated to the international observation campaign of a near-Earth asteroid Eros, because a close encounter with an asteroid of this kind was very time-critical. The purpose of the observations was to try and determine a precise value for the solar parallax (or the astronomical unit).

In spite of the expectations of TAO astronomers, this large telescope did not generate any important scientific results. The reasons of this failure are considered to be due to the large chromatic aberration of the telescope objective and the worldwide shift to 1 m–class reflectors for astrophysical research—a 65-cm refractor was simply too small for most up-to-date astrophysical observations.

Nevertheless, some useful observations were made with this telescope. Figure 2.16 shows stellar spectra of some early-type bright stars obtained with a prismatic spectrograph by Sekiguchi et al. (1939). We also see below two spectra through optical wedges exposed on the same plate for calibrations. These observations of nearly 30 objects were conducted to make quantitative analyses of hydrogen absorption lines for A-B type stars, and spectral profiles such as those of the Hβ-line shown in Fig. 2.16 were measured with a photo-densitometer.

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[4] The Mitaka campus is the same place where the present-day National Astronomical Observatory of Japan (NAOJ) is located.

Fig. 2.15 The 65 cm equatorial refractor installed at Mitaka campus in 1929. The main telescope is mounted in parallel with a 38 cm guiding telescope, having the same focal length of 10 m. Currently, the 65 cm telescope is on display at the NAOJ campus as an historic instrument (*Courtesy* National Astronomical Observatory of Japan)

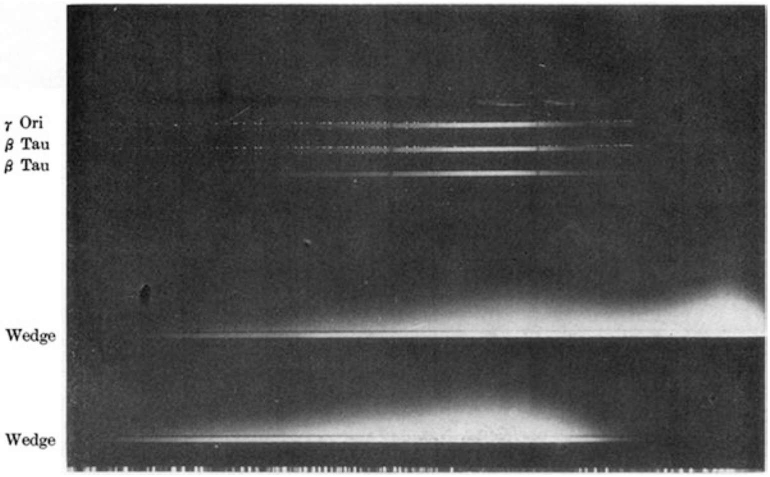

Fig. 2.16 Spectra of some of bright early-type stars taken in 1939 with a prismatic spectrograph attached to the 65 cm refractor (after Sekiguchi et al. 1939: 482)

2.4.1.2 The Einstein Tower

Another large telescope that soon was built at Mitaka was the so-called "Einstein Tower" (or the Solar Tower), which was completed around 1930 (see Fig. 2.17). This instrument was inspired by the Einstein Tower at the Potsdam Astrophysical Observatory at Babelsberg in Germany. This type of the solar telescope was constructed to prove observationally the gravitational red-shift of the light from the Sun, theoretically predicted by Einstein's General Theory of Relativity. A coelostat in the dome on the top of the tower directed the solar light down the tower to an underground darkroom where high-dispersion spectrographs were located for precise measurements. Although the solar telescope at Mitaka was never used to study the General Theory of Relativity, it provided post-WWII Japanese astronomers with good opportunities to gain experience in high-dispersion spectroscopy.

2.4.2 Einstein's Visit to Japan

Responding to the invitation from a certain Japanese publishing company, Albert Einstein came to Japan in 1922 (Kaneko 1981). The construction of the Einstein Tower at Mitaka may have had something to do with his visit to Japan, and the Japanese

Fig. 2.17 The Einstein Tower (Solar Tower) at Mitaka (*left*; *photograph* Tsuko Nakamura), and its 'twin' (*right*; Wikipedia Commons), build in 1924 at the Potsdam Astrophysical Observatory in Germany

Fig. 2.18 Einstein's visit to the University of Tokyo in 1922. He is seated in the middle of the front row (*Courtesy* University of Tokyo)

Einstein Tower also was actively promoted by Hirayama Shin, the second Director of TAO.[5] Erwin Freundlich (1885–1964; Kragh 2014) had built the Germany solar tower telescope at the Potsdam astrophysical observatory in 1924, and he succeeded in detecting the spectral red-shift predicted by Einstein (Freundlich 1924, 1925, 1930; Yokoo 1999). Figure 2.18 is a group photograph with Einstein in the center, taken at the campus of the University of Tokyo after a series of lectures that he gave.

Although the main purpose of Einstein's visit to Japan was to give lectures on his General Theory of Relativity to both professional scientists and the general public in various cities, he also discussed his relativistic theories with some Japanese physicists during his 40-day stay in Japan. According to Einstein's diary (Kaneko 1981), on his journey he made calculations of the electromagnetic energy tensor with Ishiwara Atsusi of Tohoku University, who was Einstein's colleague in Zürich back in 1913. Furthermore, in regards to proof of his General Theory of Relativity Einstein also showed strong interest in laboratory spectroscopic experiments relating to the Stark Effect that were being conducted by Kimura Masamichi of Kyoto University and his collaborators.

Excitement brought about by the Einstein's visit later stimulated Hagihara Yusuke, who was a student at the University of Tokyo at that time, to be involved in studies of relativistic celestial mechanics. Later, in 1960, he was awarded the James

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[5] Probably this was because after graduating from the University of Tokyo Hirayama Shin went to the Potsdam Astrophysical Observatory, where he studied astrophysics and particularly solar physics.

Craig Watson Medal. In the 1970s, Hagihara published nine books in five volumes overviewing the field of theoretical celestial mechanics (Hagihara 1970–1972, 1974–1976)

2.4.3 The Founding of the Astronomical Society of Japan

The founding of the Astronomical Society of Japan (ASJ) took place in 1908, more than 100 years ago. The initial purpose of launching the ASJ was heavily biased towards promotion and education of astronomy among ordinary people, rather than astronomical research. But this situation is understandable because at that time the number of professional astronomers in Japan was only about ten while the total membership of the ASJ was ~650.

Terao became the first President of the ASJ. It issued a monthly journal in Japanese titled *Tenmon Geppo* (*The Astronomical Herald*). On the other hand, the official English journal *Publication of Astronomical Society of Japan* (*PASJ*) started in 1949, and now counts more than 60 volumes, with 6 issues per year. The membership breakdown, as of 2008, was about ~2000 professional astronomers and ~1000 amateur astronomers.

2.4.4 The Science Data Book Rika Nenpyo

Here it may be worth mentioning the unique scientific data book called *Rika Nenpyo* (*Chronological Scientific Tables*), which has been published by TAO and the NAOJ every year (see Fig. 2.19). The first volume was issued in 1925 as a concise ephemeris book. It included up-to-date numerical data and tables from a range of scientific disciplines, such as astronomy, planetary sciences, meteorology, geosciences, physics, chemistry and biology. In 2005, a new chapter on the terrestrial environment was added, in response to the increased concern about global warming and chemical pollution.

The *Rika Nenpyo* seems to have originated from the *Annual Book* that was issued by the Bureau des Longitudes, Paris Observatory, because the book size and the item contents are very similar and the library at the University of Tokyo had continued to purchase the French book from around the time when the University was founded.

It is also likely that when the first TAO Director, Terao, was at Paris Observatory in the 1880s he was impressed by the *Annual Book* and later he imitated the style of that book when he launched the *Rika Nenpyo*. Incidentally, Paris Observatory largely changed the style of publication of the *Annual Book* during the 1970s. Therefore, the *Rika Nenpyo* may be regarded as a successor of the historic French *Annual Book*.

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東京天文臺編纂
理科年表
第一冊

大正十四年
1925

Fig. 2.19 (*Top left*) *Annuaire pour l'Anne* 1880 (*Annual Book for 1880*), issued by the Bureau des Longitude, Paris Observatory. (*Top right*) The first *Rika Nenpyo*, issued in 1925 from TAO. (*Bottom*) The *Rika Nenpyo* of 2008 (the 81st volume, 998 pages), published by the NAOJ

2.5 The Rise of Astrophysics in Japan

In the modern history of astronomy, it is a common recognition that the emergence of astrophysics[6] is a major theme (e.g., Herrmann 1984; Hoskin 1997), so that I believe that the problem of when the rise of astrophysics took place in each country deserves serious consideration.

In general, it is said that the world-wide rise of astrophysics happened in the second half of nineteenth century. In fact, according to the *Oxford English Dictionary*, the first use of the term 'astrophysics' is found in the book *The Midnight Sky*, which Edwin Dunkin (1821–1898) published in 1869. Thus one can understand that the concept of astrophysics was established around the middle of the nineteenth century.

2.5.1 A Quantitative Analysis of the Development of Astrophysics at the University of Tokyo

In this subsection, a statistical analysis is attempted to examine when activities of astrophysical research caught up with those of classical astronomy in Japan, by taking the University of Tokyo as a typical example. Accordingly, I surveyed papers published in Japan before WWII. From the book *Gakujutsu Taikan* (*Research Overview at the University of Tokyo*) published in 1942, I compiled a list which included ~580 papers published during 1880–1940, whose authors were mainly from the Department of Astronomy and TAO.

Then, in order to make my analysis quantitatively tractable and simple I adopt an approach of dichotomic analysis. Namely, each paper was classified into one of two groups, classical astronomy or astrophysics. The former included positional astronomy, astrometry, celestial mechanics, geodesy, and applied astronomy, etc. On the other hand, we refer to stellar spectroscopy and photometry, stellar structure and evolution, solar physics and relativistic astronomy as 'astrophysics'. Papers belonging to the two groups were assigned to 3-year bins and were counted.

Figure 2.20 shows a plot of the paper numbers per 3 year intervals as a function of the Christian year, where the filled circles (the CA curve) refer to classical astronomy, and the open squares (the AP curve) to astrophysics. The number ratio of astrophysics papers relative to the total number of papers, i.e. AP/(CA + AP), is shown by the open triangles, and the percentage values are given in the right-hand ordinate. This ratio can be regarded as a measure of activities in astrophysical research.

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[6] Astrophysics was referred to as the 'New Astronomy' at that time. According to Herrmann (1984) it was Johann Karl Friedrich Zöllner, the German physicist and a pioneer of astronomical photometry, who first suggested the use of the term 'astrophysics'.

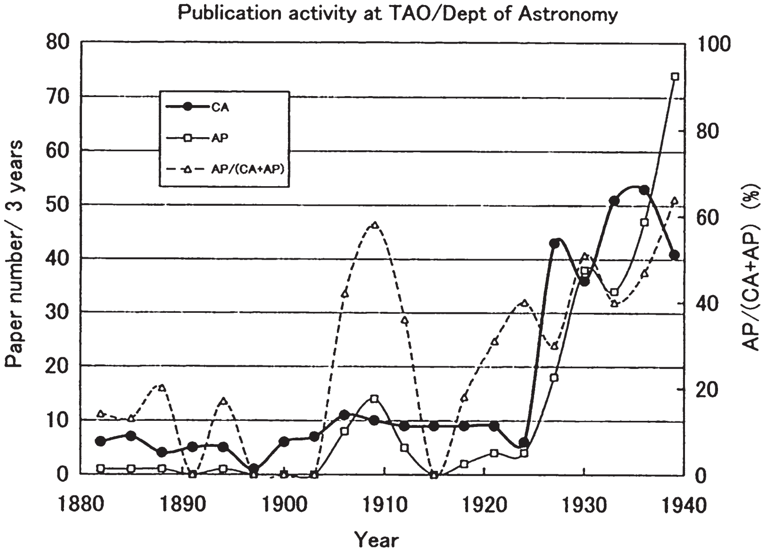

Fig. 2.20 A plot showing the chronological evolution of research publications by staff in the Department of Astronomy at the University of Tokyo. The CA and AP curves respectively show the numbers of papers in classical astronomy and astrophysics (after Nakamura 2008)

From Fig. 2.20 it can be seen that research activities were a fairly low level for both classical astronomy and astrophysics until the 1920s. This period corresponds to the time when the first TAO Director, Terao, struggled with few staff and little funding. The temporary rise in astrophysical output for several years from around 1910 was due to the papers on variable stars by Ichinohe (as described in Sect. 2.3.5). Then after 1930, one can see that both the total number of papers and astrophysical activities increased rapidly and by the mid-1930s the number of papers on astrophysics almost rivalled those on classical astronomy. From this analysis, therefore, we may conclude that most astrophysical developments in Japan took place after 1930.

The rapid rise in the total number of papers after 1930 can be interpreted as follows: one reason is the increase in the number of research staff at the University of Tokyo. But another important reason was the emergence of nationalism in Japan. Because of the prevailing militarism among the Japanese before WWII, Japan gradually became isolated from the international community, and as a result both the Government and individual scientists—including astronomers—strongly encouraged original research and stimulated autonomous studies. I suppose that this is a major reason for the rapid increase in the papers published and for the rise of astrophysics in Japan during the 1940s; such a situation seems to be unique to Japan.

It is therefore interesting to compare the situation in Japan with the world trend. The diagram in Fig. 2.21 shows the changing number of active professional astronomers in the world, given in the book by Struve and Zeberg (1962).

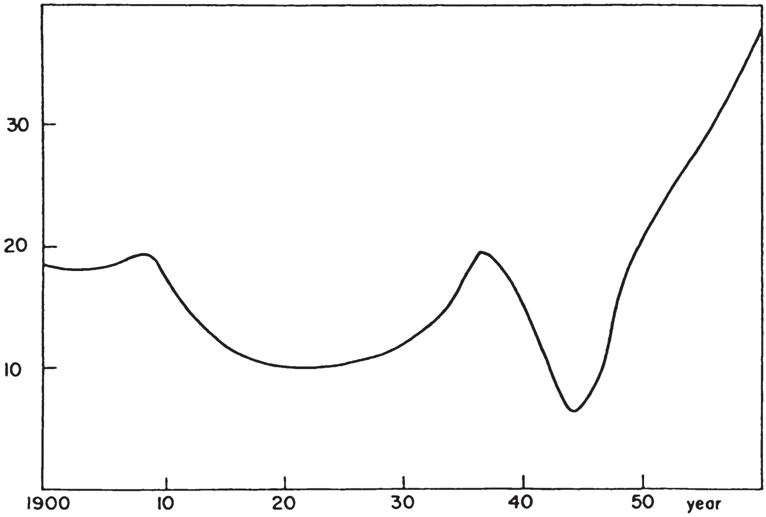

Fig. 2.21 Number evolution of active astronomers; the ordinate is expressed by the unit of 100 astronomers (after Struve and Zeberg 1962)

The ordinate expresses the number of astronomers per one hundred persons. Since the number of astronomers is approximately proportional to the number of papers published, we may compare Fig. 2.20 for Japan with Fig. 2.21, at least in a qualitative sense. The wide dip of the curve centered around 1920 shown in Fig. 2.21 was caused by WWI (1914–1918). In this war, both the defeated countries and the victorious allies suffered from a long-term depression. On the other hand, WWI had little effect on Japan. I suppose that this difference in the situation between Japan and other countries is reflected in the different curves shown in Figs. 2.20 and 2.21.

Finally, I must admit that the analysis presented in this section is obviously a one-sided view and may be somewhat oversimplified. Thus, it may be unfair for us to compare—with equal weighting—the monumental paper by Hirayama announcing the discovery of asteroid families with a paper reporting, say, astrometric measurements of known comets. Nevertheless, I believe that the analysis presented here at least indicates the overall chronological trend of astrophysical research in Japan.

2.5.2 The Riken Institute and Spectroscopy

The Riken was established in 1917 as a non-government Institute of physics and chemistry, with abundant research funding, thanks largely to studies of nuclear physics and the cyclotron. The laboratory of spectroscopy at the Riken Institute was headed by the physicist Takamine Toshio (1885–1959), who played a leading role in high precision spectroscopy of the Stark Effect, and also studied infrared and ultraviolet spectra. Takamine also collaborated with TAO astronomers by applying the results of laboratory spectroscopy to astrophysical observations (DeVorkin 2002). This helped TAO astronomers conduct serious stellar spectroscopy with large telescopes after WWII.

2.5.3 Astronomy at Kyoto and Tohoku Universities

Prior to 1920 the University of Tokyo was the only one in Japan that had a Department of Astronomy dedicated to astronomical education and research. Then in 1921 another Department for Astronomy was founded, at Kyoto University, and led by Shinjo Shinzo (Kogure 2008).

After studying physics at the University of Tokyo, Shinjo (1873–1938; Fig. 2.22) got a position in the Department of Physics at Kyoto University. He then spent 1905–1907 at the University of Göttingen in Germany where, under the expert supervision of Karl Schwarzschild (1873–1916; Habison 2014), he studied the theory of stellar atmospheres and Einstein's General Theory of Relativity as applied to the internal structure of stars. In 1921 the Ministry of Education approved the establishment of a new Department of Astronomy at Kyoto University, and Shinjo was nominated as the founding Professor. Just like

Fig. 2.22 An undated photograph of Shinjo Shinzo (*Courtesy* Kyoto University)

Terao in Tokyo (Sect. 3.2), Shinjo also was so busy with administrative duties and educating students in astronomy that he failed to publish any significant research on modern astronomy. However, his works on the history of the ancient calendars of China (Shinjo 1928) are cited, often now. Fortunately, the astrophysics that Shinjo had learnt in Germany later was developed by his disciples, such as Araki Toshima (1897–1978) and Miyamoto Shotaro (1912–1992). The Department of Astronomy at Kyoto University is unique in that some of its graduates later became eminent specialists in the history of astronomy, as perhaps best represented by Yabuuchi Kiyoshi (e.g., see Yabuuchi 1969). In 1968 Kyoto University opened the Hida Observatory on a high mountain in Japan's main island, Honshu. This Observatory is equipped with a 65-cm refractor, which was used mainly for research on Martian meteorology.

Although Tohoku University was founded in 1911, it was only in 1934 that this University acquired a Department of Astronomy (Takeuchi and Seki 2008). The early staff in astronomy at this University, just like those at Kyoto University, were mainly graduates from the Department of Physics and Astronomy at the University of Tokyo. Matsukuma Takehiko (1890–1950) was the first Professor of Astronomy at Tohoku University, and it seems that because of insufficient funding and limited staff the astronomers at this University have concentrated on theoretical astronomy, such as celestial mechanics, the internal structure of stars, fundamental processes in the interstellar medium and galactic dynamics. However, Matsukuma's equation (a special class of non-linear differential equations) that he proposed in 1930 as a means to calculate the gravitational potential to explain motions of member stars in a globular cluster, is now being seriously reconsidered.

Nowadays, the University of Tokyo, the NAOJ, Kyoto University, Tohoku University and Departments of Astronomy and Physics at other universities and institutes in Japan have good collaborative working relations in regards to personnel and the funding of major national astronomy projects.

2.5.4 Post-WWII Developments led by Hagihara Yusuke

Astronomical research from the outbreak of WWII to the surrender of Japan is summarized in the book *Nihon Tenmongaku-no Gaikan 1940–1945* (*Overview of Japanese Astronomy during 1940–1945*; Astronomical Society of Japan 1951). In 1946, Hagihara Yusuke (1897–1979; Fig. 2.23; Kozai 2014a) was nominated to be the Director of TAO. Under his strong leadership, TAO was able to recover rapidly from the damage suffered during WWII. Although Hagihara (1970–1972, 1974–1976) was an eminent celestial mechanician, he concentrated on developing astrophysical studies in Japan (Nakamura et al. 2008). His efforts resulted in the construction of a 74-in. reflector in 1960, the

Fig. 2.23 Hagihara Yusuke, the Fifth Director of Tokyo Astronomical Observatory (*Courtesy* National Astronomical Observatory of Japan)

first large telescope erected in Japan for astrophysical observations, and in fostering radio astronomical research at TAO—see the next two chapters in this book (Tajima 2017; Orchiston and Ishiguro 2017). In 1961 he was elected the Vice-President of the International Astronomical Union (Kozai 1979).

Acknowledgements My thanks are due to Suzanne Débarbat of Paris Observatory, who informed me of the location of the remaining buildings of the Montsouris Astronomical School. I also thank Sakuma Seiichi and the late Yokoo Hiromitsu for providing me with some valuable information and literature.

References

Allen, C. (2005). The Mexican expedition to observe the 8 December 1874 transit of Venus in Japan. In D.W. Kurtz (Ed.), *Transits of Venus: New Views of the Solar System and Galaxy* pp. 111–123. Cambridge: Cambridge University Press.

Astronomical Society of Japan (1951). *Nihon Tenmongaku-no Gaikan* (*Overview of Japanese Astronomy during 1940–1945*). Tokyo: Japan Society of Promotion of Science. (in Japanese).

Astronomical Society of Japan (2008). *One Hundred Years of Astronomy in Japan.* Tokyo: Astronomical Society of Japan. (in Japanese).

Bartholomew, J.R. (1989). *The Formation of Science in Japan*. New Haven: Yale University Press.

Baum, R. (2014). Brown, Ernest William. In T. Hockey et al., pp. 321–322.

Beaugé, C., & Roig, F. (2001). A semianalytical model for the motion of the Trojan asteroids: proper elements and families. *Icarus,* 153, 391–415.

Boistel, G., Lamy, J., & Le Lay, C. (Eds.) (2010). *Jérôme Lalande (1732–1807). Une Trajectoire Scientifique*. Rennes, Presses Universitaires de Rennes. (in French).

Brosche, P. (2000). Küstner's observations of 1884–5: the turning point in the empirical establishment of polar motion. In S. Dick, D. McCarthy, & B. Luzum (Eds.), *Polar Motion: Historical and Scientific Problems,* pp. 101–108. San Francisco: Astronomical Society of the Pacific.

Coyne, G.V. (2014). Verbiest, Ferdinand. In T. Hockey et al., pp. 2227–2229.

Débarbat, S. (2014). Tisserand, François-Félix. In T. Hockey et al., pp. 2160–2162.

Débarbat, S., & Launay, F. (2006). The 1874 transit of Venus observed in Japan by the French, and associated relics. *Journal of Astronomical History and Heritage, 9,* 167–171.

DeVorkin, D. (2002). Toshio Takanime's contact with Western astrophysics. In S.M.R. Ansari (Ed.), *History of Oriental Astronomy,* pp. 145–157. Dordrecht: Kluwer.

Dick, S.J., Orchiston, W., & Love, T. (1998). Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy,* 29, 221–255.

Fosmire, M. (2014). Brouwer, Dirk. In T. Hockey et al., pp. 320–321.

Freundlich, E. (1924). Das neue Einstein-observatorium in Potsdam. *Die Sterne,* 5, 33–41. (in German).

Freundlich, E. (1925). Das neue Einstein-observatorium. *Zeitschrift für Physik,* 26, 102–105. (in German).

Freundlich, E. (1930). Über den Verlauf der Wellenlängen der Fraunhoferschen Linien längs der Sonnenoberfläche. *Zeitschrift für Astrophysik,* 1, 43–57. (in German).

Fukushima, N. 2014. Kimura, Hisashi. In T. Hockey et al., pp. 1204–1205.

Grillot, S. (2014). Mouchez, Ernest Amédée Barthélémy. In T. Hockey et al., pp. 1528–1529.

Habison, P. (2014). Schwarzschild, Karl. In T. Hockey et al., pp. 1960–1963.

Hagihara, Y. (1970–1972). *Celestial Mechanics. Volumes 1, 2(I), and 2(II)* (revision of the 1947 edition). Cambridge, MA: MIT Press.

Hagihara, Y. (1974–1976). *Celestial Mechanics. Volumes 3(I), 3(II), 4(I), 4(II), 5(I), 5(II)*. Tokyo: Japan Society for the Promotion of Science.

Herrmann, D.T. (1984). *The History of Astronomy from Herschel to Hertzsprung.* Cambridge: Cambridge University Press.

Hirayama, K. (1918). Groups of asteroids probably of common origin. *Astronomical Journal,* 31, 185–188.

Hirayama, S., Hirayama, K., & Sotome, K. (1910). Report on the total eclipse of the Sun observed at Padang, Sumatra on May 18, 1901. *Annales de l'Observatoire Astronomique de Tokyo,* IV, 1–26.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hoskin, M. (Ed.), (1997). *The Cambridge Illustrated History of Astronomy*. Cambridge: Cambridge University Press.

Kaneko, T. (1981). *Einstein Shock to Taisho Era* (2 Vols). Tokyo: Kawade-shobo Shinsha Publishing Co.. (in Japanese).

Kimura, H. (1902). A new annual term in the variation of latitude independent of the components of the pole's motion. *Astronomical Journal,* 22, 107–108. (Also see) *Astronomische Nachrichten,* 158, 234–240.

Kogure, T. (2008). Origin and tradition at Kyoto University. In *One Hundred Years of Astronomy in Japan,* pp. 27–35. Tokyo: Astronomical Society of Japan. (in Japanese).

Kozai, Y. (1979). Yusuke Hagihara. *Quarterly Journal of the Royal Astronomical Soc*iety, 20(3), 325–328.

Kozai, Y. (2014a). Hagihara, Yusuke. In T. Hockey et al., pp. 880–882.

Kozai, Y. (2014b). Hirayama, Kiyotsuga. In T. Hockey et al., pp. 986–987.

Kozai, Y., et al. (1993). *Seventy-five Years of Hirayama Asteroid Families: The Role of Collisions in the Solar System History*. San Francisco: Astronomical Society of the Pacific (PASP Conf. Series, No.63).

Kragh, H. (2014). Freundlich, Erwin. In T. Hockey et al., pp. 757–758.

Lalande, J.J. (1771). *Astronomie.* Paris: la Veuve Desaint. (in French).

Launay, F. (2012). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. New York: Springer.

Launay, F., & Hingley, P.D. (2005). Jules Janssen's 'Revolver Photographique' and its British derivative, 'The Janssen Slide'. *Journal for the History of Astronomy,* 36, 57–79.

Luzum, B. (2014). Küstner, Karl Friedrich. In T. Hockey et al., pp. 1257–1258.

Mouchez, E.A.B. (1890). *Rapport annual sur l'Etat de l'Observatoire de Paris, 1890–91*, Paris: l'Observatoire de Paris.

Nakamura, T. (2008). The dawn of Japanese modern astronomy. In *One Hundred Years of Astronomy in Japan,* pp. 3–12. Tokyo: Astronomical Society of Japan. (in Japanese).

Nakamura, T. (2016). A French astronomer of multiple misfortune, Émile Lépissier (1826–1874) and Japan. *Tenmon Geppo*, 109, 799–810 (in Japanese, with English abstract).

Nakamura, T., & Orchiston W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nakamura, T., Yokoo, H., & Unno, W. (2008). The first-half century of astronomy in Tokyo. In *One Hundred Years of Astronomy in Japan,* pp. 3–12, 13–20. Tokyo: Astronomical Society of Japan (in Japanese).

Nakayama, S. (1969). *A History of Japanese Astronomy*. Cambridge (Mass.): Harvard University Press.

Nakayama, S. (1989). *Biography of Astronomer Ichonohe Naozo.* Tokyo: Libro-port Co.. (in Japanese).

Nesvorny, D., Bottke, W.F., Dones, L., & Levison, H.F. (2002). The recent breakup of an asteroid in the main-belt region. *Nature,* 417, 720–721.

Orchiston, W., & Ishiguro, M. (2017). The early development of Japanese radio astronomy. In T. Nakamura, & W. Orchiston (2017).

Orchiston, W., & Pearson, J. (2017). American observations of the 22 February 1898 total solar eclipse from Jeur, India. In T. Nakamura, & W. Orchiston.

Paris Observatory (1890). Rapport annuel sur l'État de l'Observatoire de Paris pour l'année 1890/1891. Paris: l'Observatoire de Paris. (in French).

Pearson, J., & Orchiston, W. (2017). American observations of the 16 May 1901 total solar eclipse from Padang, Dutch East Indies. In T. Nakamura, & W. Orchiston.

Ragozzine, D., & Brown, M.E. (2007). Candidate members and age estimate of the Family of Kuiper Belt Object 2003 EL61. *Astronomical Journal,* 134, 2160–2167.

Rubinger, R., & Mendenhall, T.C. II (1989). *An American Scientist in Early Meiji Japan: The Autobiographical Notes of Thomas C. Mendenhall.* Honolulu: University of Hawaii Press (Asian Studies at Hawaii, No. 35).

Saito, K. (1974). The "Black Ship" of science: the transit of Venus a hundred years ago. *Tenmon Geppou,* 67*,* 50–56. (in Japanese).

Saito, K., & Shinozawa, S. (1972). On the transit of Venus observations of 1874 in Japan: Part I. *Tokyo Tenmondai-Ho,* 16, 72–162. (in Japanese).

Saito, K., & Shinozawa, S. (1973). On the transit of Venus observations of 1874 in Japan: Part II. *Tokyo Tenmondai-ho,* 16, 259–385. (in Japanese).

Sakuma, S. (2002). Japan's first variable star observer, Dr. Naozo Ichinohe, *Journal of the American Association of Variable Star Observers,* 31, 63–64.

Sekiguchi, R., Okuda, T., & Shimizu T. (1939). Note on the spectrophotometric study of hydrogen line in early type stars. *Tokyo Astronomical Bulletin,* No. 481–483.

Shinjo, S. (1928). *Toyo Tenmongaku-shi Kenkyo* (*Studies on the History of Oriental Astronomy*). Kyoto: Kobundo Publishing Company. (in Japanese).

Struve, O., & Zeberg, V. (1962). *Astronomy of the 20th Century.* New York: MacMillan.

Tajima, T. (2017). The National Astronomical Observatory of Japan and post-war Japanese optical astronomy. In T. Nakamura, & W. Orchiston.

Takeuchi, M., & Seki, M, (2008). Foundation of the Department of Astronomy at Tohoku University. In *One Hundred Years of Astronomy in Japan,* pp. 37–42. Tokyo: Astronomical Society of Japan. (in Japanese).

Terao, H. (1890). Communication sur les travaux géodésiques au Japon. *Proceedings of the International Geodetic Congress*. Berlin: von Georg Reimer (Annex B-XXII) (in French).

Terao, H., & Hirayama, S. (1910). Report on the total eclipse of the Sun observed at Jeur, in western India on January 22, 1898. *Annales de l'Observatoire Astronomique de Tokyo,* III, 1–12.

Trachet, T. (2014). Poincaré, Jules-Henri. In T. Hockey et al., pp. 1741–1742.

University of Tokyo (1942). *Gakujutsu Taikan* (*Research Overview of the University of Tokyo*). Tokyo: University of Tokyo. (in Japanese).

Verdun, A. (2014). Euler, Leonhard. In T. Hockey et al., pp. 676–680.

Wako, Y. (1970). Interpretation of Kimura's annual Z-term. *Publications of the Astronomical Society of Japan,* 22, 525–544.

Yabuuchi, K. (1969). *Chugoku no Tenmon Rekihou* (*Chinese Calendrical Sciences*). Tokyo: Heibon-sha. (in Japanese).

Yokoo H. (1999). E.F. Freundlich and his Einstein Tower. *Tenmon-Geppou*, 92, 452–453 (in Japanese, with English abstract).

Yoshida, S., & Nakamura, T. (2017). Hirayama Kiyotsugu: discoverer of asteroid families. In T. Nakamura, & W. Orchiston.

Chapter 3
Hirayama Kiyotsugu: Discoverer of Asteroid Families

Seiko Yoshida and Tsuko Nakamura

3.1 Introduction

According to the history of astronomy in Japan after the Meiji Restoration Japanese observational and theoretical researches received an international boost with two discoveries. One was the Z-term in latitude variation (1902) discovered by Kimura Hisashi (1870–1943), and the other was the existence of families of asteroids (1918b) by Hirayama Kiyotsugu (1874–1943; Fig. 3.1), which is the main theme of this paper. The Z-term has now passed into the realm of classical history, although it played an important role during the early development stage of Japanese astronomical studies (Wako 1967). On the other hand, the Hirayama families have continued to attract the interest of the international astronomical community through to the present day (e.g. see Bottke et al. 2002; Fujiwara 1982; Gehrels 1979; Kozai et al. 1994).

When modern Western astronomy was introduced into Japan, we Japanese met for the first time not only the high skills of positional astronomy but also celestial mechanics and early developing astrophysics. Kimura and Hirayama were both students of Terao Hisashi (1855–1923), who was the first Director of Tokyo Astronomical Observatory at Azabu (TAO) and the first Professor of Astronomy at the Tokyo Imperial University (TIU). Terao taught them classical astronomy and introductory celestial mechanics.

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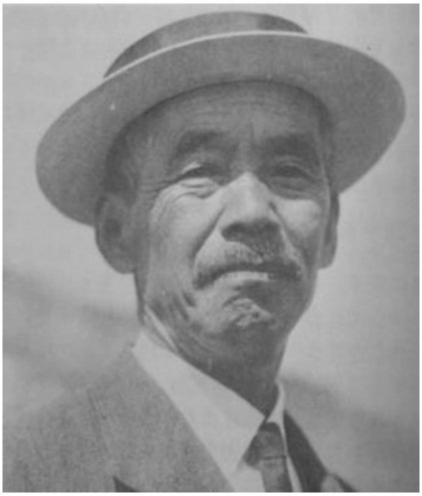

Fig. 3.1 A portrait of Hirayama Kiyotsugu (after Hirose Hideo 1979; *Courtesy* Abe Akira)

Hirayama opened up a new field in Japanese astronomical studies, research on the motion of asteroids using advanced techniques of celestial mechanics such as secular perturbation theories. On the other hand, his later studies in astrophysics eventually resulted in failure in spite of his eagerness. In this paper, we will explain his early interests and investigations in astronomy, detail his discovery of the asteroid families, relate subsequent changes in his astronomical interests, and finally overview his other research achievements.

3.2 The Hirayama Families of Asteroids

Prior to the discovery of 1918, Hirayama's approach to the families of asteroids was basically statistical, but when he began investigating unusual characteristics noticed in asteroidal data his focus shifted to advanced dynamics of secular perturbations.

3.2.1 A Statistical Approach as the First Step of Discovery

In the opening paragraph of his hallmark 1918 paper which was published in the *Astronomical Journal*, Hirayama (1918b: 185; our italics) gives us a clue about the discovery:

> On examining the distributions of the asteroids with respect to their orbital elements, particularly to the mean motion (n), the inclination (i) and the eccentricity (e), we notice condensations here and there. In general, they seem to be due to chance. *But there are some which are too conspicuous to be accounted for by the laws of probability alone.*

Table 3.1 Classification table of orbits with respect to the inclination (after Hirayama 1918b: 185)

i (°)	Actual number	Total	Proportional number	Diff.	Corr. prop. no.	Diff.
0–4	16	149	7	+9	5	+11
4–8	6	213	10	–4	7	–1
8–12	6	191	9	−3	6	0
12–16	6	131	6	0	4	+2
16–20	3	55	3	0	2	+1
>20	0	48	2	–2	2	–2
Sum	37	787	37	0	26	+11

Upon classifying 37 asteroids with daily mean motions between 720″ and 740″ into six regions of inclination (*i*), Hirayama (ibid.) noticed that 16 of the orbits in the $i = 0° - 4°$ region were surely "… out of proportion."

He first assumed the existence of a physically-connected asteroid group, and tentatively excluded those objects in that region. Computing the proportional number (the number calculated under the assumption of a flat distribution) using the remaining asteroids (37–16 = 21), which was called the 'corrected proportional number' in the column of Table 3.1, he found that the number of the asteroids belonging to the group should probably be 11. Next, he classified these 16 asteroids by eccentricity, and again saw a non-proportionality between 0° and 4° of the angle of eccentricity. In all, 10 orbits were out of proportion. He was then convinced of the existence of a group of asteroids, which differed from the already-established Trojan Group (Hirayama 1918b).

3.2.2 *Discovery of the Asteroid Families*

Furthermore, taking the 16 asteroids which were out of proportion in the region near $n = 730''$, he plotted the poles of their orbital planes on the *p*-*q* plane, and noticed that 15 asteroids were located on the circumference of a circle (see the left graph in Fig. 3.2). At the same time, 13 objects were distributed on another circumference of the *u*-*v* plane relating to the eccentricity (the right graph in Fig. 3.2).

Here are given the definitions of *p, q* as functions of inclination (*i*) and nodal longitude (*Ω*), and *u, v* as those of eccentricity (*e*) and longitude of perihelion (ϖ):

$$p = \tan i \sin\Omega = p' + N\sin(ht + \beta) \qquad u = e\sin\varpi = ku' + M\sin(gt + \alpha)$$

$$q = \tan i \cos\Omega = q' + N\cos(ht + \beta) \qquad v = e\cos\varpi = kv' + M\cos(gt + \alpha)$$

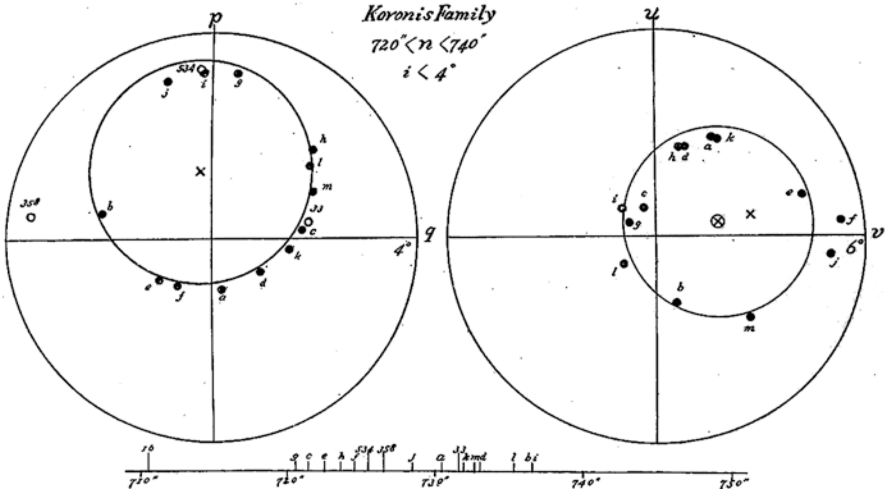

Fig. 3.2 Inclination and eccentricity diagrams showing the grouping of asteroids as a family (after Hirayama 1918b: 186)

where the rightmost terms of *p, q* represent a constant-velocity (*h*) circular motion with its radius of *N* and center at *p*', *q*', and the *u* and *v* equations are for a similar circular motion on the *u*-*v* plane. These equations can be derived from a general theory of planetary secular perturbations, and *N* and *M* are obtained as arbitrary constants in the solution of the relevant differential equations. Hirayama applied these equations to asteroid motions, with Jupiter as the main perturbing body, and for the first time was able to explain theoretically the circular distributions of the observed asteroids on the *p*-*q* and *u*-*v* planes from a dynamical viewpoint.

As to the formation process of the asteroid families, Hirayama imagined as follows: an asteroid was broken into a number of fragments at a time in the past. Since the additional velocities given to the fragments were small compared with that of the original body, each of the fragments initially stayed close each other. But after a long elapse of time, under the perturbation by Jupiter, the points *p* and *q* of the fragments were scattered irregularly, due to the term of $ht + \beta$, along the whole circumference of a circle with a radius approximately equal to *N* (Hirayama 1918b).

Hirayama had little doubt that there was a physical relationship between those fragmentary asteroids, so he named the asteroids in such a group a *family*. In his 1918 paper he announced three families (Koronis, Eos, Themis) from 790 asteroids.

At this point, he did not yet call *N* and *M* the proper inclination and the proper eccentricity respectively, but recognized the importance of those quantities (Fig. 3.2). This indicates that he directed his attention not to the osculating (i.e. observed) orbital elements but to the proper elements (Hirayama 1918b, 1919, 1920).

At that time, it was not easy to judge whether or not a particular asteroid belonged to a family (and the situation is more or less the same even today), so Hirayama needed some systematic criteria of judgment. He did not use the terminology "… the invariable elements …" (meaning, the proper elements) until the appearance of his 1922 paper, titled "Families of Asteroids". This was a theoretical paper based upon secular perturbations, and among 950 asteroids he found the following five families, all with small inclinations and eccentricities: Koronis, Eos, Themis, Maria and Flora.

At this stage, Hirayama avoided including some groups of asteroids with large inclinations and eccentricities as families, but in 1927, after careful examination, he added two new families, Phocaea and Pallas, both characterized by large inclinations and eccentricities (Hirayama 1927).

Initially, Hirayama (1922) only mentioned that the asteroids belonging to a group were disrupted by some unknown cause. Then, to explain the destruction of the original asteroid, he adopted an explosion theory whereby the parent body was broken into individual asteroids belonging to the one family (Hirayama 1927). However, in a later paper (Hirayama 1935a), he also added as a possible cause collisions between asteroids (see Yoshida and Sugiyama 1997; Yoshida 2001).

3.2.3 Responses to and Evaluations of Hirayama's Discovery

Hirayama devised a method of finding the asteroids belonging to a single family by using invariable elements, that is, their proper inclination and eccentricities. His discovery of asteroid families was warmly received by the international astronomical community, although it took some time before papers by other authors began to appear that made reference to the 'Hirayama families' (e.g. Barton 1924; Recht 1934).

Dirk Brouwer (1902–1966; Fosmire 2014),[1] a leading astronomer who specialized in celestial mechanics, mentioned that his work was a modification of Hirayama's research. Specifically, what he did (Brouwer 1951) was to develop the secular variation theory of the orbital elements of asteroids based upon Hirayama's papers. Boosted by Brouwer's investigation, many planetary astronomers then directed their attention to asteroid families. In 1993, an international conference was held in Tokyo to commemorate the 75th anniversary of the discovery of the Hirayama Families and the proceedings was published by the Astronomical Society of the Pacific (Kozai et al. 1994).

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[1] Hirayama (1933b) remembers that he first met Dirk Brouwer in 1932 at the 4th IAU Meeting, and that he also met William Wallace Campbell (1862–1938; Tenn 2014) again at this meeting (Hirayama 1933a). When they first met, around 1916, Campbell told him about the abnormal variable star SS Cygni (Hirayama 1917). This star had a strong impact on him and subsequently motivated him to launch research on variable stars (Hirayama 1933b).

Hagihara Yusuke (1897–1979; Kozai 2014), well known as an authority on theoretical celestial mechanics, reviewed Hirayama's work in the obituary that he published in *Monthly Notices of the Royal Astronomical Society* in 1947. He emphasized the excellence of Hirayama's technique of celestial mechanics. Later, Nakayama Shigeru (1981) wrote a short article for *the Dictionary of Scientific Biography*, saying that "Based on statistics as well as on the known principles of celestial mechanics, Hirayama's hypothesis was a rare accomplishment, considering the level of research in astronomy in Japan at that time." In an attempt to correct the wrong understanding by some overseas astronomers that Hirayama found groupings of asteroids simply by plotting the *osculating* orbital elements on the p–q and u–v diagrams, Kozai (1994) showed that Hirayama actually discovered the asteroid families by using proper elements earlier than Brouwer did.

3.3 Why could Hirayama Discover the Families of Asteroids?

In this section we analyze in more detail the discovery situation of the asteroid families, relating it to Hirayama's life and academic circumstances. We explain why he could find the condensations of asteroids in the data. After reviewing the academic milieu of that era we mention three background circumstances to his discovery, and try to reconstruct the early stage when he first noticed unusual characteristics in the orbital elements of the asteroids.

3.3.1 The Academic Milieu of that era

Hirayama was born on 13 October 1874, in the city of Sendai in northern Japan. He was the only son of a civil engineer and was educated at Sendai High School under the old educational system up to the age of 20 (Fig. 3.3). In 1894 he entered the Tokyo Imperial University (henceforth TIU). Further biographical details are supplied in Appendix 1.1.

Around that time, a new phenomenon called latitude variation was discovered in Germany and the USA, and in 1894 the International Association of Geodesy asked Japan to found a latitude observatory as part of an international geodetic collaboration, in order to study and reveal the worldwide nature of latitude variation. Responding to this movement, the Mizusawa Latitude Observatory was established in 1899, headed by the young Director, Kimura Hisashi (1870–1943; Fukushima 2014), who was just 29 years of age. Subsequently, Kimura discovered the Z-term in latitude variation. Hence we may say that Japanese astronomy was much influenced by geodesic interests in those days. Observations of latitude variation then started at the Tokyo Astronomical Observatory (henceforth TAO) in order to check Mizusawa's results, and 25-year old Hirayama was one of the observers.

Fig. 3.3 *Sendai Nikou* (The Second High School—the name used under the old educational system). This photograph was probably taken in the early 1890s, and Hirayama is in the second row from the bottom and third from the left (*Courtesy* Tomita Yoshio)

Towards the end of the nineteenth century, the level of astronomical research in Japan was catching up with that of the leading European countries: courses in astronomy were first established at the TIU in 1877, and the TAO was founded in 1888. Early astronomical research at the University and at the TAO was heavily biased towards positional astronomy and geodesy. Since the Department of Astronomy in the Science College at the TIU maintained close relations with the Departments of Physics and Mathematics, staff and students in astronomy could share lectures and share a common cultural background with people in these latter departments.

When the curriculum was reformed in 1897, Hirayama Shin (1867–1945) lectured on astrophysics, while TAO Director, Terao, taught celestial mechanics. In addition, Kimura and Hirayama were taught by Tanakadate Aikitsu (1856–1952) and Nagaoka Hantaro (1865–1950), who were respectively an experimental physicist and a theoretical physicist in the Department of Physics. Tanakadate was one of Kimura's academic superintendents. Details of subsequent curriculum reforms in astronomy during the early twentieth century are presented in Appendix 1.2.

3.3.2 Why did Hirayama Notice Concentrations of Asteroids?

Here we discuss three aspects of the likely background that led Hirayama to the discovery of the asteroid families. First, he had mastered the famous textbook *Traité de Mécanique Céleste* (Tisserand 1889–1896) before he went to the USA. Secondly, he was able to study there as E.W. Brown's Research Assistant. Thirdly, he first noticed unusual characteristics in the orbital elements of asteroids in the course of elucidating the nature of the Kirkwood gaps. In the following subsections we will examine these three points more closely.

3.3.2.1 Early Background in Mathematical and Astronomical Training

We would say that if Hirayama had not reached an advanced level of knowledge of celestial mechanics (including secular perturbation theory) before he went to the USA, he could not have developed his theory of asteroid families; it was obviously insufficient only to work under a famous astronomer like Professor Ernest William Brown (1866–1938; Baum 2014). We stress the importance of his encounter with the famous text book on celestial mechanics, *Traité de Mécanique Céleste*, after his graduation from TIU in 1897. This masterpiece by the reputable French astronomer François-Félix Tisserand (1845–1896; Débarbat 2014) was published between 1889 and 1896, and Hirayama would quickly have learnt a lot from its careful reading.

In addition to theoretical studies, Hirayama received practical training in both astronomy and astrometry. Entering the graduate school at the TIU in 1897, he began his scientific career as an observer of the latitude observation, and then went to Sumatra (Indonesia) as a member of the 1901 Japanese solar eclipse expedition. Because the TAO library lacked some important star catalogues, Hirayama determined the declinations and proper motions of 246 stars himself, and published his results in the form of a catalogue (Hirayama 1907b).

3.3.2.2 New Interests Motivated by E.W. Brown

From 1907 onward, Hirayama's interests gradually changed from observational astronomy to theoretical astronomy, and as Kimura's successor he obtained a position as a teacher in the Engineering School attached to the General Staff Office of the Japanese Army where he taught practical astronomy from 1897 to 1901. In 1906 he was appointed an Associate Professor in the Department of Astronomy at the TIU, where he lectured students on observational and practical astronomy. Two years later, he was appointed for a further period at the TAO, where he assisted the Director, Terao, in computing the ephemerides of the Sun, Moon and the planets, for which the TAO had a responsibility to the Government. This led him to take an interest in the historical calendars of East Asia later in his career.

For Hirayama, this new tour of duty proved a turning point, and in 1915 he arranged through the U.S. Naval Observatory to go to Yale University in order to study celestial mechanics for calendar-making under Brown who had already published his famous lunar theory (in 1908) and his libration theory (in 1912). When Hirayama arrived Brown was busy computing tables of the motion of the Moon and Hirayama helped with the tedious calculations and was acknowledged by Brown (1919: 140) when this three volume work finally was published.

Hirayama was at Yale University from 1915 to 1917, and according to his reminiscences Brown suggested to him that one of the most interesting research topics in Solar System astronomy would be to research the distribution of the mean motion of the asteroids (Brown et al. 1922).[2] Therefore, it was Brown's suggestion that led Hirayama to direct his attention to the study of asteroids.

But we must not forget another factor: in Japan, Hirayama was regarded as a member of an educated research elite, so he did not have to be deeply involved in administration of the TIU or the TAO. By around 1915, the educational system at these two organizations had been established and fundamental research environments had been much improved, so when Hirayama returned to Tokyo he was able to continue to study this new research topic.

3.3.2.3 The Kirkwood Gaps as a Clue to the Discovery of Asteroid Families

After returning to Japan, Hirayama (1918a) published his first theoretical paper on asteroid motions (and since he finished writing the paper in November 1917, we will call that paper the 1917 paper). Some asteroids show a special type of motion called 'libration', in which a certain orbital parameter does not circulate but swings just like the motion of a pendulum. Using a modified and simplified version of the libration theory studied by Brown, Hirayama classified the types of the asteroid motions and thereby tried to explain the formation of the Kirkwood gaps. The gaps, discovered by the American astronomer Daniel Kirkwood (1814–1895; Edmondson 2014), are the regions of mean motion (or the semi-major axis) distribution where very few asteroids exist, and the position of a mean motion gap had a simple integer ratio with that of Jupiter, such as 3/1 (called commensurability), due to the dynamical resonance with Jupiter.

First, assuming that resisting materials in the Solar System move around the Sun in circular orbits, Hirayama examined their effects on the elliptic motion of the planets. Second, he investigated the motions of the asteroids whose mean motions

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[2] According to the *Bulletin of the National Research Council* (Brown et al. 1922), the report of the Committee on Celestial Mechanics consisted of three general divisions: I, the Solar System (the Moon, the eight major planets, their satellites other than the Moon, the asteroids or minor planets and comets); II, celestial mechanics as applied to the stars (the problems of the orbit determination for cases of visual, spectroscopic or eclipsing binaries; the internal constitution of stars; the oscillations of a gaseous star about its normal equilibrium (Cepheids), the origin and evolution of binary stars); and III, the theory of the problem of three or more bodies. This report did not refer to the Hirayama families.

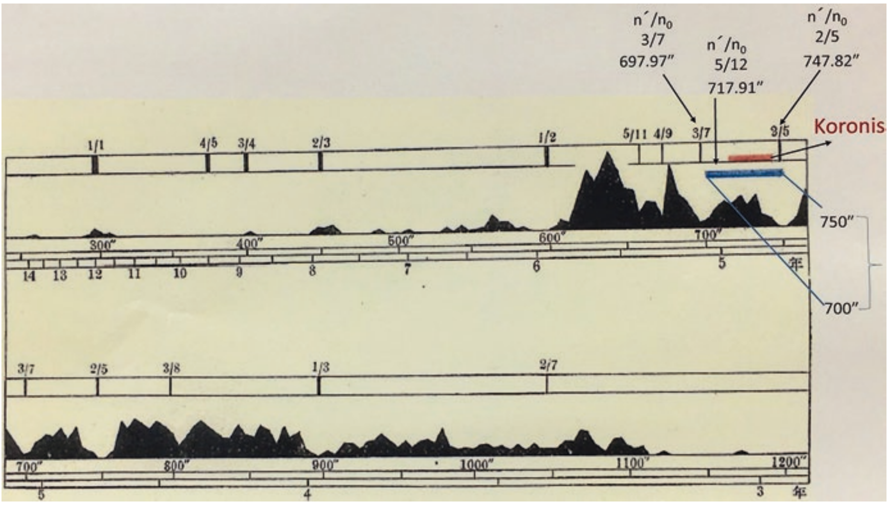


Fig. 3.4 Condensations of asteroids indicated on the mean motion diagram (adapted from Hirayama 1935a, 102)

are nearly commensurable with that of Jupiter. Third, he estimated theoretically the effects of the resistance on the motion of the asteroids. Regarding a specific angular orbital element called ‘critical argument’, he considered its transition mechanism from the librational (vibrational) motion to the revolutional one, and vice versa. Fourth, he investigated the two peculiarities seen in the distribution of the mean motions of asteroids, namely, the gaps found by Kirkwood and the three concentrated regions of asteroids (the Trojan, Thule and Hilda groups); these opposing peculiarities had been a very difficult theme to tackle within the framework of pure Newtonian dynamics of gravity. Finally, based upon the types of the motion that Hirayama had studied, he tried to give possible explanations for the Kirkwood gaps.

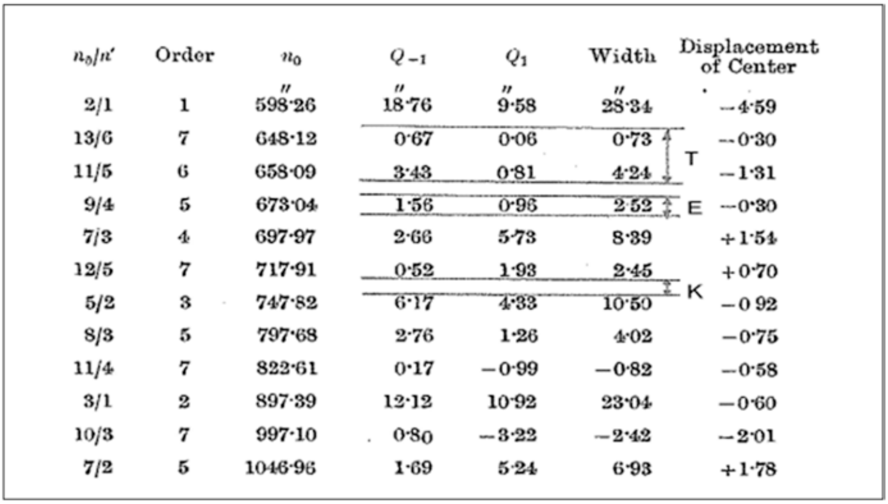
In the next subsection, more concrete explanation will be given about Hirayama’s line of thought towards a better understanding of the asteroid gaps.

3.3.3 Discovery Processes of the Hirayama Families

When he attempted to solve the problem of Kirkwood gaps using a modified version of Brown’s libration theory, Hirayama came across some strange features in the distribution of asteroidal orbital elements. In short, he noticed that there were too many asteroids with small inclinations and eccentricities between the mean motions of 700″ and 750″, sandwiched by the two void regions (see Fig. 3.4 written in 1935).

Table 3.2 lists nearly all the asteroids examined by Hirayama in his 1917 paper. In order to know the behavior of asteroids around the class $n_0/n' = 12/5$, Hirayama needed to calculate orbital elements of asteroids on both sides of the gap, and he

Table 3.2 Asteroids commensurable with Jupiter where n_0 is the mean motion per day of an asteroid and n' is that of Jupiter



n_0/n'	Order	n_0	Q_{-1}	Q_1	Width		Displacement of Center
		″	″	″	″		
2/1	1	598·26	18·76	9·58	28·34		−4·59
13/6	7	648·12	0·67	0·06	0·73	T	−0·30
11/5	6	658·09	3·43	0·81	4·24		−1·31
9/4	5	673·04	1·56	0·96	2·52	E	−0·30
7/3	4	697·97	2·66	5·73	8·39		+1·54
12/5	7	717·91	0·52	1·93	2·45	K	+0·70
5/2	3	747·82	6·17	4·33	10·50		−0·92
8/3	5	797·68	2·76	1·26	4·02		−0·75
11/4	7	822·61	0·17	−0·99	−0·82		−0·58
3/1	2	897·39	12·12	10·92	23·04		−0·60
10/3	7	997·10	0·80	−3·22	−2·42		−2·01
7/2	5	1046·96	1·69	5·24	6·93		+1·78

Following Hirayama, we call n_0/n' the class. T is the Themis family ($620'' < n_0 < 660''$); E the Eos family ($670'' < n_0 < 685''$) and K the Koronis family ($720'' < n_0 < 740''$) (after Hirayama 1918a: 47)

even extended calculations to outside the gap in order to scrutinize a possible displacement from the 12/5 exact commensurability of motions, as given in the last column in Table 3.2. Also, he did similar computations for the class $n_0/n' = 5/2$, and eventually his calculations covered all known asteroids with mean motions between 700″ and 750″. As a result, he could be sure about a conspicuous concentration of asteroids which we indicate by the symbol ‘K’ in Table 3.2; later Hirayama named this the Koronis family. Similarly, the discovery of other families, shown by the ‘T’ and ‘E’ in Table 3.2 was also brought about through painstaking computations of secular perturbation theory.

From our description above of Hirayama’s line of thought in attempting to solve the mystery of the Kirkwood gaps, we can see that the concept of asteroid families emerged as an unexpected byproduct of his initial research. However, we also have to emphasize that the discovery of these families could never have been achieved without the combined use of advanced perturbation theory, skillful statistical analysis of the asteroid data and Hirayama’s wide knowledge and deep insight. For a more detailed discussion, refer to Hirayama (1935a) and Yoshida and Sugiyama (1997).

Here it may be worth noting that Hirayama’s main interest was not to solve the dynamics of individual objects but to consider the behavior of asteroids as a *group* (see Nakamura 2008). His attitude towards conducting astronomical research seems to be found in other subjects he studied as well, such as the formation hypothesis of a binary star system in which he treated stars orbiting in nebular matter as a whole; this theme will be mentioned later, in Sect. 3.5.

3.3.4 Japanese Perspectives on Hirayama's Discovery

Because of the importance of asteroid families in planetary science astronomers currently tend to regard Hirayama as a theoretical astronomer who achieved his historic discovery using secular perturbation theories. But according to Hagihara (1943), at the time he made his discovery the Japanese scientific community held a different view: that the discovery of the Hirayama families was merely the outcome of statistical work.

Considering that Japanese astronomy was evolving from classical positional astronomy to a more advanced level involving theoretical celestial mechanics when Hirayama discovered the asteroid families, it might be understandable that Hirayama's monumental achievements were seen by the majority as being simply statistical. It is also possible that such a view was influenced by his statistical analysis of the Z-term discussed in the next Section. In addition, it is evident that the first half of his series of papers on asteroids implanted strong impressions in readers' minds that his work was purely statistical. Because of this perception the theoretician Y. Hagihara (1943, 1947) could not help but emphasize the excellence of Hirayama's technique in celestial mechanics, and this approach also was adopted by Y. Kozai (1994).

3.3.5 Recent Developments in the Study of Asteroid Families

In the last decade or so, the number of binary and multiple asteroid systems has rapidly increased (e.g. see Merline 2002). The existence of such systems is further evidence of collisions between asteroids. Regarding it, we call attention to the fact that Hirayama predicted the possibility of these types of asteroids and discussed their cosmological significance in the preface of his famous book *Showakusei* (Asteroids) in 1935, more than three-quarters century ago, thereby indicating his far-reaching foresight.

3.4 Statistical Analysis of Latitude Observations

In this section we introduce Hirayama's research on latitude observations based on a statistical approach during the years 1898–1905. In this respect, it is noted that he opposed the then widely-accepted view on the cause of Kimura's Z term.

3.4.1 The E-W Problem in Latitude Observations

As mentioned in Sect. 3.3.1, Hirayama was involved in latitude observations at the TAO. In 1907 he noticed that an unusual phenomenon was present in the data collected during 1902–1905 (Hirayama 1907a). This was first pointed out by H. Battermann and A. Marcuse (see Marcuse 1902) and was called the 'East-West problem' of latitude observations meaning that in zenith telescope observations there exists a systematic difference between the latitudes obtained from stars on the eastern side of the zenith and the western side. Later this was discussed by S. Abe (1996) and S. Uematsu (1967). This phenomenon is quite different from the Z-term in the latitude variation. In the following discussion we adopt Hirayama's notation and refer to it as the O-W problem.

Hirayama did not agree with the conclusions reached by Battermann and Marcuse that this systematic difference should be attributed to physiological effects of the micrometer reading, which was dependent upon the stellar magnitudes. With his own observations and analysis (see Table 3.3), Hirayama (1907a) claimed that no correlation was detected between the O-W differences and the magnitudes of stars. Namely, he computed the systematic differences (O-W) – (W-O) for the pairs of stars selected by Battermann in Berlin, and we present his results in Table 3.3, where Z_1 stands for the zenith distance. After computing an arithmetical mean of eight successive values (Table 3.4), Hirayama drew a graph with the (O-W) – (W-O) on the ordinate and Z_1 on the abscissa (Fig. 3.5).

Hirayama obtained similar results during his first observations in 1898–1900 and 1901, and then noticed similar trends in the data of Mizusawa, Potsdam and Berlin. He thought that there existed a common peculiarity in all of the variations of (O-W) – (W-O) with respect to Z_1, and analyzed the difference by fitting an odd function of Z_1.[3]

Hirayama (1907a) also suggested the cause of the systematic difference:

> Such an effect might be physiologically produced by the speed of the star in the field of view varying proportionally as the cosine of declination. It is natural that the personal error of bisection should be governed by the speed of the stars as well as their magnitudes.

However, he did not say whether the trend shown in Fig. 3.5 was due to personal errors or instrumental ones; he merely stressed the existence of these systematic errors.

3.4.2 *Hirayama's View on Kimura's Z-Term in Latitude Variation*

Based on the results of the International Latitude Service during the years 1900–1904, Hirayama (1908) inferred that Kimura's Z-term was not absolutely invariable, but depended on the mean zenith distance. He also thought that he found a new difference which seemingly included Kimura's Z-term, and mentioned that the cause was due to the difference in the thermal expansion coefficients between the steel of the micrometer-screw and the telescopic tube which was made of brass (ibid.).

Later, when this interpretation was criticized by an overseas astrometrist, Hirayama reconsidered a large error in the results of the observations made with zenith telescopes in 1909. He thought that these might have been caused by a gradual change in flexure of the telescope, and he speculated that the variability of the flexure could be attributable to the heat from an observer's body, or a hand-lantern in the case of meridian circle observations (Hirayama 1909).

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[3] When Uematsu argued the E-W problem in latitude observations in 1967, he referred to Hirayama's work.

Table 3.3 O-W – W-O differences at TAO, 1902–1905 (after Hirayama 1907a: 97–98)

Group and pair	Z_1	O-W – W-O	Group and pair	Z_2	O-W – W-O	Group and pair	Z_1	O-W – W-O	Group and pair	Z_2	O-W – W-O
B 7	−21.5	−0.08	F 7	−11.1	−0.02	G 6	−0.8	−0.06	A 8	+11.1	+0.01
D 6	−20.7	+0.01	E 4	−10.8	−0.13	C 5	0.0	−0.03	G 4	−11.6	−0.08
G 7	−20.0	−0.07	D 2	−10.8	−0.11	D 5	+0.4	−0.04	H 6	+12.1	0.00
C 2	−19.8	− 0.17	F 1	−10.3	−0.15	D 4	+1.1	−0.07	C 4	+12.3	+0.07
C 6	−19.2	+0.03	D 7	−10.0	−0.05	H 1	+1.2	+0.06	A 2	+4.8	+0.01
E 2	−17.9	−0.01	G 5	−8.8	−0.06	D 8	+1.8	−0.02	F 5	+16.6	−0.04
B 8	−17.7	+0.01	F 8	−8.6	−0.11	B 6	+1.8	−0.01	E 5	+16.9	−0.05
H 8	−16.9	+0.03	B 2	−7.2	+0.01	C 8	+2.4	−0.04	B 3	+17.1	−0.01
H 2	−16.8	−0.11	H 3	−7.1	−0.07	E 8	+2.5	−0.01	E 1	+18.3	+0.04
H 4	−16.7	−0.06	C 1	−6.1	−0.16	D 3	+2.8	+0.03	A 7	+18.4	−0.04
A 3	−16.3	−0.08	G 2	−3.9	−0.04	H 7	+3.9	+0.01	D 1	+18.7	−0.10
H 5	−16.2	−0.11	B 4	−0.3.5	−0.01	F 4	+3.9	0.00	E 3	+19.0	−0.05
B 1	−15.0	−0.11	C 3	−3.4	−0.08	G 1	+5.3	−0.01	A 6	+19.2	−0.01
E 7	−14.1	−0.04	C 7	−2.7	−0.03	E 6	+5.9	+0.04	F 2	+19.3	−0.05
F 6	−13.5	+0.01	B 5	−1.5	−0.12	G 8	+6.4	−0.02	F 3	+19.4	−0.05
G 3	−13.0	+0.02	A 5	−1.0	−0.04	A 4	+7.5	+0.09	A 1	+21.4	−0.06

Cited from Table 1 of Hirayama’s paper (1907a).

Table 3.4 List of the E−W differences analyzed by Hirayama (after Hirayama 1907a: 97–98)

Z_1 (°)	O-W − W-O (°)	Deviation of O-W − W-O from the mean (°)	Z_1 (°)	O-W − W-O (°)	Deviation of O-W − W-O from the mean (°)
−19.2	−0.031	+0.006	+1.0	−0.025	+0.012
−15.2	−0.060	−0.023	+4.8	+0.016	+0.053
−9.7	−0.078	−0.041	+14.1	−0.011	+0.026
−3.7	−0.069	−0.032	+19.2	−0.040	−0.003
			Mean −0.037		

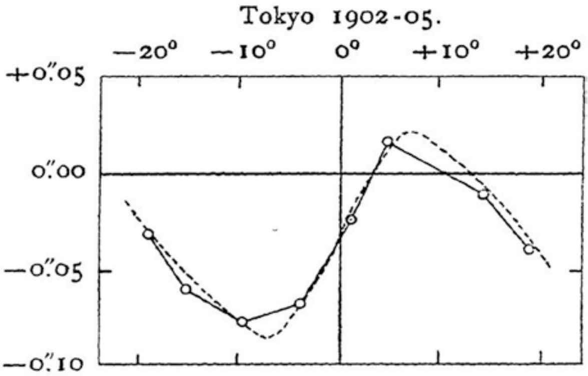

Fig. 3.5 The (O-W) – (W-O) difference as a function of zenith distance, Z_1 (after Hirayama 1907a: 99)

We comment that Hirayama did not intend to solve the Z-term problem completely. However, he was regarded as an opponent to the common Japanese view that the Z-term was not caused by the telescopes used for the observations (Hagihara 1947).[4] Japanese scientists, including Tanakadate, a senior physicist and Kimura's collaborator, were convinced that the cause of the Z-term problem was not instrumental.

3.5 Hirayama's Other Scientific Work

3.5.1 *Determination of the Japan-Russia Border on Sakhalin Island*

After the Russo-Japanese War of 1904–1905 as a result of the Portsmouth Peace Treaty Conference it was decided that Russia should cede half of Sakhalin Island to Japan. On 29 May 1906, just 3 weeks after he had been promoted to Associate Professor at the TIU, the Japanese Government appointed Hirayama as a member of the Committee that would determine the Russo-Japanese border.

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[4] Astronomers and physicists discussed the Z-term and Hirayama's opinion openly at a colloquium held at the TAO on 7 May 1908 (see Shinzi Honda, 1908).

Although the Portsmouth Peace Treaty ruled that the border should be located at 50° north latitude, nobody knew what type of latitude should be used. There were three options, namely geocentric, astronomical and geographical latitude, and each of these would influence the location of the border between the two countries. It was a very delicate problem, from both a political and a scientific viewpoint.

The Committee, which consisted of Russian and Japanese members, decided to adopt astronomical latitude after one of the Russian astronomers and Hirayama pointed out that astronomical latitude was the most suitable option in this case; moreover, they recognized that luckily the latitude variation affecting the border was very small from 1906 to 1907. Hirayama then went to Sakhalin Island by sea, and actually conducted latitude observations. Expeditions involving military and astronomical personnel were dispatched twice: first in June–November 1906 and actually conducted latitude observations. Expeditions involving military and astronomical personnel were dispatched twice: first in June–November 1906 and later in May–October 1907. The Japanese Committee adopted the Talcot- Horrebow method, using meridian transit instruments to measure twenty star pairs taken from Newcomb's catalogue. Then as a final outcome, they erected four cornerstones along the new border (see Figs. 3.6 and 3.7).

Fig. 3.6 An historic oil painting by Yasuda Nen. showing members of the Japanese–Russian geodetic expedition on Sakhalin Island (*Courtesy* the Meiji Memorial Art Museum)

Fig. 3.7 The *circular* inset image shows one of the boundary stones, on both sides of which the national emblems of the two countries were inscribed. The main photograph shows how trees around each stone and along the border between the four stones were all removed in order to allow clear highlight the location of the border (*Courtesy* Otaru Museum)

At the end of the first expedition's visit, a Committee meeting was held on 13 November in the special guest room at the Otaru branch office[5] of the Nippon Yusen Kabushiki Kaisya (the Japan Mail-steamer Company) (see Fig. 3.8). Determining the 50° latitude on Sakhalin Island was a career highlight for Hirayama as a practical astronomer, and he was awarded St. Anna's Decoration by the Russian Government, and by the Japanese Government as well (Anonymous 1910; Hirayama 1907c, 1935b; Hayakawa 1976).

3.5.2 Research on the Stability of Motions of Solar System Small Bodies

We can say that research on the stability of the motions of small bodies in the Solar System (i.e. asteroids and satellites) which originated from Hirayama subsequently became one of Japanese astronomy's research traditions. As we mentioned in Sect. 3.3.2.3, Hirayama's studies began with the Kirkwood gaps while he was in the USA (Hirayama 1918a), but he maintained an interest throughout his life in the motions of those asteroids whose mean motions were nearly commensurable with that of Jupiter.

Ten years after his seminal 1917 paper, Hirayama applied his theory of the libration to the motion of the asteroid Hecuba. According to Hagihara Yusuke, after a long computation, Hirayama

> … pointed out the incorrect view of Wilkens (1927) that Wilkens's computation showed the asymptotic behavior in the secular recession of Hecuba's mean motion from the exact commensurability with Jupiter's mean motion. (Hagihara 1947: 43).

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[5] At that time, Otaru (Hokkado) was a key port of the Sakhalin Line, linking Japan and Russia.

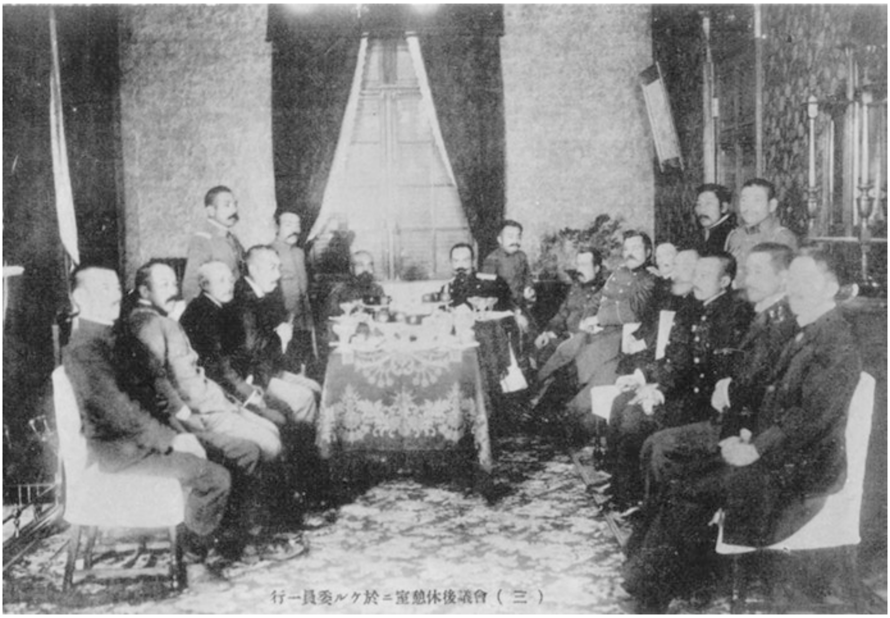

Fig. 3.8 Group photograph of the Japan–Russia Committee meeting at Otaru on 13 November 1906. Hirayama is possibly the man on the extreme right (*Courtesy* Otaru Museum)

Hirayama concluded that Hecuba would never stay long near the calculated position but would come back very close to its initial position. His finding was that after a long interval of about 34 revolutions of Jupiter, the variations in the mean motion and eccentricity of Hecuba would be repeated. Hirayama (1928) added the following: if Wilkens had continued his computations for 17 more revolutions of Jupiter he would surely have altered his conclusion (Yoshida 2002).[6] Hirayama revealed in his 1918a paper (which dealt with the types of motion of asteroids) that Hecuba exhibited revolutional motion, as outlined in Sect. 3.3.2.3.

In his final paper, which was published just 6 years before his death, Hirayama, with help from K. Akiyama, discussed the orbit of Hilda (Hirayama and Akiyama 1937).

3.5.3 The Resisting Medium and the Hirayama Families

The resisting medium—comprising particles and gas-like material—was a key element in Hirayama's research on asteroids, and he confessed (Hirayama 1917) that Brown had suggested the idea to him. It is also no exaggeration to say that Hirayama felt an enthusiasm for the planetesimal hypothesis of Thomas Chrowder Chamberlin (1843–1928; Suresh 2014) and Forest Ray Moulton (1872–1952;

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[6] In 1927, Hagihara Yusuke reached a conclusion similar to Hirayama about the stability of Hecuba, but he used a different approach (see Hagihara, 1927, 1947).

Hetherington 2014) in 1901 and 1905 respectively (Chamberlin 1901; Moulton 1905). According to S.G. Brush (1996), many astronomers were interested in the resisting medium in those days.

Hirayama's supposition was that.

(1) resisting materials the sizes of ordinary meteoroids move around the central body in circular orbits; (2) they consist of loose aggregates of small bodies with rare gaseous envelopes; and (3) most of the resisting particles pass freely through this met-eoric swarm.

The fact that this resisting medium was purely hypothetical did not seem to pose a problem for Hirayama. This was probably because he needed the resisting medium to explain the Kirkwood gaps. If the resisting materials existed at all, then the effect of the resistance should be larger for smaller asteroids, and would work naturally to decrease the eccentricity and at the same time to increase the mean motion of asteroids. However, such results obviously conflicted with his research on asteroid families so he had no choice but to abandon the assumption of a resisting medium. He then conjectured that the formation of the asteroid families may have occurred after the resisting medium had dissipated (Hirayama 1933d).

3.5.4 The Resisting Medium and the Capture of Stars

The resisting medium was a convenient tool for Hirayama, and between 1931 and 1935 he considered the motion of stars in nebulous matter where the latter served as the resisting medium. Starting with his capture theory of stars, he tried, in succession, to apply this idea to the Solar System, a binary system, the origin of the energy in stars and the interpretation of periodic variable stars. Thus, for Hirayama (1931a, b, c, 1932) the resisting medium provided a way for him to investigate problems associated with stellar evolution.

Based on the two-body problem and using an approximately qualitative means, he considered first the case in which a star passes through a spherical cloud. He says that the transit of the star is repeated, decreasing the value of its semi-major axis every time, until the star is completely captured. So the cloud can capture a star by this repeated action, and the remaining matter, being absorbed gradually, will become small in mass compared with that of the captured star. A star system, like our Solar System, may have been formed in this way.

According to Hirayama (1931c), if the cloud is large and dense enough, it can capture two or more stars. He also speculated, using the same mechanism, on the formation of a binary star system,[7] and even on the formation of a globular cluster. Here we would like to stress that Brown (1921) had much earlier discussed the motion of the stars entering a nebulous cloud.

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[7] Hirayama (1931c: 183) was very interested in seeing how the relative motion of the two stars was influenced by the absorption of the cloud. He said that the case of a planet was treated by Tisserand (1896: Chapter XIII) and by Poincaré (1911: Chapter VI).

Another aspect of Hirayama's capture theory is that the stellar energy can be provided not by sub-atomic energy or the annihilation of matter but by the energy originating from meteoric materials (Hirayama 1931d). Karl Hufbauer (1981) has shown that since 1920 Eddington's ideas on sub-atomic energy have been effective in explaining the stellar energy problem. In 1983, David DeVorkin and R. Kenat reviewed the literature on the stellar energy problem that existed in the 1930s, and discussed the situation connecting the formation of elements with stellar energy. While these developments were occurring, Japanese astronomers were shifting their interests from classical astronomy to astrophysics (Blaauw 1994). This subject is discussed further by Yoshida and Nakamura (2011).

But Hirayama did not (or could not) use a physical approach to the heavenly bodies and their observed phenomena: rather, he tried by all means at his disposal to solve the problems using only celestial mechanics. It is commonly recognized that in those days most older astronomers lacked the knowledge of atomic physics required to solve the above-mentioned problems. In this sense it could be said that although Hirayama addressed astrophysical issues he remained a disciple of classical astronomy.

3.5.5 Speculation on Periodic Variable Stars

Hirayama (1931b) refused to accept that pulsation theory was a suitable model for explaining the behavior of periodic variable stars. Instead, he felt he could interpret the behavior of some types of periodic variable stars, such as Cepheids, by using a combination of his binary theory and his capture theory of stars under the influence of nebulous matter. Developing this line of thought, he imagined that a Cepheid variable was a contact system consisting of a giant star and an almost dark dwarf star. Their relative orbits were supposed to be nearly circular, in accordance with a general tendency of the binary stars, so the small companion was destined to be abraded by the surface of the primary star (see Fig. 3.9).

Hirayama's speculation originated from an explanation presented by Johannes Hellerich (1888–1963) in 1925, but in fact Hellerich considered neither abrasion of the small companion by the primary's surface nor a resultant dropping into the primary star. On the other hand, Hirayama (1931b) neglected several of the preconditions that Hellerich set in order for his concepts to be valid.

3.5.6 A Survey of the Archival Astronomical Records of China, Korea and Japan

In 1908, Hirayama started computing ephemerides of the Moon and the planets at the TAO. As part of his new duties he subsequently directed his attention towards ancient eclipses and comets that appeared in Chinese, Korean and Japanese historical records,

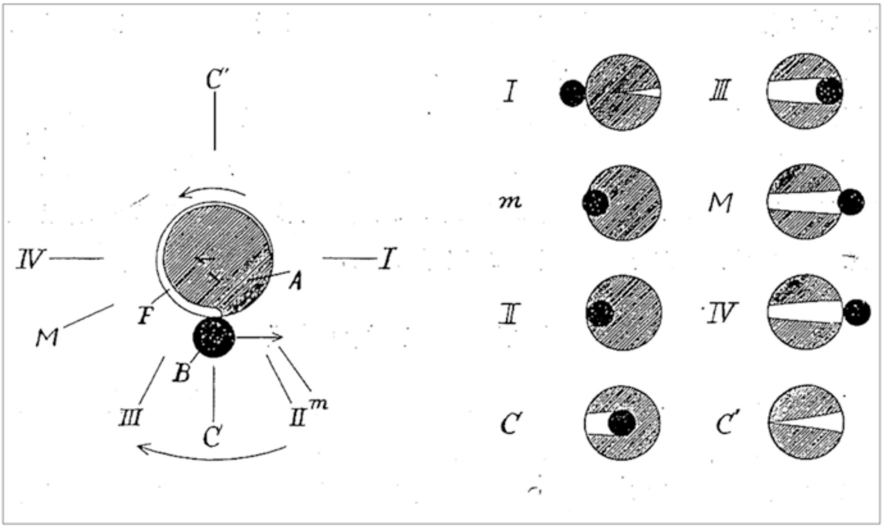

Fig. 3.9 Schematic illustrations of Hirayama's abrasion process for a contact binary (after Hirayama 1931a)

and between 1910 and 1929 published a number of papers on them (see Hirayama 1910, 1911, 1929; Hirayama and Ogura 1915). His 1933 book, *Rekihou to Jihou* (*Calendrical and Time Systems*) (Hirayama 1933c) has long been cited, mainly for its material on historical calendars in China and Japan. Indeed, Hirayama lectured on the Chinese *Shoushi* calendar (*Juji reki* in Japanese) at the second Annual Meeting of the History Science Society of Japan held in 1942, and then reported on the history of the solar calendar in Japan at a regular meeting of this Society later that same year.[8]

According to Hagihara (1947), after Hirayama retired his professorship "… he was eagerly engaged in the study of the history of astronomy in Japan. He never published his results … but only talked about them at the colloquia at the Azabu Observatory." These comments need correcting, because a survey of the old publications by Kanda (1962) revealed that Hirayama assembled the first extensive catalogue of Japanese books on astronomy before the Meiji Restoration (of 1868).[9] It is likely that his interest in compiling a catalogue of such pre-modern Japanese books was nurtured through the correspondence with Kano Kokichi, a famous Japanese bibliographer, who used to the president of Kyoto University (Nakamura 2005). Second, we have to add that Hirayama acted as a scholastic advisor when Yabuuchi Kiyoshi (1906–2000) launched his study on the history of astronomy. Yabuuchi later became a leading specialist in Chinese history of science and technology, rivaling Sir Joseph Needham (1900–1995) in that field.

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[8] See the following web site: http://wwwsoc.nii.ac.jp/jshs/his_jshs/hist.html.

[9] By about 1940 Hirayama had assembled an extensive card catalogue of Japanese books on astronomy that pre-dated the Meiji Restoration. Unfortunately this invaluable research tools was destroyed by fire during WWII (Kanda 1962).

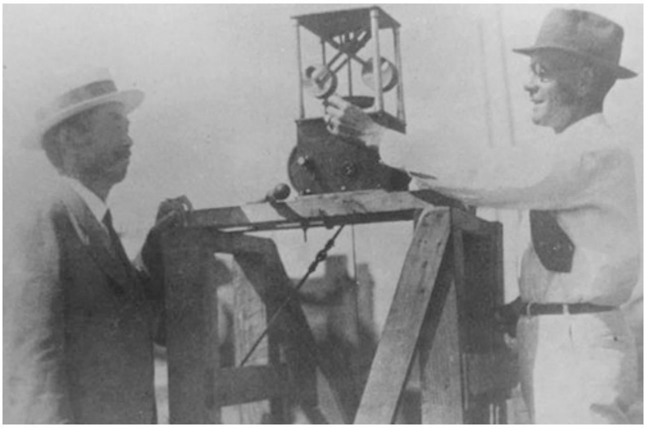

Fig. 3.10 Photograph of the 1932 solar eclipse expedition to the state of Maine (USA). Hirayama is on the left and the name of the gentleman on the right is unknown (after Hirose Hideo 1979: 15; *Courtesy* Abe Akira)

Finally we mention that Hirayama participated in several overseas solar eclipse expeditions (e.g. see Hirayama et al. 1903), sometimes in collaboration with Terao and Hirayama Shin (e.g. see Fig. 3.10).

3.6 Conclusion

Hirayama Kiyotsugu was Japan's first theoretical astronomer, although during his career his astronomical interests and research gradually shifted from observational astronomy to theoretical astronomy. His success culminated in the discovery of the asteroid families but recognition of these by the international astronomical community was slow until his research was taken up by Dirk Brouwer. Although Hirayama also contributed in the field of the orbital stability of asteroids and satellites, he continued to adhere to the autonomous explosion hypothesis for the origin of asteroids, and his attempts to address astrophysical problems, such as the capture of stars and an explanation of periodic variable stars, were unsuccessful.

If Kimura's Z-term was the first 'big crop' cultivated within the framework of so-called classical astronomy that the Japanese learned from the West, then Hirayama's discovery of the asteroid families could be called a 'victorious harvest' for Japanese astronomy, allowing us to move to the next phase of more modern astronomical research.

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Appendices

The Biographical Table of Hirayama Kiyotsugu (1874–1943)

The following table was developed from a hand–written manuscript by Kanda Shigeru (1894–1974), which is a biographical note of several eminent astronomers in Japan (courtesy of National Astronomical Observatory of Japan).

1874	As a son of a civil engineer, he was born on 3 October in Sendai.
1894	He entered the Tokyo Imperial University after his graduation from high school.
1897	He graduated from the Imperial University (Astronomy) and started to study the textbook of celestial mechanics by Tisserand.
	He obtained a position as a teacher in the engineering school attached to the General Staff Office of the Japanese Army, where he taught practical astronomy from 1897 to 1901.
1898	On 25 September he began latitude observations at Tokyo Astronomical Observatory (1898 ~ 1903).
1901	In February he was a member of a solar eclipse expedition to Sumatra, with Hirayama Shin.
1906	On 9 may he was appointed Assistant Professor of Astronomy at Tokyo Imperial University (specializing in practical astronomy).
	On 29 may the Japanese Government appointed him a member of Committee to determine the latitude 50° border at Sakhalin after the Russo–Japanese war. He went to Sakhalin (1906–1907), and was awarded St. Anna's decoration by Russia.
1908	He was one of the promoters of the Japanese Astronomical Society. Assisted by Terao, he started to compute the ephemeris of the Moon and the planets at the TAO.
1909	He discussed the E–W problem of latitude observation and the cause of Kimura's Z term from 1907 to 1909.
1910	He surveyed historical records (ancient eclipses and comets) in China, Korea and Japan.
1911	He received a doctoral degree with several papers about latitude variation.
1915	He went to the U.S. Naval Observatory in Washington and Yale University (1915 ~ 1917). At Yale he helped to compute a part of Brown's lunar table. Brown inspired him with an explanation of gaps in the distribution of the mean motion of the asteroids.
Mar. 1918	He published the paper "Researches on the distribution of the mean motions of the asteroids" in the *Journal of the College of the Science, Imperial University of Tokyo*.
Oct. 1918	He published the paper "Groups of asteroids probably of common origin" in *The Astronomical Journal*.
1919	He became a Professor of Astronomy at Tokyo Imperial University after Terao's retirement (celestial mechanics).
1922	He published the paper "Families of asteroids" in the *Japanese Journal of Astronomy and Geophysics*.
1928	He published the paper "Note on an explanation of the gaps of the asteroidal orbits" in *The Astronomical Journal*.
1931	He tried to consider the motion of stars in a nebulous matter as the resisting medium from 1931 to 1935.
1932	When he attended the fourth IAU Meeting at Cambridge in the USA, he saw young Dirk Brouwer at the meeting.
1935	He published his main work, *Asteroid*, and retired from the Tokyo Imperial University.
1943	He died on 8 April 1943 in Tokyo.

The Historical Evolution of Subjects Taught in the Department of Astronomy, at Tokyo Imperial University

1878–1886	Summary of astronomy, astronomy, astronomical observation theory and field work required for gravity measurement
1886–1897	Astronomy, spherical astronomy, celestial mechanics, practical astronomy
1897–1919	Astronomy, least squares method, spherical astronomy, astronomical observation, celestial mechanics, astrophysics, practical astronomy, lecture on calendar and solar eclipse and lunar eclipse
1919–1945	*Compulsory subjects*: spherical astronomy, least squares method, orbital theory, celestial mechanics, practical astronomy, astrophysics, calendar calculation exercise, astronomical observation 1, astronomy exercise or field study *Elective subjects*: astronomical observation 2, astronomical observation 3 *Reference subjects*: general astronomy, periodic orbit theory, theory of satellite's motion, special perturbation theory, theory of figures of celestial bodies, tidal theory

References

Hirayama's Papers

Hirayama, K. (1907a). On a systematic error of the latitude observed with a zenith telescope. *Astronomische Nachrichten,* 176, 97–104.

Hirayama, K. (1907b). Declinations and proper motions of 246 stars. *Annales de l'Observatorie Astronomique de Tokyo,* IV, 1–181.

Hirayama, K. (1907c). Determination of latitude made in Sakhalin by members of the Russo-Japanese Boundary Commissions in 1906 and 1907. *Proceedings of the Tokyo Mathematico-Physical Society, Second Series,* 4, 329–336.

Hirayama, K. (1908). On the results of the International Latitude Observations. 1900–1904. *Astronomische Nachrichten,* 179, 133–190.

Hirayama, K. (1909). On the flexure of the tubes of zenith telescopes. *Astronomische Nachrichten,* 181, 183–190.

Hirayama, K. (1910). Halley's Comet in Japanese history. *The Observatory,* 33, 130–133.

Hirayama, K. (1911). On the comets of A.D. 373 and 374. *The Observatory,* 34, 193–199.

Hirayama, K. (1917). Beikoku no Tenmongaku to Tenmondai. *Tenmon Geppou* (*The Astronomical Herald),* 11(1), 2–10. (in Japanese).

Hirayama, K. (1918a). Researches on the distribution of the mean motions of the asteroids. *Journal of the College of the Science, Imperial University of Tokyo,* 41, 1–58.

Hirayama, K. (1918b). Groups of asteroids probably of common origin. *The Astronomical Journal,* 31, 185–188.

Hirayama, K. (1919). Further note on the families of asteroids. Proceedings *of the Tokyo Mathematico-Physical Society, Third Series,* 1, 52–59.

Hirayama, K. (1920). New asteroids belonging to the families. Proceedings *of the Tokyo Mathematico-Physical Society, Third Series,* 2, 236–240.

Hirayama, K. (1922). Families of asteroids. *Japanese Journal of Astronomy and Geophysics,* 1(3), 55–93.

Hirayama, K. (1927). Families of asteroids. Second paper. *Japanese Journal of Astronomy and Geophysics,* 5, 137–162.

Hirayama, K. (1928). Note on an explanation of the gaps of the asteroidal orbits. *The Astronomical Journal,* 38, 147–148.

Hirayama, K. (1929). Records of Leonids in the Far East. *The Observatory,* 52, 241–246.

Hirayama, K. (1931a). An explanations of periodic variable stars. *Nihon Tenmongakkai Youhou* (*Reports of Astronomical Society of Japan*), 1, 182–199. (in Japanese).

Hirayama, K. (1931b). An explanation of the periodic variable stars. *The Proceeding of the Imperial Academy of Japan,* 7, 247–250.

Hirayama, K. (1931c). Motion of the stars in nebulous matter. *The Proceeding of the Imperial Academy of Japan,* 7, 182–185.

Hirayama, K. (1931d). On stellar evolution. *Nihon Tenmongakkai Youhou (Reports of Astronomical Society of Japan),* 1, 182–199. (in Japanese).

Hirayama, K. (1932). An explanation of the quasi-periodic variable stars. *The Proceeding of the Imperial Academy of Japan,* 8, 143–146.

Hirayama, K. (1933a). Beia Ryoko zakki(1). *Tenmon Geppou (The Astronomical Herald*), 26(4), 68–70. (in Japanese).

Hirayama, K. (1933b). Beia Ryoko zakki(2). *Tenmon Geppou (The Astronomical Herald),* 26(5), 88–90. (in Japanese).

Hirayama, K. (1933c). *Calendrical and Time Systems*. Tokyo: Kouseisya. (in Japanese).

Hirayama, K. (1933d). Present state of the families of asteroids. *The Proceeding of the Imperial Academy of Japan,* 9, 482–485.

Hirayama, K. (1935a). *Showakusei* (*Asteroids*). Tokyo: Iwanami Syoten. (in Japanese).

Hirayama, K. (1935b). On the Japan-Russia borderline on Sakhalin island [1]-[2]. *Tenmon Geppou (The Astronomical Herald),* 28*,* 89–92, and 28, 110–112 (in Japanese).

Hirayama, K., & Akiyama, K. (1937). Libration of the Asteroid Hilda. *Japanese Journal of Astronomy and Geophysics,* 15, 137–148.

Hirayama, K., & Ogura, S. (1915). On the eclipses recorded in the Shu Ching and Shih Ching. *Proceedings of the Tokyo Mathematico-Physical Society, Second Series,* 8, 2–8.

Hirayama, S., Hirayama, K., & Sotome, K. (1903). Report on the total eclipse of the Sun observed at Padang, Sumatra, on May 18, 1901. *Annales de l'Observatoire Astronomique de Tokyo,* III, 1–26.

Other References

Abe, S. (1996). On the systematic error in the latitude observations with the visual zenith telescope at Mizusawa. *The Proceedings of the International Latitude Observatory of Mizusawa,* 6, 32–41.

Anonymous (1910). *The Borderline Determination on Sakhalin Island.* Tokyo: Army of Japan. (in Japanese).

Barton, G. (1924). The inter-relations of the asteroid elements. *The Astronomical Journal,* 35, 159–162.

Baum, R. (2014). Brown, Ernest William. In T. Hockey et al., pp. 321–322.

Blaauw, A. (1994). *History of the IAU: The Birth and First Half-century of the Internal Astronomical Union*. Dordrecht: Kluwer.

Bottke, W.M. Jr., Cellino, A., Paolicchi, P., & Binzel, R.P. (Eds.), (2002). *Asteroids III.* Tucson: University of Arizona Press.

Brouwer, D. (1951). Secular variations of the orbital elements of the minor planets. *The Astronomical Journal,* 56, 9–32.

Brown, E.W. (1912). On librations in planetary and satellite systems. *Monthly Notices of the Royal Astronomical Society,* 72, 609–630.

Brown, E.W. (1919). *Tables of the Motion of the Moon* (3 Vols). New Haven: Yale University Press.

Brown, E.W. (1921). On the passage of a star through a nebula. *The Astrophysical Journal,* 53, 169–178.

Brown, E.W., Birkhoff, G.D., Leuschner, A.O., & Russell, H.N. (Eds.), (1922). Celestial mechanics. *Bulletin of the National Research Council,* 19, 1–22.

Brush, S. (1996). *Fruitful Encounters. A History of Modern Planetary Sciences. Volume 3*. Cambridge: Cambridge University Press.

Chamberlin, T.C. (1901). On a possible function of disruptive approach in the formation of meteorites, comets, and nebulae. *The Astrophysical Journal,* 14, 17–40.

Débarbat, S. (2014). Tisserand, François-Félix. In T. Hockey et al., pp. 2160–2162.

DeVorkin, D.H., & Kenat, R. (1983). Quantum physics and the stars (II): Henry Norris Russell and the abundances of the elements in the atmospheres of the Sun and stars. *Journal for the History of Astronomy,* 14, 180–222.

Edmondson, F.K. (2014). Kirkwood, Daniel. In T. Hockey et al., pp. 1221–1224.

Fosmire, M. (2014). Brouwer, Dirk. In T. Hockey et al., pp. 320–321.

Fujiwara, A. (1982). Complete fragmentation of the parent bodies of Themis, Eos, and Koronis families. *Icarus,* 52, 434–443.

Fukushima, N. (2014). Kimura, Hisashi, In T. Hockey et al., pp. 1204–1205.

Gehrels, T. (Ed.), (1979). *Asteroids*. Tuscson: University of Arizona Press.

Hagihara, Y. (1927). A preliminary study on the stability of a certain satellite system. *Japanese Journal of Astronomy and Geophysics,* 5, 1–79.

Hagihara, Y. (1943). To the memory of Prof. Hirayama. *Tenmon Geppou,* 36, 66–68. (in Japanese).

Hagihara, Y. (1947). Obituary Notices: Kiyotsugu Hirayama. *Monthly Notices of the Royal Astronomical Society,* 107, 42–44.

Hayakawa, K. (1976). A borderline determination by astronomical means. *Tenmon Geppou,* 69, 175–181. (in Japanese).

Hellerich, J. (1925). Untersuchungen zum δ Cephei-problem. *Astronomische Nachrichten,* 224, 277–284.

Hetherington, N.S. (2014). Moulton, Forest Ray. In T. Hockey et al., pp. 1529–1531.

Hirose, H. (1979). Hirayama Kiyotsugu. *Hoshino Techo,* 6, 11–16. (in Japanese).

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Honda, S. (1908). Tenmongaku danwakai kizi (Report of astronomical seminar). *Tenmon Geppou (The Astronomical Herald),* 1, 30. (in Japanese).

Hufbauer, K. (1981). Astronomers take up the stellar-energy problem, 1917–1920. *Historical Studies in the Physical Sciences, 11,* 277–303.

Kanda, S. (1962). Catalogues of astronomical books of the Edo Period. In *Report on Astronomy of the Edo Period,* pp. 1–3. Tokyo: Japan Society for the Promotion of Science. (in Japanese).

Kimura, H. (1902). A new annual term in the variation of latitude independent of the components of the pole's motion. *Astronomical Journal,* 22, 107–108.

Kozai, Y. (1994). Kiyotsugu Hirayama and his families of asteroids. In Y. Kozai et al., pp. 1–6.

Kozai, Y. (2014). Hagihara, Yusuke. In T. Hockey et al., pp. 880–882.

Kozai, Y., Binzel, R.P., & Hirayama, T. (Eds.), (1994). *Seventy-five Years of Hirayama Asteroid Families: The Role of Collisions in the Solar System History*. San Francisco: Astronomical Society of the Pacific (Conference series, Volume 63).

Marcuse, A. (1902). Ergebnisse der Pohlöhenbestimmungen in Berlin ausgeführt in der Jahren 1889, 1890 und 1891 am Universal-atransit der Königlichen Sternwarte. *Centralbureau der Internationalen Erdmessung. Neue Folge der Veröffentlichungen,* 6, 16 (in German).

Merline, W.J. (2002). Asteroids do have satellites. In W.M. Bottke et al., pp. 289–314.

Moulton, F.R. (1905). On the evolution of the Solar System. *The Astrophysical Journal,* 22, 165–182.

Nakamura, T. (2005). Kano Kokichi's collection of pre-modern Japanese astronomy books and communion with astronomer Hirayama Shin. *Toyo Kenkyu,* 155, 1–36. (in Japanese).

Nakamura, T. (2008). The early development of astrophysics in Japan. In *One Hundred Years of Astronomy,* pp. 3–19. Toyko: The Astronomical Society of Japan. (in Japanese).

Nakayama, S. (1981). Hirayama Kiyotsugu. *Dictionary of Scientific Biography*. Volume 6 (p. 431). New York: Charles Scribner.

Poincaré, H. (1911). *Leçons sur les Hypotheses Cosmogoniques Professés à la Sorbonne*. Paris: A. Herman et Fils In French.

Recht, A.W. (1934). Magnitudes and color indices of asteroids. *The Astronomical Journal, 64,* 25–32.

Suresh, R.S. (2014). Chamberlin, Thomas Chrowder. In T. Hockey et al., pp. 399–402.

Tenn, J. (2014). Campbell, William Wallace. In T. Hockey et al., pp. 360–363.

Tisserand, F.F. (1889–1896). *Traité de Mécanique Céleste* (4 Vols). Paris: Gauthier-Villars et fils. (in French).

Uematsu, S. (1967). On the E-W problem in latitude observations. *Proceedings of the International Latitude Observatory of Mizusawa,* 7, 157–186.

Wako, Y. (1967). On the Z term. *Proceedings of the International Latitude Observatory,* 73, 165–186.

Wilkens, A. (1927). Zur Erklärung der Planetoidenlücken im Sonnensystem. *Sitzungsberichte der mathematische-naturewissenschaftlichen Abteilung der Bayerische Akademie der Wissenschaften zu München, Jahrgang 1927,* 197–204. (in German).

Yoshida, S. (2001). K. Hirayama and S. Suzuki. *Kagakusi Kenkyu, Series II,* 40, 129–136. (in Japanese).

Yoshida, S. (2002). Asteroids and stars and K. Hirayama. *Kagakusi Kenkyu, Series II,* 41, 203–213. (in Japanese).

Yoshida, S., & Nakamura, T. (2011). Hirayama Kiyotsugu: discoverer of asteroid families. In W. Orchiston, T. Nakamura, & R. Strom (Eds.), *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference* (pp. 171–197). New York: Springer.

Yoshida, S., & Sugiyama, S. (1997). K. Hirayama and the families of asteroids. *Kagakusi Kenkyu, Series II,* 36, 218–228. (in Japanese).

Chapter 4
Japanese Studies of Asteroids Following the Discovery of the Hirayama Families

Tsuko Nakamura

4.1 Introduction

As mentioned in other papers of these proceedings (Nakamura 2017; Yoshida and Nakamura 2017), in 1918 Kiyotsugu Hirayama from the University of Tokyo announced the discovery of asteroid families (Hirayama 1918). But it took quite some time before the importance of his discovery was recognized by the international astronomical community (Fig. 4.1). According to the *Astronomischer Jahresbericht*, the earliest citation of Hirayama's work on asteroid families was made in the *Russian Astronomical Journal* (Staude 1926), followed by Bobrovnikoff (1931) and Senesplada (1932), but all three only contained brief mentions of Hirayama's paper. This slow response may have been due to a lack of new asteroidal data that could be used to evaluate Hirayama's results, or to the international unrest in the period between WWI and WWII, during which interest in minor planets remained at a low level.

After WWII eminent celestial mechanicians such as Dirk Brouwer (1902–1966; Fosmire 2014), of Yale University and Adriaan van Woerkom (1915–1991) began to publish follow-up studies of Hirayama's results based on the secular perturbation theory of celestial mechanics, and they increased the number of families by identifying new ones (Van Woerkom and Brouwer 1950; Brouwer 1951). During this era, the concept of asteroid families and their theoretical origin were gradually established. Brouwer (1950) noted that

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Historical & Cultural Astronomy, DOI 10.1007/978-3-319-62082-4_4

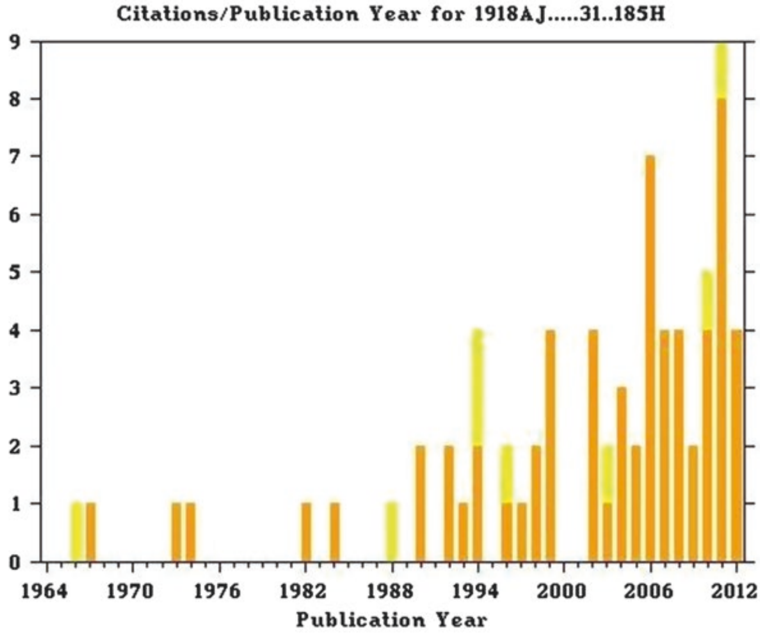

Fig. 4.1 Citation history of Hirayama's 1918 paper on asteroid families (after Astronomical Data Center, NASA). We should not forget that there have been many papers about asteroid families that do not cite Hirayama's 1918 paper (*Plot* Astronomical Data Center, NASA)

> While anyone familiar with celestial mechanics could have recognized this [importance of using the proper elements of minor planets for classifying them], Hirayama was the first to go through the rather laborious calculations.

As is currently well known, studies of asteroid families have grown into a major field in planetary sciences that can be systematically investigated using various disciplines, such as the long-term orbital evolution for Solar System small bodies (analytical/numerical); photometry; spectrophotometry; spectroscopy; radiometry; radar investigation; geology and mineralogy; laboratory impact experiments; the interrelation between asteroids and meteorites (meteoritics); space exploration using spacecraft; etc.

In this paper I provide a short overview of the development history of asteroid studies conducted in Japan since Hirayama's achievements. Through this work I conclude that Japan has produced quite a few asteroid researchers, and this is likely to be due to the influence of Hirayama's work. A similar situation also seems to be found among Italian astronomers, and it may be attributable to the tradition nurtured in Italy since Giuseppe Piazzi's discovery of the first asteroid Ceres in 1801 (Cunningham 1988, 2001).

4.2 Studies on the Dynamics of Asteroids

4.2.1 The Eros Observing Campaign to Determine the Astronomical Unit

Asteroid (433) Eros was discovered in 1898 by Carl Gustav Witt (1866–1946) in Berlin and Auguste Charlois (1864–1910) in Nice (Minor Planet Center), and soon recognized to be the first of the Mars-crossing asteroids (or more generally a member of the near-Earth asteroids). Because of the nature of Eros' orbit, this object was then regarded as the most appropriate candidate to be used to improve the value of the Astronomical Unit (the mean Earth-Sun distance). Thus, world-wide astrometric observing campaigns were conducted during the 1900–1901 and 1930–1931 oppositions, and the final results were published by Arthur Hinks (1909) and Harold Spencer Jones (1940) respectively.

Tokyo Astronomical Observatory (TAO) participated in the 1931 campaign, because photographic observations of Eros were considered to be a good project for the scientific 'first-light' of the 26-in (66-cm) Zeiss refractor that had been installed at TAO in 1929. Observed astrometric positions of Eros were reported to the Central Bureau for Astronomical Telegrams in Copenhagen.

4.2.2 Secular Perturbation Theory of Asteroids

The secular perturbation theory of celestial mechanics that Hirayama had used extensively to discover the asteroid families thereafter became part of the tradition of subsequent Japanese astronomers who studied motions and dynamics of asteroids, and adopted both analytical and numerical approaches. Takenouchi (1950) and Kozai (1953) examined the long-term behaviour of the motion of asteroid Thule, which is in the 4:3 commensurability (mean-motion resonance) with Jupiter.

Since Hirayama (1918), astronomers have proposed several improved criteria for identifying asteroid families (e.g., see references in Knezevic et al. 2002 and Bendjoya and Zappalà 2002). Among them, Yoshihide Kozai (b. 1928) tabulated 72 families using a new perturbation theory that took into account higher order and higher degree terms in the disturbing functions (Kozai 1979). The basis of the theory had been developed by Yuasa (1973) in response to Kozai's suggestion.

In an introductory part of Kozai's paper (1979) reviewing the classical linear theory of secular perturbations on which the Hirayama families are based, Kozai devotes some words to emphasize the correctness of Hirayama's approach that used the proper orbital elements for classifying family asteroids by saying:

> I would like to make clear what Hirayama did as there have been several possible misquotings of his work in subsequent papers except Brouwer's. To do this I shall quote the following sentences from three papers[1]…

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[1] Kozai points out that the three papers by Arnold (1969), Lindblad and Southworth (1971) and Williams (1971) quote Hirayama as if he simply regarded groupings of asteroids seen in a space of

This suggests that the dynamical concept of Hirayama asteroid families has not been correctly understood among astronomers, even as late as the 1970s (also see Fig. 4.1): the above three papers misunderstood that Hirayama could discover the asteroid families by simply using *osculating* orbital elements, not proper ones. The long-term orbital motions of asteroids with secular perturbation methods have subsequently been investigated by Kozai's students and followers (e.g., Nakai and Kinoshita 1985; Yoshikawa 1990).

4.2.3 The Kozai Mechanism[2]

In his paper of 1962, Kozai discussed possible motions of asteroids with very large eccentricities and inclinations—such a possibility had never been considered before. By applying secular perturbation theory of an asteroid with Delaunay's canonical variables, he showed that the z-component of the angular momentum of the asteroid is conserved along its motion. Since this relation can be expressed as

$$\sqrt{\left(1-e^{2}\right)}\cos i = \text{constant} \tag{4.1}$$

(where e is the eccentricity and i is the inclination), this means that a near-circular orbit with large inclination can evolve to a very eccentric one with low inclination, and *vice versa* (see Fig. 4.2). Developments of high-speed computers and efficient numerical intergration methods since the 1980s have enabled us to perform orbital calculations of asteroids over many millions of years without accumulation of errors (e.g., Holman and Wisdom 1993). As a result, very large orbital changes in eccentricity and inclination have been confirmed not only for asteroids but also other Solar System small bodies.

We now know that the Kozai Mechanism can explain unusual orbital behavior for various kinds of celestial bodies that used to be enigmatic in the past (Fig. 4.3). Such examples are irregular motions of the outer satellites of Jupiter; the origin of Sun-grazing comets; orbital motions of Kuiper-belt objects; the existence of upper bounds of inclinations for asteroids and the outer satellites of Jupiter; curious motions of planets in extra-solar systems and multiple stellar systems, etc. (for example, see Innanen et al., 1997, Murray and Dermot 1997).

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the *osculating* orbital elements as 'families'.

[2] It has recently been noted that Russian astronomer Michail L'vovich Lidov (1926–1993) published a Russian paper in 1961 (translated into English in 1962) including essentially the same theory as the 'Kozai mechanism' (Lidov 1961). So the Kozai mechanism is also sometimes referred to the 'Lidov and Kozai mechanism'.

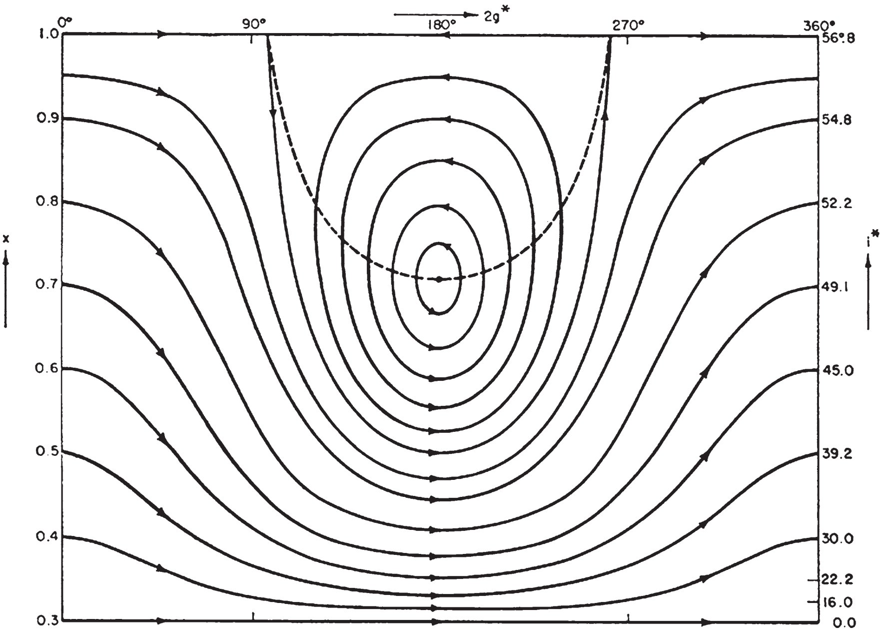

Fig. 4.2 An example of the phase diagram for large coupled variations in eccentricity and inclination due to the Kozai mechanism; the left-hand ordinate, the right-hand one, and the abscissa respectively stand for a measure of eccentricity, the inclination, and the argument of perihelion; the central part of the diagram shows the region in which the libration motion for the argument of perihelion takes place (after Kozai 1962)

4.3 Early Astrophysical Observations of Asteroids

4.3.1 Photometry

Regarding Eros mentioned above, its close approach to the Earth in 1931 inspired TAO astronomers to study the physical nature of this asteroid, looking for clues to its origin and evolution. Near the oppositions of this asteroid in 1930–1931, 1935, and 1937–1938, they recorded its light-curves by both visual and photographic means (Huruhata 1935, Kanda 1934). Since Shigeru Kanda was an experienced visual observer of variable stars, he was able to obtain reasonably good light-curves, as shown in Fig. 4.4.

As previous observations had suggested, large amplitude variations in Eros' light-curve were confirmed (Fig. 4.4), revealing the elongated shape of the asteroid.

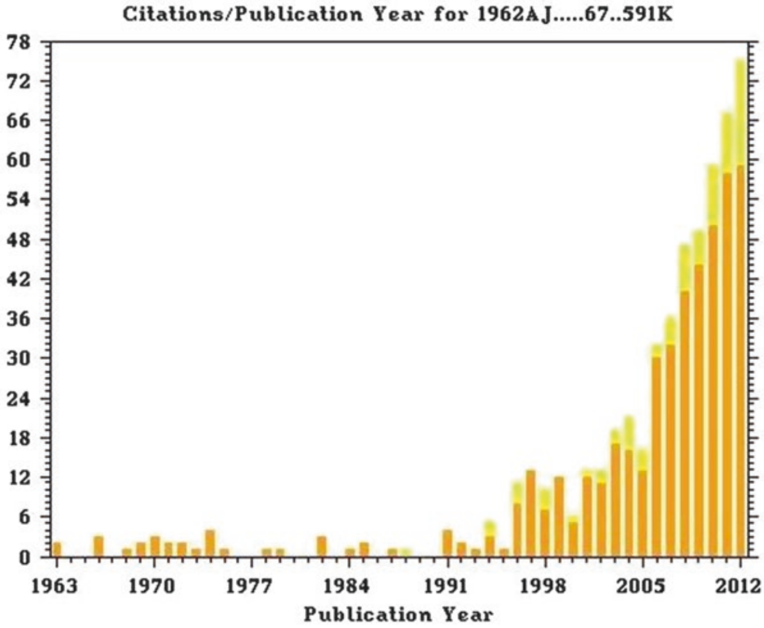

Fig. 4.3 Citation history of Kozai's paper (1962) on the Kozai mechanism (*Plot* Astronomical Data Center, NASA)

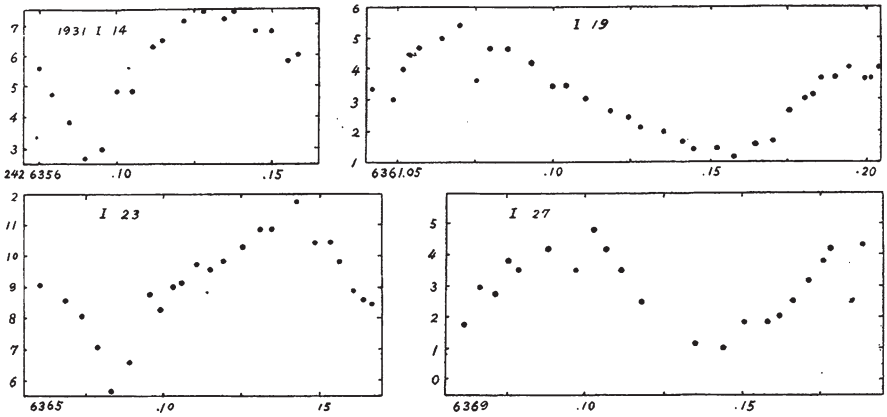

Fig. 4.4 Visual light-curves of Eros in January 1931 (after Kanda 1934)

At a later date (1968–1969), photoelectric measurements of the light variation of asteroid (15) Eunomia were used to determine its rotation period (0.2534 days, retrograde) and the pole orientation in the sky (Nakagiri and Kobayashi 1972).

4.3.2 Color Observations

It was not until in the 1930s that observations of the surface color of asteroids relative to the solar spectra were made by photographic means, but with little success, due to faintness of asteroids and subtlety of the color differences (Bobrovnikoff 1929, Recht 1935). Around 1953, a photoelectric photometer with the 1P21 photomultiplier was installed to the 65-cm Zeiss refractor at the TAO, and Masatoshi Kitamura (1926–2012) made some photometric observations of asteroids in a bid to detect a correlation between their colours and their assumed surface materials, and also to examine whether there was a correlation between asteriodal colors and their orbital elements (Kitamura 1959). He used two broad-band filters with effective wavelengths centered at 4760 and 5610 Å. In the early 1970s, when Gehrels summarised the UBV photoelectric photometry of asteroids, the number of objects listed by him was only 50 (Gehrels 1970, 1971, 1979), indicating that Kitamura's paper was one of the pioneering works in this field (Bowell and Lumme 1979).

Kitamura (1959) conducted photoelectric observations of 42 asteroids between 1953 and 1956, and he found that these asteroids did not show any color variation with rotational phase. Nor did he detect any meaningful correlation between asteroid colors and proper orbital elements.

Kitamura also measured in the laboratory the reflectance spectra of nine meteorites recovered in Japan and some rock minerals, using a standard light source operated at a color temperature near 6000 K (a solar analog). Upon comparing the laboratory results with asteroidal colors observed by him, he found that the colors of meteorites and asteroids on the whole were quite similar. It is unfortunate that Kitamura did not pursue his spectral studies of asteroids further, but he decided to change his field of research and focus on binary stars.

4.4 Impact Experiments

4.4.1 Japanese Early Experiments before WWII

In the 1920s, Professor Torahiko Terada (1878–1935) of University of Tokyo had attempted to systematize the physics of *fracturing* widely seen in natural phenomena. Soon after learning of Hirayama's discovery (1918), Terada realized that the asteroid family was a good example of his conceived new discipline. So he suggested that one of his disciples, Seitaro Suzuki (1886–1977), conduct impact experiments, in view of the fact that members of asteroid families were the products of collisional events.

Responding to his Professor's request, Suzuki began impact experiments in his laboratory and published the first result in 1921 (Yoshida 2001). The main purpose of Suzuki's experiments was to acquire clues on whether members belonging to an asteroid family were produced by a self-explosion of a large parent body or mutual

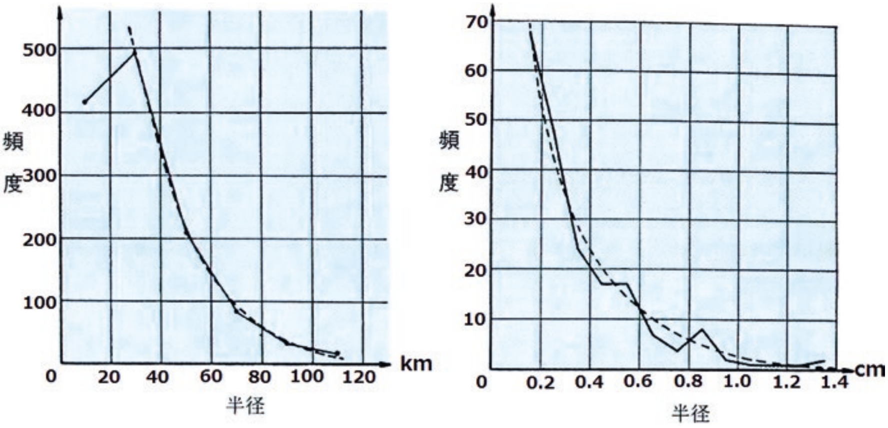

Fig. 4.5 Experiments by Suzuki and Nagashima (1938), cited in Yokoo (1997); the left hand figure is a plot of the radius (abscissa) versus number (ordinate) distribution of asteroid brightness based on data then available and assuming an average albedo for all asteroids; the right-hand figure shows the size distribution of broken fragments collected when clay balls fell freely onto a flat steel from the height of 6 m; notice the obvious similarity between the two curves

impacts between asteroids. This question about the origin of asteroid families was shared by Suzuki and Terada as well as by Hirayama, so they frequently communicated with each other.

Following the appearance of his first paper, Suzuki (1921) continued to publish further results in a series of papers that examined free-fall, head-on collisions of two small balls and gunpowder detonation. His last paper (Suzuki and Nagashima 1938) appeared in 1938—see Fig. 4.5. Not only did Suzuki collect impact fragments, but he also set up two cameras at different positions to measure the spatial velocities of each fragment. From all the obtained data, he examined the distributions of the size, shape, momentum, kinetic energy, and sometimes the spin state of collisional outcomes. However, in his quest to understand the origin of asteroid families, Suzuki never succeeded in differentiating the self-explosion hypothesis from the mutual impact one, and it is possible that Suzuki's experiments influenced Hirayama in preferring the self-explosion theory.[3]

We must admit that Suzuki's experiments were fairly primitive compared with modern laboratory experiments, in terms of collisional speeds and the time resolution of recorded photographs. Nevertheless, considering that modern high-speed impact experiments were first attempted in the US around 1970 to explain the origin

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[3] Modern papers published after WWII, such as those in Sect. 4.8.2, adopt a representation of size distributions different from the one shown in Fig. 4.5. They are commonly expressed by the equation:

$$\log N = a + b \log D$$

where D is the diameter and N the cumulative number of asteroids larger than D, so that it looks like a straight line on a log-log graph.

of craters on airless celestial objects, probably in conjunction with the Apollo Lunar Mission, we may say that the collision experiments by Suzuki and his colleagues were really a pioneering and foreseeing project (Yokoo 1997).

4.4.2 Modern Impact Experiments

From 1975 Akira Fujiwara (b. 1943), as a graduate student in the Department of Physics at Kyoto University, initiated hypervelocity impact experiments under the supervision of Professor Hirokazu Hasegawa (1926–1991) who led a group to study the nature of the interplanetary dust. Fujiwara used a two-stage light-gas gun (Fig. 4.6), which had just been installed at the Department of Aviation Engineering for other purposes. This facility used not explosives but compressed light-gas to accelerate sample projectiles. The first results from his experiments were published in *Icarus,* a journal dedicated to the planetary science (Fujiwara et al. 1977).

Fujiwara and his colleagues impacted polycarbonate projectiles of mass ~ 0.4 g against targets made of basaltic rocks in sizes of about a few centimeters, with a velocity of 2.6 km/s, close to interplanetary speed. They could classify their observed impact phenomena into four typical modes: catastrophic (complete) destruction, core leaving, transition phase and cratering. They also gave an empirical formula for estimating the cumulative mass of shattered fragments and one for the maximum fragment, and attempted to apply their results to explain the origin of the two Martian satellites.

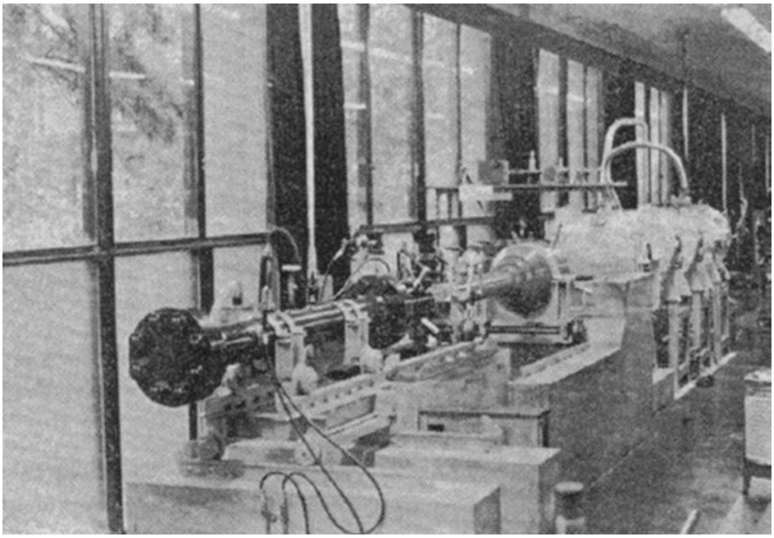

Fig. 4.6 A two-stage light-gas gun used in A. Fujiwara's first hypervelocity impact experiments around 1975 at Kyoto University (after Fujiwara 2012)

Fujiwara’s paper and his subsequent work (Fujiwara et al. 1989) subsequently received wide attention from scientists who studied asteroids, comets and satellites, and the origin of the Solar System. Stimulated by Fujiwara’s activities, people in the USA, Italy and Japan started impact and explosion experiments in laboratories and outdoors, aiming to apply their results to planetary science. In Japan geophysicists from the University of Tokyo and Nagoya University carried out hyper-speed impact facilities and repeated experiments by changing collisional conditions and using different materials, e.g., rocks, metals and ice (for details see the review by Fujiwara et al. 1989). In such developing processes, they also explored scaling laws in order to link collisional outcomes to the physical nature of Solar System bodies; these scaling laws were indispensable in interpreting experimental results correctly, because sizes of projectiles in impact experiments and those of real asteroids are different by 10^5–10^6 times. Following a proposal by an Italian astronomer, Paolo Farinella (1953–2000) and others, the first Catastrophic Disruption Workshop was held at Pisa in 1985 (Davis et al. 1986), and thereafter similar conferences have continued irregularly up to the present. Now laboratory impact experiments have grown into an important field of planetary science. The main achievements thus far in this field, and relevant disciplines like numerical simulations of impact phenomena, are reviewed by Holsapple et al. (2002).

4.5 Efforts Towards the Exploration of Asteroids by Spacecraft

4.5.1 The Establishment of ISAS

The history of the Japanese spacecraft development goes back to experiments with miniature rockets led by Professor Hideo Itokawa (1912–1999). In 1955 at a laboratory of University of Tokyo, he launched for the first time so-called ‘pencil rockets’, less than 30 cm long. This determined a basis of the subsequent Japanese policy of developing rockets used for scientific observations. Since then it has been a tradition in Japan that solid fuel rockets are exclusively adopted for launching artificial satellites and interplanetary spacecraft for astronomical purposes.

In order to support the development of advanced rockets and encourage collaboration between engineers and scientists who were engaged in space- and geo-science, a special institute was established in 1964 at the University of Tokyo. This institute was reorganized in 1981 into a new and expanded organization, the Institute of Space and Astronautical Science (ISAS, now part of the Japan Aerospace Exploration Agency, JAXA), which was supposed to be responsible for leading space science and developing advanced technology for space exploration. From 1971 on, this institute has so far put 38 satellites and spacecraft into orbit (as of December 2016): ten for ionosphere and magnetosphere observations, three for solar observations, six for X-ray and γ-ray astronomy, two for radio and infrared astronomy, ten for Solar System science and seven for other purposes (NAOJ 2012: 167). Among these, the Hayabusa asteroid mission will be mentioned in Sect. 4.5.4 below.

4.5.2 Research on Solar System Science

From the start, ISAS worked as a hub-institute for inspiring both domestic and international cooperation from various disciplines, including planetary sciences. For Solar System research, the first Lunar and Planetary Symposium was organized in the summer of 1968, with the proceedings publishing in English, and continued every year thereafter.[4] This ISAS Symposium very much encouraged participants to make close collaborations in conducting group studies and experimental works. Also from 1979, another symposium called the Solar System Science Symposium was held annually (the proceedings published in Japanese), with emphasis on synergistic effects between planetary scientists and space engineers.

A highlight in this period was the international symposium, 75 years of Hirayama Asteroid Families, held in 1993 at ISAS in conjunction with the NAOJ, to commemorate the 75th anniversary of the discovery of asteroid families (Kozai et al. 1994). A considerable fraction of leading asteroid researchers from around the world gathered at the ISAS campus near Tokyo, and presented numerous papers on theoretical studies, observational programs and impact experiments on asteroids, and discussed the future possibility of space exploration of near-Earth asteroids. It is likely that those activities eventually led the Japanese Solar System community to propose an asteroid mission to the ISAS headquarters.

4.5.3 Radar Observations of Near-Earth Asteroids

Since the first radar detection of asteroid Icarus in 1968,[5] radar observations of asteroids have been conducted almost exclusively by the USA, using the Goldstone and Arecibo (Puerto Rico) parabola antennas. By the end of 2011 they had observed as many as 130 main-belt asteroids and about 340 near-Earth asteroids.

During 1995–1996 an international experiment was proposed to observe by radar two near-Earth asteroids, 1991 JX and Toutatis (4179) while they were on close approaches to the Earth. The 64-m ISAS antenna at Usuda and the 34-m antenna of the Communications Research Laboratory at Kashima, Japan, received the radio signals reflected from the surface of the two objects, transmitted from the Goldstone antenna at the wavelength of 3.5 cm (Koyama et al. 2001). Because this experiment was the first intercontinental astronomical radar observation, asteroid 1991 JX later

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[4] It is worth noting that NASA's Lunar and Planetary Conference only started in 1970.

[5] See http://echo.jpl.nasa.gov/asteroids/PDS.asteroid.radar.history.html.

was given the permanent name Golevka (Minor Planet Center, IAU) to honor the success, this being an abbreviated combination of the names of places where the radar observatories were located, *Gol*dstone (US), *Ev*patoria (Crimia, Russia), and *Ka*shima (Japan). Although this experiment failed to generate a more advanced level of international collaboration, Japanese scientists were able to master basic techniques of planetary radar astronomy through this experience.

4.5.4 The Hayabusa Mission and Asteroid Itokawa

In May of 2003, Hayabusa (meaning falcon), the asteroid exploration spacecraft, was launched from the Uchinoura station of ISAS and successfully put into orbit to rendezvous with the near-Earth asteroid Itokawa. This was the first Japanese asteroid mission ever. The Hayabusa project had a nearly two-decades-long history before its realization: in 1985 a few ISAS engineers formed a working group to investigate an asteroid sample return mission—a very ambitious plan at that time.

For a decade the working group struggled to locate appropriate target asteriods and the practical technology needed to return the collected surface material from the asteroid to the Earth, mainly because of the limitations of the ISAS rockets then in use. However, during the first half of the 1990s a more powerful rocket, code-named the MV, became available for the Solar System exploration. Thus the asteroid sample return mission received serious consideration, and was officially approved in 1994. However, this was primarily regarded as an engineering-proof mission, rather than a scientific one. The primary aims of this mission, called MUSES-C, were fourfold:

(a) long-term test of the ion-engine propulsion system;
(b) orbital control by the Earth gravity swing-by;
(c) autonomous sample catching under micro-gravity conditions on the surface of a small asteroid; and
(d) re-entry of the sample capsule into the atmosphere of the Earth.

Each of these was a new challenge, never experienced before in the space exploration history of Japan.

In spite of the engineering nature of MUSES-C, instruments also were installed to maximize the scientific outcomes of this mission. They were a multi-band imaging camera (Fig. 4.7), a near-infrared spectrometer, a fluorescent X-ray spectrometer and a laser altimeter, some of which were indispensable for attaining engineering goals as well. A sampling mechanism was of course incorporated at the bottom of the spacecraft, which a group led by Fujiwara developed (see Sect. 4.4.2). Due to insufficient information on the orbit of a planned asteroid and the launch failure of the previous mission, the target asteroid of MUSES-C was changed twice, and the finally-selected object was asteroid 1998SF36 (25143), later named Itokawa in memory of the Japanese rocketry pioneer (Sect. 4.5.1) by the IAU after the launch of Hayabusa. Following ISAS tradition, MUSES-C was renamed Hayabusa.

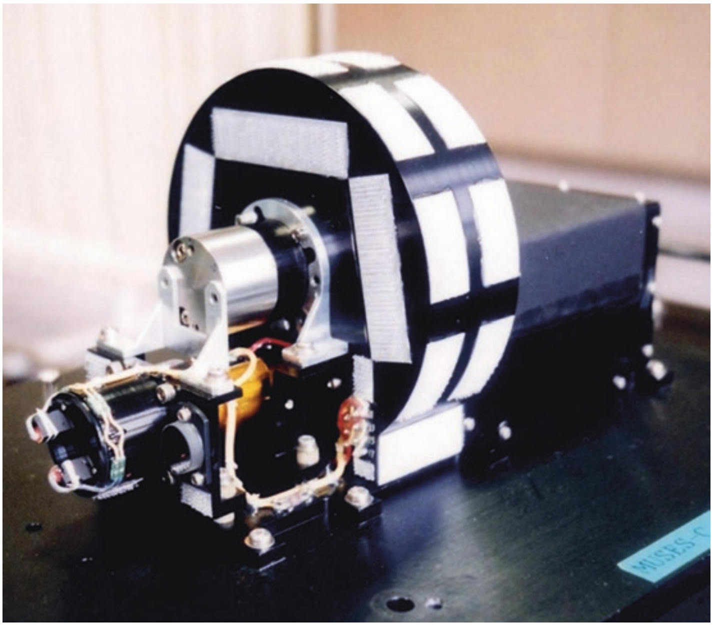

Fig. 4.7 The Asteroid Multi-band Imaging CAmera (AMICA) aboard the Hayabusa spacecraft. This camera system was designed by the author of this paper and developed by his group of astronomers (see Nakamura et al. 2001). Shown here is a photograph taken in 2001 of an AMICA engineering model, with many adhesive strain-guage plasters for stress testing. The cylinder in the middle is a filter wheel containing eight band-filters. Two small protrusions before the objective lens in the front are lamps for the flat-field calibration (*Courtesy* ISAS)

After Hayabusa's arrival at the orbit of Itokawa in September 2005, it took more than 1500 close-up images of the asteroid through several band-filters (e.g. see Fig. 4.8). Other scientific instruments also were successful in obtaining observational data. Those achievements and scientific results were reported in a special issue of the journal *Science* (e. g., Fujiwara et al. 2006; Saito et al. 2006). Hayabusa twice attempted touch-down operations for sample collecting by shooting projectiles onto Itokawa's surface, but it was not certain that the ejected surface materials were definitely stored in the sample container. On the return mission, Hayabusa encountered various fatal troubles. They were leakage of chemical propellant, resulting in the loss of attitude control; the subsequent loss of radio linkage between Hayabusa and the Earth for more than a month; heavy battery shortage; failure of two of the four ion-engines; and so on. Those at ISAS mission control made every effort to overcome these difficulties one by one, and Hayabusa finally succeeded in landing its sample capsule in the Australian desert on 13 June 2010.

The inside of the recovered capsule was scrutinized in the laboratory by means of an electron microscope, and numerous micron-sized particles found in it were identified to be ones that surely originated from Itokawa, using microanalyzers. Detailed analyses of those particles are still under way on an international collab-

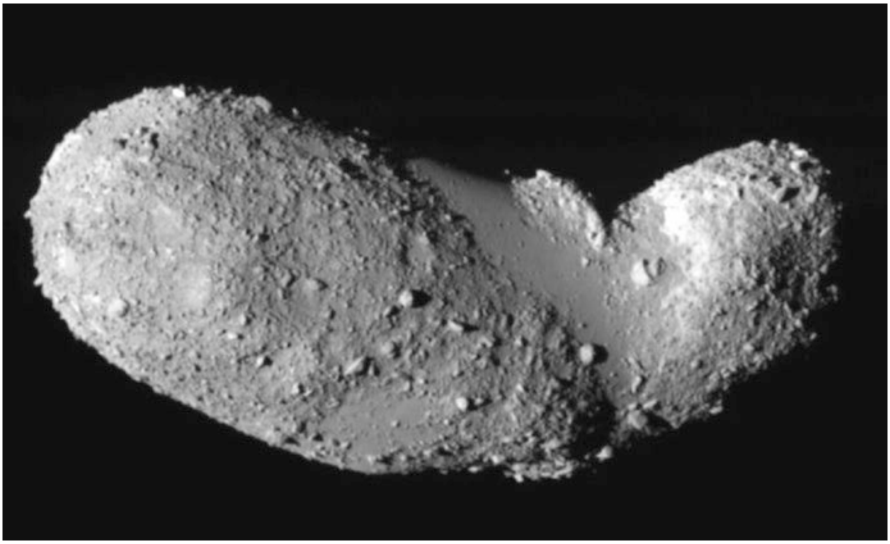

Fig. 4.8 Close-up image of asteroid Itokawa taken with the AMICA camera aboard Hayabusa spacecraft in 2005; note its unusual shape and the surface roughness (*Courtesy:* ISAS)

orative basis (e.g., Nakamura et al. 2011, and see the six papers in *Science*, Volume 333, 26 August 2011). In addition to the fact that Hayabusa's samples were the first extraterrestrial substances caught by spacecraft—except for the lunar rocks recovered during the Apollo Mission—we may safely say that scientific achievements of the Hayabusa Mission were unique, even in light of the outcomes of several asteroids missions conducted by NASA.

4.6 Antarctic Meteorites

4.6.1 The Discovery of Antarctic Meteorites

In 1959 a brilliant fireball was observed to fall at the town of Pribram near Prague, and its orbit outside the atmosphere was determined, along with many recovered meteorites. The orbit was found to be from the main asteroid belt. Since then, there have been reports of five similar meteorites, whose orbital aphelia reached the main asteroid belt or near-Earth orbits (e.g., Spurny et al. 2003). Therefore it became certain that meteorites are fragments of impacted asteroids and play a vital role in our studies of the physical nature of asteroids.

In 1957 an international scientific project called the International Geophysical Year (IGY) started, with research fields encompassing aurora and airglow, ionospheric physics, gravity, meteorology, oceanography, seismology, solar activity and cosmic rays. Studies of Antarctica were also an important target of the IGY and

Fig. 4.9 The first Antarctic meteorite discovered by Japan in 1969; this is an E3 chondrite, with many small chondrules (white spherules) in it (after Yanai et al. 1987)

several advanced countries established new research bases on the Antarctic continent.

During the half-century from Amundsen (Norway) and Scott (Britain) to the IGY only a handfull of meteorites had been collected in Antarctica, but in 1969 the Japanese Antarctic Expedition team discovered eight meteorites at the foot of the Yamato Mountains (Fig. 4.9), near where the Japanese Antarctica Research Base was located. On Earth, often it is not easy to distinguish chondrites from ordinary terrestrial rocks because of their similar appearance and surface erosion, but on the Antarctic continent most rock-like objects on the surface of the snow plains are actual meteorites and they stand out clearly (e.g., see Fig. 4.10). It was inferred that at the foot of rocky mountains like the Yamato, flowing ice grounds welled up to the surface, carrying imbedded meteorites with them.

4.6.2 The Development of Antarctic Meteoritics

The discovery of 1969 triggered systematic meteorite survey expeditions, which were first conducted by Japan from 1974, and later mainly by the Japanese, US or Japan-US international teams. In particular, the 1974–1980 expeditions around the Yamato Mountains by Japan found as many as 3600 meteorites (Yanai and Kojima 1986). As a result, the total number of meteorites discovered in the Antarctica by all nations as at the end of 1985 totaled ~7500. This amazing progress in terms of the sample number is highlighted by the fact that the total number of meteorites recorded and/or collected all over the world from ancient times through the 1960s was ~2400.

The huge collection of Antarctic meteorites and their international collaborative studies spawned the new research field of Antarctic Meteoritics (Yanai et al. 1987). Antarctic meteorites are characterized by the fact that they have suffered far less chemical erosion and environmental contamination than other terrestrial meteorites.

Fig. 4.10 A Japanese snowmobile searching for meteorites on the Yamato plain in 1974; in the foreground of the snowmobile a new meteorite is seen (after Yanai et al. 1987)

More than 80% of 7500 Antarctic meteorites were found to be ordinary chondrites (Yanai et al. 1987), which was consistent with the trend in the taxonomic-type distribution of meteorites for non-Antarctic sites. There were also several Antarctic meteorites that were inferred to have come from the Moon and Mars, due to their unusual chemical compositions. Analyses and classification of the whole Antarctic meteorite assemblage is still in progress.

4.7 The Discovery Race by Asteroid Hunters

4.7.1 The Early History of Asteroid Discoveries by TAO Astronomers

In 1896 Tokyo Astronomical Observatory at Azabu in downtown Tokyo purchased a 20-cm (8-in.) astrographic telescope from the Brashear Company of USA (Fig. 4.11). This instrument, generally called the 'Brashear Telescope', later was installed on an equatorial mounting fabricated by Warner-Swasey.[6]

On photographic plates taken with this astrograph in 1900, Shin Hirayama (1868–1945)—a different and unrelated Hirayama to the discoverer of asteroid families—

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[6] The TAO Brashear telescope is sometimes called a sister telescope of the 'Bruce Telescope' of the Yerkes Observatory, since both used a twin equatorial mounting produced by Warner and Swasey (King 1979: 317).

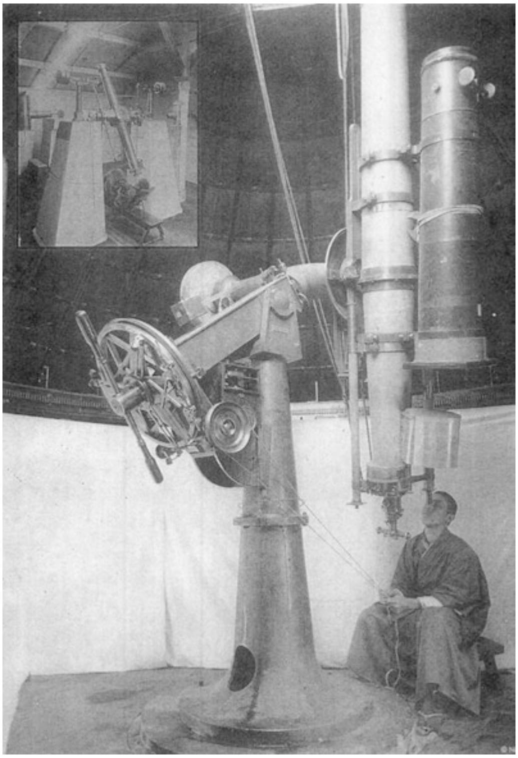

Fig. 4.11 The Brashear astrograph (the tube on the right) at the Azabu campus of TAO, co-mounted on the 20-cm Troughton & Simms equatorial telescope (*Courtesy* National Astronomical Observatory of Japan)

found two new asteroids, which were later named Tokio (498) and Nipponia (727). These were the first asteroids discovery by a Japanese astronomer.

After the transfer of TAO to Mitaka in the suburbs of Tokyo in 1924, Okuro Oikawa (1896–1970) used the Brashear telescope for much of the next 4 years for an asteroid survey. This resulted in the discovery of eight new asteroids, which received permanent designations. Along with such activities, the number of TAO astronomers increased who were expert in making orbital determinations of asteroids and comets. Soon after the end of WWII, Professor Hideo Hirose (1909–1981), who later became the Director of TAO, wrote a compendium textbook on orbital determinations for his TAO subordinates. This book played a primary role for popularizing orbit determination of asteroids and comets among Japanese amateur observers after the 1970s.

4.7.2 Systematic Asteroid Surveys

In 1950–1952 the historic Yerkes-MacDonald asteroid surveys was conducted under the leadership of Gerard Kuiper (1905–1973) (see Kuiper et al. 1958). This survey detected more than 1500 asteroids down to a photographic magnitude of about 16, and their size distributions were obtained. The Japanese astronomer Yoshio Fujita (1908–2013) participated in this project, although he was not an asteroid specialist but was an astrophysicist who researched the spectroscopic properties of low temperature stars.

The next systematic survey of faint asteroids were made in 1960 using the 1.22-m (48-in.) Schmidt telescope at the Mount Palomar (van Houten et al. 1970). The size distributions of asteroids derived from the Palomar-Leiden survey would be regarded as the standard for the next three decades (see Sect. 4.8.2 below).

In 1974 TAO founded a new branch observatory near Kiso Mountain in the central part of Honshu, the main island Japan, where a 1.05-m (41.4-in.) Schmidt telescope produced by the Nikon company was installed. This telescope was mainly intended for observational studies of distant galaxies, so it covered a sky area of 6° × 6° with a 36 cm-square photographic plate. By utilizing the wide-field merit of the Kiso Schmidt telescope, TAO astronomers H. Kosai and K. Hurukawa began an asteroid survey program in about 1976 (see Fig. 4.12). According to the Minor Planet Center of the IAU, about 90 asteroids detected by these two astronomers have thus far been assigned permanent numbers.

4.7.3 Amateur Hunters

The first non-professional discovery of an asteroid by a Japanese astronomer was made by Takeshi Urata (1947–2012) at his private observatory on 12 March 1978, and it was given a provisional designation of 1978EA in the *Minor Planet Circular* 4482. Later it was registered as a numbered asteroid 2090 with the proper name Mizuho, after his daughter.

Urata's discovery ignited subsequent discovery enthusiasm among Japanese amateur astronomers, which culminated in Takao Kobayashi's achievements. Kobayashi (b. 1961) is an engineer of Gunma prefecture working for a major electronic company, and during 1991–2002 he discovered 2373 new asteroids using a home-made telescope equipped with a CCD camera that automatically scanned the sky, detected moving objects and calculated their preliminary orbits from observed data for a night or two. Several other groups have also made contributions, thereby increasing the number of asteroid discoveries by hundreds. As a result, the numbered asteroids detected by Japanese astronomers by 2008 amounted to more than several thousands. In attaining such achievements, we must be aware of the role of the orbit calculator Shuichi Nakano, who was trained under the supervision of Brian G. Marsden (1937–2010), the then Director of the

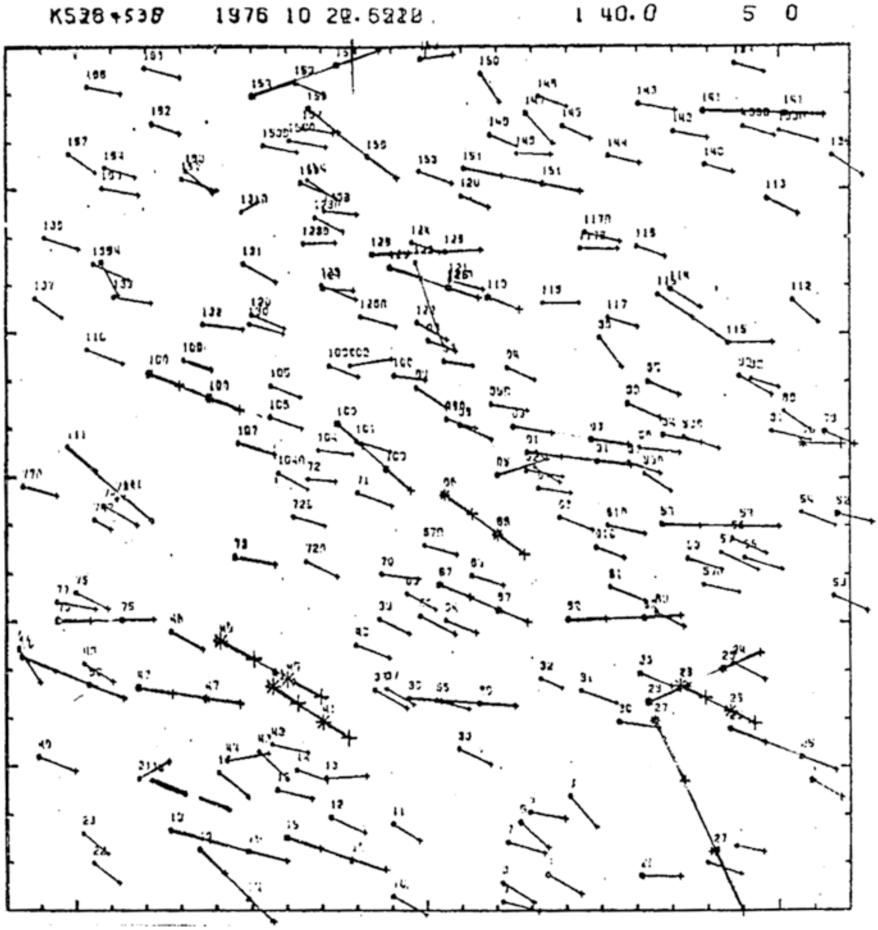

Fig. 4.12 Detected asteroids on a plate (6° × 6°) taken by the Kiso Schmidt Telescope on 29 and 31 October 1976; for each asteroid, its 2-day motion is drawn as a bar; some objects with unusual motions are likely to be near-Earth asteroids (after Kosai 1979)

Minor Planet Center (MPC) at the Smithsonian Astrophysical Observatory. After returning to Japan, Nakano set up a branch of the MPC and encouraged and organized the activities of Japanese asteroid hunters, leading to the Japanese 'Golden Age' in the asteroid discovery race.

However, several years ago the situation changed drastically, due to the advent of professional observatories dedicated to all-sky surveys such as LINEAR, Spacewatch and NEAT. Each of these has led to the discovery of thousands of new asteroids every year, and the MPC has assigned priority to discoveries by these observatories. Accordingly, the discovery rate of asteroids by amateur hunters has decreased abruptly, and many amateur astronomers have lost their enthusiasm for asteroid hunting. Some have turned their attention to other areas of astronomy, such as hunting for new nova and supernova.

4.8 Other Recent Studies

4.8.1 Space Weathering of Asteroid Surfaces

It had been understood implicitly that color and spectroscopic observations of asteroids could reveal the mineralogical and geological nature of the surface of those objects, by comparing spectroscopic measurements of meteorites in the laboratory. In particular, it is known that absorption bands in the near-infrared spectra of asteroids give the most useful diagnostics of their surface materials.

However, along with the accumulation of the spectral database of asteroids, an annoying enigma has appeared: Why are there so few asteroids in the main belt with spectral features that correspond to the laboratory-measured ones of ordinary chondrites (which is the most dominant type of meteorites recovered on Earth)? Then, as a probable solution to this question, an hypothesis of ‘space weathering’ was proposed. This effect explains how long-term insolation of an asteroid’s surface from the solar wind and micrometeoroid bombardment substantially weakens or masks the spectral characteristics diagnostic of ordinary chondrites, microscopically caused by accumulation of nanometer-scale particles of metallic-iron on the surface of regolith grains on asteroids.

Recently, plausibility of the space weathering hypothesis was experimentally proved by the Japanese geophysicist Sho Sasaki and his group (Sasaki et al. 2001). They succeeded in producing many nanometer-sized iron particles on the surface of lunar-like rocks using strong laser emission that simulated the solar wind. Resulting samples actually reproduced commonly-observed spectral features of S-type asteroids. The experimental outcomes were later supported by physical modeling as well.

4.8.2 Detection of Very Small Asteroids, and their Significance

As the view that asteroids are shattered fragments produced by repeated hypervelocity impacts between larger asteroids has become common among planetary scientists, the importance of the size distribution of asteroids, smaller ones in particular, has been recognized. The reason is that theoretical considerations predicted that asteroids smaller than ~1 km in diameter are more or less solid (the size region ruled by the material strength), whereas larger ones are so-called ‘rubble piles’ (the gravity-dominant size regime), aggregates of fragments gravitationally bound to each other (Chapman 1978). It was thought that such differences in the supposed internal structure of asteroids should also be reflected in their size versus number distribution. In particular, it was of interest to know where the borderline of sizes lies separating the gravity regime from the strength one, and how different each of these size distributions is. But the most elaborate size distribution available at that time was the one obtained by the 48-in. Palomar Schmidt telescope, which only covered diameters larger than ~5 km (van Houten et al. 1970). For the study of the behaviour of main-belt asteroids smaller than 1 km (sub-km-sized asteroids), much larger telescopes were obviously needed.

The latter half of the 1990s witnessed for the first time the advent of 8-m class telescopes. However most of these gigantic telescopes were designed mainly for spectroscopy of distant galaxies and quasars, and their cameras thus had very narrow field-of-views. The Japanese 8.2-m Subaru Telescope located on Mauna Kea (Hawaii) was only exception. It was equipped with a wide-field mosaic CCD camera covering a field of view of as large as 30 arcmin × 30 arcmin. Towards the end of the 1990s Nakamura and his co-workers started an observational survey with the Subaru telescope to look into the nature of sub-km asteroids in the main belt—a research field that until then was *Terra Incognita* (Nakamura 1997).

During observations made in 2001–2002 with exposure times of just a few minutes the mosaic CCD camera at the prime focus of the Subaru telescope recorded >100 small asteroids on a single exposure (Yoshida et al. 2003). Figure 4.13 is an example of such CCD images (Dermawan et al. 2011). Since it was impossible to calculate an elliptic orbit of each asteroid from a single night's observation,

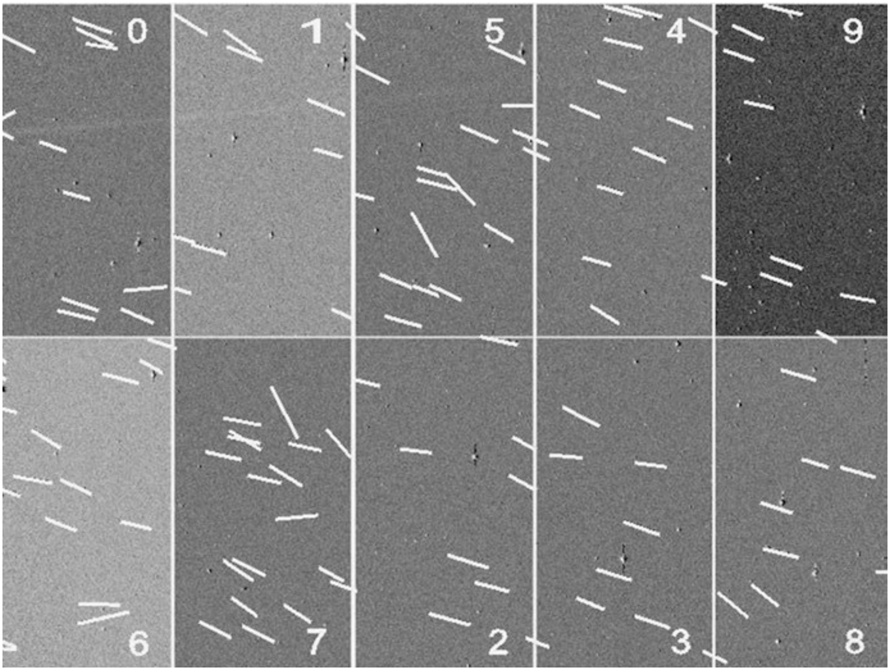

Fig. 4.13 Faint asteroids detected on 21 October 2001 in the ~30′ × 30′ field of view of the wide-field mosaic CCD camera attached to the prime focus of the 8.2-m Subaru Telescope; a single exposure time was 2 min; each white bar represents the motion of a detected asteroid made by combining eight consecutive images during about 2 h (after Dermawan et al. 2011); compare the field of view of this camera with that of the Kiso Schmidt Telescope shown in Fig. 4.12

Nakamura and Yoshida (2002) also devised a method to determine statistically a reliable size distribution of the observed asteroids from their motion vectors during several hours on a single night.

As a result of this Subaru survey, Nakamura and his collaborators found out that the number of sub-km asteroids is twice to three times more depleted than the estimate extrapolated from the size distribution obtained by the Palomar-Leiden survey. They attribute likely causes of the depletion to the following two possibilities:

1. Smaller asteroids are incorporated into chinks between fragmentary components of large rubble-pile asteroids, resulting in a seeming depletion;
2. Smaller asteroids were selectively removed from their orbits in the main asteroid belt by the Yarkovsky effect (Bottke et al. 2002b). This is a repulsive force caused by anisotropic thermal photons re-emitted from the irregular surface of an asteroid illuminated by the Sun, and its reality has already been demonstrated in accurate orbit determination of some small asteroids (Bottke et al. 2002b).

Other important insights into small asteroids revealed for the first time by this Subaru survey are as follows:

(a) The relative abundance of S-like sub-km asteroids (rocky) and C-like ones (carbonaceous) was examined. It has been shown that the heliocentric distribution of S-like objects was almost flat throughout the entire main belt, while the number of C-like asteroids increases with the heliocentric distance (Yoshida and Nakamura 2007).
(b) The size distributions of L4 and L5 Trojan asteroids of Jupiter were investigated down to the sizes <1 km in diameter (D), in which a similar depletion of the number for smaller members was seen as in the case of small main-belt asteroids. The number asymmetry between L4 and L5 Trojans clearly increases towards smaller ones (Yoshida and Nakamura 2005).
(c) About 70 reliable light-curves of main-belt asteroids with $0.2 \text{ km} < D < 2 \text{ km}$ were obtained from observations on a single night. From their periodogram analysis, spin periods and shapes of those objects were estimated. Nearly half of them were found to be so-called ‘fast rotators’ having a spin period of <2.2 h (the limiting period for rubble-pile objects to be spin-stable), and the majority of them had spherical shapes (Dermawan et al. 2011).

The last-mentioned finding was an unexpected one, because ground-based and spacecraft observations of near-Earth asteroids had suggested a contrary trend (e.g., Fujiwara et al. 2006).

4.9 Summary and Conclusion

Here we summarize asteroid studies performed by the Japanese between the 1920s to the 2000s, after the discovery of asteroid families by Hirayama (1918). Reviewed fields covered celestial mechanics, spectral comparison of observed asteroids with laboratory measurements of meteorites, the discovery of and systematic research on an enormous number of Antarctic meteorites, asteroid exploration using spacecraft as a powerful means of planetary science, hypervelocity laboratory impact experiments started in the 1970s, and the statistics of very small main-belt asteroids with 8-m class telescopes. We emphasize that collision experiments in the laboratory had already been done in Japan as early as half a century prior to modern impact experiments, to interpret the origin of the asteroid family.

From those historical achievements, it is concluded that one of the main motives for current activities in asteroid studies by Japanese astronomers could be attributed more or less to the discovery of asteroid families by Kiyotsugu Hirayama. Hopefully, this influence and tradition will continue to work as an incentive to advance the study of asteroids further at least in the near future.

References

Arnold, J.R. (1969). Asteroid families and “jet streams”. *Astronomical Journal,* 74, 1235–1242.

Bendjoya, P., & Zappalà, V. (2002). Asteroid family identification. In W.F. Bottke et al., 2002a, pp. 613–618.

Bobrovnikoff, N.T. (1929). The spectra of minor planets. *Lick Observatory Bulletin,* 407, 18–27.

Bobrovnikoff, N.T. (1931). The origin of asteroids. *Publications of the Astronomical Society of the Pacific,* 43, 324–333.

Bottke, W.F. Jr., Cellino, A., Paolicchi, P., & Binzel, R.L. (Eds.), (2002a). *Asteroids III*. Tucson: University of Arizona Press.

Bottke, W.F. Jr., Vokrouhlický, D., Rubincam, D.P., & Broz, M. (2002b). The effect of Yarkovsky thermal forces on the dynamical evolution of asteroids and meteoroids. In W.F. Bottke et al, 2002a, pp. 395–408.

Bowell, E., & Lumme, K. (1979). Colorimetry and magnitudes of asteroids. In T. Gehrels, pp. 132–169.

Brouwer, D. (1950). Families of minor planets and related distributional problems. *Astronomical Journal,* 55, 162–163.

Brouwer, D. (1951). Secular variations of the orbital elements of minor planets. *Astronomical Journal,* 56, 9–32.

Chapman, C.R. (1978). Asteroid collisions, craters, regolith, and lifetimes. In D. Morrison, & W.C. Wells (Eds.), *Asteroids: An Exploration Assessment* (pp. 145–160). Washington: NASA (Conference Publication 2053).

Cunningham, C.J. (1988). *Introduction to Asteroids*. Richmond: Willmann-Bell.

Cunningham, C.J. (2001). *The First Asteroid: Ceres 1801–2001*. Surfside: Star Lab Press.

Davis, D.R., Farinella, P., Paolicchi, P., & Zappalà, V. (1986). *Catastrophic Disruption of Asteroids and Satellites. Proceedings of the International Workshop, Pisa, Italy, July 30-August 2, 1985*. Società Astronomia Italiana (Memorie, 57, No. 1).

Dermawan, B., Nakamura, T., & Yoshida, F. (2011). Subaru lightcurve observations of sub-km-sized Main-Belt asteroids. *Publications of the Astronomical Society of Japan,* 63, S555–S576.

Fosmire, M. (2014). Brouwer, Dirk. In T. Hockey et al., pp. 320–321.

Fujiwara, A. (2012). From retrospect of impact experiments to spacecraft Hayabusa and toward future. *Nihon Wakusei Kagaku Kaishi* (*Journal of the Japan Planetary Society*), 21, 168–174. (in Japanese).

Fujiwara, A., Kamimoto, G., & Tsukamoto, A. (1977). Destruction of basaltic bodies by high-velocity impact. *Icarus,* 31, 277–288.

Fujiwara, A., Cerroni, P., Davis, D., Ryan, E., & di Martino, M. (1989). Experiments and scaling laws for catastrophic collisions. In R.P. Binzel et al. (Eds.). *Asteroids II,* pp. 240–265. Tucson: University of Arizona Press.

Fujiwara, A., Kawaguchi, J., Yeomans, D.K., Abe, M., Mukai, T., and 17 co-authors (2006). The rubble-pile asteroid Itokawa as observed by Hayabusa. *Science,* 312, 1330–1334.

Gehrels, T. (1970). Photometry of asteroids. In A. Dollfus (Ed.), *Surfaces and Interiors of Planets and Satellites,* pp 317–375. New York: Academic.

Gehrels, T. (Ed.), (1971). *Physical Studies of Minor Planets*. Washington: NASA (SP-267).

Gehrels, T. (Ed.), (1979). *Asteroids*. Tucson: University of Arizona Press.

Hirayama, K. (1918). Groups of asteroids probably of common origin. *Astronomical Journal,* 31, 185–188.

Hinks, A.R. (1909). Solar Parallax Papers No. 7: The general solution from the photographic right ascensions of Eros, at the opposition of 1900. *Monthly Notices of the Royal Astronomical Society,* 69, 544–567.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Holman, M.J., & Wisdom, J. (1993). Dynamical stability in the outer Solar System and the delivery of short period comets. *Astronomical Journal,* 105*,* 1987–1999.

Holsapple, K, Giblin, I., Housen, K., Nakamura, A., & Ryan, E. (2002). Asteroid impacts: laboratory experiments and scaling laws. In W.F. Bottke et al, 2002a, pp. 443–462.

Huruhata, M. (1935). Photometric observations of Eros. *Astronomische Nachrichten,* 257*,* 9.

Innanen, K.A., Zeng, J.Q., Mikkola, S., & Valtonen, M.J. (1997). The Kozai mechanism and the stability of planetary orbits in binary star systems. *Astronomical Journal,* 113, 1915–1919.

Jones, H.S. (1940). On the suitability of Eros for the accurate determination of the solar parallax. *Monthly Notices of the Royal Astronomical Society*, 100, 422–434.

Kanda, S. (1934). Brightness observations of asteroid Eros in 1930–31. *Tokyo Astronomical Observatory Report,* 2(6), 107–127. (in Japanese).

King, H.C. (1979). *The History of the Telescope*. New York: Dover.

Kitamura, M. (1959). A photometric study of colors of asteroids and meteorites. *Publications of the Astronomical Society of Japan,* 11, 79–89.

Knezevic, Z., Lemaître, A., & Milani, A. (2002). The determination of asteroid proper elements. In W.F. Bottke et al, 2002a, pp. 603–612.

Kosai, H. (1979). Status report of asteroid survey project by the Kiso Schmidt telescope. *Proceedings of the First Solar System Symposium,* pp. 22–27. Tokyo: The Institute of Space and Aeronautical Science (in Japanese).

Koyama, Y., Nakajima, J., Sekido, M., Yoshikawa, M., Nakamura, A.M., and 5 coauthors (2001). Radar observations of Near Earth Asteroids 6489 Golevka and 4197 (1982 TA). *Review of the Communications Research Laboratory,* 47, 145–155.

Kozai, Y. (1953). Preliminary studies on the motion of asteroid Thule (279) (II). *Publications of the Astronomical Society of Japan,* 4, 172–179.

Kozai, Y. (1962). Secular perturbations of asteroids with high inclination and eccentricity. *Astronomical Journal,* 67*,* 591–598.

Kozai, Y. (1979). The dynamical evolution of the Hirayama family. In T. Gehrels, pp. 334–358.

Kozai, Y., Binzel, R.P., & Hirayama, T. (Eds.), (1994). *Seventy-five Years of Hirayama Asteroid Families: The Role of Collisions in the Solar System History*. San Francisco: Astronomical Society of the Pacific.

Kuiper, G.P., Fujita, Y., Gehrels, T., Groeneveld, I., Kent, J., van Biesbroeck, G., & van Houten, C.J. (1958). Survey of asteroids. *Astrophysical Journal Supplement,* 3, 289–427.

Lidov, M.L. (1961). The evolution of orbits of artificial satellites of planets under the action of gravitational perturbations of external bodies. *Planetary and Space Science,* 9*,* 719–759. (in Russian).

Lindblad, B.A., & Southworth, R.B. (1971). A study of asteroid families and streams by computer techniques. In T. Gehrels, pp. 337–352.

Murray, C., & Dermott, S. (1997). *Solar System Dynamics*. Cambridge: Cambridge University Press.

Nakagiri, M., & Kobayashi, N. (1972). Rotation of the minor planet (15) Eunomia. *Tokyo Astronomical Observatory Report*, 15, 710–732. (in Japanese).

Nakai, H., & Kinoshita, H. (1985). Secular perturbations of asteroids in secular resonance. *Celestial Mechanics*, 36, 391–407.

Nakamura, T., Noguchi, T., Tanaka, M., Zolensky, M.E., Kimura, M., and 17 coauthors (2011). Itokawa dust particles: a direct link between S-type asteroids and ordinary chondrites. *Science,* 333*,* 1113–1116.

Nakamura, T. (1997). An observation plan of sub-km-sized asteroids with the Subaru telescope. In H. Kinoshita, & H. Nakai (Eds.), *Proceedings of the 29th Symposium on Celestial Mechanics,* pp. 274–279. Tokyo: National Astronomical Observatory of Japan. (in Japanese).

Nakamura, T., (2014). Japanese studies of asteroids after the discovery of Hirayama families. *Asian Journal of Physics*, 23(1&2), 189–208.

Nakamura, T. (2017). The development of astronomy and emergence of astrophysics in Japan. In T. Nakamura, & W. Orchiston.

Nakamura, T.., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nakamura, T., & Yoshida, F. (2002). Statistical method for deriving spatial and size distributions of sub-km Main-Belt asteroids from their sky motions. *Publications of the Astronomical Society of Japan,* 54, 1079–1089.

Nakamura, T., Nakamura, A.M., Tholen, D.J., and 5 coauthors (2001). Multi-band imaging camera and its sciences for the Japanese near-Earth asteroid mission MUSES-C. *Earth Planets Space*, 53, 1047–1063.

National Astronomical Observatory of Japan (2012). *Rika Nenpyo* (*Chronological Science Tables*). Tokyo: NAOJ.

Recht, A.W. (1935). Note on the color indices of asteroids. *Astronomical Journal,* 44, 104.

Saito, J., Miyamoto, H., Nakamura, R., Ishiguro, M., Michikami, T., Nakamura, T., and 28 coauthors (2006). Detailed images of Asteroid 25143 Itokawa from Hayabusa. *Science,* 312, 1341–1344.

Sasaki, S., Nakamura, K., Hamabe, Y., Kurahashi, E., & Hiroi, T. (2001). Production of iron nanoparticles by laser irradiation in a simulation of lunar-like space weathering. *Nature,* 410, 555–557.

Senesplada, E.G. (1932). Familias de asteroids. *Boletin de la Astronomico Observatorio de Madrid,* 1(2).

Spurny, P., Oberst, J., & Heinlein, D. (2003). Photographic observations of Neuschwanstein, a second meteorite from the orbit of the Pibram chondrite. *Nature,* 423, 151–152.

Staude, N. (1926). La classification des asteroids. *Russian Astronomical Journal,* 2, 45–53.

Suzuki, S. (1921). On the number of the pieces of the plates broken by a blow. *Proceedings of the Physico-Mathematical Society of Japan, 3rd Series,* 3, 168–174.

Suzuki, S., & Nagashima, H. (1938). On the distribution of mass, velocity and momentum, and energy of the broken pieces of exploded bodies. *Proceedings of the Physico-Mathematical Society of Japan, 3rd Series,* 20, 517–539.

Takenouchi, T. (1950). The long periodic term of Thule. *Publications of the Astronomical Society of Japan,* 1, 159–162.

Van Woerkom, A.A.J., & Brouwer, D. (1950). *Astronomical Papers American Ephemeris*, Vol. 13, Part II.

van Houten, C.J., van Houten-Groeneveld, I., Herget, P., & Gehrels, T. (1970). The Palomar-Leiden survey of faint minor planets. *Astronomy & Astrophysics Supplement Series,* 2(5), 339–388.

Williams, J.G. (1971). Proper elements, families, and belt boundaries. In T. Gehrels, pp. 177–181.

Yanai, K., & Kojima, H. (1986). Over 5600 Japanese collection of Antarctic meteorites. *Lunar and Planetary Institute Technical Report*, 86–01, Houston, Lunar and Planetary Institute.

Yanai, K., Takeda, H., & Shimoyama, A. (eds.) (1987). *Nankyoku Inseki (Antarctic Meteorites).* Tokyo: National Institute of Polar Research. (in Japanese).

Yokoo, H. (1997). Early experiments on collisional-breaking to test theories on the origin of Hirayama Family of asteroids by Seitaro Suzuki (1887–1977) in 1938. *Tenmon Geppou (The Astronomical Herald*), 90, 273–276 (in Japanese, Abstract in English).

Yoshida, F., & Nakamura, T. (2005). Size distribution of faint Jovian Trojan L4 asteroids. *Astronomical Journal,* 130, 2900–2911.

Yoshida, F., & Nakamura, T. (2007). Subaru main belt asteroid survey (SMBAS): size and color distributions of small main-belt asteroids. *Planetary and Space Science,* 55, 1113–1125.

Yoshida, F., Nakamura, T., Watanabe, J.-I., Kinoshita, D., Yamamoto, N., & Fuse, T. (2003). Size and spatial distributions of sub-km Main-Belt Asteroids. *Publications of the Astronomical Society of Japan,* 55, 701–715.

Yoshida, S. (2001). Kiyotsugu Hirayama and Seitaro Suzuki: Suzuki's destruction experiments in laboratory with astronomical interest. *Kagakusi Kenkyu (Journal of History of Science, Japan*), 129–139 (in Japanese, abstract in English).

Yoshida, S., & Nakamura, T. (2017). Hirayama Kiyotsugu: discoverer of asteroid families. In T. Nakamura, & W. Orchiston.

Yoshikawa, M. (1990). Motions of asteroids at the Kirkwood gaps. I - On the 3:1 resonance with Jupiter. *Icarus,* 87, 78–102.

Yuasa, M. (1973). Theory of secular perturbations of asteroids including terms of higher order and higher degree. *Publications of the Astronomical Society of Japan*, 25, 399–445.

Chapter 5
The National Astronomical Observatory of Japan and Post-war Japanese Optical Astronomy

Toshiyuki Tajima

5.1 Introduction

The National Astronomical Observatory of Japan (henceforth NAOJ) plays a role as the 'center of excellence' in Japanese astronomy today. At the time of the immediate aftermath of the Meiji Restoration, however, when the predecessor of the NAOJ was established, it had characteristics quite different from what it is now. In the course of its century-long history, the Observatory has changed its characteristics and role entirely.

At first, as an introduction, we will take a brief look at the NAOJ and the astronomical community of Japan as it is now. After that, I would like to trace a brief history of the NAOJ from its establishment as an observatory (Kanshoudai) attached to the Department of Astronomy at the University of Tokyo. Then, I would like to outline my concerns for the future of the astronomical communities of Japan.

5.1.1 The National Astronomical Observatory of Japan Today

The NAOJ as we know it today has several facilities throughout Japan, as well as in Hawaii and Chile.

The main campus is located at Mitaka, in the western part of suburban Tokyo, which has the administrative office as well as the offices of four research Divisions: Optical and Infrared Astronomy, Radio Astronomy, Theoretical Astronomy and Solar and Plasma Astrophysics. In addition, there are three service Centers: Astronomy Data, Advanced Technology and Public Relations. Practical observation is hardly conducted these days at Mitaka, but there are many historic telescopes on

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site, including the Solar Tower Telescope, equatorially-mounted refractors, meridian circles, and so on.

In Hawaii, the NAOJ has the 8.2-m Subaru Telescope, the flagship reflector of Japanese optical and infrared astronomy. Construction of this telescope, which we will mention later in detail, started in 1991, and 'first light' was in 1999.

The Okayama Astrophysical Observatory (OAO) has been a center of observational astronomy in Japan for half a century. It has a 1.88-m reflector as well as a 91-cm reflector. Both of them saw their 'first light' in 1960, and their shared use was started in 1962. The OAO also had a 65-cm Coudé solar telescope, but this already has been closed down.

The Norikura Solar Observatory was the first facility founded outside of the home campus of the Tokyo Astronomical Observatory (TAO) of the University of Tokyo, the predecessor of the NAOJ. From its foundation in 1949, observations using its 10 and 25-cm coronagraphs were conducted continuously until it was closed in March 2010. Although this Observatory played a important role in the development of solar astronomy in Japan, we are not concerned with it in this paper.

The Nobeyama campus of the NAOJ consists of a radio observatory and a solar radio observatory. The Nobeyama Radio Observatory has a 45-m millimeter-wave radio telescope, which has been operating since 1981. The Nobeyama Solar Radio Observatory has a radioheliograph that was constructed in the 1970s, as well as radio polarimeters.

The Mizusawa campus of the NAOJ used to be the International Latitude Observatory, which was founded in 1899. Since merging with the NAOJ, it has operated as one of the stations of the VLBI network. Though the contribution of this Observatory to the development of the scientific research in pre-war Japan was quite important, this is not our present concern.

Finally, the NAOJ recently witnessed the completion of the ALMA (Atacama Large Millimeter/submillimeter Array) Project in Chile. This ambitious project has been promoted in partnership with Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA had partially started scientific observation already in October 2011 in advance of its official opening ceremony on the 14th March 2013.

5.1.2 A Brief Time-Line for Recent Japanese Astronomy

Table 5.1 shows an abbreviated chronological table for the history of the NAOJ. In Japan, the old tradition of astronomy was extinguished at the end of the Edo Shogunate in the late nineteenth century. Soon after the Meiji Restoration (1867), the new Government set up a few organizations and their associated observatories to conduct duties such as the compilation of the calendar and timekeeping that were needed for governance. Their roles and functions were relegated to the Tokyo Astronomical Observatory (TAO), which was established as an institute attached to the University of Tokyo in 1888. After the TAO moved to Mitaka in 1924 and a

Table 5.1 An abbreviated chronological table outlining the history of the NAOJ

1877 Meiji 12	The University of Tokyo was founded and a Department of Astronomy was established
1878	An observatory for education in the Faculty of Science was established
1888	The Tokyo Astronomical Observatory (TAO) was established by the Faculty of Science of the University of Tokyo
1899	The Latitude Observatory was established in Mizusawa under the jurisdiction of the Ministry of Education
1924	The TAO was moved to Mitaka (but the Department of Astronomy remained in the Tokyo urban area)
1929	A 65-cm refractor was installed at Mitaka
1930	The tower spectroheliograph was constructed
1948	Reorganization was conducted by the Director, Yusuke Hagiwara
1949	The Norikura Solar Observatory began observations
1960	The Okayama Astrophysical Observatory began observations
1969	The Nobeyama Solar Radio Observatory began observations
1982	The Nobeyama 45-m radio telescope began observations
1988	The Tokyo Astronomical Observatory was reorganized to be the National Astronomical Observatory of Japan (NAOJ) as an Inter-university Research Institute
1991	Construction of the Subaru Telescope was started in Hawaii
1999	The Subaru Telescope saw the first light
2001	The NAOJ joined the ALMA Project
2004	The NAOJ became an independent corporation

number of telescopes and other instruments were installed, it began to acquire the appearance of a modern observatory.

In the pre-war period, however, the primary services of the TAO were the management of calendars and time-keeping. Founded using European national observatories such as the Royal Observatory at Greenwich and the Paris Observatory as models, the TAO was ill-equipped and understaffed—it had only a few researchers and several technicians—to conduct astrophysical research such as spectroscopic observations of faint objects.

In 1948, soon after the end of the WWII, the Director, Yusuke Hagihara (who was in office from 1946 to 1957), reorganized the TAO, creating new posts for researchers and introducing a series of new research divisions This was the first major transformation of the TAO. On the hardware side, one after another new observational facilities were founded outside of the main Mitaka campus.

In 1988, construction of the Subaru Telescope was approved, and the Tokyo Astronomical Observatory was rebadged as the National Astronomical Observatory of Japan, as a new inter-university research institute that merged with the International Latitude Observatory in Mizusawa and a part of the Research Institute of Atmospherics at Nagoya University. Then construction of the Subaru Telescope was actually started in Hawaii in 1991, and finally it saw first light in 1999. This was a long-awaited moment for Japanese astronomers, who had longed to have direct access to one of the world's best telescopes.

5.1.3 The Astronomical Community in Japan

In 1908, the Astronomical Society of Japan was established as a private organization consisting of professional and amateur astronomers. Then in 1935 it became an incorporated association authorized by the Ministry of Education. The membership has gradually increased: as of 27 June 2014 the number of members was ~3000 (including Full Members, Student Members, Associate Members, Cooperative Members and Supportive Members).

Apart from the NAOJ, in each research area of astronomy in Japan, there are some autonomous organizations of researchers. For optical and infrared astronomy, the Group of Optical and Infrared Astronomers (GOPIRA) was established in 1980, and in 2011 had 223 members. The Japan Radio Astronomy Forum (JRAF) for radio astronomy was established in 1970, and by 2011 had 365 members. In addition, those conducting theoretical research organized the Japan Theoretical Astronomy and Astrophysics Forum, in 2011 totalled about 200 members. The roles and the contributions of these organizations will be mentioned later.

The astronomical community in Japan seems to be comparable in size to that in the United Kingdom. The Royal Astronomical Society, established in 1820, had >3000 Fellows by the end of 2003, so the current figure would be marginally greater than the ASJ membership, but the IAU is a different story. According to the IAU web site, in April 2017 the total IAU membership (individual members) stood at just over 10,000, with 734 in the UK and an almost identical 733 in Japan.

5.1.4 The Culture and the Practice of Optical Astronomers in Japan

In a previous paper (Tajima and Sugiyama 2002) I looked at the research and development project on mosaic CCD cameras conducted at the NAOJ and University of Tokyo around 1990. Among the members of that project there was one researcher who had experience in doing large-scale experiments in high-energy physics and played a key part in the ultimate success of the project. A comparison between the behaviour and way of thinking of that physicist and the other project members showed up the characteristics of the epistemic culture of Japanese optical astronomers: while they had full knowledge of the operation and maintenance of observational instruments, they had little experience in large-scale and systematic R&D. Although they did not show a lack of concern for state-of-the-art instruments, to them R&D was not necessarily a matter of life and death.

In this paper we will investigate the causes of these cultural characteristics by focusing on the construction of three large Japanese telescopes: (1) The 1.88-m reflector at the Okayama Astrophysical Observatory; (2) The 45-m radio telescope at the Nobeyama Radio Observatory; and (3) The 8.2-m Subaru Telescope in Hawaii. These case studies are intended to present a wide spectrum of astronomers' attitudes towards these large-scale construction projects and the changes that occurred at the TAO/NAOJ and in the astronomical community effected by these projects. In particularly, I would like to focus on the effort of astronomers to build the 'Japan New Large Telescope', Subaru, in 1980–1999, comparing with the case of the Gemini Telescopes which were also planned and built at around the same time in the United States. Then, I would like to examine the lineages and the traditions of Japanese optical and infrared astronomers and the origins of the characteristics of their cultures.

For this study, the Subaru Archives at the NAOJ were an important historical resource. These archives store a variety of records such as minutes and proceedings of various meetings, notes and letters written by researchers and all kinds of publications, as well as technical documents actually used by researchers and engineers. Various publications as well as many audio and visual records relating to the Subaru Project are also available. In addition to using these records, I also conducted interviews with relevant parties.

5.2 Construction of Large Japanese Telescopes—Three Case Studies

5.2.1 The Okayama 1.88-m Reflector

Figure 5.1 shows the 74-in. (1.88-m) reflector at the Okayama Astrophysical Observatory. As a background to the purchase of this large telescope, there was the situation where astrophysics was developing dramatically during the first half of the twentieth century. In the USA, the appearance of the 100-in. (2.5-m) Hooker Telescope in 1917 and the 200-in. (5-m) Hale Telescope in 1948 were symptomatic of this situation. These new telescopes, and others elsewhere in the world, produced remarkable results one after another.

After WWII the Tokyo Astronomical Observatory started to build the framework for modern astrophysical research, as I mentioned earlier. Japanese astronomers wanted to embark on front-line astrophysical studies of stars and galaxies, but they had no telescope which was capable of carrying out detailed spectroscopic investigations of such objects.

Supported by a resolution from the Science Council of Japan recommending the construction of a large telescope, the TAO started the planning process in the 1950s. Thus, some researchers were sent to advanced observatories in the United States and Europe in order to acquire the skills needed to conduct observations using large telescopes. When the budget for the purchase of telescope was approved by the Diet in 1954, the TAO established a '74-in. Committee', and found a suitable site for the observatory at Okayama.

In 1955 the TAO signed a contract with Grubb Persons Inc., a well-known British telescope manufacturer, for the purchase of the 74-in. (1.88-m) reflector. Grubb

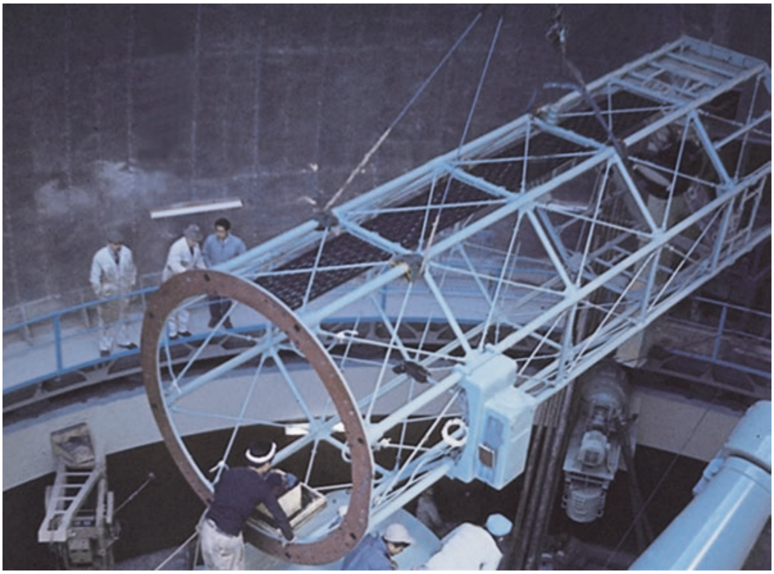

Fig. 5.1 Installation of the Okayama 1.88-m Reflector (*Courtesy* NAOJ)

Fig. 5.2 A view of the completed 1.88-m Okayama Reflector (*Courtesy* NAOJ)

Persons' engineers and Japanese astronomers worked together on the installation and adjustment of the telescope (see Fig. 5.1).

Thus, the Okayama Astrophysical Observatory (OAO) of the TAO opened in 1960 (Fig. 5.2), and 2 years later, shared use of the 74-in. reflector by astronomers both from within and beyond the University of Tokyo commenced. Although its performance was not sufficient for the observation of extra- extragalactic objects, and the targets of study were limited to stars within our Galaxy, in any case Japanese

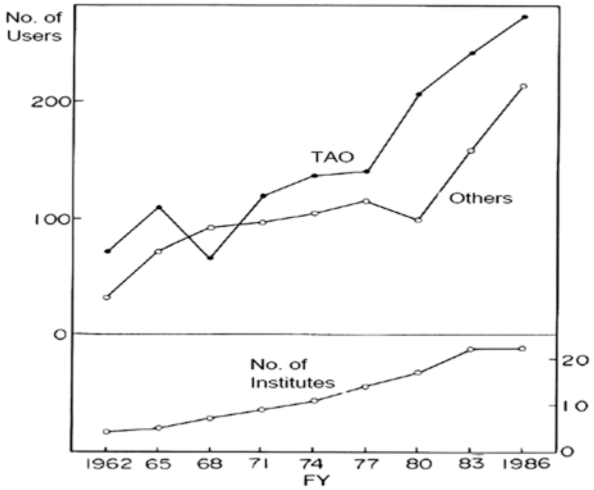

Fig. 5.3 The change in the number of users of the Okayama Astrophysical Observatory (adapted from *The Directory of The National Astronomical Observatory of Japan*, Ministry of Education, Culture, Sports, Science and Technology 1989: 15)

astronomers for the first time had access to a locally-based telescope suited to astrophysical studies.

A whole new generation of astronomers and technicians was trained through the operation of the OAO, which greatly enhanced the growth of the community of Japanese optical astronomers. Figure 5.3 shows the chronological increase in the number of users of the OAO.

Skills and know-how in making and processing observations, maintenance of instruments and management of an observatory were accumulated by many, and these were the most important contribution that the 74-in. reflector made to the Japanese astronomical community.

5.2.2 The Nobeyama 45-m Radio Telescope

Soon after WWII groups from the TAO and Nagoya University group started fundamental research in radio astronomy (Tanikawa 1984), and since this is reviewed in the next chapter of this book (Orchiston and Ishiguro 2017) in this section I will only discuss the construction of the Nobeyama 45-m radio telescope.

In 1965, just 5 years after the Okayama Astronomical Observatory was opened, the Japan National Committee for Astronomy started planning a large radio telescope, but the budget was not approved until the late 1970s. Finally, construction of the radio telescope began at Nobeyama, and in 1981 the new 45-m radio telescope was completed (Fig. 5.4). The shared use of the Nobeyama Radio Observatory started in 1982.

The first event that we have to take notice here was the establishment of the Japan Radio Astronomy Forum (JRAF) in 1970. The goal of this group was to unite all the

Fig. 5.4 The 45-m radio telescope of the Nobeyama Radio Observatory (*Courtesy* NAOJ)

interested researchers in Japan for the planning of the first large radio telescope project. About one hundred people—not just astronomers but also some engineers—came together for the establishment of the Forum. The JRAF is regarded as "… the first independent and democratic organization of researchers in the Japanese astronomical community" (Kaifu 1986). The activities of the JRAF exerted remarkable influence on the entire astronomical community in Japan, and this organization became a model for the Group of Optical and Infrared Astronomers (GOPIRA) which we will discuss in the next section.

The construction of the 45-m radio telescope provided Japanese astronomers with the chance to conduct research using one of the world's top research tools. And what is more, this project left behind a legacy of successful experience and confidence. Astronomers had established a cooperative structure with engineers, physicists and the contractor (Mitsubishi Electric). Knowledge and experience needed to conduct such a huge project was shared and accumulated among them. It can be said that such a relationship would become one of the keys to the success of the Subaru Project, which we will now discuss.

5.2.3 The Subaru Telescope in Hawaii

The third case study is the Subaru Telescope, which in the early days was called the Japanese National Large Telescope (JNLT) Project.

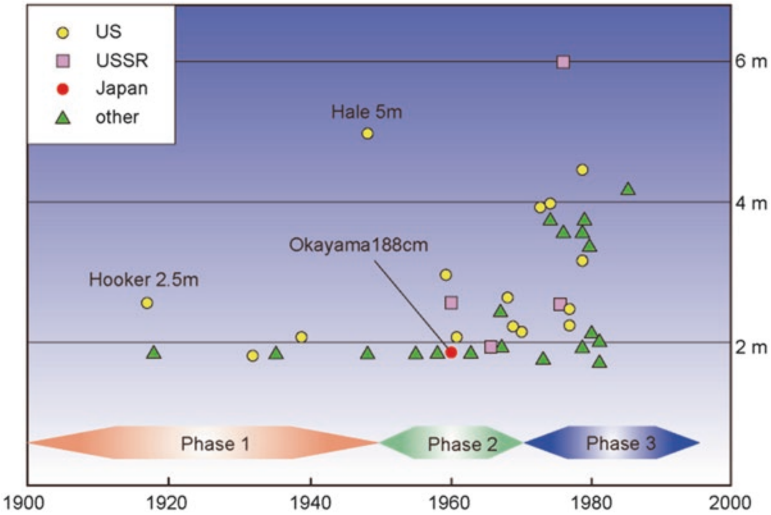

Fig. 5.5 Large reflecting telescopes of the world built by 1980s

As we have already seen, although Japanese optical astronomers got a 188-cm telescope, it was not sufficient in capability for the study of most cutting-edge themes on extragalactic objects and cosmology, which were attracting more and more astronomers worldwide.

Figure 5.5 shows the large reflectors of the world that had been built by the 1980s, from which we can see the declining status of Okayama 1.88-m Reflector. When it was installed in 1960, it was the equal-seventh largest telescope in the world. However, as a series of ‘new generation’ large telescopes were built one after another in 1980s, the position of the Okayama Reflector dropped to below thirtieth place.

What is more, as the number of optical astronomers in Japan grew rapidly, the user capacity of the Okayama 1.88-m reflector quickly became insufficient. Proposals for observational programs submitted by users amounted to more than twice the actual telescope time available in the late 1970s. The 1.88-m telescope simply could not meet the needs of the Japanese astronomical community any more.

Under these circumstances, discussion about the construction of a large new optical and infrared telescope began in the beginning of the 1980s. At advisory bodies of the Education Ministry, such as the Japan National Committee for Astronomy of the Science Council of Japan, the need for the new telescope was placed on the agenda. Meanwhile, the University of Tokyo and the TAO established a series of working groups and study groups.

The most notable movement that we should take note of here is the establishment of the Group of Optical and Infrared Astronomers (GOPIRA). Following discussions held on 1 October 1980 at the First Symposium for the Future Program, 135 astronomers came together on 1 December to form GOPIRA.

The organization was modelled on the Japan Radio Astronomy Forum (JRAF) as we have mentioned, and its goal was to "… find out the position that optical and IR astronomy should take, and put together the astronomers' opinions in the next large telescope program."

The main agenda to be discussed by the Forum members was wide-ranging, and included the type and specifications of the telescope, the time-frame for construction and operation, and the reorganization of the TAO. Forum members also had to review the technologies which they could utilize, and look for a regime dedicated to R&D. As a result, they established three working groups:

1. The Telescope Working Group;
2. The Framework Working Group; and
3. The International Collaboration Working Group.

Frequent meetings and workshops were held, intended to reflect the collective opinion of members on the policy of the TAO and the JNLT project.

However, actual consensus-building was not straight forward. In the discussion at "A Meeting on the Optical Telescope" in 1980, we can see the wide range of astronomers' interests and opinions. For example, some researchers who mainly studied stellar astrophysics wanted to construct a new telescope at an accessible site in Japan, while others who were interested in observations in the infrared wavelength believed that it must be installed on the best site of the world. Optical astronomers were anxious about the feasibility of constructing a large telescope outside of Japan without going through all the necessary steps. On the other hand, the infrared astronomers recognized that there were no suitable sites for an infrared observatory within Japan.

As for the TAO's involvement, the Director at that time was the solar physicist Zenzaburo Suemoto (in office from 1977 to 1981) who was negative about moving overseas, whereas his successor from 1981 to 1994, Yoshihide Kozai (who specialized in celestial mechanics), was eager to have an overseas telescope. Some researchers in other areas, such as radio astronomy, and some members of the Japan National Committee for Astronomy, thought that a 'halfway telescope' would not contribute to the development of Japanese astronomy, and they strongly recommend that a top-level telescope should be constructed on the best site in the world.

In the event, GOPIRA proposed the so-called 'triplet plan' in 1982 which can best be summarized as follows. First, a 3-m class reflector should be constructed in Japan. Almost simultaneously, they advocated the installation of another 1.5–2-m (infrared) telescope out of Japan as a test case of overseas deployment. Then, 10 or 20 years later, a very large telescope would be constructed on the best site in the world.

As a matter of fact, in the 1970s, before the GOPIRA was established, the TAO and Kyoto University had independently planned the construction of new moderate-sized (2–3-m) telescopes, and the first and second stages of the triplet plan were nothing but a repackaged version of their plans. So it could be said that the triplet plan proposed by GOPIRA was a compromise since GOPIRA did not propose any innovative program.

This triplet plan was, however, not approved by the Japan National Committee for Astronomy in 1983. GOPIRA had to restart with a clean slate, and finally consensus

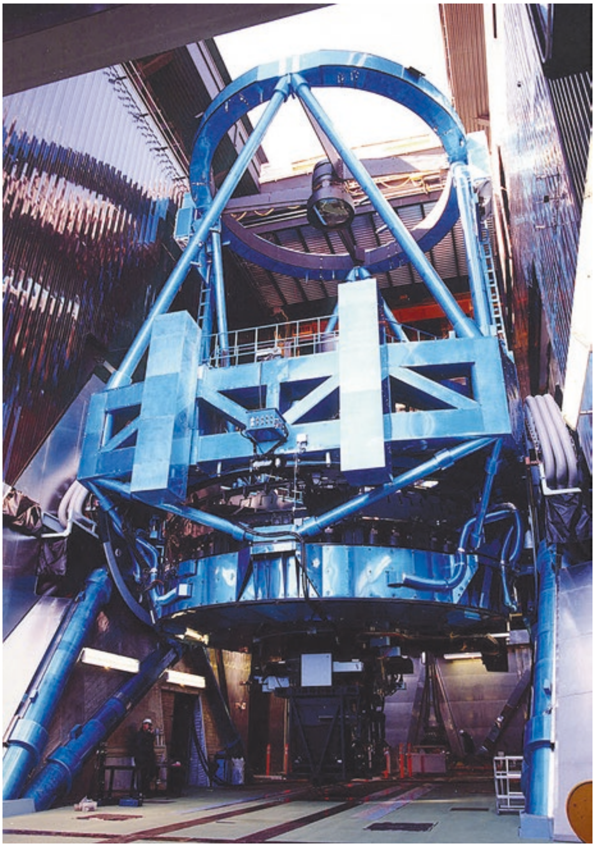

Fig. 5.6 The Subaru Telescope (*Courtesy* NAOJ)

was reached to construct a 7-m class advanced telescope outside of Japan. At that time Kozai said: “Researchers in radio astronomy and other areas apart from optical and infrared astronomy commented that we should advance overseas, so all I had to do was go along with their opinions.”[1]

In response to the policy decision that the JNLT would be constructed outside of Japan, practical planning was started by the JNLT Working Group at the TAO and other groups in 1983. In the following year, the Japan National Committee for Astronomy approved the JNLT project, and detailed specifications for the 7.5-m class telescope were then discussed by the Telescope Technology Study Group consisting of TAO astronomers and contractors.

Funding for the JNLT was approved in 1991, with the aperture increased to 8.2 m, and the construction of the facility on the summit of Mauna Kea (Hawaii) began in the following year. By a concerted effort of the astronomers, engineers and processing staff, the Subaru Telescope (Fig. 5.6) saw first light in 1999. Shared use

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[1] This quote is taken from an interview with Yoshihide Kozai conducted by UN Limited.

of the Subaru Telescope started in 2000, and since then it has produced a number of impressive results, such as the discovery of extra-solar planets and the most distant galaxies.

As a key factor in the success of this project, we can point to the establishment of a framework for the promotion of the JNLT project. Through long-standing discussions, the JNLT came to be recognized as a project which demanded the support of the entire Japanese astronomical community. Behind this realization was the crisis awareness by Japanese astronomers that they would otherwise be left behind in the global competition.

Furthermore, the close cooperative partnership between the astronomers and the contractors was also essential, and a relationship of trust was built through mutual respect. Both parties recognized that this was a truly collaborative project rather than a mere business connection, and through the 'trading zone' between them, the experience and technology of the manufacturers and the knowledge of the astronomers was merged. In addition, the personal connections that some leading astronomers had with politicians came into play when it was time for approval of the budget (see Kodaira 1999).

With the success of the JNLT project, Japanese astronomers have been able to conduct observations using a very large aperture telescope in excellent condition, and the status of Japanese astronomy in the international arena has improved. Consequently, it was possible to discuss cooperative projects involving other large telescopes on an equal basis. While these situations gave Japanese optical and infrared astronomers the confidence to conduct major projects, the culture and tradition of the Japanese astronomical research community has been altered in various ways and the sense of unity that once prevailed may have been lost.

5.3 Discussion of the Japanese Astronomical Community

5.3.1 Comparison with the Astronomical Community in the USA

Now, we will take a close look at the characteristics and origin of the Japanese astronomical community. The comparison of the case of JNLT and other cases should offer valuable insight. Take the prehistory of the Gemini Telescopes in the United States for example (McCray 2001, 2004). In the 1980s, around the same time as the JNLT project was under discussion, the 15-m National New Technology Telescope (NNTT) project was planned in the USA by the Association of Universities for Research in Astronomy (AURA) and several universities. However, as the two groups proposed completely different design—the multi-mirror telescope of the Arizona group and the segmented-mirror telescope of the California group (see Fig. 5.7)—AURA failed to bridge the gap. They then had to start all over again and

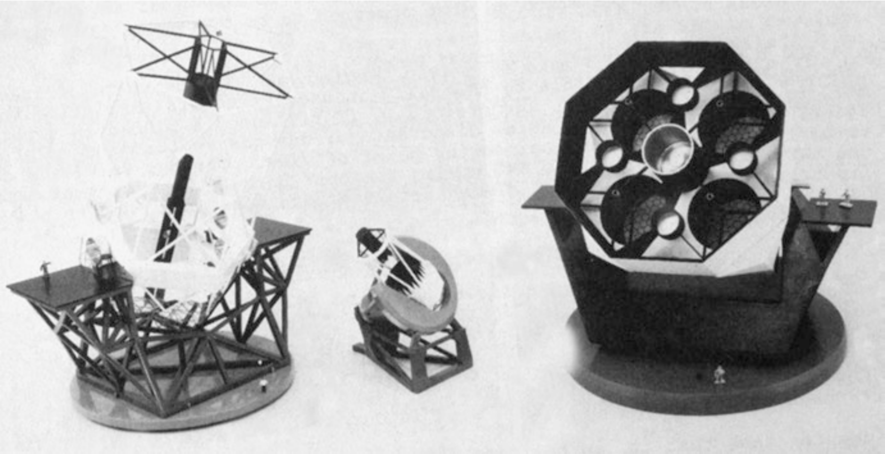

Fig. 5.7 The segmented-mirror (*left*) and multiple-mirror (*right*) designs for the NNTT, with a scale model of the Kitt Peak 4-m telescope in the centre (copyright: Association of Universities for Research in Astronomy Inc.)

agree on a totally new plan, which ultimately led to the Gemini Telescopes as we know them today.

As just described, the astronomical communities in both Japan and the United States failed to promote original ideas and had to start again from the beginning in a similar way, but their backgrounds were quite different. In the United States, while some universities had rich experience in the research and development of large telescopes, ironically this became a major obstacle for consensus forming—the 'inertia' of their technology prevented agreement between the two major groups (McCray 2001). In this sense, the astronomers in Arizona and California rather resembled high-energy physicists in the way in which they decided their priorities from practice in their research lives (Galison 1998; Knorr Cetina 1999).

In contrast, Japanese astronomers had little experience in the construction of large telescopes, so they could only produce the half-hearted 'triplet plan' at first. Because Japanese astronomers—especially those who studied at optical wavelengths—had neither experience in the R&D of large telescopes and instruments nor experience in construction of facilities outside of Japan, they were not sure that they could carry through such a large ambitious project.

As another factor, the diversity in practice of astronomical research—a significant characteristic of astronomy as an academic discipline—should be pointed out. Unlike other disciplines such as high-energy physics, which simply pursue the frontier of highest energy, there can be many different targets in astronomy, so even the largest telescope can not always provide all of the answers. Furthermore, astronomers who study relatively-bright objects do not need these large telescopes and are able to publish significant papers based on observations made with moderately-sized telescopes. But of course, they might be ambitious to have these superb telescopes and instruments if they have enough resources, just like the California group. Still, they do not necessarily have to unite and construct a very large telescope in order to continue their research work.

Finally, on the difficulty of consensus-building within the Japanese astronomical community, there were differences in the traditions and cultures of the optical and IR astronomers, as we will examine in the next section.

5.3.2 The Traditions of Optical and Infrared Astronomy in Japan

Let us now focus on the traditions of optical and infrared astronomy in Japan, and reveal the origin of their subcultures which became obvious as the communities confronted the challenge of the JNLT project.

Once the modern system of higher education was introduced in Japan after the Meiji Restoration in the late nineteenth century, education and training in astronomy and astrophysics was offered by just three universities, the University of Tokyo, Kyoto University and Tohoku University. Although students can now study astronomy at various other universities, these three universities formed the mainstream of the Japanese astronomical tradition—especially in the area of optical astronomy—during the pre-war period. For example, if you look at the Tokyo Astronomical Observatory before 1980, the majority of the research staff were educated at the University of Tokyo, and a rather hierarchical and somewhat formal social structure was found in the relationships between staff members.

Concerning the attitude toward technological aspects of astronomy, it was thought that instruments should be made by commercial manufacturers or technicians and that astronomers should only do research. Consequently, they were not encouraged to engage in R&D on telescopes and instruments. Senior researchers often said, "If you have some time to do R&D on instruments, then you should devote it to studying 'astronomy'."[2] Still, there were a few astronomers who were interested in R&D, but their contribution in R&D was not appreciated when it came to personnel evaluation. Moreover, because neither the TAO nor the Department of Astronomy supported them sufficiently, all they could do was DIY-like R&D which usually did not yield outstanding results. For example, although a group of astronomers tried to introduce charge-coupled devices (CCDs) into their research programs in 1980, this effort was not sustained and CCDs only were widely-accepted in Japanese astronomy in the 1990s, once they and their driver circuits became available commercially.

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[2] See, for example, the website of Takashi Ichicawa, Professor of Astronomy at Tohoku University: http://www.astr.tohoku.ac.jp/~ichikawa/instrumentation.html (in Japanese).

Fig. 5.8 The 1-m infrared telescope of Kyoto University (*Courtesy* Kimiaki Kawara)

More of the same sorts of things could be said about the astrophysics group at Kyoto University, which formed the other large tradition in optical astronomy in Japan. In addition, there was limited communication between astronomers in Kyoto and Tokyo before 1980, when GOPIRA was established.

On the other hand, astronomical research at infrared wavelengths in Japan was started in the Faculty of Physics at Kyoto University. Around 1965, when a series of remarkable findings were reported one after another in this new research area, cosmic-ray physicists at the University entered the field. Although they had to fabricate all the observational instruments themselves, they could take advantage of knowledge and skills they had acquired through physics experiments. So they started fundamental studies, attaching their hand-made detectors to balloons, rockets and the Okayama 1.88-m telescope, then in 1973 they constructed a telescope dedicated to infrared astronomy (Fig. 5.8). In those days, fabrication of new instruments led them directly to new discoveries. There was a rather free and easy atmosphere in this young new discipline, and during the 1980s the IR astronomers were highly-motivated in planning a new telescope for Kyoto University. Nevertheless, unlike the high-energy physicists, their practice of R&D did not take on the features of a 'big science'—the scale of organization was moderate and the division of labour was not noticeable. The mode of their R&D often meant that the instruments they manufactured had a rather home-made look about them.

5.3.3 What has the JNLT Project Changed?

With these issues in mind, we will now take a look at the JNLT project again. As described above, two communities—optical and infrared astronomers, with very different cultural characteristics—worked together as a team right from the planning stage, and it was the first time for both of them to pursue such a large-scale project. While some of the researchers felt discomfort, they still managed to operate within a viable framework.

Through these processes, the boundary between the Japanese optical and infrared astronomers seems to have disappeared, and their subcultures may have blended and become homogenized. Once the NAOJ was formed, the optical and infrared astronomers were no longer divided into separate groups, and with the passage of time and the emergence of a new generation of astronomers the cultural differences that formerly existed have simply evaporated.

In addition, the stance that observational instruments should be developed by astronomers themselves seems to have been accepted by the entire Japanese astronomical community. There has been a significant change in the organization of the NOAJ in order to promote R&D. It is often said, however, that the evaluation of the contribution toward R&D may still not be enough. What is more, the skills and tacit knowledge acquired through Subaru-related R&D may not be fully inherited by the next generation.

In summary, the Tokyo Astronomical Observatory was founded as an agency for practical astronomical observation as well as public education, but in its present guise as the National Astronomical Observatory of Japan it has firmly established itself as an international centre for all types of astrophysical research and a facility that can successfully plan and oversee the construction of large optical and radio telescopes.

Observatory life of Japanese astronomers has changed noticeably. A number of astronomers and technicians have been trained through the experience of construction and operation of large telescopes. Research and development of telescopes and observational instruments have become an important part of the astronomers' practice.

The NAOJ joined the Thirty Meter Telescope (TMT) project as a participating institution in 2008. However, the NAOJ seems not to acquire sufficient centripetal force for TMT compared to the Subaru Project in 1990s. While the big science-like character of modern astronomy is getting more and more pronounced in many aspects, astronomers of the day can easily access a number of telescopes as well as existing archival data to work on their own papers. Some Japanese universities are planning to have their own large to middle-sized telescopes, so there is a distinct possibility that the status of the NAOJ will change even further in the future.

References

Ando, H. (1998). *World's Largest Telescope, Subaru*. Tokyo: Heibonsha Ltd.. (in Japanese).

Annual Reports of the National Astronomical Observatory of Japan, 1988–2008 (in Japanese).

Annual Reports of the Tokyo Astronomical Observatory, 1957–1987 (in Japanese).

The Astronomical Society of Japan, Editorial Committee for One Hundred Years of Astronomy in Japan (2008). *One Hundred Years of Astronomy in Japan*. Tokyo: Kouseisha-kouseikaku Corporation. (in Japanese).

Editorial Committee for One Hundred Years of the Tokyo Astronomical Observatory (1978). *One Hundred Years of the Tokyo Astronomical Observatory of University of Tokyo: 1878–1978*. Tokyo: University of Tokyo Press. (in Japanese).

Editorial Committee for The Commemoratives of the Fortieth Anniversary of Okayama Astrophysical Observatory (2000). The commemoratives of the Fortieth Anniversary of Okayama Astrophysical Observatory.; available at http://www.oao.nao.ac.jp/stockroom/extra_content/com40pdf/index.htm (in Japanese).

Editorial Committee for The Commemoratives of the Twentieth Anniversary of Nobeyama Radio Observatory (2002). The Commemoratives of the Twentieth Anniversary of Nobeyama Radio Observatory of National Astronomical Observatory of Japan (in Japanese).

Edmondson, F.K. (1997). *AURA and its US National Observatories*. Cambridge: Cambridge University Press.

Galison, P. (1998). *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press.

GOPIRA Newsletters, No. 1 (10 Dec. 1980)–No. 81 (2 May 1997) (in Japanese).

Isobe, S. (2004). Jubilee publication in commemoration of Dr. Shuzo Isobe (in Japanese).

Kabumoto, K. (1996). The roles of Shinzo SHINJO in the modern astronomy in Japan. *Journal of History of Science, Japan*. *[Series 2] 35*(200), 260–270.

Kaifu, N. (1986). *The Making of the Radio Telescope*. Tokyo: Ohtsuki Shoten. (in Japanese).

Kaifu, N. (2007). *The Universe of the Subaru Telescope: The Challenge from Hawaii*. Tokyo: Iwanami Shoten. (in Japanese).

Kodaira, K. (1999) *Toward the End of the Universe: 20 Years of the Subaru Telescope Project*. Tokyo: BungeiShunju Ltd.. (in Japanese).

Knorr Cetina, K. (1999). *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge (Mass.): Harvard University Press.

Lankford, J. (Ed.), (1997). *History of Astronomy: An Encyclopedia*. New York: Garland Publishing.

Large Optical Telescope Planning Group of the Department of Astronomy and Tokyo Astronomical Observatory of University of Tokyo (1980). The Summary of the Data for the Large Optical Telescope Program (in Japanese).

McCray, W.P. (2001). What makes a failure? Designing a new National Telescope, 1975–1984. *Technology and Culture, 42,* 265–291.

McCray, W.P. (2004). *Giant Telescopes: Astronomical Ambition and the Promise of Technology*. Cambridge (Mass.): Harvard University Press.

Nakayama, S. (2000). *Japanese Astronomy: Astrology, Calendar, Visions of Universe*. Tokyo: The Asahi Shimbun Co.. (in Japanese).

National Astronomical Observatory of Japan (1989). The Account for the Large Optical and Infrared Telescope Project (in Japanese).

Orchiston, W., & Ishiguro, M. (2017). The early development of radio astronomy in Japan. In T. Nakamura, & W. Orchiston (Eds.), *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Proceedings of the GOPIRA Symposium "Optical and Infrared Astronomy and Telescope Technology", 9–11 November 1981 (in Japanese).

Proceedings of the GOPIRA Symposium "Telescope Future Planning Symposium", 8 November 1982 (in Japanese).

Proceedings of the Optical and Infrared Telescope Future Planning Symposium, 12–13 July 1983 (in Japanese).

Proceedings of the Project Promotion Symposium for the Large Optical and Infrared Telescope, 19–20 November 1984 (in Japanese).

Proceedings of the Project Promotion Symposium for the Large Optical and Infrared Telescope, 12–13 January 1986 (in Japanese).

Proceedings of the Workshop on the Observational Instrument, 23–24 October 1985 (in Japanese).

Proceedings of the Workshop on the Observational Instrument for JNLT, 25–26 September 1987 (in Japanese).

Tajima, T., & Sugiyama, S. (2002). Cultural heterogeneity in different scientific disciplines; an analysis from the viewpoint of sociology of science: trading zones between optical astronomy and high energy physics. *Japan Journal for Science, Technology & Society, 11,* 67–89. (in Japanese).

Tajima, T. (2011). The National Astronomical Observatory of Japan and postwar Japanese optical astronomy. In T. Nakamura, W. Orchiston, M. Sôma, & R. Strom (Eds.), *Mapping the Oriental Sky. Proceedings of the Seventh International Conference on Oriental Astronomy* (pp. 217–226). Tokyo: National Astronomical Observatory of Japan.

Tanikawa, H. (1984). Development of solar radio astronomy in Japan up until 1960. In W.T. Sullivan III (Ed.), *The Early Years of Radio Astronomy. Reflections Fifty Years After Jansky's Discovery* (pp. 335–348). Cambridge: Cambridge University Press.

Tokyo Astronomical Observatory (Ed.), (1968). *Ninetieth Anniversary of Tokyo Astronomical Observatory: The History and the Prospects*. Tokyo: Tokyo Astronomical Observatory. (in Japanese).

Chapter 6
The Early Development of Japanese Radio Astronomy

Wayne Orchiston and Masato Ishiguro

6.1 Introduction

Radio astronomy started in Japan in 1948 (Ishiguro et al. 2012), about the same time it was launched in France (see Orchiston et al. 2007, 2009), and just 2 years after the first post-war solar radio observations were made in Australia (Orchiston et al. 2006), Canada (Covington 1984) and England (Edge and Mulkay 1976; Hey 1973). But as Tanaka (1984: 335) points out, "… considering the difficult social circumstances arising from the nation's defeat in World War II, its development was not so slow." Part of the reason for this was the ready availability of suitable equipment:

> Radar was also intensively developed in Japan during World War II, although it was not as technically advanced as that of the Allies. Once the defeated nation began to recover in the 1940s, however, radio physicists could draw not only on domestic stores, but also on American radar parts, readily available from War surplus dealers. (Sullivan 2009: 225).

In this chapter we will summarise the key elements in the development of Japanese radio astronomy from 1948 until 1960, building on the excellent foundation that Tanaka provided in his classic paper of 1984. However, Tanaka (1984: 347) was quick to point that "I am afraid my selection is far from complete, and not a few hidden topics have been left out." Hopefully we will fill some of these gaps with this chapter. However, further research is required. Consequently, an ambitious international project is currently underway through the IAU Historic Radio Astronomy Working Group that will lead to a series of papers by the above authors and their

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collaborators and provide a more detailed account of these early Japanese achievements in radio astronomy. Now, before summarising these post-war developments we must first examine one of Nakagami and Miya's experiments in telecommunications that was conducted in 1938.

6.2 A Missed Opportunity: The Dellinger Effect and Solar Radio Emission

The Dellinger Effect (1937: 1253) was defined by its discoverer as:

> … the occurrence of a very sudden change in ionization of a portion of the ionosphere. It manifests itself by the complete fading out of high frequency radio transmission for a period of a few minutes to an hour or more, and by perturbations of terrestrial magnetism and earth currents. The effect was discovered in 1935.

Daitaro Arakawa (1936) and J. Howard Dellinger (1937) both reported that "… a kind of 'grinder' like noise sometimes appeared almost simultaneously with [the] Dellinger phenomena in short-wave telecommunication receivers." (Tanaka 1984: 335).

In 1938 Drs Nakagami and Miya from the International Telecommunication Co. Ltd. in Tokyo were interested in the origin of this 'grinder' noise, so they erected two horizontal half-wave dipoles, one at $h = \lambda/2$ and the other at $h = 5\lambda/4$ above the ground, and compared their outputs. With this arrangement they could measure the incident angles of the incoming radiation if it was >70° (Nakagami and Miya 1939). From April through to September 1938 they monitored telecommunication signals, watching the output meters and writing down the observed values in a notebook every minute. Their patience was rewarded on 1 August when they noted a short-term increase in noise that coincided with a Dellinger phenomenon. This is shown in Fig. 6.1, where the noise

> … suddenly increased to 40–50 dB as soon as the communication signal from station PLJ at 14.6 MHz faded out. The noise decreased rapidly in five minutes. They were surprised that the noise received by the $h = 5\lambda/4$ antenna was more than 10dB stronger than the one received by the $h = \lambda/2$ antenna, which clearly showed that the incident angle was more than 70 degrees, as plotted in the upper part of the Figure. As the Sun was then placed at about 70 degrees in elevation angle, Miya believed naturally that the noise came directly from the sun. However, his senior Nakagami was too cautious to accept the young Miya's simple idea, and imagined that the noise originated around the E-layer, connected with a Dellinger disturbance of the atmosphere. In the end, the possibility of direct noise from the Sun was not mentioned in their paper. (Tanaka 1984: 336–337).

Dr. Kenichi Miya, who provided Tanaka with this account, subsequently became the President of the International Telecommunications Installation Co. Ltd., and made many research contributions in the fields of radio waves and satellite communications. At one time he was the President of the International Communications Society (ISCS), and he was involved in ionospheric research during the International Geophysical Year. In honor of his many achievements, he received the IEEE Award

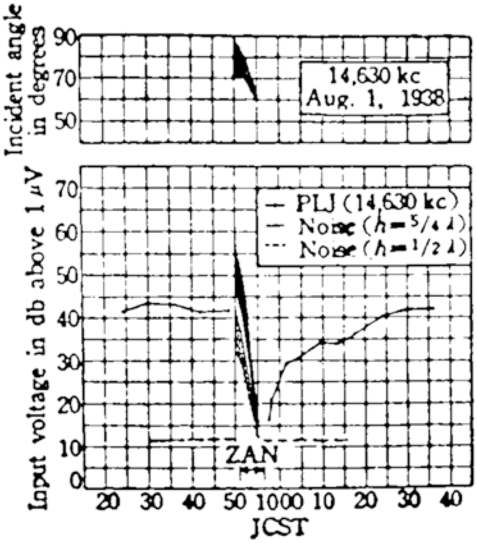

Fig. 6.1 Observations conducted on 1 August 1938 showing (lower) the fade-out of the telecommunications signal (ZAN), and (upper) a simultaneous increase in noise received by the two antennas, which we can now associate with solar radio emission (after Nakagami and Miya 1939: 176)

in International Communications in 1987. He died in 2004 at the age of 89 (see Smith 2004).

Finally, it is of interest to note that although these pre-War Japanese observations were carried out in isolation, 'ham radio operators' in England and a number of other countries also recorded anomalous noise during the 1930s (Ham 1975). While some of them also assumed that the noise was of solar origin, they were unable to take the vital step and attribute it directly to radio emission from the Sun (for an excellent overview see Sullivan 2009: 85–89). Sullivan (1984: 89) appropriately refers to the Nakagami and Miya episode as "Another near-miss …".

6.3 Early Developments in Japanese Solar Radio Astronomy

6.3.1 Koichi Shimoda and the Solar Eclipse of 1948

Tanaka (1984) claims that Japanese solar radio astronomy began in 1949, but he was not aware of an earlier investigation which was conducted by Koichi Shimoda in 1948. Nor does this investigation feature in Sullivan's (2009) encyclopaedic history of early radio astronomy.

The foundations for Shimoda's 1948 experiment can be traced back to 1930 when two 2-m parabolic reflectors were manufactured for the Aeronautical Research Institute (ARI) at the University of Tokyo. Following WWII the Institute of Science and Technology was established in 1947 to replace the ARI, and after completing his graduate studies in physics at the University of Tokyo Koichi Shimoda began research at the Institute. He then discovered one of the two 2-m antennas among the relics of the ARI:

> One day in the early spring in 1948, I happened to find a nice parabolic reflector among scraps of the Aeronautical Research Institute. The surface of the reflector was made of copper plates mounted on a hardwood frame. The shape of the paraboloid was precise to within a few millimetres with a focal length of about 73 cm.
>
> I was much delighted with this reflector, because it had the quality comparable to, or better than the best radar antenna for 10 cm waves. Moreover, the size of 2 m in diameter and 35 cm in depth was just [what] I wanted. (Shimoda 1982: 32).

Shimoda then hurriedly installed a microwave feed at the focus of the dish, and a "… 3-GHz radar receiver using a magnetron local oscillator was modified into a rudimentary Dicke-type radiometer." Shimoda then used this simple radio telescope to conduct the first radio astronomical experiment made from Japan when he observed the partial solar eclipse of 9 May 1948. A copy of the oscilloscope display during this pioneering observation is reproduced here in Fig. 6.2.

As Shimoda (1982: 32–33) was quick to point out,

> Because of the poor sensitivity and stability of the receiver, a decrease in received power can barely be recognized. The background noise and external disturbance prevented me from revealing any fine structures. The observed result was only orally reported at a meeting and has not been published anywhere.

Somewhat belatedly, Shimoda rectified this by including his observations and a copy of the above record in the 'After Dinner Talk' he presented at the 13th Okazaki Conference in 1982, and his account was subsequently published in the record of that meeting (Shimoda 1982). Much later, we joined him in publishing a more detailed account in the *Journal of Astronomical History and Heritage* (Shimoda et al. 2013), thereby bringing his pioneering observations to an international astronomical audience.

As an aside, it is important to point out that Shimoda's antenna was just beginning its career in radio astronomy, for in 1952 it was transferred to the Tokyo Astronomical Observatory by Kenji Akabane where it went on to do good service in the name of Japanese solar radio astronomy. Moreover, solar eclipses would continue to play a key role in the development of solar radio astronomy in Japan, as in other countries

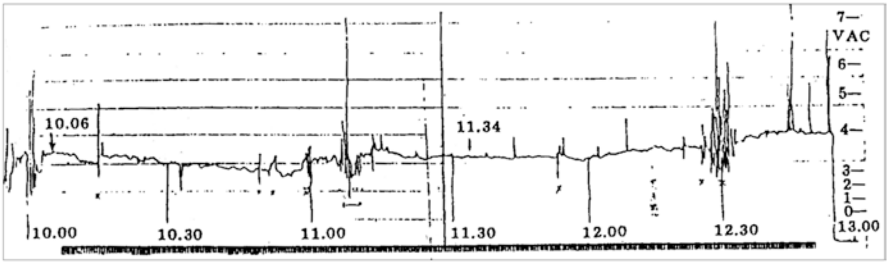

Fig. 6.2 A copy of the oscilloscope display during the 3000 MHz observations of the 9 May 1948 partial solar eclipse, as observed from Tokyo; this pioneering observation marked the start of Japan's early radio astronomy program (after Shimoda 1982: 33)

(e.g. see Hey 1955; Orchiston and Steinberg 2007; Orchiston et al. 2006; Wendt et al. 2008a).

6.3.2 *Observations by Oda and Takakura in Osaka*

After Shimoda's exploits, the next experiment in Japanese radio astronomy occurred in November 1949 when Minoru Oda and Tatsuo Takakura (see Orchiston et al. 2016) from the Physics Department at Osaka University observed solar noise at 3300 MHz using the hand-made horn shown in Fig. 6.3, which was mounted on a salvaged ship-born searchlight mounting (Tanaka 1984). They then moved to Osaka City University, where the horn was replaced by a small parabolic dish (see Fig. 6.4). Oda and Takakura (1951) then carried out solar observations for about 2 h each day over a 15-month period from April 1950, and noticed that there was a linear relationship between solar noise and sunspot number. They concluded that

> … it is most probable that the solar noise comes from the sunspots, but it should be noted that the period of a source is rather short. Then it may be supposed that the magnetic field in the sunspot might have [an] important role in the generation of radio waves. (ibid.).

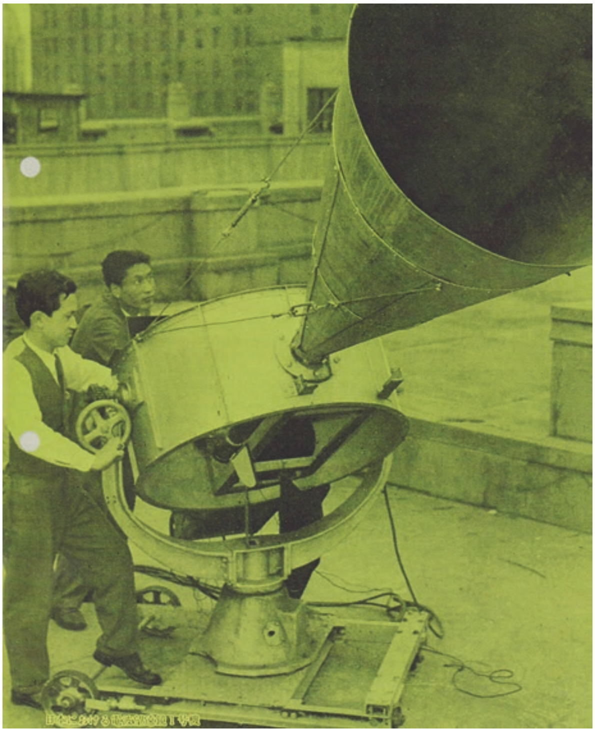

Fig. 6.3 A 1949 photograph showing Drs Oda (*left*) and Takakura (*right*) observing 3300 MHz solar emission from Osaka University with their hand-made horn (after Takakura 1985: front cover)

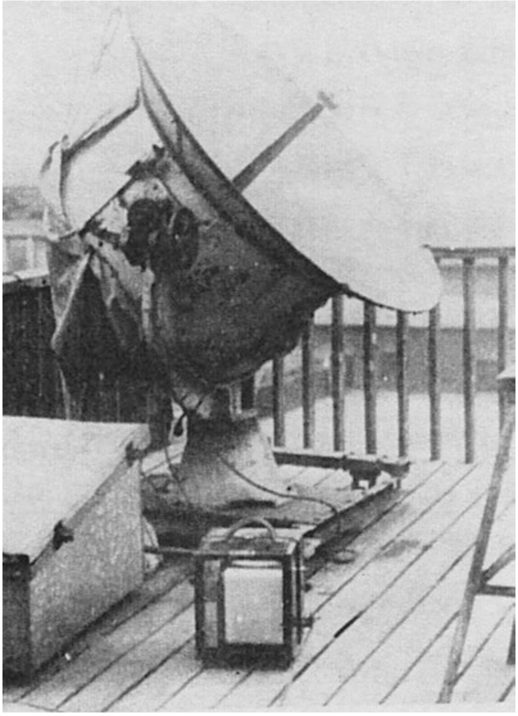

Fig. 6.4 A photograph taken after the move to Osaka City University, showing the refurbished radio telescope which now features a solid-surface parabolic reflector in place of the horn; this instrument was used to monitor solar radio emission from April 1950 to July 1951 (after Takakura 1985: 163)

Oda and Takakura were "… physicists who were interested in the origin of solar noise." (Tanaka 1984: 337). Oda had been involved in the development of microwave radar during WWII, and in 1951 quickly switched his attention back to cosmic rays (Sullivan 2009: 226), but his graduate student, Takakura, persevered with radio astronomy until 1953. Although he never published results derived from any of these early Osaka observations, this all was to change in 1954 when he joined the solar radio astronomy group at Tokyo Astronomical Observatory. Tatsuo Takakura had served his apprenticeship well while in Osaka.

6.3.3 The Solar Radio Astronomy Group at the Tokyo Astronomical Observatory

Radio astronomy began at Tokyo Astronomical Observatory (henceforth TAO) at Mitaka, Tokyo, in September 1949 under Professor T. Hatanaka, who was assisted by F. Moriyama and S. Suzuki. They received strong support from the Director of the Observatory, Professor Y. Hagihara, who realised the potential of this new line of research. Most of these individuals are shown in the 1954 photograph reproduced here as Fig. 6.5.

In 1949 the first radio telescope was installed at Mitaka. It comprised a 5 m × 2.5 m equatorially mounted broadside array that operated at 200 MHz and

Fig. 6.5 A meeting of the Japanese National Commission V of URSI held at Toyokawa Observatory in 1954; front row (left to right): Professor A. Kimpara (Director, Research Institute of Atmospherics, Nagoya University) and Professor Y. Hagihara (Director, Tokyo Astronomical Observatory); back row (left to right): H. Jindo (Toyokawa), K. Akabane (TAO), T. Takakura (TAO), T. Kakinuma (Toyokawa), H. Tanaka (Toyokawa), S. Suzuki (TAO) and T. Hatanaka (TAO) (after Tanaka 1984: 345); the only other Japanese radio astronomers active at this time, but missing from the photograph, were F. Moriyama (TAO) and T. Takahashi (Hiraiso)

was constructed for the Observatory by the Radio Research Laboratories of the Ministry of Posts and Telecommunications. This instrument is shown in Fig. 6.6. In 1950, 60 and 100 MHz Yagi antennas were installed, and multi-wavelength observations of solar bursts began. Two years later this program was enhanced with the completion of a 100–140 MHz spectrometer using a rhombic antenna. At the same time the radio telescope that Shimoda had used during the 1948 eclipse was set up at Mitaka for observations at 3000 MHz in order to investigate the slowly varying component of solar radio emission. The range of instruments was expanded further in the following year (1953) with the completion of two more rhombic antennas allowing solar spectral observations from 200 to around 700 MHz, and with the erection of a 10-m equatorially mounted parabolic dish that could operate at both 200 and 3000 MHz. At the time, this was the second-largest radio telescope of this type in the world. This dish, along with one of the rhombic antennas, is shown in Fig. 6.7. In 1954 Suzuki (1959) completed the construction of an interferometer comprising four 2 m × 5 m broadside arrays, which was designed to investigate the positions of the sources of 200 MHz solar bursts with an accuracy of a fraction of an arc-minute. A close-up of one of these broadside arrays is shown in Fig. 6.8. Finally, in 1957 a 1.2-m dish was erected to detect solar emission at 9500 MHz. Most of these instruments were installed in a dedicated ‘radio astron-

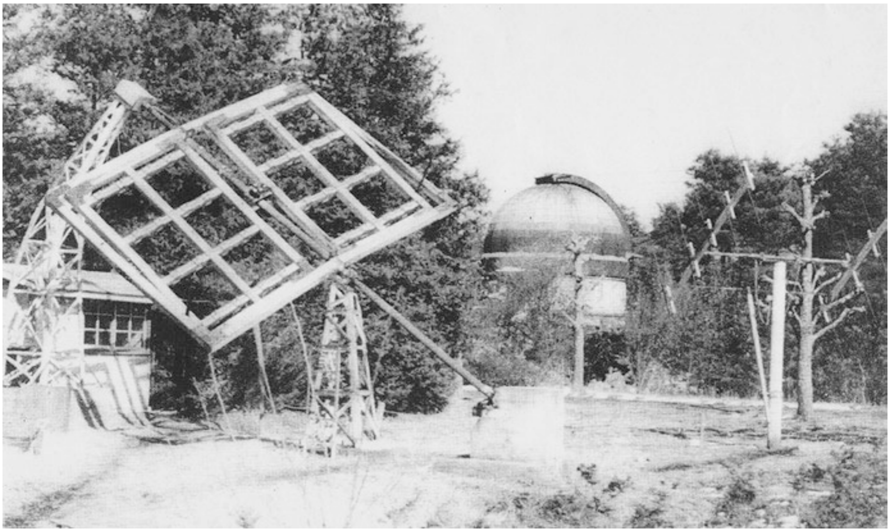

Fig. 6.6 On the left is the broadside array that was the first radio telescope erected at the Tokyo Astronomical Observatory. From September 1949 it was used to monitor solar radio emission at 200 MHz. On the far right is a 2-element 60 MHz Yagi antenna that was installed in 1950 (*Courtesy* National Astronomical Observatory of Japan)

Fig. 6.7 Left of centre is the 10-m equatorially mounted dish erected at the TAO in 1953, which was used to monitor solar radio emission at 200 and 3000 MHz; on the left is the rhombic aerial of one of the solar radio spectrographs, and on the far right is a grating interferometer that was subsequently installed to identify the positions of active regions at 9000 MHz (*Courtesy* National Astronomical Observatory of Japan)

omy precinct' near the south-western boundary of the Observatory grounds, far from the main buildings and their associated electrical interference. After a short hiatus, further instruments were added from 1963 onwards, but these lie outside the scope of this chapter.

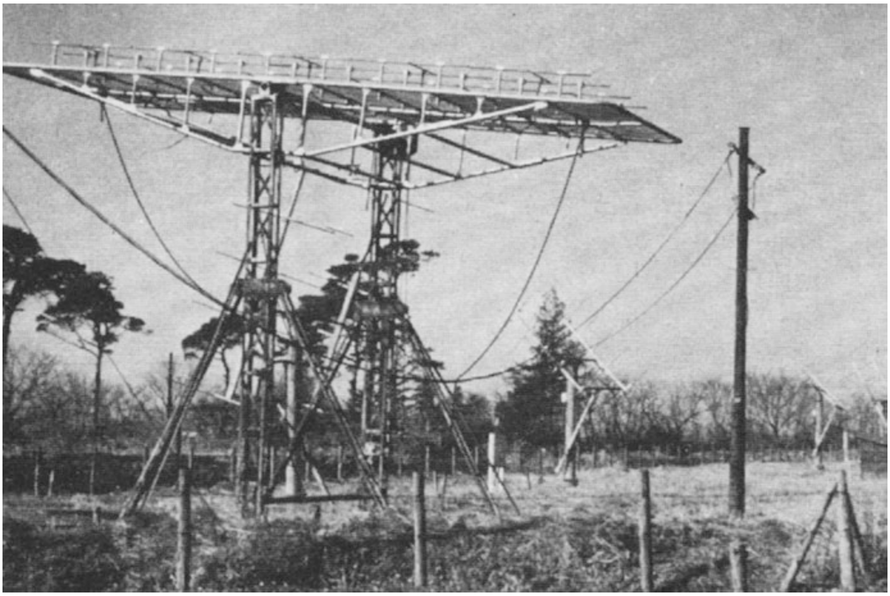

Fig. 6.8 One of the broadside arrays in Suzuki's 4-element interferometer that was installed at the TAO in 1954 and was used to research the positions and heights of the sources of the 200 MHz solar bursts (after Tanaka 1984: 343)

The initial research at 200 MHz by the Tokyo Astronomical Observatory radio astronomers focussed on the relationship between solar bursts and sunspots and calcium plages (Hatanaka et al. 1955c) and the polarization of these bursts (e.g. see Hatanaka et al. 1955a, b). With the construction of the Suzuki 4-element interferometer research turned to the positions and heights of the sources responsible for the 200 MHz bursts. Given access to this new instrumentation and the low-frequency spectrometers, from 1961 Kai and Morimoto began an investigation of specific types of solar bursts, with emphasis on the characteristics, polarization parameters and source heights of Type 1, Type III and Type IV bursts (Kai 1962, 1963, 1965; Morimoto 1961; Morimoto and Kai 1961; Takakura and Kai 1961; see, also, Tsuchiya 1963). Meanwhile, observations conducted at 3000 and 9000 MHz centred on long-term variations in solar emission at these higher frequencies (Hatanaka and Moriyama 1953), and included observations of a partial eclipse in 1955 which produced a model for the region assumed to be responsible for the emission (see Hatanaka et al. 1956).

Tanaka (1984) notes that by 1960 there were about ten TAO staff actively studying solar radio emission.

For a detailed account of the TAO solar radio astronomy program see Nakajima et al. 2014.

6.3.4 The Solar Radio Astronomy Group at the Toyokawa Observatory

The Research Institute of Atmospherics at Nagoya University was established in June 1949 under the Directorship of Professor A. Kimpara, and a radio astronomy field station was established at Toyokawa, a former naval arsenal and radio-quiet site 60 km south-east of Nagoya. The plan was to observe the Sun at high frequencies in connection with the ionospheric disturbances that impact on radio communications and terrestrial radio noise.

At the end of 1949 Haruo Tanaka was appointed to lead a radio astronomy group, and he was joined by T. Kakinuma almost one and a half years later. At exactly the same time (in April 1951) the first Toyokawa radio telescope was completed. This comprised a 2.5-m dish, which was connected to a 3750 MHz receiver (Fig. 6.9). This instrument was used as a total power radiometer to monitor solar emission.

Tanaka (1984: 339) describes what happened next:

> After the completion of our first radiometer at 3750 MHz, we designed a one-dimensional grating interferometer and applied for funds for construction in 1951. The frequency of the interferometer was 4000 MHz … The budget was partly approved in 1952, and the first 5-element interferometer was completed in March 1953 …

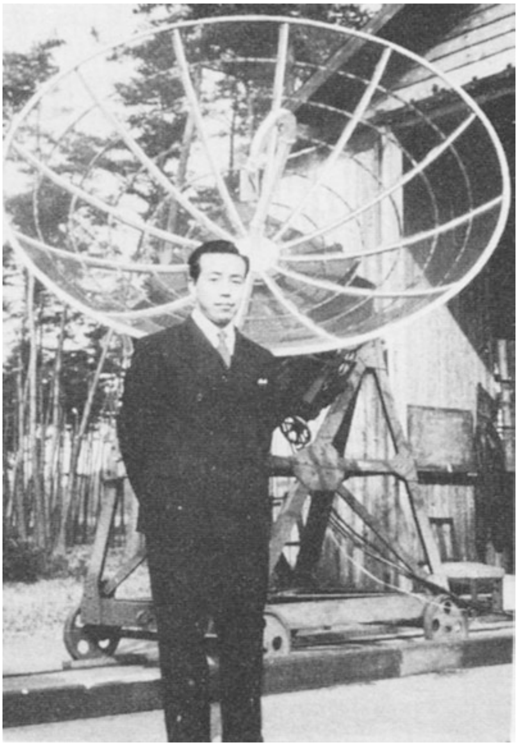

Fig. 6.9 Haruo Tanaka with the first radio telescope installed at Toyokawa in 1951, a 2.5-m parabola that recorded solar emission at 3750 MHz (after Tanaka 1984: 344)

The 5-element interferometer dishes were 1.5 m in diameter (see Fig. 6.10). The following year this interferometer was expanded to eight elements (Tanaka and Kakinuma 1953b). As Tanaka (1984: 340) emphasizes, this grating interferometer was planned and built quite independently of the one at Potts Hill in Sydney which was constructed by W.N. Christiansen at about the same time (see Wendt et al. 2008b). In 1954, polarization screens were added to the Toyokawa dishes (see Fig. 6.11).

The next phase in the development of the Toyokawa Observatory involved the construction of three dishes with diameters of 3 m, 2.2 m and 1.2 m, which operated at 1000 MHz, 2000 MHz and 9400 MHz respectively (Tanaka and Kakinuma 1956a). These were used as total power radiometers in conjunction with the original 2.5 m dish (which continued to record at 3750 MHz). These four radiometers are shown in Fig. 6.11, behind the 8-element grating array.

The final phase in the development of the pre-1961 instrumentation at Toyokawa occurred in 1959 when another 8-element grating array was constructed, but this one utilized 1.2-m dishes and operated at 9400 MHz. During the 1960s, a two-dish antenna, another grating array, two compound interferometers and a radioheliograph were constructed, but these lie outside the chronological scope of this chapter.

The Toyokawa radio telescopes were used to study the characteristics of radio plages at 4000 and 9400 MHz (Kakinuma 1956; Tanaka et al. 1956) and the intensity and polarization of bursts at these two frequencies and at 2000 and 1000 MHz (Kakinuma 1958; Kakinuma and Tanaka 1961; Tanaka and Kakinuma 1956b; Tanaka and Kakinuma 1962). Tanaka and Kakinuma (1958) also used multi-

Fig. 6.10 A view of the 4000 MHz five-element grating interferometer installed at Toyokawa in 1953 (*Courtesy* Tanaka Family)

Fig. 6.11 The expanded 8-element solar grating array, complete with polarisation screens, and behind it the four total power radiometers that monitored the Sun at 1000, 2000, 3750 and 9400 MHz (*Courtesy* Tanaka Family)

frequency observations of the partial annular solar eclipse of 19 April 1958 to examine the brightness distribution over the solar disk. International collaborative programs were also undertaken with Australian, Canadian, French, Indian and U.S. colleagues to carry out multi-frequency investigations of radio plages (see Christiansen et al. 1960; Kakinuma and Swarup 1962; Swarup et al. 1963).

Tanaka (1984) notes that by 1960 there were five technicians, four assistants and a few students from the Faculty of Engineering at Nagoya University supporting Tanaka and Kakinuma in their radio astronomical research.

6.3.5 *The Solar Radio Astronomy Program of the Radio Research Laboratories, Ministry of Posts and Telecommunications*

The Radio Research Laboratories of the Ministry of Posts and Telecommunications was interested in monitoring solar noise in connection with Japan's international telecommunications network, and in order to achieve this they maintained a field station at Hiraiso, on the east coast of Japan about 150 km northeast of

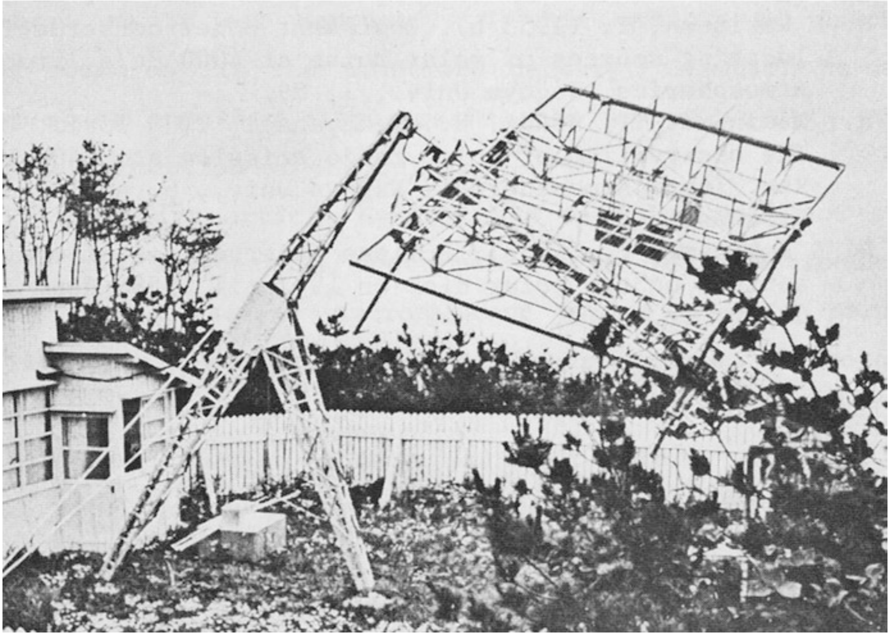

Fig. 6.12 The broadside array at Hiraiso that was used to monitor 200 MHz solar emission from 1952 in connection with the overseas telecommunications network (after Tanaka 1984: 347)

Tokyo (Obayashi 1954). In 1950 they erected a broadside array which operated at 61.2 MHz, and used it to carry out experimental solar observations. But they only commenced regular solar monitoring in 1952, using the new broadside array shown in Fig. 6.12 which operated at 200 MHz. This antenna was modelled on the one that they had constructed for the TAO back in 1949. The frequency range of the solar monitoring program was expanded in 1961 and 1962 when new radio telescopes were installed, but these lie outside the chronological scope of this chapter.

Although the Hiraiso Radio Wave Observatory was basically set up to contribute solar data that could be used in providing shortwave radio disturbance warnings, between January and September 1954 Takahashi et al. (1954) carried out a comparison of the 200 MHz flux densities observed at Hiraiso with those obtained at Mitaka (Tokyo), Nera (in the Netherlands) and Sydney (Australia). They found the daily mean flux densities were similar at the four different sites and that

> … increases in solar noise intensity for two or three days centering on September 11 and October 16, 1953, and March 15, 1954, were the common phenomena of the various places. However, the rates of increase and their absolute values differed much from one to another. (Takahashi et al. 1954: 53).

6.4 Galactic Radio Astronomy

6.4.1 Early Observations of the Cosmic Microwave Background

Soon after beginning solar radio astronomy the Toyokawa group observed the background sky temperature at 3750 MHz in a bid to calibrate solar flux density at that frequency. They obtained a result of 0–5 K, which was reported in Tanaka et al. (1951), but only the abstract was written in English. Two years later a full English-language version was published (Tanaka and Kakinuma 1953a), 14 years before Penzias and Wilson reported the discovery of the 3 K cosmic microwave background.

Observations of the 21 cm hydrogen line by some of the TAO radio astronomers in the late 1960s lie outside the chronological range of this review, but will be detailed in one of the papers on the IAU Early Japanese Radio Astronomy Project.

6.5 Discussion

6.5.1 Instrumentation: The Original Idea of the Solar Grating Interferometer

In the course of their solar observations at the Osaka City University, Oda's group developed the concept of a grating interferometer that would operate at 4000 MHz and would be used to identify the locations of the sources responsible for the solar noise. The interferometer would consist of 25 circular horns each 50-cm in diameter arranged in the configuration illustrated in Fig. 6.13. While this interesting concept was presented at the annual assembly of the Physical Society of Japan in 1950 (see Oshio et al. 1950), it was never acted on. Had it been, then Japan rather than Australia would have hosted the world's first solar grating array. However, Tanaka was inspired by this idea, which led him to construct the grating interferometers at Toyokawa mentioned above in Sect. 6.3.4. Meanwhile, for further details of the mooted Osaka solar grating array see Wendt et al. (2017).

6.5.2 Research: The Focus of Early Japanese Radio Astronomy

It is notable that all of Japan's early (pre-1961) radio astronomical investigations focussed on the Sun, and even Tanaka and Kakinuma's measurement of what we would now term the 'cosmic microwave background' was motivated by solar observations. However, as Sullivan (2009: 225) has pointed out, this solar pre-occupation is

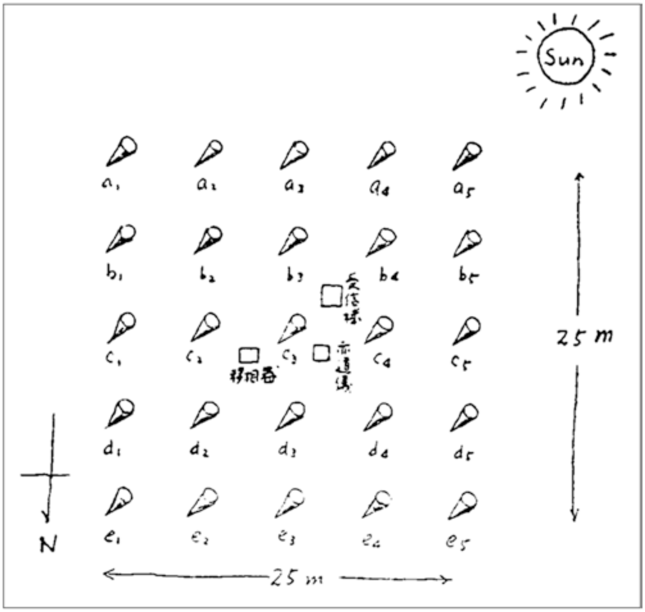

Fig. 6.13 The solar grating array that was designed by Oda's group in 1950 but was never built (after Tanaka 1984: 338)

easy to understand considering "Japan's long tradition of research on the ionosphere and radio communications …, [which was] natural for an island nation …" The solar program at Hiraiso was linked to Japan's telecommunications efforts, and this was also the motivation for the early initiatives at Toyokawa (although this was soon to change).

What is perhaps puzzling though is that during this formative period Japanese radio astronomers made no effort to observe 'radio stars', those discrete localized sources of intense radio emission that were reported in the international literature by British and Australian radio astronomers and "… long remained the most mysterious and hotly debated [objects] in astronomy." (Sullivan 2009: 101). Cygnus-A, the first radio star, was announced in *Nature* by J. Stanley Hey, S. John Parsons and James W. Phillips in 1946, and by 1950 when three Japanese groups were actively involved in radio astronomy, the number of confirmed discrete sources had grown to seven (see Sullivan 2009: Table 14.1 on page 316), and Sydney-based Bolton et al. (1949) had correlated three of them with distinctive galactic and extragalactic optical objects, namely the Crab Nebula (Taurus-A), Messier 87 (Virgo-A) and NGC 5128 (Centaurus-A). The Japanese had the requisite instrumentation to join in the investigation of these enigmatic objects but chose not to, and even when the steerable 10-m dish was erected at the TAO in 1953, its very obvious non-solar potential was all but ignored. Ten years were to elapse before a 24-m spherical transit dish was erected at the TAO and serious research began on 1420 MHz H-line emission. Then 3 years later, in 1966, an altazimuth-mounted 10-m antenna was erected at Toyokawa so that the Nagoya University radio astronomers could launch a serious non-solar research program.

6.5.3 *Heritage Issues: The Survival and Preservation of Japan's Early Radio Telescopes*

One of the projects of the IAU Working Group on Historic Radio Astronomy is to compile a worldwide inventory of all surviving pre-1961 radio telescopes, and—where relevant—lobby for their preservation. It is a sad fact that none of the early Japanese radio telescopes described in this chapter has survived, although a full-scale replica of the initial 200 MHz TAO broadside array, incorporating the original polar axis from Mitaka, has been erected at Nobeyama Radio Observatory and is accessible to visitors (see Fig. 6.14). However, a field examination of the original 'radio astronomy precinct' at Mitaka in December 2011 failed to reveal any vestiges—even foundations—of the original instruments at this site.

Likewise, a visit by the authors to the Toyokawa Observatory site in November 2010 failed to reveal remains from any of the antennas discussed in this chapter, but just prior to the visit a number of rusting antennas belonging to a T-shaped solar grating array erected by the second author of this chapter in the 1970s were discovered during a detailed examination of the area by Dr. T. Watanabe. Two of these antennas are shown in Fig. 6.15, surrounded by dense vegetation.

Fig. 6.14 A replica of the original TAO broadside array on display at the Nobeyama Radio Observatory; only the polar axis is from the original radio telescope of 1949 (*Photograph* Wayne Orchiston)

Fig. 6.15 Two of the surviving antennas of a T-shaped array erected in the 1970s, discovered overgrown by dense vegetation just prior to a visit to the Toyokawa Observatory site by the authors of this chapter in November 2010 (*Photograph* Wayne Orchiston)

6.6 Concluding Remarks

It should be noted that Shimoda's experiment in 1948 was the first radio astronomical experiment in Japan, even though his attempt to detect a significant change in the level of solar radio emission during the eclipse was unsuccessful. Yet, as Shimoda (1982) states, these were "… the first microwave astronomical observations in Japan …", and as such they have a very important place in the history of Japanese radio astronomy.

During the 1950s competition between the separate research groups at Tokyo Astronomical Observatory and at Toyokawa Observatory was very effective in promoting the development of radio astronomical research in Japan, and inspired the construction of an impressive range of instrumentation designed to investigate solar radio emission between 60 and 9000 MHz. Eventually this led to a merger of the two groups into a single strong research team that would construct the Nobeyama Radioheliograph.

With the passage of time the non-solar radio astronomy group in Japan grew rapidly, and their efforts finally crystallised in the construction of the Nobeyama Millimeter Array, the 45-m radio telescope at Nobeyama and eventually the Atacama Large Millimeter/submillimeter Array (ALMA). Thanks to the firm foundations established in the 1950s, the future of Japanese radio astronomy was assured.

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References

Arakawa, D. (1936). Abnormal attenuation in short radio wave propagation. *Report on Radio Research in Japan, 3*(4), 31–38.

Bolton, J.G., Stanley, G.J., & Slee, O.B. (1949). Positions of three discrete sources of galactic radio-frequency radiation. *Nature, 164,* 101–102.

Christiansen, W.N., Mathewson, D.S., Pawsey, J.L., Smerd, S.F., Boischot, A., and 5 coauthors (1960). A study of a solar active region using combined optical and radio techniques. *Annales d'Astrophysique, 23,* 75–101.

Covington, A. (1984). Beginnings of solar radio astronomy in Canada. In W.T. Sullivan, pp. 317–334.

Dellinger, J.H. (1937). Sudden disturbances of the ionosphere. *Proceedings of the Institute of Radio Engineers, 25,* 1253–1290.

Edge, D.O., & Mulkay, M.J. (1976). *Astronomy Transformed: The Emergence of Radio Astronomy in Britain*. New York: John Wiley.

Ham, R.A. (1975). The hissing phenomenon. *Journal of the British Astronomical Association, 85,* 317–323.

Hatanaka, T., & Moriyama, F. (1953). A note on the long-term variation in the radio-frequency radiation from the Sun. *Publications of the Astronomical Society of Japan, 4,* 145–152.

Hatanaka, T., Suzuki, S., & Tsuchiya, A. (1955b). Polarization of solar radio bursts at 200 mc/s. I. A time sharing radio polarimeter. *Publications of the Astronomical Society of Japan, 7,* 114–120.

Hatanaka, T., Suzuki, S., & Tsuchiya, A. (1955c). Observations of polarization of solar radio bursts. *Proceedings of the Japan Academy, 31,* 81–87.

Hatanaka, T., Akabane, K., Moriyama, F., Tanaka, H., & Kakinuma, T. (1955a). Solar radio spot and calcium plage. *Publications of the Astronomical Society of Japan, 7,* 161–162.

Hatanaka, T., Akabane, K., Moriyama, F., Tanaka, H., & Kakinuma, T. (1956). A model for the solar enhanced region at centimetre range derived from partial eclipse observations. In W.J.G. Benyon, & G.M. Brown (Eds.), *Solar Eclipses and the Ionosphere* (pp. 264–271). London: Pergamon Press (Special Supplement Volume 6 to the *Journal of Atmospheric and Terrestrial Physics*).

Hey, J.S. (1955). Solar radio eclipse observations. *Vistas in Astronomy, 1,* 521–531.

Hey, J.S. (1973). *The Evolution of Radio Astronomy*. London: Elek Science.

Hey, J.S., Phillips, J.W., & Parsons, S.J. (1946). Cosmic radiations at 5 metres wavelength. *Nature, 157,* 296–297.

Ishiguro, M., Orchiston, W., Akabane, K., Kaifu, N., Hayashi, M., and 3 coauthors (2012). Highlighting the history of Japanese radio astronomy. 1: An introduction. *Journal of Astronomical History and Heritage, 15,* 213–231.

Kai, K. (1962). Some characteristics of Type I bursts. *Publications of the Astronomical Society of Japan, 14,* 1–11.

Kai, K. (1963). Linear polarization of solar radio emission of spectral Type IV. *Publications of the Astronomical Society of Japan, 15,* 195–203.

Kai, K. (1965). Polarization characteristics of Type IV bursts. I. Observational results. *Publications of the Astronomical Society of Japan, 17,* 294–308.

Kakinuma, T. (1956). Observations of radio spots at 4000 Mc/s. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 4,* 78–85.

Kakinuma, T. (1958). Polarization of solar radio bursts at microwave frequencies. I. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 5,* 71–80.

Kakinuma, T., & Swarup, G. (1962). A model for the sources of the slowly varying component of microwave solar radiation. *Astrophysical Journal, 136,* 975–994.

Kakinuma, T., & Tanaka, H. (1961). Solar radio bursts at microwave frequencies. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 8,* 39–49.

Morimoto, M. (1961). The motion and height of Type III and Type IV bursts of solar radio emission. *Publications of the Astronomical Society of Japan, 13,* 285–293.

Morimoto, M., & Kai, K. (1961). The height of solar radio bursts at 200 Mc/s. *Journal of the Astronomical Society of Japan, 13,* 294–302.

Nakagami, M., & Miya, K. (1939). On the incident angle of short radio waves and high frequency noise during the "Dellinger effect". *Journal of the Institute of Electrical Engineers of Japan, 59,* 176 (in Japanese).

Nakajima, H., Ishiguro, M., Orchiston, W., Akabane, K., Enome, S., and 4 coauthors (2014). Highlighting the history of Japanese radio astronomy. 3: Early solar radio research at the Tokyo Astronomical Observatory. *Journal of Astronomical History and Heritage, 17,* 2–28.

Obayashi, T. (1954). Radio disturbance warnings in Japan. *Quarterly Review of the Radio Research Laboratories,* 57–62 (in Japanese).

Oda, M., & Takakura, T. (1951). A study on the solar noise at 3300 m.c. *Journal of the Physical Society of Japan, 6,* 202.

Oshio, T., Takakura, T., & Kaneko, S. (1950). A plan for the localization of solar sources on the solar surface by 5-column 5-row electromagnetic horns. Preprint of the 5th. Annual Assembly of the Physical Society of Japan, November 5, 5C7, 1–8 (in Japanese).

Orchiston, W., & Steinberg, J.-L. (2007). Highlighting the history of French radio astronomy: 2: The solar eclipse observations of 1947–1954. *Journal of Astronomical History and Heritage, 10,* 11–19.

Orchiston, W., Nakamura, T., & Ishiguro, M. (2016). Highlighting the history of Japanese radio astronomy. 4: Early solar research in Osaka. *Journal of Astronomical History and Heritage, 19,* 240–246.

Orchiston, W., Slee, B., & Burman, R. (2006). The genesis of solar radio astronomy in Australia. *Journal of Astronomical History and Heritage, 9,* 35–56.

Orchiston, W., Lequeux, J., Steinberg, J.-F. & Dellanoy, J. (2007). Highlighting the history of French radio astronomy. 3: The Würzburg antennas at Marcoussis, Meudon and Nançay. *Journal of Astronomical History and Heritage, 10,* 221–245.

Orchiston, W., Steinberg, J.-L., Kundu, M., Arsac, A., Blum, E-J., & Boischot, A. (2009). Highlighting the history of French radio astronomy. 4: Early solar research at the École Normale Supérieure, Marcoussis and Nançay. *Journal of Astronomical History and Heritage, 12,* 175–188.

Shimoda, K. (1982). After Dinner Talk: Two reflectors made in 1930. In *13th Okazaki Conference 1982* (31–35). Tokyo, Institute for Molecular Science, Publication No. 10.

Shimoda, K., Orchiston, W., Akabane, K., & Ishiguro, M. (2013). Highlighting the history of Japanese radio astronomy. 2: Koichi Shimoda and the 1948 solar eclipse. *Journal of Astronomical History and Heritage, 16,* 98–106.

Smith, E.K. (2004). In memorium: Dr Kenichi Miya. *Antennas and Propagation Magazine, IEEE, 46,* 117–118.

Sullivan, W.T. III (Ed.), (1984). *The Early Years of Radio Astronomy. Reflections Fifty Years after Jansky*. Cambridge: Cambridge University Press.

Sullivan, W.T. III (2009). *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge: Cambridge University Press.

Suzuki, S. (1959). Multiphase radio interferometers for locating the sources of solar radio emission. *Publications of the Astronomical Society of Japan, 11,* 195–215.

Swarup, G., Kakinuma, T., Covington, A.E., Harvey, G.A., Mullaly, R.F., & Rome, J. (1963). High resolution studies of ten solar active regions at wavelengths of 3–21 cm. *Astrophysical Journal, 137,* 1251–1267.

Takahashi, T., Onoue, M., & Kawakami, K. (1954). Characteristics of 200 mc solar noise observation equipment installed at Hiraiso Radio Wave Observatory. *Journal of the Radio Research Laboratories, 1,* 41–53 (in Japanese).

Takakura, T. (1985). 35 years with solar radio astronomy. *The Astronomical Herald, 78*(6), 163–166 (in Japanese).

Takakura, T., & Kai, K. (1961). Spectra of solar Type IV bursts. *Publications of the Astronomical Society of Japan, 13,* 94–107.

Tanaka, H. (1984). Development of solar radio astronomy in Japan up until 1960. In W.T. Sullivan, pp. 335–348.

Tanaka, H., & Kakinuma, T. (1953a). On the substitution measurement of sky temperature. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 1,* 85–88.

Tanaka, H., & Kakinuma, T. (1953b). Equipment under construction for locating sources of solar noise at 4000 Mc/s. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 1,* 89.

Tanaka, H., & Kakinuma, T. (1956a). Equipment for the observation of solar radio emission at 9400, 3750, 2000 and 1000 Mc/s. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 4,* 60–73.

Tanaka, H., & Kakinuma, T. (1956b). The most intense burst of solar radio emission observed on February 23, 1956. *Proceedings of the Research Institute of Atmospherics, Nagoya University, 4,* 74–77.

Tanaka, H., & Kakinuma, T. (1958). Eclipse observations of microwave radio sources on the solar disk on 19 April, 1958. *Report on Ionospheric Work in Japan, 12,* 273–284.

Tanaka, H., & Kakinuma, T. (1962). Some comments on Type IV bursts. *Journal of the Physical Society of Japan, 17 Supplement A-11,* 211–214.

Tanaka, H., Kakinuma, T., Jindo, H., & Takayanagi, T. (1951). On the substitution measurement of sky temperature at centimetre waves. *Bulletin of the Research Institute of Atmospherics, Nagoya University, 2,* 121–123 (in Japanese).

Tanaka, H., Kakinuma, T., Jindo, H., Takayanagi, T., & Torii, C. (1956). The observation of solar radio emission at 9,400 MC. *Bulletin of the Research Institute of Atmospherics, Nagoya University, 6,* 61–66 (in Japanese).

Tsuchiya, A. (1963). Polarization of storm bursts of solar radio emission at 200 Mc/s. *Publications of the Astronomical Society of Japan, 15,* 368–375.

Wendt, H., Orchiston, W., & Slee, B. (2008a). The Australian solar eclipse expeditions of 1947 and 1949. *Journal of Astronomical History and Heritage, 11,* 71–78.

Wendt, H., Orchiston, W., & Slee, B. (2008b). W.N. Christiansen and the development of the solar grating array. *Journal of Astronomical History and Heritage, 11,* 173–184.

Wendt, H., Orchiston, W., Ishiguro, M., & Nakamura, T. (2017). Highlighting the history of Japanese radio astronomy. 5: The 1950 Osaka solar grating array proposal. *Journal of Astronomical History and Heritage, 20,* 112–118.

Part II
South Korea

Chapter 7
The Development of Astronomy in Korea and the Emergence of Astrophysics in South Korea

Il-Seong Nha, Sarah L. Nha, and Wayne Orchiston

7.1 Introduction: A Short History of Astronomical Exchanges Between China and Korea

As a tradition, astronomical activities in Korea had been maintained systematically by the Government. Individual activities by some civilians would also be acknowledged, but theirs were beneath notice compared to those of the Government. The Joseon Dynasty of Korea (1392–1910) inherited the Seo'un-gwan 書雲觀, the Board of Astronomy of the preceding Koryo Dynasty (918–1392). But, soon after the beginning of the reign period (1419–1450) of King Sejong 世宗大王, the fourth king of Joseon, this Board was renamed *Gwansang-gam* 觀象監 (*Annals* … 1419–1450: Volume 77: 9b) and became one of the best-equipped astronomical organizations in the world (Cho 1999). This Board of Astronomy maintained (1) several observatories in Seoul and observing stations at other sites, (2) a large number of employees, and (3) a variety of astronomical instruments. Therefore, the emergence

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of classical Korean astronomy was rooted in the activities of King Sejong's observatories.

However, the dawn of the new astronomy did not occur until after the first encounter with European Jesuit astronomers in 1631. In that year Jeong Du-won鄭斗源, a member of the envoy to China, returned home with gifts from Joao Rodrigues, S.J. 陸若漢, a pioneering Jesuit in China. Rodrigues was 97 year old but still had a keen interest in astronomy, and was a friend of Matteo Ricci, S.J. 利瑪竇. The gifts, which are documented in the *Jeungbo Munheon Bigo* 增補文獻備考, abbreviated *JMB*, the *Comprehensive Study of [Korean] Civilization, Revised and Expanded*), were: two books on astronomy (*Zhili Yuanqi* 治曆緣起 and *Tianwenlue* 天文略), a mechanical clock 自鳴鐘, a telescope 千里鏡, and a set of sundials (*JMB* 1980a). As early in 1644, Royal astronomer Kim Yuk 金堉 initiated a calendar reform using the *Shixian-li* 時憲曆 calendar of Johann Adam Schall von Bell, S.J. 湯若望 to replace the classical calendars, *Shoushi-li* 授時曆 by Guo Shoujing 郭守敬 from the Yuan Dynasty and *Chiljeong Sanbeob* 七政算法 by Jeong Inji 鄭麟趾and others from the reign period of King Sejong. In 1645 and 1648, respectively, King Hyojong 孝宗 sent two young astronomers, Han Heung-il 韓興一 and Song In-yong 宋仁龍, to China, and 3 years later (in 1651) Kim Sang-beom (金尚范) also was sent to China to study the *Shixian-li* calendar. Then in 1653 Kim Yuk went to China again and brought back with him a copy of the *Shixian-li* calendar and asked Royal Astronomers to study and then adapt this calendar for use in Korea. However, their understanding was limited only to the calculation of days, seasons and eclipses, so later that year (1653) Kim Sang-beom was sent once again to China to learn how to calculate the motions of the five planets, but unfortunately he died on his way to China. In later years the method of calculation was completely understood by using the *Tables of the Sun, Moon and Five Planet*s 時憲法七政表, which was brought back by Heo Won 許遠, and by the effort of the Board's astronomers. This new calendar system was then officially announced for use nationwide in 1708, and it was revised using the *Revised Tables of the Sun, Moon and Five Planet*s 新修時憲七政法 in 1725. The final reform to the Gregorian calendar was made in 1895 nearly two centuries after the adaptation of the *Shixian-li* calendar. The Gregorian New Year's Day in this year was the seventeenth day of the 11th month in the *Shixian-li* calendar in the 32nd year of Emperor Kojong 高宗, the 26th King of the Joseon Dynasty.

There is an early record of the importation into Korea of a Chinese star chart, which was influenced by Western astronomy. In 1708, the star map *General Map of Stars in the Northern and Southern Hemispheres on Equatorial Coordinates*赤道南北兩總星圖 was presented to King Sukjong 肅宗 by the Board of Astronomy (*JMB* 1980b). It was made in Beijing in 1633 by Adam Schall von Bell and Giacomo Rho, S.J. 羅雅谷 with their Chinese collaborators, including Xu Quangqi 徐光啓. Using this star map, the Korean astronomers learnt for the first time that stars near the southern polar region did exist.

The *JMB* also records the importation of the *Litai Yixiang-zhi* 靈台儀象志, which was published in 1674 by Ferdinand Verbiest, S.J. 南懷仁 in Beijing. This is a star catalogue with 1129 old Chinese stars. There are twenty-four constellations with 335 stars less than shown in the *Butian-ge* 步天歌, but altogether 597 new stars are included in the *Yixiang-zhi*, with an additional 150 stars in 23 new constellations in the southern polar region. The *JMB* also reports that in the 11th month of the 17th year of King Yeongjo's 英祖 reign An Guk-rin 安國麟 and Byeon Joong-wha 卞重和 visited a Catholic church in Beijing and became friends with Ignatius Kögler, S.J. 戴進賢. They brought home with them a *New Star-Map* 天文圖新本 in which the sky was depicted in two diagrams, which showed the northern and southern hemispheres respectively. Upon a detailed study of this map it was found that the stars were clearly marked, and that there were 28 lunar lodges 宿 and other constellations of stars. The stars were grouped into six types according to their brightness (*Ilgi* 1742). This *New Star-Map* is the *Huangdao Zongxingtu* 黃道總星圖, which was made in 1723 by Ignatius Kögler and Fernando Bonaventra Moggi 利白明 or 利博明. This means that the importation into Korea of this star map was made only 18 years after it was first printed in Beijing. It was received enthusiastically by the Korean astronomers, and as a result two large eightfold screen star maps were made at the Board of Astronomy sometime between 1741 and 1744.

Large numbers of astronomy-related books, regardless of whether of Chinese or Jesuit Western origin, were imported into Korea as soon as they became available, but for the purposes of this chapter we will confined ourselves only to books of Western origin. We have already introduced two books, the *Zhili Yuanqi* and the *Tianwen-lue*, which were the gifts from Joao Rodrigues S.J. in 1631 and the *Shixian-li* 時憲曆 by Kim Yuk in 1644. Regarding this last-mentioned book, there is an interesting statement:

> When I was a director of the Board of Astronomy, I went to Beijing accompanied by two calendar officers, and I wished to learn the theory from Adam Schall von Bell directly but failed because of a heavy guard at the gate. In the 22nd year of Your Highness (1644) I sent Kim Sang-beom, with a wealth of gifts to them, to Beijing to learn the theory and he came home but without knowing the calculation of the five planetary motions. Two years later Kim was again sent to Beijing, but on his way he died. (*JMB* 1980c).

In Table 7.1 we list only a few important books, including those already mentioned above, but to try and include all astronomy books imported from China is beyond the scope of this chapter.

Beside these book, many sundials and star maps were imported from China during the seventeenth and eighteenth centuries.

We now wish to introduce an important remark on the exchange of astronomy in this period of time between China and Korea. It is a fact that no Jesuit astronomer ever visited Korea. While Korean astronomers went to Beijing at least two or three times every year during the period and Chinese envoys came to Korea regularly, these envoys were only accompanied by nameless Chinese astronomers, never Jesuit astronomers. The Korean astronomers were eager to gain advanced knowledge from both Jesuits and Chinese authorities in Beijing, whether they were welcomed or not. The eighteenth century in particular was

Table 7.1 Astronomy books imported into Korea from China, 1631–1823

No	Name of book	Author(s)	Year imported and by whom
1	*Zhili Yuanqi* 治曆緣起	----	1631 by Jeong Doo-won
2	*Tianwen-lue* 天文略	P. Emmanuel Diaz	1631 by Jeong Doo-won
3	*Shixian-li* 時憲曆	J. Adam Schall von Bell	1644 by Kim Yuk
4	*Riyue Wuxing Lizhi* 日月五星曆指	Xu Quangqi and Li Tianjing	1644 by Kim Yuk
5	*Huntianyi-shuo* 渾天儀說	Xu Quangqi and Li Tianjing	1644 by Kim Yuk
6	*Shixian Lifa* 時憲曆法	J. Adam Schall von Bell	1653 by Kim Yuk
7	*Wuwei Lizhi* 五緯曆指	Adam Schall von Bell and Giacomo Rho	??
8	*Horizontal Sundial* 地平日晷	Adam Schall von Bell and Giacomo Rho	1664 placed at the Hongmun-Gwan 弘文館
9	*Chidao Nanbei Liang Zong Xingtu* 赤道南北兩總星圖	Adam Schall von Bell and Xu Quangqi	1708 by *Gwansang-gam*
10	*Kunyu-tu* 坤輿圖	Adam Schall von Bell and Xu Quangqi	1708 by *Gwansang-gam*
11	*Xinxiu Shixian Qizheng*-fa 新修時憲七政法	----	1725
12	*Lixiang Kaocheng* 曆象考成	Ignatius Kögler 1723–1730	??
13	*Riyue-shi Jiaoshi-piao* 日月食交食表	----	1741 by An Guk-rin and Byeon Joong-wha
14	*Baxian Duishu Baxian-piao* 八線對數八線表	----	Same as above
15	*Duishu Chanwei-piao* 對數闡微表	----	Same as above
16	*Riyue Wuxing-piao* 日月五星表	----	Same as above
17	*Shuli Jingwen* 數理精蘊	----	Same as above
18	*Rishi Chougao* 日食籌稿	----	Same as above
19	*Yueshi Chougao* 月食籌稿	----	Same as above
20	Tianwen-tu Xinben 天文圖新本	----	1742 by envoy to China
		(This could be the *Huangdao Zong Xingtu* 黃道總星圖 by Ignatius Kogler with Fernando Bonaventra Moggi)	
21	*Lixiang Kaocheng Houphien* 曆象考成後篇	Ferdinand Verbiest	1744 by An Myeong-yeol 安命說, 安命說, Kim Jeong-ho 金挺豪 and Yi Ki-heung 李箕興
22	*Qingguo Xinfa Lixiang Kaocheng Houphien* 淸國新法曆象考成後篇	----	1744 by Kim Tae-seo 金泰瑞
23	*Sundial* 日晷	Adam Schall von Bell	1770 found by Seo Ho-su in a storage room
24	*Yixiang Kaocheng* 儀象考成	Ignatius Kögler, 1752	???
25	*Gujin Jiaoshi-piao* 古今交食表	----	1823 by Kim Geom 金檢

the century during which the introduction of Western astronomy was highlighted.

Astronomy in Korea began to decline rapidly in the nineteenth century and only began to recover in the 1970s. At this time, because South Korea had seen little exposure to ‘Western’ international astronomy, astrophysics was slow to develop. Therefore, we will concentrate on the seventeenth and eighteenth centuries in the following narrative, and then merely summarize key astrophysical developments that occurred in the post-WWII era, since these have already been discussed—but primarily in the Korean language—by the first author of this chapter (see Nha 1997a, 2000, 2016).

7.2 Observatories

In Seoul there was one large observatory, the *Gan’ui-dae* 簡儀臺, at Gyeongbok Palace 景福宮, and there were three small observatories 瞻星臺 in other parts of the city.

7.2.1 *The Gan’ui-dae* 簡儀臺*, the Simplified Armillary Platform*

This was the large observatory equipped with Gan’ui 簡儀, the Simplified Armillary Platform, which is the square box-shaped structure to the right of the high gnomon at the north-western corner of an old map of Gyeongbok Palace and shown in Fig. 7.1. This facility was used extensively as a major observatory from 1425, but it has since disappeared entirely and there is no field evidence of it.

7.2.2 *Gyeonghui Palace Observatory* 慶熙宮瞻星臺

This was a small observatory, which was built during the reign of King Sejong in the northern grounds of Gyeonghui Palace 慶熙宮, but it was destroyed completely by the (Japanese) Government-General of Joseon 朝鮮總督府, and no traces of it have survived (Nha 1997b). However, an old map, the *Doseong-do* 都城圖, shows the location of this small observatory and surrounding buildings at Gyeonghui Palace (see Fig. 7.2).

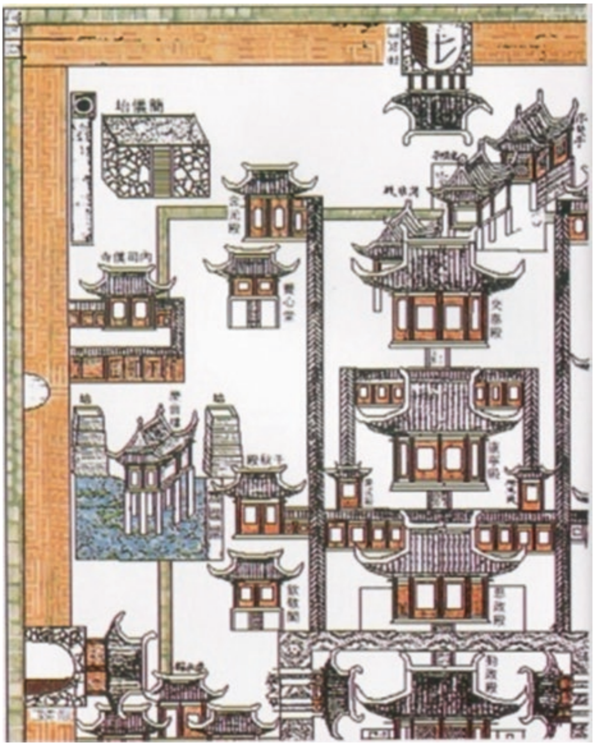


Fig. 7.1 An old map of Gyeongbok Palace in Seoul showing the location (top left) of *Gan'ui-dae*, the Simplified Armillary Platform (after Nha and Nha 2010a, b)

7.2.3 *Changgyeong Palace Observatory* 昌慶宮瞻星臺

This is the second small observatory, which also was built during the reign of King Sejong in Changgyeong Palace 昌慶宮 and is shown on an old map of the Palace (Fig. 7.3). The observatory was relocated at least twice by the (Japanese) Government-General of Joseon when they rebuilt the Palace for animals and gardens, but fortunately in the 1980s the Palace was restored to almost its original state, and the observatory (Fig. 7.4) was relocated to its original site in the Palace grounds (Nha 1997b).

7.2.4 *Gwangwha-bang Observatory* 廣化坊瞻星臺

This is the third small observatory, which was built during the reign period of King Sejong, and has survived through to the present day (see Figs. 7.5 and 7.6).

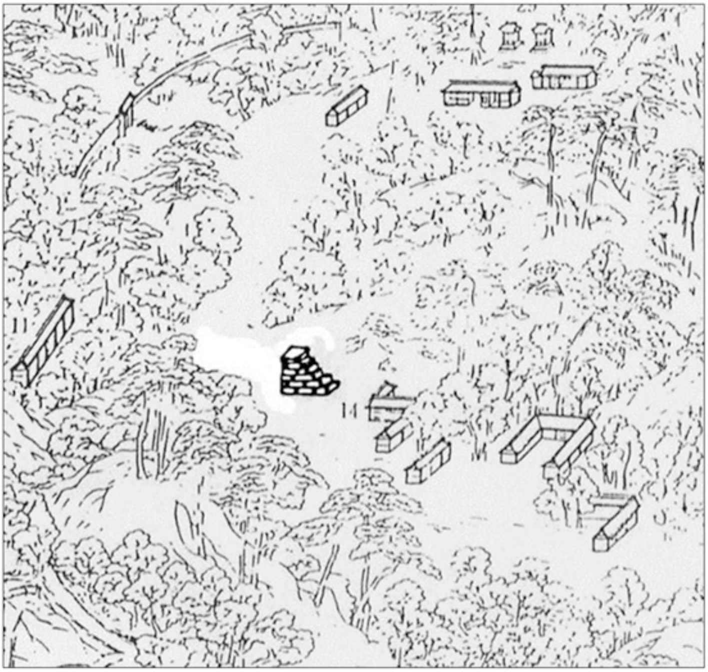


Fig. 7.2 A drawing showing the small stone observatory (centre) and surrounding buildings in the grounds of Gyeonghui Palace in Seoul (after Nha and Nha 2010a)

Fig. 7.3 An old map of Changgyeong Palace showing a small observatory featuring a simplified armillary sphere (after Nha and Nha 2010b)

Fig. 7.4 The reconstructed small observatory in the grounds of Changgyeong Palace (after Nha and Nha 2010a)

This observatory particularly attracted our attention because of its intensive use after the Hideyoshi Invasions of 1592–1594 and 1597–1598 (Nha 1997b). Fire destroyed Gyeongbok Palace during these wars, so King Seonjo 宣祖 moved his residence and office to Changdeok Palace 昌德宮, whose outside wall was beside the major offices of the *Gwansang-gam*. This area was named Gwangwha-bang 廣化坊 in those days, and the small observatory was located there and adopted this name.

The equipment at this observatory comprised a small simplified armillary sphere 小簡儀—because of the restricted size of the platform—and a small *Ilseong Jeongsi-ui* 日星定時儀, or Sun-and-Stars Time-determining Instrument. From the beginning of the seventeenth century astronomical observations regularly were carried out at this observatory, and they were listed in the *Joseon Wangjo Sillok* 朝鮮王朝實錄 (*The Veritable Records of the Joseon Dynasty*, abbreviated to *Sillok*) and in other records.

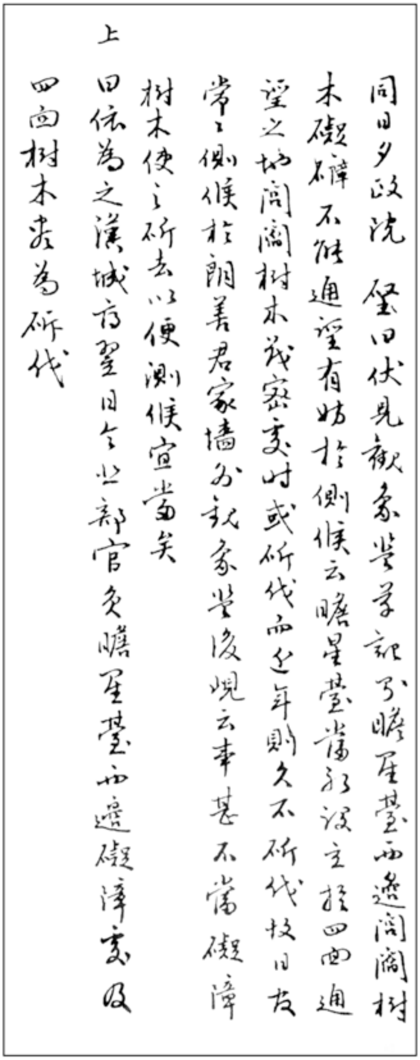
Records of some of the astronomical observations have been preserved to the present day, the best examples being the *Seongbyeon Chookhoo Danja* 星變測候單子 and the *Seongbyeon Deungrok* 星變謄錄. The former is the Observer's report of celestial and terrestrial phenomena (*Danja* for short), and the latter the edited book of *Danja*s (*Deungrok* for short).

Figure 7.7 shows a 1668 observation preserved in the *Seongbyeon Deungrok*, an English translation of which follows.

> In the evening of the same day the Jeongwon (a name of an office) reported to His Royal Highness with reference to a short report which had been received, stating that although the Observatory needed to have a clear view, the nearby trees obscured the view. These trees

Fig. 7.5 (*left*) The small observatory at Gwangwha-bang in 1935 when W.C. Rufus (on the right) visited it with Lee Won Chul (after Rufus 1936)

Fig. 7.6 (*right*) Present-day Gwangwha-bang Observatory (after Nha and Nha 2010a, b)



同日夕政院 啓曰伏見觀象監草記則瞻星臺西邊閭閻樹木礙障不能通望有妨於測候云瞻星臺當初設立於四面通望之地閭閻樹木茂密處時或斫伐而近年則久不斫伐故日者常常測候於朗善君家墻外觀象監後峴云事甚不當礙障樹木使之斫去以便測候宜當矣

上

曰依爲之漢城府 啓曰令北部官員瞻星臺西邊礙障處及四面樹木盡爲斫伐

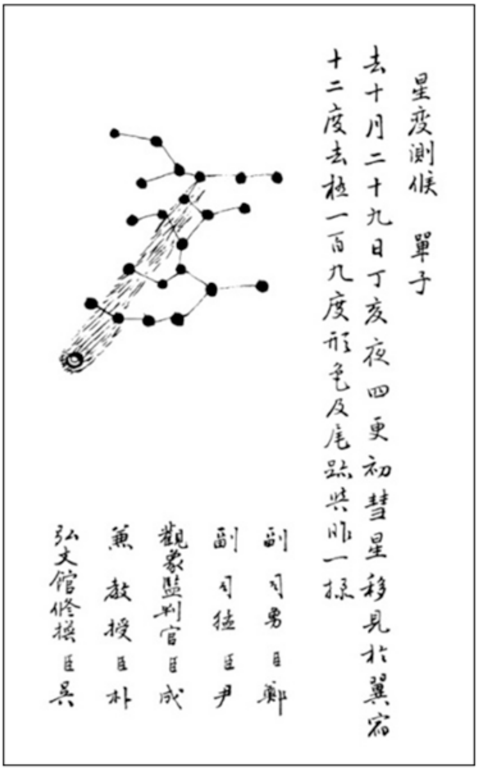
Fig. 7.7 An observational record from 1668 recorded in the *Seongbyeon Deungrok*

had not been cut back for several years, so that the observers made their observations at the house of Rangseon-goon (a grandson of King Seonjo). Therefore it was proposed to cut back the trees to facilitate observation.

His Royal Highness gave his approval to the Mayor. Next day, officials of the northern section cut back all the trees surrounding the Observatory.

The second example (Fig. 7.8) is a *Danja* of the Great Comet of 1664 (C/1664 W1). The English translation of this record reads:

Fig. 7.8 An account of the Great Comet of 1664 recorded in the *Seongbyeon Chukhoo Danja*



星變測候 單子

去十月二十九日丁亥夜四更初彗星移見於翼宿

十二度去極一百九度形色及尾點與昨一様

副司勇 臣 鄭

副司猛 臣 尹

觀象監判官 臣 成

兼教授 臣 朴

弘文館修撰 臣 吳

On the twentieth-ninth day, dinghai [24], of the tenth month of this year (= 16 December 1664), at night at the beginning of the fourth gyeong [= approximately 1 h], the broom star was seen at 12 du in Yi lunar lodge and its polar distance was 109 du. Its shape, colour and tail were unchanged.

Observers: Jeong 鄭 / Yoon 尹 / Seong 成 / Bak 朴 / O 吳

In this *Danja*, only the surnames of the five observers on duty that night are given.

The third example (Fig. 7.9, below) was made in 1759 for Halley's Comet (1P/Halley) at the time of its first return after Halley's prediction. Five observers were on duty each night in turn, and their official positions are given along with the names of all of the observers. For further details of Korean observations of this famous comet see Nha et al. (2017).

Fig. 7.9 An account of Halley's Comet in 1759 preserved in the *Seongbyeon Deungrok*; from right to left are seven successive nights' observations, from the 7th day to the 13th day of the 11th month of the 35th year (1759) in the reign of King Yeongjo 英祖 (after Nha and Lee 2006)

Fig. 7.10 Mt. Samgak-san to the north of Seoul (after Nha and Nha 2010a)

7.3 Observing Stations

There were at least three temporary observing stations outside of Seoul, and they were used on particular occasions from time to time.

7.3.1 Mt. Samgak-san Station

This was located to the north of Seoul City Wall (Fig. 7.10). Observers from the Board of Astronomy went to this mountain station whenever any celestial event was expected near the northern horizon.

Fig. 7.11 Mt. Namsan (after Nha and Nha 2010a)

7.3.2 Mt. Namsan Station

This station (Fig. 7.11) was located between the southern city wall of Seoul City and the Han River. This observing station was used frequently throughout the Joseon Dynasty for celestial objects or events expected near any of the horizons other than the northern one.

7.3.3 Mt. Mani-san Station

This was on the top of Mani Mountain 摩尼山 on Kangwha Island (Fig. 7.12), which faces the West Sea 黃海 and is ~100 km west of Seoul. On this mountain top there is a Chamseong-dan 塹星臺 or 參星臺 where Dangoon 檀君, who began Korean history and lore in 2333 BC., made offerings to heaven (Fig. 7.13). This observing station was used frequently, especially when solar eclipses were visible near the western horizon at nightfall.

Fig. 7.12 A distant view of Mt. Mani-san on Kangwha Island (after Nha and Nha 2010a)

Fig. 7.13 A close-up of the alter on the top of Mt. Mani-san (after Nha and Nha 2010a)

7.4 Organization and Who's Who

7.4.1 Organization

According to the *Seoungwan-ji* 書雲觀志, a book about the Board of Astronomy written by Seong Joo-deok 成周悳, in 1818 there were 34 staff listed for the 12 positions on the Board. The highest ranking was the Prime Minister of the Cabinet, whose role was to represent the organization and develop major policy regarding the interpretation of celestial phenomena. But these figures merely reflect the days before and after 1800, and at other times the number of positions was flexible. During the most active period, for example, full-time employment exceeded 60 personnel for much of the eighteenth century: ~20 for astronomy-meteorology and ~40 for time-keeping. This number, however, does not include personnel belonging to the Departments of Education, Geomancy, Rainfall, Calendar, Instruments, Security, etc.

As Tamura (1954) has recounted, there also were two important contributions that were made by civil scholars, namely a classical theory of the rotation of the Earth by Kim Seok-moon 金錫文 and a theory of the infinite Universe by Hong Dae-yong 洪大容. Although these theories were published by them in the eighteenth century, both scholars were unfamiliar with Western astronomical knowledge at this time.

7.4.2 The Board of Astronomy Who's Who

As already mentioned earlier, no Jesuit astronomer ever visited Korea. Those who came to Korea early in the twentieth century were a small number of Japanese and American astronomers. By this time Korean astronomy was completely ruined by the policy of the Japanese Government-General of Joseon. The reason for this situation will be discussed from time to time throughout this chapter.

7.4.2.1 Wada Yuji 和田雄治 (1859–1918)

Arguably the most accomplished of the three Japanese who came to Korea, in succession, was Wada Yuji (Fig. 7.14) who arrived just 3 years before the Japanese occupation of Korea in 1910. He was assigned to the Department of Agriculture-Commerce-Engineering 農商工部 of the Korean Government, but his primary task was to establish meteorological stations throughout the Korean Peninsula under the authorization of the mainland Japanese Government. This was a time when the Japanese wielded great power throughout Korea.

In 1910 Wada Yuji was named as the first Director of Incheon Meteorological Observatory 仁川氣象測候所 (IMO) which was established by the Japanese Government-General of Joseon 朝鮮總督府. With the founding of the IMO, the Board of Astronomy of Joseon Dynasty was closed, and no Korean astronomers or meteorologists were allowed to work with the Japanese at the IMO.

During his stay in Korea Wada was deeply impressed by the great number of observational records on astronomy and meteorology which were preserved in the old buildings of the Board of Astronomy in Seoul. While attending to his official duties at the IMO, he also began researching these documents and old Korean astronomical instruments.

Fig. 7.14 Wada Yuji 1859–1918 (*Courtesy* Han Sangbok)

Fig. 7.15 The 1837 copy (Treasure No. 561) of King Sejong's Rain Gauge, with its 1770 stone base (Treasure No. 842) (after Nha and Nha 2010b)

Let us review Wada's contribution to meteorology first. After researching Korean meteorological observations, Wada (1910a) published his first paper on the rain gauge, where he stated that it was invented in Korea during the 23rd reign year (i.e. 1441) of King Sejong (Fig. 7.15), two centuries before it was independently developed by European meteorologists. This was the first paper ever published on the non-European origin of the rain gauge. Wada (1917a) also conducted pioneering research on the 160-year rainfall measurements taken in Seoul during the period 1740–1902.

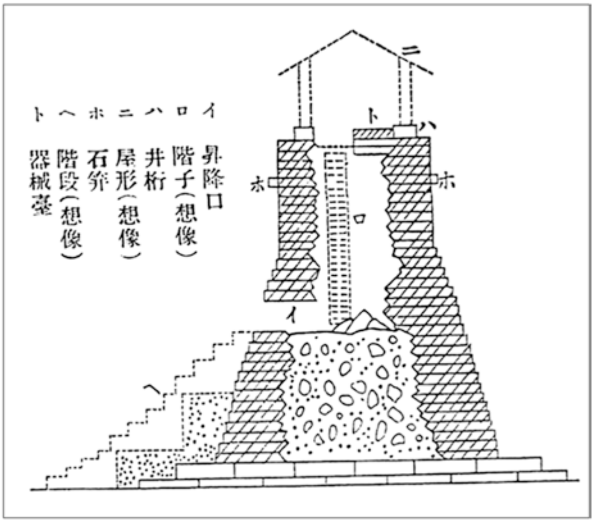


Fig. 7.16 Wada's drawing of Silla Observatory (after Wada 1910b)

Wada's contribution to the history of Korean astronomy, on the other hand, is just as important today as his research on the origin of the rain gauge. His first paper on the history of astronomy in Korea introduced Silla Observatory 新羅瞻星臺 (Fig. 7.16), which was founded during the reign period (AD 632–647) of Queen Seondeok 善德女王 of the Silla Kingdom, 57 BC–935 AD. This outstanding Observatory is still standing, and has retained its original structure for more than fourteen centuries (Fig. 7.17). Apart from some Chinese astronomers, this Observatory was unknown to foreign scholars until Wada (1910b) published his paper.

Wada's second history of astronomy paper worth mentioning is his account of the Striking Clepsydra 自擊漏, King Sejong's water clock (Wada 1910c). This was made in 1434 and was kept in the Annunciating Clepsydra Pavilion in Gyeongbok Palace 景福宮 and moved here and there several times later, but it remained as the standard night-time time-keeping instrument until the Hideyoshi Invasions. After these Korean-Japanese wars were over, a new Pavilion for a renovated Striking Clepsydra functioned again from 1614, and a time-keeping service was maintained in Changgyeong Palace until the early nineteenth century 昌慶宮. A photograph of this clepsydra is presented later in Sect. 7.5.3, where further information is provided.

A third paper by Wada is very interesting and attracted our attention. This is Wada (1917b), which deals with his discovery of the *Seongbyeon Chukhoo Danja* 星變測候單子 and the *Seongbyeon Deungrok* 星變謄錄. These were already discussed above in Sect. 7.2.4 (see Figs.7.7, 7.8, 7.9).

Fig. 7.17 Silla Observatory today (*Photograph* Nha Il-Seong)

7.4.2.2 Sekiguchi Rikichi 關口理吉 (b. 1886)

Sekiguchi joined Wada at the IMO in 1911 where his duty was calendar making. This involved slightly reforming the Korean calendar in line with the policy of the (Japanese) Government-General of Joseon. Sekiguchi returned to Japan in 1917, where he had several positions other than calendar calculation. But, much later his name was listed as an adviser in the 1935 calendar, which was edited by the Department of Commerce of Machu. Thus it is assumed that he was invited to join the work of calendar-making of the newly founded Imperial Manchu probably in 1932, the year of the foundation of this puppet country of Japan.

While he was in Korea, Sekiguchi published papers on comets (Sekiguchi 1917a) and meteor showers (Sekiguchi 1917b) recorded in old Korean records.

7.4.2.3 Yumi Shigeru 弓 滋 (1939–1940 in Korea)

Yumi (Fig. 7.18) came to Korea in 1939 to join the IMO for calendar-making and astronomical observations right after he commenced a degree at Tokyo Imperial University. However, his work at the IMO was short-lived, lasting only 2 years. The reason was that he was mobilized into the Army in 1940 for the Sino-Japanese war. Despite his short time at the IMO he was a committed astronomical observer, using a 6-in equatorially mounted refractor with a drive (Lee et al. 2011b). Yumi (1939)

Fig. 7.18 Yumi Shigeru (after Nha 2004a)

first tried visual observations of two comets, 35P/Herschel-Rigollet and Comet Kaminsky.[1] Although observations of the latter comet were hampered by a bright Moon and clouds, the former comet was a favorite thanks to a run of clear weather. Yumi (1939) proceeded to make a large number of visual positional measurements of what we now know to be Comet 35P/Herschel-Rigollet, more than anyone else in Japan.

7.4.2.4 Arthur Lynn Becker 白雅悳 (1879–1978)

Unlike the Japanese astronomers mentioned above, two American scientists who came to Korea in the early part of the twentieth century are different in regard to their status and activity. The Japanese were in Korea as Government employees and worked mainly for the benefit of the Japanese Government, while on the other hand the American scientists, supported financially by the Methodist Episcopal Church of the USA, worked for the promotion of education in Korea. Wada and the two other Japanese scientists mentioned above spent their lives among their own social class and never established any relationships with native Korean scientists. Thus we could say that the Japanese destroyed the astronomical organization of Korean astronomy and astronomers.

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[1] This comet is not included in Marsden and Williams' (1996) catalog. It was supposedly discovered on 24 July, but so few observations were made of it that its existence was questioned (see Van Biesbroeck 1939). It is a pity, therefore, that Yumi could not observe it.

In 1903, when he was only 24, Arthur Becker made up his mind to go to Korea as an educational missionary. His major at Albion College in Michigan was in physics and mathematics, both of which were sorely needed by young Koreans. The first place he taught at was Pyeongyang, and he lived there for 12 years until the founding of the new Liberal Arts College in Seoul, which was named Chosen Christian College (CCC, 延禧專門學校, the former name of the present-day Yonsei University).

Two years after his arrival in Korea, Arthur's fiancée Louise A. Smith (a music major) arrived at the port of Yokohama. The young couple married at an American church in Yokohama and arrived in Pyeongyang as a married couple. Louise's belongings were to arrive the following year but there was no room for her piano—one of the first such instruments in Pyeongyang—until their house was renovated. Their lives were similar to ordinary Koreans: they mingled with the young students at the school and with adults at the church. Arthur was warned by seniors not to play childishly with the young students and to remain dignified, but his attitude toward children never changed in the way that his seniors hoped. Nonetheless, his teaching of physics and mathematics and Louise's music harmonized to provide real education for the Korean children. Year after year little children studied steadily and advanced to higher levels of education.

In 1907 Arthur Becker was joined by Will Carl Rufus, and they assisted the Reverend Dr Horace Grant Underwood 元杜尤 in planning a new higher education institute, like an American-style Liberal Arts College, in Seoul, the leading city in Korea. CCC finally was founded and Dr Becker became the Chair of the Mathematics-Physics Department in 1915 (Fig. 7.19). He earned a Ph.D. in physics at the University of Michigan while on sabbatical leave in 1921. As the first physicist in Korea he taught mainly physics and mathematics, but he also taught astronomy when Rufus went back to University of Michigan, until he was joined by the mathematician Lee Chun Ho 李春昊 in 1926.

Dr Becker finally was banished from CCC when he was issued with a deportation order by Military Japan on 16 November 1940, but in 1986—at the age of 97—he paid his last visit to the then Yonsei University (see Fig. 7.20).

7.4.2.5 Will Carl Rufus 劉芙秀 (1876–1946)

Will Rufus was a classmate of Arthur Becker at Albion College and a devoted supporter in various ways while Arthur was in Pyeongyang. While sending scholarships and newly published mathematics and physics books to Arthur, he transferred to the University of Michigan for his astronomical career and earned a Masters Degree. When he arrived in Pyeongyang in 1907 he was accompanied by his wife Maud (also a music major) and their two young sons.

Responding to the call from Reverend Underwood, the Becker and Rufus families moved to Seoul and became the central pillars of the CCC science education program in 1915. However, Carl Rufus resigned from CCC 2 years later, in 1917,

Fig. 7.19 Arthur Becker (*left*) in a physics class room in 1918 (*Courtesy* Yonsei University Museum)

Fig. 7.20 A photograph of Dr Becker (center) taken during his last visit to Yonsei University, in 1986 (*Courtesy* Yonsei University Museum)

Fig. 7.21 Will Carl Rufus after he returned to the University of Michigan (*Courtesy* University of Michigan faculty and staff portrait collection)

because of his dissatisfaction with the Education Policy of the Government-General (Rufus 1917) and he returned to the University of Michigan where he accepted a Chair in the Astronomy Department (see Fig. 7.21). On the other hand, Maud Rufus became an aeroplane pilot and achieved a degree of fame through her book *Flying Grandma*. Maud died in an accident in June 1945 when she was flying over Mt. Hickory, Pennsylvania. A year after her death, Carl followed her while still active as the Chairman of the Department of Astronomy.

People praise Arthur Becker as a devoted educator, but Carl Rufus was known as a good writer of poems and scientific essays, particularly on the history of astronomy in Korea. He left us a goodly number of papers on the history of astronomy, a research topic which preoccupied him during his short time in Korea. The highlight undoubtedly is his "Astronomy in Korea" (Rufus 1936), which was published later, during a return visit to Korea in 1935–1936 (Fig. 7.22).

7.4.2.6 Lee Chun Ho 李春昊 (1893–1950, abducted to North Korea)

Lee Chun Ho (Fig. 7.23) went to the United States in 1914, via China, because Koreans were prohibited from going abroad by the (Japanese) Government-General of Joseon. At the time he was 21 and married, but he had to start his life in America as a high school student. Two years later he enrolled at Ohio Wesleyan College for an undergraduate degree, and later he attended Ohio State University for a Master's degree in mathematics. He earned this degree in 1921 with a thesis titled "Algebra

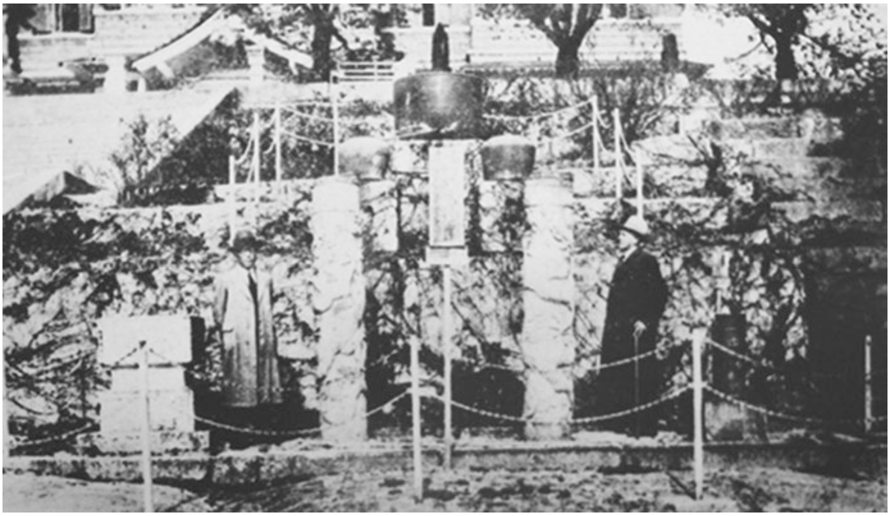


Fig. 7.22 W.C. Rufus (*left*) and Lee Won Chul inspecting the remaining parts of the Striking Clepsydra (*Courtesy* Yonsei University Museum)

Fig. 7.23 Lee Chun Ho (*Courtesy* Yonsei University Museum)

and Analytical Geometry of Finite Field”. He continued to study for a Ph.D. in mathematics at Ohio State University until 1924, when he had to return to Korea because his father was ill.

Lee then became a Professor of Mathematics at CCC, and was the first Korean to teach undergraduate astronomy in Korea (Fig. 7.24), when he took over Dr Becker’s astronomy classes.

Fig. 7.24 Lee Chun Ho and his 1926 astronomy class (*Courtesy* Yonsei University Museum)

Fig. 7.25 Dr Lee Won Chul (*Courtesy* Korean Astronomical Society)

7.4.2.7 Lee Won Chul 李源喆 (1896–1963)

Lee Won Chul (Fig. 7.25) was the only modern astronomer of Korean nationality in the early 1900s, but he experienced ill luck throughout most of his life. With three other students he enrolled in the Mathematics-Physics Department at CCC when it was founded and worked well for 4 years under the guidance of Becker and Rufus. The year 1919 was his graduation year but it also happened to be the year of the independent movement against Japan. Most social gatherings were prohibited by the Government-General of Joseon, and there was no ceremony for the first graduates of CCC. But fortunately all four science graduates succeeded in going to the USA, one after another, for advanced studies. In 1922 Lee went to Albion College to be tested for his academic ability because Becker in Seoul and Rufus in Ann

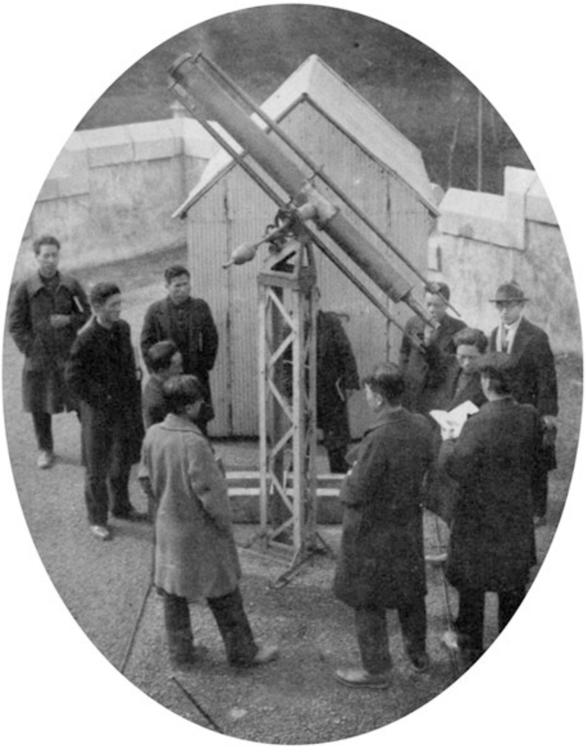


Fig. 7.26 Dr Lee Won Chul teaches students in the CCC astronomy class of 1929. Because the mounting of the 6-in refractor was metal, probably iron, it was requisitioned by the Japanese military in around 1940 so that it could be used to make weapons. The 6-in. lens then was stored in a laboratory, but in 1950 it was buried somewhere on the campus before the North Korean Army occupied the campus. No one knows where it is now (*Courtesy* Yonsei University Museum)

Arbor wondered if he would be able to adapt to this new environment. When Lee registered for only one semester, Albion College decided not hold him in a senior class any longer but encouraged him to go to the University of Michigan for graduate studies. Rufus was there of course, and he was delighted to welcome Lee as his student.

While he was in Michigan, Lee observed pulsating stars under Rufus' guidance, since at this time Rufus was a strong supporter of the pulsation theory for unknown regular variations of some stars. Lee reported on his observations at various meetings in the USA, and he finally submitted his Ph.D. thesis, "Motions in the atmosphere of Eta Aquilae", which the committee accepted. Thus, the first 'modern' astronomer of Korean nationality only dates from 1926!

After graduating, Lee rushed to return to Korea to join CCC, leaving behind his three former classmates who had settled in the USA. In Seoul, his time was taken up totally with teaching mathematics, physics and astronomy (Fig. 7.26) in collaboration with Lee Chun Ho and Arthur Becker. However, what he did do during his earlier period at CCC was publish his Ph.D. thesis (Lee 1932), even if this only occurred 6 years after he returned to Korea. It is difficult for us to imagine how demoralizing the astronomical situation was in Korea at that time. Lee was totally alone, without any colleagues to work with, and he had no time, literature or facilities—let alone a

Fig. 7.27 Dr Lee Won Chul checks an instrument when he was Director of the CMO (*Courtesy* Yonsei University Museum)

telescope—for research. Furthermore, apparently there was no interaction between the astronomers at CCC and staff at the IMO of the Government-General.

Later in his career, Lee's educational activities at CCC and his public lectures at Seoul YMCA gradually decreased, and he was under Japanese police surveillance. Just 6 years after the publication of thesis he was imprisoned and had to resign from CCC. The Government-General classified him as an 'unqualified educator' because of his involvement with the independence movements, the so-called Sooyang Dongwoo-hue 修養同友會 and the Heung'up Club 興業俱樂部. After losing his position at CCC he struggled to survive until the end of WWII. This last period of his life symbolizes the death of astronomy in Korea.

However, new hope reached him in September 1945 when US Army soldiers landed in Incheon harbor and were stationed in Seoul. Lee was appointed Director of the Observatory of Meteorology and Astronomy (Fig. 7.27), which was called the Joong'ang Gwansang-dae中央觀象臺 (Central Meteorological Observatory, or CMO for short). He had only a few lower-level staff for meteorology, but no help at all in astronomy. Nevertheless, in just 2 months he made all the necessary computations for a 1946 calendar and almanac. Thanks to his efforts the Korean calendar continued during the transition period. Lee's major work at the CMO for the next 5 years was to try and re-establish the meteorological network which had collapsed when the Japanese withdrew from Korea.

Just 5 years later, in 1950, the Korean War began between the North and the South. When the North Korean Army took over Seoul Dr Lee and his wife sought

Fig. 7.28 Dr Lee Won Chul watches the younger generation of students on the campus of Yonsei University (*Courtesy* Yonsei University Museum)

refuge in a secret location. During August 1950, the North Korean Army surrounded this house and tried unsuccessfully to capture him, so they took all his books to Pyeongyang instead. When he received this sad news he and his wife took poison, but fortunately they were saved from death. Instead, Lee Won Chul died in 1963; sadly he never lived to witness the emergence of astrophysics in Korea, which began to grow spontaneously during the mid-1970s, even though he visited the revitalized Yonsei University in his twilight years (Fig. 7.28).

Finally, we wish to add one more story about Dr Lee's later life. When the Korean War was over, through the ceasefire between the UN forces and the North Korean Army, he came back to Seoul from Busan, the emergency capital during the War. Seoul was in ruins, but a few years later he was searching old bookshops and bought a book titled *Calculation Method of the Experimental Observation* 實驗觀測計算法 which was written in Japanese. This book is now in Konkuk University Library. This was an old outdated book, of course, and would not have been any help to Dr Lee in his task of calendar calculations. One of us (NI-S) wondered why he bought this book at the time, given his strained economic circumstances. In those days everybody experienced a very hard life every single day, and we also know about Dr Lee's emotional response to the Japanese occupation. We can conjecture that he bought this book for just one reason: that it was a book about astronomy. Surely a man who had suddenly lost all of his books would have been filled with nostalgia upon seeing this book in an old secondhand book shop. The original purchaser's stamp is on an inside page of this book. He was Nakamura Hiroshi 中村拓, a Professor of Medicine at Keijou Imperial University 京城帝國大學 at that time and the father of the well-known Japanese astronomer Tsuko Nakamura 中村士—who just happens to be one of the editors of this book on *The Emergence of Astrophysics in Asia*!

7.5 The Instruments

Under King Sejong's direct leadership, the Board of Astronomy employed highly competent scholar-officials during the period 1432–1442 who were able to manufacture eighteen different astronomical instruments (see Nha 1997b). These were allocated to palaces, including Gyeongbok Palace, and other regions of the country. Regarding their locations within the Palace grounds, we introduce here as an example Gyeongbok Palace. As can be seen in Fig. 7.29, there were four observing platforms around Kyonhoe-ru Pavilion 慶會樓, while two buildings for clepsydras were located in the western part of the Palace grounds. A platform for a Sun-and-Stars Time-Determining Instrument 日星定時儀 is seen in the eastern part of the Palace grounds. This was the distribution of these instruments in the eighteenth and nineteenth centuries.

Another map shows more detail of the north-west corner of Gyeongbok Palace (Fig. 7.30). The square box-shaped *Gan'ui-dae*, Simplified Armillary Platform, is illustrated better than in Fig. 7.29, and it is alongside the High Gnomon in the north-western corner of this map. Two observing towers are located on both sides of Kyonhoe-ru Pavilion, which is located inside an artificial pond.

Now let us examine the types of instruments that were used by the Board of Astronomy astronomers throughout much of the eighteenth and nineteenth centuries. The various time-keeping instruments will be presented one by one. Some of them are currently preserved—as originals or faithful replicas—at the Nha Il-Seong Museum of Astronomy (see Nha 2002a).

7.5.1 Angbu Ilgui 仰釜日晷*, the Scaphe Sundial*

This type of sundial (see Fig. 7.31) was invented in 1434 during the reign of King Sejong, and was in use from that date as the standard sundial during the day time. Two sundials, marked with twelve time-gods instead of Chinese characters and inscribed for illiterate people, were made and positioned at two different places in Seoul. Thus these sundials have the honor of being the first public time-determining instruments for the citizens of Seoul. A visual estimate of the position of the shadow

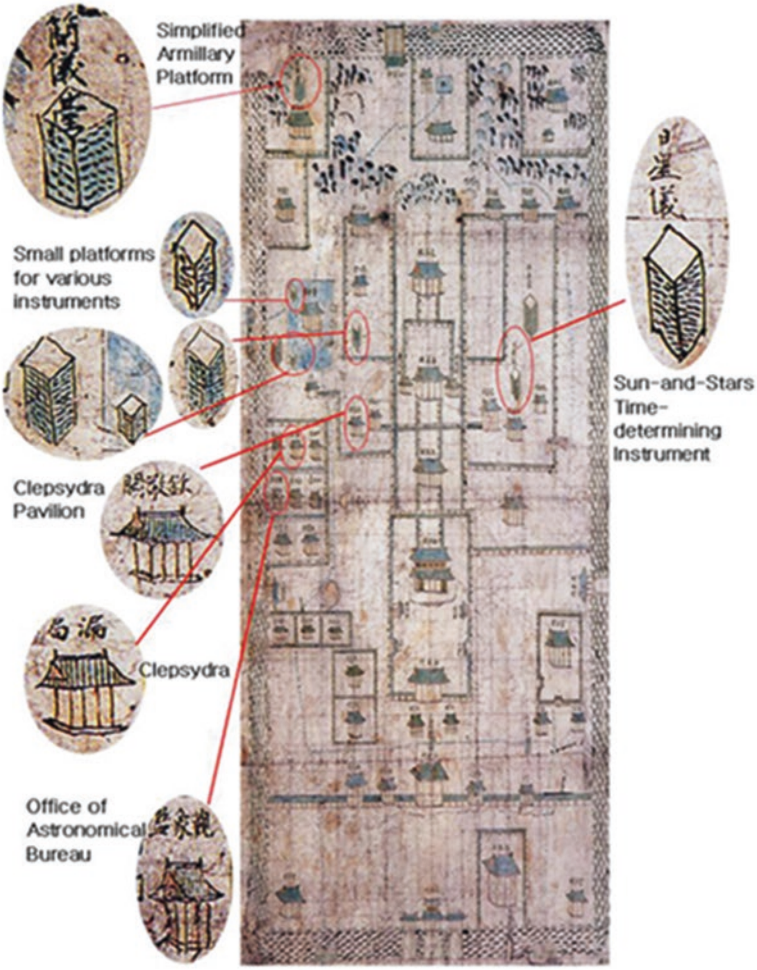


Fig. 7.29 An old map of Gyeongbok Palace, which is reduced in the left-right direction in order to show details of the positioning of the various astronomical instruments (after Nha and Nha 2010b)

edge using a ruler with a millimeter scale can easily enable the determination of local time with an accuracy of 1 min (Nha 2004b), and thus the sundial was used for the regulation of clepsydra at the Observatory in those days. It is also possible to determine the day within a fortnightly period of 24 solar periods with an accuracy of two or three days throughout the year. From the position of the shadow of the pointer the number of days elapsed can easily be estimated. When one adds this estimated number of days to the previous 24 solar period date, the result is the day of the year. Therefore, this sundial can also be used as an ever-lasting calendar.

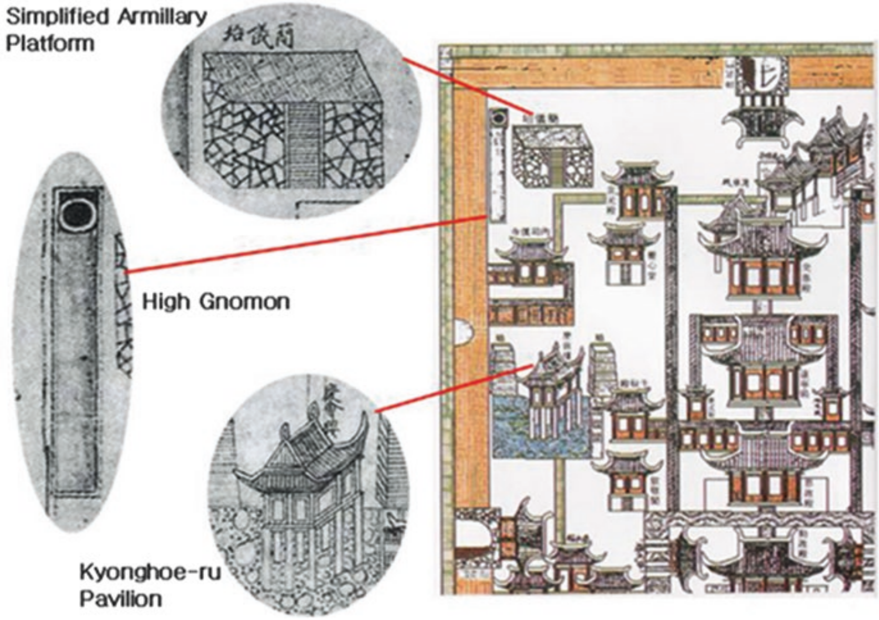


Fig. 7.30 The north-west corner of Gyeongbok Palace in detail (after Nha and Nha 2010a)

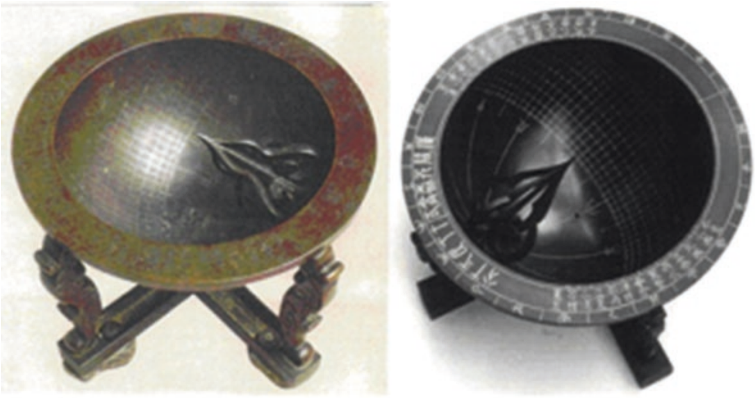


Fig. 7.31 *Angbu Ilgui* 仰釜日晷, the Scaphe Sundial. The left-hand one is a copy of a late eighteenth century model, and the right-hand one is a recent copy of another model (after Nha 2004b)

Fig. 7.32 A recent reproduction of the Sun-and-Stars Time-Determining Instrument from the reign period of King Sejong (after Nha and Nha 2010a)

7.5.2 *Ilseong Jeongsi-ui* 日星定時儀, *the Sun-and-Stars Time-determining Instrument*

This instrument (Fig. 7.32) was a compound instrument that functioned as both a sundial and a star-dial (Needham et al. 1986b). It was first made in 1437, and from that date was used widely to measure time at the observatories in the Palaces. A Small Sun-and-Stars Time-determining Instrument 小日星定時儀, which was easy to carry, also was used on the battle field.

7.5.3 *Jagyeok-nu* 自擊漏, *the Striking Clepsydra*

Time-keeping was highly developed in Korea (see Nam and Jeon 1997), and the first clepsydra (see Fig. 7.33) was housed in the Annunciating Clepsydra Pavilion (報漏閣) in Gyeongbok Palace and used as a standard time-keeping instrument at night from 1434 until the Hideyoshi Invasion in 1592. According to Nam Moon-Hyon 南文鉉, the uniqueness of this clepsydra was its capacity to announce twelve double-hours and five night-watches automatically with visual and acoustic signals. Nam (2011) also reports that there were reproductions and repairs made in 1536 (Fig. 7.34) and in 1618 respectively. From the mid-eighteenth century the Striking Clepsydra operated without parts of the time-announcing striking system, and it was used in Seoul for the abolition of a curfew alert and the lifting of regulations until 1895 (ibid.).

Fig. 7.33 A recent restoration of King Sejong's *Jagyok-nu*, Automatic Striking Clepsydra, carried out by Nam and his collaborators (after Nam 2006)

Fig. 7.34 Surviving vessels of the 1536 copy of the original Automatic Striking Clepsydra are now in the south-west corner of Deoksu Palace in Seoul (after Nha and Nha 2010a, b)

7.5.4 *Song I-yong's Armillary Clock* 渾天時計

This is the first mechanical clock in Korea and was made by Song I-young 宋以潁 in 1669, incorporating an armillary sphere (see Fig. 7.35). Needham and his collaborators, particularly John H. Combridge, have made an intensive study of it, and they

Fig. 7.35 The armillary clock of Song I-Young and Yi Min-Cheol preserved in the Korea University Museum (*Courtesy* Korea University Museum)

claim (Needham et al. 1986b) that the Song I-young/Yi Min-cheol clock deserves widespread recognition as a landmark in the history of East Asian horology.

In 2005 Kim and Lee (2011) restored what was left of the original Song I-young and Yi Min-cheol armillary clock, and they also constructed a full-scale functioning replica of this clock. They describe these activities in detail (accompanied by numerous drawings and close-up photographs) in their 2011 paper.

7.6 Star Maps

The earliest-known Korean star maps were painted on the walls of Royal tombs during the period of the Koguryo Kingdom, which dates between 37 BC and AD 668. These tombs

> … are scattered along the northern side of the Yalu river, [which is] now the border between China and North Korea, and in the area nearby Pyongyang, the North Korean capital city. The present survey counted nineteen such tombs. (Nha 2016).

These wall paintings show the earliest groupings of stars into constellations known from East Asia.

Apart from painted star maps at archaeological sites, there were two other principal types of ancient star maps found in Korea: those engraved on stone slabs, and those printed on paper or fabric. Although we have documentary evidence that a number of star maps were made during the Koryo Dynasty (AD 918–1392), none of them is known to have survived. In contrast, during the later part of the Joseon Dynasty, which followed,

> …a large number of star maps of various forms were made; many of them are still preserved in good condition by both public museums and private collectors around the world. (ibid.).

Arguably one of the best-known early monumental engraved star maps was King Taejo's star chart, known officially as *Cheonsang Yeolcha Bunya-Ji-Do*, made in 1395 (Nha 1996; Nha and Nha 2011; Rufus 1913), and over the years many copies of it have been produced (e.g. see Fig. 7.36). During the early Joseon Dynasty, most scholars who watched the skies used this star map.

Given its popularity, this remained the standard star map until better ones made by Jesuit astronomers were imported from China through the *Gwansang-gam*. The first of these was the *Chidao Nanbei Liang Zong Xingtu* with *Kunyu-tu* 赤道南北兩總星圖 by Adam Schall von Bell and Xu Quangqi, which was made in 1623. Thereafter, a series of new star maps made by both Jesuit and Chinese astronomers was brought to Korea (Lee et al. 1999), the long and difficult return journeys to Beijing involving considerable expense.

As was mentioned earlier, no Jesuit astronomer ever came to Korea, but close contacts with Jesuits were possible through the efforts of Korean astronomers who visited China (Nha and Kim 2006). However, they were treated contemptuously by Chinese guards at the gates of the residences, and only a few Koreans were successful in gaining entry, after offering bribes. Even when they did gain entry, intensive discussions between the Jesuit and Korean astronomers often were not possible owing to a lack of qualified interpreters. Because of these and other difficulties, astronomers at the Board of Astronomy in Seoul were forced to develop their own resources—which they did with a considerable degree of success.

One of their results was the local manufacture of star maps. Many different star maps were made by the Board of Astronomy astronomers, and over the years a number of these have drawn the attention of scholars—e.g. see Lee (1966), Lee and Ahn (2011), Oh (2011), Nha (2002b), Nha and Nha (2011) and Stephenson (1994). We will now examine just three of these.

7.6.1 Large-Screen Star Map (A)

This large star map on an eight-fold screen (Fig. 7.37) was made with ecliptical coordinates at the Board of Astronomy of Joseon in 1743, and introduced southern hemisphere stars for the first time in Korea (Nha 2002b). The Board of Astronomy

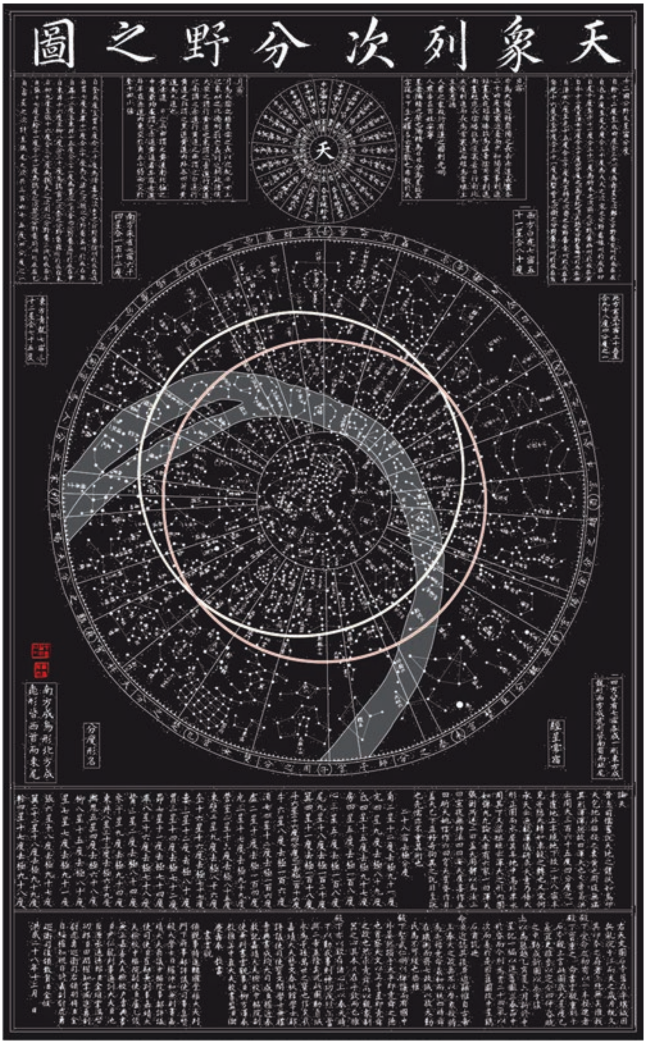


Fig. 7.36 A recent copy made by Nha Il-Seong of King Sejong’s 1433 New Celestial Planisphere 新法天文圖 (*Photograph* Nha Il-Seong)

did not want to give up its long tradition, so the 1395 planisphere occupies three panels on the right hand side of this screen, even though this old map was out of keeping with the northern and southern hemisphere star charts, which were on the 4th–5th and 6th–7th panels respectively and were based on European star maps. The final (eighth) panel shows the relative perceived sizes of the Sun, the Moon and the five known planets with satellites.

Because of this combination of panels, this Large-Screen Star Map has a long name: the *Cheonsang Yeolcha Bunya-do/Whangdo Nambuk Yangchong Seongdo/*

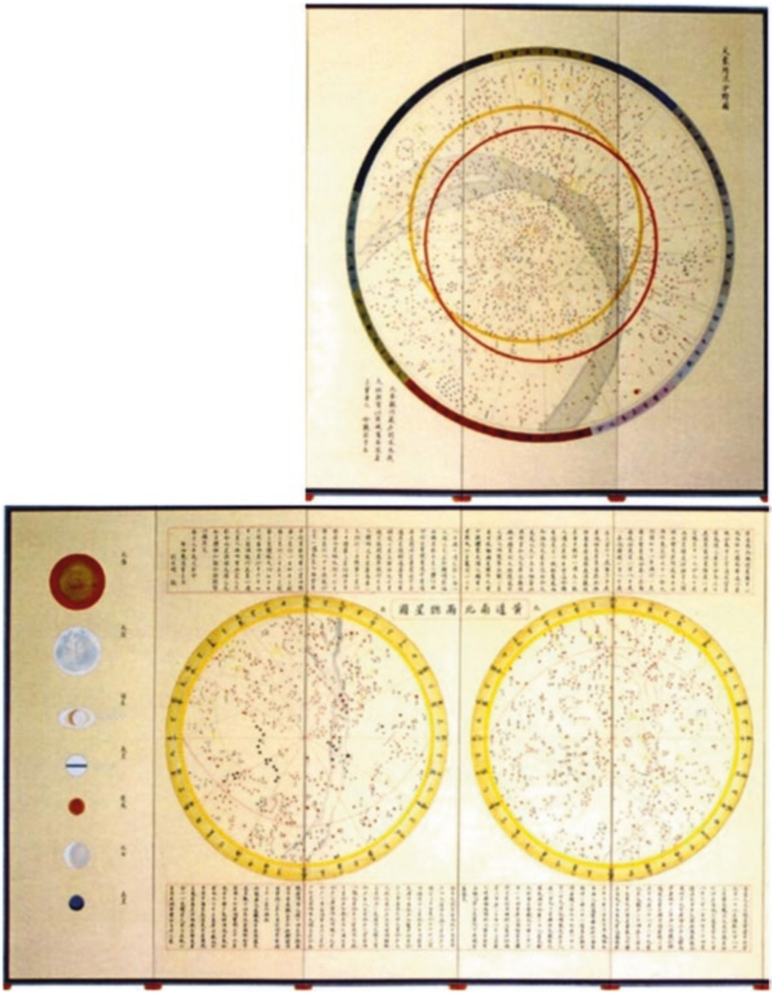


Fig. 7.37 A copy, shown in two parts (panels 1 to 3 on the right, and 4–8 below), of the Large Screen Star Map (A) made recently by Nha Il-Seong after consulting three surviving star maps of this kind (*Photograph* Nha Il-Seong)

Chiljeong-do Hapdo 天象列次分野圖/黃道南北兩總星圖/七政圖 合圖 in order to distinguish it from other large star maps, especially map (B) (which is discussed below). The overall size of this Large-Screen Star Map is 168 cm high and 464 cm wide.

At least four of these star maps are preserved in various places, and Needham and his associates studied the copy in the Whipple Museum (see Needham et al. 1986c).

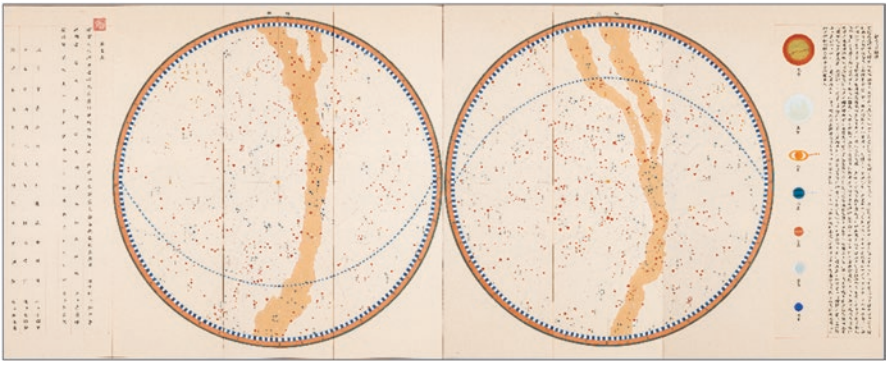


Fig. 7.38 Nha Il-Seong's recent copy of Large-Screen Star Map (B), which was made after consulting the original star map in Beopju-sa Temple (*Photograph* Nha Il-Seong)

7.6.2 Large-Screen Star Map (B)

This is another large star map (Fig. 7.38), which is preserved in Beobju-sa Temple 法住寺 in Korea (Nha 2002b). Unlike star map (A), this Large-Screen Star Map is unique, and there is no way of determining whether other copies of it originally were made.

The Board of Astronomy of Joseon was brave enough to omit the 1395 Planisphere, having northern and southern hemisphere star maps enlarged on six panels 2–7, instead. Therefore, this was possibly made just a few years after the Large-Screen Star Map (A). The first panel on this screen has an introduction and sketches of the Sun, Moon and five planets, and the last panel has the names of the six officials who made this star map.

The overall size of this Large-Screen Star Map is 147 cm high and 456 cm wide, so it is slightly smaller than Large-Screen Star Map (A).

7.6.3 Honcheon Jeondo 渾天全圖

Unlike the two Large-Screen Star Maps presented above, *Honcheon Jeondo* (Fig. 7.39) is a block printed planisphere measuring 90 cm high and 62.7 cm wide. It was made at about the same time as the two Large-Screen Star Maps, in the 1780s, by the Board of Astronomy.

Even though the overall size of the *Honcheon Jeondo* is small, astronomical information was compactly inscribed on the upper and lower parts of a circular map that is 57.5 cm in diameter. Five different symbols are adopted for stars of different brightness, down to about the 5th magnitude.

This star map has been intensively investigated by one of us (NI-S) (see Nha 2002b, 2006).

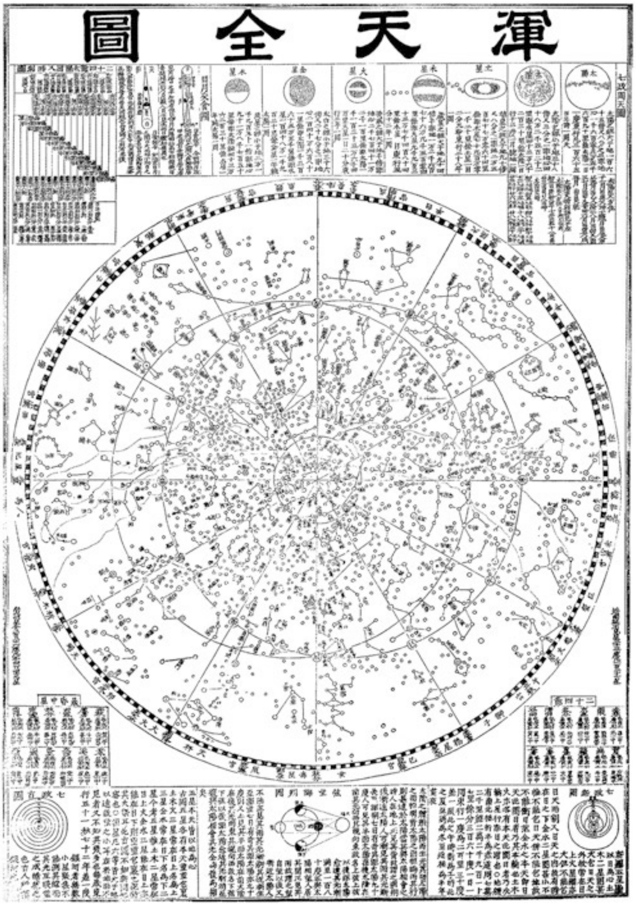


Fig. 7.39 A block print of the *Honcheon Jeondo* planisphere (*Photograph* Nha Il-Seong)

7.6.4 The Computer Replication of Korean Star Maps

Although the first to apply computer scanning techniques to a Korean star map apparently were Lee and Park (1997), we are in awe of Oh Gil-Sun's (2004, 2011) later efforts to perfect the art of replicating ancient Korean star maps on the computer. His incentive for doing this is admirable:

> Ancient star maps are an important resource for historians of astronomy, but because they are often old their use is limited by their condition and their accessibility. In this paper, I demonstrate how commercially-available computer software can be used to reproduce old star maps and to create brand new star maps based on numerical data contained in ancient sources. These modern digitally-generated star maps can be used by astronomers for educational purposes and for serious historical research. (Oh 2004: 165).

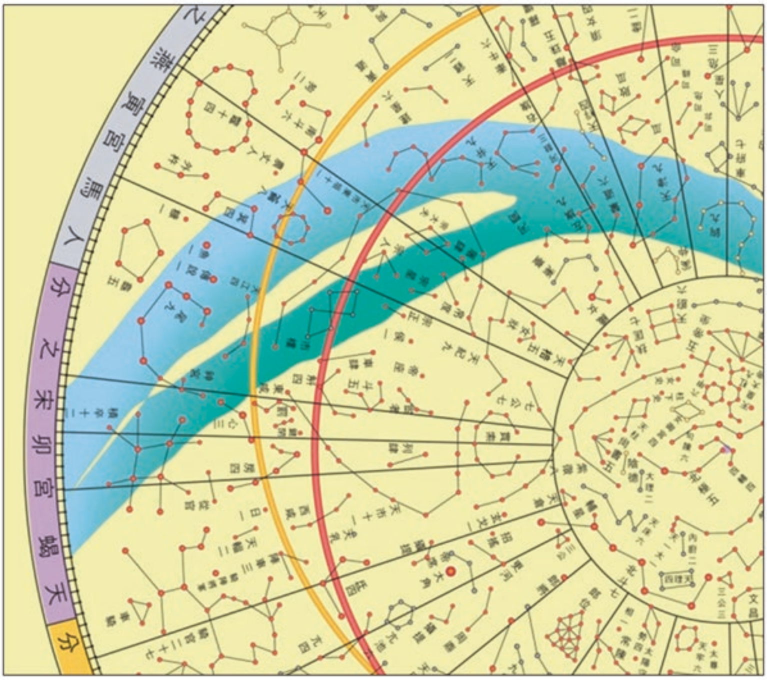


Fig. 7.40 A close-up of part of the computer-generated *Honhap Byongpung-songdo* (adapted from Oh 2011: 161)

Figure 7.40 shows a close-up of part of a computer-generated replica of an ancient Korean star map.

7.6.5 *An Ambitious Project to Replicate Old Star Maps from China, Korea and Japan*

Although computer replications were made of a few old star maps (e.g. see Fig. 7.40), perfection was not guaranteed because at that time it was practically impossible to replicate the original brush strokes of the hundreds, or in many cases thousands, of Chinese characters on each star map. Although a great many old star maps of historical and/or scientific value remain in a poor condition or are confined by the small sizes of pages in a book, without professional skill it is very unlikely that these star maps can be reproduced at full size and retaining their original shape.

Accordingly, for the past two decades two of us (NI-S and NSL) have been working on the restoration of old star maps from China, Korea and Japan, applying both computer graphic techniques and hand-brush writings. Some of the results are already shown above (see Figs. 7.36, 7.37 and 7.38), and a volume titled *Masterpieces* *of Chinese, Korean and Japanese Star Maps* (中國·韓國·日本古星圖寶典) will soon go to press that will contain replicas of 113 individual star maps, 52 from China, 36 from Korea and 25 from Japan. Since many of these are of large size and with many different parts, some star maps are composed of multiple figures, totaling more than 600.

7.7 Calendars and Almanacs

As Jeong (2004: 177) reflects,

> The calendar, which records the movement of history, also predicts basic laws that control human life. A calendar published in the form of a book and made for people to use in their everyday lives is called an 'almanac' …

In Korea there was a great reformation of the calendar system during the late Joseon Dynasty, following the importation of Adam Shall von Bell's *Shixian-shu Calendar*, and even as early as the seventeenth century

> … people attached enormous importance to almanacs, and viewed them as one of the necessities of life. As a result, a great number of almanacs were printed in order to satisfy the needs of the people. For instance, while ~4,000 copies were printed at the beginning of the Choson = [Joseon] Dynasty [around AD 1400], more than 15,000 were being distributed by the end of the Dynasty [1910] … (ibid.).

During the Joseon Dynasty various kinds of calendars were produced by the *Gwangsang-gam*, the Office of Astronomy. The first calendars printed in any 1 year were given to the King, members of the Royal Family, and high-ranking officials. Common people living in cities and towns bought their calendars from shops in the markets, while those in rural areas purchased them from local agents. Because there was usually a substantial shortage of calendars, especially in rural areas, some individuals took advantage of this situation and printed illicit copies and sold them (even though they faced the death penalty if caught). Indeed, staff at the *Gwangsang-gam* were even known to make and sell their own calendars, in order to increase their annual incomes.

In this Section we will focus on just four different well-known Korean calendars. Anyone wanting further information on these or other Korean calendars, should consult Jeong (2000) and Lee et al. (2011a), while Lee (1997) discusses the Chinese origin of the earliest Korean calendars.

7.7.1 *The Shixian-shu* 時憲書 *Calendar*

This *Calendar* (Fig. 7.41) was published every year following the late Joseon calendar reform, and used its original Chinese name.

大清乾隆五十六年歲次辛亥時憲書

Fig. 7.41 The front cover (*left*) and the first page (*right*) of the *Shixian-shu Calendar* (*Photograph* Nha-Il-Seong)

7.7.2 The Myeongsi-ryeok 明時曆

This was a Korean reformed version of the *Shixian Calendar* and is shown in Fig. 7.42.

7.7.3 The Cheonse-ryeok 千歲曆and Manse-ryeok 萬歲曆 Calendars

The *Cheonse-ryeok Calendar* (Fig. 7.43) began as a perpetual annual calendar for 1000 years, which was published for the first time in the sixth reign year of King Jeongjo 正祖 (i.e. 1782). This then was published repeatedly by a later monarch, and was renamed the *Manse-ryeok* 萬歲曆 *Calendar* in 1904 (*JMB* 1980d). This is shown in Fig. 7.44.

大韓光武六年明時曆

1902

大韓光武六年歲次壬寅明時曆

正月大

二月小

三月大

四月小

五月小

六月大

Fig. 7.42 The front cover (*left*) and the first page (*right*) of the *Myeongsi-ryeok Calendar* (*Photograph* Nha Il-Seong)

Fig. 7.43 The *Cheonse-ryeok* perpetual *Calendar* (*Photograph* Nha Il-Seong)

正廟壬寅 起元乙未今酉

千歲曆

觀象監藏板

Fig. 7.44 The *Manse-ryeok* perpetual *Calendar* (*Photograph* Nha Il-Seong)

The main purpose of these calendars was to help local intellectuals count days for about 100 years in advance. This *Calendar* was published at the beginning of each monarch's reign.

7.7.4 The Min-reki 民暦 *Civil Calendar*

This is a *Calendar* (Fig. 7.45) that was issued annually by the Government-General of Joseon 朝鮮總督府 from 1911 to 1945, during the Japanese occupation of Korea (see Choi 1910; Lee et al. 2011b).

7.8 The Emergence of Astrophysics in South Korea

Writing in 1997, one of us (NI-S) described the 'recent history' of astronomy in South Korea:

> After 1945, for nearly three decades, astronomy was almost non-existent in Korea. During the last two decades, however, Koreans have re-established that science in their country … The first bachelor's programme [in astronomy] offered in a university of the Republic of Korea was established in 1958 at Seoul National University, followed ten years later by Yonsei University. Both these institutions now offer full Masters and Doctoral programmes.

朝鮮總督府編製

昭和四年朝鮮民曆

昭和四年朝鮮民曆

日曜表

日食 五月九日

昭和四年中陰曆歲次己巳年月表及節候表

Fig. 7.45 The cover (top) and two interior pages of the 1929 *Civil Calendar*; the upper part of the (lower) right hand page lists eleven Japanese national holidays (*Photograph* Nha Il-Seong)

> Since 1980, at least another five universities have begun graduate programmes in astronomy. (Nha 1997a: 314).

The founding of the Korea Astronomy and Space Science Institute (KASI) in Daejeon in 1974 also was a major factor in the emergence of astrophysics in South Korea. With a charter that spanned optical and radio astronomy, space sciences and theoretical astronomy, over a relatively short period this led to a quantum jump in

Fig. 7.46 A recent photograph of Bohyunsan Optical Astronomy Observatory (www.kasi.re.kr)

Table 7.2 South Korea optical telescopes used for astrophysical research (adapted from Nha 1997a: 316)

Institute or individual	Aperture (m)
KASI	1.8
	1.0[a]
	0.6
Kyonghi University	0.75
Sejong University	0.75
Yonsei University	0.6
Busan National University	0.4
Chonbuk National University	0.4
Kongju National University	0.4
I-S. Nha Observatory	0.4

[a] Note that this telescope is located at Mt Lemmon in Arizona, USA

the number of trained astronomers employed in South Korea. It also led to the founding of KASI's Bohyunsan Optical Astronomy Observatory (Fig. 7.46).

Another important development occurred in 1965 when "… a handful of astronomers and scientists, ill-trained as they were at the time, gathered together … to start the Korean Astronomical Society … [and] In 1973 the Korean society joined the IAU …" (Park 2000: 421).

By the year 2000 Bohyunsan Optical Astronomy Observatory and a number of universities and one of the authors of this chapter (NI-S) maintained telescopes (see Table 7.2) that were used regularly for a variety of research projects, although the initial emphasis was on photoelectric photometry of variable stars and stellar

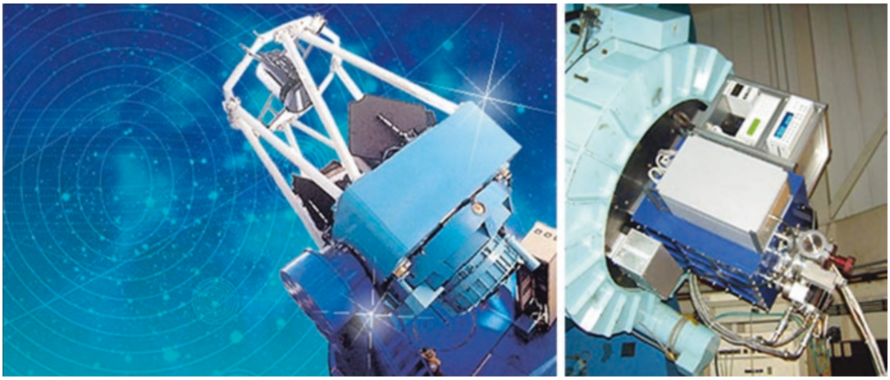


Fig. 7.47 The 1.8-m reflecting telescope at Bohyunsan Optical Astronomy Observatory, with the KASI Near-Infrared Camera System (KASINICS) shown in close-up on the right (www.kasi.re.kr)

spectroscopy (as discussed below in Sects. 7.8.1 and 7.8.2). A notable feature of this table is the modest aperture of the telescopes, the 1.8-m reflector at Bohyunsan Optical Astronomy Observatory (Fig. 7.47) still being the largest optical telescope sited in South Korea. However, many South Korean astronomers and graduate students now successfully compete for observing time on much larger overseas telescopes—following a trend that is apparent world-wide.

7.8.1 *The Emergence of Photoelectric Photometry in South Korea*

Photoelectric photometry was introduced into South Korea in 1975 by Nha Il-Seong. He analyzed the *UBV* light curves of an eclipsing binary star CW Cephei (Nha 1975) and established a group for the long-term intensive observation of various types of eclipsing binary stars. For instance: (1) the spotted star AR Lacertae (Kang and Nha 1992; Lee et al. 1986; Nha and Kang 1982; Nha et al. 1985); (2) Nova V1500 Cygni (Nha and Jeong 1976); (3) times of minima of eclipsing variables (Kreiner et al. 2001; Nha and Jeong 1979); (4) Ca II emission stars (Andrews et al. 1988; Nha and Oh 1983; Sarma et al. 1985), (5) ε Aurigae (Nha 1992); (6) Be stars (Jeong et al. 1986; Pavlovski et al. 1993); (7) apsidal motion binary (Gimenez et al. 1987); (8) W Serpentis-type binary stars (Nha and Kim 1993); and (9) general studies (Kim et al. 2005; Nha 1988a, b, 1997c; Nha et al. 1991).

In particular, a fruitful outcome of this research was the publication in Poland of the book *An Atlas of O-C Diagrams of Eclipsing Binary Stars* … in six parts (Kreiner et al. 2001). This is shown in Fig. 7.48. A large number of research papers based on this atlas have been published, including by Kim Chun-Hwey (Kim et al. 2003a, b, 2005, 2014) and Lee Jae Woo (2009, 2010). Most of their papers focused on the

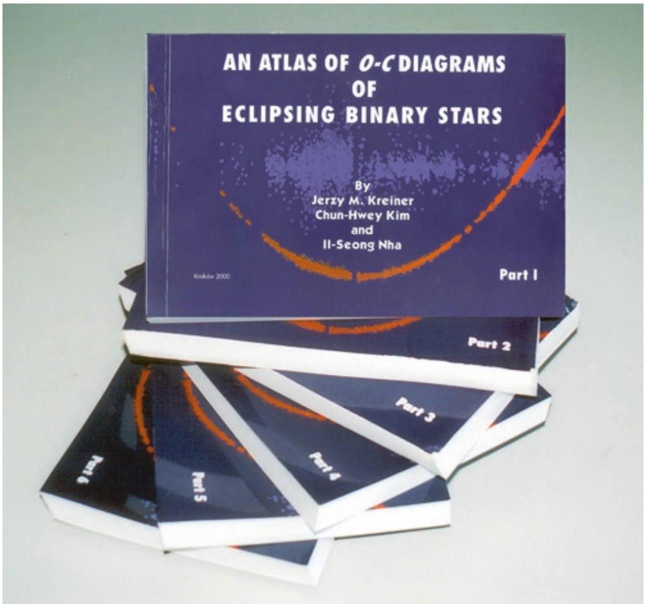


Fig. 7.48 Six Volumes of *An Atlas of O-C Diagrams of Eclipsing Binary Stars* (*Photograph* Nha Il-Seong)

finding of unseen third-bodies, including planets, in eclipsing binary systems. These extra-bodies can be found by detecting light-time effects in the *O(bserved)-C(alculated)* diagrams of times of minimum light of their host binary stars, requiring the help of the *Atlas*.

7.8.2 The Emergence of Stellar Spectroscopy in South Korea

Under the directorship of Lee Sang Gak, stellar spectroscopic research has been undertaken in South Korea since the 1980s. Among many achievements, the followings are the most recent.

Abundances of refractory elements for G-type stars with extrasolar planets have been determined by measuring the equivalent widths in high-resolution spectra taken with the 1.8-m Bohyunsan telescope equipped with an echelle spectrograph (Kang et al. 2011). The Tool for Automatic Measurement of Equivalent Width (TAME) in high-resolution stellar spectra has been developed by Kang and Lee (2012). TAME provides the equivalent widths of spectral lines by profile fitting in an automatic or interactive mode that can yield a more precise result through the adjustment of the local continuum and fitting parameters (see Fig. 7.49).

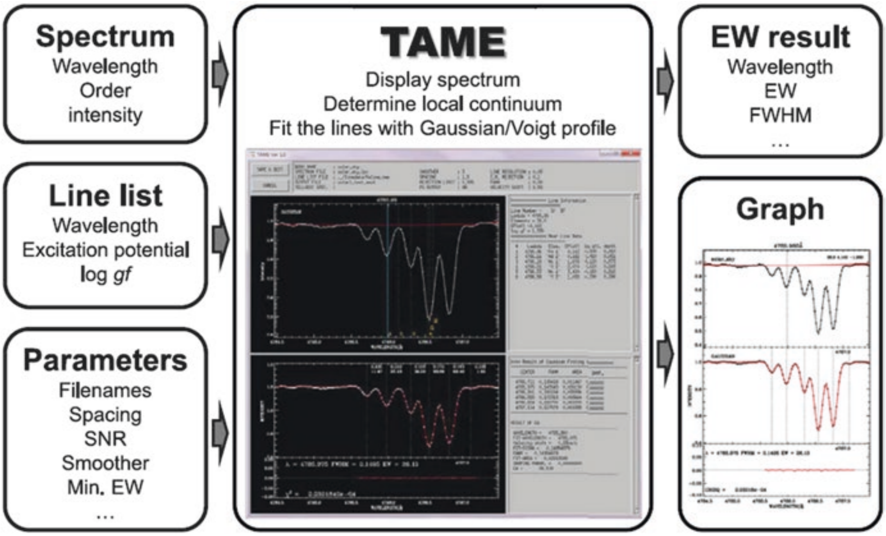


Fig. 7.49 Inputs, outputs and user interface in the TAME program (after Kang and Lee (2012)

7.8.3 *The Emergence of Radio Astronomy in South Korea*

The development of KASI also has seen South Korea emerge as a key ‘player’ in international radio astronomy. In 1986 Daedeok Radio Astronomy Observatory was founded, with a 13.7-m parabolic antenna that operates between 86 and 115 GHz. Later the Korean VLBI network was established (Fig. 7.50), with three 21-m antennas that can simultaneously receive radio emission at 22, 43, 86 and 129 GHz.

Recently, South Korea joined the East Asian Observatory, which took over the 15-m James Clerk Maxwell Telescope, an antenna on Mauna Kea, Hawaii, designed to operate in the wavelength range of 0.4–1.4 mm range. South Korea also has become a partner in the ALMA consortium, thereby giving its radio astronomers even greater access to leading international ‘cutting-edge’ instrumentation.

For further details of recent Korean achievements in optical and radio astronomy and theoretical astronomy consult the KASI web site (www.kasi.re.kr)

7.8.4 *Space Exploration*

Since an early primitive report on ‘modern astronomy’ in Korea was presented at a UN/ESU Workshop (Nha 2004c), space exploration has boomed in Korea, and a variety of instruments has been developed for different types of objects, mainly by scientists of younger generations.

Two space telescopes, FIMS (Far-ultraviolet Imaging Spectrograph) and MIRIS (Multi-purpose InfraRed Imaging System), were developed by KASI, with interna-

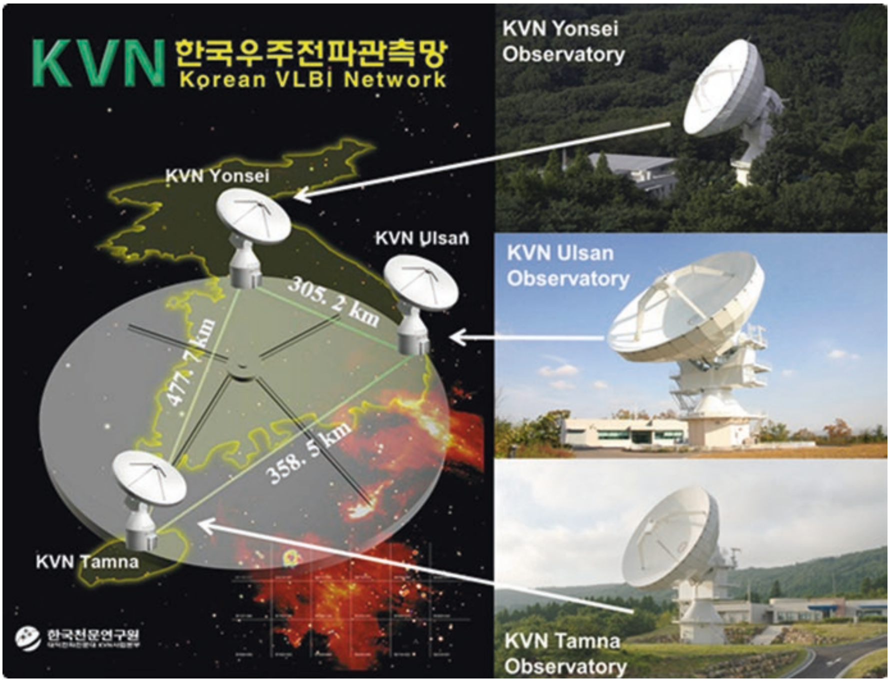


Fig. 7.50 The Korean VLBI Network uses 21-m antennas located at Yonsei, Ulsan and Tamna Observatories (www.kasi.re.kr)

tional collaboration. FIMS was launched in 2003, and more than 40 resulting research papers have been published in international journals. Apart from these it is worth noting that in 2006 a special issue of the *Astrophysical Journal Letters* was published to commemorate the success of FIMS2006 (see Fig. 7.51).

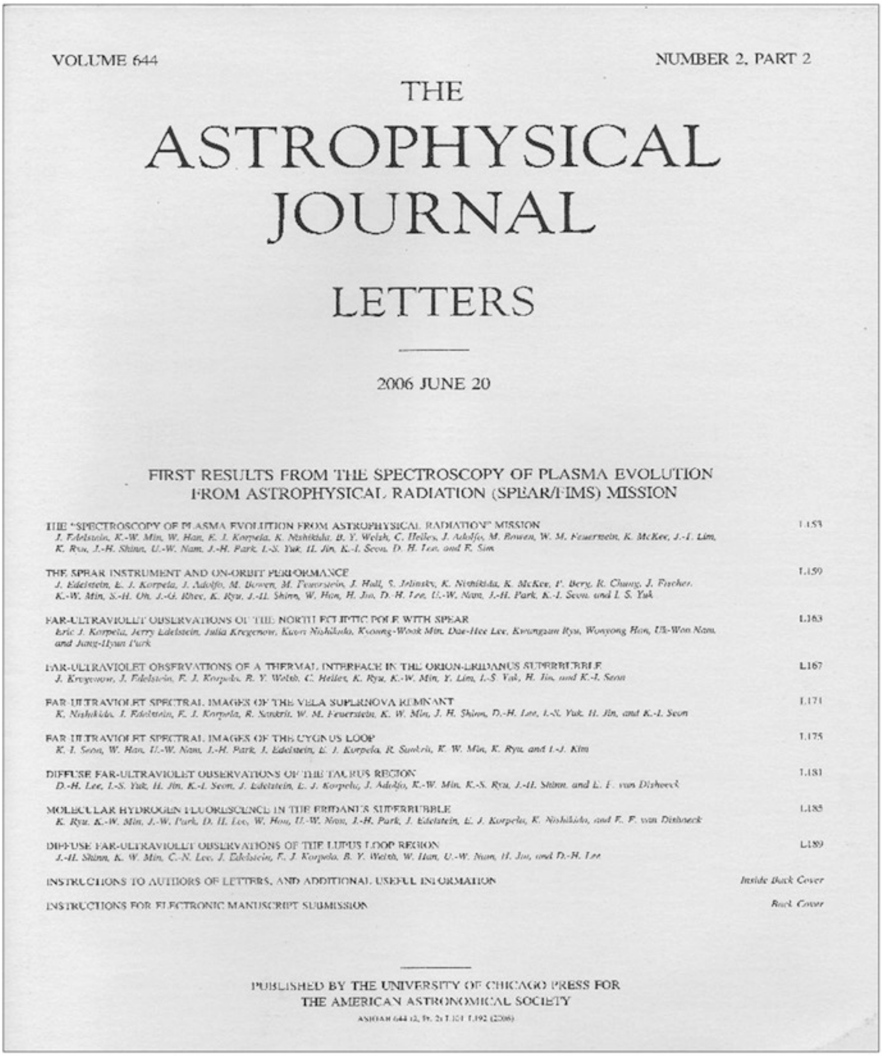
MIRIS was developed by KASI, and was launched onboard the Science and Technology Satellite-3 of Korea (STSAT-3) in 2013 November. The main mission of MIRIS is the Paschen-α emission line survey along the Galactic Plane and the cosmic infrared background (CIB) observation. One of the results is presented here in Fig. 7.52, with the first images of M42 and the Rosette Nebula.

7.9 Applied Historical Astronomy

As Lee and Nha (2004: 35) have stressed,

> Astronomical records since the beginning of the Three-Kingdom Era are well documented in Korean history. These records span ~2,000 years and they contain a rich treasury of astronomical objects and events.

In particular, these records include information on comets (as we have seen), solar and lunar eclipses (Stephenson 1999, 2002), lunar occultations of planets and



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THE
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LETTERS

2006 JUNE 20

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INSTRUCTIONS TO AUTHORS OF LETTERS, AND ADDITIONAL USEFUL INFORMATION *Inside Back Cover*

INSTRUCTIONS FOR ELECTRONIC MANUSCRIPT SUBMISSION *Back Cover*

PUBLISHED BY THE UNIVERSITY OF CHICAGO PRESS FOR
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ASJOAB 644 (2, Pt. 2) L153–L192 (2006)

Fig. 7.51 Nine FIMS research papers were included in this 2006 issue of the *Astrophysical Journal Letters*

stars, sunspots, aurorae, meteor showers (Imoto and Hasegawa 1958; Sekiguchi 1917b), novae and a supernova (Kim 1997). Some of these records can be used by astronomers to address contemporary issues in astrophysics, a specialized field known as Applied Historical Astronomy (see Stephenson 1996, 1997).

One of the most useful, but relatively neglected sources of astronomical information is the *Seungjeongwon Ilgi*, surviving copies of which date from AD 1623–1894 (Stephenson 2011). Meanwhile, Stephenson (2004) also found invaluable astronomical records in the *Seonjo Sillok*.

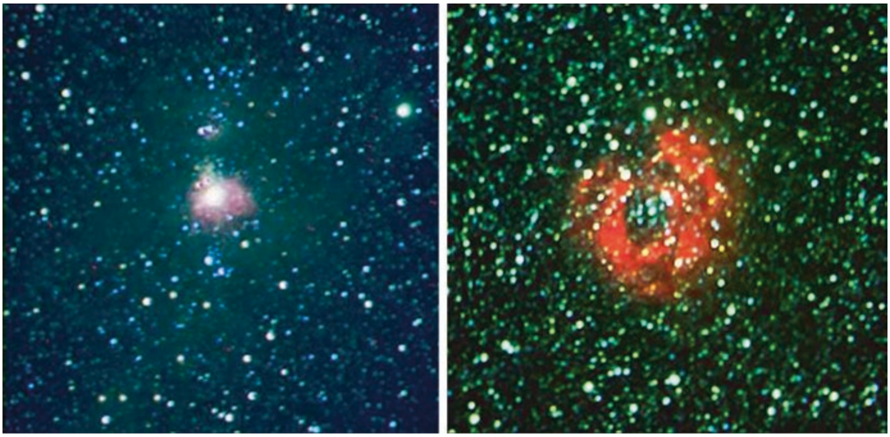


Fig. 7.52 MIRIS images of M21 (*left*) and the Rosette Nebula (*right*) (after Han et al. 2014)

Two different types of Applied Historical Research stand out when we examine the Korean archival sources. Firstly, there is the information they contain on historical supernovae. Stephenson and Green (2002) have shown that there is evidence of only six supernova events in our Galaxy during the past two millennia, and there are Korean records of three of these, in AD 1054, 1572 and 1604 (cf. Chu 1968). By far the best observed of these was the supernova of 1604 (see Fig. 7.53):

> One of the most important series of astronomical in the *Sillok* relates to the supernova of AD 1604/5. This brilliant 'guest star' was monitored for several months by the Korean astronomers … (Stephenson 2011: 211).

The first Korean observations were made on 13 October 1604:

> King Seojong, 37th year, ninth lunar month, (day) *wuchen* 戊申 [5] [=1604 October 13]. In the first watch of the night there was a guest star; it was 10 *du* in *Wei* lunar lodge and its distance from the [North Celestial] pole was 110 du. Its form was smaller than Jupiter and its colour was yellowish-red. It was scintillating (*Seonjo Sillok*: 178).

This was followed by nearly 100 more observational reports in the *Seonjo Sillok*, and Stephenson (2004: 16) notes that "… such consistency is unrivalled anywhere else in the world—including Europe—for any Galactic supernova." On the basis of Korean observations, Stephenson (2004) has pinpointed the position of this supernova, also known as 'Kepler's Supernova', which now coincides with a distinctive supernova remnant that is very apparent at radio and X-ray wavelengths (see Dickel 2006). Thanks to the plethora of Korean records, Stephenson (2004) was able to determine the light curve of this supernovae, and this is shown in Fig. 7.54. Note that the earliest observations took place well before the supernova reached its maximum visual brightness of –2.5. Note, also, that the supernova remained visible to the naked eye for well over a year.

A second area of Applied Historical Astronomy where Korea has played a key role is in tracking changes in solar activity over time. Although we know there have

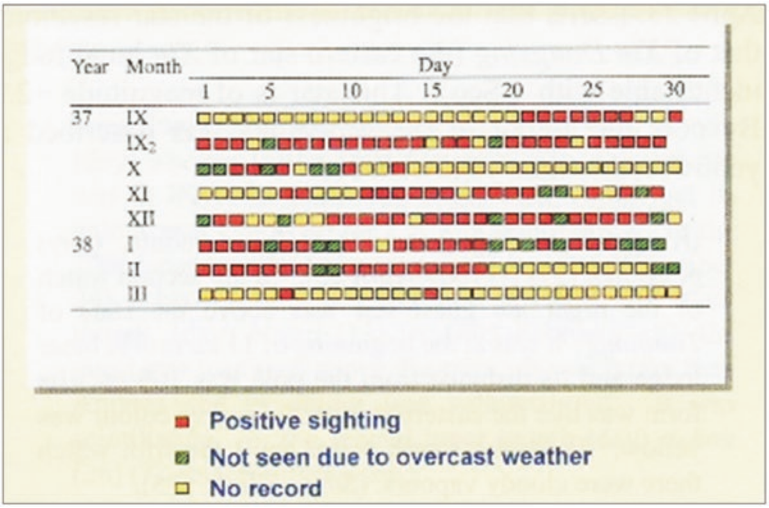
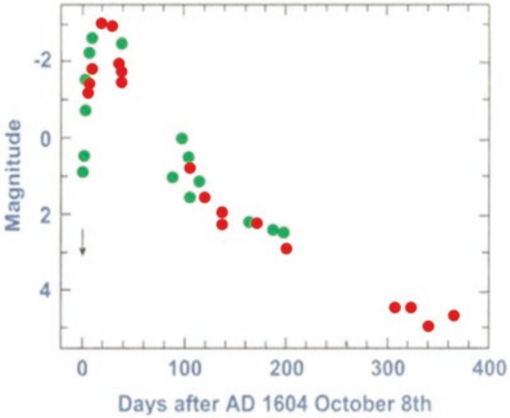


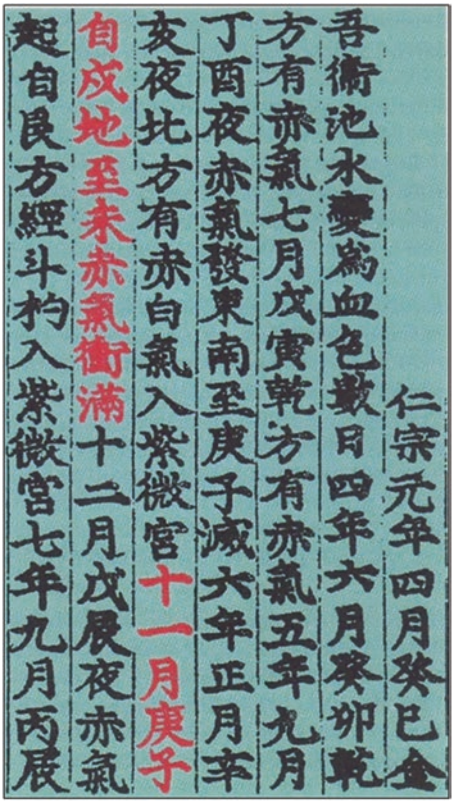
Fig. 7.53 A summary of Korean observations of SN1604 recorded in the *Seonjo Sillok* in the 37th and 38th reign years of King Seonjo (after Stephenson 2004: 17)

Fig. 7.54 The light curve of SN1604 based on Korean (*green*) and European (*red*) observations (adapted from Stephenson 2004: 20)



been marked changes in the incidence of sunspots over the past millennia or more (Eddy et al. 1989; Yau and Stephenson 1988), unfortunately complete datasets of sunspot numbers are not readily available as a means of monitoring solar activity. However, it is well known that there is a direct correlation between sunspot numbers and auroral activity (Lee et al. 2004), and since reports of aurorae are found in Korean astronomical records (see Fig. 7.55), as documented by Dai and Chen (1980), Willis and Stephenson (2001) and Willis et al. (2005), these can be used as proxies to track solar activity.

For example, during the twelfth century, Willis and Davis (2015) noted numerous Korean records of aurorae between 17 October 1127 and 10 January 1129 (see Table 7.3).



仁宗元年四月癸巳金吾衛池氷變爲血色數日四年六月癸卯乾方有赤氣七月戊寅乾方有赤氣五年九月丁酉夜赤氣發東南至庚子滅六年正月辛亥夜北方有赤白氣入紫微宮十一月庚子自戌地至未赤氣衝滿十二月戊辰夜赤氣起自艮方經斗杓入紫微宮七年九月丙辰

Fig. 7.55 In this record from the *Goryeosa*, the characters in red print document the existence of an aurora on 13 December 1128 (after Willis and Davis 2015: 66)

Table 7.3 Auroral observations recorded in Korean archival sources between October 1127 and January 1129 inclusive (adapted from Willis and Davis 2015: Table 1)

Date	Description
17–20 October 1127	King Injong, 5th year, 9th month, day *ding-you* (34). “At night, a red vapour appeared in the SE. On day *keng-tzu* (37) – 20 October – it was finally extinguished.” (Jeong 1454: 53)
28 February 1128	King Injong, 6th year, 1st month, day *xinhai* (48). “At night, in the N direction, there was a red-white vapour entering *Tzu-wei-kung* (Purple Subtlety Palace).” (Jeong 1454: 53)
20 October 1128	King Injong, 6th year, 9th month, day *bingwu* (43). “A red vapour from the NW passed *Tzu-wei* (Purple Subtlety) and entered the NE. Also, dark vapours were running into it from the S and N.” (*JMB*, 1980e)
13 December 1128	King Injong, 6th year, 11th month, day *gengzi* (37). “From the NW to the SW, a red vapour soared and filled the sky.” (Jeong 1454: 53)
10 January 1129	King Injong, 6th year, 12th month, day *wuchen* (5). “At night, a red vapour rose from the NE direction. It passed through *Tou-shao* (handle of the Northern Dipper) and entered *Tzu-wei-kung* (Purple Subtlety Palace).” (Jeong 1454: 47, 53)

More recently, Stephenson (2011) has found a veritable treasure trove of auroral records in the *Seungjeongwon Ilgi*, and he is currently engaged in a detailed analysis of these. When it is published, this study will surely throw welcome new light on the incidence of sunspots during the Maunder and Dalton Minima (Hoyt and Schatten 1996); Ribes and Nesme-Ribes 1993).

7.10 Concluding Remarks

The Korean region has a long record of astronomical achievement that extends back thousands of years, and includes early paintings of asterisms on the walls of tombs in an area that is now on the border of North Korea and China.

During the Joseon Dynasty (AD 1392–1910), Korean astronomy acquired its own unique flavor, with important developments in celestial instrumentation, timekeeping devices and the production of calendars and star maps—but sometimes with input from China.

These Chinese influences accelerated in the seventeenth century, following the arrival of Jesuit astronomers in Beijing, but no Jesuits ever visited Korea or were based in Korea, and although the telescope and mechanical clock were introduced to Korea from China in 1631, Korean observational astronomy remained dedicated to naked-eye observations with locally produced astronomical instruments. To achieve this, the *Gwansang-gam* (Board of Astronomy) maintained observatories in Seoul and rural observing stations beyond the capital, and employed a large pool of astronomers who were rostered in 8-h shifts, 24 h a day, 7 days a week, regardless of weather conditions.

This observational focus led to an avalanche of astronomical records, but a significant percentage of these was lost through wars and internal unrest. However, some of those records that have survived contain invaluable observations of supernovae, comets and aurorae, and have proved particularly valuable to those involved in Applied Historical Astronomy.

During the period 1880–1930 many nations worldwide gradually changed their astronomical research strategies as they tried to abandon positional astronomy and espoused the 'new astronomy' astrophysics. But occupation of the Korean Peninsula by the Japanese from 1910 to 1945 and then the Korean War stifled any aspirations that Korean astronomers may have had in this direction, and it was only in the 1960s that South Korea finally began to experience its first 'astrophysical awakening.'

Following this modest beginning, the development of astrophysical research in South Korea over the past three decades has been nothing short of phenomenal, especially in the area of radio astronomy, as the nation races to make up for lost time—and the lost opportunities associated with occupation and war.

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References

Andrews, S.D., Rodono, M., Linsky, J.L., Brown, A., Butler, C.J., and 9 other authors (1988). Rotational modulation and flares on the RS CVn and BY Dra stars. IX. IUE spectroscopy and photometry of II Peg and V711 Tau during Feb. 1983. *Astronomy and Astrophysics, 204,* 177–192.

Ansari, S.M.R. (Ed.), (2002). *History of Oriental Astronomy. Proceedings of the Joint Discussion-17 at the 23rd General Assembly of the International Astronomical Union* … Dordrecht: Kluwer.

Chen, K.-Y., & Sun, X. (Eds.), (2006). *Frontiers of Oriental Astronomy*. Beijing: China Science and Technology Press.

Chen, K.-Y., Orchiston, W., Soonthornthum, B., & Strom R. (Eds.), (2006). *Proceedings of the Fifth Conference on Oriental Astronomy*. Chiang Mai: University of Chiang Mai.

Cho, S.-K. (1999). *Soun-gwan*, the Bureau of Astronomy and Meteorology during King Sejong's reign period. In M. Hirai, pp. 185–192.

Choi, G.E. (1910). *A Study of Korean Astronomical Almanacs for 1864–1945*. M.Sc. Thesis, Chungbuk National University. (in Korean).

Chu, S.-I. (1968). Supernovae from ancient astronomical Korean records. *Journal of the Korean Astronomical Society, 1,* 29–36.

Dai, N.-Z., & Chen, M.-D. (1980). Historical auroral data from China, Korea and Japan from the legendary period to A.D. 1747. *Kejishiwenji, 6,* 87–146. (in Chinese).

Dickel, J. (2006). The structure and expansion of the remnants of historical supernovae. In K.-Y. Chen et al., pp. 57–63.

Eddy, J.A., Stephenson, F.R., & Yau, K.K.C. (1989). On pre-telescopic sunspot records. *Quarterly Journal of the Royal Astronomical Society, 30,* 65–73.

Gimenez, A., Kim, C.-H., & Nha, I.-S. (1987). Apsidal motion in the early-type eclipsing binaries CW Cephei, Y Cygni and AG Persei. *Monthly Notice of the Royal Astronomical Society, 224,* 543–555.

Han, W., Lee, D.-H., Jeong, W.-S., Park Y., Moon, B., and 22 other authors (2014). MIRIS: a compact wide-field infrared space telescope. *Publications of the Astronomical Society of the Pacific, 126,* 853–862.

Hirai, M. (Ed.), (1999). *Proceedings of the Third International Conference on Oriental Astronomy*. Fukuoka: Fukuoka University of Education.

Hoyt, D.V., & Schatten, K.H. (1996). How well was the Sun observed during the Maunder Minimum? *Solar Physics, 165,* 181–192.

Ilgi (1742). [= *Seungjeong-won Ilgi* 承政院日記, *Daily Journals by Scholar-officials in the Office of the [Korean] Royal Secretary*]. King Sejong Memorial Society, 73–74 (in Korean).

Imoto, S., & Hasegawa, I. (1958). Historical records of meteor showers in China, Korea, and Japan. *Smithsonian Contributions to Astrophysics, 2,* 131–144.

Jeong, I.-J. (compiler), (1454). *Koryo-sa (History of Koryo)*. (in Korean).

Jeong, J.-H., Sur, C.-W., & Nha, I.-S. (1986). Photometric behavior of the Be star EW Lacertae. *Astrophysics and Space Science, 119*(1), 73–76.

Jeong, S.-H. (2000). *Cosmology and the Calendar System in the Late Joseon Period*. Kyonggi: The Academy of Korean Studies.

Jeong, S.-H. (2004). Calendar-making in seventeenth and eighteenth century Korea and the present archives. In W. Orchiston et al., pp. 177–180.

JMB (1980a) [= *Jeungbo Munheon Bigo* 增補文獻備考, *Comprehensive Study of [Korean] Civilization, Revised and Expanded*]. King Sejong Memorial Society, 1, 4b–5a (in Korean).

JMB (1980b) [= *Jeungbo Munheon Bigo* 增補文獻備考, *Comprehensive Study of [Korean] Civilization, Revised and Expanded*]. King Sejong Memorial Society, 3, 3b–6a (in Korean).

JMB (1980c) [= *Jeungbo Munheon Bigo* 增補文獻備考, *Comprehensive Study of [Korean] Civilization, Revised and Expanded*]. King Sejong Memorial Society, 1, 6a (in Korean).

JMB (1980d) [= *Jeungbo Munheon Bigo* 增補文獻備考, *Comprehensive Study of [Korean] Civilization, Revised and Expanded*]. King Sejong Memorial Society, 1, 9a (in Korean).

JMB (1980e) [= *Jeungbo Munheon Bigo* 增補文獻備考, *Comprehensive Study of [Korean] Civilization, Revised and Expanded*]. King Sejong Memorial Society, 8, 3b (in Korean).

Kang, W., & Lee, S.-G. (2012). Tool for Automatic Measurement of Equivalent width (TAME). *Monthly Notice Royal Astronomical Society*, 425, 3162–3171.

Kang, Y.-W., & Nha, I.-S. (1992). Spots of AR Lacertae. In P.B. Byrne and D.J. Mullan (Eds.), *Proceedings of Armagh Bicentenary Colloquium on Surface Inhomogeneities in Late-type Stars* (pp. 286–297). Berlin: Springer.

Kang, W., Lee, S.-G., & Kim, K.-M., (2011). Abundances of refractory elements for G-type stars with extrasolar planets. *Astrophysical Journal, 736,* 87. (13 pp).

Kim, C.H., Nha, I.S., & Kreiner, J.M. (2005). A possible detection of a second light-time orbit for the massive, early-type eclipsing binary star AH Cephei. *Astronomical Journal, 129,* 990–1000.

Kim, C.H., Lee, J.W., Kim, H.I., Kyung, J.M., & Koch, R.H. (2003a). Photometric studies of the triple star ER Orionis. *Astronomical Journal, 126,* 1555–1562.

Kim, C.H., Lee, J.W., Kim, S.L., Han, W., & Koch, R.H. (2003b). A period study and light synthesis for the W Ursae Majoris Type binary SS Arietis. *Astronomical Journal, 125,* 322–331.

Kim, C.H., Song, M.H., Yoon, J.N., Han, W., & Jeong, M.J. (2014). BD Andromedae: A new short-period RS CVn eclipsing binary star with a distant tertiary body in a highly eccentric orbit. *Astrophysical Journal, 788*(2), 134. (22pp).

Kim, S.H., & Lee, Y.S. (2011). An analysis of the operating mechanism and restoration of Song I-Yeong's armillary clock. In T. Nakamura et al., pp. 109–115.

Kim, Y. (1997). Statistics of astronomical records in Korea during AD 1200–1450. In I.-S. Nha & F.R. Stephenson, pp. 143–158.

Kreiner, J., Kim, C.-H., & Nha, I.-S. (2001). *An Atlas of O-C Diagrams of Eclipsing Binary Stars, Parts 1, 2, 3, 4, 5, 6.* Krakow: Wydawnictwo Naukowe Akademii Pedagogicznej.

Lee, J.-B., & Nha, I.-S. (2004). The long-term project of astronomical archives in Korean history. In W. Orchiston et al., pp. 35–39.

Lee, E.-H. (1997). The Ch′iljŏngsan Naepiŏn, an adopted version of the Shoushi-li and Datong-li. In I.-S. Nha & F.R. Stephenson, pp. 339–348.

Lee, E.H., & Ahn, Y.S. (2011). Tenmon bunya nozu of Sibukawa Harumi and star maps of Joseon. In T. Nakamura et al., pp. 146–151.

Lee, E.-H., Chen, K.-Y., & Nha, I.-S. (1986). A study of unitary light curves of AR Lacertae. *Astronomical Journal, 91,* 1438–1442.

Lee, E.-H., Ahn, Y.-S., Yang, H.-J., & Chen, K-Y. (2004). The sunspot and auroral activity cycle derived from Korean historical records of the 11th-18th century. *Solar Physics, 224,* 373–386.

Lee, K.-W., Ahn, Y.-S., Mihn, B.-H., & Shin, J.-S. (2011a). Database construction and textual analysis of Korean astronomical almanacs. *Publications of the Korean Astronomical Society, 26,* 1–24.

Lee, K.-W., Ahn, Y.-S., Mihn, B.-H., & Kim, B.-G. (2011b). The Incheon Meteorological Observatory and its astronomical activities. In T. Nakamura et al., pp. 238–243.

Lee, J.W., Kim, S.L., Kim, C.H., Koch, R.H., Lee, C.U., and 2 other authors (2009). The sdB+M eclipsing system HW Virginis and its circumbinary planets. *Astronomical Journal, 137,* 3181–3190.

Lee, J.W., Kim, C.H., Kim, D.H., Kim, S.L., Lee, C.U., & Koch, R.H. (2010). The first comprehensive photometric study of the Algol-type system CL Aurigae. *Astronomical Journal, 139,* 2669–2678.

Lee, M.-S., Nam, K.-U., & Lee, Y.-S. (1999). Transmission of modern Western astronomy through the star maps of Choson Dynasty. In M. Hirai, pp. 59–62.

Lee, W.-C. (1932). Motions in the atmosphere of η Aquilae. *Publication of the Observatory of the University of Michigan*, *4*(8).

Lee, Y.-B. (1966). On the new star map preserved in the Bŏbju-sa Temple. *Yoksa Hakhoi, 31,* 1–66. (in Korean).

Lee, Y.-S., & Park, K.-K. (1997). Computer scanning techniques applied to the 1395 stone star map Ch′ŏnsang Yŏlcha Bunya Jido. In I.-S. Nha & F.R. Stephenson, pp. 265–274.

Marsden, B.G., & Williams, G.V. (1996). *Catalogue of Cometary Orbits 1996*. Cambridge (Mass.): Minor Planet Center.

Nakamura, T., Orchiston, W., Soma, M., & R. Strom, R. (Eds.), (2011). *Mapping the Oriental Sky*. Tokyo: National Astronomical Observatory of Japan.

Nam, M.-H. (2006). Restoration of Jagyok-nu. *Journal of Industrial Science and Technology (Kongkuk University), 31,* 63–65. (in Korean).

Nam, M.-H. (2011). Reconstruction of a striking clepsydra from the Joseon period of King Sejong. In T. Nakamura et al., pp. 116–125.

Nam, M.-H., & Jeon, S.-W. (1997). Timekeeping systems of early Joseon Dynasty. In I.-S. Nha & F.R. Stephenson, pp. 305–324.

Needham, J., Lu, G.-D., Combridge, J.H., & Major, J.S. (1986a). *The Hall of Heavenly Records, Korean Astronomical Instruments and Clocks 1380–1780*. Cambridge: Cambridge University Press.

Needham, J., Lu, G.-D., Combridge, J.H., & Major, J.S. (1986b). The Armillary Clock of Song IYong and Yi Minchol (1669). In *The Hall of Heavenly Records, Korean Astronomical Instruments and Clocks 1380–1780* (pp. 115–152). Cambridge: Cambridge University Press.

Needham, J., Lu, G.-D., Combridge, J.H., & Major, J.S. (1986c). A Korean Astronomical Screen of the Eighteenth Century. In *The Hall of Heavenly Records, Korean Astronomical Instruments and Clocks 1380–1780* (pp. 153–179). Cambridge: Cambridge University Press.

Nha, I.-S. (1975). CW Cephei, an important close binary member of III Cephei Association. *Astronomical Journal, 80,* 232–238.

Nha, I.-S. (1988a). Long period eclipsing binary star, an important bridge between the close and wide binaries. *Vistas in Astronomy, 31,* 185–192.

Nha, I.-S. (1988b). Calibration of the stellar magnitude scales prior to Pogson (revised version). *Historia Scientiarum, No. 35* (September), 39–44.

Nha, I.-S. (1992). Atmospheric eclipsing binary star Zeta Aurigae in 1987–1988 eclipse. In K. Kondo, & R.F. Sistero (Eds.). *Proceedings of IAU Symposium No. 151 on Evolutionary Processes in Interacting Binary Stars* (pp. 394–402). Dordrecht: Klumer.

Nha, I.-S. (1996). The stone-carved star map, *Chonsang Yolcha Bunya-Ji-Do*, and its 600th memorial reconstruction. *The Journal of Korean Studies*, 93, 41–132. (in Korean).

Nha I.-S. (1997a). Astronomy in Korea. In K.-C. Leung (Ed.), *The Third Pacific Rim Conference on Recent Developments in Binary Star Research* (pp. 313–316). San Francisco: Astronomical Society of the Pacific (ASP Conference Series, Volume 130).

Nha I.-S. (1997b). Refined revivals of Guo Shoujing's instruments and the invented instruments made for King Sejong's Royal Observatory. In I.-S. Nha & F.R. Stephenson, pp. 199–220.

Nha, I.-S. (1997c). Long term photometry with a small telescopes in the crowded large city Seoul. In K.-C. Leung (Ed.), *Proceedings of the Third Pacific Rim Colloquium on Binary Star Research* (pp. 243–249). San Francisco: Astronomical Society of the Pacific (ASP Conference Series, Vol. 130).

Nha I.-S. (2000). *The History of Astronomy in Korea*. Seoul: Seoul National University Press. (in Korean).

Nha, I.-S. (2002a). A new museum of astronomy in Korea. In S.M.R. Ansari, pp. 203–207.

Nha, I.-S. (2002b). Three star maps: results of the impact of Western astronomy on Korean tradition in the 18th century. In S.M.R. Ansari, pp. 45–57.

Nha I.-S. (2004a). *Importation of Western Science into Korea and the Joseon Christian College*. Seoul: Yonsei University Press. (in Korean).

Nha I.-S. (2004b). King Sejong's sundial, Angbu Il-gui. In W. Orchiston et al., pp. 21–26.

Nha I.-S. (2004c). Astronomy in Korea (a revised version). In W. Wamsteker, R. Albrecht, & H.J. Haubold (Eds.), *Developing Basic Space Science World-Wide, a Decade of UN/ESU Workshops* (pp. 95–97). Dordrecht: Kluwer.

Nha I.-S. (2006). Honchon Jon-do, a star map in the 18th century. In K.-Y. Chen, & X. Sun, pp. 53–66.

Nha, I.-S. (2016). *History of Cosmology in Korea*. Seoul: Yonsei University Press.

Nha, I.-S., & Jeong, J.-H. (1976). Light curves of Nova V1500 Cygni 1975. *The Research Publications of Yonsei University, 13,* 157–167.

Nha, I.-S., & Jeong, J.-H. (1979). Times of minimum of six eclipsing variables. *IAU Information Bulletin on Variable Stars, No. 1712,* 1–2.

Nha, I.-S., & Kang, Y.-W. (1982). Photoelectric photometry of RS CVn-type close binary AR Lacertae. *Publications of the Astronomical Society of the Pacific, 94,* 496–514.

Nha, I.-S., & Kim, H.-I. (1993). Problems arising for modeling of W Ser-type Binary RX Cas. In E.F. Milone (Ed.), *Improvements to Eclipsing Binary Light Curve Modeling* (pp. 167–173). Berlin, Springer-Verlag.

Nha I.-S., & Kim, Y. (2006). Jesuit astronomers' contribution to the 17th and 18th century Korean astronomy. In K.-Y. Chen, & X. Sun, pp. 121–129.

Nha I.-S., & Lee, J.-B. (2006). Progress Report on the long-term project of astronomical archives in Korean history. 2: Comets. In K.-Y. Chen et al., pp. 103–108.

Nha I.-S., & Nha, S.L. (2010a). Astronomy in China and Korea before Galileo. In C. Sigismondi (Ed.), *Orbe Novvs* (pp. 65–87). Roma: Univers Italia.

Nha I.-S., & Nha, S.L. (2010b). Two historical observatories before Galileo. In L. Pigatto, & V. Zanini (Eds.), *Astronomy and its Instruments Before and After Galileo* (pp. 111–126). Padova: Cooperativa Libraria Editrice Universita di Padova (CLEUP).

Nha, I.-S., & Nha, S.L. (2011). The 1395 planisphere, *Cheongsang Yeolcha Bunya-Ji-Do*, and two earlier star maps in Korea. In W. Orchiston et al., pp. 199–207.

Nha, I.-S., & Oh, J.Y. (1983). Light curves and Ca II emissions of V711 Tauri during 1981–82. In *Activity in Red Dwarf Stars. Proceedings of the Seventy-first Colloquium, Catania, Italy …* (pp. 409–410). Dordrecht: Reidel.

Nha, I.-S., & Stephenson, F.R. (Eds.), (1997). *Oriental Astronomy from Guo Shoujing to King Sejong*. Seoul: Yonsei University Press.

Nha, I.-S., Lee, Y.-S., & Kim, H.-I. (1991). Photometric monitoring of the long-period eclipsing binaries at Yonsei University Observatory. *Journal of Astronomical Society of Australia, 9*(1), 144–145.

Nha, I.-S., Oh, W.-T., Oh, Y.-H., & Nha, S. (2017). Scientists of the *Gwuansang-gam*. 1: Observers of Comet 1P/Halley in 1759. *Journal of Astronomical History and Heritage, 20,* 21–34.

Nha, I.-S., Park, H.-S., Kang, Y.-W., Wood, F.B., Williamon, R.M., & Leviton, D.B. (1985). *UBV* light curves of AR Lacertae during 1980–81 and 1981–82. *Journal of the Korean Space Science Society, 2*(2), 69–99.

Oh, G.-S. (2004). Creating ancient star maps using a computer. In W. Orchiston et al., pp. 165–176.

Oh, G. (2011). Replication of ancient star charts by computer. In T. Nakamura et al., pp. 152–163.

Orchiston, W., Nakamura, T., & Strom, R. (Eds.), (2011). *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference*. New York: Springer.

Orchiston, W., Stephenson, F.R., Débarbat, S., & Nha, I.-S. (Eds.), (2004). *Astronomical Instruments and Archives from the Asia-Pacific Region*. Seoul: IAU Commission 41.

Park, S.-R. (2000). History of astronomy in Korea. In H. Selin, & X. Sun (Eds.), *Astronomy Across Cultures: The History of Non-Western Astronomy* (pp. 409–421). Dordrecht: Kluwer.

Pavlovski, K., Ruzic, Z., Pavlovic, M., Jang-Hae Jeong, J.-H., & Nha, I.-S. (1993). Abrupt light changes and multi-periodicity in Be stars: EW Lacertae revisited. *Astrophysics and Space Science, 200,* 201–210.

Ribes, J.C., & Nesme-Ribes, E. (1993). The solar sunspot cycle in the Maunder Minimum AD1645 to AD1715. *Astronomy & Astrophysics, 276,* 549–563.

Rufus, C.W. (1913). The celestial planisphere of King Yi Tai-jo. *Transactions of the Korean of the Branch of the Royal Asiatic Society, 4,* 23–72.

Rufus, W.C. (1917). My dear Brother. *The Korea Mission Field, XIII*(8), 209.

Rufus, W.C. (1936). Astronomy in Korea. *Transactions of the Korea Branch of the Royal Asiatic Society, XXVI,* 1–69.

Sarma, M.B.K., Ausekar, B.D., Rao, B.V.N.S.P., Oh, J.Y., & Nha, I.-S. (1985). Light curves of the RS CVn system V711 Tauri during 1981–82. *Publications of the Astronomical Society of Japan, 37,* 107–122.

Sejong Sillok 世宗實錄 (1419–1450) (in Korean).

Sekiguchi, R. 關口理吉 (1917a). Ancient records of comets in Korea. *Josen Kodai Kansoku Kiroku Chosa Hokoku* 朝鮮古代觀測記錄調查報告, 177–194. (in Japanese)

Sekiguchi, R. 關口理吉 (1917b). Meteor showers in Korean records. *Josen Kodai Kansoku Kiroku Chosa Hokoku* 朝鮮古代觀測記錄調查報告, 196–200. (in Japanese)

Seong, J.-D. 成周悳 (1818). *Seo'un Gwan-ji* 書雲觀志. Seoul: Seo'un Gwan. (in Korean).

Seonjo Sillok (1604) 178: 24b (in Korean).

Seungjeongwon Ilgi (1623–1894) (in Korean).

Stephenson, F.R. (1994). Chinese and Korean star maps and catalogs. In J.B. Harley& D. Woodward (Eds.), *The History of Cartography. Volume 2. Book 2: Cartography in the Traditional East and Southeast Asian Societies* (pp. 511–578). Chicago: University of Chicago Press.

Stephenson, F.R. (1996). Modern uses of ancient astronomy. In C. Walker (Ed.), *Astronomy Before the Telescope* (pp. 329–341). London: British Museum Press.

Stephenson, F.R. (1997). *Historical Eclipses and Earth's Rotation*. Cambridge: Cambridge University Press.

Stephenson, F.R. (1999). Solar and lunar eclipse records in early Korean history. In M. Hirai, pp. 103–110.

Stephenson, F.R. (2002). Eclipse records in early Korean history: the *Koryo-sa*. In S.M.R. Ansari, pp. 237–243.

Stephenson, F.R. (2004). Korean observations of the supernova of A.D. 1604. In W. Orchiston et al., pp. 15–20.

Stephenson, F.R. (2011). The *Seungjeongwon Ilgi* as a major source of Korean astronomical records. In W. Orchiston et al., pp. 209–222.

Stephenson, F.R., & Green, D.A. (2002). *Historical Supernovae and their Remnants*. Oxford: Clarendon Press.

Tamura, S. 田村專之助 (1954). On the rotating-Earth theory of Yi Dynasty scholars. *Kagakushi Kenkyu, 30,* 23–24. (in Japanese).

Van Biesbroeck, G. (1939). Comet notes. *Popular Astronomy, 47,* 444–446.

Wada, Y. 和田雄治 (1910a). The rain gauges of Kings Sejong and Yeongjo. *Kankoku Kansosokusho Gakujutsu Hobun* 韓國觀測所學術報文*, 1,* 26–31. (in Japanese).

Wada, Y. 和田雄治 (1910b). Silla's Observatory. *Kankoku Kansosokusho Gakujutsu Hobun* 韓國觀測所學術報文*, 1,* 32–38. (in Japanese).

Wada, Y. 和田雄治 (1910c). Clepsydra. *Kankoku Kansosokusho Gakujutsu Hobun* 韓國觀測所學術報文*, 1,* 39–46. (in Japanese).

Wada, Y. 和田雄治 (1917a). Recent 140-year rainfall in Seoul. *Josen Kodai Kansoku Kiroku Chosa Hokoku* 朝鮮古代觀測記錄調查報告, 30–78. (in Japanese).

Wada, Y. 和田雄治 (1917b). Seongbyeon Chookhoo Danja 星變測候單子. *Josen Kodai Kansoku Kiroku Chosa Hokoku* 朝鮮古代觀測記錄調查報告, 173–176. (in Japanese).

Willis, D.M., & Davis, C.J. (2015). Evidence for recurrent auroral activity in the twelfth and seventeenth centuries. In W. Orchiston, D.A. Green, & R. Strom (Eds.). *New Insights From Recent Studies in Historical Astronomy: Following in the Footsteps of F. Richard Stephenson. A Meeting to Honor F. Richard Stephenson on His 70th Birthday* (pp. 61–90). Cham: Springer.

Willis, D.M., & Stephenson, F.R. (2001). Solar and auroral evidence for an intense recurrent geomagnetic storm during December in AD 1128. *Annales Geophysicae, 19,* 289–302.

Willis, D.M., Armstrong, G.M., Ault, C.E., & Stephenson, F.R. (2005). Identification of possible intense geomagnetic storms using combined sunspot and auroral observations from East Asia. *Annales Geophysicae, 23,* 945–971.

Yau, K.K.C., & Stephenson, F.R. (1988). A revised catalogue of Far Eastern observations of sunspots 165 BC to AD 1918. *Quarterly Journal of the Royal Astronomical Society, 29,* 175–197.

Yumi, S. 弓滋 (1939). On the two comets that recently were discovered: Rigollet and Kaminsky. *Kisho Kowa Kaiho* 氣象講話會報*, 13,* 159–163. (in Japanese).

Part III
China

Chapter 8
The Development of Astronomy and Emergence of Astrophysics in China

Xiaoyu Ning, Xiaochun Sun, Wayne Orchiston, and Tsuko Nakamura

8.1 The Legacy of Ancient Chinese Astronomy

Chinese Astronomy can be traced back to remote antiquity (Feng 2001). Recently, remains of a 4000 year old astronomical observatory (Fig. 8.1) were discovered at the Taosi archaeological site (see He 2004), where observations made when the Sun rose in different gaps between a series of pillars were used to monitor the calendar and identify the seasons.

Oracle bone inscriptions (Fig. 8.2) from Yin-Shang times (eleventh to seventeenth centuries BC) include a complete table of the Chinese sexagesimal system *gan zhi* (干支), calendrical dates and records of extraordinary celestial phenomena (e.g. see Xu et al. 2000: 13–24; Zhang 1999; cf. Li 2001).

For more than 2500 years from the Spring Autumn and the Warring States period (770–221 BC), through the succeeding dynasties China saw a more or less independent development of astronomy, in parallel, and in great contrast, to the astronomical tradition of the ancient Greeks.

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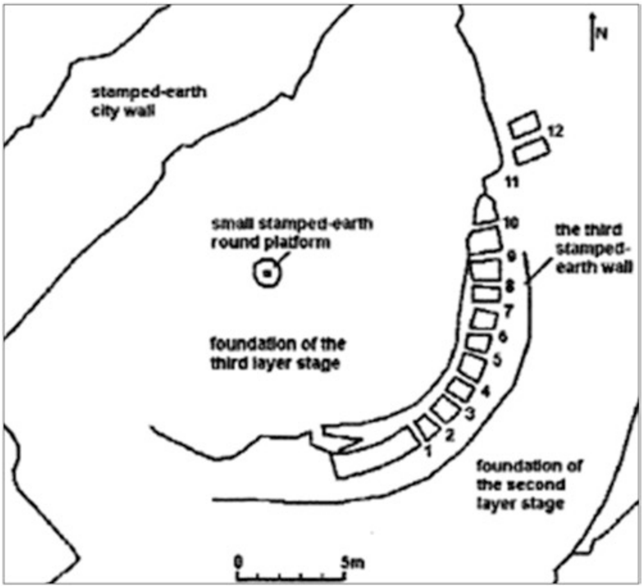

Fig. 8.1 A plan of the Taosi prehistoric observatory showing the centrally located observing site (*circle with a dot*) and positions of the 11 pillars (after Liu et al. 2005: 129)

Fig. 8.2 Examples of oracle bone with astronomical inscriptions from Yin-Shang times (after Institute of Archaeology … 1980: 19)

8.1.1 Characteristics of Traditional Chinese Astronomy

As Sun (2000: 423) has pointed out, Chinese and Western astronomy were similar in many ways:

> Both had the same sky as the common object of study, both made observations and measurement of the heavens and formed certain models or theories to understand or explain celestial phenomena, and both used sophisticated mathematical techniques for prediction and retrodiction.

But over a period of several millennia, ancient Chinese astronomy also acquired its own characteristics. Firstly, there was great emphasis on calendar-making (e.g. see Sun 2000: 428–437; Yabuuti 1990), which

> … not only served agricultural production, but also formed a part of the superstructure. To promulgate the calendar was a symbol of dominion and only the court should have it in hand. To use the calendar promulgated by an emperor meant recognition of his political power (Xi 1987: 36).

The purpose of Chinese calendar-making was to construct an astronomical system for calculating ephemerides. As in Greek astronomy, the calculation of planetary motions was at its core, but unlike the Greeks, the Chinese adopted a very different approach to the problem. While the Greeks used geometrical models the Chinese used arithmetical methods to solve the problem. To approximate planetary motions, the Chinese developed interpolations of first, second and even third orders (Chen 1995).

Secondly, the Chinese had the most complete and systematic, and the longest, continuous records of celestial phenomena in the world (Xu et al. 2000). These records have played important roles in modern astronomical studies, a field now referred to as ‘Applied Historical Astronomy’ (see Steele 2004). For example, Chinese records of novae (Ho 1962; Hsi 1958) and supernovae (Stephenson and Green 2002) have attracted great international attention; records of solar (Liu et al. 2003; Pang et al. 2002) and lunar eclipses (ibid.; Stephenson 1997a) and planetary events (Huang 1990; Huang 1999; Stephenson and Baylis 2012) over a long time-span have been used to study the secular change in the speed of the rotation of the Earth (Stephenson 1997b; Stephenson et al. 2016); records of sunspots (Clark and Stephenson 1978; Eddy et al. 1989; Yau and Stephenson 1988) and the *aurora borealis* (Dai and Chen 1980; Teboul 1987) have been used to detect periods of solar activity; records of Comet 1P/Halley (Stephenson and Yau 1985; Yeomans and Kiang 1981) and other periodic comets (Hasegawa 1980; Ho 1962; Jansen 1991) have been used to calculate changes in the parameters of their orbits; while records of meteor showers (Imoto and Hasegawa 1958; Zhuang 1966) and sporadic meteors (Hasegawa 1992) can be used to track connections with specific comets, and the evolution of the Solar System. These studies, and others, have demonstrated the high accuracy and reliability of ancient Chinese records of astronomical phenomena (Stephenson 1997a; Strom 2015; Zhuang 2009), but Eddy (1987: 253) sounds a note of caution: Applied Historical Astronomy,

> Like archaeoastronomy … is also a dangerous field, for the temptation is always there, born of hunger or desperation, or national pride, to read more into dusty records than they were ever meant to tell, or to lose sight of the context in which they were made.

Looking beyond 'conventional records', as early as the Warring States period, the Chinese also were adept at recording astronomical data in catalogues (Maeyama 1977; Maspero 1929; Sun et al. 1997), and later on star charts (Stephenson 1994; Sun and Kistemaker 1997, 2006). Among the latter,

> The Dunhuang Star Atlas is one of the most spectacular documents in the history of astronomy. It is a complete representation of the Chinese sky, including numerous stars and asterisms, depicted in a succession of maps covering the whole sky … Apart from its aesthetic appeal, this document found on the Silk Road is remarkable, as *it is the oldest star atlas known today from any civilization* (Bonnet-Bidaud et al. 2009: 39; our italics).

This unique atlas has been dated to between AD 649 and 684 (i.e. early Tang Dynasty). Two of the 13th individual maps in the Atlas are shown in Fig. 8.3. Finally, because of their abundance, various types of astronomical data (e.g. see Liu 2002a; Liu et al. 2003) were widely used to establish a reliable chronology for Chinese history through the Xia-Shang-Zhou Chronology Project (Li 2006; Liu 2002b; The Expert Group … 2000).

Thirdly, the Chinese were very accomplished astronomical instrument-makers (e.g. see Bo 1997: 17–22; Chen 1999). The gnomon is perhaps the oldest astronomical instrument of ancient China (Deng and Li 2006; Li and Sun 2010). The Chinese might have used the gnomon by 2000 B.C., and continued to use it up to the end of the nineteenth century AD (Chen 2002; Situ and Yi 1997). The accuracy of the measurement of the gnomon shadow was critical for calendar-making (Lee and Chen 2006), and in order to increase it Guo Shoujing 郭守敬 (1231–1316) constructed a large gnomon with a height of 40 *chi* 尺, about 12 m, which is five times the height of the traditional gnomon (The Research and Editorial Group … 1981: 179). This is shown in Fig. 8.4.

The gnomon shadow measurements also played a role in the construction of Chinese cosmology. One of the theories of Chinese cosmology was called '*gai tian*' 盖天 (the hovering sky), which saw the sky as parallel to the Earth. Gnomon shadow measurements were used to construct the size of the sky and the Earth and the distance between the two. These calculations are included in *Zhoubi Suanjing* 周髀算経, one of the oldest Chinese textbooks on mathematics, written to explain this cosmology (Needham and Wang 1959).

Around 100 BC a new cosmological theory called '*hun tian*' 浑天 (the celestial globe) was developed and with it a new type of instrument was invented. It was called *hun yi* 浑仪 (the armillary sphere). For more than a 1000 years from the Han Dynasty to the Song and Yuan Dynasties, the Chinese armillary sphere went through a process of elaboration and sophistication: more rings were added to the instrument to represent the ecliptic and the lunar path. Cosmologically it was certainly sound to have these rings, but the drawback was that too many concentric rings blocked off large areas of the sky. Guo Shoujing focused on this issue (Bo 1997). He moved the equatorial rings to the lower end of the polar axis, and he transferred the meridian

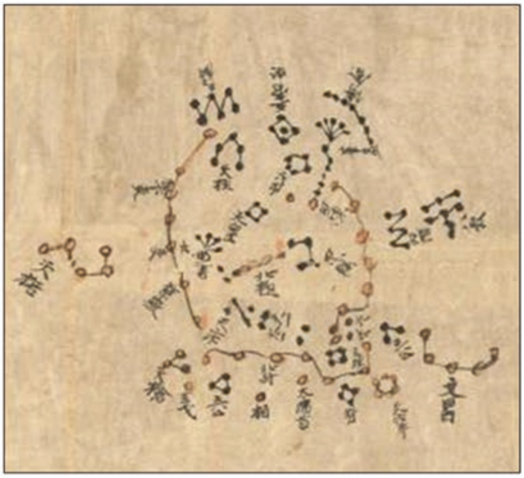

Fig. 8.3 Two of the 13th individual star maps that make up the Dunhuang Star Atlas. *Top*: Orion (Star Map 5), showing the Western constellation; on the *left* are additional calendar texts, while culmination texts are towards the *bottom* of the map. *Bottom*: The North Circumpolar region (Star Map 13) (after Bonnet-Bidaud et al. 2009: 43 and 46 respectively)

Fig. 8.4 The 12-m high stone gnomon that Gou Shoujing constructed at Dengfeng Observatory (Wikimedia Commons)

and the horizon to a separated structure. In this way he constructed '*Jian yi*' 简仪 (the Simplified Instrument; Fig. 8.5), similar to the equatorial mounting of a modern telescope, but as Stephenson (1997c: 9) reminds us, "The equatorial did not make its appearance in Europe until 1585 when it was designed independently by Tycho Brahe." Guo constructed his 'equatorial' more than 300 years earlier, between 1276 and 1279, and it could measure to the nearest 0.1 *du*, whereas other armillary spheres at this time could only be read to the nearest 0.25 *du* (Bo 1997).

The Chinese also made a great effort in the construction of seismological (see Huang et al. 2005) and automatic astronomical instruments. During the Song Dynasty, in the eleventh century, Su Song 苏颂 (1020–1101) and his team constructed a large astronomical clock tower which combined an armillary sphere, a

Fig. 8.5 An example of *Jian yi* (after Chen 2003: Plate 4)

celestial globe and time-keeping mechanisms. All were driven by a central wheel which was powered by water from a clepsydra. It contained a mechanical controlling system which amounts to the escapement mechanism in a modern clock (Needham et al. 1960). In a broader context, clepsydra (water clocks) were an important element of Chinese astronomical instrumentation (see Hua 1997; Quan 1987).

In addition to these more monumental astronomical instruments, Chinese scientific instrument-makers were adept at manufacturing sundials and compasses (e.g. Nha et al. 2006). This specialized craft has continued through to the present day (see Fig. 8.6).

Compared with the Greeks, the Chinese did not develop a cosmological theory as geometrical and sophisticated as the Ptolemaic system. But the Chinese *hun tian* and *gai tian* theories could explain many daily and annual motions of the sky (Chen 2003; Ning 2010). The Chinese also had such notions as ‘left-spinning’ and ‘right-spinning’ to explain complicated planetary motions (ibid.).

In its long history, Chinese astronomy had another important feature: it was largely political and bureaucratic (Eberhard 1957). It was said that in remote antiquity the legendary Emperor of Yao commissioned astronomical officers to observe the sky in order to make the calendar. Starting from the Zhou Dynasty (1046–221 BC), all successive dynasties had astronomical observatories managed by the Imperial governments (e.g. see Chen 1995; Guan 2006; Li 1997; Xu 1997). Astronomers at the Imperial observatories had strict divisions of labor relating to: the observation of the sky, the calculation of astronomical ephemerides, the making of the civil calendar books, and other astrological responsibilities. For all abnormal

Fig. 8.6 A compass made in Xin'an Xiuyu, Anhui Province, in 2014 (Orchiston Collection)

astronomical phenomena, the Imperial astronomers were responsible for providing the imperial ruler with astrological interpretations (Pankenier 1995).

Thus,

> Ancient Chinese astronomy was not an isolated and objective discipline, but was conceived and elaborated in combination with the cultural complexity of ancient China. It is misleading to analyse Chinese astronomy out of its social and cosmological context …
>
> The main purpose of Chinese astronomy was to study the correlation between man and the universe. The universe was conceived not as an object independent of man, but as a counterpart and mirror of human society (Sun 2000: 425).

8.1.2 Introduction of Western Astronomy to China

Towards the turn of seventeenth century, European Jesuit missionary-astronomers introduced Western astronomy to China, and from that time Chinese astronomy embarked on a course to merge with Western astronomy (e.g. see Dehergne 1973; Fung 2004; Hashimoto and Jami 1997; Pigatto 2004; Udias 1994). It was a process of contact, confrontation, controversy, and finally convergence (see Hashimoto 1988; Hashimoto and Jami 1997; Sivin 1995; Zhang 1924; Wang 1966). In the seventeenth century, Xue Fengzuo 薛凤祚 (1600–1680), Wang Xishan 王锡阐 (1628–1682), and Mei Wending 梅文鼎 (1633–1721) made important progress in reconciling Chinese and Western astronomies (e.g. Bo 2003; Hu 1992; Liu 1986; Sivin 1995; Ning 2007, 2013; Shi 2000; Yan 1989). Although the Qing Imperial Government employed Western missionary-astronomers such as Johann Adam Schall von Bell (1591–1666; Fig. 8.7), Ferdinand Verbiest (1623–1688), Ignatius Kögler (1680–1746) and Augustin Haller von Hallerstein (1703–1774) as Directors of the Imperial Astronomical Observatory astronomical work more or less continued to be carried out in the traditional Chinese manner, which placed great emphasis on calendar-making (Elman 2005). Then

> In 1773, the great era of astronomical observations by Jesuits in China came to an end, as did their role in reforming the Chinese calendar, for in that year Pope Clemente XIV used political reasons to suppress the Order of Jesuits (Pigatto 2004: 65).

It was not until towards the end of the Qing Dynasty that staff at the state-owned observatory began doing astronomy in a modern sense. Then in May 1912, following the overthrow of the Qing Empire, Gao Lu 高鲁 (1877–1947; Fig. 8.8), represented the Republic Government and abolished the Qing Imperial Observatory. Gao Lu had earned his doctoral degree from the University of Brussels in Belgium and, following Europe practice, he went and established a Central Astronomical Observatory (Chen 1985; Ning and Sun 2014). All of the old Imperial astronomers were dismissed and astronomers with recent scientific training were recruited. In 1912 the Gregorian Calendar also was adopted to replace the traditional Chinese luni-solar calendar (Chen 1985). Traditional Chinese astronomy gave way to modern astronomy, and astrophysics would become its most essential component.

8.2 The Beginnings of Astrophysics in China

8.2.1 Astrophysical Knowledge Transmitted by Westerners

Astrophysics studies the physical properties of celestial bodies. Traditional Chinese astronomy was positional. Some new astrophysical knowledge began to be transmitted into China during the mid-nineteenth century, also by Western missionaries. In 1853, Zhang Fuxi 张福僖 (d. 1862) and the American missionary Dr. Joseph Edkins (1823–1905; Fig. 8.9) translated a book titled *On Light,* in which it was mentioned that the spectrum of the Sun contained dark and bright lines:

> In the spectrum of sunlight, there are numerous dark lines, while in light from burning gas, oil, alcohol, etc. there are bright lines and no dark lines. From this we know light is something which is real, not illusionary (Zhang 1985: 1).

Fig. 8.7 A hand-coloured engraving of Adam Schall von Bell, one of the best-known Chinese Jesuit missionary-astronomers (https://en.wikipedia.org)

This was perhaps the first transmission of astrophysical knowledge within China.

Edkins also translated into Chinese several other books on astronomy. In *Elementary Astronomy* (*Tian wen qi meng* 天文启蒙) he explained the study of the physical nature of nebulae by means of spectroscopy (see Ye and Tian 2016); in *Introduction to General Science* (*Ge zhi zhong xue qi meng* 格致总学启蒙) he recounted the relationship between solar activity and agricultural production, and between the interruption of radio communication and sunspots; and in *An Outline of Western Learning* (*Xi xue lue shu* 西学略述) he discussed the absorption lines in solar and stellar spectra and the chemical composition of the stars.

Fig. 8.8 Gao Lu (http://www.baike.com/wiki/高鲁)

Fig. 8.9 The Reverend Dr. Joseph Edkins (after Thompson 1906)

Some Chinese elite when travelling abroad also acquired astrophysical knowledge. In his *Diary in England* Guo Songtao 郭嵩焘 (1818–1891) mentioned experiments on spectra, and told stories about how spectroscopy was used to determine the components of minerals and to identify the chemical elements in the Sun and the stars.

But these early transmissions of astrophysical knowledge were sporadic and fragmentary and appeared in various unspecialized books, so their influence was very limited.

8.2.2 Chinese Efforts to Construct Modern Astronomical Observatories

The decisive transformation of astronomy into astrophysics in China was made by scientists who had been educated in Europe and America in the 1920s and 1930s. Although Gao Lu did not major in astronomy when he studied in Europe, he had a deep interest in astronomy. During his stay in Europe, he visited Paris Observatory, and was aware of the trends that were then current in astronomy. He said: "In matters of learning, new science will have no foundation if studies are not made in astrophysics, mechanics and optics." That is why he insisted that the emphasis should be put on astrophysics when he established the Central Astronomical Observatory. He said, "The Observatory should lay its foundation on astrophysics. Therefore we should purchase advanced instruments, and recruit astronomers for observations." (Gao 1921: 13–14; our English translation).

In the West Hills of Beijing, he planned to build domes for equatorial and meridian telescopes, and he proposed the establishment of a research group on 'physical observations' that would study solar physics. He also ordered an equatorial telescope from the Carl Zeiss company in Germany. Although Gao Lu did not achieve his goal of establishing an astrophysical observatory in Beijing, his advocacy and planning helped to launch astrophysics in China.

In 1928 the National Astronomical Institute of Academia Sinica was founded in Nanjing, and Gao Lu was appointed its first Director. Not surprisingly, he made his first priority the construction of an astrophysical observatory. Soon after he was dispatched abroad on a diplomatic mission, but before his departure he recommended the well-known astrophysicist Yu Qingsong take over the Directorship.

Yu Qingsong 余青松 (1897–1978; Fig. 8.10) had already made internationally recognized contributions to stellar spectroscopy when he clearly explained the nature of the Balmer lines, which was critical for an understanding of stellar physics. He made an important discovery when he noted that stellar radiation was similar to black body radiation. He also established the relationship between a star's spectral type and its temperature, which confirmed that the Harvard classification of stellar spectra was based on temperature. Also, by measuring the value of the absorption in the Balmer jump or Hr lines and the effective temperature he developed a method for determining the absolute magnitude of A-type stars and therefore their parallaxes. In 1926 the International Astronomical Union officially named his method of classifying stellar spectra the 'Yu Qingsong Method' (Ding 1999). Furthermore, Yu studied the spectrum of the Cepheid variable ζ Gem. By measuring the intensity curve of its continuous spectrum as the luminosity of the star changed he determined the corresponding effective temperatures, thus quantitatively documenting the variation in the spectrum of Cepheid variables (ibid.; Ding and Li 1997).

In 1929 Yu Qingsong was appointed Director of the National Astronomical Institute, and he then took charge of the construction of Purple Mountain Observatory, personally designing the buildings according to the needs of modern astronomy and astrophysics:

Fig. 8.10 Yu Qingsong (www.et97.com/subview/162581/19037326.htm)

> He personally decided on all of the instruments to be purchased. In order to carry out research in four major fields (stellar physics, solar physics, variable stars and positional astronomy) he planned to build four domes, respectively for a large equatorial, a small equatorial, a telescope for variable star research and a meridian instrument, each equipped with the most advanced instrumentation available at that time. More specifically, the dome for the large equatorial was equipped with a 60 cm reflector, together with a double quartz prism spectrograph. They were used to do spectroscopy of stars up to the ultra-violet band. The dome for the small equatorial had two floors. On the upper floor were mounted a 20 cm refractor, and a 15 cm astrograph, and as their accessories a solar eyepiece projection mechanism, a filter for observing solar prominences and an objective prism. On the lower floor there was the Haier solar spectrometer, which was prepared for the International Collaborative Project for the spectrometry of the sun. Other accessory instruments were purchased for measuring the wavelength of the stellar spectrum, for spectrophotometry, and for measuring the brightness of variable stars, etc. (Ding 1999: 316–317; our English translation).

In September 1934 the construction of Purple Mountain Observatory was completed (Fig. 8.11). In 1933 as the Japanese invasion was imminent, the Chinese Government ordered that antique instruments be moved from Beijing to Nanjing. The ancient astronomical instruments in Beijing were brought to Nanjing, and the Armillary Sphere and Simplified Instrument from the Ming Dynasty were exhibited at Purple Mountain Observatory (Fig. 8.12). The Observatory thus boasted both ancient and modern astronomical instruments, and "Its buildings and equipment are not only the most complete in China, but also the most advanced in East Asia." (Yu 1935: 1; our English translation). When the Battle of Shanghai broke out in 1937, the Astronomical Institute decided to evacuate the Observatory, and the smaller and

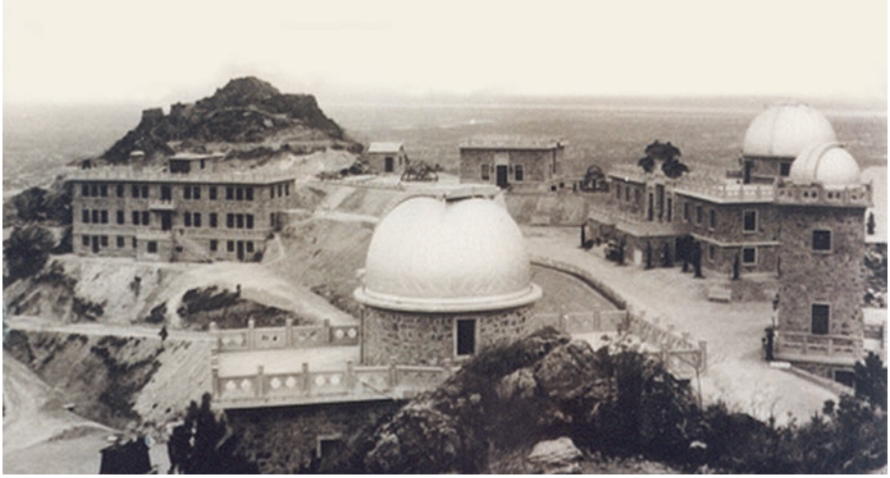

Fig. 8.11 The newly completed Purple Mountain Observatory (English.pmo.cas.cn)

Fig. 8.12 The armillary sphere on display at Purple Mountain Observatory (www.study-in-china/ChinaEducation/TopUniversity/20122/71140337928.htm)

lighter instruments (including the lenses of the telescopes, the solar spectrometer, the variable star spectrophotometer, etc.) were taken to Kunming in Yunnan Province. In 1939 Phoenix Mountain Observatory was established in Kunming, and the year following the end of the War the Astronomical Institute returned to Nanjing.

In the 1950s, Phoenix Mountain Observatory would become an observing station of Purple Mountain Observatory, but in the 1970s it was expanded into an important research base for astrophysics in China and renamed Yunnan Observatory of the Chinese Academy of Science.

8.2.3 Solar Eclipse Expeditions and Variable Star Observations

Following the end of WWII China was still plagued by civil war, and it was very hard to carry out any substantial astronomical research in these difficult times. Nevertheless, staff at the Astronomical Institute did some observations and research in astrophysics. They organized three solar eclipse expeditions (Du et al. 2008; Jiang and Chen 2008). For the total eclipse of 19 June 1936 the Institute sent two observing teams: Yu Qingsong, Chen Zunkuei 陈遵妫, Zou Yixin 邹仪新 and others went to Hokkaido (Japan), while Zhang Yuzhe 张钰哲 and Li Heng 李珩 went to Khabarovsk in the Soviet Union. The second was for the total eclipse of 21 September 1941, and a team comprising Zhang Yuzhe, Li Heng, Chen Zunkuei, Li Guoding 李国鼎 and Gong Shumo 龚树模 travelled to Lintao in Gansu Province. The third expedition was for the annular eclipse of 9 May 1948, and this time the Astronomical Institute sent teams to Yuyao in Zhejinag Province. They carried out two programmes that were part of the International Collaborative Observation Project, one of which was spectroscopic observation of the Sun. This was one of the most important initiatives that the Astronomical Institute undertook in solar physics (ibid.).

Solar eclipse expeditions constituted one of the earliest, most systematic and frequently implemented projects undertaken by the Institute. The other was the photography of Cepheid variables. The developed negatives and results of the magnitude measurements were sent to Harvard Observatory in the United States (Ding and Li 1997). In addition, from 1946 to 1949 astronomers at Phoenix Mountain Observatory carried out visual observations of sunspots, and used the Haier Solar Telescope to observe solar prominences. They also made some observations of the Moon, planets, comets, meteors, novae, etc. (Ding and Li 1997; Du et al. 2008).

Meanwhile, Zhang Yun 张云 (1897–1958, Fig. 8.13) graduated from Lyon University in France with a Ph.D. in astronomy, and in 1926 he established the Department of Mathematics and Astronomy at Zhongshan University. Formerly, Zhang's major research was on intrinsic variables; the photometry of eclipsing variables; and the statistics of Cepheid variables and pulsation theory. In 1929 the Department built its own observatory, which was equipped with a 15-cm equatorial, an 11-cm astrograph, and 20-cm and 15-cm French-made telescopes. Zhang used these instruments to make systematic observations of short-period variables, and he published papers on astronomical photography (Liu and Lu 2015).

Fig. 8.13 Zhang Yun (after Liu and Lu 2015)

8.2.4 Astronomical Observatories Operated by Europeans in China

From the second half of the nineteenth century, three observatories administrated by foreign nations were built in China. They were Xujiahui 徐家匯 Observatory, Sheshan 佘山 Observatory and Qingdao 青島 Observatory.

Xujiahui Observatory (Fig. 8.14) was built in 1872, and was administrated by French Jesuit missionaries until 1950 (Udias 2003). It served as a branch of the French Academy of Science, focusing on regional observations and research. Its major work was meteorology and to provide a time service. Staff carried out time measurements with three transit instruments, using two astronomical pendulum and three mean solar clocks for timekeeping, and some radio equipment for the broadcast and reception of time signals. Since Xujiahui Observatory pioneered the use of new technology to provide a radio time service from 1914, it is regarded as the birthplace of the modern time service in China (Lo 1955; Zhu 1986).

In 1900 Xujiahui Observatory established an astronomical section—Sheshan Observatory (Fig. 8.15)—mainly for observational research in astronomy, terrestrial magnetism and atmospheric physics. It was equipped with a 40-cm refractor and a 10-cm refractor on a single equatorial mounting (Fig. 8.16), together with accessories, such as plate-holders for solar and cometary photography, a solar polarimeter, a filar micrometer and a spectroscope. From 1904 Sheshan Observatory was involved in some important research. The 40-cm telescope was used to observe sunspots and solar granulation (Zhu 1986), and Observatory staff re-measured 1122

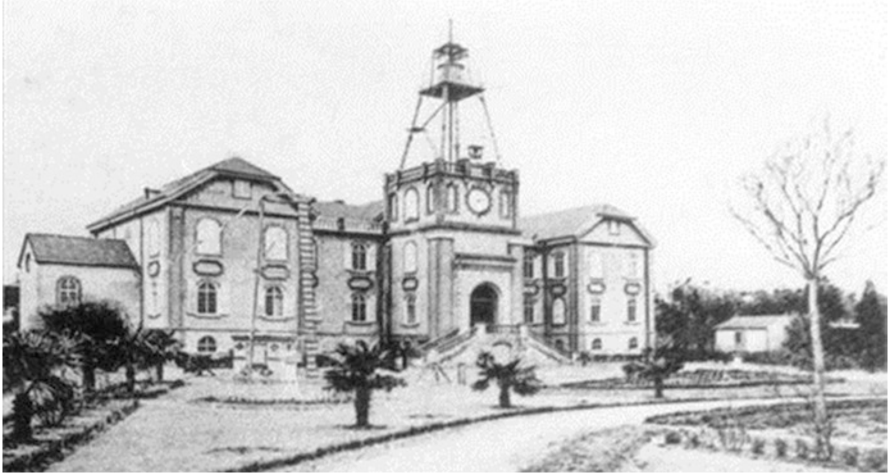

Fig. 8.14 Xujiahui Observatory in Shanghai (after Wang 2014)

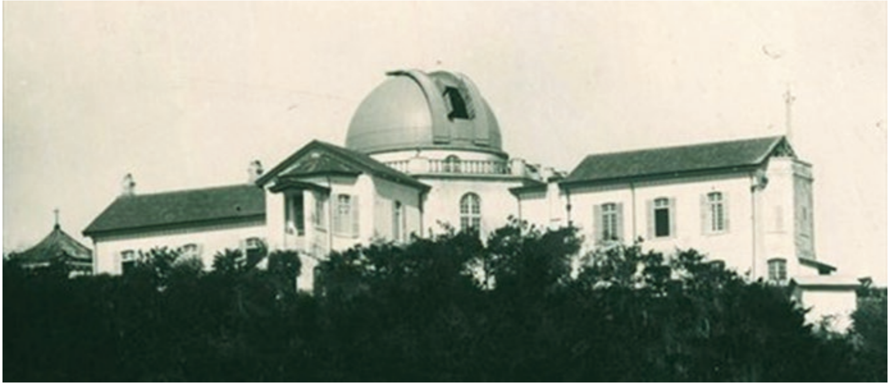

Fig. 8.15 Sheshan Observatory in Shanghai (after Wang 2014)

Herschel double stars and took more than 3000 negatives of regular stars, variable stars, novae and comets. In 1910 observations were made of Comet 1P/Halley, and in 1918 the spectrum of Novae Aquila was investigated. In addition, photographs were taken of many galactic clusters, including NGC1750, NGC1817, NGC2682 and NGC2437, and as we shall see, some of these observations later would prove particularly useful (Li 1954; Zhu 1986).

One of the astronomers at Sheshan Observatory was the Japanese-born Jesuit, Father Yachita Tsuchihashi 土橋八千太 (1866–1965; Fig. 8.17) who attended the Jesuit mission school in Xujiahui where he studied philosophy, mathematics, astronomy and ethics for 6 years. For part of this time he also worked at Xujiahui

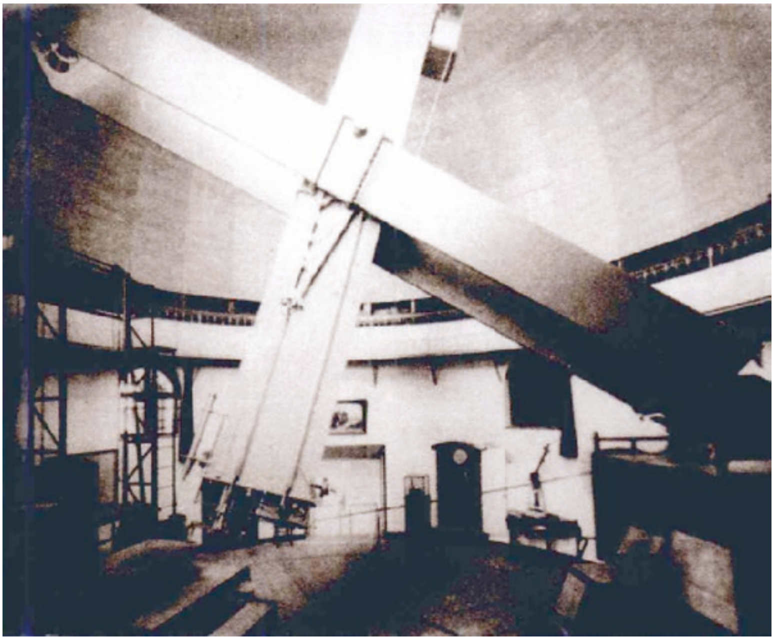

Fig. 8.16 The double refractor at Sheshan Observatory (after Tsuchihashi 1909). The 40-cm refractor (f = 6.9m) was used for photography and the 10-cm refractor (f = 7m) for visual guiding. The objectives were produced by the Henry Brothers at Paris Observatory

Fig. 8.17 Father Yachita Tsuchihashi (*Courtesy* Sofia University)

Observatory. In 1896 Tsuchihashi went to France, and completed a Ph.D. in celestial mechanics. In 1904 he returned to Shanghai and was appointed Deputy-Director of Sheshan Observatory (Kanda 1967). From an historical astronomy point of view, undoubtedly the most important research that he conducted at Sheshan Observatory, in collaboration with the Director the Reverend Father Stanislaus Chevalier (1852–1930), was the identification of traditional Chinese star names and their European counterparts (see Tsuchihashi and Chevalier 1911). In 1911 Tsuchihashi returned to Japan as the President of the Sofia Christian University, where he died in 1965 at the age of 98 (Kanda 1967).

Qingdao Observatory was built in 1989 by the German Navy, but from 1914 to 1924 was occupied by the Japanese. From 1924 to 1938 it was under the control of the Chinese Republic Government. During the Sino-Japanese War it was occupied by the Japanese again, then after the War it was once more returned to China. Most of the instruments at the Observatory were provided by the Chinese Government after its first take over, and these included a 32-cm refractor (once the largest telescope in China), a 16-cm refractor, and several other instruments relating to time measuring and time keeping. The 32-cm refractor was used for stellar spectroscopy, and to observe binaries and variable stars. Thus, in 1933 Li Heng observed the Cepheid variable RT Auriga and obtained its light curve. During the annular eclipse of 9 May 1948 Observatory staff displayed the solar image, photographed the eclipse and measured the solar spectrum (Chen 1985; Zhu 1985).

8.2.5 Early Scientific Outcomes by Chinese Astronomers

During the Republic era (1912–1949) some scientists did astrophysical research in other institutions. For example, in 1935, Zhou Peiyuan 周培源 (1902–1993) published a paper on "A relativistic theory of expanding universe" in *Acta Physica Sinica Physics* (Zhou 1935). This was the first paper on modern cosmology written by a Chinese scientist. Another example is Huang Kun黄昆 (1919–2005). From 1942 to 1944 while he was a candidate for a Masters degree at the United Southwest China University he carried out research on the spectra of solar prominences under the supervision of Wu Dayou 吴大猷 (1907–2000) and published two papers, "On the excitation of the coronal lines" and "The continuous absorption of light by negative sodium ions", in the *Astrophysical Journal* (Huang 1945a, b).

In summary, China made a good start in astrophysics during the Republic era. Yu Qingsong opened the first page of Chinese astrophysics by building Purple Mountain Observatory and equipping it with the most advanced telescopes and auxiliary instrumentation available at that time. But the number of astronomers involved in astrophysics was very small, and they worked independently and with limited support from the Government. Because of the Sino-Japanese War and the civil war that followed, China could not make full use of the advanced instruments that were available, therefore the opportunity to develop astrophysical research was lost. While there were some sporadic studies, these hardly constituted a comprehensive discipline.

8.3 Progress in Astrophysics Under State Planning and Management

8.3.1 Reorganization of Observatories Under the People's Republic of China

The People's Republic of China was founded in 1949, and the Chinese Academy of Science (CAS) was established the same year. In 1950, the former National Astronomical Institute was renamed the Purple Mountain Observatory of the Chinese Academy of Science, and Zhang Yuzhe (1902–1986; Fig. 8.18) was appointed its Director. Xujiahui Observatory, Sheshan Observatory, Qingtao Observatory and Phoenix Mountain Observatory were all affiliated with Purple Mountain Observatory, becoming observing stations. This infrastructure did not change until 1962 when Shanghai Observatory was founded. In 1952, by integrating existing astronomical faculties at Zhongshan University and Qilu University, the Department of Mathematics and Astronomy was established at Nanjing University, and this new institution then became the foremost centre for astronomical education and research in China.

The development of astrophysics in the People's Republic of China was greatly influenced by this sort of state planning and management. In 1956 China issued *The*

Fig. 8.18 Zhang Yuzhe (after National Astronomical Observatories of China 2010)

Strategic Plan for Scientific Development from 1956 to 1967 (often referred to as *The Strategic Twelve Year Plan*) (see Ministry of Science and Technology … 2005; Hu 2007). The general guideline for developing science in China was to emphasize practical and national needs, and the country's scientific programs should be guided by this philosophy. Meanwhile, within this overall *Strategic Plan* was "The Strategic Twelve Year Plan for Astronomy", which identified the main tasks for developing astronomy at an early stage:

> Because China does not have a good basis for modern astronomy, we should not try to do everything in just 12 years. Our emphasis should be on studies about the time service, changes in the geographical latitude, positional astronomy, celestial mechanics, astronomical ephemerides, solar physics, nebulae physics and radio astronomy (*The Strategic Plan* … 1956; c.f. Ning and Sun 2014: 18; our English translation).

The *Plan for Astronomy* also urged the construction of a comprehensive astrophysical observatory in Beijing, the capital of new China. These plans would have great impact on the development of astronomy (and especially astrophysics) in China, and astronomers tried very hard to achieve these goals with the astronomical facilities that were available at that time.

The adjustment and reorganization of astronomical human resources by the State in the 1950s helped greatly with the development of astrophysics in China. Purple Mountain Observatory established three astrophysical research groups, on solar astronomy, stellar evolution and radio astronomy, respectively. These groups forecast solar activity, and carried out research on the physics of active solar regions, and on stellar spectroscopy and the internal structure and evolution of stars. At this time Xujiahui Observatory and Sheshan Observatory were affiliated with Purple Mountain Observatory. Xujiahui Observatory had been responsible for the national time service in China since the 1950s, and Sheshan Observatory carried out some research on solar physics until 1962, when the two observatories were merged into the newly created Shanghai Observatory. At the Qingtao and Phoenix Mountain observing stations, astronomers observed sunspots. Clearly, astrophysics in this early period of the People's Republic of China was mainly focused on solar physics and stellar astrophysics (The Editorial Committee of Purple Mountain Observatory 1985).

8.3.2 Astronomical Achievements Made in Solar Physics and Stellar Astrophysics

In the field of stellar astrophysics, Purple Mountain Observatory (Fig. 8.19) started photographic photometry in 1953. In 1955 staff made the first successful photoelectric photometer, and this was installed on the 60-cm telescope and could detect stars down to the 10th magnitude. This was a major breakthrough for Chinese astronomy. In June 1956 astronomers at Purple Mountain Observatory started doing stellar spectroscopy, and 2 years later a paper titled "Spectrometric study made with the 60 cm reflector" was published (Astrophysical section … 1958). By 1959 staff at the Observatory had obtained 100 stellar spectrograms. At Sheshan Observatory Li

Fig. 8.19 Purple Mountain Observatory, Nanjing (Wikipedia commons)

Heng and his group compared negatives taken before the 1950s and recently obtained negatives to study the proper motions of stars in five different galactic clusters, and in 1954 Li published a paper titled “Photographic studies of five galactic clusters, NGC 1750, 1817, 2286, 2548, 7380.” (Li 1954). This marked the beginning of star cluster research in China (Ding and Li 1997; Zhu 1986). Other research was carried out on the internal structure and evolution of stars, the rotation of our Galaxy, and the distribution and motion of stars in our Galaxy, and several papers were published on these topics (see Gong et al. 1959).

In the field of solar physics, the visual observation of sunspots started first, then in 1954 Purple Mountain Observatory astronomers combined their own observations with those made at Sheshan and Phoenix Mountain Observatories to establish a sunspot observation and publication network. At the same time, staff in the Department of Mathematics and Astronomy at Nanjing University carried out some photoelectric measurements of sunspots. Meanwhile, astronomers at Sheshan Observatory took the lead in monochromatic observation of the solar chromosphere, and in 1956 they carried out spectroscopy of prominences, plages and flares in the solar chromosphere. From 1956 on, they photographed the solar spectrum, concentrating mainly on the calcium H and K lines. In 1957, video cameras were added to the spectroscope, making it possible to observe flare puffs and plages. In 1958 a flare indicator was installed, which was used to predict the appearance of solar flares. In addition, Sheshan Observatory astronomers completed a 10-year study of solar thermal radiation (Zhu 1986: 212).

In 1957 Purple Mountain Observatory technical staff successfully manufactured an apparatus that could video and photograph the solar spectrum, and in 1958 this instrument was used to videotape the solar image in Hα. In 1959 analysis of the solar spectrum also was started. In order to efficiently study solar activity (but mainly flares), two automatic recorders of chromospheric phenomena were purchased: one was a chromosphere telescope that was installed in Beijing, and the other was the solar chromosphere video camera that was installed in Nanjing. In 1959 an Hα filter was installed on the horizontal solar telescope at Phoenix Mountain Observatory. All of these instruments made the observation of solar flares much easier. It should also be mentioned that during the annular solar eclipse of 19 April 1958, with the help of Soviet colleagues Chinese astronomers were able to make photoelectric measurements of the solar flux and record the solar spectrum. Soon after this, China acquired the capacity to observe solar radio emission (see Wang 2017). Theoretical research in solar physics mainly focussed on the internal energy and surface physical processes of the Sun (Chen et al. 1959).

8.3.3 The Establishment of Beijing Observatory

The second major goal mentioned in the Strategic Twelve Year Plan was to build in Beijing an observatory that specialized in astrophysics. In November 1957 the Construction Plan for Beijing Observatory was passed. The Plan suggested that "Beijing Observatory should focus on two equally important tasks: astrophysics and time service." (The Editorial Committee of National Astronomical Observatory 2010; our English translation).

To lead the astrophysical work at the planned Beijing Observatory, Tcheng Maolin 程茂兰 (1905–1978; Fig. 8.20), a well-known astrophysicist working in France, was invited to return to China in July 1957. Tcheng went to France for part-time studies in 1925, and in 1939 earned his Ph.D. in mathematical sciences. His early research was on spectroscopy of celestial bodies, and he made long period observation of Be stars and symbiotic stars and discovered and identified several new spectral lines. He was one the first astronomers to study the infra-red spectrum of stars by means of photographic spectroscopy. For the first time, he determined the value of the Paschen jump and established its relation to the Balmer jump. His spectroscopic observations of the Great Orion Nebula revealed 1162 emission lines between 3700 and 6700 Å. He also did research on the spectrum of the night sky, and developed a photographic spectroscopic method of determining the thickness of the ozone layer in the atmosphere (Jiang 2008, 2014).

On 22 February 1958 Tcheng was appointed Director of the Steering Committee for the Construction of Beijing Observatory. In France he had worked mainly on stellar spectroscopy and also had made important contributions to photographic spectroscopy. Now that he was in Beijing, Tcheng concentrated on building Beijing Observatory and guiding China's astrophysical research program. Under his leadership, after 7 years of site testing it was decided that the major observing station of

Fig. 8.20 Tcheng Mao-lin (after National Astronomical Observatories of China 2010)

Beijing Observatory should be at a site in Xinglong County (Ning and Sun 2014). Construction began in 1965, and it was finished in 1968 (Fig. 8.21). A 40-cm double astrographic camera and a 60/90-cm Schmidt telescope were then installed at Xinglong Station in 1964 and it was ready for observations.

While the site testing and construction work were underway, some astrophysical research programs were already being carried out at the Shahe Field Station in Beijing. This was first set up in 1958 for the time service, but it also served as a temporary base for astrophysical research. In early 1960 an Astrophysics Section was established under Tcheng Mao-Lin's leadership, and it consisted of four groups: Site Testing, Spectroscopy, Electrophotographic Imaging and Photography. In 1965 the Astrophysics Section was renamed the Stellar Physics Section and, in 1969, was transferred to Xinglong Station after the two major telescopes mentioned above were installed there. In 1958, after the solar eclipse expedition to Hainan Island, the Chinese borrowed two radio telescopes from the Soviet Union and set these up at Shahe Station (Chu 2016). In 1959 a Radio Astronomy Section was set up consisting of three research groups: a Meter Wave Group, a Centimeter Wave Group and a Theoretical Research Group. Regular radio monitoring of the Sun began in 1965 (see Wang 2017).

Optical solar observation started in Beijing in 1958, and in 1960 a Solar Physics Section was set up. In 1963 a chromosphere telescope was installed, and in 1965 observations began of sunspot magnetic fields using a 60-cm solar telescope. By 1965 the Shahe Station had become a *de facto* comprehensive astrophysical observatory (The Editorial Committee of National Astronomical Observatory 2010).

Fig. 8.21 Xinglong Station of Beijing Observatory (Wikiwand)

After these developments in the 1950s and 1960s, astrophysics in China gained remarkable momentum. But this development was severely interrupted by the Cultural Revolution that started in 1966. For 10 years, observations and research work nearly stopped and astronomers were politically harassed and persecuted. Thus, the astronomical achievements of the previous years were severely compromised, and astrophysics had to wait another 10 years before a revival could begin.

8.4 Conclusions

Although China had a strong tradition in astronomy in ancient times, this did not provide a good base for the emergence of astrophysics because traditional Chinese astronomy was fundamentally different from modern astrophysics.

During the Republic period China recruited astronomers who had been educated abroad and built an astronomical observatory with advanced instrumentation, but these excellent facilities could not play a key role in promoting astrophysical research because of the Sino-Japanese War and the following civil war.

In the 1950s and 1960s astrophysics built a solid foundation and there was potential for it to continue developing, thanks largely to the sponsorship and management of the Government of the People's Republic of China, but unfortunately this was interrupted by the tumultuous Cultural Revolution that started in 1966. Once again the social and political environment conspired to stifle the development of astrophysics in China and prevent it from emerging as an independent and fully fledged scientific discipline.

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References

Ansari, S.M.R. (Ed.), (2002). *History of Oriental Astronomy. Proceedings of the Joint Discussion-17 at the 23*rd *General Assembly of the International Astronomical Union* … Dordrecht: Kluwer.

Astrophysical Section … (1958). Spectroscopic work with the 60cm reflector. *Acta Astronomica Sinica.* 6, 79–86 (60 厘米反光鏡的光譜工作[J].天文学报,1958 ,第1期) (in Chinese).

Bo, S. (1997). An outline of Gou Shoujing's astronomical work. In I.-S. Nha, & F.R. Stephenson, pp. 15–24.

Bo, S. (2003). *The Collected Papers of Bo Shuren*. Hefei: The University of Science and Technology of China Press (薄树人. 薄树人文集. 合肥:中国科学技术大学出版社, 2003.08) (in Chinese).

Bonnet-Bidaud, J.-M., Praderie, F., & Whitfield, S. (2009). The Dunhuang Chinese sky: a comprehensive study of the oldest known star atlas. *Journal of Astronomical History and Heritage, 12,* 39–59.

Chen, B., et al. (1959). The Sun. In The Editorial and Translation Committee of the Chinese Academy of Sciences (Ed.), *Chinese Astronomy: 1949–1959* (pp. 28–35). Beijing: Science Press (陈彪等.太阳. 见:中国科学院编译出版委员会主编. 十年来的中国科学天文学 1949–1959. 北京:科学出版社, 1959.12) (in Chinese).

Chen, K.-Y. (2002). Gnomon measurements and the obliquity of the ecliptic. In S.M.R. Ansari, pp. 67–73.

Chen, K.-Y., & Sun, X. (Eds.), (2006). *Frontiers of Oriental Astronomy*. Beijing: China Science & Technology Press (陈广瑜,孙小淳主编. 东方天文学前沿. 北京:中国科学技术出版社, 2006.10).

Chen, K.-Y., Orchiston, W., Soonthornthum, B., & Strom, R. (Eds.), (2006). *Proceedings of the Fifth International Conference on Oriental Astronomy Held in Chiang Mai, Thailand, 4–8 October, 200*4. Chiang Mai: Chiang Mai University.

Chen, M. (1995). *New Studies on Ancient Calendars*. Shengyang: Liaoning Jiayu Press (陈美东著. 古历新探. 沈阳:辽宁教育出版社, 1995.12) (in Chinese).

Chen, M. (1999). A study of the adventurous life of an astronomical instrument-maker: Geng Xun. In M. Hirai, 143–148.

Chen, M. (2003). *Chinese History of Science and Technology. Volume on Astronomy*. Beijing: Science Press (卢嘉锡主编;陈美东著. 中国科学技术史 天文学卷. 北京:科学出版社, 2003.01) (in Chinese).

Chen, Z. (1985). *The Memories of Astronomy in Modern China*. Yunnan Observatory of CAS Press. Unofficial Publication (陈展云.中国近代天文事迹. 昆明:中国科学院云南天文台, 1985. 10) (in Chinese).

Chu, S. (2016). The 1958 Sino-Soviet solar eclipse expedition to Hainan and the beginning of radio astronomy in China. *The Chinese Journal for the History of Science and Technology, 37,* 284–295 (储姗姗. 1958 年中苏联合海南岛日食观测与中国射电天文学的开端 [J].中国科技史杂志, 2016, 第3期) (in Chinese).

Clark, D.H., & Stephenson, F.R. (1978). An interpretation of the pre-telescopic sunspot records from the Orient. *Quarterly Journal of the Royal Astronomical Society, 19,* 387–410.

Dai, N.-Z., & Chen, M.-D. (1980). Historical auroral data from China, Korea and Japan from the legendary period to A.D. 1747. *Kejishiwenji, 6,* 87–146 (戴念祖, 陈美东. 中、朝、日历史上的北极光年表——从传说时代到1747年. 见:中国天文学史整理研究小组编. 科技史文集 6 天文学史专辑 2.上海:上海科学技术出版社, 1980.08) (in Chinese).

Dehergne, J. (1973). *An Index of the Jesuits in China from 1552 to 1800*. Rome: Institutum Historicum S.I. (in French).

Deng, K., & Li, D. (2006). Some view on the origin of gnomon in China. In K.-Y. Chen,& X. Sun, pp. 9–15.

Ding, W. (1999). The Chinese astrophysicist Yu Ching-Song and his scientific achievements. In Y. Wang (Ed.), *Proceedings of the Seventh International Conference on the History of Science in China* (pp. 314–320). Zhengzhou: Daxiang Press (丁蔚.天体物理学家余青松及

其成就. 见:王渝生主编. 第七届国际中国科学史会议文集. 郑州:大象出版社, 1996.01) (in Chinese).

Ding, W., & Li, D. (1997). The establishment of fundamental scientific disciplines, second half, astronomy. In G. Dong (Ed.), *A History of Science and Technology in Modern China* (pp. 812–869). Changsha: Hunan Jiaoyu Press (丁蔚, 李东生. 基础科学的建立(下):天文学. 见:董光璧主编. 中国近现代科学技术史. 长沙:湖南教育出版社, 1997.04) (in Chinese).

Du, S., Cui, Z., Miao, Y., & Xiao, N. (2008). *The Transformation of Ancient Chinese Astronomy and Modern Astronomy*. Beijing: China Science and Technology Press (杜升云等主编. 中国古代天文学的转轨与近代天文学. 北京:中国科学技术出版社, 2008.12) (in Chinese).

Eberhard, W. (1957). The political function of astronomy and astronomers in Han China. In J.K. Fairbank (Ed.), *Chinese Thought and Institutions* (pp. 33–70). Chicago: University of Chicago Press.

Eddy, J.A. (1987). Uses of ancient data in modern astronomy. In G. Swarup et al., pp. 253–260.

Eddy, J.A., Stephenson, F.R., & Yau, K.K.C. (1989). On pre-telescopic sunspot records. *Quarterly Journal of the Royal Astronomical Society, 30,* 65–73.

Elman, B.A. (2005). *On Their Own Terms. Science in China, 1550–1900*. Cambridge (Mass.): Harvard University Press.

Feng, S. (2001). *Archeoastronomy in China*. Beijing: China Social Science Documentation Publishing House (冯时著. 中国天文考古学. 北京:社会科学文献出版社, 2001.11) (in Chinese).

Fung, K.-W. (2004). The transmission of Georg von Peurbach's *Theoricae Novae Planetum* in sixteenth and seventeenth century China. In W. Orchiston et al., pp. 81–86.

Gao, L. (1921). *The Past and Future of the Central Astronomical Observatory*. Beijing: Jinghua Press (高鲁著. 中央观象台之过去与将来. 北京:京华印书局代印, 1921) (in Chinese).

Gong, S., et al. (1959). Astrophysics and stellar astronomy. In The Editorial and Translation Committee of the Chinese Academy of Science (Ed.), *Chinese Astronomy: 1949–1959*. (pp. 21–27). Beijing: Science Press (龚树模等. 天体物理和恒星天文学. 见:中国科学院编译出版委员会主编. 十年来的中国科学天文学 1949–1959. 北京:科学出版社, 1959.12) (in Chinese).

Guan, Z. (2006). The historical and cultural value of Dengfeng Observatory. In K.Y. Chen et al., pp. 117–120.

Hasegawa, I. (1980). Catalogue of ancient and naked eye comets. *Vistas in Astronomy, 24,* 59–102.

Hasegawa, I. (1992). Historical variation in the meteor flux as found in Chinese and Japanese chronicles. *Celestial Mechanics and Dynamical Astronomy, 54,* 129–142.

Hashimoto, K. (1988). *Hsü Kuang-ch'i and Astrronomical Reform–The Process of the Chinese Acceptance of Western Astronomy 1629–1635*. Osaka: Kansai University Press.

Hashimoto, K., & Jami, C. (1997). Kepler's Laws in China: a missing link. *Historia Scientiarum, 6,* 171–185.

He, N. (2004). Notes about the excavation of a large building II FJT1 in the small city of the Middle Taosi Phase. *Bulletin of Studies in Ancient Civilizations, 23,* 47–58 (何驽. 陶寺中期小城内大型建筑II FJT1 发掘心路历程杂谈[J].古代文明研究通讯, 23,47–58) (in Chinese).

Hirai, M. (Ed.), (1999). *Proceedings of the Third International Conference on Oriental Astronomy*. Fukuoka, Fukuoka University of Education.

Ho, P.-Y. (1962). Ancient and medieval observations of comets and novae in Chinese sources. *Vistas in Astronomy, 5,* 127–225.

Hsi, T. (1958). A new catalog of ancient novae. *Smithsonian Contributions to Astrophysics*, *2*(6), 109–130.

Hu, T. (1992). The cosmological model in *Li Xue Hui Tong. Studies in the History of Natural Sciences, 11,* 224–232(胡铁珠.《历学会通》中的宇宙模式[J].自然科学史研究, 1992, 第 3 期) (in Chinese).

Hu, W. (Ed.), (2007). *Studies of the Plans and Policies for the Scientific and Technological Development of China*. Jinan: Shandong Education Press (胡维佳等编. 中国科技规划、计划与政策研究. 济南:山东教育出版社, 2007.12) (in Chinese).

Hua, T. (1997). The water clock of the Ming Dynasty. In I.-S. Nha, & F.R. Stephenson, pp. 325–328.

Huang, K. (1945a). On the excitation of the coronal lines. *The Astrophysical Journal, 101,* 187–195.

Huang, K. (1945b). The continuous absorption of light by negative sodium ions. *The Astrophysical Journal, 101,* 196–203.

Huang, T.-T. (1990). A study of five-planet conjunctions in Chinese history. *Early China*, 15, 97–112.

Huang, Y., Yuan, G., Liu, D., & Wang, X. (2005). An outline Zhang Heng's seismograph. In Z. Xi, Z. Zhang, & Y. Liu (Eds.), *Proceedings of the Fourth International Conference on Oriental Astronomy and Symposium on Zhang Heng* (pp. 131–142). Nanyang: Academic Forum of Nandu.

Huang, Y.-L. (1999). The remarkable five-planet conjunctions of 185 B.C. and AD 710. In Hirai, pp. 199–202.

Imoto, S., & Hasegawa, I. (1958). Historical records of meteor showers in China, Korea, and Japan. *Smithsonian Contributions to Astrophysics, 2,* 131–144.

Institute of Archaeology Chinese Academy of Social Sciences (1980). *Album of Ancient Relics and Documents Connected with Astronomy*. Beijing: Wenwu Publishing Co. (中国社会科学院考古研究所编. 中国古代天文文物图集. 北京:文物出版社, 1980.06) (in Chinese).

Jansen, J. (1991). Additions and corrections to the Hasegawa catalogue. *Vistas in Astronomy, 34,* 179–186.

Jiang, S. (2008). Cheng Maolan—the pioneer of observational astrophysics in modern China. *Chinese National Astronomy, 2008*(11). 36–44 (蒋世仰.中国近代实测天体物理学的领路人:程茂兰[J].中国国家天文, 2008, 第 11 期) (in Chinese).

Jiang, S. (2014). Cheng Maolan. In Ye, S. (Eds.), *The Compendiums of the Academic Achievements of Famous Chinese Scientists in the 20th entury*. *Volumes on Astronomy* (pp. 191–202). Beijing: Science Press. (蒋世仰. 程茂兰. 见:叶叔华主编. 20 世纪中国知名科学家学术成就概览 天文学卷 第 1 分册. 北京:科学出版社, 2014.01) (in Chinese).

Jiang, X., & Chen, Z. (2008). *A Short History of the Chinese Astronomical Society*. Shanghai: Shanghai Jiaotong University Press (江晓原,陈志辉编著. 中国天文学会往事. 上海:上海交通大学出版社, 2008.10) (in Chinese).

Kanda, S. (1967). Obituary of Father Yachita Tsuchihashi, S.J. *Tenmon Geppo*, *60,*. 159 (in Japanese).

Lee, E.-H., & Chen, K.-Y. (2006). Accuracy of the gnomonic measurements in Korea and China. In K.-Y. Chen et al., pp. 137–141.

Li, G., & Sun, X. (2010). The painted stick of Taosi IIM22 and gnomon measurements. *The Chinese Journal for the History of Science and Technology, 31,* 363–372 (黎耕,孙小淳.陶寺 IIM22 漆杆与圭表测影 [J].中国科技史杂志, 2010, 第 4 期) (in Chinese).

Li, H. (1954). Photographic studies of five galactic clusters, NGC 1750, 1817, 2286, 2548, 7380. *Acta Astronomica Sinica*, 2, 23–42 (李珩.五个银河星团的照相研究 [J]. 天文学报, 1954, (第 1 期) (in Chinese).

Li, Q. (1997). Beijing Astronomical Observatory in the Yuan Dynasty. In I.-S. Nha, & F.R. Stephenson, pp. 63–70.

Li, Y. (2001). A new way of dating oracle bones scripts in the late Shang Dynasty by astronomical methods—analyzing the law of monthly order in the Yin Dynasty. *Acta Astronomica Sinica, 42*, 215–224 (李勇.用天文方法建立商后期甲骨文年代序列的新途径——解析殷历月法[J].天文学报, 2001, 第 2 期) (in Chinese).

Li, Y. (2006). Astronomical methods applied in Chinese chronology. In K.-Y. Chen et al., pp. 155–158.

Liu, C. (2002a). Analysis of dates of lunar phases recorded in *Wucheng*. *Journal of Astronomical History and Heritage, 5,* 115–121.

Liu, C. (2002b). Astronomy in the Xia-Shang-Zhou Chronology Project. *Journal of Astronomical History and Heritage, 5,* 1–8.

Liu, C., Liu, X., & Ma, L. (2003). Examination of early Chinese records of solar eclipses. *Journal of Astronomical History and Heritage, 6,* 53–63.

Liu, C., Liu, X., & Ma, L. (2005). A Chinese observatory site of 4,000 years age. *Journal of Astronomical History and Heritage, 8,* 129–130.

Liu, D. (1986). Mei Wen Ding: the master of both calendar-calculations and mathematics in the Early Qing Dynasty. *Journal of Dialectics of Nature, 1986*(1), 52–79 (刘钝.清初历算大师梅文鼎[J].自然辩证法通讯, 1986, 第1期) (in Chinese).

Liu, X., & Lu, L. (2015). The establishment and development of Sun Yat-sen University Observatory. *The Chinese Journal for the History of Science and Technology, 1,* 13–27(刘心霈,吕凌峰.中山大学天文台的创建、发展[J].中国科技史杂志, 2015, (第1期) (in Chinese).

Lo, D. (1955). The time service at Zi-Ka-Wei Observatory. *Acta Astronomica Sinica, 3*, 275–291 (罗定江.徐家匯观象台的授时工作 [J]. 天文学报, 1955, (第2期) (in Chinese).

Maeyama, Y. (1977). The oldest Star Catalogue of China, Shih Shen's Hsing Ching. In Y. Maeyama, & W.G. Salzer (Eds.), *Prismata*: *Naturwissenschaftsgeschichtliche Studien*. *Festschrift* für *Willy Hartner* (pp. 211–245). Wiesbaden: Franz Steiner.

Maspero, H. (1929). Chinese astronomy before the Han. *T'oung Pao, 26,* 267–356.

Ministry of Science and Technology of the People's Republic of China (2005). *The Strategic Plan for Scientific Development from 1956 to 1967.* (http://www.most.gov.cn/ztzl/gjzcqgy/zcqgylshg/200508/t20050831_24440.htm) (中华人民共和国科学技术部网站 (2005). 1956–1967年科学技术发展远景规划纲要(修正草案) (in Chinese).

Needham, J., & Wang, L. (1959). *Science and Civilization in China. Volume 2, Part 2, Mathematics*. Cambridge: Cambridge University Press.

Needham, J., Wang, L., & Price, D.D. (1960). *Heavenly Clock: The Great Astronomical Clock of Medieval China*. Cambridge: Cambridge University Press.

Nha, I.-S., & Stephenson, F.R. (Eds.), (1997). *Oriental Astronomy From Guo Shoujing to King Sejong*. Seoul, Yonsei University Press.

Nha, I.-S., Oh Gilsun, & Chen Kaige (2006). Xin'an Xiuyu, a city of Chinese sundials and compasses. In K.-Y. Chen et al., pp. 129–136.

Ning, X. (2007). The characteristics of Wang Xichan's system of the Universe. *Chinese Journal for the History of Science and Technology, 28,* 123–131 (宁晓玉.试论王锡阐宇宙模型的特征 [J]. 中国科技史杂志, 2007, 第2期) (in Chinese).

Ning, X. (2010). A comparative study of ancient Chinese and Western astronomical theories. *Science and Culture Review, 7,* 71–83 (宁晓玉.比较视野下的中国古代天文理论的探讨 [J]. 科学文化评论, 2010, 第2期) (in Chinese).

Ning, X. (2013). Wang Xichan and Tycho's system. *Journal of Dialectics of Nature, 35,* 81–85 (宁晓玉.王锡阐与第谷体系 [J]. 自然辩证法通讯, 2013, 第3期) (in Chinese).

Ning, X., & Sun, X. (2014). The 20th century development of astronomy in China. In S. Ye (Ed.), *The Compendiums of the Academic Achievements of Famous Chinese Scientists of the 20th Century*. *Volumes on Astronomy* (pp. 1–58). Beijing: Science Press (宁晓玉, 孙小淳. 20 世纪中国天文学. 见:叶叔华主编. 20世纪中国知名科学家学术成就概览 天文学卷 第1分册. 北京:科学出版社, 2014.01) (in Chinese).

Orchiston, W., Stephenson, R., Débarbat, S., & Nha-I.-S. (Eds.), (2004). *Astronomical Instruments and Archives from the Asia–Pacific Region*. Seoul: IAU Commission 41.

Pang, K.D., Yau, K.K., & Chou, H.-H. (2002). Astronomical dating and statistical analysis of ancient eclipse data. In S.M.R. Ansari, pp. 95–119.

Pankenier, D.W. (1995). The cosmo-political background of heaven's mandate. *Early China, 20,* 121–176.

Pigatto, L. (2004). Astronomical observations made by Jesuits in Peking during the seventeenth and eighteenth centuries. In W. Orchiston et al., pp. 55–66.

Quan, H. (1987). Research on scale and precision of the water clock in ancient China. In G. Swarup et al., pp. 57–61.

Shi, Y. (2000). Tian Xue Zhan Yuan and the early diffusion of Copernican astronomy in China. *China Historical Materials of Science and Technology, 21,* 83–91 (石云理.《天步真原》与哥白尼天文学在中国的早期传播 [J]. 中国科技史料, 2000, 第1期) (in Chinese).

Situ, D., & Yi, S. (1997).The gnomon in the Yuan Dynasty and Dengfeng Observatory. In I.-S. Nha, & F.R. Stephenson, pp. 237–241.

Sivin, N. (1995). *Science in Ancient China*. Farnham: Variorum Ashgate Publishing.

Steele, J.M. (2004). Applied historical astronomy: an historical perspective. *Journal for the History of Astronomy, 35,* 337–355.

Stephenson, F.R. (1994). Chinese and Korean star maps and catalogs. In J.B. Harley, & D. Woodward (Eds.), *The History of Cartography. Volume 2. Book 2: Cartography in the Traditional East and Southeast Asian Societies* (pp. 511–578). Chicago: University of Chicago Press.

Stephenson, F.R. (1997a). Accuracy of Medieval Chinese measurements of lunar and solar eclipse times. In I.-S. Nha, & F.R. Stephenson, pp. 159–187.

Stephenson, F.R. (1997b). *Historical Eclipses and Earth's Rotation*. Cambridge: Cambridge University Press.

Stephenson, F.R. (1997c). The impact of Guo Shoujing and King Sejong on Oriental astronomy. In I.-S. Nha, & F.R. Stephenson, pp. 7–12.

Stephenson, F.R., & Baylis J.T. (2012). Early Chinese observations of occultations of planets by the Moon. *Journal for the History of Astronomy, 43,* 455–477.

Stephenson, F.R., & Green, D.A. (2002). *Historical Supernovae and their Remnants*. Oxford: Oxford University Press.

Stephenson, F.R., & Yau, K.C. (1985). Far Eastern observations of Halley's Comet: 240 BC to AD 1368. *Journal of the British Interplanetary Society, 38,* 195–216.

Stephenson, F.R., Morrison, L.V., & Hohenkerk, C.Y. (2016). Measurement of the Earth's rotation: 720 BC to AD 2015. *Proceedings of the Royal Society A*, 472, 20160404.

Strom, R. (2015). Some statistical aspects of historical Chinese astronomy records. In W. Orchiston, D.A. Green & R. Strom (Eds.), *New Insights from Recent Studies in Historical Astronomy: Following in the Footsteps of F. Richard Stephenson. A Meeting to Honor F. Richard Stephenson on His 70th Birthday* (pp. 61–90). Cham: Springer.

Sun, X. (2000). Crossing the boundaries between heaven and man: astronomy in ancient China. In H. Selin, & X. Sun (Eds.), *Astronomy Across Cultures: The History of Non-Western Astronomy* (pp. 423–454). Dordrecht: Kluwer.

Sun, X. & Kistemaker, J. (1997). *The Chinese Sky during the Han – Constellating Stars & Society*. Leiden: Brill.

Sun, X., & Kistemaker, J. (2006). The first Chinese catalogue of stars in the South-polar region and its Western origin. In K.Y- Chen & X. Sun, pp. 130–143.

Sun, X., Bo, S., & Kistemaker, J. (1997). The *Tian Wen Hui Chao Star Catalogue* of the early Ming. In I.-S. Nha, & F.R. Stephenson, pp. 275–282.

Swarup, G., Bag, A.K., & Shukla, K.S. (Eds.), (1987). *History of Oriental Astronomy. Proceedings of an International Astronomical Union Colloquium No. 91, New Delhi, India 13–16 November 1985*. Cambridge: Cambridge University Press.

Teboul, M. (1987). Ancient Chinese auroral records: interpretation problems and methods. In G. Swarup et al., pp. 41–50.

The Editorial Committee of National Astronomical Observatory, CAS. (Ed.), (2010). *The History of Beijing Astronomical Observatory of the Chinese Academy of Science, 1958–2001.* Beijing: China Science and Technology Press (中国科学院国家天文台编. 中国科学院北京天文台台史 1958–2001. 北京:中国科学技术出版社, 2010.07) (in Chinese).

The Editorial Committee of Purple Mountain Observatory, CAS. (Ed.), (1985). *50 Years' Development of Purple Mountain Observatory: 1934–1984*. Nanjing: Nanjing University Press (中国科学院紫金山天文台编. 紫金山天文台50年1934–1984. 南京: 南京大学出版社, 1985) (in Chinese).

The Research and Editorial Group of the History of Chinese Astronomy (Ed.), (1981). *The History of Chinese Astronomy*. Beijing: Science Press (中国天文学史整理研究小组编著. 中国天文学史. 北京:科学出版社, 1981.05) (in Chinese).

The Expert Group … (2000). *The Concise Report of the Xia-Shang-Zhou Chronology Project, 1996–2000*. Beijing: World Company (夏商周断代工程专家组编著. 夏商周断代工程1996--2000年阶段成果报告简本. 北京:世界图书出版公司, 2000) (in Chinese).

Thompson, R.W. (1906). *Griffin John: The Story of Fifty Years in China*. London: Religious Tract Society.

Tsuchihashi, Y., S.J. (1909). Correspondence from Sheshan Observatory. *Tenmon Geppou, 1*(10), 99–101 (in Japanese).

Tsuchihashi, Y., & Chevalier, S. (1911). *Catalogue of Fixed Stars Observed from Pékin under the Emperor K'ien-long*. Shanghai: Sheshan Observatory. (in French).

Udias, A. (1994). Jesuit astronomers in Beijing, 1601–1805. *Quarterly Journal of the Royal Astronomical Society, 35,* 463–478.

Udias, A. (2003). *Searching the Heaven and the Earth: The History of Jesuit Observatories*. Dordrecht: Kluwer.

Wang P. (1966). *The Introduction of Western Astronomy and Mathematics*. Nankang, Taiwan: Institute of Modern History, Academia Sinica (Monographs, 17) (王萍 (1966). 西方历算学之输入. 中央研究院近代史研究所专刊 (17). 台湾: 精华印书馆) (in Chinese).

Wang, S. (2017). The early development of Chinese radio astronomy: the role of W.N. Christiansen. In T. Nakamura, & W. Orchiston (Eds.), *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Wang, Z. (2014). Seeing stars. *Global Times*, 15 January (http://www.globaltimes.cn/content/837646.shtml).

Xi, Z. (1987). The characteristics of ancient China's astronomy. In G. Swarup et al., pp. 33–40.

Xu, Z.-T. (1997). Two observatories at the beginning of the Ming Dynasty. In I.-S. Nha, & F.R. Stephenson, pp. 55–62.

Xu, Z., Pankenier, D.W., & Jiang, Y. (2000). *East Asian Archaeoastronomy. Historical Records of Astronomical Observations of China, Japan and Korea*. Amsterdam: Gordon and Breach.

Yabuuti, K. (1990). *Chinese Astronomical Calendar Systems. Second Edition*. Tokyo: Heibonsha.

Yan, D. (1989). Mei Wending's mathematical and astronomical work. *Studies in the History of Natural Science, 8,* 99–107 (严敦杰.梅文鼎的数学和天文学工作 [J]. 自然科学史研究, 1989, 第2期) (in Chinese).

Yau, K.K.C., & Stephenson, F.R. (1988). A revised catalogue of Far Eastern observations of sunspots (165 BC to AD 1918). *Quarterly Journal of the Royal Astronomical Society, 29,* 175–197.

Ye, L.,& Tian, F. (2016). The study of two translated versions of Tianwen Qimeng. *The Studies in Dialectics of Nature, 32,* 76–81 (叶璐,田锋.《天文启蒙》两个中译本考略 [J]. 自然辩证法研究, 2016, (第11期) (in Chinese).

Yeomans, D.K., & Kiang, T. (1981). The long-term motion of Comet Halley. *Monthly Notices of the Royal Astronomical Society, 197,* 633–646.

Yu, Q. (1935). The Purple Mountain Observatory of the National Astronomical Institute of Academia Sinica. *Yu zou, 6*(1), 1–10 (余青松. 国立中央研究院天文研究所 [J]. 宇宙. 1935(1): 1–10) (in Chinese).

Zhang, F. (trans.) (1985). *On Light*. Beijing: Zhonghua Shuju.

Zhang, P. (1999). The identification of oracle bone inscriptions relating to solar and lunar eclipses and Shang Dynasty dating. *Social Sciences in China, 5*, 172–197 (张培瑜.日月食卜辞的证认与殷商年代 [J]. 中国社会科学, 1999, 第5期) (in Chinese).

Zhang Y. (1924). A brief examination of the introduction of Western astronomy into China in the Ming-Qing Dynasties. *The Tsing Hua Journal, 1,* 38–69 (张荫麟. 明清之际西学输入中国考略. 清华大学学报. 1924 1(1): 38–69) (in Chinese).

Zhou, P. (1935). A relativistic theory of the expanding Universe. *Acta Physica Sinica Physics* [J]. (周培源. 膨胀宇宙新论. 中国物理学报, 1935, (第1期) (in Chinese).

Zhu, L. (1985). Historical materials on the Kunming Astronomical Station and Qingdao Observatory. *Publications of the Purple Mountain Observatory, 4*(4), 66–73 (朱楞.昆明天文工作站和青岛观象台史料 [J]. 紫金山天文台台刊, 1985, 第4期) (in Chinese).

Zhu, L. (1986). Historical Materials on Xujiahui Observatory. In *Collected Works on the History of Chinese Astronomy, Volume. 4* (Pp. 198–212).Beijing: Science Press (朱楞. 徐家汇天文台史料 (1872–1962)《中国天文学史文集》编辑组编. 中国天文学史文集 第4集. 北京:科学出版社, 1986.08) (in Chinese).

Zhuang, T. (1966). Ancient Chinese records of meteor showers. *Acta Astronomica Sinica, 1966*(1), 197–220.

Zhuang, W. (Ed.), (2009). *Research and the Application of Ancient Chinese Records of Celestial Phenomena*. Beijing: China Science and Technology Press (庄威凤主编. 中国古代天象记录的研究与应用. 北京:中国科学技术出版社, 2009.01) (in Chinese).

Chapter 9
The Early Development of Chinese Radio Astronomy: The Role of W.N. Christiansen

Wang Shouguan

9.1 Introduction

Childhood memory is precious. The ‘childhood’—or early days—of Chinese radio astronomy went through the usual trials and tribulations. The first team of Chinese researchers in radio astronomy, so very young at the time, and so deeply engulfed in stormy weather during their first steps, will hold dear in their memory the arrival of a senior colleague from the West. During this period, Professor W.N. Christiansen (affectionately known by us as ‘Prof. Ke’, ‘Ke’ being the first of the five Chinese characters that transcribe his surname) made the long journey to us more than a dozen times (see Fig. 9.1), and brought to us valuable scientific information, specialist guidance and assistance.

The memories of our discipline’s infancy are still fresh with us, and our feelings cannot be expressed by ordinary words. Here, we recall a couple of the most typical events, as emissaries carrying the thoughts of an entire era.

9.2 Recollections of the Shahe Experiment

Prof. Ke visited China for the first time in 1963. At that time, the Chinese Academy of Sciences’ Beijing Observatory had a site in a Beijing suburb, Shahe, and the Radio Astronomy Section had installed there 2 cm-wave solar radiometers, copies of ones then in Soviet Russia.

In the early 1960s, our contact with Russia had fallen to a low ebb, and our contact with the West was nil. Members of our team at that time, with one or two

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Fig. 9.1 Professor and Mrs. Christiansen with the then young Chinese team of radio astronomers in Beijing in 1987 (*Courtesy* Beijing Astronomical Observatory)

exceptions, were all young people in their early 20s. In line with the whole of China, we subscribed to the slogans, 'Self-Renewal Through Self-Effort' and 'March Into Science'. However, electronics in China was just being born, and if we were to pull ourselves up by our own boot straps the only option that was technically feasible at all was working at meter wave-lengths.

After going over the problem again and again, we opted to start with solar observations at meter wave-lengths, and we considered constructing a copy of the Chris Cross (Fig. 9.2) which Professor W.N. ('Chris') Christiansen had erected at Fleurs near Sydney (Australia) in 1957 (see Christiansen et al. 1961; Orchiston and Mathewson 2009).[1] In 1963, we were working on the 32 antennas specified in the project, having basically decided on the site for the antenna array, but we had not solved the key technical problem of the transmission lines. At that time, China still could not produce coaxial cables, and they were hard to import from Russia or from Eastern Europe. And, in particular, none of us had any idea on the overall technology of the antenna array. So, when we were told that Professor Christiansen, the inventor of the Chris Cross, was coming to visit us, it was like a happiness that had fallen from heaven.

Our joy was redoubled by a fact known to all: the Chinese scientific community at the time had been cut off from the West for more than a decade, as though we

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[1] Christiansen was on the staff of the CSIRO's Division of Radiophysics in Sydney when the Chris Cross was built, but in 1960 he moved to a Chair in Electrical Engineering at the University of Sydney. Professor Christiansen died on 26 April 2007 (see Frater and Goss 2011; Wendt et al. 2011).

Fig. 9.2 View of the central part of the Chris Cross, looking west at sunset. This array comprised E-W and N-S arms each with 32 steerable parabolic antennas of 5.8-m diameter. This was the world's first crossed-grating interferometer and it was used to produce daily isophote maps of solar emission at 1423 MHz (*Courtesy* John Leahy)

were sealed inside an hermetic wall. And this was the first time that a small door would open in this wall, and who should come through that door but the very man we most wanted to meet, Professor W.N. Christiansen.

After a brief meeting, the Professor invited the author to visit Australia, and in 1964 Dr. Wu Huai-wei and I took up this invitation and went to Sydney. At that time there were no diplomatic relations between China and Australia, so we stayed in Professor Christiansen's home and at the Hall of Residence at the University of Sydney.

During this trip, we made a point of visiting all of the radio astronomy establishments in Australia (but especially Fleurs), and we got an inkling of the scientific developments of the time and established many useful contacts. We discussed in detail with Prof. Ke ways of developing radio astronomy at Beijing Observatory, and we arranged for Prof. Ke to visit us again in 1965 in order to help us with some of the technical challenges of the antenna array.

In 1965 we installed four 6-m antennas at Shahe (Fig. 9.3), so that we could carry out 'interim tests'. As soon as Prof. Ke arrived, he guided us to start building the twin wire transmission line system that he himself had specially designed, using a material which we could easily obtain at that time, copper wire. Two parallel copper wires of 4 mm diameter made up the transmission lines, and the copper tubes that encased the wires were used to make an 'adder' that added up two radio frequency signals, and a connector that served as a 'matching transformer' between the cable and the copper tube. And there was the detector Prof. Ke himself designed for testing stationary waves. By left-right sliding movements of the adder the relative phase of the two signals was adjusted, thereby completing the 'two-two addition'.

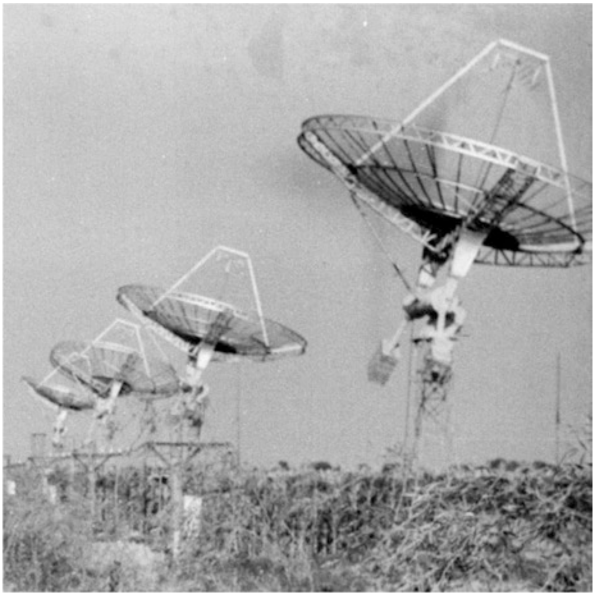

Fig. 9.3 The four-antenna Shahe test array (*Courtesy* Beijing Astronomical Observatory)

When the Shahe Experiment was entering its final stage, China began sliding into a 10-year period of chaos, and all work was derailed, and even stopped completely at one stage. Nevertheless, by 1967 a meter wave ‘Christiansen array’ of 16 east-west elements was installed at the new Miyun Observing Station, and test observations produced the first one-dimensional maps of the Sun. Originally the aim was to erect a 32-element crossed-grating interferometer (similar to the Fleurs one), but we had to revise this plan and ended up with the 16-element array instead.

The realisation of the twin-wire transmission line system marked not only the completion of the new radio telescope, but equally important, it taught us (complete ‘new hands’ at the game) a profound lesson: by making the best of the situation, one can successfully carry out scientific research under difficult conditions. And this is precisely what we understood by the term ‘Christiansen Style’.

9.3 The Making of the Miyun Meter Wave Aperture Synthesis Telescope

After 1966, work at observatories throughout China stopped for a time, but the situation relaxed somewhat during the 1970s and from time to time we were able to carry out some work at the Miyun Observing Station. During this period, Prof. Ke came to China many times to bring us news of developments in radio astronomy abroad. And whatever little work we could do at the time always got support from him (on occasions he even brought us small electronics components that we needed).

Fig. 9.4 The Miyun 28-antenna Meter Wave Aperture Synthesis Array (*Courtesy* Beijing Astronomical Observatory)

When in 1973 Prof. Ke told us the news that the Fleurs array was being converted into an aperture synthesis instrument,[2] we felt that once work resumed at Miyun this would also be the best goal for our endeavour. During his next visit we discussed this idea in detail, and the Professor then made a move that was most extraordinary at the time: he proposed that China send two radio astronomers to Australia on a cultural exchange. As a result, in 1975 two members of the Miyun team, Drs Chen Hong-shen and Ren Fang-bin, spent 8 months based in the School of Electrical Engineering at the University of Sydney where they learnt about the hardware associated with the analogue receiver system of the Fleurs Aperture Synthesis. This provided, ahead of time, useful preparation for our later work.

The year 1976 saw the end of chaos in China and order was gradually restored at Miyun. Our first task was to convert the Miyun array into an Earth-rotation aperture synthesis instrument. Originally 32 antennas had been constructed when we began making the Miyun array, but many of these found their way to various locations in China during the years of unrest. Fortunately, we managed to track down most of these surplus antennas and bring them back to the Miyun Observing Station, ending up with a 28-element east-west array (Fig. 9.4), where the diameter of each aerial was increased from 6 to 9 m.

The making of the Miyun Aperture Synthesis Telescope was a gradual process. We started at a very low point, when the material conditions were difficult and the technological base was weak. But we had made preparations beforehand, and our target was clearly defined (as during the earlier Shahe period), so by making the best

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[2] For details of the Fleurs Synthesis Telescope see the various papers in the September 1973 special issue of the *Proceedings of the Institution of Radio and Electronics Engineers Australia* (Vol. 34, No. 8).

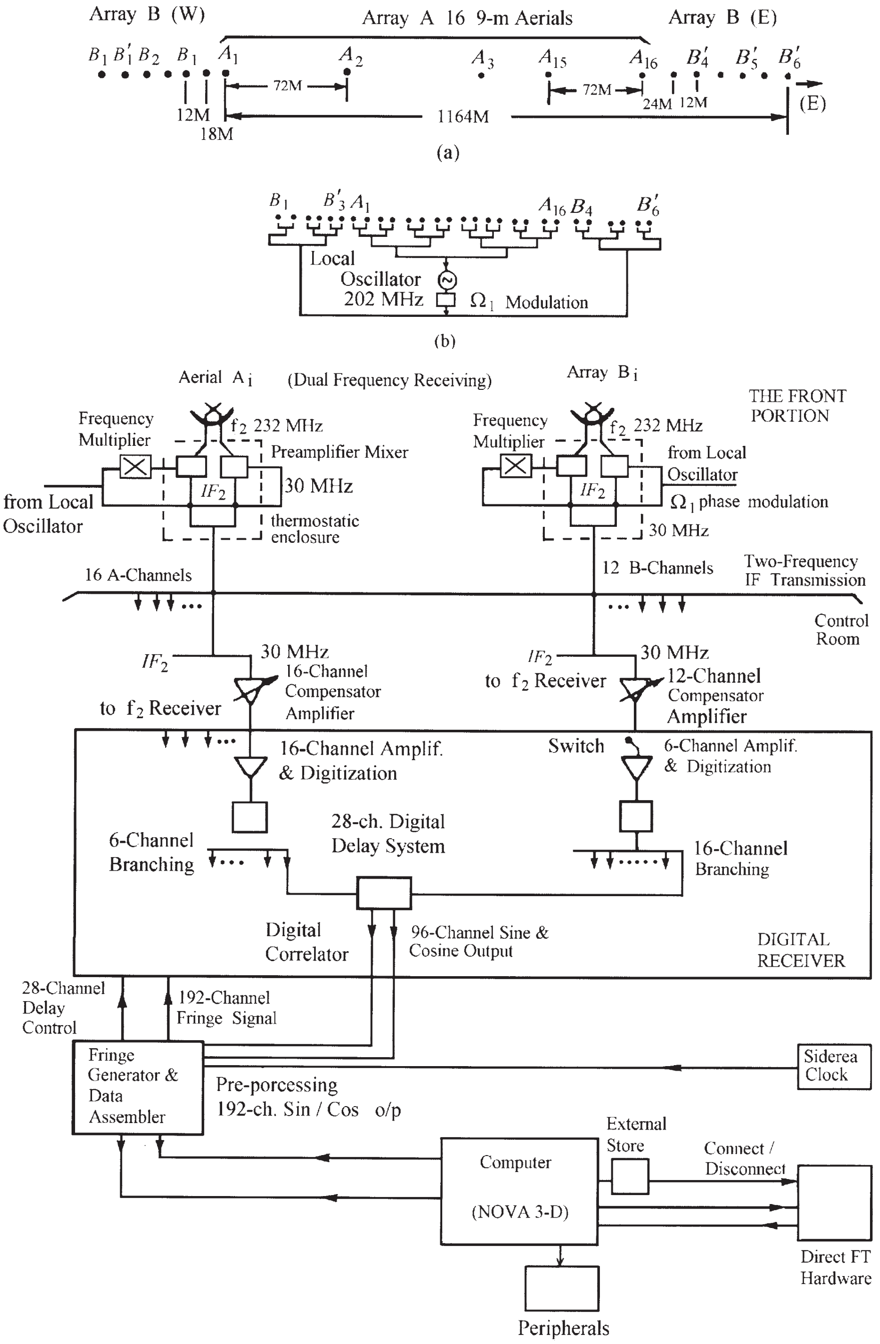

Fig. 9.5 A structural overview of the Miyun Aperture Synthesis Telescope system (after Wang 1986)

Fig. 9.6 The Appraisal Committee of the Miyun Meter Wave Aperture Synthesis Telescope (*Courtesy* Beijing Astronomical Observatory)

of a very difficult situation and bringing out our hidden potential we were able to keep forging ahead. The main problem at this time was the introduction of digital techniques and solving the complicated problem of data processing. Here, again, we had Prof. Ke's whole-hearted support. In 1979, he sent his research student, Dr. C.K. Kwong, to Beijing to help set up a digital receiver, and in 1980 he again invited two Miyun colleagues, Drs Chen Hong-shen and Zheng Yi-jia to Sydney to familiarize themselves with the software and hardware of the Fleurs Synthesis Telescope.

At this point the blueprint of the Miyun Meter Wave Aperture Synthesis System was finalized, but it then took another 4 years to complete the experimentation, installation and testing.

The Miyun Aperture Synthesis Telescope consists of 28 antennas each of 9-m in diameter, divided into Array A (16 antennas) and Array B (12 antennas) arranged as shown in Fig. 9.5), making up 192 interferometer pairs, with baselines 3do, 4do, …194do (where do = 6 m). The system works at two frequencies, 232 and 408 MHz. At 232 MHz, each cycle of 12 h' observation gives an overall resolution of 3.8 × 3.8 arc min. Csc δ, and a 'thermal noise limited' sensitivity of 0.05 Jy (SNR = 6) covering a field of 8 × 8 square degrees.

Now, when we recall this series of efforts, we recognize it to be precisely what enabled the Miyun team to pass the starting line of technological modernization, and throughout this eventful journey, which lasted 10 years, we benefited from the guidance and concern of our good teacher and friend, Prof. Ke.

The Miyun Meter Wave Aperture Synthesis Telescope was formally commissioned in 1984 (see Wang 1986), and Prof. Ke made a special journey to take part in the appraisal of the Facility. He and other Appraisal Committee members are shown in Fig. 9.6.

9.4 Prof Ke and the Chinese Academy of Sciences (CAS)

Although just two examples may not do full justice to the history of 'Prof. Ke and China', which spanned more than a third of a century, these two examples are typical, and are so deeply and indelibly impressed in our memories that they serve to illustrate the impact of his strong personality on our hearts and his contribution to the establishment and growth of radio astronomy in China. Over thirty-plus years, he became familiar with all of China's astronomical institutions and their radio astronomy divisions. Besides Beijing Observatory, the Purple Mountain Observatory, Shanghai Observatory, Yunnan Observatory and the Urumqi Astronomical Station all kept records of the many lectures and visits by Prof. Ke, and of the numerous astronomers (and not just radio astronomers) from various places in China who visited Australia over the years and enjoyed kind hospitality and concrete help from Prof. and Mrs. Ke.

Furthermore, Prof. Ke encouraged other Western radio astronomers to come to China, and many of them—including Rob Frater, Miller Goss, George Miley, Bruce Slee and Richard Wielebinski—have established deep friendships with us. Like Prof. Ke, many of them made personal efforts to help China move out of isolation and rejoin the international astronomical community. Prof. Ke also, through his personal influence in international academic circles, did much to help return China to such international organizations as the IAU, URSI and the ICSU.

Prof. Ke's deep friendship towards China was not confined to the Miyun radio astronomy team, or even to the Chinese astronomical community. His academic distinction and his sincerity elicited widespread respect and admiration in the wider scientific community. Apart from his aforementioned dealings with astronomers, especially the younger ones, many scientists from our older generations, including Go Moruo, Y.H. Woo and Chou Peiyuan, became close personal friends of his. Figure 9.7 is an historically significant photograph. It was taken in the 1960s and although rather 'formal', it records some of these 'older scientists'—who were not very old then—in company with Prof. and Mrs. Ke.

In recognition of his long and important contribution to Chinese astronomy, in 1996 Professor Christiansen was elected a Foreign Member of the Chinese Academy of Sciences.

9.5 Concluding Remarks

I would like to conclude this short chapter with two photographs taken during the Ninth Assembly of Members of the CAS in 1998 (Figs. 9.8 and 9.9), for this was to be the last of the many occasions when Prof. Ke was with us (since 1963).

Let these solemn records convey from all of us—friends in a country that he loved—our deepest feelings for him as we look on the passing of history.

Fig. 9.7 Professor and Mrs. Christiansen with Guo Moruo, the first President of the Chinese Academy of Sciences (front row sixth from left), Y.H. Woo, physicist and Vice-President of the Chinese Academy of Sciences (front row fourth from left), Chou Peiyuan, physicist and President of Peking University (front row third from left) and the astronomer Tcheng Mao-lin (front row second from left) (*Courtesy* Chinese Academy of Sciences)

Fig. 9.8 Professor Christiansen (front row, second from left) at the Ninth Assembly of Members of the Chinese Academy of Sciences in 1998, during his last visit to China (*Courtesy* Chinese Academy of Sciences)

Fig. 9.9 Professor Christiansen speaking at the Ninth Assembly of Members of the Chinese Academy of Sciences (*Courtesy* Chinese Academy of Sciences)

Acknowledgements I am grateful to Dr. John Leahy (through Professor Wayne Orchiston) for kindly supplying Fig. 9.2, and to Dr. T. Kiang for translating the original version of this chapter from Chinese into English.

References

Christiansen, W.N., Labrum, N.R., McAlister, K.R., & Mathewson, D.S. (1961). The crossed-grating interferometer: a new high-resolution radio telescope. *Proceedings of the Institution of Electrical Engineers, 108*, 48–58.

Frater, R.H., & Goss, W.M. (2011). Wilbur Norman Christiansen 1913–2007. *Historical Records of Australian Science, 22*, 215–228.

Orchiston, W., & Mathewson, D. (2009). Chris Christiansen and the Chris Cross. *Journal of Astronomical History and Heritage, 12*, 11–32.

Wang Shouguan (1986). Miyun Meter Wave Aperture Synthesis Radio Telescope. *Chinese Astronomy and Astro-physics, 10*, 3–11.

Wang Shouguan (2009). Personal reminiscences of W.N. Christiansen and the early days of Chinese radio astronomy. *Journal of Astronomical History and Heritage, 12*, 33–38.

Wendt, H., Orchiston, W., & Slee, B. (2011). An overview of W.N. Christiansen's contribution to Australian radio astronomy, 1948–1960. In W. Orchiston, T. Nakamura, & R. Strom (Eds.), *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference* pp. 547–587. New York: Springer.

Part IV
Taiwan

Chapter 10
The Development of Astronomy and Emergence of Astrophysics in Taiwan

Wing-Huen Ip

10.1 Introduction

Because of its checkered history, Taiwan did not get involved in the mainstream of astronomical research in the past. That is, while the Jesuits were rushing to Peking via Macau to report to the Imperial Court on the discovery of the Medicean moons by Galileo in 1610 in distant Padova, Taiwan was still very much outside the center of the world order and scientific realm. In spite of its isolation, Taiwan was the scene of several pitched battles in the seventeenth century between the East and the West for political and military control of this beautiful island that just happened to lie on an important international sea route. Taiwan was a place for adventurers then.

When a naval skirmish far away at the mouth of the Yalu River near Korea occurred on 7 September 1894 Taiwan was once again ushered into the limelight of history, with Meiji Japan taking over the administration of the island from the Qing Dynasty of China in 1895. Scientific explorations carried out in Taiwan during the early part of the twentieth century focused mostly on its fauna and flora, even though the majesty of the Jade Mountain, nearly 4000 m in height, was much admired.

Kazuo Kubokawa 窪川一雄 (1903–1943) was instrumental in the plan to develop Taiwan into an international center of solar astronomy (Tsai 2003). Construction of the New High Mountain Observatory proceeded as WWII approached, but finally stopped when Kazuo Kubokawa died in 1943.

Following in the footsteps of the Chinese administration re-installed in 1945, scholars and scientists started to pay attention to scientific infrastructure in Taiwan. It is recorded that Ping-Tse Kao (1888–1970), an astronomer from the Purple

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Fig. 10.1 The present author, Professor Jiunsan Shen and Dr. Chang-Hsien Tsai (*left* to *right*) photographed on 3 June 2005 (*Photograph* Hung-Chin Lin)

Mountain Observatory in Nanjing, moved from Shanghai to Taipei in 1948 and established the Chinese Astronomical Society (see http://en.wikipedia.org/wiki/Ping-Tse_Kao and http://www.qdgxt.cn/show.aspx?id=11&cid=11). But not much happened after that, and even in the early 1980s the only astronomical observatory of any significance in Taiwan was the Taipei Yuan Shan Observatory (1963–2000) with Chang-Hsien Tsai 蔡章獻 (1923–2009) as its long-term Director (see Fig. 10.1).

In spite of its modest scale, the Taipei Yuan Shan Observatory played an important role as a gateway to modern astronomy in Taiwan. This is because most of the present generation of Taiwanese astronomers gained their first experience in and excitement about astronomy by visiting this small observatory which overlooked the crowded city of Taipei (Fig. 10.2).

Another pioneer in the development of astronomy in Taiwan was Professor Jiunsan Shen 沈君山 (b. 1932; Fig. 10.1) who tirelessly wrote many articles and books to popularize science and introduce astronomical knowledge to the young generation during the 1960s.

Such time-honored tradition has been followed, and in keeping with the maintenance of national astronomical infrastructures on the island. It is also for this reason that this historical account will not cover the different scientific fields of astronomy as such but rather will focus on the rapid expansion of Taiwan's astronomical facilities since the early 1990s.

To some extent, the story of Taiwan's astronomy is about how its footprint has spread rapidly in recent years to many corners of the world. But it is also about human nature and academic dynamics.

Fig. 10.2 The Taipei Yuan-Shan Observatory (*Courtesy* Taipei Astronomical Museum)

10.2 Local Developments

Human resources are the most important ingredient in any major enterprise, and astronomy, as the oldest field of modern science, is no exception. The emergence of astronomy in Taiwan was signaled by the establishment of the Graduate Institute of Astronomy at the National Central University and the Institute of Astronomy and Astrophysics of the Academia Sinica (ASIAA), both in 1992. Several universities have subsequently formed institutes of astronomy and astrophysics or related programs. These include the National Taiwan Normal University (1992), National Tsing Hua University (2001), National Taiwan University (2002), and National Cheng Kung University (2008). The combined graduate program is expected to admit each year up to about 30 Master's degree students and 10–15 Ph.D. students. If Taiwanese Ph.D. students trained aboard (typically 5–10 each year) are also taken into account, a quite significant pool of scientific talent is being built up. As for the ASIAA, it first began with radio astronomy, but has since branched out into many different areas of astronomy, with a mushrooming cast of international astronomers. Figure 10.3 shows the explosive growth of the total number of astronomers in Taiwan. It is quite clear that Taiwan is making a mark on international astronomy, with ever-faster pace.

It is generally recognized that the success of Taiwan's astronomy in the long term will depend critically on the interrelation and complementary roles of the ASIAA and

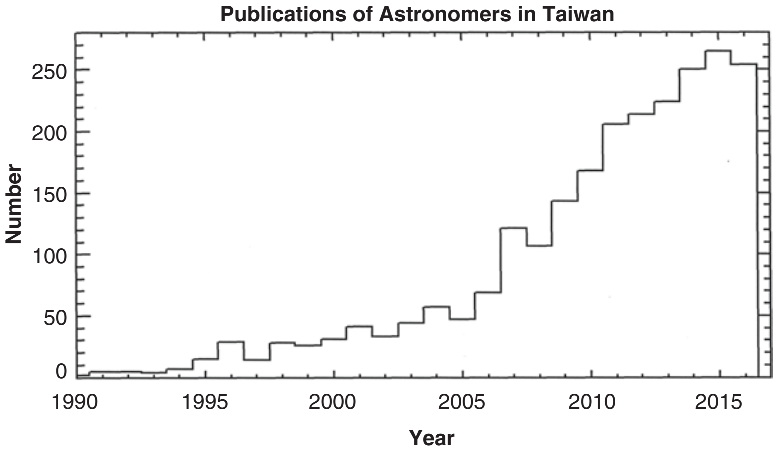

Fig. 10.3 Growth of the number of publications in astronomy in Taiwan (*Courtesy* Wen-Ping Chen)

the university research institutes. The interaction and cooperation between them is thriving. But all this was predated by the joint effort between the ASIAA and the NCU's Institute of Astronomy on the Taiwan America Occultation Survey (TAOS) Project in collaboration with a research group at Smithsonian Astrophysical Observatory (SAO). This project team pioneered a new technique in stellar occultation measurements and has become a hall-mark of how important science can be done with very limited resources (Lee 2009; Lehner et al. 2009; Zhang et al. 2008). In addition to deployment of a new upgraded system (TAOS II) in San Petro Martir, Baja California, Mexico, which will ensure the detection of small Trans-Neptunian Objects, it has also inspired many other similar observations in X-ray and optical wavelengths on space telescopes and ground-based facilities (Chang et al. 2006; Schlichting et al. 2009).

Figure 10.4 shows the site of the Lulin Observatory which hosts the four 50-cm wide-field TAOS telescopes. The Lulin Observatory, which is at 2862 m altitude, was founded in 1998 and is managed by NCU Institute of Astronomy. Its history dates back to the site survey carried out by Wen-Hsiang Tsai 蔡文祥 (then at NCU) in the early 1990s. The working and living conditions were very difficult because of a lack of electricity and a water supply. The push to make Lulin a functioning observatory was only achieved when a grant from the Ministry of Education and National Science Council was approved for building up the national infrastructure in astronomy. A 1-m telescope (called the Lulin One-meter Telescope, or LOT) and a 40-cm telescope (called the Super-Light Telescope, or SLT) are now the 'workhorses' of the Lulin Observatory. The major results are the discovery of about 1000 new asteroids since 2002, and a number of supernovae. The brightest comet (C/2007 N3 Lulin) to appear in the International Year of Astronomy (2009) was discovered at Lulin in 2007 (Chen and Wang 2009a, b). The geographical location of Taiwan provides certain advantages in terms of time coverage (with no major observatories a few hours ahead or behind) and hemispherical coverage (north and south) for

Fig. 10.4 A bird's eye view of the Lulin Observatory which is dedicated to follow-up observations of time-variable phenomena and as a test bed for instrument development (*Courtesy* Institute of Astronomy, National Central University)

time-critical observations such as supernovae detection and gamma-ray burst optical afterglow follow-up monitoring (Huang et al. 2005; Wang et al. 2008). The addition of a 2-m telescope plus advanced instrumentation in 2019 will place Lulin in an important position for the study of time-variable astrophysical objects.

The ASIAA, in cooperation with NTHU Institute of Astronomy, has established the Theoretical Institute for Advanced Research in Astrophysics (TIARA) as an arm for theoretical study and numerical simulations. Besides its own research program with a number of research staff members and postdoctoral fellows, TIARA regularly organizes summer and winter schools on timely topics. This program is of great value in educating and attracting young people to astronomy and hence has been a major asset in the advancement in Taiwanese astronomy (Taam 2009).

10.3 Hawaii

The inroad to Hawaii by the Taiwanese astronomers was spearheaded by the SMA project of the ASIAA. SMA is the abbreviation for the Submillimeter Array which is a joint effort of the Smithsonian Astrophysical Observatory. Located atop Mauna Kea in the Big Island of Hawaii, it composes an interferometric array of eight antennas (Fig. 10.5), with two of them provided by the Taiwanese partner. The radio frequency is from 180 to 700 GHz for observations of rotational transitions of

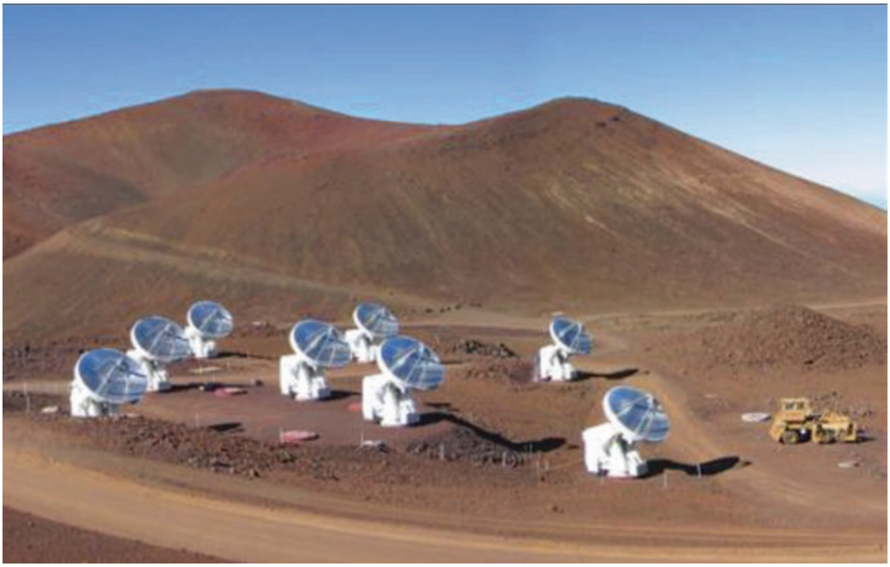

Fig. 10.5 The Submillimeter Array (SMA) on Mauna Kea (*Courtesy* Institute of Astronomy and Astrophysics, Academia Sinica)

dozens of molecular species as well as continuum emission from interstellar dust grains. It has been in operation since 2003 and many exciting results have been produced (e.g., Ho et al. 2004; Ohashi 2009). As will be described later, the SMA was in fact a forerunner for Taiwan's participation in the Atacama Large Millimeter/Submillimeter Array (ALMA) project in Chile (Ohashi 2009).

The Yuan-Tseh Lee Array for Microwave Background Anisotropy (Fig. 10.6), also known as AMiBA (for Array for Microwave Background Anisotropy), was installed on Mauna Loa in 2006. It is a collaborative project of the ASIAA with the Institute of Astronomy of National Taiwan University. Operating as a 13-element interferometer at wavelengths between 86 and 102 GHz, it is used to study distant galaxy clusters and probe the structure of the early Universe (Ho et al. 2009; Umetsu 2009). In its final form, AMiBA with be a 19-element interferometer.

By any measure, the successful construction and scientific operations of SMA and AMiBA by a startup institute in such a short time span would be considered a major achievement. Traced back, credits should be given to a group of American and Canadian astronomers of Chinese origin who made the decision to help Taiwan develop astronomy at the highest level possible. Over the years (i.e., since 1992), they followed step-by-step the road map they had drawn up, setting an example of how scientific enterprise should be nurtured. After radio astronomy, with which much was accomplished, the agenda was to move optical and infrared astronomy forward. The strategy was first to gain access to a middle-sized telescope like the 3.6-m Canada-France-Hawaii-Telescope (CFHT) (see Fig. 10.7). The financial payment to the time subscription (about 7–10 nights per year) over several years since 2002 was to be coupled to the first-hand participation in the development of

Fig. 10.6 The Yuan-Tseh Lee Array for Microwave Background Anisotropy (AMiBA) on Mauna Loa (https://en.wikipedia.org)

Fig. 10.7 The dome of the 3.6-m Canada-France-Hawaii Telescope on Mauna Kea (*Courtesy* The Canada-France-Hawaii Telescope Corporation)

the Wide-field Infrared Camera (WIRCam) instrument. With its 0.5° × 0.5° field of view, WIRCam has rendered CFHT a very powerful telescope for observations in the J, H, K bands. At the same time, access to CFHT (and other infrared telescopes of similar size) has been introduced into the local Taiwanese astronomical community as something of common necessity (Chen and Wang 2009a, b).

The experience gained in the operation and scientific analyses of the four TAOS wide-field telescopes was the driving force behind the motivation of a multi-university group led by NCU Institute of Astronomy to join the Pan-STARRS 1 (PS1) consortium. The PS1 project currently has a 2-m wide-field telescope equipped with the world's largest CCD containing 1.4 Gega pixels in one single image (see Fig. 10.8). The main scientific purpose of this telescope, which is located on Mauna Haleakala in the Maui Island, is to detect fast-moving objects like asteroids and near-Earth objects or transient phenomena like supernovae and GRB optical afterglows (see http://pan-starrs.ifa.hawaii.edu/public/). The Pan-STARRS science is therefore of major interest to some astronomers in Taiwan. But many different topics, including data management issues, are open to Taiwanese astronomers. The Pan-STARRS project has now advanced to the second stage of adding another 2-m telescope (CPS2) to the system, with scientific participation by NCU.

Taiwan's engagement in the development of OIR astronomy became even more visible with the direct participation of the ASIAA in the construction of the HyperSuprime Camera (HSC) for Subaru in collaboration with the National Astronomical Observatory of Japan (NAOJ) and Princeton University. A number of

Fig. 10.8 The Pan-STARRS 1 (PS1) 2-m wide-field telescope on Mauna Haleakala (*Courtesy* Institute for Astronomy, University of Hawaii)

Fig. 10.9 A ‘family portrait’ of the major observatories on Mauna Kea, Hawaii (*Courtesy* The Canada-France-Hawaii Telescope Corporation)

the astronomers in the Taiwanese university community are closely involved in the scientific preparation of the HSC. This activity addresses, albeit to a limited extent, the need for access to 10-m class telescopes like Subaru and Keck. In any event, as shown in Fig. 10.9, astronomers in Taiwan can now gain observational opportunity on most of the major facilities/projects in Hawaii which is a dramatic improvement over the situation barely 20 years ago—just after the demise of the Taipei Yuan-Shan Observatory.

10.4 Chile

ALMA is an extremely ambitious project on millimeter and submillimeter astronomy (see Fig. 10.10). Taking advantage of the dry climate of the Atacama Desert in Chile, this interferometric array consists of sixty-four 12-m antennas that are used for high-resolution imaging and spectroscopic measurements. The ASIAA worked with both the Japanese partner (NAOJ) and the North American partner (NRAO) on the instrumentation and scientific preparations (see http://www.alma.nrao.edu/partners/) leading up to the commissioning of the radio telescopes in 2014. With prior experience gained from using the SMA and other radio telescopes (i.e., the 10-m Submillimeter Telescope (SMT) and the Kitt Peak 12-m Telescope (KP12M), both in Arizona), Taiwanese astronomers can now take full advantage of the technical capabilities of ALMA in producing revolutionary science. Even though Taiwan’s participation in the ALMA project is being led by the ASIAA, the university community has strong participation in the science. In turn, the cooperative efforts and contributions of the university researchers will permit the reaping of the maximum amount of scientific returns.

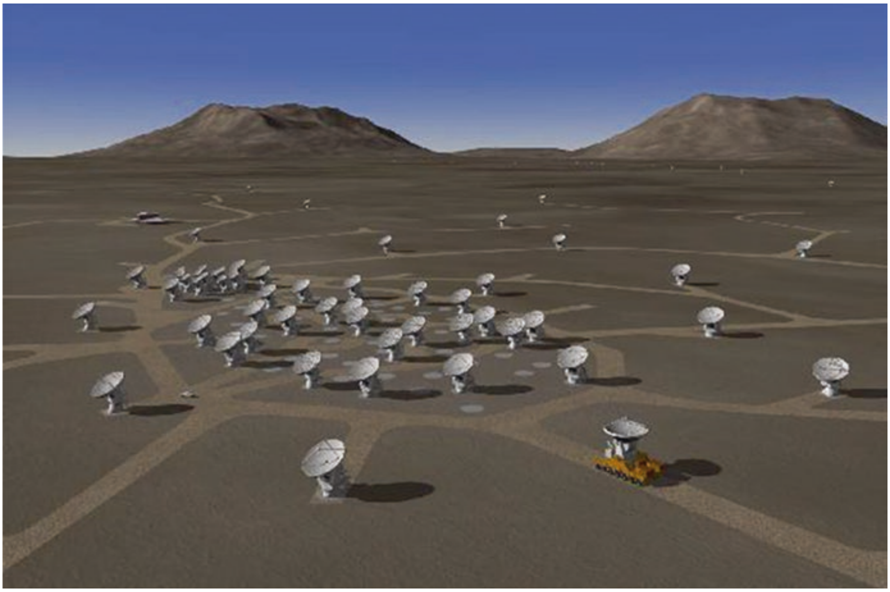

Fig. 10.10 The ALMA radio telescope array in the Atacama Desert, Chile (*Courtesy* ALMA.ESO/NRAO/NAOJ)

10.5 The Future

Though astronomy has a very short history in Taiwan, its recent development and rise over the last two decades must be considered as nothing short of spectacular. In one stroke, Taiwan has secured a foothold in some of the most prestigious international projects and advanced facilities (like ALMA) which will almost guarantee scientific excellence.

This fact should be taken pride of and recognized by the scientific community and society at large. The outstanding role played by the ASIAA and its advisory committee has already been commented on and praised. Similar tributes must be applied to their counterparts in the university research institutes, which will be responsible for sustaining these achievements and the education of a new generation of astronomers who will ‘keep the torch burning’.[1]

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[1] Extract from “Keep the torch burning, or you haven’t won the race” by Sydney J. Harris, *Chicago Sun Times*, 7 May 7 1986: We are so obsessed with “winning the race” in our society that it may be worth remembering that among the ancient Greeks, the runner who won the race was not the one who crossed the line in the shortest time, but the one who crossed it in the least time with his torch still burning. If we run too fast to keep our torch burning, it’s no victory. Many kinds of people make a lot of money preparing for war, nobody immediately gains anything by planning for peace—which no doubt helps explain why we have failed to convert a peace-keeping intent into a peace-keeping capability.

Who knows what the future will bring. A possibility which many of us are hoping for is that, because of its historical background, cultural heritage and academic lineage, Taiwan's astronomical community can serve as the nucleation center and catalyst of a broader Asian consortium grouping the resources and expertise into an international organization similar to the European Southern Observatory. Considering that the total sum of the potential investments by Asian institutions in China, India, Japan, Korea and Taiwan in the next generation of giant telescopes, like the Thirty Meter Telescope or/and the Giant Magellan Telescope, could be ~50% of the cost of any one of these projects, this represents a tremendous amount of capability. Should we plan for it? This move might be a real adventure, with many uncertainties and obstacles. But as history has taught us, Taiwan always has a place for adventurers—and astronomers.

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References

"Astronomy in Taiwan". (2009). A special issue of the *Association of Asia Pacific Physical Societies Bulletin, 19*(5).

Chang, H.K., King, S.K., Liang, J.S., Wu, P.S., Liu, L.C.C., & Chiu, J.L. (2006). Occultation of X-rays from Scorpius X-1 by small trans-Neptunian objects. *Nature, 442*, 660–663.

Chen, M.T., & Wang, S.Y. (2009a). Instrumentation development in Taiwan. *AAPPS Bulletin, 19*, 7–10.

Chen, W.P., & Wang, S.Y. (2009b). Status and initiatives of optical/infrared astronomy in Taiwan. *AAPPS Bulletin, 19*, 17–20.

Ho, P.T.P., Altamirano, P., Chang, C.-H., Chang, S.-H., Chang, S.-W., & 50 coauthors (2009). The Yuan-Tseh Lee Array for Microwave Background Anisotropy. *Astrophysical Journal, 694*, 1610–1618.

Ho, P.T.P., Moran, J.M., & Lo, K.Y. (2004). The submillimeter array. *Astrophysical Journal, 616*, L1–L6.

Huang, K.Y., Urata, Y., Filippenko, A.V., Hu, J.H., Ip, W.H., & 6 coauthors (2005). Optical afterglow observations of the unusual short-duration gamma-ray burst GRB 040924. Astrophysical Journal, 628, L93–L96.

Lee, T. (2009). Catching the shadow of Kuiper Belt Objects: The TAOS Project. *AAPPS Bulletin, 19*, 21–23.

Lehner, M.J., Wen, C.-Y., Wang, J.-H., Marshall, S.L., Schwamb, M.E., & 16 coauthors (2009). The Taiwanese-American Occultation Survey: The Multi-Telescope Robotic Observatory. *Publications of the Astronomical Society of the Pacific, 121*, 138–152.

Ohashi, N. (2009). Submillimeter astronomy in Taiwan. *AAPPS Bulletin, 19*, 11–13.

Schlichting, H.E., Ofek, E.O., Wenz, M., Sari, R., Gal-Yam, A., & 3 coauthors (2009). A single sub-kilometre Kuiper Belt object from a stellar occultation in archival data. *Nature, 462*, 895–897.

Taam, R.E. (2009). The Academia Sinica Institute of Astronomy and Astrophysics. *AAPPS Bulletin, 19*, 3–6.

Tsai, A.L. (2003). The history of astronomy in Taiwan. See: http://www.asiaa.sinica. edu. tw/~altsai/hat/hat.20031229.pdf

Umetsu, K. (2009). The Yuan-Tseh Lee Array for microwave background anisotropy: AMiBA. *AAPPS Bulletin, 19*, 14–16.

Wang, J.-H., Schwamb, M.E., Huang, K.-Y., Wen, C.-Y., Zhang, Z.-W., & 13 coauthors (2008). Early optical brightening in GRB 071010B. *Astrophysical Journal, 679*, L5–L8.

Zhang, Z.-W., Bianco, F.B., Lehner, M.J., Coehlo, N.K., Wang, J.-H., & 20 coauthors (2008). First results from the Taiwanese-American Occultation Survey (TAOS). *Astrophysical Journal, 685*, L157–L160.

Part V
Thailand

Chapter 11
The Development of Astronomy and Emergence of Astrophysics in Thailand

Boonrucksar Soonthornthum

11.1 Introduction: Ancient Astronomy in the South-East Asian Region

The ancient civilization in the South-East Asian region that prospered over 1000 years ago showed some evidence of the development of astronomy. Several ancient temples were built using astronomical principles to mark auspicious occasions for peoples' daily lives.

In ancient times, the civilized Khmer Kingdom ruled a vast area in the South-East Asian region, as shown in Fig. 11.1. For religious purposes, several Khmer temples were built that were dedicated to the Hindu god Shiva. The construction of these temples was not only for religious purposes but also for indicating some important astronomical phenomena relating to people's way of life. A good example of an ancient Khmer temple which still exists in Thailand is Prasat Phnom Rung, which is located in Buriram Province in the north-eastern part of Thailand (Fig. 11.2). The orientation of this temple is 5.5° from due east, and the setting Sun penetrates all 15 doorways of the sanctuary during 5–7 March and 5–7 October and the rising Sun all 15 doorways during 2–4 April and 8–10 September each year. The reason for the orientation of this Khmer temple is still unknown. One possible reason is that the ruler of the Empire used this phenomenon to mark the beginning of the season for cultivation or the beginning of the 'Tropical Year' since, in ancient times, there was no solar calendar and the lunar calendar did not give a precise prediction for the changing of the seasons (Mollerup 2007).

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Historical & Cultural Astronomy, DOI 10.1007/978-3-319-62082-4_11

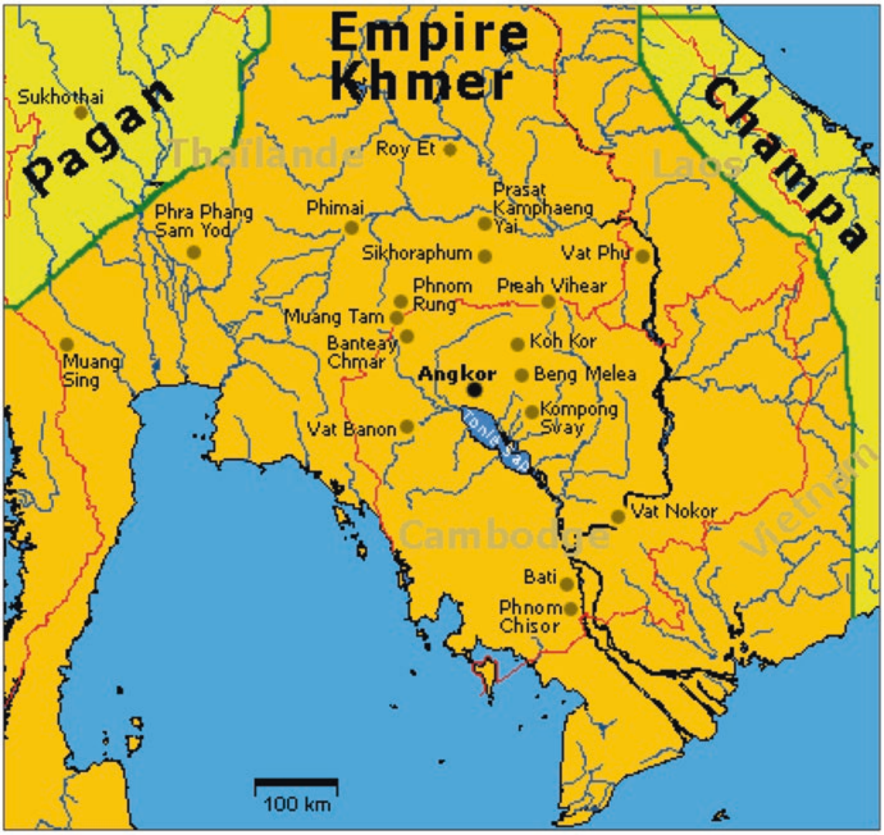

Fig. 11.1 A map of the ancient Khmer Kingdom in South-East Asia, which included parts of present-day Thailand, Cambodia, Laos and Vietnam (http://www.mbs.maine.edu)

Nearly all Khmer temples are found in Thailand, Cambodia and Laos: Kuti Ruesi Ban Khok Mueang and Prasat Plai Bat (both in Buriram, Thailand); Prasat Khorat Kao, Prasat Non Ku and Prasat Phanom Wan (all in Khorat, Thailand); Phu Phek (in Sakon Nakon, Thailand); Preah Vihear (in Cambodia); and Wat Phou (in Laos).

A detailed account of the Phnom Rung Khmer temple is presented by Komonjinda (2011).

11.2 Lanna Astronomy

The Lanna Kingdom was a state in the northern part of Thailand during the thirteenth to eighteenth centuries. It was a prosperous kingdom and its first ruler was King Mangrai. The territories claimed by Mangrai's Lanna included provinces of

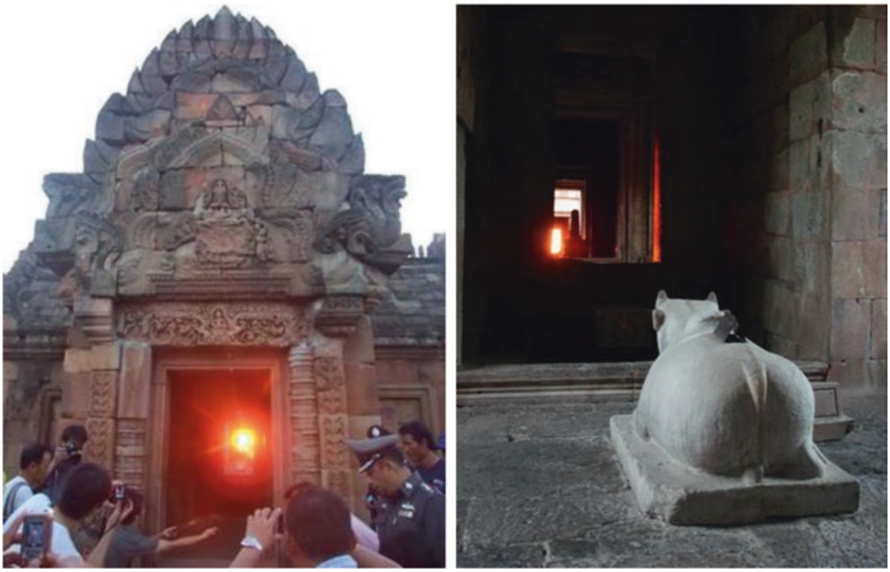

Fig. 11.2 One of the Khmer temples, Prasat Phnom Rung, in the north-eastern part of Thailand at sunset on 6 March 2009 at 6.15 p.m. when sunlight penetrates all 15 doorways of the sanctuary (*Photographs* Boonrucksar Soonthornthum)

modern Thailand, namely Chiang Mai, Chiang Rai, Lamphun, Lampang and Mae Hong Son, but it also included Kengtung and Mong Nai in Myanmar and Chiang Hung (Jinghong) in Southern China. After uniting all of these provinces into a kingdom, King Mangrai established Chiang Mai as its capital city on 12 April 1296 AD. The new city was built and named 'Nopburi Sri Nakorn Ping Chiang Mai'. Folk traditions of the Lanna people partly involved astronomical phenomena and celestial bodies. The Lanna people believed in the cardinal directions dictated by Buddhism, and in the relationship between human lives and celestial bodies. Some evidence of astronomy relating to the Lanna community still exists today, for example, in the orientation of the city walls of Chiang Mai, and in wall or ceiling paintings of the constellations found in temples in Thailand, Cambodia and Myanmar. For further details see Soonthornthum (1999).

11.2.1 The City Walls of Chiang Mai

The actual day when the city of Chiang Mai was founded is recorded on Wat Chiang Man's stone inscription as follows:

> … Sakkarat 658, a rawai-san year, Vaisakha lunar month, the eight waxing day, a Thai muang-plao day in the watch near dawn, 2 luknadi plai 2 bat of water, a Thursday, the Lagna in Mina-po rasi …

The city of Chiang Mai was surrounded by two rows of walls (Fig. 11.3), each of which had five main gates. The design of the city wall was based on Buddhist cosmological principles, with Wat Chedi Luang serving as the center of the Universe.

The concept of the center of the Universe was influenced by Hinduism and comprised a mountain called 'Mount Su Meru'. On its summit was a pavilion to the highest Indian god, Indra. The city walls of Chiang Mai have a square shape (Fig. 11.3), reflecting the belief that the Earth was a flat square figure floating on water with Mount Su Meru serving as the Earth's axis as well as that of the Universe (see Soonthornthum 2004).

11.3 History of Astronomy in Siam

11.3.1 The Ayudhya Period

Siam owes much of the development and popularization of modern astronomy to one particular King of the Ayutthaya era—King Narai the Great—who had a mission to help Siam grow via exposure to Western culture.

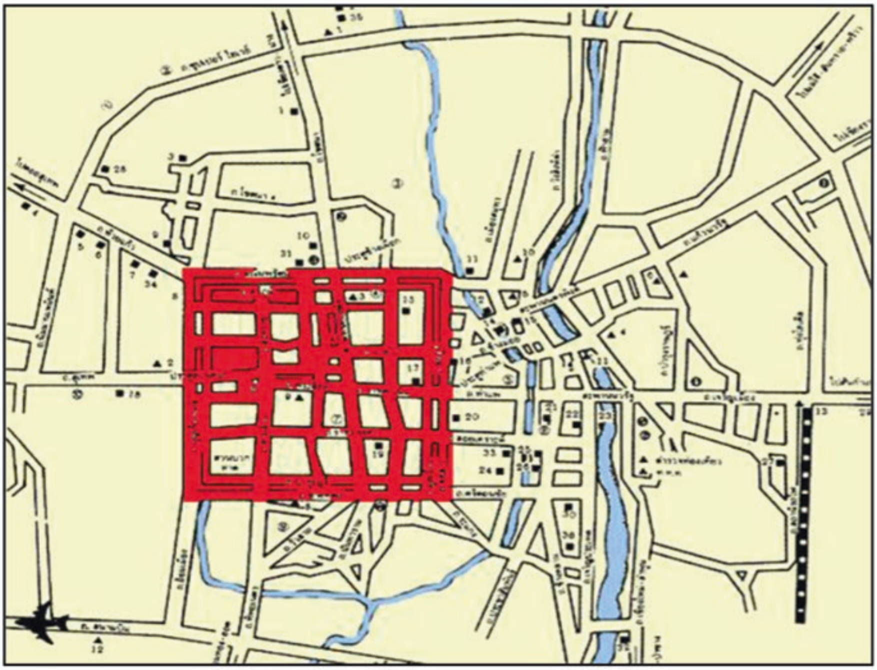

Fig. 11.3 A map showing in *red* the square city walls and the main streets within the 'old city' of Chiang Mai (after Asanajinda 1986)

King Narai had an intrinsic interest in astronomy and Western technology. His fascination with European clocks and telescopes and his overall interest in astronomy began in his youth and was maintained right up to the end of his life. Out of his far-sightedness and well-planned systematic foreign policy, King Narai helped Siam to grow via exposure to Western culture. Shortly after the arrival of a French mission from the court of King Louis XIV (see Fig. 11.4) that included Jesuit missionary-astronomers, King Narai recognized that these sorts of Christians had much to offer the Siamese people, such as knowledge of science, medicine and architecture (see Orchiston et al., 2017). Siam benefited from having such an open-minded and curious King who embraced, rather than pushed away, the outside world. Among various disciplines, astronomy was one of the fields of science that was introduced to the Kingdom of Siam.

To further his own astronomical interests, King Narai invited the visiting Jesuit astronomers to join him at his country retreat near Lop Buri early in the morning on 10 December 1785 and observe a total lunar eclipse. This event is discussed in detail by Orchiston et al. (2016). Figure 11.5 is a copy of a painting that is reputedly of this event, but this has been shown (Orchiston et al. 2016) to include a considerable degree of artistic license.

Fig. 11.4 The French envoy during his audience with King Narai (*Courtesy* National Archives of Thailand)

Fig. 11.5 A painting of King Narai and French Jesuit astronomers observing the lunar eclipse on 10 December 1685 from near Lop Buri (*Courtesy* National Archives, Paris)

These eclipse observations so impressed King Narai that he soon approved the construction of a large astronomical observatory called Wat San Paulo Observatory, which was built in Lop Buri province during 1686–1687. Figure 11.6 shows the general appearance of this octagonal tower observatory—which was modelled on part of Paris Observatory (Orchiston et al. 2017)—and Fig. 11.7 shows current ruins of this impressive structure.

Once it was operational, a variety of astronomical observations were made at Wat San Paulo (Orchiston et al. 2017). The last observations of any consequence made by the French Jesuit missionary-astronomers were of a partial eclipse of the Sun that was viewed from King Narai's Palace in Lop Buri on 30 April 1688 (see Orchiston et al. 2018). Thus, it can be said that 'modern astronomy' began in present-day Thailand at Lop Buri during the seventeenth century (Sawasdee 2000).

This was a particularly challenging undertaking, which aimed to shape a modern knowledge-based nation, something that King Narai endeavored to fulfill throughout his enlightened reign. However, due to changing foreign policy and some restrictions in the country after his death, scientific astronomy was not able to continue in Siam.

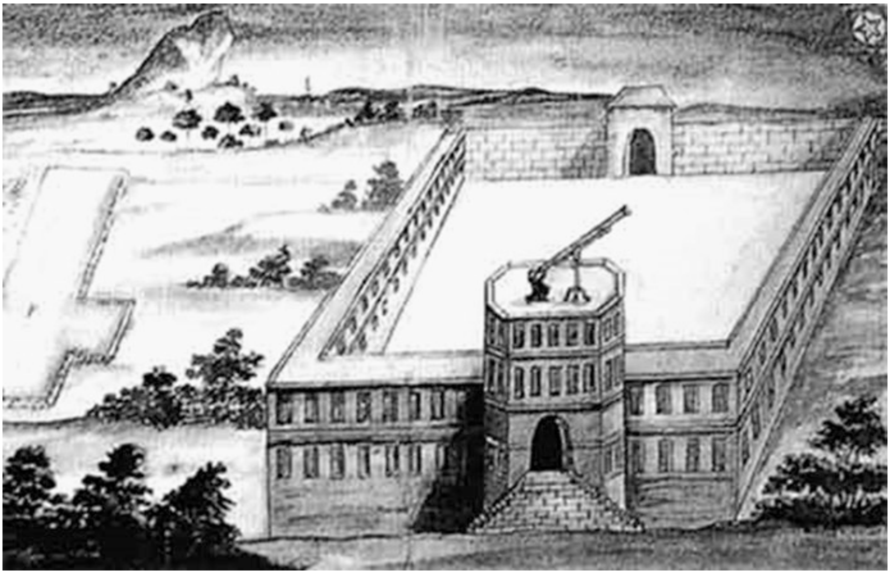

Fig. 11.6 (**above**) A drawing of Wat San Paulo, the first scientific astronomical observatory in Siam (*Courtesy* National Archives, Paris)

Fig. 11.7 (**right**) Ruins of Wat San Paulo Observatory (*Photograph* Boonrucksar Soonthornthum)

11.3.2 The Rattanakosin Period

A number of different kings of Siam were interested in and gave patronage to astronomy so that it could flourish in Siam. The first after King Narai was King Rama IV of the Chakri Dynasty, better known as King Mongkut (Fig. 11.8; Saiberja 2006), and he gave life back to modern astronomy in Siam during the second half of the nineteenth century. King Mongkut was an accomplished scientist who was particularly interested in astronomy. At that time, Siamese astrologers did not believe it was possible to predict solar and lunar eclipses or, to use their own words, "… the mysterious act of stars' gods and goddesses which left no space for human beings to mess with."

In his spare time, King Mongkut studied Hinduism and Western astronomical text books imported from Europe. Equipped with telescopes and other scientific instruments, he was able to study the sky and celestial phenomena in depth. His masterpiece was the accurate calculation and prediction of the time and location of the path of totality of the total solar eclipse of 18 August 1868—to the acclaim of professional European astronomers. In his endeavor to establish a scientific community in the country, he had the Royal Family and members of the foreign community accompany him to witness the eclipse at Wah Koa sub-district in

Fig. 11.8 A portrait of King Mongkut (*Courtesy National* Archives of Thailand)

Fig. 11.9 King Mongkut's expedition to Wah-koa to observe the total solar eclipse of 1868; and inset photograph shows the eclipse during totality (*Courtesy* National Archives of Thailand)

Prachaubkhirikhan Province (Fig. 11.9). He also invited a French observing team to Siam, which likewise was based at Wah-Koa (see Orchiston and Orchiston 2017).

King Rama IV publicized scientific information on astronomical phenomena for the public and brought Siam into the modern scientific era. For this reason, in 1982 during Bangkok's Bicentennial Anniversary Year, the Thai Government designated King Rama IV the 'Father of Thai Science'.

Just 7 years after King Rama IV died from a fever contracted on the journey to observe the 1868 eclipse, another total solar eclipse was visible from Siam. King Rama V expressed great interest in observing this event on 6 April 1875, following his father's lead. He therefore invited British & French astronomers to Siam, promising every possible aid with their observations. An observatory was built by order of the King on Chao Lai Peninsula in Petchaburi Province. The British expedition to Siam was led by Dr. Arthur Schuster (Fig. 11.10) from the University of Manchester (see Hutawarakorn-Kramer and Kramer, 2017). The observatory and telescopes were set up and the observations of the total solar eclipse were successful (e.g., see Fig. 11.11). The results of the observations proved for the first time the existence of calcium in the solar chromosphere and in prominences.

The seventh monarch of Siam of the House of Chakri, King Rama VII, also took an entourage to visit German astronomers who set up an observing camp to watch a total solar eclipse at Khok Pho District in Pattani on 9 May 1929. A

Fig. 11.10 A photograph showing the British observing team and the Royal Family of Siam during the observations on 6 April 1875 (*Courtesy* University of Manchester Library)

number of astronomers from the USA, Japan and England also came to the site, bringing with them modern astronomical equipment for scientific observation of the eclipse (Fig. 11.12). This, in a way, aroused much public interest in astronomy.

The continuing interest in astronomy by members of the Thai Royal Family extended to the revered late King, Bhumibol Adulyadej (Rama IX) who died on 13 October 2016, and one of his daughters, Her Royal Highness Princess Maha Chakri Sirindhorn. Two total solar eclipses observable from Thailand occurred during King Rama IX's reign, on 20 June 20 1955 and 24 October 1995.

However, in spite of the fact that astronomy was popularized in Thailand for more than a 100 years, there is no record of astronomy education in the past.

11.4 The Recent Development of Astronomy in Thailand

In recent years, the development of research, education and public outreach in astronomy and astrophysics in Thailand has been carried out progressively. During the last 85 years attempts were made to develop astronomical research in Thailand. Thus, in 1930 astronomical research was established at Chulalongkorn University

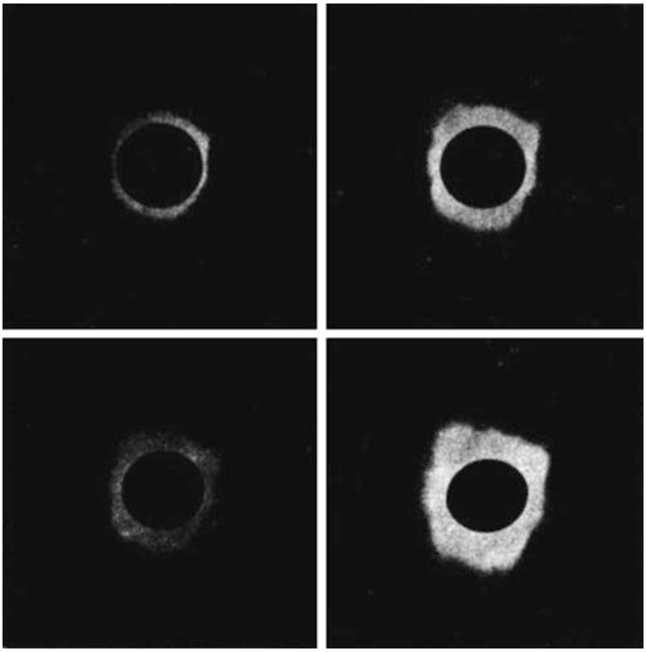

Fig. 11.11 Four photographs of the total solar eclipse taken by a Mr. Beasley of the British team, using a small camera (*Courtesy* University of Manchester Library)

in Bangkok, the first university in Thailand (and named after King Rama V). A solar observatory and a research group in solar physics were established, led by Professor Rawee Bhavilai, a solar physicist. In October 1989 a 0.45-m reflecting telescope was donated to Chulalongkorn University by the Government of Japan under a cultural grant aid program for the promotion of astronomical education and research in Thailand. More recently, a new astronomy and astrophysics research group has been initiated at Chulalongkorn University. The main research is on the study of high energy particles in space, in cooperation with Mahidol University.

In 1977, astronomical research was initiated at Chiang Mai University, the first university in northern Thailand, in Chiang Mai Province. An observatory, named Sirindhorn Observatory, was established, and a small research telescope, a 40-cm Cassegrainian reflector, was installed under the supervision of foreign experts from the UK and USA. Astronomical research, particularly photometry of variable stars, was systematically introduced, and more detectors were provided for use with the telescope. Meanwhile, staff were trained in foreign countries such as the UK, Australia and New Zealand. Later, a 50-cm Ritchey-Chrétien reflector was installed at Sirindhorn Observatory, and used for binary star research.

In recent years, astronomical research groups have developed at several other universities, such as Mahidol University in Bangkok (work on high energy astrophysics and space weather), Naresuan University in Pitsanulok Province (variable

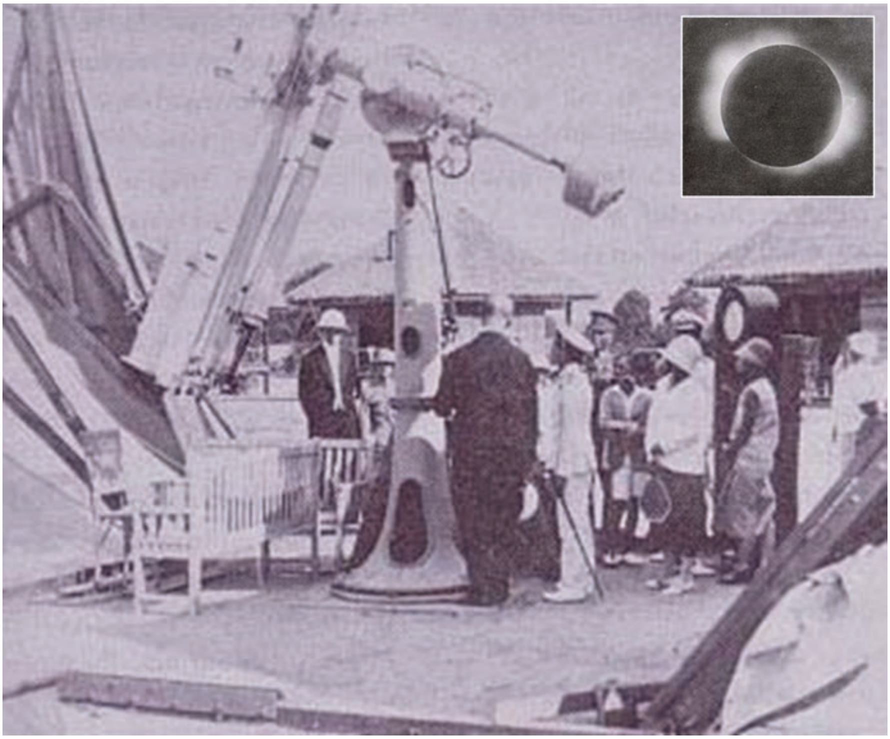

Fig. 11.12 King Rama VII observed the total solar eclipse of 9 May 1929; the inset shows a photograph of the eclipse taken at totality (*Courtesy* National Archives of Thailand)

stars, transient phenomena and theoretical astrophysics and cosmology), Khon Kaen University in Khon Kaen Province (galactic structure and radio astronomy), Ubon Rachathani University in Ubon Rachathani Province and Rajabhat Udon Thani University in Udon Thani Province (radio astronomy) and Mae Fah Luang University in Chiang Rai Province (very high energy gamma ray astronomy). Various universities in Thailand are responsible for higher education in astronomy both at undergraduate and postgraduate levels. Although degree programs up to the Ph.D. in astronomy and astrophysics are now offered at most Thai public universities, professional telescopes and equipment, and staff with teaching and research experience are still needed at most universities.

Many academic institutes and science centers throughout Thailand are involved in promoting education and the popularization of astronomy. At present, astronomy is becoming popular in Thailand. Communities enjoy participating in astronomical activities and learning more about astronomy. Astronomy is one of the important tools for promoting public science awareness and alertness. Many organizations, including the Thai Astronomical Society, the Promotion of Academic Olympiads and the Development of Science Education Foundation, universities, schools, etc., organize various astronomical activities and public outreach programs.

Astronomy camps for students are organized by universities and the Thai Astronomical Society. The Promotion of Academic Olympiads and Development of Science Education Foundation in collaboration with universities organizes intensive training courses for students in the astronomy Olympiad and the National Astronomy Olympiad Competition. The first International Olympiad in Astronomy and Astrophysics (first IOAA) was held in Chiang Mai Province, Thailand, from 30 November to 9 December 2007. This international astronomical activity involved many organizations in Thailand and had a high visibility among the public.

Astronomical public services have become more popular in Thailand. Many observatories, mostly belonging to universities, open regularly to the public, especially when some interesting astronomical phenomena such as eclipses, meteor showers, planetary oppositions, etc., can be observed. Members of the public are always alerted by the media to share the observation of these astronomical phenomena.

During the past decade, several organizations have established an astronomy information system through computer networks. The Institute for Promotion in Teaching Science and Technology in collaboration with the Faculty of Science at Chiang Mai University has initiated an ‘Astronomy Network for Schools’. The purpose of this network is to provide up-to-date astronomical information for schools and the public. Many hands-on activities and astronomical images are provided through this network.

In previous decades, astronomy education at school the level was for the most part neglected, with some astronomy content only offered in secondary schools for Arts students. In 2001, the Ministry of Education carried out a major revision of the Science content for schools, and decided to add Astronomy to the National Science Curriculum in Basic Science and make it compulsory at all levels from Grade 1 to Grade 12. The Basic Education Curriculum B.E. 2544 was established, and learning material was organized into eight subject groups, including Science. Within the Science group, Astronomy and Space is one of the eight topics.

The result of this major revision of the National Science Curriculum was a serious shortage of teachers who were capable of teaching Astronomy. Moreover, the lack of suitable astronomy text books and teaching resources for schools was another barrier to teaching Astronomy in schools. The Institute for Promotion in Teaching Science and Technology is in charge of the development of the astronomy content in the National Science Curriculum, with the close collaboration of universities and the National Astronomical Research Institute of Thailand (NARIT).

11.5 The Development of NARIT

During the past decade, the Government's national plan for the development of science and technology has focused on human resources and given priority to the development of basic science, including astronomy.

The development of astronomical research in Thailand took a crucial leap forward when on 20 July 2004 the Government approved the "Establishment of the National Astronomical Research Institute of Thailand (NARIT)" under the Ministry of Science and Technology. On 1 January 2009 NARIT was approved by the Government and officially established with the status of a public organization responsible for policy-making and strategic planning in the development of astronomy in Thailand. It was decided that NARIT would be based in northern Thailand, in Chiang Mai, Thailand's second-largest city. It was anticipated that the establishment of NARIT would lead to the national development of astronomical infrastructure and human resources.

In January 2013, just 4 years after NARIT was founded, Her Royal Highness Princess Maha Chakri Sirindhorn officially opened the Thai National Observatory (TNO) on Doi Inthanon, Thailand's highest mountain (Fig. 11.13). The flagship

Fig. 11.13 The Thai National Observatory (TNO) is located near the summit of Doi Inthanon, a 2-h drive west-southwest of Chiang Mai (travel.mthai.com)

Fig. 11.14 Two views of the automated 2.4-m Richey-Crétien Thai National Telescope. *Left*: undergoing testing prior to its installation at the TNO; *right*: installed and operational at the TNO (*Courtesy* NARIT)

instrument at the TNO is a 2.4-m Richey-Crétien telescope (Fig. 11.14), which is available to Thai and overseas researchers. To provide real-time research access to the entire sky, NARIT also has established an international network of 70-cm remote telescopes, in Australia, Chile, China and the USA.

From the start NARIT also had plans to establish six public observatories throughout Thailand, as follows:

1. Central/Eastern Thailand: Cha-Cheong-Sao Province
2. Upper North-Eastern Thailand: Konkaen Province
3. Lower North-Eastern Thailand: Nakhon Rachasima Province
4. Southern Thailand: Songkla Province
5. Upper Northern Thailand: Chiang Mai Province (at Princess Sirindhorn AstroPark in Chiang Mai)
6. Lower Northern Thailand: Pitsanulok Province

Their geographical distribution is shown in Fig. 11.15. By the time this book is published (i.e., in late 2017), four of these (numbers 1, 3, 4 and 5) will be operational. Each regional observatory (Fig. 11.16) will include trained staff, astronomy displays, class rooms, a lecture theatre, a planetarium, a (Fig. 11.17), dedicated facilities for telescope observing (Fig. 11.18) and a 0.5-m telescope (see Fig. 11.19).

Fig. 11.15 A map showing the distribution of existing or planned NARIT regional observatories in Thailand (*Map* NARIT)

The purpose of establishing these public observatories is to distribute opportunities in research, education and public outreach activities throughout the entire country. Meanwhile, the data and astronomical images taken by the 2.4-m telescope at the TNO can be transmitted in real-time to the public observatories through fiber optics.

NARIT is a public organization established directly under the Ministry of Science and Technology. Therefore, NARIT is directly involved in policy making for astronomical research, promoting astronomy education and popularization plans for Thailand. NARIT has arranged 4-year strategic and action plans with concrete

Fig. 11.16 A typical NARIT regional observatory, showing the main building with its class rooms, lecture theatre and the planetarium (*Courtesy* NARIT)

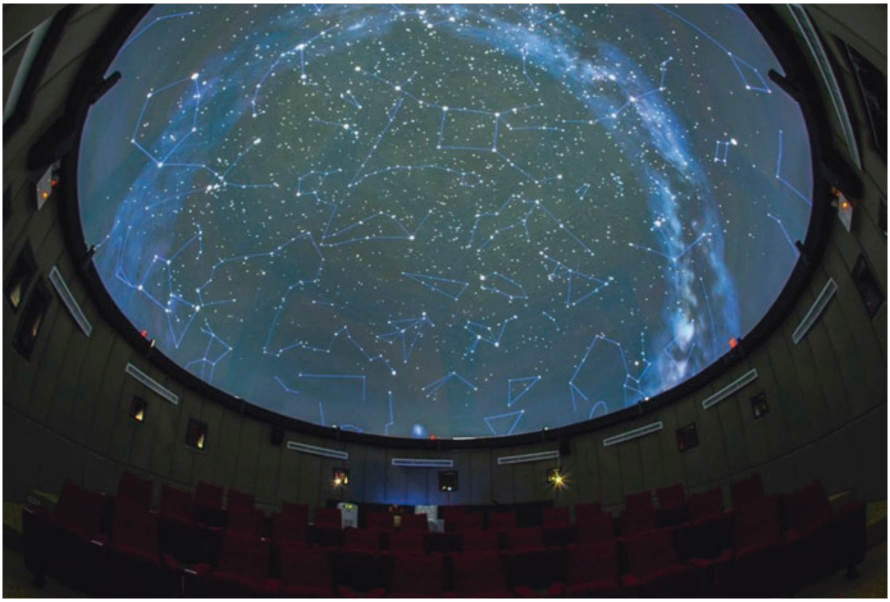

Fig. 11.17 The 50-seat 25-m planetarium, with an all-sky digital projector (*Courtesy* NARIT)

indicators for outputs and outcomes in correspondence with the Government's National Science and Technology policy and strategic plan (Kramer 2006).

One of the key success factors for the development of astronomical research activities in Thailand and South-East Asian countries is to promote an astronomical research network with research institutes and universities at both national and international levels. At the national level, in July 2007 NARIT signed an official

Fig. 11.18 The separate observing precinct with portable telescopes, and the dome of the main telescope (*Courtesy* NARIT)

Fig. 11.19 The 50-cm telescope in the dome (*Courtesy* NARIT)

memorandum of understanding (MOU) with 24 public Thai universities that had Faculties of Science that were able to collaborate in astronomical research, public outreach and human resource development. At the international level, NARIT now has official collaborations with various institutes, such as Jodrell Bank Observatory of the University of Manchester, the Astrophysics Research Institute (ARI) of Liverpool John Moores University in the U.K. and Yunnan Observatory, Chinese Academy of Sciences, Peoples Republic of China. NARIT currently (i.e., in early 2017) has MOUs with universities, observatories and research institutes in 15 different countries. These MOUs relate to research or instrumentation collaborations in various areas of astronomy.

Being aware of the importance of promoting and strengthening astronomical research in ASEAN nations, representatives of astronomy from throughout South-East Asia organized a meeting on 23 March 2007 in Bangkok, Thailand, to discuss the possibility of establishing a ‘South-East Asian Astronomy Network’ (SEAAN), with well-established astronomy institutes in some developed countries acting as mentors. The goals of this network were to establish strong research collaborations, identify key science appropriate to the region, share instruments and develop and utilize human resources among South-East Asian countries. The network now has annual meetings in different cities throughout the region, and acts as a regional platform to bring the advancement in astronomy to each member country. Research collaborations have been organized or are planned in optical and radio astronomy, in the development of instrumentation, and in history of astronomy, not just within the SEAAN region, but also with institutes in Australia, China, India, Japan, Korea and Taiwan.

As a further development of its international charter, in 2016 NARIT was approved by UNESCO to host the ‘International Training Centre in Astronomy’, and in 2017 began a schedule of workshops and training programs in astrophysics, astronomical instrumentation and ethnoastronomy. International astronomy collaborations and networks seem to flourish and go smoothly in the Kingdom of Thailand.

After all of this impressive and intensive activity in optical astronomy, the next phase in the development of Thai astronomy will be in radio astronomy. NARIT has secured Government funding for the erection in 2017 of a 40-m radio telescope in northern Thailand. This will be used as a stand-alone research facility, and also for Very Long Baseline Interferometry (VLBI) both with radio telescopes to the north, in China, South Korea and Japan, and to the southeast, in Australia and New Zealand. In addition, a 13-m radio telescope will be erected at the same time for geodetic research.

11.6 Concluding Remarks

The role of NARIT, with strong support from the Government and collaboration with other countries as keys to success, is crucial for the future development of astronomy in Thailand. Achievement in astronomical research will improve academic standards in science and technology and strengthen astronomical activities not only in Thailand, but also in the international astronomical community as a whole.

NARIT’s role in supporting education and popularization will help promote astronomical public activities in Thailand. Students and people in Thailand will have more opportunities to access standard astronomical facilities and learning materials. Within the next decade, all astronomy school teachers should be well-trained and able to conduct both formal and informal astronomy education programs efficiently. Consequently, the final goal of NARIT in supporting astronomy education and popularization is to assist Thailand in becoming a learning- and knowledge-based society.

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References

Asanajinda, P. (1986). Aiming directions for the construction of Chiang Mai's city wall. In *Chiang Mai City Wall. Inauguration and Celebration of Tha Pae Gate*. Chiang Mai (in Thai).

Hutawarakorn-Kramer, B., & Kramer, M. (2017). King Rama V and British observations of the 6 April 1875 total solar eclipse from the Chao Lai Peninsula, Siam. In T. Nakamura, & W. Orchiston.

Komonjinda, S. (2011). The Sun and fifteen doorways of *Phnom Rung*. In *Proceedings of the International Astronomical Union, 7,* 325–330.

Kramer, B. (2006). Astronomy in Thailand. In J.B. Hearnshaw, & P. Martinez (Eds.), *Astronomy for the Developing World* (pp. 123–127). Cambridge: Cambridge University Press.

Mollerup, A. (2007). The Sun, the Moon and *rahu* at Prasat Phanom Rung. *Muang Boran Journal, 33*(2), 32–44.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Orchiston, W., & Orchiston, D.L. (2017). King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-koa, Siam. In T. Nakamura, & W. Orchiston.

Orchiston, W., Orchiston, D.L., George, M., & Soonthornthum, B. (2016). Exploring the first scientific observations of lunar eclipses made in Siam. *Journal of Astronomical History and Heritage, 19,* 25–45.

Orchiston, W., Orchiston, D.L., George, M., Soonthornthum, B., & Komonjinda, S. (2017). Seventeenth century Jesuit astronomical activities in Siam. In Y.-L. Shi (Ed.), *Astronomical Heritages in Asia-Pacific Areas*. Hefei: University of Science and Technology of China.

Orchiston, W., Orchiston, D.L., George, M., Gislén, L., Débarbat, S., Husson, M., & Launay, F. (2018). The first scientific observations of a solar eclipse made from Siam. In W. Orchiston & M. Vahia (Eds.), *Exploring the History of Southeast Asian Astronomy: A Review of Current Projects and Future Prospects and Possibilities*. Cham: Springer.

Saiberja, N. (2006). King Mongkut: the Father of Thai Science. In K.Y. Chen, W. Orchiston, B. Soonthornthum, & R. Strom (Eds.), *Proceedings of the Fifth International Conference on Oriental Astronomy* (pp. 15–18). Chiang Mai: Chiang Mai University.

Sawasdee, A. (2000). In Bhumadhon, P. (Ed.), *Astronomical Archives from France Concerning the Kingdom of Siam during the Reign of King Narai* (pp. 89–127). Bangkok: The Thai Astronomical Society (in Thai).

Soonthornthum, B. (1999). Astronomy in old Lanna's culture. In M. Hirai (Ed.), *Proceedings of the Third International Conference on Oriental Astronomy, Fukuoka, Japan 27–30 October 1998* (pp. 41–46). Fukuoka: Fukuoka University of Education.

Soonthornthum, B. (2004). The solar shadow and city walls of Chiang Mai. In W. Orchiston, F.R. Stephenson, S. Débabat, & I.-S. Nha (Eds.), *Astronomical Instruments and Archives from the Asia-Pacific Region* (pp. 51–54). Seoul: IAU Commission 41.

Soonthornthum, B. (2011). The emergence of astronomy in Thailand. In T. Nakamura, W. Orchiston, M. Sôma, & R. Strom (Eds.), *Mapping the Oriental Sky: Proceedings of the Seventh International Conference on Oriental Astronomy* (pp. 179–186). Tokyo: National Astronomical Observatory of Japan.

Chapter 12
King Rama IV and French Observations of the 18 August 1868 Total Solar Eclipse from Wah-koa, Siam

Wayne Orchiston and Darunee Lingling Orchiston

12.1 Introduction

During the second half of the nineteenth century total solar eclipse expeditions were an important element of international astronomy, as scientists strove to better understand the nature of prominences, the chromosphere and the corona. By 1868 most astronomers associated all three with the Sun rather than the Moon or the Earth's atmosphere (Clerke 1893), but their precise nature and composition were the subject of much debate (see Meadows 1970; Pearson 2010).

The introduction of astronomical photography and astronomical spectroscopy at this time led to new breakthroughs, as photography provided astronomers with a permanent record and took the onus away from that remarkably unreliable photon discriminator, the human eye (Lankford 1984), while spectroscopy revealed—for the very first time—the elemental composition of prominences, the chromosphere and the solar corona (Lockyer 1887).

As Clerke explains (1893: 209, our italics), the total solar eclipse of 18 August 1868 has a special place in the history of solar physics:

> In the year 1868 *the history of eclipse spectroscopy virtually began* … On the 18th of August 1868, the Indian and Malayan peninsulas were traversed by a lunar shadow producing total obscuration during five minutes and thirty-eight seconds. Two English and two French expeditions were dispatched to the distant regions favoured by an event so propitious to the advance of knowledge, chiefly to obtain the verdict of the prism as to the composition of prominences.

In this chapter we focus on one of the two French expeditions, which was based at what is now called Wah-koa in Siam (or the Kingdom of Thailand, as it is now known).

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Historical & Cultural Astronomy, DOI 10.1007/978-3-319-62082-4_12

12.2 The 1868 Eclipse

Figure 12.1 shows the path of totality of the 18 August 1868 eclipse, which extended from Aden in the Arabian Peninsula, across India, Thailand, Borneo, Sulawesi (at the time known as the Celebes), the well-known Indonesian Spice Islands of Ambon and Ceram, through the extreme southern part of New Guinea and on to islands in the New Hebrides. Sunset took place at those localities within the right hand ellipse, so the end of the eclipse was not visible; conversely, the start of the eclipse could not be observed from places within the left hand ellipse, for the eclipse was already in progress there at sunrise. Meanwhile, the dashed and solid lines to the north and south of the path of totality indicate regions where a partial eclipse would be visible (weather permitting).

One year before the eclipse the Austrian astronomer Edmund Weiss (1837–1917) commented on the unique nature of this particular eclipse:

> At the commencement of the eclipse the Moon has just passed a perigee of uncommon proximity, and reaches during it the ascending node of her orbit. The eclipsed Sun rises therefore nearly to the zenith of those countries where the eclipse takes place at noon: hence the augmentation of the Moon's diameter, due to her altitude, is a maximum, and the velocity, with which the shadow hurries over the surface of the Earth, a minimum. The result of the coincidence of all these favourable conditions is an eclipse, which, as to its size, belongs to the largest that can happen in general, and has indeed in the annals of mankind no rival … (Weiss 1867: 307–308).

Weiss also pointed out that the maximum duration of totality of this—the longest eclipse then known—would take place " … in the Gulf of Siam where it reaches on the central line 6 m 50 s …" (Weiss 1867: 307), which is more than 1 min longer than those observing from India could expect. While one of

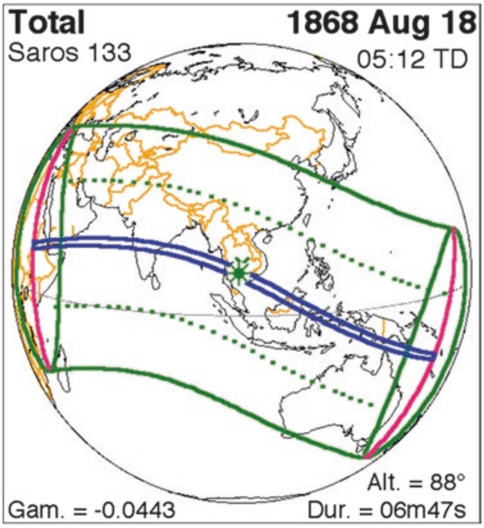

Fig. 12.1 A map showing the path of totality of the total solar eclipse of 18 August 1868 (after Espenak and Meeus 2006)

Fig. 12.2 A map showing Wah-koa (the *red bull's eye*) and the path of totality across Siam (*Map modification* Wayne Orchiston)

the French observing sites was indeed in India, it is notable that the other site, Wah-koa, was in Siam (Fig. 12.2) and very close to the point where the totality was of maximal duration. In this regard, it could not have been more ideally situated, but the nature of the observing site did provide some grounds for concern: because the eclipse would occur during the monsoon (wet) season there was no guarantee of clear skies on the vital day, but if an observing site was chosen on the eastern margin of a continent, shielded to the west by hills or mountains, this afforded the greatest likelihood of success. As Fig. 12.2 reveals, Wah-koa was on the east coast of a narrow isthmus linking Siam and Malaya (as it then was), but its one saving grace was the presence of nearby 500–1500 m high mountains immediately to the west of the narrow coastal flat where the eclipse camp was sited.

12.3 Initial Planning

As Launay (2012: 35) reveals, the origin of the French Wah-koa expedition was steeped in intrigue and frustration, and almost never happened. Thus,

> While the British were getting organized to observe from India, the Germans from Aden, and the Dutch from the Celebes, France, which has initially thought to entrust observations to seamen, rather than astronomers … vacillated.

The fact that totality would last an unbelievable 6 m 57 s and that there might be time for the spectroscope to reveal new scientific secrets of prominences and the solar corona eventually forced a change of heart, but by the time Paris Observatory's highly unpopular Director, Urbain Le Verrier (1811–1877; Lequeux 2013) got around to approaching the Minister of Science, Victor Duruy had already committed Government funding to an expedition led by the ever-popular Jules Janssen (as Janssen was only too happy to report to Le Verrier).

But Le Verrier was a shrewd and tenacious tactician, and eventually he got approval for 'his' eclipse expedition, although

> The decisions were not taken without bitter tensions. Duruy had to intervene once more, and signed the order for the expedition on 29 May, that is, 2 months after Janssen's [and just 2 and a half months before the eclipse]. The French team for Siam had the remarkable credit [i.e., budget] of 50,000 F, the [i.e., one] third of the Paris Observatory annual budget. (Lequeux 2013).

12.4 The Personnel

For the French expedition to Siam Le Verrier selected three astronomers, one from Marseille Observatory and two from his own institution, Paris Observatory.

Leading the expedition was Édouard Stephan (whose name is sometimes incorrectly spelled Stéphan), the Director of Marseille Observatory. Édouard Jean-Marie Stephan (Fig. 12.3; Tobin 2014) was born in Sainte Pezenne on 31 August 1837 and "… after entering the École Normale Supérieure in 1859, he demonstrated his academic brilliance, graduating in first place in 1862." (Bosler 1924: 10; our English translation). He then joined Paris Observatory and 3 years later was awarded a D.Sc. In 1866 Stephan "… was assigned to complete a transfer of the Observatory of Marseilles from the Montée des Accoules to its new site on the Plateau Longchamp. In 1873 he was appointed the observatory's official director …" (Tobin 2014: 2053), a positon he held when he went to Siam in 1868 and retained until his retirement in 1907. During his time in Marseille Stephan discovered and measured the positions of hundreds of galaxies, including 'Stephan's Quintet' (Tobin 2014), at a time when their extragalactic nature was not known. He also was the first to try to use optical interferometry to determine the diameter of a star, in this case Sirius. This investigation, which was carried out in 1873 with the Observatory's 80-cm reflector, was unsuccessful (Tobin 2014). Stephan became an Officer of the Légion d'honneur in

Fig. 12.3 Édouard Stephan (https://en.wikipedia.org)

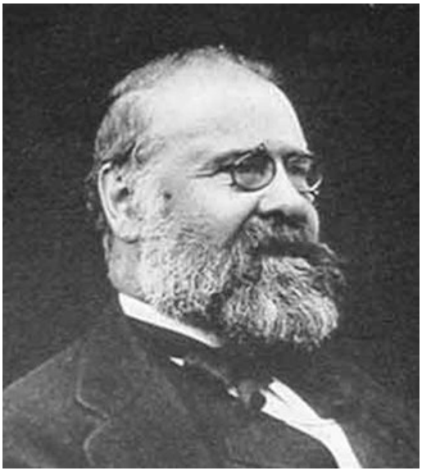

Fig. 12.4 Georges Rayet (adapted from *Astrophysical Journal* 1907: facing page 53)

1879 and was awarded the Vals Prize in 1884 by the Académie des Sciences. He died on 31 December 1923 (Bosler 1924). Strangely, Tobin's Stephan essay in the *Biographical Encyclopedia of Astronomers* (2014) does not mention the 1868 solar eclipse expedition. Should this be taken as a portent of its international significance? We will return to this issue later.

Supporting Stephan on the solar eclipse expedition was Georges-Antoine-Pons Rayet (Fig. 12.4), who was born near Bordeaux on 12 December 1839 (nearly two and a half years after Stephen). According to Baum (2014), Rayet received no formal schooling until he was 14, when his parents moved the family to Paris. Like Stephan, he then trained at the École Normale Supérieure, and in 1863 he joined the newly formed weather-forecasting service at Paris Observatory, but "He was also attracted by spectroscopy, then a new branch of research …" (Georges Rayet 1907: 53).

In 1867 Rayet and fellow Paris Observatory staff member, Charles-Joseph-Étienne Wolf (1827–1918; Grillot 2014)

> … detected a class of rare, exceptionally hot stars whose spectra show strong broad emission lines of helium, carbon, and nitrogen. Wolf-Rayet stars, as they are known after their discoverers, are about twice the size of the Sun, and have a rapidly expanding outer shell—the source, it is thought, of the emission lines. The residual hydrogen envelopes of these stars have been stripped away (by stellar winds or mass transfer), revealing their deeper layers. Most central stars of planetary nebulae are of this type (Baum 2014: 1804).

Presumably it was the discovery of this new class of star (see Wolf and Rayet 1866) and his spectroscopic experience that prompted Rayet's appointment to the 1868 solar eclipse expedition. After the Siamese sojourn Rayet returned to Paris Observatory but eventually he and Director, Urbain Le Verrier, fell out and Rayet was dismissed. In 1877 he accepted a Professorship in Bordeaux and 2 years later also was appointed founding director of the new Bordeaux Observatory at Floirac, where he carried out astrometric research on stars and nebulae. In his later years, Rayet arranged for Bordeaux Observatory to join the International Carte du Ciel Project, and he died in Floirac on 14 June 1906 a year after publishing the first Bordeaux Carte du Ciel results (Wolf and Rayet 1866).

The third astronomer to join the Siamese expedition was the youthful François-Félix Tisserand (Fig. 12.5). Tisserand was born in Nuits-Saint-Georges, Burgundy, on 13 January 1845, and like the other two expedition astronomers studied at the École Normale Supérieure, mimicking Stephan by topping his class and then joining the staff of Paris Observatory (Debarbat 2014). After the solar eclipse expedition he returned to Paris Observatory, only to accept the Directorship of Toulouse Observatory in 1873. Five years later he was teaching celestial mechanics at the Sorbonne, and in 1892 he was appointed Director of Paris Observatory. Tisserand's greatest gift to astronomy was his masterful *Traité de Mécanique Céleste*, which appeared in four volumes. Notwithstanding the passage of time, Debarbat (2014) assures us that "After reading Newton and Laplace, specialists [in celestial

Fig. 12.5 Felix Tisserand (after *Bulletin de la Société Astronomique de France* 1913)

mechanics] must read Tisserand to best understand Jules Henri Poincare and Albert Einstein." Sadly, Tisserand died at Paris Observatory on 20 October 1896 when he was only 51 years of age.

Rounding out the expedition were a Mr. Hildebrand, who was a technician from the Eichens company, and a French naval officer, Lieutenant Chabirand. Later they were joined by another naval officer, Lieutenant Olry, who was Rear-Admiral Ohier's Chief-of-Staff, and a Mr. Hatt, who was a hydrographic engineer from Saigon (Stephan 1869).

12.5 Instrumentation and Preparations

It was only in February 1868—less than 6 months before the eclipse—that Le Verrier set up a Commission composed of astronomers and marines to plan the expedition. Once funding was approved, the first thing the Commission did was to settle on the observing site.

The selection of Siam for one of the two French observing stations was influenced, in part, by the prior decisions made by other nations. The Germans were based in Aden at the far western end of the path of totality; the British (Orchiston et al. 2017), along with Janssen's French party (Launay 2012), were in India; while Oudemans (Mumpuni et al. 2017) from Batavia was based further east, in the Celebes. A site in Siam therefore filled an obvious longitudinal gap, but it also took advantage of the fact that the eclipse reached its maximum duration in this region. The French would also have been very aware that the ruler of Thailand at that time, King Rama IV, had a personal interest in and some knowledge of astronomy (see Aubin 2010; Saibejra 2006), and therefore would almost certainly agree to the siting of a foreign eclipse station on Siamese soil (Georgelin and Arzano 1999; Lingberg 1985).

If choosing Siam for the observations was a non-issue, selecting the precise spot where the eclipse camp should be situated was not quite as straight forward. The path of totality crossed the Malaccan Peninsula, that narrow isthmus of land linking mainland southeast Asia to Malaya, and meteorological data supplied by Monsieur Aubaret, the French Consul in Bangkok, clearly indicated the preferred coast:

> All the coasts bordering on the Indian Ocean, from the entry of the Red Sea to China, are more of less effected [*sic*] by the monsoons. During the South-West monsoon, the sky is generally covered and rainy. Then Mr. Aubaret confirmed, based on his personal experience and the claims of the Englishman Captain Richards, that during the August monsoon the occidental [east] coast of the Gulf of Siam in general enjoys better weather than the oriental coast.
>
> At that time of the year the rains are noticeably reduced, and they become heavy again by the middle of September. The eastern coast of the Malaccan peninsula seem therefore a little more sheltered from the monsoon; lastly at a latitude of 11° 30′ there is a chain of mountains, the Koew-Luang, which runs parallel to the coast and intercepts some of the clouds coming from the west. (Stephan 1869: 4).

Table 12.1 Scientific instruments taken to Siam for the 1868 solar eclipse (after Stephan 1869: 5, 21, 28, 40)

Item(s)	Manufacturer
40-cm reflector	Foucault-Secretan-Eichens
20-cm reflector	Eichens
15-cm refractor	Cauche
Meridian telescope	Eichens
Three spectroscopes	Duboscq
Arago polariscope	
Savart polariscope	
Many accessories for the above instruments	
Astronomical clock	
Four chronometers	
Three thermometers	
Two barometers	
Hygrometer	
Gauss magnetometer	Rayet

The precise location of the eclipse camp along this stretch of coast would be determined at a later date based upon personal examination and evaluation of the various options.

The Commission also had to decide on the instrumentation to be used at the eclipse camp. While Janssen's French expedition to India placed great reliance on the spectroscope, visual and spectroscopic observations would form the mainstay of the Siamese French expedition. In fact, photography was the preferred option, but to Stephan's great regret (1869: 5) there was insufficient time available to obtain and adequately test the necessary photographic equipment. The instruments that were taken on this expedition are listed in Table 12.1.

Some of these instruments are discussed separately below.

12.5.1 The 40-cm Reflector

Paris Observatory's 40-cm equatorially mounted silver-on-glass reflector (Fig. 12.6) would be used to carry out visual and spectroscopic observations of the eclipse. This historic telescope was made for the Observatory in 1859 by two of the 'giants' of French telescope-making, the Observatory's optical expert, Léon Foucault (1819–1868; Fig. 12.7; Tobin 1987, 2003) and Marc Secretan (1804–1867; Fig. 12.8; Brenni 1994), who maintained his own scientific instrument-making company in Paris. However, one of Secretan's staff, Wilhelm Eichens (1818–1884; Fig. 12.9) was responsible for the fork mounting (see Tobin 2016), although if we can believe the following excerpt from a letter by Léon Foucault (1862), Eichens was responsible for far more than this:

Fig. 12.6 The 40-cm reflector (astro2009.futura-sciences.com and X. Plouchart)

Fig. 12.7 Léon Foucault, photographed in the 1860s by Paris-based Robert J. Bingham (www.thenewstribe.com)

Fig. 12.8 Marc Secretan (after de Gramont and Peigné 1902; *Courtesy* Bibliothèque Nationale de France)

Fig. 12.9 Wilhelm Eichens (after de Gramont and Peigné 1902; *Courtesy* Bibliothèque Nationale de France)

> Although the instruments in question have been made in the firm known by the Secretan name, in reality all these works of precision mechanics are the creations of M. Eichens, who for many years has been head of the workshops, and, one can say, of the company.

Although the 40-cm telescope was only 9 years old in 1868, before it could be shipped to Siam it needed to be changed in two distinctive ways. First, the cell of the primary mirror had to be modified, and this was done by Eichens (1868) by introducing three support points and a three-pronged spring with an adjustment screw. Secondly, the equatorial mounting was altered to allow for a change of observing site, from Paris (latitude 48.8° N) to Siam (11.7° N).

12.5.2 The 20-cm Reflector

A 20-cm equatorially mounted reflector with a silver-on-glass mirror was "… constructed specially for the expedition by Mr. Martin." (Stephan 1869), to be used during visual and spectroscopic observations of the eclipse. The afore-mentioned "Mr. Martin" was Adolphe A. Martin (1824–1896; Fig. 12.10) a former science teacher, who became Léon Foucault's pupil, but after Marc Secretan and Léon Foucault died (in 1867 and 1868 respectively) he created considerable disquiet by publishing some of Foucault's mirror-making and lens-making secrets (Tobin 2016: 137–138). Despite this, Martin continued to do some work for the Secretan company, but he also accepted private orders. Thus, when funding was approved for the Siam solar eclipse expedition he was commissioned to make the 20-cm telescope, and reportedly was so busy with this order that he did not have time to complete the partly made 0.8-m reflector that Léon Foucault had started for Toulouse Observatory (Tobin 2016: 148).

Although neither Martin nor Stephan provided descriptions of this telescope, it is shown in Fig. 12.11, and despite the blurry image we can deduce that because it was made in a hurry it did not have the fine finish of the Secretan

Fig. 12.10 Adolphe A. Martin (after de Gramont and Peigné 1902; *Courtesy* Bibliothèque Nationale de France)

Fig. 12.11 An enlargement of the 20-cm reflector made especially by Adophe Martin for the Siam solar eclipse expedition and shown in Fig. 12.13. Note the crude wooden tube, even cruder equatorial mounting and primitive wooden mirror support (*Courtesy* Archives, Observatoire de Marseille, 132 J 84)

telescopes that Martin normally used as his role models. Thus, this telescope had a simple, but functional, wooden equatorial mounting, and a simple mirror support system.

12.5.3 The 15-cm Refractor

Little is known about Cauche who supplied the 15-cm equatorially mounted refractor listed by Stephan (1869), except that he was active from the 1850s (perhaps earlier), and made refractors, including one for Marseille Observatory that was used to discover new minor planets (William Tobin, pers. comm., 2017).

12.5.4 The Meridian Telescope

Wilhelm Eichens was asked to fabricate a portable meridian telescope that would be used to (a) provide a local time service at the Wah-koa eclipse station, and (b) provide the latitude and the longitude of the site. By the time Government funding was approved for the Siam eclipse expedition, Eichens had already left the Secretan firm (back in 1866) and founded his own company (Tobin, 2016: 144).

Fig. 12.12 Jules Duboscq (after Rosenfeld 1999: 264)

Through his contacts at Paris Observatory Eichens was familiar with meridian circles and transit telescope, so to manufacture one for the French expedition was no problem.

12.5.5 The Three Spectroscopes

Stephan (1869) reports three spectroscopes "… of great dimension were ordered from Mr. Duboscq." Jules Louis Deboscq (Fig. 12.12) was born in Villennes, France, on 5 March 1817, and after serving an apprenticeship with Jean Baptiste Francois Soleil and marrying one of Soleil's daughters he took over the business in 1849 when his father-in-law retired. Duboscq was famous for developing the stereoscope (see Rosenfeld 1999), and his company prospered to the point where he was "… one of the most famous instrument makers in the world. *The reputation of his instruments for optical physics was unsurpassed* …" (Brenni 1996: 11; our italics), so Paris Observatory could do no better than order its three solar eclipse spectroscopes from him. Duboscq maintained an international reputation right up to his death on 24 September 1886.

12.5.6 The Other Equipment Listed in Table 12.1

Of the remaining instruments listed in Table 12.1, the two polariscopes were to be used to determine whether light from the corona was polarised; the astronomical clock would provide a vital master time-service before, during and after the eclipse—when used in conjunction with the Eichens meridian circle—while the chronometers would be used at each of the telescopes while observations were in train; and the thermometers, barometers and hygrometer would be used to monitor weather conditions before, during and after the eclipse observations. Finally, the Gauss magnetometer, which was constructed by expedition member Georges Rayet, had nothing to do with the eclipse, but would to be used extensively during the expedition as part of an international geomagnetic project (for details, see Stephan 1869: 75–91).

12.6 Establishing the Eclipse Camp

With the means to observe the eclipse and general locality of the eclipse camp finalized, the race was on to finalise arrangements with the Thais and to transfer equipment and personnel to what was then known as Siam. Accordingly, at the end of March 1868, less than 5 months before the eclipse,

> A telegram was hurriedly dispatched to Rear-Admiral Ohier, the provisional governor of Cochinchina [the collective French territories in south east Asia], with the intervention of His Excellency the Minister of the Navy, requesting him to obtain from the government in Bangkok authorisation to install our eclipse camp on the peninsula coast and to allow us to explore this region [in order to finalise the precise location of the eclipse camp] (Stephan, 1869: 5).

Despite the unreasonably short lead-in time, all of the instruments were dispatched from Marseille on schedule, and soon after, on 19 June, the members of the expedition also embarked from Marseille on the Imperial Méssagaries ship, *Le Péluse*. The voyage took them to Alexandria in Egypt, and all of the personal luggage, along with the 17 boxes of instruments, were transferred by rail to Suez. There the expedition boarded *L'Impératrice*, bound for Aden at the entrance to the Red Sea, Galle in Ceylon and Singapore. With the oppressive heat of the Red Sea behind them, expedition members began to enjoy ship-board life during the long crossing of the great Indian Ocean, and this was there they caught their first tantalizing glimpses of the unfamiliar stars of the southern sky:

> … we could already observe the Southern Cross, which, together with the beautiful stars in the Centaur, constitutes such a remarkable group; the Scorpion, almost invisible in Paris, seemed to us by its admirable glitter, a completely different constellation; while the Pole Star became lower and lower on the northern horizon. (Stephan 1869: 8).

On 19 July, exactly 1 month after leaving Paris, they arrived safely in Singapore, where they discovered that a large steamer, the *Sarthe*, had been assigned to the expedition, and would transport them to the site of the eclipse camp. Baron Letourneur Hugon, the Commanding Officer of the *Sarthe*, also formally joined the eclipse party. Meanwhile, Stephan was pleased to discover after visiting Bangkok and obtained the necessary authorisation from the King, that Mr. Hatt (the hydrographic engineer who was assigned to the eclipse party) had spent 2 weeks on the gun-boat *Frelon* surveying the coast, before settling on a suitable site for the eclipse camp. This was assigned the name 'Wha-Tonne' (which mean 'the place of observations'), and was located on ancient sand dunes, adjacent to the beach and fringed to the west by thick forest that extended up to the summit of the nearby mountains. The setting was idyllic:

> … in the morning on the 25th [of July, 1868] … the *Sarthe* anchored in 8 m of water, directly in front of our future observatory, and about two miles from the coast. From our anchorage we could faintly distinguish a hut on the beach and we could also clearly see the *Frelon*, which because of its low draught was able to get very close to the beach.
>
> The coast ahead of us, sheltered to the west by the mountains of Kow-Luang, formed a large semi-circle and was bounded to the north by a point that was topped by a peak with a bizarre shape, which Captain Richards called the "South-Horn", to distinguish it from another peak of similar appearance situated further to the north. Towards the south, the curvature of the beach was less pronounced. Inside this semi-circular bay there were several scattered islands, of which the most remarkable towards the north was Koh-Luem while to the south at a distance there was another island shaped exactly like a turtle. (Stephan 1869: 10–11).

Yet this beautiful setting was deceptive for it masked the ever-present danger from malaria-carrying mosquitoes, and from tigers that supposedly were abundant in the forests adjacent to the eclipse camp and frequently attacked the local Siamese villagers.[1]

Upon proceeding ashore Stephan was heartened to find that Mr. Hatt had been far from idle: before leaving Saigon he had arranged for prefabricated observatories to be built for the meridian telescope and the Cauche refractor, and these were now on site. Meanwhile, he also had arranged for the local people to build a very large bamboo house parallel to the beach. This was fully 80 m in length, and was open towards the sea and flanked by two long galleries which were subdivided into numerous compartments.

A flat area to the south-west of the large bamboo building was reserved for the astronomical instruments, and their installation now became the main priority of the eclipse party. Mr. Hatt had successfully erected a large granite column inside the 'meridian house', and the meridian telescope was attached to this, and the astronomical clock was installed on its own column in this same building.

Unfortunately, the second prefabricated observatory building did not prove to be quite as accommodating: the intention was that it should house the Cauche refractor and the 20-cm reflector, but there was not room for both so only the refractor took up residence there. The 20-cm reflector and the large Foucault reflector were then set up outdoors, with their own foundations and locally fabricated covers to protect them from the elements (Fig. 12.13). The magnetic instruments were also installed on foundations, and the meridian house was connected to the various telescope enclosures so that accurate time would be available to all observers during the eclipse.

All that remained was to determine the latitude and longitude of the eclipse camp, and the first observations in this direction were made with the meridian telescope on 28 July, just 3 weeks before the eclipse. Lunar observations made by Stephan and Tisserand on 30 July, 1 August and 8 August produced a mean longi-

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[1] Writing after his return to Paris, Stephan remarked (1869: 17) that despite their initial uneasiness, in fact he and his colleagues never caught sight of any of tigers.

Fig. 12.13 A photograph by Rayet of the French eclipse camp, showing instrument huts and the 40-cm (*left*) and 20-cm (*right*) reflecting telescopes set up outdoors (*Courtesy* Archives, Observatoire de Marseille, 132 J 84)

tude of 6 h 29 m 50.33 s East of Paris, while the mean of observations taken on 7 and 10 August revealed the latitude was 11° 42′ 35″ N (Stephan 1869: 16). While Stephan and Tisserand were so involved, Mr. Rayet was busy trying to carry out spectroscopic observations of southern stars using the 20-cm telescope, and we will discuss this innovative project briefly in Sect. 12.8.3, below.

All was now in readiness for eclipse day, and by this time the original French retinue had been expanded to include Mr. Pierre (the well-known naturalist, who had created a rich botanic garden in Saigon), Mr. Garnault (a pharmacist at the military hospital in Saigon), and the officers from both the *Sarthe* and the *Frelon* (Stephan 1869: 19).

12.7 Observing the Eclipse

Prior to the eclipse Stephan (1869: 20–22) had finalised the intended roles of the various members of the eclipse expedition, but all these well-laid plans looked dashed on eclipse day when the weather rapidly deteriorated and the sky was soon completely covered by clouds. A violent storm seemed to be approaching and it was raining in the village of Wha-Whan a few miles to the north-east. First contact was missed and all seemed lost when, about 20 min before totality, the weather improved, little by little the clouds dissipated, and 10 min later the sky was completely clear in the region where the Sun was.

The expedition members were fully briefed and ready for the grand event. Stephan was at the large Foucault telescope; Tisserand at the Cauche equatorial;

Rayet at the 20-cm telescope; Hatt at the portable meridian telescope which was now on an altazimuth mounting; and Olry would observe the eclipse with strong binoculars. Rayet, Chabirand and Hatt were charged with carrying out the spectroscopic observations, and Letourneur and Béhic with the polariscopic observations. Garnault was responsible for the magnetic observations, and he and Mr. Coupe from the *Sarthe* oversaw the meteorological observations. Meanwhile, other officers from the *Sarthe* and *Frelon* were there to assist where required (Stephan 1869: 20–22; 40).

As soon as totality occurred (see Fig. 12.14) Stephan was preoccupied with the prominences (or 'protuberances', as he called them), which "… appeared to me in the big telescope in marvellous clarity …" (Stephan 1869: 25). At different locations on the solar limb he saw

> … a small serrated protuberance … a second one of almost the same form but of greater dimensions … an elongated protuberance of extraordinary height, [and] finally … a large area of protuberances of a fleecy aspect … They appeared to me like flames. Their colour was that of coral pink with a slightly violet hue. The big protuberance … presented tones of different intensities (Stephan 1869).

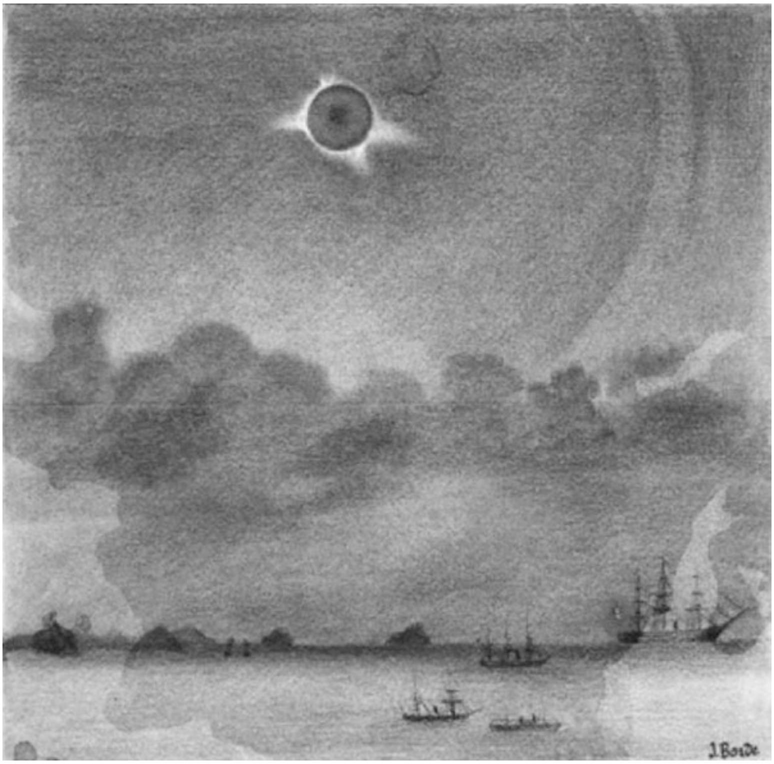

Fig. 12.14 A sketch by J. Bordes, an officer on the *Sarthe*, showing the 1868 total solar eclipse and various vessels at anchor off the Wah-koa observing sites (*Courtesy* Bordeaux Observatory)

Stephan used a micrometer that was specially fabricated for the 1860 total solar eclipse to measure the positions and heights of these prominences, and he concluded that they were definitely associated with the Sun and not with the Moon. The most remarkable of the prominences noted by Stephan was dubbed 'The Great Horn' by British astronomers who observed this eclipse from India, and is shown in Fig. 25.8 in the chapter by Orchiston et al. (2017) in this book.

While Stephan was measuring the various prominences, Rayet was busily exploring their spectra using a three-prism direct-vision spectroscope. As soon as totality occurred he focussed on The Great Horn,

> … and I immediately saw a series of nine brilliant lines … distributed on a uniform, almost black or very dark violet background; no trace whatsoever of a coloured spectrum being given by the corona … by their location, their relative spacing, and their colour … it seemed to me that these lines can be correlated with the principal lines of the solar spectrum, B, D, E, b, an unknown line[,] F, and two lines of the G group … [These observations showed that the prominences] are therefore accumulations of jets of gaseous incandescent matter, flames of a chemical phenomenon of extreme power, because the actual height of the protuberance examined … was about 34,000 leagues [~143,000 km]. (Cited in Stephan 1869: 30).

The most prominent lines were: "... red line B, the brown line D, the green line E, the blue line F, and finally the most infrangible violet line; all the other lines were much weaker and, above all, much narrower." (Cited in Stephan 1869: 31). Rayet provided a sketch showing the relative locations and intensities of the lines, and this is reproduced below as Fig. 12.15.

The current identification of these lines is indicated in Table 12.2—note that from Fig. 12.15 and his vague description it is not known whether Rayet's twin 'b line' equates with the b_2 Magnesium line at 5172.9 Å and the b_3 Iron line at 5169.2 Å, or this latter line and the b_4 Magnesium line at 5167.6 Å; likewise his 'unknown line' between the b and F lines cannot be identified. Note, further, that one of the conspicuous lines that Rayet did observe, the mysterious D line, subsequently was identified with helium, but in his book *The Story of Helium and the Birth of Astrophysics* Nath (2013) is correct in not giving Rayet credit for this discovery.

Rayet also observed the spectrum around the solar limb where prominences were absent, and subsequently he summarised his findings:

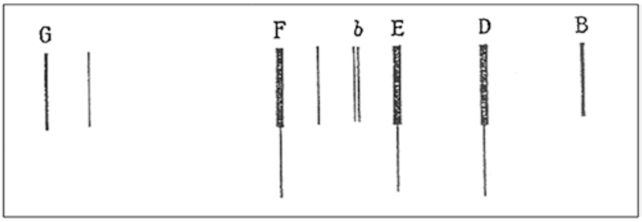

Fig. 12.15 Rayet's sketch of the relative positions and intensities of the prominence emission lines (after Stephan 1869:31)

Table 12.2 Identification of the main emission lines noted by Rayet (after Young 1902: 206–207)

Line	Element	Wavelength (Å)
B	Hydrogen (Hα)	6563.05
D	Helium	5875.98
E	Magnesium	5183.8
F	Hydrogen (Hβ)	4861.50
Near G	Hydrogen (Hγ)	4340.66

1. The protuberances are accumulations of gaseous matter and definitely belong to the Sun. Until now, this result has been suspected by several astronomers, but there has never been any direct experimental proof.
2. The Sun is surrounded by a gaseous incandescent atmosphere … the minimum height of which corresponds to the maximum height of the protuberances, and is about three arc minutes.

The composition of that atmosphere is variable with height … certain vapours … rise very high; others … only reach much lower altitudes. (Cited in Stephan 1869: 32–33).[2]

The bright emission lines reported by Mr. Rayet also were observed by Mr. Hatt, but because he was using inferior equipment he only saw the lines twice, and just two of them, not the suite of eight seen by Rayet (Stephan 1869: 34).

Because of his preoccupation with the prominences Stephan did not have time to examine the full extent of the corona, but Messrs. Olry and Bordes made sketches of it (e.g., see Fig. 12.14) and some of the other officers on the *Sarthe* tried unsuccessfully to measure its diameter. The polariscopic observations also yielded negative results.

Although clouds returned soon after the eclipse ended, Stephan (1869: 38) was pleased to be able to report that "Throughout the duration of the most scientifically interesting part of the eclipse, the sky was superb in the vicinity of the Sun; [and] we had every reason to be satisfied."

Another thing the astronomers were able to do during the eclipse was to use the timings of the contacts to obtain three independent determinations of the longitude of the observing site, and their weighted mean value was 6 h 29 m 47 s East of Paris Observatory, which compared very favourably with the value of 6 h 29 m 50.33 s that Stephan and Tisserand obtained from lunar observations prior to the eclipse.

Stephan concluded his account of the Siam phase of the eclipse expedition by noting that the unhealthy climate and marshy environment at Wah-koa combined to generate widespread sickness among expedition members and crew members of

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[2] It is interesting that Georges Rayet included the spectroscopic observations of prominences and the corona that he made during this Siamese eclipse in his doctoral thesis, which was submitted in 1871 (Levy 2008).

both the *Sarthe* and *Frelon*,[3] which prompted him to bring the date of their departure forward. Accordingly, on 21 August—a mere 3 days after the eclipse—the *Sarthe* abandoned her anchorage at Koh Luem and set sail for Saigon.

Once settled in Saigon the evenings of 26 and 27 August were clear, and Stephan and Tisserand were able to carry out stellar observations, regulate their chronometers and determine the local latitude and longitude. Illness also was prevalent in Saigon, and Chabirand, Hatt, Rayet, Stephan and Tisserand all contracted fever, causing the local doctors to advocate an immediate return to Paris. Thus, on 31 August the expedition members once more boarded the *Impératrice*, and one and a half months later they were home.

12.8 Discussion

12.8.1 Other Observations of the 1868 Eclipse Made At or Near Wah-koa

In 1868 King Rama IV (also known as King Mongkut) and other members of the Thai Royal Family had a strong interest in astronomy, so when astronomers on the French eclipse expedition arrived at Wah-koa they were not surprised to find that a substantial observing camp, complete with various wooden buildings (see Fig. 11.9 in the previous chapter), had already been established about 1 mile north-east of their compound (Stephan 1869: 12). The brother of the Prime-Minister of the Kingdom of Siam was already in residence, and local workers were busy constructing a temporary palace for the King.

Eventually the King's compound included facilities for a large number of Thai and international guests, and on 18 August all were treated to views of the eclipse once the clouds parted (Bacon 1881; Lingberg 1985). Observations of this eclipse by King Rama IV and his entourage have already been discussed in Thai (Euarchukiati 2015). A detailed account, in English, is beyond the scope of this chapter, but it remains—and deserves—to be written.[4]

While the French eclipse party and King Rama IV and his guests observed from Wah-koa, the Saigon-based naturalist, Mr. Pierre, decided the view the eclipse from the top of nearby 1495 m Mount Luang,

> … a very open spot that offered me a wide horizon of some 12 miles, extending from the Long-Wang mountain, situated to the North-East of our observatory up to beyond the arc formed in the South-East by the Luang mountain (Cited in Stephan 1869: 42).

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[3] During their Wha-koa sojourn, ten members of the French expedition caught malaria, but King Rama IV, who was based nearby, was the principal casualty: he also contracted malaria during the eclipse expedition and died soon after, on 1 October (Aubin 2010).

[4] One of King Rama IV's guests was Sir Harry Ord, the Governor of Singapore, and his involvement in the August 1868 eclipse is examined by Orchiston and Orchiston (2018).

From this spot he conducted careful observations of the reactions of the local flora and fauna to the eclipse, and he also noted an unusual meteorological phenomenon:

> It remains for me to tell you of the luminous bands which I observed eleven times during the course of the eclipse. The moon had covered two tenths of the sun, when they began to appear on the horizon. At first I counted three of them, then seven, which was the maximum number I saw. They were perpendicular to the horizon and parallel to each other and each appeared about 40 cm in width. They appeared and disappeared with the undulations of the atmosphere, but they always reappeared at the same point on the horizon. They were not all of the same brilliance. They covered all of the colours from red to a purple violet. It seemed to me that from right to left, that is from North to South, these bands varied in colour and intensity. Thus, the last one to the South-East was purple, while the one which was present at the extremity of the arc against Kow-Long-Wong was slightly tinted red (Cited in Stephan 1869: 45).

Stephan (1869) described Pierre's observation as "… most remarkable." but he noted that a similar phenomenon had been noticed during a previous eclipse (although he does not state which one).

12.8.2 Janssen Versus Stephan: Publication of the 1868 Eclipse Results

Given the intrigue surrounding the organization and funding of two discrete 1868 French solar eclipse expeditions (Aubin 2010), it is illuminating to compare and contrast the principal astronomers that led each expedition, and their respective record of publication following the eclipse.

Pierre Jules César Janssen (Launay 2012) was born in 1824, so was 13 years older (and more street-wise) than Édouard Stephan, and this shows up in his strategy to get Board of Longitude support for an expedition to India long before Le Verrier entertained the idea of a second French expedition, organised by Paris Observatory and led by Stephan.

By 1868 Janssen was already well known in French scientific and astronomical circles, despite lacking a formal academic affiliation. He had carried out geomagnetic research and solar and stellar spectroscopy, and observed an annular solar eclipse from Italy, so he was ideally placed to make a thorough spectroscopic investigation of the Sun from India during the up-coming eclipse. And this is precisely what he did (see Launay 2012: 35–47), in the process hinting at the existence of an unidentified emission line (later identified with helium) and (along with Lockyer) establishing a way of observing prominences without the aid of a solar eclipse. After his Indian sojourn, Janssen reported on his observations in five different research papers (Janssen 1868; Janssen 1869a, b, c, d), all of which were published in the prestigious *Comptes Rendus de l'Académie des Sciences*. Janssen went on to achieve further international fame, especially for his wide-ranging spectroscopic work and his observations of other solar eclipses and the 1874 transit of Venus, and he was installed as the founding Director of France's first astrophysical observatory, which was established at Meudon (on the outskirts of Paris).

By way of contrast, Édouard Stephan had a long career at Marseille Observatory, and although he did carry out some enterprising research projects (see Sect. 12.4 above) he did not achieve the international recognition that Jannsen enjoyed. Nor did he publish as prolifically on the 1868 eclipse, although his two monographs (Stephan 1869, 1870) did exceed the total number of pages covered by Janssen's five papers. Yet in the long run, Janssen's papers undoubtedly made a greater impact on international astronomy, and solar physics, and this is reflected in comments made by Hervé Faye (1814–1902) from the École Polytechnique to Henriette, Janssen's wife, in February 1869:

> Before this expedition, M. Janssen was known as a talented person, and highly intelligent, but now, he has made a name for himself, he is perfectly set … His observations of the eclipse succeeded perfectly, whereas the expedition to Malacca has returned sheepishly … (Cited in Launay 2012: 44; his original underlining).

12.8.3 *Non-solar Astronomical Observations Made by the French at Wah-koa*

One of the objectives of the Wah-koa expedition was to study the spectra of southern stars, but persistent cloudy skies towards the south proved frustrating and in the end spectra were obtained for just 21 stars. These are listed below in Table 12.3.

Note that all but one of these stars resembled the white star α Lyrae in Secchi's scheme (1863; 1867), at a time when stellar spectroscopic nomenclature was in its infancy and the association between spectral lines and the compositions and relative ages of stars had still to be unravelled (see Hearnshaw 1986).

Despite this somewhat frustrating situation, Stephan (1869: 60) was able to conclude:

> These results, which the unfavourable state of the sky rendered in many ways incomplete are, however, interesting; they show, in effect that, in the austral sky, the same as in the boreal sky, the beautiful stars belong in the greatest majority to the class of stars emitting a white bluish light, of which the α Lyre is such a beautiful type.

12.8.4 *Power, Politics and the Wah-koa Eclipse*

Thus far we have focused on the astronomical aspects of the 1868 solar eclipse, but in a perceptive paper David Aubin (2010) reminds us that there are important non-astronomical dimensions that cannot be ignored.

He suggests that King Rama IV used the eclipse both for domestic and international political ends. On the one hand he exploited the eclipse to consolidate his authority within Siam by demonstrating the superiority of Western science—in this case astronomy—over local long-entrenched astrology and superstition, although

Table 12.3 Observations of stellar spectra made from Wah-koa (adapted from Stephan 1869: 58–59)

Star name	Spectral type (after Secchi)	Spectral features
α Gruis	α Lyrae	D, F and V lines
β Gruis	α Herculis	
γ Gruis	α Lyrae	F and V lines;? D
α Pavonis	α Lyrae	D, F and V lines
α Piscis Austrini (Fomalhaut)	α Lyrae	D, F and V lines
η Ophiuchi	α Lyrae	
α Sagittarii	α Lyrae	F line,? V
β Sagittarii (north)	α Lyrae	F and V lines
β Sagittarii (south)	α Lyrae	F line clear
δ Sagittarii	α Lyrae	D, F and V lines
ε Sagittarii	α Lyrae	D, F and V lines
ζ Sagittarii	α Lyrae	F and V lines
σ Sagittarii (variable)	α Lyrae	F and V lines
φ Sagittarii	α Lyrae	F and V lines
ω Sagittarii	α Lyrae	F line
ε Scorpii	α Lyrae	D, F and V lines
θ Scorpii	α Lyrae	D, F and V lines
λ Scorpii	α Lyrae	F and V lines
ρ Scorpii	α Lyrae	D and F lines
τ Scorpii	α Lyrae	Lines hardly visible
χ Scorpii	α Lyrae	F and V lines

he still had to find a way of balancing his Western astronomical knowledge and interests against his inherited Thai astrological commitments and obligations (see Cook 1993). He somehow achieved this, so that in Thailand today King Rama IV is formally acknowledged as the "Father of Thai Science" (see Saibejra 2006), and his eclipse expedition

> … now stands for the establishment of modern science, which by and large followed western norms and applied western technology, but remained respectful towards traditional belief systems. (Aubin 2010: 89).

In a totally different context, King Rama IV also used the 1868 eclipse as a weapon again foreign powers with colonial ambitions. He saw Siam as an 'appetizing morsel' in an 'inter-colonial sandwich', with British colonies to the west (present-day India, Sri Lanka, Bangladesh and Myanmar) and French counterparts (present-day Laos, Cambodia and Vietnam) to the east. So he adopted a time-honoured strategy used successfully by sovereign nations intent on maintaining their autonomy:

> To show the value and richness of their own knowledge traditions, they attempted to channel the symbolic power of eclipses in a manner more flexible than that of westerners. In syncretistic fashion they mustered the strength of both endogenous and occidental knowledge traditions. In their view solar eclipses were an ideal terrain for seducing Europeans

> into believing in *both* their ability to adapt to modern science *and* the value of traditional knowledge. Such demonstrations played a key role in the defence of Thailand's political independence. (Aubin 2010: 91).

But this strategy had its origins some years before the Wah-koa eclipse, for in 1863 France had forced independent Cambodia to accept its 'protection'. This caused a dilemma in Bangkok (Tuck 1995), and King Rama IV is reported to have asked:

> Since we are now being constantly abused by the French because we will not allow ourselves to be placed under their domination like the Cambodians, it is for us to decide what we are going to do; whether to swim up-river to make friends with the crocodile [the French] or to swim out to sea and hang on to the whale [the British] … (Moffat 1968: 124).

In the end King Rama IV decided to adopt both strategies simultaneously: he would invite the French to base their eclipse camp on Siamese territory, near his own observing site, and at the same time encourage British diplomats and others of importance to join his own eclipse entourage (see Bacon 1881). This way, the solitary French expedition ship anchored off Wah-koa in the Gulf of Thailand was greatly outnumbered by the 17 Siamese and British warships and other vessels that came to attend the eclipse (some of which are depicted in Fig. 12.14).

All-in-all, Aubin (2010: 89) believes that "… the eclipse expedition of 1868 was—and remains—one of the king's shrewdest political acts." We heartily agree.

As a postscript, it is interesting to note that King Rama IV's son, Rama V, adopted a similar strategy 7 years later when he invited a British contingent to observe the 6 April 1875 total solar eclipse from Siam (see Kramer and Kramer 2017).

12.9 Concluding Remarks

The August 1868 total solar eclipse was a 'watershed event' in the history of astronomy and attracted British, French, German expeditions and local observers to Aden, India, Siam and the Dutch East Indies.

One of the two French expeditions was the 'brain child' of Paris Observatory Director, Ubain Le Verrier, and was based at Wah-koa in Siam (present-day Thailand). Leading the expedition was Marseille Observatory Director, Édouard Stephan, who was assisted by Georges Rayet and François-Félix Tisserand, both from Paris Observatory. Rayet had prior experience in stellar spectroscopy, and both he and Tisserand would later achieve international eminence as astronomers.

Members of the French expedition were treated to clear skies at Wah-koa during the eclipse, and although naked eye and spectroscopic observations were made of the prominences, the corona received little attention. Stephan concentrated on measuring the positions and sizes of the various prominences and noted their obvious solar association, while Rayet concentrated on their spectra. Although Rayet noted the existence of nine different emission lines he saw nothing unusual about these or that the D line was slightly misplaced—something that Madras Observatory Director, Norman Robert Pogson (1829–1891), did notice (Nath 2013). Consequently, Rayet was not party to the discovery of the element helium. Without doubt, this ‘missed opportunity’ arose from Rayet’s familiarity with stellar rather than solar spectra. Had he made the connection, his name would now be much better known as the co-discoverer of helium rather than of Wolf-Rayet stars.

One other ‘missed opportunity’ marred the French Wah-koa eclipse expedition: there were no serious spectroscopic observations of the corona, so its elemental composition was not investigated (although polariscopic observations did suggest that its light was not polarised).

These comments notwithstanding, the Wah-koa expedition was a success. Despite the almost-impossible lead-in time, the scientific instruments were constructed, assembled and dispatched on schedule, and they and the eclipse expedition reached their observing station in time for the eclipse. Successful observations of the eclipse were made and useful new data on the nature of the prominences were accumulated, even if the overall scientific outcomes paled into insignificance when measured against those published by Jules Janssen on the basis of his observations of this same eclipse made from India.

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References

Astrophysical Journal, 25, facing page 53 (1907).

Aubin, D., 2010. Eclipse politics in France and Thailand, 1868. In D. Aubin, C. Bigg, & H.O. Sibim (Eds.), *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Cu*lture (pp. 86–117). Durham (North Carolina): Duke University Press.

Bacon, G.B. (1881). *Siam. The Land of the White Elephant as It Was and Is*. New York: Charles Scribner’s Sons.

Baum, R. (2014). Rayet, Georges-Antoine-Pons. In T. Hockey et al., pp. 1803–1804.

Bosler, J. (1924). Édouard Stephan. Honorary Director of the Marseille Observatory (1837–1923). *Journal des Observateurs, 7,* 9–10 (in French).

Brenni, P. (1994). 19th century French scientific instrument makers. III: Lerebours and Secretan. *Bulletin of the Scientific Instrument Society, 40,* 3–6.

Brenni, P. (1996). 19th century French scientific instrument makers. XIII: Soleil, Duboscq, and their successors. *Bulletin of the Scientific Instrument Society, 51,* 7–16.

Bulletin de la Société Astronomique de France (1913).

Clerke, A.M. (1893). *A Popular History of Astronomy during the Nineteenth Century*. London: Adam & Charles Black.

Cook, N. (1993). A tale of two city pillars: Mongkut and Thai astrology on the eve of modernization. In G. Wijeyewardene, & E.C. Chapman (Eds.), *Patterns and Illusions: Thai History and Thought* (pp. 276–304). Canberra: Australian National University, Department of Anthropology.

Debarbat, S. (2014). Tisserand, Francois-Felix. In T. Hockey et al., p. 2160.

de Gramont, A., & Peigné, P. (1902). *Musée Rétrospectif de la Classe 15 Instruments de Précision à l’Exposition Universelle Internationale de 1900 à Paris. Rapport du Comité d’Installation.* Saint-Cloud: Belin.

Eichens, W. (1868). Undated invoice. Paris Observatory Archives (Ms 1060-I-A, Comptabilité, Exercice 1867, Bordereau No. 24, dated March 1868).

Espenak, F., & Meeus, J. (2006*). Five Millennium Canon of Solar Eclipses: −1999 to +3000*. Greenbelt: NASA (Technical Publication TP-2006-214141).

Euarchukiati, V. (2015). *Siamese Astronomical Archives: From the Reigns of King Rama V to Rama VIII.* Chiang Mai: National Astronomical Research Institute of Thailand (in Thai).

Foucault, L. (1862). Draft case prepared for Le Verrier. Bibliothèque de l'Institut de France, Paris (Ms 3711, Eichens envelope, item 7).

Georgelin, Y., & Arzano, S. (1999). The eclipse of the Sun of 18 August 1868, Stephan and Rayet, hosts of the King of Siam at Wah-Thonne. *L'astronomie, 113,* 12–17 (in French).

Georges Rayet. *Astrophysical Journal, 25,* 53–54 (1907).

Grillot, S. (2014). Wolf, Charles-Joseph-Étiene. In T. Hockey et al., pp. 2365–2366.

Hearnshaw, J.B. (1986). *The Analysis of Starlight. One Hundred and Fifty Years of Astronomical Spectroscopy*. Cambridge: Cambridge University Press.

Hockey, T. et al. (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Janssen, J. (1868). An indication of several of the results obtained at Cocanada [*sic*] during the eclipse of last August, and the sequel to this eclipse. *Comptes Rendus de l'Académie des Sciences, 67,* 838–839 (in French).

Janssen, J. (1869a). On the existence of a hydrogen atmosphere around the Sun. *Comptes Rendus de l'Académie des Sciences, 68,* 112 (in French).

Janssen, J. (1869b). On the spectral study of solar prominences. *Comptes Rendus de l'Académie des Sciences, 68,* 93–95 (in French).

Janssen, J. (1869c). Spectral observations made during the eclipse of 18 August 1868, and a method for observing prominences outside of eclipses. *Comptes Rendus de l'Académie des Sciences, 68,* 367–376 (in French).

Janssen, J. (1869d). A summary of acquired ideas on the composition of the Sun. *Comptes Rendus de l'Académie des Sciences, 68,* 312–314 (in French).

Kramer, B., & Kramer, M. (2017). King Rama V and British observations of the 6 April 1875 total solar eclipse from the Chao Lai Peninsula, Siam. In T. Nakamura, & W. Orchiston.

Lankford, J. (1984). The impact of photography on astronomy. In O. Gingerich (Ed.), *The General History of Astronomy. Volume 4. Astrophysics and Twentieth-Century Astronomy to 1950: Part A* (pp. 16–39). Cambridge: Cambridge University Press.

Launay, F. (2012). *The Astronomer Jules Janssen: Globetrotter of Celestial Physics*. New York: Springer.

Lequeux, J. (2013). *Le Verrier – Magnificent and Detestable Astronomer.* New York: Springer.

Levy, J.R. (2008). Rayet George-Antoine-Pons. In *Complete Dictionary of Scientific Biography.* New York: Charles Scribner's Sons (http://www.encyclopedia.com)

Lingberg, O. (1985). King Mongkut's solar eclipse. *Astronomy, 13*(1), 24–26.

Lockyer, J.N., (1887). *Chemistry of the Sun*. London: Macmillan and Co.

Meadows, A.J. (1970). *Early Solar Physics*. Oxford: Oxford University Press.

Moffat, A.L. (1968). *Mongkut, the King of Siam*. Ithica: Cornell University Press.

Mumpuni, E.S., Orchiston, W., & Steinicke, W. (2017). J.A.C. Oudemans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In T. Nakamura, & W. Orchiston.

Nakamura, T., & Orchiston, W. (Eds.) (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nath, B.B. (2013). *The Story of Helium and the Birth of Astrophysics*. New York: Springer.

Orchiston, W., & Orchiston, D.L (2018). Sir Harry Ord and the total solar eclipse of 18 August 1868: power, politics and astronomy. In W.Orchiston, & M. Vahia (Eds.), *Exploring the History of Southeast Asian Astronomy: A Review of Current Projects and Future Prospects and Possibilities*. Cham: Springer.

Orchiston, W., Lee, E.-H. & Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In T. Nakamura, & W. Orchiston.

Pearson, J. (2010). *The Role of the 40 Foot Schaeberle Camera in the Lick Observatory Investigations of the Solar Corona*. Ph.D. thesis, Centre for Astronomy, James Cook University, Townsville, Australia.

Rosenfeld, L. (1999). *Four Centuries of Clinical Chemistry*. Philadelphia: CRC Press.

Saibejra, N. (2006). King Mongkut, the Father of Thai Science. In K.-Y. Chen, W. Orchiston, B. Soonthornthum, & R. Strom, R. (Eds.), *Proceedings of the Fifth International Conference on Oriental Astronomy* (pp. 15–18). Chiang Mai: Chiang Mai University.

Secchi, A. (1863). Schreiben des Herrn Prof. Secchi. *Astronomische Nachrichten, 59,* 193–196.

Secchi, A. (1867). Spectral studies of some of the planetary nebulae. *Astronomical Register, 5,* 40.

Stephan, M. (1869). Report on the Observation of the Eclipse of the Sun of 18 August 1868. English translation (pp. [vi] +93) of the French original published in *Archives des Missions Scientifique et Littéraires …, 5,* 535–610.

Stephan, M. (1870). Voyage of the French Commission sent by the Minister of Education to the eastern coast of the Malacca Peninsula to observe the total solar eclipse of 18 August 1868. *Annales Scientifique de l'E.N.S., 1* (7) (in French).

Tobin, W. (1987). Foucault's invention of the silvered-glass reflecting telescope and the history of his 80-cm reflector at the Observatoire de Marseille. *Vistas in Astronomy, 30,* 153–184.

Tobin, W. (2003). *The Life and Science of Léon Foucault. The Man who Proved the Earth Rotates.* Cambridge: Cambridge University Press.

Tobin, W. (2014). Stephan, Jean-Marie-Edouard. In T. Hockey et al., pp. 2053–2054.

Tobin, W. (2016). Evolution of the Foucault-Secretan reflecting telescope. *Journal of Astronomical History and Heritage, 19,* 106–184.

Tuck, P. (1995). *The French Wolf and the Siamese Lamb: The French Threat to Siamese Independence, 1858–1907*. Bangkok: White Lotus.

Weiss, E. (1867). Remarks on the total solar eclipse of August 17th, 1868. *Monthly Notices of the Royal Astronomical Society, 27,* 305–311.

Wolf, C., & Rayet, G. (1866). Notes on two stars. *Comptes Rendus de l'Académie des Sciences, 62,* 1108–1109 (in French).

Young, C.A. (1902). *The Sun*. New York: Appleton.

Chapter 13

King Rama V and British Observations of the 6 April 1875 Total Solar Eclipse from the Chao Lai Peninsula, Siam

Busaba Hutawarakorn Kramer and Michael Kramer

13.1 Introduction

The year 2004 saw the 200th birthday of King Mongkut, known as King Rama IV. His great interest in science and astronomy is well known (e.g. see Saibejra 2006). We also celebrated the 150th birthday of his son, Prince Chulalongkorn, later known as King Rama V, in 2003. Both Kings are remarkable for their modern views of the world at that time, and their interest in recent developments in science and technology. This is reflected in their personal interest in the observations of the total solar eclipses which occurred in Siam (now Thailand) within a period of only 7 years. King Rama IV even calculated the totality path himself and made efforts to educate the people of Siam about the phenomenon that was going to happen.

King Rama IV had calculated that the totality region would cross the southern part of Siam on 18 August 1868 and he had invited a number of French and British astronomers to take part in the observations (see Orchiston and Orchiston 2017). He organized an expedition which he joined with his son Prince Chulalongkorn and other family members. The observations were successful but the King died only a few weeks later from malaria, presumably contracted during the journey. Prince Chulalongkorn followed his father on the throne as King Rama V.

Only 7 years later, it happened that yet another total solar eclipse would be visible from Siam. Inspired by the memory of his father and his great interest in and knowledge of astronomy, King Rama V invited British and French

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astronomers again to send expeditions to Siam, promising to provide any possible help needed (Lockyer and Schuster 1878). While the French expedition was led by Janssen, this paper will concentrate on the resulting expedition to Siam organized by the Royal Society.

13.2 The Plan for the British Expedition

The Committee of the Royal Society initially decided to send observers to three stations, i.e. to the Chao Lai Peninsula in Siam, to the Nicobar Islands and to the Mergui Islands. In the end, only the expeditions to Siam and the Nicobar Islands took place. Even though the journey to Siam was much longer than to the other stations, and hence the time available for preparation before the eclipse was much shorter, the invitation of the King of Siam and his generous offer of help ensured that all preparation would be done before the actual arrival of the expedition team.

The expedition to Siam was supposed to be led by Sir Joseph Norman Lockyer (1836–1920; Frost 2014), but other duties prevented him from leaving England for the required time. So the Royal Society appointed the young Arthur Schuster (1852–1934; Knill 2014) from the University of Manchester instead. Schuster (1932: 69) was less than 24 years old at that time, and he considered the task to lead the expedition a great challenge, the outcome of which would determine his further career. As we will detail below, the expedition was successful.

Arthur Schuster was Professor of Applied Mathematics (1881–1888) and Professor of Physics (1888–1907) at Manchester, and carried out important pioneering work in spectroscopy and terrestrial magnetism. Today, the building of the Physics and Astronomy Department at the University of Manchester is named after Sir Arthur Schuster, and several instruments and memorabilia of his expedition to Siam and other later eclipses are on display in the Department.

13.3 The Journey

The British expedition set sail from Southampton on 11 February 1875, passing Gibraltar and Malta, and reaching Cairo on 27 February. The journey continued through the Suez Canal and the Red Sea into the Indian Ocean. On 16 March, Schuster and his team reached Point de Galle in Ceylon (now Sri Lanka), before arriving in Singapore on 23 March. Originally, the team was supposed to continue the journey to Bangkok on a Royal Navy vessel, but instead Schuster needed the help of a Siamese merchant steamer, *S.S. Kromahtah*, and when he finally arrived in Bangkok on 28 March he was greeted by two ships that had been ordered by the

King of Siam to look out for the expedition. The journey from England took 45 days and only left the team with 8 days to prepare for the eclipse.

During an audience with the King, Schuster was again promised every necessary assistance, and indeed the King later ordered one of the princes, Mom-Dang, to accompany the expedition, and he afterwards proved to be of very great help (Schuster 1932: 79–82). The King also sent the Thai officer, Francis Chit, who was a skilled photographer, to assist the expedition, and he was later charged with the preparation and development of the photographic plates (Lockyer and Schuster 1878).

The expedition departed on the Siamese *S.S. The Northern Siam Enjoying*, and on 31 March finally reached the observatory on the coast of the Chao Lai Peninsula.

13.4 The Observatory

The observatory which had been prepared for the team was located at 13° 0′ 30″ N and 100° 2′ 10″ E, being ~2.4 km southwest of the central line of totality. The forest had been cut down to make space for two observatory buildings and a number of dwellings (see Fig. 13.1). Each house reserved for the expedition contained a dining room, bedrooms, bathroom facilities and storage space for provisions. A small village had been prepared nearby, and arrangements had been made to supply food and drinking water (Schuster 1932: 84–85).

The observatory consisted of two parts, separated by about 35 m. The smaller part was intended for a siderostat to obtain a spectrum of the prominences and the lower corona (see Fig. 13.2). The larger part of the observatory was bounded by a dark room on each side, with preparation of the photographic plates on one side and development of them on the other (Lockyer and Schuster 1878). The main part contained an equatorial telescope with a prismatic camera which was of shorter focal length than the camera attached to the siderostat (see Fig. 13.3). Another equatorial telescope, which was lent to the expedition, had a spectroscopic camera attached in order to also obtain spectra of the prominences and the corona. In addition, a number of small cameras were available, the pictures from which were to be supplemented by sketches made during the eclipse.

The prismatic camera had an objective prism placed before the lens, and the Sun would then have been photographed in as many images as spectral lines were visible. The distribution of elements could then be inferred from the shapes of the different images. Interestingly, while Pannekoek (1961: 411) notes that the prismatic camera was devised and constructed by Lockyer, he also mentions that prismatic cameras were only in regular use during solar eclipses after 1896. As we will describe below, it was the prismatic camera which provided the bulk of the results obtained during the eclipse of 1875.

Fig. 13.1 One of the houses erected at the observatory, with members of the expedition (*Courtesy* The University of Manchester)

13.5 The Observations and Results

The eclipse took place on 6 April 1875, tracing a path of totality that extended from South Africa, over the Indian Ocean, across Siam to the South China Sea. Totality occurred at the observatory at 11 h 30 min in the morning, according to the expedition team and a number of members of the Royal family.

No useful results were obtained with the spectroscopic camera mounted on the equatorial telescope. Lockyer and Schuster (1878) later attributed this failure to the fact that the telescope used was not designed for this purpose, as it had a focal ratio that was far less suitable than that of similar equipment used by Janssen and the French expedition.

Some details of the expedition were published in *Monthly Notices of the Royal Astronomical Society* (RAS Council 1876), *Nature* (Lott 1875) and the *Philosophical Transactions of the Royal Society* (Lockyer and Schuster 1878). In this last-mentioned paper, the authors summarize the results of the expedition as follows:

Fig. 13.2 The siderostat used during the expedition (*Courtesy* The University of Manchester)

Fig. 13.3 The astronomers and other members of the expedition next to the equatorial telescope. Sir Arthur Schuster is visible in the white suit to the *right* of the telescope (*Courtesy* The University of Manchester)

1. Two lines from prominences observed with the prismatic camera were attributed to the hydrogen lines Hβ and Hγ.
2. The strongest protuberance was found to lie in the UV.
3. The upper corona was found to emit a 'homogeneous' photographic spectrum which was attributed to the "… hydrogen line near (Fraunhofer line) G".
4. The lower corona was found to emit a strong continuous spectrum extending into the UV up to a wavelength of 353 nm (i.e. "beyond N"), reaching to a height of about 3′ from the Sun.
5. Photographs showed that the extent of the corona rapidly increased with increasing exposure time, suggesting that the corona had no definite outline.
6. The photographic results including sketches were found to be very similar to those obtained earlier by Stone (1874) during an eclipse at the Cape of Good Hope in April 1874. The similarities extended to the observation that the corona appeared to be axisymmetric with the greatest extent being in the direction of the solar equator.

The final result was mostly based on a number of photographs and sketches that were made during totality and were reported by Lockyer and Schuster (1878). The authors emphasized the large number of drawings made by Siamese observers, and they included drawings made by H.R.H. Chau Fa Maha Mala, H.R.H. Prince Devanndaywongse and H.R.H. Prince Chetochereun. In particular, they mention that the similarity to the 1874 results is most strikingly given by the drawing made by H.R.H. Prince Tong. A drawing of the prominences, as seen by King Rama V himself, is also included in the paper.

Later, reflecting on the results of the eclipse, Schuster (1932: 92–93) reported that he had revised their first impression of the results and concluded that the strong prominence lines were not due to hydrogen but in fact to calcium. While these results were confirmed by later eclipse observations, Schuster points out that the importance of calcium in the chromosphere and prominences was first proven by the Siamese eclipse of 1875.

13.6 Conclusions

The observation of a total solar eclipse is a fascinating experience for almost everyone. Until William Huggins (1824–1910; Becker 2011), Jules Janssen (1824–1907; Launay 2012) and Norman Lockyer (Meadows 1972) realized that it was possible to observe the solar spectrum outside of an eclipse (see Meadows 1970), observations made during solar eclipses were essential for our increased understanding of solar physics. The eclipses observed by Schuster and his predecessors in Siam (Thailand) in 1868 and 1875 even caught the interest of the Siamese kings, who not only took part in the observations, but in the case of King Rama IV even made their own calculations (see Saibejra 2006). The invitations issued by King Rama IV and King Rama V to French and British astronomers to come to Siam and observe the eclipses of 1868 and 1875 represent good examples of early international collaboration in science.

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References

Becker, B.J. (2011). *Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy*. Cambridge: Cambridge University Press.

Chen, K.Y., Orchiston, W., Soonthornthum, B., & Strom, R. (Eds.), (2006). *Proceedings of the Fifth International Conference on Oriental Astronomy*. Chiang Mai: Chiang Mai University.

Frost, M. (2014). Lockyer, Joseph Norman. In T. Hockey et al., pp. 1336–1338.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hutuwarakorn-Kramer, B., & Kramer, M. (2006). The King Rama V total solar eclipse of 1875: Schuster's expedition to Siam. In K-Y. Chen, et al., pp. 19–22.

Knill, O. (2014). Schuster, Arthur. In T. Hockey et al., pp. 1957–1959.

Launay, F. (2012). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. Springer: New York.

Lockyer, J.N., & Schuster, A. (1878). Report on the total solar eclipse of April 6, 1875. *Philosophical Transactions of the Royal Society of London, 169,* 139–154.

Lott, F.E. (1875). The Government Eclipse Expedition to Siam. *Nature, 12,* 172–173.

Meadows, A.J. (1970). *Early Solar Physics*. Oxford: Oxford University Press.

Meadows, A.J. (1972). *Science and Controversy. A Biography of Sir Norman Lockyer*. Cambridge (Mass.): MIT Press.

Orchiston, W., & Orchiston, D.L. (2017). King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-koa, Siam. In T. Nakamura, & W. Orchiston (Eds.). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Pannekoek, A. (1961). *A History of Astronomy*. New York: Dover Publications.

RAS Council (1876). Report of the Council to the 56th Annual General Meeting. The total eclipse of the Sun of April 6, 1875. *Monthly Notices of the Royal Astronomical Society, 36,* 181–185.

Saibejra, N. (2006). King Mongkut, the Father of Thai Science. In K.-Y. Chen et al., pp. 15–18.

Schuster, A. (1932). *Biographical Fragments*. London: Macmillan.

Stone, E.J. (1874). *Memoirs of the Royal Astronomical Society, 42,* 31. Cited by Lockyer, J.N. & Schuster, A. (1878). *Philosophical Transactions of the Royal Society of London* 169, 139–154.

Part VI
Indonesia

Chapter 14
The Development of Astronomy and Emergence of Astrophysics in Indonesia

Bambang Hidayat, Hakim L. Malasan, and Emanuel Sungging Mumpuni

14.1 Introduction: The Rise of Observational Astronomy in Indonesia

Long before science was recorded in Indonesia, astronomy played an important role throughout the archipelago (e.g., see Ammarell 1987). One prominent example was the implementation of a calendrical system known as *Pranotomongso* (*Pranoto* = keeper, *Mongso* = season), which served as an invaluable guide to farmers from its introduction about 1300 years ago (Hidayat 2000a). This practice flourished until at least the nineteenth century, and has been reviewed by Daldjoeni and Hidayat (1987).

Every ethnic group in the Indonesia archipelago had their own world-view, which included the role of celestial objects and events. For example, in Javanese tradition the Milky Way was depicted as the hero *Bima* from the Mahabarth epic, fighting the dragon in the sea, with the reflection imprinted in the sky, known as the '*Bima Sakti*' epic (Fig. 14.1). During the mid-1950s the name *Bima Sakti* inspired Indonesian astronomers in Indonesia to study the Milky Way, and it also was the name given to the first Schmidt telescope in Indonesia.

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Fig. 14.1 The depiction of the Milky Way according to Javanese tradition, with the hero *Bima* fighting the dragon in the sea, and the reflection imprinted in the sky (Mumpuni collection)

When Europeans began to explore *terra incognita*, they brought a new perspective on the heavens to the Indonesian region, and ushered in a new chapter on the study of astronomy. The Dutch explorer Frederick de Houtman (1571–1627) catalogued about 303 stars in the southern hemisphere (Fig. 14.2; Knobel 1917). As a result of his voyage of 1603, de Houtman's astronomical studies came to the attention of astronomers in Europe (see Dekker 1987; Hidayat 2000b).

De Houtman reported that during his visit to the 'East Indies' the indigenous people already had a knowledge of the celestial bodies, as well as a practical calendrical system that was used for agriculture, navigation and religious ceremonies.

In essence, celestial knowledge does not belong to one particular ethnic group or nation, but obviously its form depends on the cultural context for the practitioners. As an example, the *Pranotomongso* system relied on the yearly movement of the Sun in the sky, and only applied to one specific location, namely the island of Java. From about 1600 to 1850, accurate measurement of the Sun's position was conducted using a *bencet* (Fig. 14.3), which was actually a simple gnomon, and the year was divided into 12 unequal periods known as *mangsa*.

Ammarell (1987: 243) describes how two different *mangsas* "… began on days … when the sun cast no shadow [on the *bencet*] at local solar noon, and another two of which begin on the two solstices, when the sun casts its longest mid-day shadows." The precise design of the *bence*t was determined by the fact that the island of

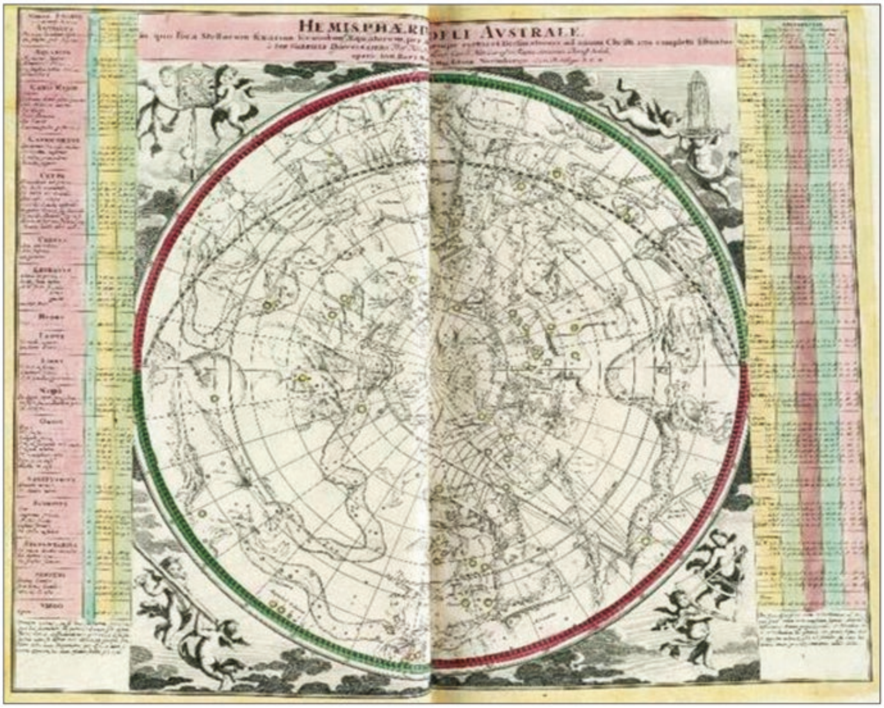

Fig. 14.2 A seventeenth century celestial map of the Southern Hemisphere, the *Atlas Coelestis* (1742) from the work of Johann Gabriel Doppelmayr (after http://www.staff.science.uu.nl/~gent0113/doppelmayr/doppelmayr.htm)

Java is 7° south of the Equator. Because of this, the number of days in each *magsa* varied between 23 and 43 days (Ammarell 1987).

In marked contrast to the central Javanese *Pranotomongso* solar calendar' were lunar calendars of the Balinese and the Javanese Saka calendar, which was in vogue from the eighth to the sixteenth centuries. "Both are apparently of a common Hindu origin and … employ complex mathematical techniques to provide the intercalary days which periodically synchronize the lunar with the solar year …" (Ammarell 1987: 245).

14.2 The Renaissance: An era of Exploration and the Beginning of Modern Astronomy

Long before European maritime exploration, those from other continents also were adept in exploration. For instance, the museum at the Borobudur temple records that even the ancestors of present-day Indonesians had already explored the Madagascar region, near the east coast of Africa.

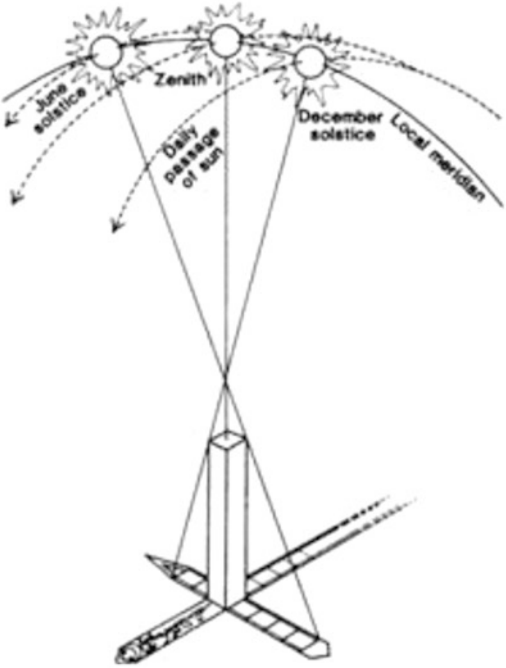

Fig. 14.3 The *bencet*, the sundial used by the Javanese to segment the year by following the noontime shadow of the gnomon over equal intervals of length on the base plate (after Aveni 1981)

But the different knowledge of navigation and cartography developed by the Europeans, opened a new chapter, which also impacted on the progress of astronomy. This specific era, around the sixteenth and seventeenth centuries and known as the Renaissance, marked a new beginning of world exploration, better utilizing astronomy and navigation.

During this era, one major challenge for astronomy was the determination of the distance from the Earth to the Sun, the so-called ‘Astronomical Unit’ (AU). Building on the ideas of James Gregory (1638–1675), in 1716 Edmund Halley (of comet fame) documented how one could use observations of a transit of Venus to calculate the solar parallax, and hence the AU. Such transits would occur in 1761 and 1769, and a preferred observing location was Batavia, on the island of Java in the Dutch Indies—later the Dutch East Indies.

A new phase in the development of astronomy in Java emerged when a Dutch Pastor named Johan Maurits Mohr (1716–1775), who had previously studied theology in Groningen, moved to the East Indies in 1737 to lead the Portuguese Church in Batavia (which he did until his death in 1775). Apart from religion, Mohr had a passion for astronomy, and in 1765 he set up a well-equipped observatory at his home (Zuidervaart and van Gent 2004). Of particular interest to him were the transits of Venus of 1761 and 1769, and he succeeded in observing both (van Gent 2005). His observations of the 1769 transit (Mohr 1771) were published in the *Philosophical Transactions of the Royal Society*, London (Fig. 14.4), but the quality of his results were questioned by some.

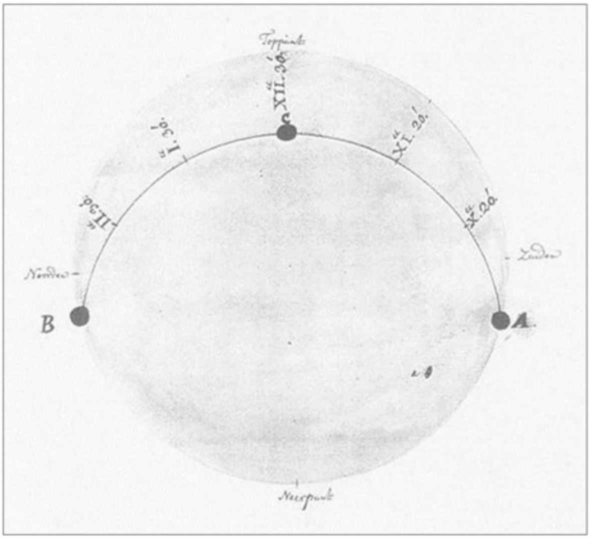

Fig. 14.4 A manuscript drawing showing Mohr's observations of the 1769 transit (after Zuidervaart and van Gent 2004: 17)

In this context, it is of interest to note that during this era the VOC (Verenigde Oostindiscche Compagnie) was the company that organized the trading activities between the East Indies and the Netherlands, and it had no interest in developing science as it was solely motivated by profit. Another factor that lay outside the geo-social-politic arena was that Pastor Mohr was not educated in astronomy—rather, he was driven by passion and inspired by his faith.

After Mohr's death his abandoned observatory was damaged by an earthquake and subsequently was demolished, but until quite recently the location was known colloquially as 'Gang Torong' (tower alley). Most of Mohr's scientific instruments were lost, but a few have survived and are preserved at Amsterdam University (Zuidervaart and van Gent 2004).

Zuidervaart and van Gent (Zuidervaart and van Gent 2004) have shown that following the 1769 transit there were attempts by European settlers to commence systematic astronomical observations in Batavia, but the bankruptcy of the VOC in 1799 widely affected socio-political life and stifled any further scientific activity.

14.3 The Rise of Independent Science

Hidayat (2000b) has described how during the nineteenth century the Director of Leiden Observatory, Frederik Kaiser (1808–1872; Heijden 2014), advocated the use of geodetic astronomical observations to determine the latitude and longitude of localities in the East Indies (Haansbroek 1977).

Kaiser realised that these observations would have economic impact on the Netherland Colonial Government, and since Leiden Observatory was strongly supported financially by the Government, played a major role in Dutch astronomy, was a member of the Naval Institute that trained governmental officers in astronomy, and callibrating optical instruments, Leiden astronomers would be able to join foreign scientific expeditions to the Dutch colonies.

In this way, astronomical links between Holland and the East Indies began, but it was no easy path, and most of those who went to the East Indies were not able to accommodate Kaiser's wishes. A good example was the Royal Netherland Naval officer Lieutenant Sjuurd de Lange. He left Holland in 1850 at the age of 27, to take geodetic measurements in difficult terrain in the East Indies. De Lange died at the age of 39, from various causes, but most of all because there was insufficient supporting infrastructure in the colony (Haansbroek 1977).

Another one of Kaiser’s students was Jean Abraham Chrétien Oudemans (1827–1906) who in 1857 had an opportunity to work as the Head Engineer for the Geographical Service of King William III and make a topographic map of the Indonesian archipelago using astronomical observations. This work had three components: firstly, Oudemans had to make astronomical observations in order to determine the latitude and longitude of selected sites and localities, and then he had to use these data for cartographic purposes—to compile a detailed map. Thirdly, he was keen to conduct original astronomical research, and observed the 1868 and 1871 total solar eclipses, both of which were visible from the Dutch East Indies (Mumpuni et al. 2017). Oudemans sometimes found these competing demands a challenge, and after 12 years he decided to return to Holland and enjoy an academic life there, at Utrecht Observatory (see Orchiston et al. 2018). We will meet Oudemans again in the next chapter of this book.

The cases of de Lange and Oudemans, and the development of the Royal Magnetic and Meteorological Observatory (now BMKG, the Meteorological Agency of Indonesia), which took 20 years, highlight the conflict that sometimes existed between the well-intentioned requests from the homeland (the Netherlands), and the realities of achieving this in a ‘frontier land’. It was this conflict that ultimately would spark the emergence of a new independent local science at the ‘frontier’.

14.4 The Southern sky: The Need for It to be Explored

At the end of the nineteenth century and early in the twentieth century astronomy evolved rapidly with the emergence of the ‘new astronomy’, astrophysics. As Kuiper (1945) has pointed out, one of the important topics at that time was stellar evolution: where did stars come from, how did they evolve, and what happened when they aged and died?

To answer these sorts of questions astronomers needed a solid grounding in modern physics, in order to understand energy generation and nuclear processes, and to use observations to determine a star’s mass, diameter and luminosity. The best experimental object that can be used to explore these parameters was a double star. We will return to this topic later.

In 1922 the celebrated Dutch astronomer Jacobus Cornelius Kapteyn (1851–1922; Van der Kruit and van Berkel 2000) produced a seminal research paper titled "First attempt at a theory of the arrangement and motion of the Sidereal System" (Kapteyn 1922), where he showed that our understanding of the nature of the Universe was incomplete, because at that time very little information was available from the Southern Hemisphere. Many observatories already existed in the Northern Hemisphere, but the southern skies were still largely 'Terra Incognita' to astrophysicists.

The Dutch East Indies are located slightly south of the equator, but this fact did not inspire Dutch astronomers to right away begin researching the Southern sky even though there was a socio-political driver for modern astronomy to emerge. Rather, the fundamental questions were: who would carry out the research, and in which specific institutions?

In the early twentieth century the only institution involved in astronomy in the Dutch East Indies was the Royal Magnetic and Meteorological Observatory, which at the time was directed by Professor Reinout Willem Van Bemmelen (1904–1993), who had good relations with Professor Willem de Sitter (1872–1934) from Leiden, in the Netherlands. But Van Bemmelen had limited opportunities to develop astronomy in the Dutch East Indies.

In 1918 Leiden established a cooperation with South Africa in observational astronomy, then in 1923 de Sitter initiated a collaborative arrangement between the Leiden astronomers and those at the Union Observatory in Johannesburg, so observations from another southern hemisphere site (such as in East Indies) were no longer required.

But a spirit of independence still lingered in the East Indies, and a new chapter began when K.A.R. Bosscha and Dr. J. Voûte collaborated to build an independent observatory in the Dutch East Indies. In the future, their collaboration would prove to be vital for the establishment of astronomy and astrophysics in Indonesia.

Karel Albert Rudolf Bosscha (1865–1928; Fig. 14.5; van der Hucht and Kerkhoven 1982), the son of a well-know physicist in the Netherlands and a graduate of the Polytechnical School of Delft, was a third-generation tea tycoon who had a plantation in the hilly countryside at Lembang, near Bandung and also contributed to the seismic investigation of the Dutch East Indies.

Although of European descent, Joan George Erardus Gijsbertus Voûte (1879–1963; Fig. 14.6; O'Connell 1964) was born in Madiun, East Java, but after studying civil engineer in Delft he began a career in astronomy in Leiden, specializing in double stars. His interest in double stars began when he was involved in the IAU Commission on latitude determination, and for his observations he was assigned to Leiden Observatory.

During 1913–1919 Voûte worked at the Royal Observatory at the Cape of Good Hope in South Africa measuring stellar parallaxes and double stars until Professor van Bemmelen invited him to return to Java and work on time-keeping at the Royal Magnetic and Meteorological Observatory.

Fig. 14.5 (*Left*) An undated photograph of K.A.R. Bosscha in the collection of the Tropen Museum, Amsterdam (http://en.wikipedia.org)

Fig. 14.6 (*Right*) A photograph of Dr. J.G.E.G. Voûte taken in about 1908, and now in the Leiden Observatory Archives, H.G. van de Sande Bakhuyzen Collection (http://en.wikipedia.org)

Because of his knowledge of and passion for astronomy, Voûte's drive to establish modern astronomy in Java continued to grow and then he meet Bosscha and asked for his aid in building an observatory in Java and promoting modern astronomy in the Dutch East Indies. Bosscha agreed, and the *Nederland-Indische Sterrenkundige Vereeniging* (Associaton of Astronomy of East Indies) was established in 1920.

Fig. 14.7 An 1898 painting of Professor H.G. van de Sande Bakhuyszen, now in the collections of Leiden University (http://en.wikipedia.org)

The following year Bosscha and Voûte travelled to Europe to search for astronomical instruments that could be used for research on double stars. The first telescope they acquired was a 7-in. (18-cm) refractor donated by Professor de Sitter in January 1924, and the measurement of stellar parallaxes was able to begin.

During these formative years Bosscha convinced Professor Hendricus Gerardus van de Sande Bakhuyszen (1838–1923; Fig. 14.7), a retired Director of Leiden Observatory, to donate his private library to Bosscha Observatory, and even today the Observatory has the best astronomical research and reference library in Indonesia.

The primary telescope that would be used at the Observatory, a Carl Zeiss twin 24-in. (60-cm) refractor (for visual and blue band observations) was built in Jena, Germany, between 1925 and 1926, installed in a large new dome at the Observatory (Fig. 14.8) and finally was inaugurated in June 1928. This marked the launch of modern of astronomy and astrophysics in Indonesia, but unfortunately K.A.R. Bosscha would not live long enough to witness the rewards of his immense commitment to Indonesian science as he passed away in November 1928.

During these early years financial support for the Observatory came from three major sources: (a) subsidies from the Government of the Dutch East Indies; (b) the Nederlandsch-Indiesche Sterrekundige Vereeniging (a trust created by Bosscha); and (c) donations. Because of K.A.R. Bosscha's dedication and the enormous contribution that he made to the development of astronomy and astrophysics in Indonesia the Observatory was named after him.

Fig. 14.8 The dome of the 24-in. twin refractor at Bosscha Observatory, photographed from the north during the 1930s (*Courtesy* Lilian Ursone, who kindly supplied Bambang Hidayat with this image when he visited her in Torino, Italy, in 1970)

14.5 Pre-WWII Astrophysics at Bosscha Observatory

The selection of Lembang for the location of the Association's Bosscha Observatory was not a random one but was based on meteorological, climatic and vulcanological factors. The Lembang site allowed difficult celestial observations, such as precise measurements of double stars and planetary movements.

From his observations and measurements Voûte was able to confirm Robert Thorburn Ayton Innes' claim that Proxima Centauri was part of the Alpha Centauri system and at the time was the closest-known star to the Sun (Glass 2009). Many years earlier, Voûte (1917) had derived a parallax value of 0.746 ± 0.006″ for Proxima Centauri.

However, research at Bosscha Observatory was not restricted to double stars. Because of the Observatory's location 7° south of the Equator, this allowed research on the astronomical richness of the southern part of the Milky Way. In 1926, Professor Antonie Pannekoek (1873–1960; Waelkens 2014) from the University of Amsterdam spent several months at Bosscha Observatory studying galactic structure in the southern region of the Milky Way for the 'Skalnate Pleso' Star Atlas (see Fig. 14.9).

In its early days, Bosscha Observatory become a 'prominent player' in southern hemisphere astronomy, and other astronomers from the northern hemisphere visited

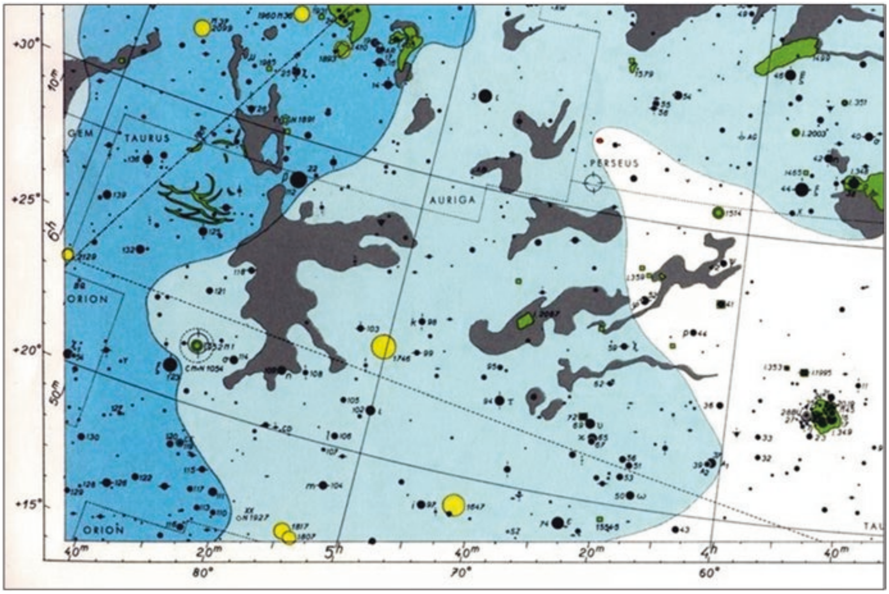

Fig. 14.9 A section of a Skalnate Pleso map showing stars, star clusters and gaseous and other nebulae (after http://www.ta3.sk/public_relation/becvar/atlasy.html)

the Observatory and conducted research that helped the development of astrophysics. For example, Dr. Paul ten Bruggencate (1901–1961; Fig. 14.10; Broughton 2014) from Göttingen University Observatory in Germany spent 2 years at Bosscha Observatory studying globular clusters, and he carried out photometry and spectroscopy of variable stars, particularly the δ Cepheid stars (Jäger 1962).

Dr. Åke Anders Edvard Wallenquist (1904–1994) from the University of Uppsala in Sweden introduced the theoretical study of southern galactic clusters using the colors and distribution of stars in Sagittarius and Opiuchus. Wallenquist worked at Bosscha Observatory for 10 years before returning to the University of Uppsala as a Professor of Astronomy in 1935.

Dr. Egbert Adriaan Kreiken (1896–1964) from the Amsterdam School of Astronomy carried out theoretical studies of double stars, and the distribution of stars in Scutum. Although Kreiken only stayed at Bosscha Observatory for a short time (1928–1930), he spent from 1931 to 1942 as a secondary school teacher in central Java and after WWII become the Head of the Higher Education Department in Jakarta before moving to Ankara, Turkey, and establishing a school of astronomy there (Fig. 14.11). Kreiken later play an important role in acquiring a Schmidt telescope for Bosscha Observatory (see Sect. 14.7 below).

Another visiting scientist at the Observatory was the Russian astronomer Dr. G.V. Simonov, who carried out double star observations with Dr. Voûte before moving to Mount Stromlo Observatory in Australia.

Fig. 14.10 An undated photograph of Dr. P. ten Bruggencate (http://dutchgenie.net/bruggencate/brugg-e-o/p4381.htm)

Fig. 14.11 An undated photograph of Dr. E.A. Kreiken after he moved to Ankara University (http://rasathane.ankara.edu.tr)

In 1939 Leiden graduate Dr. Aernaut de Sitter (1905–1944), the son of the well-known Dutch astronomer Willem de Sitter, was appointed Director of Bosscha Observatory. His major work was on the globular cluster M4. In 1941, Aernaut de Sitter's colleague and fellow-Leiden graduate Dr. Willem Christiaan Martin also joined the staff, and he concentrated on the globular cluster Omega Centauri. Soon afterwards WWII broke out, which sealed the fate of these young astronomers: they were sent to prisoner-of-war camps by the Japanese where they perished. Their sad story is mentioned by Adriaan Blaauw (2004).

During the Japanese occupation of Indonesia Bosscha Observatory was under the administration of a young Captain in the Imperial Japanese Army, Masasi Miyadi, and he was able to save the Observatory from total destruction. He even arranged for Dr. Voûte to help him run the Observatory, and at the end of WWII Captain Miyadi officially returned the facilities to Dr. Voûte. Miyadi later became the Director of Tokyo Astronomical Observatory, and he subsequently wrote about his time at Bosscha Observatory (see Miyadi 1975).

14.6 Astronomy and Higher Education

Despite Captain Miyadi's supportive attitude, Bosscha Observatory suffered heavy damage during WWII, and after the War Dr. Chris H. Hins (d. 1951) was assigned by the Netherlands to restore the Observatory. He found the situation very saddening, and it took him 3 years (between 1946 and 1949) to rehabilitate the Observatory (Hins 1950).

During this period Indonesia became an independent nation, and the Association of Astronomy of the East Indies no longer had enough funds to maintain the Observatory, so its rehabilitation was continued by the Faculty of Mathematics and Natural Sciences at the University of Indonesia in Bandung.[1]

In 1950 Dr. Gale Bruno van Albada (1912–1972; Fig. 14.12; Houziaux 2014) was appointed Director of the Observatory (replacing Dr. Hins), and the following year be became the first Professor of Astronomy at the University of Indonesia in Bandung, attached to the Faculty (while continuing to direct the Observatory). Two others who joined the Observatory staff at this time were Dr. Elsa van Albada-van Dien (1914–2007) and Bulgarian-born Iwan Nikoloff (1921–2015), who carried out research on double stars. The Indonesian scholar Santoso Nitisastro also joined the staff as an Assistant Astronomer (and he would later become the first Director of the Planetarium and Observatory in Jakarta). At this time, astronomy courses began at the University of Indonesia in Bandung, as the part of higher education learning for indigenous Indonesian astronomers.

It is worth noting that during the 1980s there was discussion about establishing a Department of Astronomy at another university, Gajah Mada University in Yogyakarta, with emphasis on radio astronomy (see Sastroamidjojo 1986), but this did not happen, and it would appear that at that time few universities in Indonesia were ready to embrace astronomy as an independent science. However, more recently, many Indonesian universities have decided to include astronomy as part of their undergraduate physics programs, as provided for example by the University of Education of Indonesia (UPI), which also decided to offer astronomy at a post-graduate level (Hidayat 2004). This reflects the steady progress that has occurred in academic astronomy, even though it has not been achieved, generally, as an independent science.

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[1] Note that in 1959 this Faculty would become the Fakultas Matematica dan Ilmu Pengetahuan Alam when the President of the Republic of Indonesia renamed the University of Indonesia in Bandung the Institut Teknologi Bandung (or ITB).

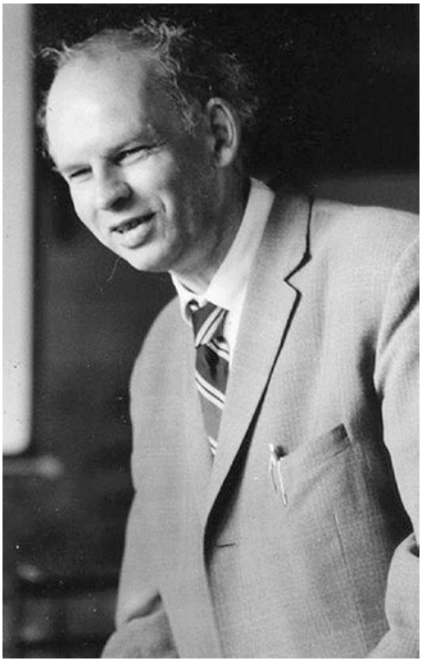

Fig. 14.12 A photograph of Professor G.B. van Albada taken in about 1955 (http://tri.astraatmadja.org)

During the 1980s, radio astronomy was not only of interest to Gajah Mada University. It also became the focus of an international collaboration when Professor Govind Swarup from India proposed the construction of a Giant Equatorial Radio Telescope (GERT) in Sumatra (Swarup et al. 1984). For various reasons this did not happen (see Swarup 2017: Sect. 27.8), and more than two decades would elapse before radio astronomy gained a firm foothold in Indonesia—as outlined later in this chapter.

14.7 The Role of Dr. Purbosiswoyo

Kusumanto Purbosiswoyo joined the staff of Bosscha Observatory as an Assistant in 1955, and immediately was keen on improving the performance of the Bamberg Telescope, a 37-cm (14.6-in.) Schmidt refractor (see Fig. 16.11) that was one of the founding instruments of the Observatory. By the end of WWII the telescope was no longer operational so Mr. Purbosiswoyo renovated the driving mechanism of the telescope, and this became the topic of his Masters thesis at the Department of Astronomy at ITB.

Later Mr. Purbosiswoyo received a graduate scholarship and from 1961 to 1963 he worked on a Ph.D. at the Case Institute of Technology in Cleveland, Ohio (USA), under the supervision of Professor Victor Blanco. His thesis topic was about correcting photographic magnitudes due to background irregularities in the photographic plates. Dr. Purbosiswojo then wrote a paper on "Correction of background effect in photographic photometry", and presented this at the Symposium on Standards for Stellar Photometry and Spectral Classification in Bandung in 1963, the first international Astronomy symposium held in Indonesia. At his time, other staff members (e.g. Messrs. Ibrahim and Santosa) were inspired to carry out research in astrophysics.

But Dr. Purbosiswoyo did more than just encourage research at Bosscha Observatory and teach astrophysics in the Department of Astronomy at ITB. Along with Air Marshall Salatun, in 1964–1965 he was responsible for founding the Indonesian Institute for Space Sciences, which flourished and later became LAPAN. Unfortunately for Indonesia, in the early 1970s Dr. Purbosiswojo moved to Holland, and he worked with Phillips until his retirement. Although he never returned to Indonesia, his important contribution to Indonesian astrophysics and space sciences deserves to be widely recognised and applauded.

14.8 The Schmidt Telescope and the Study of Galactic Structure

As mention earlier, because of its fortuitous location on the Earth, Indonesia can contribute to the study of galactic structure, but what was required was the right instrumentation. In this section we describe such a telescope, which played a key role in the development of astronomy and astrophysics in Indonesia (see van Albada-van Dien 1994).

Back to 1947 when he was Head of the Higher Education Department in Jakarta, Dr. A.E. Kreiken attended the second General Meeting of UNESCO in Mexico, and he helped arrange for UNESCO to provide new astronomical instrumentation for Bosscha Observatory.

As the Professor of Astronomy at the time at the University of Indonesia in Bandung and Director of Bosscha Observatory, Dr. G.B. van Albada also was thinking about the development of the Observatory and the need for a new telescope. Initially, he favoured photometric studies, but the seeing in Lembang prevented this so he decided to discuss various options with Dr. Gerard Peter Kuiper (1905–1973; Fig. 14.13; Trimble 2014), who was then the Director of Yerkes Observatory in the USA.[2]

Kuiper offered another option: he was willing to donate to Bosscha Observatory the optics for a 51/70-cm f/3.5 Schmidt telescope that were then stored in a workshop at Yerkes Observatory. This was an extraordinary offer, as a Schmidt telescope was ideal for galactic studies.

Despite Kuiper's generous offer a challenging financial road lay ahead as the agreement between UNESCO and the Indonesian Government involved an estimate

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[2] In fact, back in 1937 Dutch-born Dr. Kuiper had been offered the Directorship of Bosscha Observatory, but instead he chose to accept the Yerkes Observatory Directorship.

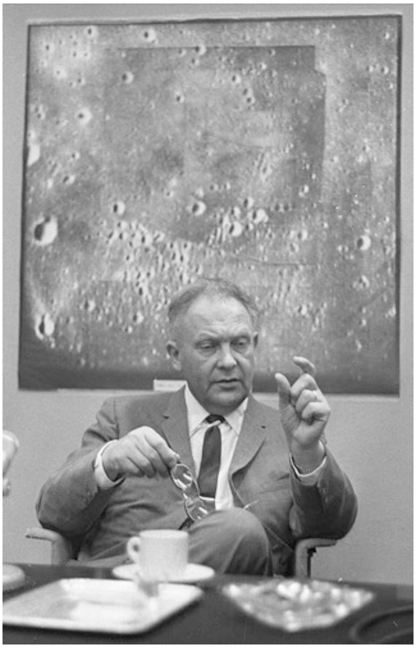

Fig. 14.13 A photograph of Dr. G.P. Kuiper that is now in the Dutch National Archives in The Hague (https://en.wikipedia.org)

of only US$16,000 for the construction of a functioning telescope, whereas to build the tube assembly, plate-holder and mounting for the Schmidt telescope would require US$150,000–200,000! To try and resolve this situation, in desperation van Albada contacted Profesor Jan Hendrik Oort (1900–1992; Fig. 14.14; Blaauw 2014), the Director of Leiden Observatory. Professor Oort helped by contacting Rademakers, a company in Rotterdam that made high-precision instrumentation and had a special interest in astronomy. Oort also contacted Mt. Wilson and Palomar Observatories, operated by the Carnegie Institution of Washington, because at that time Palomar Observatory was host to the world’s largest Schmidt telescope.

The Carnegie Institution of Washington kindly allowed Rademakers to use the Palomar Schmidt design, including the camera system, which reduced the cost of the Bosscha Observatory Schmidt telescope to US$18,000. With financial help from the Leds Kerkhoven-Bosscha Fund and UNESCO the project continued, and the telescope was finished in 1958 and shipped to Indonesia. One of the authors (BH) recalls how Professor van Albada went to the port in Jakarta, personally took delivery of the telescope and removed it from the shipping crate. It then was transferred to the Observatory, arriving there late in the evening.

Unfortunately, relations between Indonesia and the Netherlands deteriorated about this time, and van Albada and van Albada-van Dien were forced to return to the Netherlands. Now the search was on to find a new Bosscha Observatory Director.

When van Albada was still in Indonesia, he had arranged for one of his students, Thé Pik Sin, to study in the United States, and subsequently Thé received a Doctorate from Case Institute of Technology in Cleveland, Ohio; he was the first indigenous

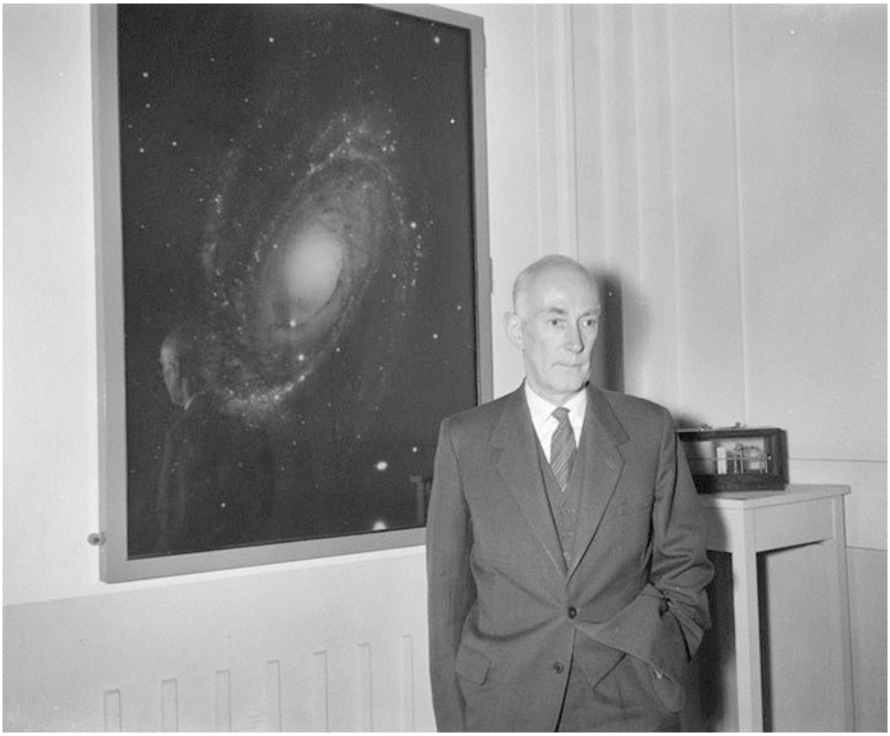

Fig. 14.14 A photograph of Professor J.H. Oort taken on 12 May 1961 and now in the Dutch National Archive Photo Collection (https://en.wikipedia.org)

Indonesian student to obtain a Ph.D. in astronomy. In 1959 he returned to Indonesia and became the first Indonesian Director of Bosscha Observatory, and the following year he invited Professor Victor Blanco (1918–2011) from the Case Institute of Technology to visit Indonesia (with financial support from UNESCO) and supervise the erection and commissioning of the Schmidt telescope (Thé 1961). Professor Blanco was still at Bosscha Observatory when UNESCO held the official dedication ceremony on 28 May 1960, thereby launching a new era in the Indonesian study of galactic structure.

The Schmidt telescope (Fig. 14.15) was christened the *Bima Sakti* Telescope, which is the name of the Milky Way in Javanese mythology (van Albada-van Dien 1994), and as depicted in Fig. 14.1. The name was fitting, for with a field of 5° × 5°, and equipped with a 6° objective prism, it was a blessing for Indonesian astronomers to have access to a remarkable telescope, which had been acquired at a relatively modest price.

Notwithstanding van Albada's earlier concerns, sky conditions at Bosscha Observatory proved ideal for the Schmidt telescope, which was used to carry out two major research projects: (1) The survey of Hα emission-line stars in the southern Milky Way, and (2) The study of the large-scale structure of the Milky Way

Fig. 14.15 The *Bima Sakti* Schmidt Telescope. Later the telescope was remounted on a fork mounting (http://www.oasi.org.uk/Obsvns/19980822_SE/Bosscha_3.jpg)

through the 3-D space distribution of stars of different spectral types. Details of these research projects are provided by Hidayat (2004), and Herbig (1967) acknowledges that Thé's research with the new Schmidt telescope made a major contribution to the study of the distribution of young stars in the Milky Way.

During the 1960s, the successful study of the structure of the Milky Way by Bosscha Observatory astronomers was partly made possible because of strong collaboration with Warner and Swasey Observatory in the USA (see McCuskey 1967). Among the various projects undertaken by Bosscha Observatory astronomers were the distribution of different types of stars in the southern Milky Way in Norma (Drilling 1968), and the use of giant M stars to reveal galactic structure (e.g. Hidayat and Blanco 1968; Raharto 1996; Raharto et al. 1984).

14.9 Astronomy Cooperation within Asian Countries

From early in the twentieth century Japanese astronomers wanted to carry out observations in Java, but mainly for the determination of latitude and longitude, as described by Miyadi (1975). However, a collaboration between Japan and Indonesia in astrophysics only began in 1975, with research in two major fields: galactic astronomy and stellar physics (Kogure 1986). A 3-year programme started in 1979, with the title ‘Spectroscopic and Photometric Study of the Galaxy’, and was followed by another 3-year programme that included stellar physics and was titled ‘Galactic Structure and Variable Stars’ (Hidayat 1985).

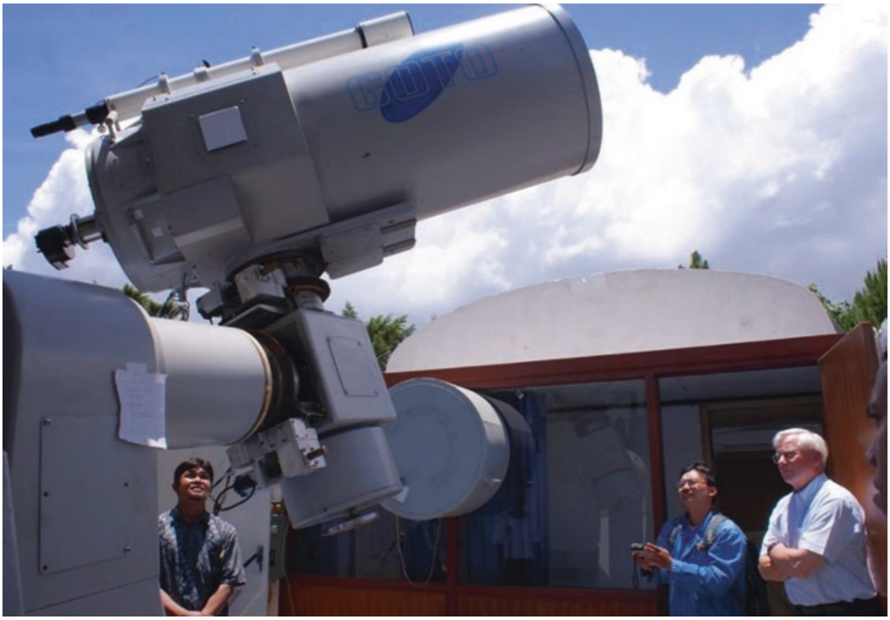

Fig. 14.16 The 45-cm reflecting telescope donated to Bosscha Observatory by the Japanese Government being inspected by an Indonesian technical staff member and a scientist, while on the right is Dr. Karl van der Hucht from the Netherlands (*Courtesy* Bosscha Observatory)

Research during this 6-year period included the study of red giants in the region around the Galactic Center; a survey of Hα emission stars; the dynamical evolution of stellar systems from galactic field studies; photoelectric observations of close binaries and Be/Ae binaries; spectroscopy of Be stars; and the evolution of neutron stars and pulsars.

This collaboration emphasized the surveying, monitoring and photometric observation of variable objects, and was important in promoting astronomy in the Asia-Pacific region. This cooperation and collaboration in research and instrumentation has continued for many years with an exchange of personnel, and many young astronomers from Indonesia obtained their doctorates through this collaboration.

In 1988 the Japanese Government kindly donated a 45-cm reflecting telescope (Fig. 14.16) to Bosscha Observatory (see Hidayat et al. 1991; Kitamura 2001). This marked a milestone in the development of astrophysical research in Indonesia, for with very little absorption loss at shorter wavelengths this telescope was particularly useful for photometric studies. It was employed extensively by Dr. Hakim Malasan and his students, with a photometer that was developed by Mr. Hartono from the Physics Department at ITB under the supervision of Professor Kitamura of Tokyo Astronomical Observatory. After the construction of the Bosscha Compact Spectrograph (see Malasan et al. 2001), the 45-cm reflecting telescope also was used for spectroscopy (e.g. to monitor southern Be stars—see Dawanas et al. 2008).

To this day, the collaboration between Indonesian and Japanese astronomers continues, with a wide range of projects that serve to promote the development of astrophysics in Indonesia.

14.10 The Expanding Universe and the Study of Cosmology

As mentioned previously, Bruno van Albada was the first Professor of Astronomy in Indonesia, and he not only laid the foundation for astronomical higher education in our nation but also introduced a variety of research themes.

During his inauguration as Professor of Astronomy in the Faculty of Mathematics and Natural Science at the University of Indonesia in Bandung (now ITB), van Albada (1951) gave a speech, in Dutch, titled "Der Hypothese van het pre-stellaire stadium" (i.e. "The hypothesis of the pre-stellar stadium").

Ibrahim (2001) later reviewed and commented on van Albada's speech. What van Albada proposed was that the creation of the Universe started with undifferentiated matter and a singularity that experienced extraordinarily high pressure and density, followed by a sudden abruptly intense detonation that led to the Universe becoming of finite density and beginning to expand. This was a dynamic view of how the Universe came into existence, and differed markedly from the well-established 'steady state' theory that prevailed at the time. The clear message that van Albada advocated was that Indonesian astronomers should embark on studying the large-scale structure of the Universe and cosmology.

One student who had studied at Bosscha Observatory, Jorga Ibrahim, has devoted much of his time to theoretical astronomy (see Ibrahim 1972; Ibrahim and Lichnerowicz 1976). His deep understanding of the mathematical concepts involved was fundamental to the emergence of cosmological studies in Indonesia, which was diversified in later years to include research on gravitational lensing (see Premadi et al. 1998, and subsequent papers).

14.11 Near-Earth Astronomy: Solar-Terrestrial Relations and Space Weather

Interest in the role of the Sun as our nearest star and how it affects the Earth led to the study of solar physics in Indonesia in the 1970s, and the formation of LAPAN. This new organisation is chartered with studying space science, and possibly exploring it in the future.

With help from Santoso Nitisastro who previously worked at Bosscha Observatory, radio astronomy was launched in Indonesia when Cornelius de Jager—a solar astronomer in the Netherlands, with secondary school teaching experience in Indonesia and a fondness for Indonesia—arranged for Post Telegraf and Telephone of Netherland to donate a 200 MHz radio telescope to LAPAN.

Fig. 14.17 The solar radio spectrograph operated by LAPAN and located in Sumedang district, West Java (*Courtesy* LAPAN)

This telescope radio was used to study ‘space weather’, i.e. solar emission and its influence on the near-Earth environment and the utilization of the Earth’s upper atmosphere for space technology.

This study called for more sophisticated instrumentation, which began with the installation of an Hα solar telescope that is used to study the solar chromosphere. This telescope is located at Watukosek in East Java (Setiahadi et al. 1996).

LAPAN also established a radio spectrograph (Fig. 14.17) that can observe solar emission over the frequency range 57–1800 MHz, and this is located at Tanjungsari in West Java. Observations at these frequencies are important for the detection of high-energy particles that are ejected by the Sun and beamed towards the Earth, where they have the potential to cause considerable danger and damage. Today the study of space weather, and particularly solar physics, is an important and growing area of research at LAPAN, and it also can be studied at several Indonesian universities.

At present, much of the research in this field focuses on solar activity and how this may affect the Earth’s environment (but especially the ionosphere and geomagnetism). Astronomers in Indonesia who work in this field, and particularly those at LAPAN, are already involved in various international collaborations and cooperative studies, such as ISWI (International Space Weather Initiative) and AOSWA (Asia Oceania Space Weather Alliance). In this way, Indonesian astronomers also can contribute to astronomy. Much of the foregoing account is based on a review written by Mumpuni et al. in 2012.

14.12 Astronomy at Present, and Future Prospects

Since the establishment of Bosscha Observatory, much time has been devoted by Indonesian astronomers to the study of binary stars, and stellar astrophysics has become the legacy of recent generations of astronomers in Indonesia. The extensive database of visual binary stars observed from Bosscha Observatory was reviewed by Jasinta (1997) in order to improve the observational programmes.

Indonesian astrophysics gained further momentum in the 1960s when the nation was selected to host a symposium on ‘Standards for Stellar Photometry and Spectral Classification’. The selection of this topic was important for Bosscha Observatory, and a framework for the transfer by astronomers of standard magnitudes from the northern and southern hemispheres was set up at this time (Thé 1963; cf. Nitisastro 1963).

In the 1970s, with the growing number of indigenous Indonesian astronomers, the types of astrophysical research also grew steadily. Sutantyo (1975) started to study low mass X-ray binaries, thus launching research on X-ray astronomy in Indonesia, while eclipsing binaries received considerable attention at Bosscha Observatory (e.g., see Malasan et al. 1989).

More recently, Indonesian astronomy has developed and diversified further, and now includes not only studies in the visual and X-ray regions of the electromagnatic spectrum but also in the radio band. Since the founding of Bosscha Observatory, much effort has been dedicated to the study of double stars, and initially this formed the backbone of modern astrophysics in Indonesia, but in the middle of the twentieth century the acquisition of the *Bima Sakti* Schmidt Telescope opened a new window to the Universe through the exploration of galactic structure.

However, there were also attempts to use ‘small’ telescopes for astrophysical research long before small commercially manufactured telescopes were common worldwide (see Malasan et al. 1986). The important role that small telescopes can play in contributing to the progress of astronomy and astrophysics in developing countries is discussed by Hidayat and Arifyanto (1998), who base their examples on the emergence of astrophysics in Indonesia.

There is an adage, “If a picture can paint a thousand words, then a spectrograph can paint a thousand pictures.” This describes how important spectroscopy has become in astrophysics, and spectroscopic studies have also played a major role in the development of astrophysics in Indonesia. This is referred to for example by Hoffleit (1967), who expounded on the unusually fine objective-prism spectrum of W Velorum obtained by Pik-Sin Thé at Bosscha Observatory using the Schmidt Telescope.

What of the future? With Indonesian astrophysics safely in the hands of such organisations as LAPAN, Bosscha Observatory and the Department of Astronomy at ITB, the future looks assured. These institutions have diverse scientific objectives and goals, which should help promote astrophysical research in Indonesia. But is this enough, for often progress brings serious challenges?

The international development of astrophysics must be recognised and addressed by Indonesia astronomers. For a long time Bosscha Observatory was the nation's sole optical observational facility, but the site is now challenged by local development and increasing light pollution and astronomers must respond to this challenge if the Observatory is to retain its pre-eminent status (see Epifania and Mumpuni 2011).

In 2013 the Government issued the National Act No. 21, 2013 which gave a mandate to the Indonesian people, and specifically to national agencies (like LAPAN), to promote space sciences and coordinate various astronomical activities. This provided the impetus to establish a new modern national astronomical facility.

From a geographical perspective, Bosscha Observatory is located in the western part of Indonesia and on a less-than-ideal site, so there is some pressure to identify a more suitable observatory site in the eastern part of Indonesia (e.g. see Anwar et al. 1996; Hidayat et al. 2012; Mahasena et al. 2010; Mumpuni 2010; Mumpuni et al. 2010), and to install a modern large telescope that far exceeds in aperture the 51/70-cm Schmidt at Bosscha Observatory (which is currently the nation's largest optical telescope).

Several locations in the eastern part of Indonesia have been considered, and LAPAN and ITB have already selected the island of Timor as the location for a new national observatory (Mumtahana and Mumpuni 2015). This will feature one major telescope with a primary mirror as large as 3.8-m as well as several smaller robotic telescopes (Mumpuni 2016). Two 50-cm telescopes have already been prepared for specific projects, and in particular the search for near-Earth asteroids, since this is part of the national mandate on 'National responsibility for risks from space, natural and artificial threats.' This project welcomes collaborations with not just one or two countries but with many countries, and the establishment of *the Asia Pacific Asteroid Observation Network*, initiated by Japan, paves the way for regional collaboration. With the establishment in the future of a new national observatory, Indonesia will be able to participate actively in this Network.

Meanwhile, in the western part of Indonesia, the Institut Teknologi Sumatra (ITERA) plans to erect a new observatory in Lampung province with a principle telescope as large as 2-m in diameter. It is ironic that back in 1983 van der Hucht was at IAU Colloquium 80 in Lembang when he suggested that Indonesia should seek to install a 2-m class telescope (van der Hucht 1984). It looks like this will finally come to pass!

The future development of astrophysics within Indonesia largely depends on a successful outcome of the above-mentioned proposals, but it is also important for Indonesian astronomers and graduate students to adopt a multiwavelength approach (Hidayat et al. 2014, 2015) to their research and increasingly compete successfully for observing time on large optical and radio telescopes not only in Asia (especially India, Thailand, China, Korea and Japan) but elsewhere in the world, thus following a trend that is apparent in many other nations. Such a strategy will provide exciting research prospects for the next generation of Indonesian astronomers.

Finally, if nothing else, this chapter has shown the enormous potential that Indonesia offers for those interested in researching astronomical history, and further areas fertile for such research are discussed by Orchiston (2017). A heartening recent development has been the realization by some graduate students in astronomy, particularly those at ITB, that they can enhance their career prospects and broaden their research output by successfully combining historical studies with astrophysics, especially in such areas as archaeoastronomy (e.g., see Hariawang et al. 2011; Khairunnisa et al. 2018) and ethnoastronomy (e.g., see Fatima 2018).

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References

Ammarell, G. (1987). Sky calenders of the Indo-Malay Archipelago. In G. Swarup et al., pp. 241–247.

Anwar, B., Kambry, M.A., & Setiahadi, B. (1996). Meteorological survey of solar observing sites in Indonesia. In N. Kaifu (Ed.), *Ground-Based Astronomy in Asia. Proceedings of the Third East-Asian Meeting on Astronomy, July 17–21, 1995, Tokyo, Japan* (pp. 538–540). Tokyo: National Astronomical Observatory of Japan.

Aveni, A.F. (1981). Tropical archaeoastronomy. *Science, 213,* 161–171.

Blaauw, A. (2004). My cruise through the world of astronomy. *Annual Review of Astronomy and Astrophysics, 42,* 1–37.

Blaauw, A. (2014). Oort, Jan Hendrik. In Hockey et al., pp. 1615–1618.

Broughton, P. (2014). Ten Bruggencate, Paul. In T. Hockey et al., pp. 2135–2137.

Daldjoeni, N., & Hidayat, B. (1987). Astronomical aspects of *pranotomongso* of the 19th century Central Java. In G. Swarup et al., pp. 249–252.

Dawanas, D.N., Malasan, H.L., Mahasena, P., & Irfan, M. (2008). Spectroscopic monitoring of Southern Be stars. In B. Prijamboedi et al. (Eds.), *Proceeding of The 2nd International Conference on Mathematics and Natural Sciences (ICMNS) 2008* … (pp. 1380–1387). Bandung: Institut Teknologi Bandung.

Dekker, E. (1987). Early explorations of the southern celestial sky. *Annals of Science, 44,* 439–470.

Drilling, J.S. (1968). Space distribution of stars in the Southern Milky Way. I. A region in Norma. *Astronomical Journal, 73,* 590–610.

Epifania, P., & Mumpuni, E.S. (2011). Bosscha Observatory: challenges as a scientific heritage of astronomy in Indonesia. In D. Valls-Gabaud, & A. Boksenberg (Eds.), *The Role of Astronomy in Society and Culture* (pp. 235–240). Cambridge: Cambridge University Press (Proceedings of the International Astronomical Union, IAU Symposium, Volume 260).

Fatima, S. (2018). Ethnoastronomy in Madura, Indonesia: The observation of lunar and solar eclipses. In W. Orchiston, & M. Vahia.

Glass, I.S. (2009). *Proxima Centauri: The Nearest Star (Other than our Sun!)*. Cape Town: Mons Mensa.

Haansbroek, N.D. (1977). *Prof. F. Kaiser and S.H. De Lange in hun Relatie tot de Astronomiesche Plaatsbepalingen van Omtrent 1850 in her Voormalige Ned Indes*. Delft: Rijkscommissie voor Geodesie (in Dutch).

Hariawang, I.I., Simatupang, F.M., Radiman, I., & Mumpuni, E.S. (2011). Orientation of Borobudur's east gate measured against the sunrise position during the vernal equinox. In T. Nakamura, W. Orchiston, M. Sôma, & R. Strom (Eds.), *Mapping the Oriental Sky:*

Proceedings of the Seventh International Conference on Oriental Astronomy (ICOA-7) (pp. 37–42). Tokyo: National Astronomical Observatory of Japan.

Heijden, P. (2014). Kaiser, Frederik. In Hockey et al., pp. 1151–1153.

Herbig, G.H. (1967). The youngest stars. *Scientific American, August,* 30–36.

Hidayat, B. (1985). Astronomy in Indonesia. In T. Kogure, & B. Hidayat (Eds.), *Galactic Structure and Variable Stars. Proceedings of the Six-Year Co-operation in Astronomy Between Indonesia and Japan 1979–1984* (pp. 8–24). Kyoto: Kyoto University.

Hidayat, B. (2000a). Indo-Malay astronomy. In H. Selin, & X. Sun (Eds.), *Astronomy Across Cultures*. *The History of Non-Western Astronomy* (pp. 371–384). Dordrecht: Kluwer.

Hidayat, B. (2000b). Under a tropical sky: a history of astronomy in Indonesia. *Journal of Astronomical History and Heritage, 3,* 45–58.

Hidayat, B. (2004). A short history of astronomy in Indonesia. In W. Wamsteker, R. Albrecht, & H.J. Haubold (Eds.), *Developing Basic Space Science World-Wide. A Decade of UN/ESA Workshops.* (pp. 61–76). Dordrecht: Kluwer.

Hidayat, B, & Arifyanto, M.I. (1998). Small telescopes utilization for research. In *Proceedings of the Symposium at Gunma Observatory, 26–27 October* (pp. 70–74). Gunma: Gunma Observatory.

Hidayat, B., & Blanco, V.M. (1968). Distribution of giant M stars in the Galactic Disk. *Astronomical Journal, 73,* 712–716.

Hidayat, B., Putra, M., McCain, C., & Malasan, H.L. (1991). The new telescope at the Bosscha Observatory. In K. Isida, & B. Hidayat (Eds.), *Evolution of Stars and Galactic Structure. Proceedings of The Three Years Cooperation in Astronomy between Indonesia and Japan, 1981–1991*. Bandung: Institut Teknologi Bandung.

Hidayat, T., Mahasena, P., Dermawan, B., Hadi, T.W., Premadi, P.W., & Herdiwijaya, D. (2012). Clear sky fraction above Indonesia: an analysis for astronomical site selection. *Monthly Notices of the Royal Astronomical Society, 427*, 1903–1917

Hidayat, T., Munir, A., Dermawan, B., Jaelani, A.T., Léon, S., & 19 other authors (2014). Radio frequency interference measurements in Indonesia. A survey to establish a radio astronomy observatory. *Experimental Astronomy, 37,* 85–108.

Hidayat, T., Dermawan, B., Mahasena, P., Munir, A., Nurzaman, M.Z., & Jaelani, A.T. (2015). Radio frequency interference measurement in site testing programs for the future multi-wavelength observatory in Indonesia. *AIP Conference Proceedings, 1677*(1), id.050002

Hins, C.D. (1950). Astronomie. In P.J.W. Macdonald, P. Braber, & H.G. Derx (Eds.), *Een Eeuw Natuurwetenschap in Indonesie*. Jakarta: Konink NatuurkVereeniging (in Dutch).

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hoffleit, D. (1967). An objective-prism spectrum of W Velorum. *Publications of the Astronomical Society of the Pacific, 79,* 607–610.

Houziaux, L. (2014). Van Albada, Gale Bruno. In T. Hockey et al., p. 2207.

Ibrahim, J. (2001). Astronomy: theme and variations. In *50 Tahun Pendidikan Tinggi Astronomi di Indonesia* (*Memoir Book of 50 years of Higher Education of Astronomy in Indonesia*) (pp. 73–87). Bandung: Institut Teknologi Bandung.

Ibrahim, J. (1972). *Sur les zéros des vecteurs holomorphes de certaines variétiés kählériennes*. *Comptes Rendus de l'Académie de Science Paris, 272,* 980–982 (in French).

Ibrahim, J., & Lichnerowicz, A. (1976). *Fibrés vectoriels, holomorphes, structure symplectiques ou unimodulaires complexes exactes*. *Comptes Rendus de l'Académie de Science Paris, 283,* 713–717 (in French).

Jäger, F.W. (1962). Paul ten Bruggencate. *Mitteilungen der Astronomischen Gesellschaft, 15,* 21–23.

Jasinta D.M.D. (1997). A database for visual double stars observed at Bosscha Observatory. In K.-C. Leung (Ed.), *The Third Pacific Rim Conference on Recent Development of Binary Star Research* (pp. 135–138). San Francisco: Astronomical Society of the Pacific (ASP Conference Series, Vol. 130).

Kapteyn, J.C. (1922). First attempt at a theory of the arrangement and motion of the sidereal system. *Astrophysical Journal, 55,* 302–328.

Khairunnisa, S.A., Nikeu, N., & Hidayat, T. (2018). Astronomical aspects of the Prambanan Temple in Central Java, Indonesia. In W. Orchiston, & M. Vahia.

Kitamura, M. (2001). Toast for the 50th Anniversary Meetings on Modern Astronomy at ITB and some personal reminiscences. In *50 Tahun Pendidikan Tinggi Astronomi di Indonesia* (*Memoir Book of 50 years of Higher Education of Astronomy in Indonesia*) (pp. 89–90). Bandung: Institut Teknologi Bandung.

Knobel, E.B. (1917). On Frederick de Houman's catalogue of the southern stars. *Monthly Notices of the Royal Astronomical Society, 77,* 414–432.

Kogure, T. (1986). Cooperation in astronomy between Indonesia and Japan. *Astrophysics and Space Science, 118,* 39–43.

Kuiper, G.P. (1945). Astronomy in the Netherlands Indies. In P. Honig, & F. Verdoorn (Eds.), *Science and Scientists in the Netherlands Indies* (pp. 221–226). New York: Board for the Netherlands Indies, Surinam and Curacao.

Malasan, H.L., Okazaki, A., Yamasaki, A., & Hadiyanto, G. (1986). Photometric research with a small telescope (Bamberg 37-cm. refractor) at Bosscha Observatory Indonesia. In J.B. Hearnshaw, & P.L. Cottrell (Eds.), *Instrumentation and Research Programmes for Small Telescopes held in Christchurch, New Zealand, December 2–6, 1985* (pp. 303–304). Dordrecht: Reidel Publishing Company.

Malasan, H.L., Yamasaki, A., Hadiyanto, G., & Kondo, M. (1989). δ Capricorni: an evolved binary or a main-sequence binary? *Astronomical Journal, 97,* 499–504.

Malasan, H.L., Yamamuro, T., Takeyama, N., Kawakita, H., Kinugasa, K., Hidayat, B., Setyanto, H., & Ibrahim, I. (2001). Design and implementation of a new compact spectrograph for astronomical research and education. In M. Djamal, O. Kanoun, E. Sesa, & H.-R. Traenker (Eds.), *Proceedings of the Indonesia-German Conference on Instrumentation, Measurements and Communication for the Future* (pp. 159–165). Bandung: Institut Teknologi Bandung.

Mahasena, P., Hidayat, T., Dermawan, B., Lestari, I.A., Irfan, M., & Herdiwijaya, D. (2010). Study of Nusa Tenggara Timur as an astronomical site using meteorological satellite data. In *Proceedings of the Conference of Indonesia Astronomy and Astrophysics* (pp. 137–142). Bandung: ITB Press.

McCuskey, S.W. (1967). Warner & Swasey Observatory report. *Astronomical Journal, 72,* 1145–1152.

Miyadi, M.M. (1975). The transfer of the Bosscha Observatory. *Astronomical Herald, 68,* 319–321. Bosscha Observatory Library collection (originally in Japanese; translated into English by Professor Naonobu Sato).

Mohr, J.M. (1771). Transitus Veneris & Mercurii in eorum exitae disco solis, 4to mensis Junii & 10mo Novembris, 1769, observata. *Philosophical Transactions of the Royal Society of London, 61,* 433–436 in Latin).

Mumpuni, E.S. (2010). Kajian pembangunan situs observatorium pengamat Matahari di Indonesia Timur. In Suratno, C.Y. Yatini, & T. Djamaluddin (Eds.), *Matahari dan Lingkungan Antariksa. Volume 4* (pp. 86–94). Dian Rakyat (in Indonesia).

Mumpuni, E.S. (2016). Mengenal Observatorium Nasional. *Buletin Cuaca Antariksa, 5*(6), 21–22., (in Indonesia)

Mumpuni, E.S., Herdiwijaya, D., & Yatini, C.Y. (2012). The present status of solar physics and space weather research in Indonesia. In S. Komonjinda, Y. Kovalev, & D. Ruffolo (Eds.), *Proceedings of the 11th Asian-Pacific Regional Meeting of the IAU, Chiang Mai, Thailand* (pp. 42–46). Chiang Mai: National Astronomical Research Institute of Thailand.

Mumpuni, E.S., Orchiston, W., & Steinicke, W. (2017). Dr J.A.C. Oudemans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In T. Nakamura, & W. Orchiston.

Mumpuni, E.S., Sulistiani, S., Yatini, C.Y., Suryana, N., Malasan, H.L., & Herdiwdjaja, D. (2010). Preliminary report from the astronomy site testing for the candidate of observatory in SPD

LAPAN Biak. In *Proceedings of the Conference of the Indonesia Astronomy and Astrophysics* (pp. 149–154). Bandung: ITB Press.

Mumtahana, F., & Mumpuni, E.S. (2015). Ekpsedisi ke kandidat situs observatorium Nasional di Kupang, NTT. *Buletin Cuaca Antariksa, 4*(3), 5–7, (in Indonesia).

Nakamura, T., and Orchiston, W. (Eds.), 2017. *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nitisastro, S. (1963). The urgent need of a well equipped observatory near the Equator for fundamental spectro-photometry of selected Standard Stars. In P.-S. Thé (Ed.), *Standards for Stellar Photometry and Spectral Classification: Proceedings of an Astronomical Symposium held in Bandung, Indonesia* ... Bandung: Institut Teknologi Bandung.

Orchiston, W. (2017). Studying the history of Indonesian astronomy: future prospects and possibilities. *Journal of Astronomical History and Heritage*, 20, 145–154.

Orchiston, W., & Vahia, M. (Eds.), (2018). *Exploring the History of Southeast Asian Astronomy: A Review of Current Projects and Future Prospects and Possibilities*. Cham: Springer.

Orchiston, W., Steinicke, W., & Mumpuni, E.S. (2018). Dr J.A.C. Oudemans and nineteenth century astronomy in the Dutch East Indies. In W. Orchiston, & M. Vahia.

O'Connell, J.K. (1964). Obituary Notices: Joan George Erardus Gijsbertus Voûte. *Quarterly Journal of the Royal Astronomical Society, 5,* 296–297.

Premadi, P., Martel, H, & Matzner, R. (1998). Light propagation in inhomogeneous Universes. I. Methodology and preliminary results. *Astrophysical Journal, 493,* 10–27.

Raharto, M. (1996). *Study of Galactic Structure Based on M-type Stars*. Ph.D. thesis, University of Tokyo.

Raharto, M., Hamajima, K., Ichikawa, T., Ishida, K., & Hidayat, B. (1984). A catalogue of M type stars. *Annals of the Tokyo Astronomical Observatory, Second Series, 19,* 469–552.

Sastroamidjojo, M.S.A. (1986). Present and future of astronomical science at Gadjah Mada University, Central Java, Indonesia. *Astrophysics and Space Science, 118,* 99–100.

Setiahadi, B., Anwar, B., Widodo, N., Kambry, M.A., & Hiei, E. (1996). Ground-based solar physics research at Watukosek Solar Observatory Lapan, Indonesia. In N. Kaifu (Ed.), *Ground-Based Astronomy in Asia. Proceedings of the Third East-Asian Meeting on Astronomy, July 17–21, 1995, Tokyo, Japan* (pp. 70–77). Tokyo: National Astronomical Observatory of Japan.

Sutantyo, W. (1975). Supernova explosions in close binary systems. II. Runaway velocities of X-ray binaries. *Astronomy and Astrophysics, 41,* 47–52.

Swarup, G. (2017). The early development of Indian radio astronomy: a personal perspective. In T. Nakamura, & W. Orchiston.

Swarup, G., Bag, A.G., & Shukla, K.S. (Eds.), (1987). *History of Oriental Astronomy. Proceedings of an International Astronomical Union Colloquium No. 91, New Delhi, India, 13–16 November 1985.* Cambridge: Cambridge University Press.

Swarup, G., Sukumar, S., & Hidayat, B. (1984). Giant Equatorial Radio Telescope. *Astrophysics and Space Sciences, 99,* 403–407.

Thé, P.-S. (1961). The new Schmidt-type telescope of the Bosscha Observatory. *Contributions of the Bosscha Observatory, 9.*

Thé, P.-S. (1963). Address. In P.-S. Thé (Ed.), *Standards for Stellar Photometry and Spectral Classification: Proceedings of an Astronomical Symposium held in Bandung, Indonesia …* Bandung: Institut Teknologi Bandung.

Trimble, V. (2014). Kuiper, Gerard Peter. In T. Hockey et al., pp. 1252–1254.

van Albada (1951). Der hypothese van het pre-stellaire stadium (in Dutch). The inaugural speech of his Professorship in Astronomy, at the Faculty of Mathematics and Natural Sciences, University of Indonesia, Bandung, 18 October 1951. Translated into Indonesian by I. Radiman, and published in *50 Tahun Pendidikan Tinggi Astronomi di Indonesia* (*Memoir Book of 50 Years of Higher Education of Astronomy in Indonesia*).

van Albada-van Dien, E. (1994). The Bosscha Schmidt Telescope. In J. Chapman, R. Cannon, S. Harrison, & B. Hidayat (Eds.), *The Future Utilization of the Schmidt Telescope* (pp. 15–18). San Francisco: Astronomical Society of the Pacific (ASP Conference Series 84).

van der Hucht, K.A. (1984). A plan for a new generation 2-meter class telescope in Indonesia. *Astrophysics and Space Sciences, 99,* 409–410.

van der Hucht, K.A., & Kerkhoven, C.L.M. (1982). De Bosccha-Sterrenwacht: van thee tot sterrenkunde. *Zenit, July–August,* 292–300 (in Dutch).

van der Kruit, P.C., & van Berkel, K. (2000). *The Legacy of J.C. Kapteyn and the Development of Modern Astronomy*. Dordrecht: Kluwer.

van Gent, R.H. (2005). Observations of the 1761 and 1769 transits of Venus from Batavia (Dutch East Indies). In D.W. Kurtz (Ed.), *Transits of Venus: New Views of the Solar System and the Galaxy* (pp. 67–73). Cambridge: Cambridge University Press.

Voûte, J. (1917). A 13th magnitude star in Centaurus, with the same parallax as α Centauri. *Monthly Notices of the Royal Astronomical Society, 77,* 650–651.

Waelkens, C. (2014). Pannekoek, Antonie. In T. Hockey et al., pp. 1641–1643.

Zuidervaart, H.J., & van Gent, R.H. (2004). A bare outpost of learned European culture on the edge of the jungles of Java – Johan Maurits Mohr (1716–1775) and the emergence of instrumental and institutional science in Dutch colonial Indonesia. *Isis, 95,* 1–33.

Chapter 15
J.A.C. Oudemans' Observations of the 18 August 1868 and 12 December 1871 Total Solar Eclipses from the Dutch East Indies

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15.1 Introduction

The 1868 total solar eclipse was a relatively long-duration event that offered the first ideal opportunity for scientists to carry out spectroscopic observations during an eclipse. Consequently, it was observed by Dutch, English, French and German astronomers from Aden, India, Siam (present-day Thailand) and the Dutch East Indies (present-day Indonesia), and when taken in conjunction (Cottam and Orchiston 2015; Launay 2012; Orchiston and Orchiston 2017; Orchiston et al. 2017) their observations led to a major breakthrough in solar physics—and the eventual discovery of the element helium (see Nath 2013).

In this chapter we will focus on J.A.C. Oudemans, a Dutch astronomer who spent nearly 20 years of his life working in the Dutch East Indies. Not only was he able to observe the much-awaited 1868 total solar eclipse, but also the total solar eclipse of 1871 which—fortuitously—also was visible from the East Indies.

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15.2 J.A.C. Oudemans: A Biographical Sketch

Jean Abraham Chrétien Oudemans (Fig. 15.1) was born in Amsterdam in 1827 and died in Utrecht in 1906. His father, Anthonie Cornelis Oudemans, was a poet, teacher and philologist, who helped J.A.C. Oudemans and his two brothers find careers in science (Pyenson 1989).

J.A.C. Oudemans entered the University of Leiden when he was just 16 of age as a student of the noted astronomer Professor Frederik Kaiser (1808–1872; Heijden 2014). After graduating he became a teacher of mathematic at a secondary school in Leiden in 1846, when he was 19, and for the next 6 years he also worked part-time on his doctoral research, which focused on the determination of the latitude of Leiden. He completed his doctorate in 1852 and the following year was appointed an Astronomer at the University Observatory, where he studied planets, comets and variable stars in the hope of obtaining an academic position. This finally occurred in 1856 when he was appointed a Professor of Astronomy at the University of Utrecht and Director of the University Observatory (Pyenson 1989; Van de Sande Bakhuysen 1907).

Oudemans must have encountered problems at Utrecht for after just 1 year he resigned in order to accept the post of Head Engineer of the Geographical Service in the Dutch East Indies, with the primary task of conducting a geodetic survey of the colony. His old mentor, Kaiser, was the Holland-based supervisor of the Survey at that time (Heijden 2014) and he would have played a key role in arranging Oudemans' appointment.

Fig. 15.1 J.A.C. Oudemans (Wikimedia commons)

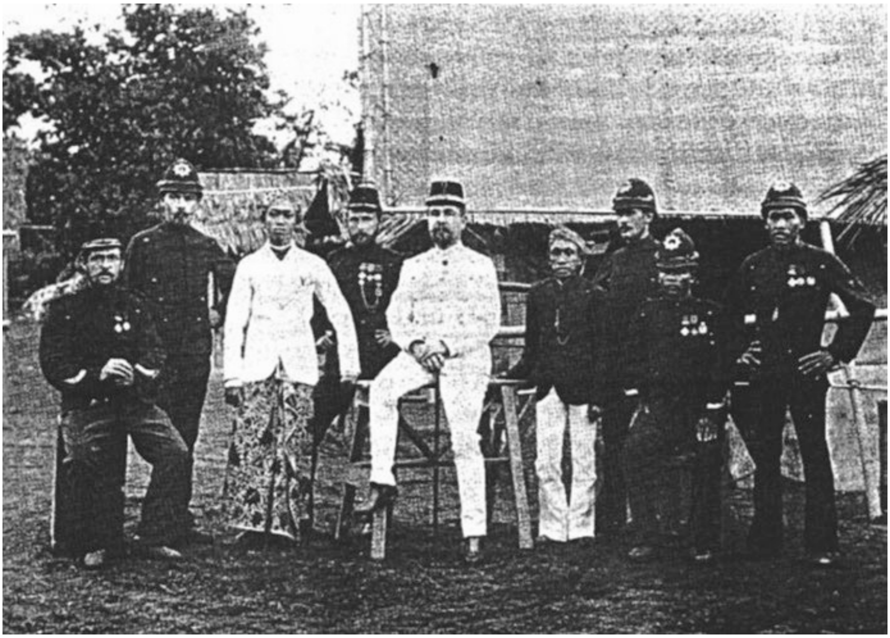


Fig. 15.2 J.A.C. Oudemans (with the cane) photographed during the trigonometrical survey of Java (after Pyenson 1989: 28)

Once settled in Java, Oudemans "… determined, in different parts of the archipelago, the latitude and longitude of a great number of stations, and executed with a staff of engineers the triangulation of the whole island of Java." (Van de Sande Bakhuysen 1907: 241). Although this geodetic work took up much of his time (Fig. 15.2), Oudemans maintained a strong interest in non-meridian astronomy and indulged this when the occasion arose. Thus, he was able to observe the total solar eclipses of 1868 and 1871, and he also hoped to record the 1874 transit of Venus but inclement weather on the vital day prevented this from happening.

It turned out that Oudemans' transit of Venus expedition to the island of Reunion in the Indian Ocean marked the end of his time in the colonies, and in 1875 he returned to the Netherlands and once again became Professor of Astronomy and Director of the Observatory at Utrecht University. He remained in these posts until he retired in 1898 (Van de Sande Bakhuysen 1907).

By the time he died in 1906 Oudemans had published a great many papers on a wide range of astronomical topics, but this aspect of his work is discussed separately by Orchiston et al. (2018), not here. In this chapter we restrict ourselves to an analysis of his 1868 and 1871 solar eclipse observations and observations made by others in the Dutch East Indies during the latter eclipse.

In an obituary published in *Monthly Notices of the Royal Astronomical Society*, his long-time colleague Hendrik Gerard Van de Sande Bakhuysen (1907: 242) mentions that Oudemans

> … was indefatigably busy with astronomical work to the end of his life … He was a painstaking astronomer, with a vast knowledge, who in all his work strove his utmost to attain the highest accuracy and completeness. He had a noble and open character, and was much esteemed and beloved by all who knew him.

15.3 Oudemans' Observations of the Total Solar Eclipses of 1868 and 1871

Given Oudemans' experience in geodetic work and his intimate geographical knowledge of the Dutch East Indies, he was able to determine ideal observing sites for the different observers and expeditions that planned to observe these two solar eclipses.

15.3.1 The 1868 Eclipse

The circumstances of the 1868 solar eclipse are discussed in Chap. 12 in this book (Orchiston and Orchiston 2017), and need not detain us here. Suffice it to say that in the Dutch East Indies the path of totality (from east to west) crossed a number of small islands in the Spice Islands region, the Celebes (now Sulawesi), and the island of Borneo (now Kalimantan).

Because all these locations were far from the optimal observing site (near Siam, and marked by the green star in Fig. 15.3), the duration of totality was reduced slightly. Thus, at 'Little-Mantawalu', where Oudemans chose to set up his eclipse station, totality would last about 5 min 30 s, rather than the 6 min 57 s enjoyed by the French who observed from Siam (Orchiston and Orchiston 2017).

Oudemans' site, 'Little-Mantawalu' (now known as Mantawalu Isle) in Sulawesi, was a small coral island in Tomini Bay in the northern part of the Celebes (Oudemans 1869a), and was accessible by ship from Batavia (present-day Jakarta), the capital of the Dutch East Indies. Its location is shown by the red bulls-eye in Fig. 15.3.

Oudemans (1869a) reports that he arrived in the Celebes port of Gorontalo on the Dutch warship *S.S. Sumatra* a few days before the 18 August eclipse. Gorontalo "… lay inside the path of totality, but near its [northern] edge, so that the duration of the eclipse there would be at most 2.5 min …" (Oudemans 1869a: 1; our English translation). This differed markedly from Little-Mantawalu which was on the mid-line of the shadow path, and this small islet had another distinct advantage: "Because this was a deserted island, we were certain that we would not be distracted by the curiosity or noise of the natives." (Oudemans 1869a).

Accordingly, on 16 August "… we left Gorontalo in the evening … and dropped anchor near our island the following morning. I determined the longitude of the

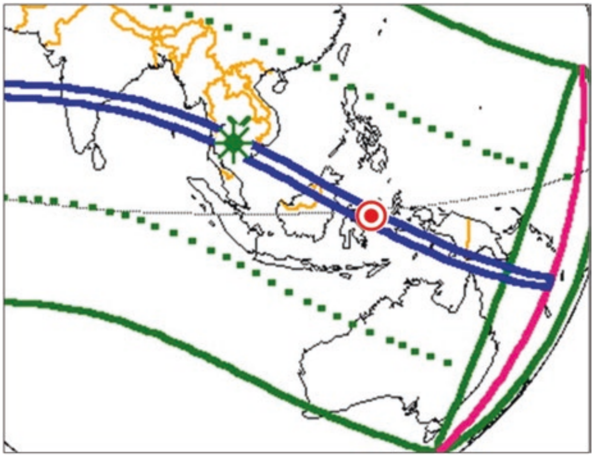
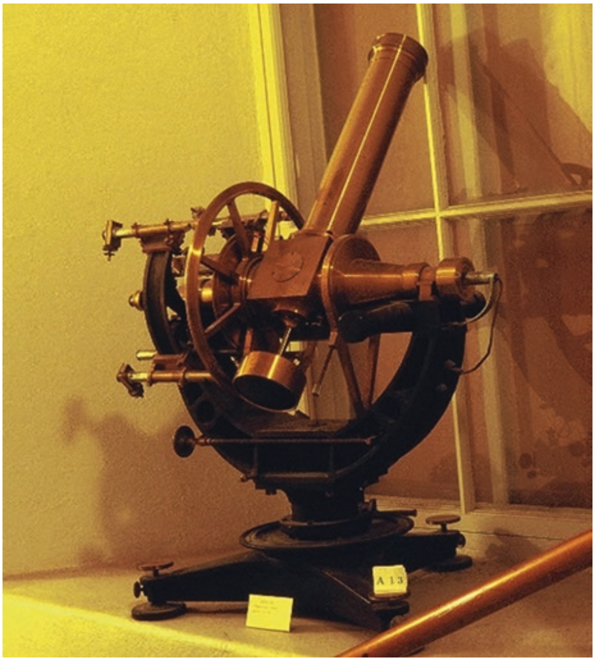


Fig. 15.3 A map showing part of the path of totality of the total solar eclipse of 18 August 1868 across islands in the Indonesian archipelago. Oudemans' eclipse station is marked by the *red bulls-eye* (*Base Map* adapted from Espenak and Meeus 2006; *Map Modifications* Wayne Orchiston)

Fig. 15.4 A Repsold Universal Instrument similar to the one used by Oudemans to observe the 1868 solar eclipse (http://www.astro.uu.se/librarynew/instruments/images/repsold_vcirkel.jpg)



observing site to be 123° 4′ 46″ east of Greenwich and the latitude 0° 32′′ 36″ south." (Oudemans 1869a). The short arrival-time before the eclipse was acceptable since Oudemans had few preparations to make. All of his observations would be made with a Repsold Universal Instrument (Fig. 15.4), one that he presumably had used during the Geodetic Survey of Java. Unlike the telescopes used by the British and French solar eclipse astronomers in India and Siam this portable instrument, which magnified only 32×, did not require a prefabricated observatory or substantial brick or concrete foundations. All of the eclipse observations that Oudemans would make would be carried out with the naked eye or with this simple instrument, for he lacked a spectroscope and photographic apparatus.

During the eclipse Oudemans was joined by the Captain of the *S.S. Sumatra*, who used a small marine telescope on a makeshift mounting, while three naval officers, Ehule, Commys and Rovers, used similar marine telescopes, but because they lacked solar filters were forced to project the solar image onto sheets of white paper. Oudemans arranged with the three officers that during the eclipse the four of them would observe the corona and note the presence of rays, whereas he also would concentrate on the prominences.

Clear skies over the atoll greeted the eclipse party on 18 August, and Oudemans' observing strategy worked perfectly. As totality approached Oudemans did not witness Baily's Beads, but

> Upon removing the solar filter, the great spectacle of the corona appeared. Immediately the two prominences a and b became visible, later c and d … [see Fig. 15.5]. Using the horizontal threads in the telescope, I measured the vertical height of prominence a three times [and] … derived from my measurements that prominence a must have extended 176″ above the solar edge, which corresponds to 10 Earth diameters. (Oudemans 1869a: 3–4; our English translation)

The prominences were rose-coloured, and looked like clouds lit by the setting Sun.

It is hard to reconcile the various prominence drawings shown in Fig. 15.5, as included are two drawings made from Gorontalo (bottom centre and right). But even discrepancies visible in the four drawings made from Little-Mantawalu

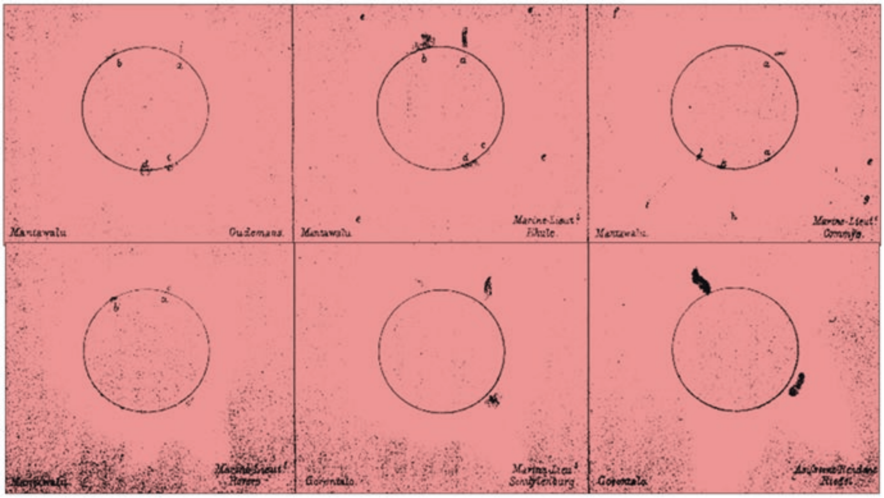


Fig. 15.5 Colour-enhanced drawings of the prominences that Oudemans and the three naval officers recorded during the 1868 solar eclipse (after Oudemans 1869b)

prompted Oudemans (1869a: 4; our English translation) to observe: "I believe that the existing differences in these drawings justify my request to the afore-mentioned gentlemen that they study the corona and its rays." Having said that, prominence 'a' stands out in all the Little-Mantawalu drawings, and this feature is reminiscent of the 'Great Horn' that was widely reported by Indian and Siamese observers of this eclipse (e.g. see Orchiston et al. 2017: Fig. 25.8). Furthermore, Oudemans' estimate of 10 Earth diameters (i.e. 79,260 miles) for its height is not dissimilar to Tennant's (1869: 33) Indian-based measurement of 88,900 miles (i.e. more than 11 times the diameter of the Earth).

Although he focused on the prominences—as intended—Oudemans also found time to sketch the form of the corona, though his (1869a) report in *Astronomische Nachrichten* does not include a description or a copy of the sketch. All that he does say is that the corona was "… pale peach-blossom …" in colour (Oudemans 1869a: 5; our English translation).

Oudemans also notes that in addition to observations of the eclipse made at Little-Mantawalu it also was observed with ordinary marine telescopes by the captains of the Dutch warships S.S. *Prinses Amalia* and *Bali* which were anchored at Gorontalo and the island of Ambon, respectively. Others of note to observe the eclipse were the Irish-born Governor of Lebuan, John (later Sir John) Pope-Hennessy (1834–1891), and the Captain of the British warship *HMS Rifleman*. Oudemans (1869a: 6; our English translation) notes that *HMS Rifleman* (see Fig. 15.6) was anchored

> … at Cape Barram, right at the point where the path of totality enters the island of Borneo [now Kalimantan]. A comprehensive report of these observations was published in the Singapore Straits-Times on 3 October 1868. The appearance of the prominences at that place seems to have been quite similar to what we saw at Little-Mantawalu 25 minute later.

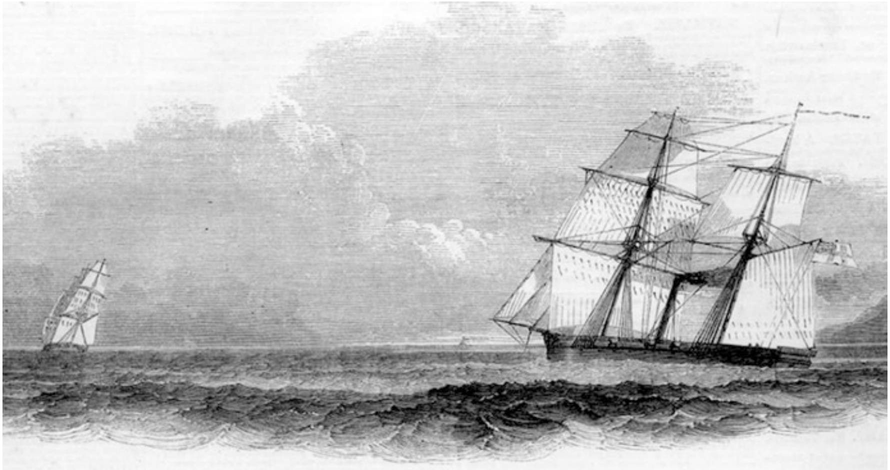


Fig. 15.6 *HMS Rifleman* (*right*) pursuing a Brazilian slaver (after *Illustrated London News* 1850)

During a visit to Singapore in March 2017, the second author of this chapter and his wife went in search of the 3 October issue of the *Straits Times*, but unfortunately no copies of this issue of the newspaper are known to have survived. Thus, we could not learn more about the observations made from *HMS Rifleman*.

In a later supplementary report on the 1868 eclipse observation, Oudemans (1869b) details the calculation that he made in order to determine the longitudes of the afore-mentioned Dutch East Indies observing sites, on the basis of observations of lunar occultations of stars.

This ends our account of Oudemans' observations of the 1868 solar eclipse. While he made some general comments about prominences, unlike his European colleagues in India and Siam he contributed little of scientific value. Would he fare any better during the 1871 eclipse?

15.3.2 The 1871 Eclipse

As Fig. 15.7 illustrates, the path of totality of the 12 December 1871 total solar eclipse passed through India, Ceylon (now Sri Lanka), the Dutch East Indies and northern Australia, and observations were made—or attempted, but prevented by the weather—in all four regions (Janssen 1873; Launay 1997; Lockyer 1874; Lomb 2016; Mahias 2010; Tennant 1875). In this section we examine the observations made by Oudemans and others based in the Dutch East Indies.

As we have seen, the 1868 solar eclipse was a seminal event in the history of solar physics, particularly because of the spectroscopic observations that were carried out. Thus, as well as offering the potential to build on the results obtained in 1868, the 1871

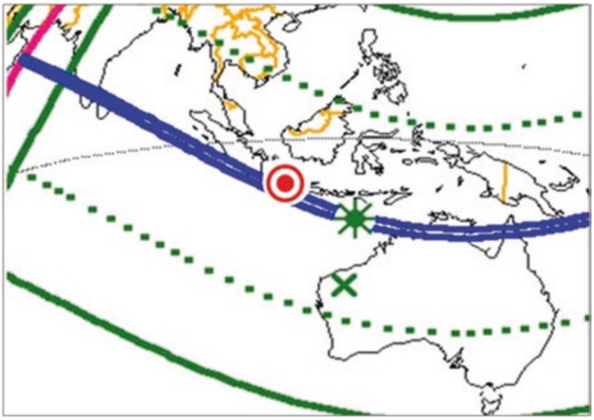


Fig. 15.7 A map showing part of the path of totality of the 12 December 1871 total solar eclipse across India, Ceylon, eastern Sumatra, western Java and northern Australia. Oudemans' observing site on Lawungan Island is marked by the *red bulls-eye* (*Base Map* adapted from Espenak and Meeus 2006; *Map Modifications* Wayne Orchiston)

eclipse invited further investigation of the green coronal line, K 1471, which the US astronomers Charles Augustus Young (1834–1908; Habashi 2014) and William Harkness (1837–1903; Hirshfeld 2014) had discovered during the 7 August 1869 eclipse and assigned to 'coronium' (see Maunder 1899). There also was more to learn about the form and composition of the corona, so the 1871 eclipse offered various research options for Oudemans and others who planned to observe it from the Dutch East Indies.

But we have to query whether Oudemans really was up with the 'state-of-play' in international solar physics at this time, or whether the fact that he was not a solar specialist, and relative isolation in the colonies, militated against this. Undoubtedly, he had not heard about the 'coronium line', but had he been able to read the five recently published papers by Janssen (1868, 1869a, b, c, d) reporting the discoveries that he made in India during the 1868 eclipse? We have to doubt this, given the following 'research directive' that Oudemans prepared for colleagues in the Dutch East Indies intent on observing the December 1871 eclipse:

For those observing with the naked eye or an opera glass, the most important topics which can be noticed during totality mainly concern the corona, and include the following:

1. Out to what distance from the limb of the Sun does an obvious atmosphere appear to extend?
2. What are the lengths, directions and colours of the coronal rays, before, during and after totality?
3. What colour are the different layers of the chromosphere (the innermost part of the corona) and the terrestrial clouds and landscape? If the colours change, what is the colour sequence?
4. Are there dark spaces between the coronal rays, and if they change with time do they reach the Moon or end above the lower layers of the solar atmosphere?
5. What colour is the corona between the bright and dark rays?
6. What changes are apparent in the corona? Is there evidence of rotation or changes to the coronal rays as sometimes reported (some observers have spoken of rotation, as in fireworks)?
7. What colours are visible in the corona, and is there a correlation between prominences and coronal rays, or do rays generally appear opposite prominences?
8. Provide a drawing of the prominences visible at the start and end of the eclipse (and note the highest point reached by each prominence).
9. Is there any sign of light and dark shadow bands that pass over white paper laid on the ground (as claimed by some observers)?
10. Is there any sign that the Moon is darker than the sky, at some distance from the Sun?
11. What is the mean time of the start and end of the eclipse and the partial phase, and what is the latitude and longitude of your observing site? (Oudemans 1873: 2–3; our paraphrasing).

This list, inspired in part by input from the renowned British solar astronomer Joseph Norman Lockyer (1836–1920; Frost 2014), is all well and good for naked eye and binocular observations, but Oudemans and his Dutch East Indies colleagues really needed to make photographic, polariscopic and spectroscopic, observations if they wished to contribute in a meaningful way to international solar physics.

Be that as it may, the position of the path of totality on this occasion was especially kind to them, offering an endless number of easily accessible observing sites on the southern tip of Sumatra and in the western part of Java.

Moreover Oedermans was in a much more powerful position to mount a successful solar eclipse expedition than in 1868 as the Colonial Government had instructed him to observe this internationally important event, and obviously agreed to supply the necessary funding. After researching the path of totality, Oudemans (1873) chose as his camp site Lawungan Island (now Pulau Liwungan) in Lada Bay (Fig. 15.7), just off the western coast of Java. This location and other sites from which eclipse observations were reported are shown in Fig. 15.8.

Oudemans' eclipse party totalled nine, a 'motley crew' that included four naval officers, two military surgeons, one of his own staff in the Trigonometrical Survey of Java, and a secondary school teacher with a passion for astronomy (see Table 15.1). Given their various backgrounds, it is a safe assumption that most—if not all—were familiar with observational astronomy. What is not clear, however, is the full suite of scientific instruments that went to Lawungan Island. We have included in Table 15.1 those that are specifically mentioned in Oudemans' (1873) very long (36-page) paper in *Astronomische Nachrichten*, but unfortunately, no details are provided of the two telescopes, the Pistors and Martin 'patent circle', or the spectroscope and polariscope taken by Oudemans. However, the origin of the makeshift telescope used by Dr. Gratama is briefly recounted:

> A few days before leaving Batavia, I [Oudemans] received, through the kind office of the former General Secretary Mr. Wattendorf, who was just back from a holiday in Europe, a lens from the French astronomer Janssen with a focal length of 3 meters, together with a letter from him … [outlining] the construction of an instrument that can project a celestial image onto a piece of paper … (Oudemans 1873: 3; our English translation).

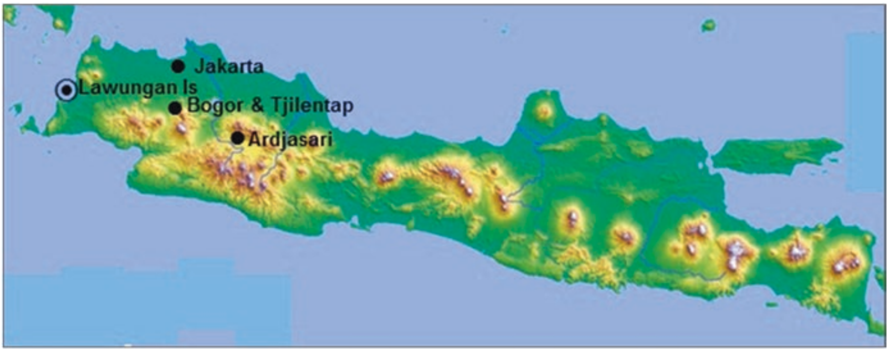


Fig. 15.8 A map of the island of Java showing locations from which observations of the 12 December 1871 eclipse were reported (*Map* Wayne Orchiston)

Table 15.1 Dutch East Indies observers of the 12 December 1871 total solar eclipse

Observers	Instruments	Observations	Comments
Lawangan Island			
J.A.C. Oudemans	Telescope; spectroscope; Polariscope	Sketches of corona and prominences	Team leader
Blaaw		Sketch of corona	*SS Sumatra* officer
Frankamp		Sketches of corona & prominences	*SS Sumatra* officer
Dr Gratama	Lens f.l. = 3 m	Sketches of corona & prominences	Military surgeon
Hardeman	Telescope 35×; Pistors & Martin 'patent circle'	Prominences; chromosphere; measured diameter of the corona	Secondary school physics teacher
Captain Meyer		Colour of the Moon	Captain of *SS Java*
Dr Pieters		Corona	Military surgeon
Rosenwald		Sketch of corona	*SS Sumatra* officer
Soeters		Corona; sketch of prominences	Engineer
Buitenzorg (=Botanical Gardens, Bogor)			
Dr Bergsma	Smart polariscope	Flying shadows; geomagnetism; corona; prominences	Team leader; engineer
Crone	Naked eye	Flying shadows; colour of flowers at totality	
Lang	Naked eye	Flying shadows; colour of flowers and landscape; corona	
Scheffer		Flying shadows; sketch of corona	Botanic Gardens Director
Van Leeuwen	Dolland reflector	Flying shadows; prominences	
C. Woldringh	Naked eye	Flying shadows; prominences	Geographical Service Assistant
Tjilentap Trig Point (near Bogor)			
Metzger	Telescope	Prominences; corona; broken horns	Team leader; engineer
Bergmann		Broken horns	
Dietrich	Camera, 4-element portrait lens; no equatorial mounting or drive	Two photographs at totality	Photographer
Hensterman	Telescope	Looked for flying shadows; colour of the Moon; corona	
van Alfensbeben		Broken horns	
van Emden	Telescope	Broken horns	

(continued)

Table 15.1 (continued)

Observers	Instruments	Observations	Comments
Telaga and Surranga (near Bogor)			
Clee			
Erxleben			
Sesink			
Ardjasari Tea Plantation (15 km south of Bandung)			
Messrs R.A. & R.E. Kerkhoven		Sketches of prominences	
Batavia (Garden of the Hydrology Section of the Navy) [Eclipse not quite total]			
J.F.F. Bruyn	Telescope	Sketch of eclipse	Naval Midshipman

The simple refracting telescope that Dr. Janssen advocated was quickly assembled in Batavia and assigned to Dr. Gratama. Where no instruments are listed alongside other observers in Table 15.1 (column 2), we can assume that most (if not all) of them relied on naked eye observations.

Oudemans (1873) describes how the eclipse expedition reached Lawungan Island on 10 December, just 2 days before the grand event, only to be greeted by cloudy skies and rain—which continued into the morning of the 12th. Then, miraculously,

> After the eclipse had started the sun became visible, through the clouds, and I rapidly measured the time … Shortly before totality, about 10 o'clock, the sky fairly cleared, though it was mostly covered by moving clouds … (Oudemans 1873: 4; our English translation).

If he wished to make important observations Oudemans realized that he had to subject the eclipse to spectroscopic and polariscopic scrutiny, so just before totality, when the sky was clear enough for observations to be made, he started with the spectroscope:

> … now the telescope, equipped with the spectroscope, was put on the mounting … and directed to the sun. But due to the arduous handling of the instrument, which was not suited for this observation, it took some time to get the image of the sickle-shaped sun to fall exactly on the slit of the spectroscope …
>
> [However] Although the slit was made as narrow as possible, to my disappointment no Fraunhofer lines appeared, although they had been clearly seen previously with the same instrument. I concluded that the spectroscope lenses, which were carefully cleaned by me the previous day, were now fogged due to the humid air; to dismantle, clean and re-assemble the spectroscope would take too much time so I did not consider it and instead I decided to remove the spectroscope and attach a common eyepiece to the telescope [in its place] in order to make my observations … (Oudemans 1873: 4; our English translation).

So much for Oudemans' spectroscopic observation of the eclipse. Instead he chose to focus on the location and nature of the prominences and the appearance of the corona.

Since totality would last a merely 3 min 50 s at Lawungan Island (Oudemans 1873: 20) and spectroscopy was a lost cause, how did the polariscopic observations fare? Sadly, in this context, Oudemans (1873: 6–7; our English translation) had to confess:

> Throughout the morning [of 12 December] I had a strong headache, and adding to this was the fact that our preparations were constantly disturbed by heavy rain, and moreover, that I was constantly distracted by different people around me, because of the need, already mentioned above, to change the original observing program. This may well explain why I was not concentrating enough when making the observations, and even though I had installed the polariscope in order to study the polarization of the coronal light … I was overtaken by the end of totality without having used this instrument.

So much for Oudemans' spectroscopic and polariscopic observations of this eclipse! But all was not lost for Dr. Bergsma, who led the eclipse party at the Botanical Gardens in Bogor (see Fig. 15.7; Table 15.1), had a Smart polariscope that had been sent out from Holland, and when he directed it at the Sun he found that the tenuous light of the corona *was* polarized (Oudemans 1873: 14).

The third astrophysical technology in the observational arsenal that the Dutch could rely on was photography, but unfortunately Oudemans had no photographic equipment at Lawungan Island. Instead it was Dietrich, a photographer in Metzger's observing team at Tjilentap Trig Point (near Bogor) who had a camera. This had

> … four lenses, the first pair consisting of a biconvex crown glass and biconcave flint glass, similar to a telescope objective by Fraunhofer, but the curvature of the focal plane was nullified by a second double lens, made of a diverging meniscus of flint glass and a biconvex lens of crown glass. (Oudemans 1873: 21; our English translation).

The camera was not equipped with an equatorial mounting, and during totality (which lasted here for about 3 min 54 s) Dietrich was only able to obtain two photographs, with estimated exposures of 1/3 and 1/2 s. Oudemans (1873) noted that "… the latter image was better exposed, the light of the corona is larger, and at its inner side already so black that the prominences cannot be distinguished … many coronal details are visible …" It is much to be regretted that Oudemans was not able to include a print of this photograph in his paper, but we can judge what the corona must have looked like by referring to Fig. 15.9.

All that Oudemans could provide in lieu of Dietrich's photograph was a series of drawings of the corona (and prominences) supplied by various observers based at Lawangan Island, the Botanical Gardens at Bogor (Buitenzorg) and the Tjilentap Trig Point near Bogor. These are shown in Fig. 15.10, where the advantage of securing photographic records is very obvious. For the purposes of research, it has to be admitted that these drawings are next to useless.

So what was Oudemans able to conclude about the corona, based on the suite of Dutch East Indies observations available to him?

1. Most observers confirmed that the colour of the corona was white and unchanging, and most noted the existence of coronal rays (although few—if any—had the artistic skill to depict these realistically). For example, Mr. Frankamp reported that the lower corona "… was a regular garland of rays, visible for up to one lunar radius from the limb." (Oudemans 1873: 11; our English translation).
2. The coronal rays did not exhibit any rapid or sudden changes, only slow ones.
3. The positions of the coronal rays were not correlated with the positions of the prominences.

Fig. 15.9 This photograph, supplied by Lord Lindsay, provides a good indication of the appearance of the corona during the 12 December 1871 solar eclipse (https://en.wikipedia.org)

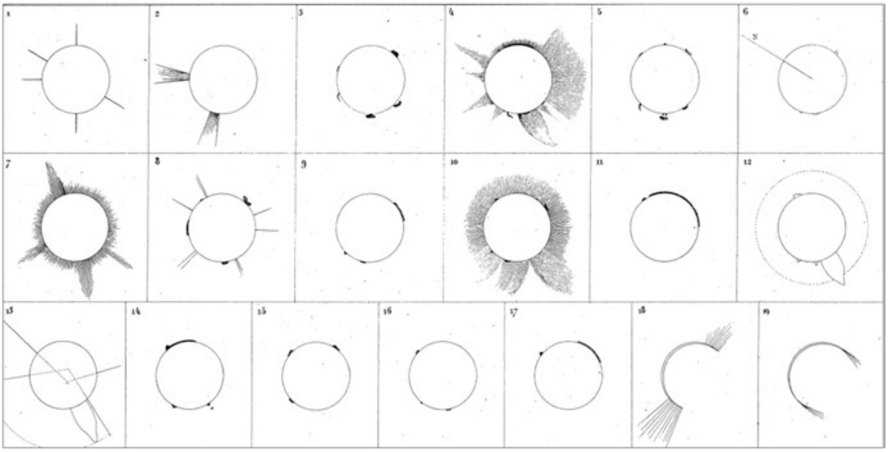


Fig. 15.10 Drawings of prominences and the corona during the 12 December 1871 total solar eclipse by Oudemans and his observing team (after Oudemans 1873: 32A)

4. Using the Pistor and Martens patent circle, Mr. Hardemann measured the maximal diameter of the corona as 41′ 50″, rather similar to the value of 38′ obtained from measuring the diameter of the faint images projected by Dr. Gramata's simple telescope (Oudemans 1873: 9).
5. As we have seen, Metzger found the light of the corona to be polarized, confirming the conclusion reached during the Indian observations of the 1868 eclipse (see Tennant 1869: 25–26).

The sky was clear at Tjilentap Trig Point during the eclipse, and the corona was conspicuous. Woldringh noted that "About 30 s after totality ended it became paler and soon was invisible to the naked eye." (Oudemans 1873: 19; our English translation).

Oudemans' comments about the chromosphere are interesting. He noted that "If a real chromosphere existed, then it must have been very insignificant." (Oudemans 1873: 5; our English translation). Other observers confirmed this, noting that at most it was only a few arc seconds in height.

By way of contrast, the prominences were obvious, but the actual number seen and their relative positions differed from observer to observer (see Fig. 15.9). Nonetheless, their colour always was "… soft charming roseate, extending to stone red, with a large richness of tinges …" (Oudemans 1873: 8; our English translation). In 1870, the Italian Jesuit astronomer Angelo Secchi (1818–1878; Cenadelli 2014) proposed a typology of prominences (Secchi 1870), and three of his types were seen during the 12 December 1871 eclipse: jets, heaps and clouds. Unfortunately, no major discoveries relating to prominences resulted from the 1871 eclipse observations in the Dutch East Indies.

Finally, there was an unusual feature terrestrial of the 12 December 1871 eclipse that was noticed by those assembled at the Botanical Gardens in Bogor (Buitenzorg), and this was the 'flying shadows.' Oudemans (1873) devotes nearly three pages to them in his *Astronomische Nachrichten* paper. Although these shadows had been noted during some previous eclipses, the reason for their occurrence still was not understood in 1871. Mr. Bergsma noted that

> This phenomenon was seen particularly clearly at Buitenzorg, even by inexperienced people who had never heard about them. Everyone who joined me near the botany museum saw them clearly.
>
> The northern side of our observing site was bordered by a white wall. The shadows were visible on this wall and also on a piece of white paper lying on the table; i.e. they were visible on vertical and horizontal surfaces …
>
> The shadows on the wall moved from east to west …
>
> The shadows had a width of 5 or 6 centimeters, limited by lines forming small irregular waves. The shadows were separated by evenly illuminated parts, I [Bergsma] estimated the distance between the shadows as about 15 centimeters, while Mr. Lang found about 1 foot [i.e., 30.5 centimeters].
>
> The shadows moved slowly and uniformly, the speed on the wall was about that of a moderately trotting horse. I [first] saw the shadows about 3 minutes before totality started.
>
> According to Mr. Lang, whom I asked to watch this phenomenon, it was not seen during totality …
>
> [But] Immediately after totality the shadows reappeared, alternating in intensity, but getting weaker and weaker. They remained visible for about 5 minutes after totality, and then they definitely were gone. (Oudemans 1873: 15–16; our English translation).

The amazing flying shadows were not seen at any of the other 12 December 1871 eclipse sites, not even at the nearby Tjilentap Trig Point.

15.4 Concluding Remarks

As the Head Engineer of the Geographical Service in the Dutch East Indies Oudemans Jean Abraham Crétien Oudemans was in a unique position in that he also could carry out non-meridian astronomical research as part of his 'official' duties. Thus he was the only Dutch astronomer to successfully observe the 18 August 1868 and 12 December 1871 total solar eclipses. During the latter eclipse he was responsible for the official party, but he also assisted other observing teams set up in Java at and near Bogor. Oudemans also assisted by calculating the latitudes and longitudes of the sites used by different observers or observing parties during eclipses.

Despite these good intentions, from a scientific perspective the observations made by Oudemans and others in the Dutch East Indies in 1868 and 1871 made little contribution to science. Unfortunate this was a critical time in the development of solar physics, when photography and spectroscopy were indispensable research tools, but neither was used with success—if at all—during the Dutch East Indies observations of the two eclipses, and descriptions or sketches of prominences and the corona added very little to existing knowledge.

Nonetheless, Oudemans used the two eclipses to promote the development of the physical sciences in the Dutch East Indies prior to deciding in 1875 to return to Europe and live out the remainder of his life in the Netherlands.

Acknowledgements We are grateful to Dr. T. de Groot, (Rijksuniversiteit Utrecht) for kindly providing Fig. 15.2.

References

Cenadelli, D. (2014). Secchi, (Pietro) Angelo. In T. Hockey et al., pp. 1970–1972.

Cottam, S., & Orchiston, W. (2015). *Eclipses, Transits and Comets of the Nineteenth Century: How America's Perceptions of the Skies Changed*. Cham: Springer.

Espenak, F., & Meeus, J. (2006*). Five Millennium Canon of Solar Eclipses: –1999 to +3000*. Greenbelt: NASA (Technical Publication TP-2006-214141).

Frost, M. (2014). Lockyer, Joseph Norman. In T. Hockey et al., pp. 1336–1338.

Habashi, F. (2014). Young, Charles Augustus. In T. Hockey et al., pp. 2400–2401.

Heijden, P. (2014). Kaiser, Frederik. In T. Hockey et al., pp. 1151–1153.

Hirshfeld, A.W. (2014). Harkness, William. In T. Hockey et al., pp. 904–905.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Illustrated London News, 14 December (1850).

Janssen, J. (1868). An indication of several of the results obtained at Cocanada [*sic*] during the eclipse of last August, and the sequel to this eclipse. *Comptes Rendus de l'Académie des Sciences, 67,* 838–839 (in French).

Janssen, J. (1869a). On the existence of a hydrogen atmosphere around the Sun. *Comptes Rendus de l'Académie des Sciences, 68,* 112 (in French).

Janssen, J. (1869b). On the spectral study of solar prominences. *Comptes Rendus de l'Académie des Sciences, 68,* 93–95 (in French).

Janssen, J. (1869c). Spectral observations made during the eclipse of 18 August 1868, and a method for observing prominences outside of eclipses. *Comptes Rendus de l'Académie des Sciences, 68,* 367–376 (in French).

Janssen, J. (1869d). A summary of acquired ideas on the composition of the Sun. *Comptes Rendus de l'Académie des Sciences, 68,* 312–314 (in French).

Janssen, J. (1873). An account relating to the observation of the eclipse of 12 December 1871 … *Journal Officiel de la République Française, Jan. 16,* 312–313; *Jan. 19,* 392–394; *Jan. 20,* 408–409 (in French).

Launay, F. (1997). On the solar eclipse of 12 December 1871. The voyage of the Janssens to the Neelgherries. *L'Astronomie, 111,* 111–115 (in French).

Launay, F. (2012). *The Astronomer Jules Janssen: Globetrotter of Celestial Physics*. New York: Springer.

Lockyer, N. (1874). *Contributions to Solar Physics*. London: Macmillan.

Lomb, N. (2016). Australian solar eclipse expeditions: the voyage to Cape York in 1871. *Journal of Astronomical History and Heritage*, 19, 79–95.

Mahias, M.-C. (2010). The black Sun of the Nilgiris: astronomy, photography and physical anthropology in South India. *Visual Anthropology, 13,* 129–148.

Maunder, E.W. (Ed.) (1899). The Indian Eclipse 1898. *Report of the Expeditions Organized by the British Astronomical Association to Observe the Total Solar Eclipse of 1898, January 22*. London: Hazell, Watson and Viney.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nath, B.B. (2013). *The Story of Helium and the Birth of Astrophysics*. Cham: Springer.

Orchiston, W., & Orchiston, D.L. (2017). King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-koa, Siam. In T. Nakamura, & W. Orchiston.

Orchiston, W., Lee, E.-H., & Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In T. Nakamura, & W. Orchiston.

Orchiston, W., Steinicke, W., & Mumpuni, E.S. (2018). J.A.C. Oudemans and nineteenth century astronomy in the Dutch East Indies. In W. Orchiston, & M. Vahia (Eds.), *Exploring the History of SE Asian Astronomy: A Review of Current Projects and Future Prospects and Possibilities*. Cham: Springer.

Oudemans, J.A.C. (1869a). Beobachtung der totalen Sonnenfinsterniss vom 18. August 1868, auf der Insel Klein-Mantawalu, in der Tomini-Bucht (Ostküste Celebes). *Astronomische Nachrichten, 74,* 1–8.

Oudemans, J.A.C. (1869b). Nachschrift zu meiner Mittheilung über die Beobachtung der totalen Sonnenfinsterniss am 18. August 1868. *Astronomische Nachrichten, 74,* 161–175.

Oudemans, J.A.C. (1873). Bericht über die Beobachtungen bei Gelegenheit der totalen Sonnenfinsterniss am 12. December 1871 im niederländischen Ostindien angestellt. *Astronomische Nachrichten, 81,* 1–36.

Pyenson, L. (1989). *Empire of Reason: Exact Sciences in Indonesia, 1840–1940.* Leiden: E.J. Brill.

Secchi, A. (1870). *The Sun: An Account of the Main Recent Discoveries*. Paris: Gauthier-Villars (in French).

Tennant, J.F. (1869). Report on the total eclipse of the Sun, August 17–18, 1868 … *Memoirs of the Royal Astronomical Society, 37,* 1–55.

Tennant, J.F. (1875). Report of observations of the total eclipse of the Sun on December 11–12, 1871, made by order of the Government of India, at Dodabetta, near Ootacamund. *Memoirs of the Royal Astronomical Society, 42,* 1–33.

Van de Sande Bakhuysen, H.G. (1907). Obituary Notices: Jean Abraham Chrétien Oudemans. *Monthly Notices of the Royal Astronomical Society, 67,* 241–242.

Chapter 16
American Observations of the 16 May 1901 Total Solar Eclipse from Padang, Dutch East Indies

John Pearson and Wayne Orchiston

16.1 Introduction: Lick Observatory Solar Eclipse Expeditions

At the time the Lick Observatory's great 36-in. (91.4-cm) refractor saw first light in 1888, the facility became a department of the University of California and solar eclipse expeditions were an integral part of the research strategy from early 1889 until 1932. This obligated the Observatory's management to solicit funding, employ staff, and allocate valuable resources for the eclipse program. Most of the solar eclipse expeditions were financed by philanthropists (see Pearson et al. 2011).

During a period of more than 40 years, 15 different solar eclipse expeditions were sent around the globe (see Pearson 2009; Pearson and Orchiston 2008). Figure 16.1 shows the locations of the various Lick Observatory stations, and the approximate paths of totality. This chapter (see Curtis 1901; Pearson and Orchiston 2011) focuses on the 1901 expedition to Padang, on the island of Sumatra in the Dutch East Indies (now the Republic of Indonesia), which is marked on the map by a red circle.

16.2 Coronal Science pre-1901

A long duration of totality and the high altitude of the eclipsed Sun for 1901 promised ideal conditions in which to carry out the Observatory's investigations of the solar corona. In fact the conditions were projected to be so ideal that solutions might be obtained for questions left over from previous eclipses. Thus, it was important that the Lick Observatory mount an expedition to this far-away location (Perrine 1901b).

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Fig. 16.1 The paths of totality, dates, and locations of the Lick Observatory expedition's stations; the Padang, Dutch East Indies station is indicated by a red *circle* (*Map* John Pearson)

Initially,knowledge of the solar corona developed at a very slow rate due to the rarity of solar eclipses. The frequency of solar eclipses was approximately one every 18 months. Widely scattered about the planet, sometimes inaccessible due to location, and with no guarantee of clear skies, an individual astronomer might accumulate less than 75 min of useful total observing time in the course of a lifetime (Campbell 1907: 1). Astronomers therefore needed to generate permanent records in a very short time so that they could carry out later analyses, and the development of photography enabled them to do just that and in a more accurate way than drawing enabled. Up to the end of the nineteenth century, drawing and photography coexisted together, with photography finally replacing drawing by the start of the twentieth century (Campbell 1907).

It was not until the period of the Lick Observatory eclipse expeditions that a very detailed examination of the solar corona by photography became the norm. As Pearson (2009) has shown, a large percentage of these detailed studies was made possible by the use of the Schaeberle Camera and the advancement of photographic techniques developed at the Observatory by E.E. Barnard (1857–1923; Sheehan 1995), S.W. Burnham, (1838–1921; Batten 2014) and J.M. Schaeberle (1853–1924; Whitsell 2014).

Prior to 1901 Lick Observatory coronal studies focused on:

1. Coronal form, structure and motion.
2. Coronal composition.
3. Coronal brightness.
4. Coronal polarization.
5. The 'flash spectrum'.
6. The identity and precise location of the Green coronal line.

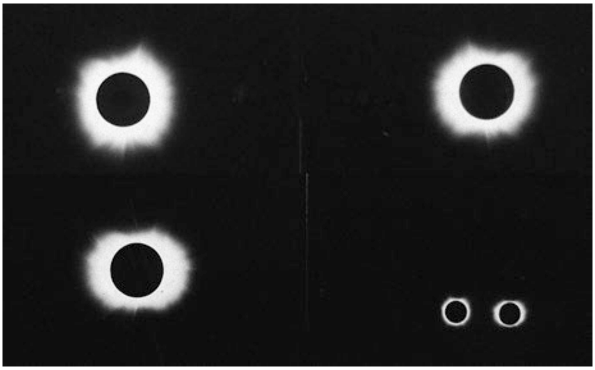

Fig. 16.2 Polarized coronal photographs (*Courtesy* Mary Lea Shane Archives)

Due to limited staff ability, in 1901 the Observatory focused mainly on items (1)–(4) in this list.

Coronal studies of form and structural detail were made of the inner and outer corona. Some of these coronal forms took on the appearance of streamers, rifts, cusps, winged appendages, curves and other interesting shapes classified as 'disturbances'. Some coronal features were found in the vicinity of solar surface disturbances such as sunspots, flares and faculae. Coronal features were found to vary considerably in appearance according to their proximity to the solar equator and the polar regions.

Coronal motion studies were made in order to explain the differences of coronal form. Other relationships were found to exist between the coronal streams of ejected matter and the rotation of the Sun. Measurements of the velocity of ejected matter from the photosphere and chromosphere were applied in the study of coronal form.

Coronal constitution studies were concerned with the particle-gas content and distribution within the inner and outer corona. Coronal brightness studies were made by photometry to measure the variability of brightness within the inner and outer corona (see Pearson 2009).

Researchers made polarization studies of the corona in order to determine particle density and distribution by measuring reflected sunlight from particle content within the corona (see Fig. 16.2).

16.3 The 1901 Lick Expedition to Padang, Dutch East Indies

16.3.1 Expedition Planning

William H. Crocker (1861–1937) funded the Lick Observatory solar eclipse expeditions after his brother Colonel C.F. Crocker (1854–1897) had passed away. Planning for the eclipse was delayed by the sudden death of the Observatory's Director, James E. Keeler (1857–1900; Osterbrock 1984), on 12 August 1900. Nonetheless, preparations involving the entire Observatory staff were completed within just 1 month, with new instruments even being designed and fabricated. Dutch-controlled Padang on the island of Sumatra was selected for the eclipse site as it was far from the high cloudy mountains present along most of the path of totality (Perrine 1901a: 349, 1901b: 59).

Lick Observatory's new Director, W.W. Campbell (1861–1938; Wright 1949), gave his very specific ideas on providing for the health and safety of the expedition members:

> My advice about the proper precautions in the tropics is very simple. Have perfectly regular habits: retire and keep regular hours, do not neglect your body so much as one day … To avoid bowel complaints—the bane of the tropics—beware of underdone food and of fruit too green or too ripe. Do not drink unboiled water, and do not trust your native to boil it as they will not boil it, but he will assume you think he does, everytime. Better drink both soda water secured from a reliable firm and coffee as white residents drink coffee before, or as they get up in the morning, do the same. Lastly, everyday, keep your circulation good, by drinking some good whiskey—whisky and soda—with your evening meal if the nights are cold, take some whisky when you turn in. It will help you to sleep as the night comes on. Don't neglect it on any account.
>
> As to clothing: Keep the sun's rays off your head and back of the neck by wearing one of the hats of the country: buy a helmet at Manilla or Singaphor [sic]. You will need several suits of white duck or linen … the latter buttoning up the neck. If you have a few days in Hong Kong or Singaphor, the Chinese tailor can make them for a song—$3 or $4 and light underclothing for the day, and shorts of canvas or linen … (Campbell 1901a).

The leader of the expedition would be C.D. Perrine (1867–1951; Teare 2014), assisted by fellow staff astronomer R.H. Curtiss (1880–1929; Hoffleit 2014).

16.3.2 The Trip to the Dutch East Indies

The party left San Francisco on 19 February on the steamer *Nippon Maru*, stopping in Honolulu, where they met the United States Naval Observatory party on the *Sheridan*. After days of rough seas they stopped at Yokohama, before reaching Hong Kong on 20 March. In Hong Kong they transferred to yet another steamer under the Koninklijke Paketvaart-Maatschappij line for the trip to Batavia, reaching there on 31 March. They transferred to the ship, *Stoomvaart-Maatschappij-Nederland* reaching Emmahaven on 5 April. Here they again met the U.S.N.O. party that had arrived the night before. The Lick party arrived in Padang, Sumatra after a 7 week voyage (Bracher 2001; Perrine 1901a: 55, 1901b: 188–189).

16.3.3 Establishing the Eclipse Station

Upon arrival, the Dutch Government helped them locate and established a station at an abandoned race course (see Fig. 16.3). Site coordinates were 06 h 41 min 20 s East of Greenwich, 00° 56 min South.

Fig. 16.3 The Lick Observatory solar eclipse station on the racecourse in Padang (*Courtesy* Mary Lea Shane Archives)

During 10 days of frequent heavy showers, Perrine and his volunteers assembled the clock-driven polar-axis mounts and installed the cameras and spectrographs. The 40-ft Schaeberle Camera was set up with its site-made towers. All of the instruments were covered by bamboo and thatch structures to provide shelter from the hot tropical Sun (Fig. 16.4). The rain was too heavy for canvas, so native material called *atap* was substituted. All of the instruments were operational by 12 May, but the promised telegraph network, for maintaining communications to other distant eclipse parties, failed to materialize (Perrine 1901b).

16.3.4 The Eclipse Instruments

The 40-ft Schaeberle Camera's towers rose 36 ft (11.0 m) high, but the daily heavy showers (over 10 in. in 3 days) at this tropical location along with soft sand and clay ground prevented the usual 9-ft (2.7-m) pit area being dug at the foot of the camera. The inner and outer towers were constructed of bamboo and covered with *atap*. A ladder, provided entry to a door that allowed access to the objective lens.

Apart from the Schaeberle Camera, there were other cameras with a range of focal-lengths that provided very wide to moderately long field of views. Two notable cameras among this array were the 5-in. (12.7-cm) aperture, 33-in. (83.8-cm) focal length Pierson Dallmeyer Camera which was basically a high quality portrait lens camera and the Floyd photographic telescope of 6-in. (15-cm) aperture and

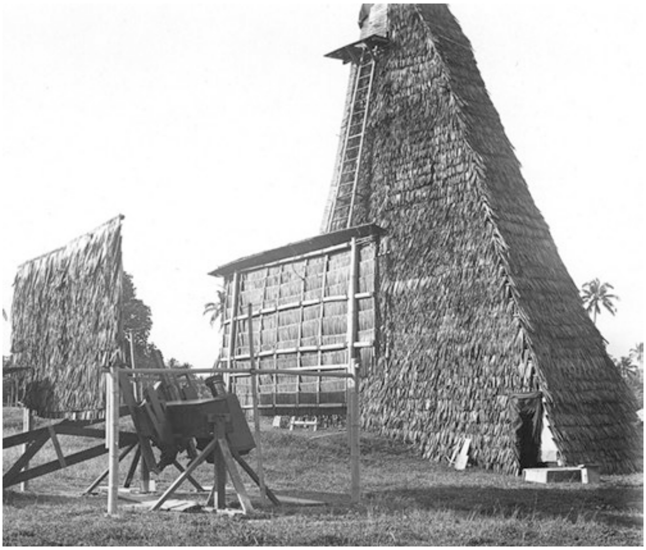

Fig. 16.4 In the foreground are the cameras and spectrographs on an equatorial mounting within the flip-top thatch shelter and in the background is the Schaeberle Camera covered in thatch (*Courtesy* Mary Lea Shane Archives)

67-in. (1.7-m) focal length (Schaeberle 1893). The first camera provided plates from which sky brightness measurements could be made, while plates from the Floyd instrument were ideal for the study of overall coronal form.

Four purpose-built cameras, made entirely at the Lick Observatory, were assigned to the search for intra-Mercurial planets. The cameras were equipped with matching 3-in. (7.6-cm) aperture, 11-ft 4-in. (3.45-m) focal length Clark lenses and fitted with 14 × 17-in. (35.6 × 43.2-cm) plate-holders. All four cameras were affixed to a single clock-driven equatorial mounting (see Fig. 16.5).

Two simple spectrographs were employed. One was a tangential 60° prism spectrograph with a N-S slit and the other a radial-slit prism spectrograph with an E-W slit orientation.

A polarigraph camera, designed by Campbell and W.H. Wright, of 20.75-in. (52.7-cm) focal length with a front-mounted double Nicol prism was used for the first time in an attempt to obtain plates suitable for coronal polarization measurements. Rotation of the prism during totality would reveal any existing polarization within the corona.

16.3.5 The Scientific Staff and Helpers

Unlike the days of Director Holden, Campbell (1901b) instructed Perrine to do his best to conduct the scientific program as preplanned, but "… if in your judgment changes in the program are necessary or advisable, you are authorized here to make them, for reasons which seem, sufficient to you."

Fig. 16.5 The Intra-Mercurial (Vulcan) cameras as they appeared at a later expedition (*Courtesy* Mary Lea Shane Archives)

Perrine and Curtiss were ably assisted with the observations by F.A. Delprat, Chief Executive of the Government Railways, and the following 14 volunteers: Lieutenants P.L. de G. Fortman, W.H. Warnsinck and E. Sieburgh; Mevrouw de Gaay Fortman; and Messrs. Cleton, d'Hanens, Guldenaar, Junius, J. Kempens, Lagerwey, Nieuwenhuys, van Leeuwen Boonkamp and von der Straeten.

Dutch officials who assisted the expedition were F. Bouman, Superintendent of construction of the Railways (who supervised construction of the eclipse station buildings); Kolonel H.F.C. Van Bijlevelt, Commander of the Army; Major Muller, who selected the eclipse station site; and His Excellency, Governor Joekes, who arranged local support personnel (Perrine 1901a).

16.3.6 *The Schedule of Solar Observations*

Because Campbell (1901c) could not spare a specialist spectroscopic man from the Lick Observatory staff for the expedition, the entire program was to be based upon photography (Perrine 1901b: 189, 1901c) even with the two spectrographs.

For this eclipse, two new areas of research were added to the regular program:

1. A search for intra-Mercurial bodies between Mercury and the Sun with the telescope-cameras especially made for this purpose.
2. A study of the level of polarization in the solar corona using the polarigraphic camera.

The remainder of the program involved obtaining photographic images of the corona with the various cameras and securing spectrograms of the general coronal spectrum, as follows:

1. To record the prominences and inner coronal structural detail with the Schaeberle Camera.
2. To conduct medium-field coronal imaging with the Floyd telescope.
3. To take wide-field images of the outer corona with the Pierson Dallmeyer camera.
4. To take spectrograms of the coronal spectrum in a search for Fraunhofer lines.

16.3.7 Eclipse day

On 16 May 1901, the day of the eclipse, the sky was covered with light cirrus clouds and haze. The different contact times and duration of totality are listed in Table 16.1. The altitude of the eclipsed Sun was 70° ± 5°, with the clouds increasing somewhat before third contact.

Local religious leaders had prophesized that the expedition would cause an epidemic in the superstitious local town of Kampong, and rumors circulated that the camp would be attacked. Consequently, on the day of the eclipse security guards were posted to protect the eclipse station, but to everyone's relief no attack occurred (Perrine 1901b: 203).

During totality, 12 plates were exposed with the Schaeberle Camera, 8 with the Floyd Camera, 10 with the Pierson-Dallmeyer camera, 3 with each of the intra-Mercurial cameras, 1 with each of the spectrographs, and 10 with the polarigraph camera.

Upon developing the camera plates in the cooler hours of the night, it was a pleasant surprise to find that negatives of value had been secured with all of the instruments. Despite the light cloud cover, the corona was obvious on the photographs, and exhibited the form characteristic of sunspot minimum (see Fig. 16.6).

As a special treat for the eclipse expedition party, the Great Comet of 1901 (C/1901 G1) was observed, and on 5 May it was photographed with the Pierson camera. The nucleus was brilliant, and the tail was 6°–8° long. Two slightly curved and nearly parallel streamers were noted in the tail, with a faint streamer to the south making an angle 35° with the principal trail (Perrine 1901a: 357–359; cf. Kronk 2007).

16.3.8 The Observations and Scientific Results

The plates revealed the inner corona and prominences well. Detail in the middle corona was visible in the two longer exposures. The longest exposure revealed the presence of streamers from the eastern equatorial extension out to one and a third

Table 16.1 Contact times and duration of totality during the May 1901 total solar eclipse

Contact times (UT)				Duration of totality
First contact	Second contact	Third contact	Fourth contact	
22 h 45 min 31 s	0 h 18 min 52.3 s	0 h 25 min 1.3 s	01 h 57 min 36 s	06 min 09 s

Fig. 16.6 A coronal image made with the 40-ft Camera (*Courtesy* Mary Lea Shane Archives)

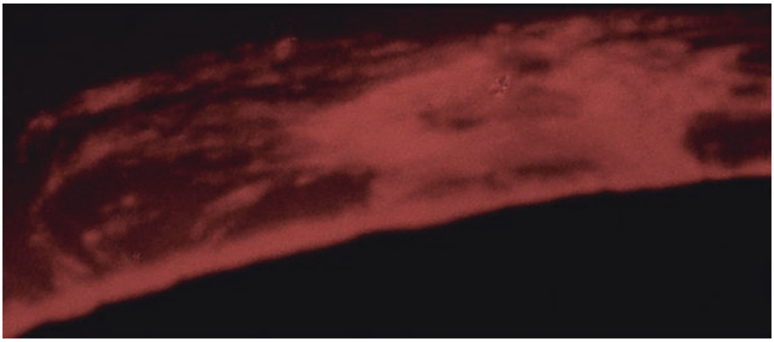

Fig. 16.7 Coronal matter in the vicinity of a disturbed area on the Sun's surface (*Courtesy* Mary Lea Shane Archives)

lunar diameters. Again the presence of hoods over prominences was observed. One of the most interesting features ever observed in the corona was a tremendous funnel-shaped disturbance appearing to emanate above the area (see Fig. 16.7), where a sunspot had been present over a 2-week period. According to Perrine (1901c: 196), it appeared that

> … clouds of coronal matter were piled up as if by an explosion of the Sun's surface … The disturbed area appeared to have its origin … near a compact prominence, and masses of matter are shown radiating from it in almost all directions. A long thread-like prominence to the south appears to emanate from this same region. The whole area resembles the condensations seen in photographs of the *Orion* and other irregular nebulae.

Upon inspecting the plates, Perrine (1902a, b, c: 147–149) was convinced that there was a direct connection between this observed occurrence and an eruption on the Sun's surface. He was certain that the observed event demonstrated that the corona was directly linked to other solar phenomena, which needed an explanation.

The corona was recorded to extend out for one lunar diameter (Campbell 1901d, e, 1904; Perrine 1901a, c, d).

Results from the polarigraph indicated that most coronal polarization occurred beyond 10 arc-minutes of the limb. Measurements within the inner corona showed a small amount of polarization. The cloudiness was actually a benefit, as some detail was retained that would have been lost to over-exposure (see Perrine 1901a: 353).

Comparisons of the spectrum of the sky with that of the corona made with the radial and tangential slit spectrographs were essentially the same in the blue and violet regions of the spectrum. The general coronal spectra were recorded to one lunar diameter and the H and K bright lines were seen within the streamers to 40 arc-minutes from the lunar disk. Like the 1898 eclipse, no Fraunhofer lines were found in the inner corona. The presence of coronal bright lines indicated a thin gaseous envelope surrounding the Sun (Perrine 1901a: 354–355, 1901c: 198–199).

Campbell (1901g) found the spectrum of the outer corona mirrored that of the general solar spectrum, whereas the spectrum of the inner corona contained little evidence of dark lines.

The results from the spectrographs and polarigraph indicated that the matter of the inner corona was primarily incandescent and the light of the outer corona could be attributed to scattered light from particles in a more solid state. It was also noted that matter was ejected from the Sun's surface at great velocity, and it was believed that the streamers and other coronal features were directly connected to eruptive events on the solar surface. Further study was needed to verify if the matter was ejected in an incandescent or solid state form (Campbell 1901g).

Perrine (1904: 331–337) summed up the Observatory's photographic strategy, knowledge of the solar corona and future studies as follows, and urged further cooperation at future eclipses:

1. Outer coronal light is almost wholly reflected or diffracted photospheric light.
2. Inner coronal light is chiefly inherent.
3. The velocity of matter within the corona appears to be <32 km s^{-1}.
4. The motion of small particles is away from the Sun and is influenced by radiant pressure.
5. Coronal structure is best photographed with cameras of ≥40-ft focal length, with those >50-ft mounted horizontally.
6. The presence of hoods over prominences and the low velocity of coronal matter is evidence of matter falling into the Sun as well as moving in an outward direction.
7. Photographs of the corona need to be made over time periods of hours in order to detect the general movement characteristics of streamers.
8. The general character of coronal light has been conclusively determined. The inner-most corona displays a bright-line spectrum of matter in a gaseous state, yet the bright-line spectrum does not match known terrestrial elements. No Fraunhofer lines are seen within the inner corona, which indicates incandescent matter in a solid or liquid state. The spectrum of the outer corona is a continuous solar spectrum as shown by polarization studies.

9. The variable line of sight conditions within the corona means that it is difficult to determine a law of the distribution of coronal matter using the polariscope.
10. Photometric measurements over a period of eclipses are a test for coronal theories.
11. Are maxima or minima coronas brightest? The Schaeberle Camera plates revealed a decrease in brightness levels from the 1893 to the 1900 eclipses, yet the English expeditions reported increased brightness levels.
12. Chromospheric, reversing-layer and coronal spectral lines should be precisely determined to permit identification of their terrestrial elements. The Sun's layers should be searched for newly found gases in the Earth's atmosphere such as argon, krypton, neon, and xenon.
13. Campbell's moving-plate spectrograph provides a continuous record of the spectrum of the Sun's limb yielding additional information on line height and line shifting that occurs as the Sun's layers are isolated by the Moon. Spectral line characteristics should be studied over several eclipses to note differences versus sunspot cycles.
14. The effects on the corona due to the rotation of the Sun should be examined in order to determine a true law of rotation.

Campbell (1901h) suggested that eclipse problems were being simplified because they were being associated with connected phenomena, rather than with a disconnected corona, prominences, the chromosphere, and so on.

The plates most affected by haze and clouds were from the Intra-Mercurial cameras where a lower limit was placed on the recorded star magnitudes. The photography recorded stars to sixth magnitude, but no suspect objects were noted (Campbell 1901d; Perrine 1902b). Only faint shadow banding was observed by Lagerwey before second contact and none after third contact as clouds obscured this part of the event (Perrine 1901a: 357–359).

Perrine (1901a) summarized the expedition with these comments, "The greatest enthusiasm was manifested by all in the preliminary rehearsals as well as in the observations on eclipse day." while Campbell (1901e; his underlining) reported that "… <u>very valuable results have been obtained with all of the ten instruments</u>." Campbell (ibid.) summarized the expedition:

> … Mr. Perrine managed the scientific, the personal and the financial details of the Expedition perfectly in every way. Without exaggeration or boasting, it can be stated that it was by far the most fruitful expedition sent to this eclipse …

The instruments returned home 3 months later than promised. There was damage from rust and extremely rough handling and dropping of the cases. One of the chronometers was badly damaged, and Campbell (1901f) subsequently filed an insurance claim.

The Dutch Eclipse Expedition to Kanrang Sago, Sumatra, under the direction of A.A. Nijland (1868–1836), did not fare as well. Likely due to the degree of cloudiness, their observations with a spectrograph, spectroscope and photometer failed, as was also the case with their large 40-ft camera (see Nijland 1903).

16.4 Discussion and Concluding Remarks

The initial settlement of the Javan region by hominids described as *Homo erectus* occurred ~1.8 million years ago (e.g. see Orchiston and Siesser 1982; Swisher et al. 1994; Tyler and Sartono 2001), so simple naked-eye astronomy has a very long history in the Indonesian archipelago but, regrettably, we know next to nothing about this early era. This is not so, though, of the present-day Indonesians who are all *Homo sapiens sapiens* and settled the region comparatively recently, during Holocene times (see Bellwood 2007). Today observational astronomy continues to play an important role in the daily lives of those in many rural Indonesian communities, as carefully documented by Bambang Hidayat (2000a, 2011). However, their type of astronomy, with its agricultural and religion overtones, differs markedly from the style of scientific astronomy that was first introduced to the then East Indies at the beginning of the seventeenth century with the arrival of the Dutchman Frederick de Houtman (see Dekker 1987). Hidayat (2000b: 46) records how

> The catalogue of stars published by Frederick de Houtman in 1603 provided the basis for the renaming of many of the southern constellations. In a publication that was brought to the attention of European astronomers, de Houtman listed 303 stars in the southern sky and provided names for the major constellations.

There was then a hiatus of well over a century before the reappearance of scientific astronomy in the region. The unlikely champion of this renaissance was Pastor Johan Maurits Mohr (1716–1775) who tended to the Portuguese community then resident in Batavia (which is present-day Jakarta, the capital of the Republic of Indonesia). Mohr had a passion for astronomy (see Zuidervaart and van Gent 2004) and after the death of his first wife he married a very wealthy local woman and finally had the financial means to indulge his hobby to the utmost. This culminated in the construction of a lavish observatory atop his four-storey mansion on the outskirts of Batavia, as depicted in Fig. 16.8.

Mohr's observatory was furnished with the latest instruments and was the envy of astronomers and scientists who visited Batavia. For example, the noted French explorer and naturalist, Louis-Antoine de Bougainville, stopped off in Batavia in October 1768 and wrote:

> I ought not to omit mentioning a monument, which a private person has there erected to the Muses. Mr. Mohr, the first clergyman at Batavia, a man of immense riches … has built an observatory, in a garden belonging to one of his country-houses, which would be an ornament to any royal palace. This building, which is scarce completed, has cost prodigious sums. Its owner now does something still better, he makes observations in it. He has got the best instruments of all kinds from Europe, necessary for the nicest observations, and he is capable of making used of them. (Cited in van Gent 2005: 69).

Mohr did indeed put his instruments to good use, especially during the transits of Venus in 1761 and 1769 (see van Gent 2005; Zuidervaart and van Gent 2004).

When Mohr died in 1775 Indonesian astronomy again went into eclipse, only to emerge as a handmaiden to allied disciplines during the nineteenth century:

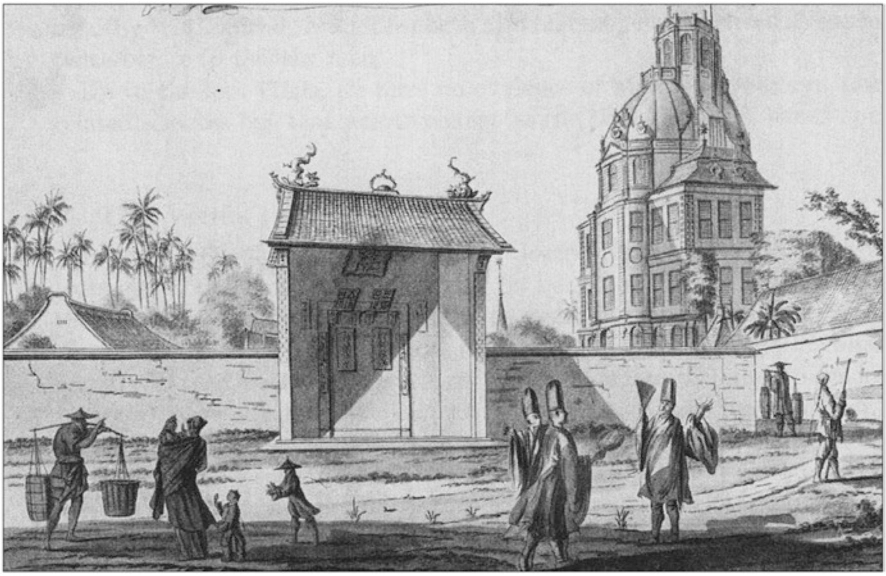

Fig. 16.8 A view of Pastor Mohr's mansion and observatory (after van Gent 2005: 69)

> … close to scientific astronomy was the founding of the first magnetic and meteorological observatory at Batavia. Although astronomical activities relating to trigonometrical surveying began in 1821, it was not until the 1850s that they really became a necessity. New economic and social order demanded the exact locations of sites in various parts of the archipelago to be known. Although the scientific aspects of triangulation cannot be separated from observational astronomy there were difficulties in developing pure astronomical science in the second half of the nineteenth century. Astronomy only persisted through its application to geodetic astronomy, and Dutch astronomers in the colony during that era strove to find a state of equilibrium between practical knowledge and pure learning. But it was also during this period that basic improvements in maritime charts of the archipelago were made, on the basis of astronomical observations … (Hidayat 2000b: 47).

It was within this framework of geodetic astronomy that the 1901 total solar eclipse occurred, offering Indonesia the chance to once more make a notable contribution to forefront mainstream astronomical science. Unlike India, with its relative plethora of total and annual solar eclipses during the second half of the nineteenth century (e.g. see Orchiston and Pearson 2017; Orchiston et al. 2017), the August 1868 (Oudemans 1869a, b), December 1871 (Oudemans 1873) and December 1901 events were the only total solar eclipses visible from Indonesia during this period. Although the two earlier eclipses did attract local observers to Sulawesi, Sumatra and Java (as discussed by Mumpuni et al. (2017) in the previous chapter), it was the 1901 eclipse that made a significant international contribution to coronal science. This eclipse therefore has an important place in the history of Indonesian astronomy.

After the 1901 eclipse, scientific astronomy only rose to its full glory in Indonesia in the 1920s with the founding of the Bosscha Observatory (Fig. 16.9) at Lembang, near the Javanese city of Bandung. The latitude and longitude of the Observatory

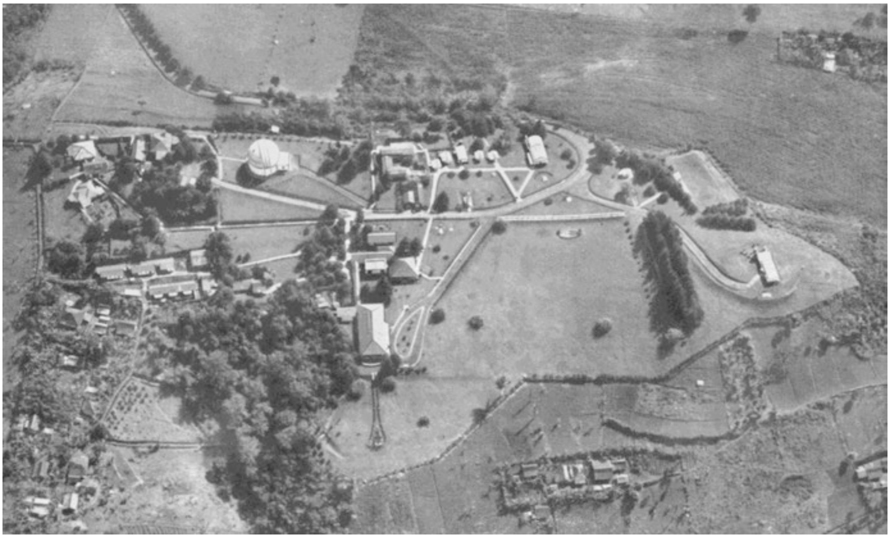

Fig. 16.9 An aerial view of Bosscha Observatory soon after its founding (after Voûte 1933: Plate III)

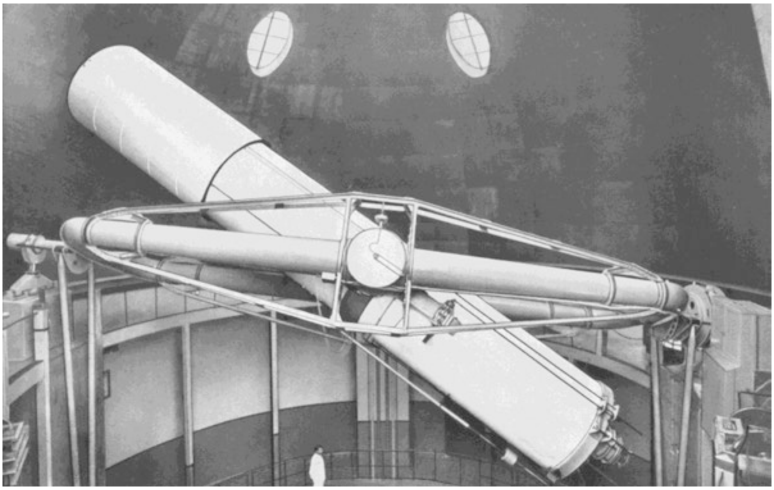

Fig. 16.10 The 60-cm Zeiss double refractor (after Voûte 1933: Plate V)

are respectively 6° 49′ 32.93″ S and 7 h 10 min 27.84 s E, and it is situated on the southern slopes of a volcano at an altitude of ~1300 m (Voûte 1933: A14).

The initial suite of instruments included a twin Zeiss refractor with an aperture of 64-cm (Fig. 16.10); a 37-cm Schmidt refractor (Fig. 16.11); the Bamberg Astrographic Refractor (Fig. 16.12); a Secretan 16-cm refractor; a Zeiss 13-cm refractor; a Zeiss 11-cm comet-seeker; and an assortment of astrocameras. Over the years, these instruments, and others acquired more recently, have been used to make a valuable contribution to southern hemisphere astrophysics (e.g. see Hidayat 2000b; Hidayat et al. 2017).

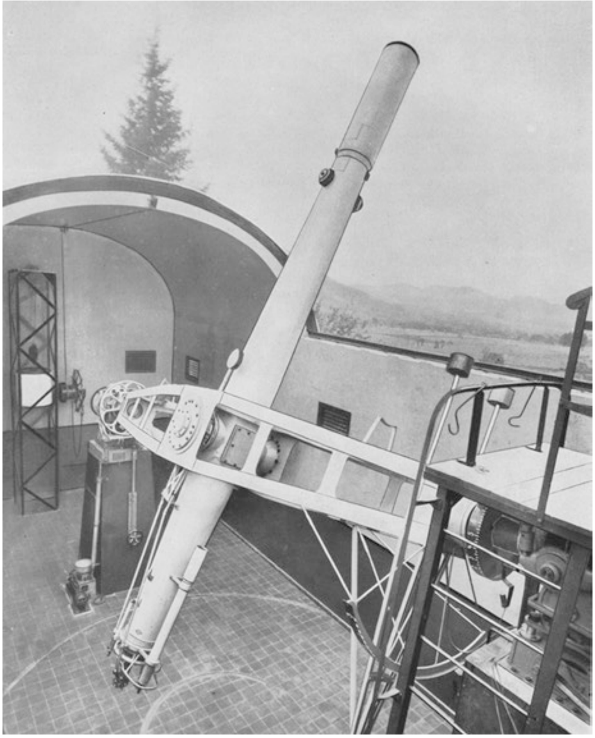

Fig. 16.11 The 'Bamberg Refractor', which boasts a 37-cm Schmidt objective (after Voûte 1933: Plate X)

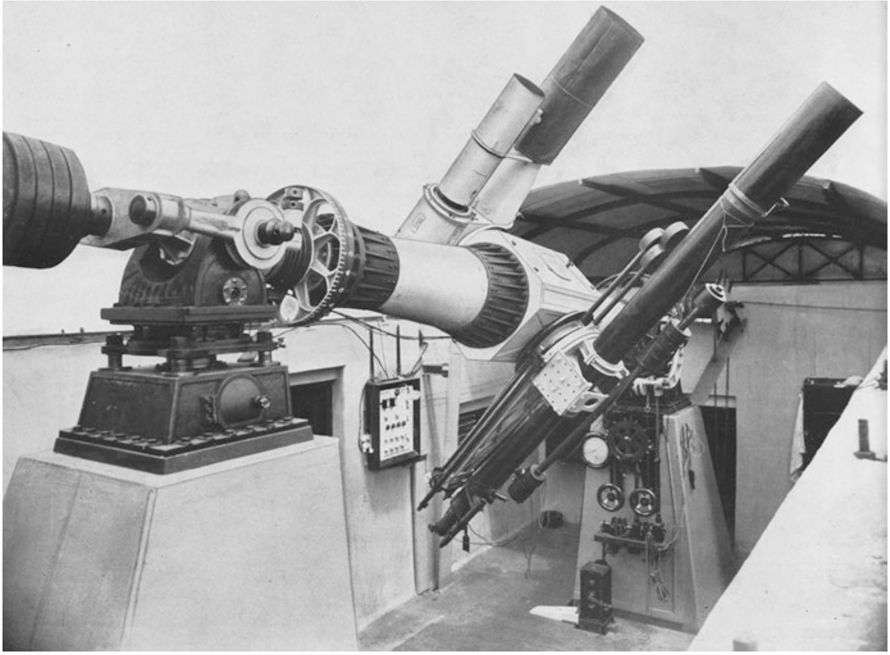

Fig. 16.12 The 'Bamberg Astrographic Refractor', which comprises a 19-cm Merz refractor and two astro-cameras, one with a 15-cm Zeiss UV-triplet objective and the other with a 12-cm Zeiss Astro-Tessar objective (after Voûte 1933: Plate IX)

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References[1]

Batten, A.H. (2014). In T. Hockey et al., pp. 343–346.

Bellwood, P. (2007). *Prehistory of the Indo-Malaysian Archipelago.* Canberra: ANU Press.

Bracher, K. (2001). A solar eclipse in Sumatra. *Mercury, 30*, 6.

Campbell, W.W., (1901a). Letter to S.A. Mitchell, Columbia University, dated 14 January. SA, Campbell letter file, 27.

Campbell, W.W. (1901b). Letter to Perrine, dated 15 February. SA, microfilm, v28, 281.

Campbell, W.W. (1901c). Letter to G.E. Hale, dated 24 January. SA, microfilm v28, 89.

Campbell, W.W. (1901d). Letter to Pickering at Harvard College Observatory, dated 12 October. SA, microfilm v30, 429.

Campbell, W.W. (1901e). Letter to President Wheeler, University of California, dated 1 October. SA, microfilm v30.

Campbell, W.W. (1901f). Letter to Northern Insurance Company, dated 12 October. SA, v30, 433.

Campbell, W.W. (1901g). Letter to A. Fowler, dated 10 March. SA microfilm v29, copybook V71.

Campbell, W.W. (1901h). Letter to A. Fowler, dated 5 April. SA microfilm v29, copybook V71, 179–180.

Campbell, W.W. (1904). The total eclipse of August 30, 1905. *Popular Science Monthly,* 97–108.

Campbell, W.W. (1907). The solar corona. *Publications of the Astronomical Society of the Pacific, 19,* 71–79.

Curtis, H.D., (1901). The U.S. Naval Observatory eclipse expedition to Sumatra. *Publications of the Astronomical Society of the Pacific, 13,* 205–213.

Dekker, E. (1987). Early explorations of the southern celestial sky. *Annals of Science, 44,* 439–470.

Hidayat, B. (2000a). Indo-Malay astronomy. In H. Selin, & X. Sun (Eds.), *Astronomy Across Cultures. The History on Non-Western Astronomy* (pp. 371–384). Dordrecht: Kluwer.

Hidayat, B. (2000b). Under a tropical sky: a history of astronomy in Indonesia. *Journal of Astronomical History and Heritage, 3,* 45–58.

Hidayat, B. (2011). The sky and the agro-bio-climatology of Java. Is there a need for a critical reevaluation due to environmental changes? In T. Nakamura, et al., pp. 43–46.

Hidayat, B., Malasan, H., & Mumpuni, E.S. (2017). The development of astronomy and emergence of astrophysics in Indonesia. In T. Nakamura, & W. Orchiston.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hoffleit, D. (2014). Curtiss, Ralph Hamilton. In T. Hockey et al., pp. 492–493.

Kronk, G.W. (2007). *Cometography. A Catalog of Comets. Volume 3: 1900–1932*. Cambridge: Cambridge University Press.

Mumpuni, E.S., Orchiston, W., & Steinicke, W. (2017). J.A.C. Oudemans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In T. Nakamura, & W. Orchiston.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nakamura, T., Orchiston, W., Sôma, M., & Strom, R. (Eds.), (2011). *Mapping the Oriental Sky. Proceedings of the Seventh International Conference on Oriental Astronomy*. Tokyo: National Astronomical Observatory of Japan.

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[1] The following abbreviation is used:
SA = Mary Lea Shane Archives, University of California at Santa Cruz.

Nijland, A.A. (1903). *Total Eclipse of the Sun, May 18, 1901. Reports on the Dutch Expedition to Karang Sago, Sumatra*. Amsterdam: Eclipse Committee of the Royal Academy.

Orchiston, W., & Pearson, J. (2017). American observations of the 22 January 1898 total solar eclipse from Jeur, India. In T. Nakamura, & W. Orchiston.

Orchiston, D.W., & Siesser, W.G. (1982). Chronostratigraphy of the Plio-Pleistocene fossil hominids of Java. *Modern Quaternary Research in Southeast Asia, 7,* 131–149.

Orchiston, W., Lee, E.-H., & Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In T. Nakamura, & W. Orchiston.

Osterbrock, D.E. (1984). *James E. Keller: Pioneer American Astrophysicist and the Early Development of American Astrophysics*. Cambridge: Cambridge University Press.

Oudemans, J.A.C. (1869a). Beobachtung der totalen Sonnenfinsterniss vom 18. August 1868, auf der Insel Klein-Mantawalu, in der Tomini-Bucht (Ostküste Celebes). *Astronomische 'Nachrichten, 74,* 1–8.

Oudemans, J.A.C. (1869b). Nachschrift zu meiner Mitteilung über die Beobachtung der totalen Sonnenfinsterniss am 18. Aug. 1868. *Astronomische 'Nachrichten, 74,* 161–176.

Oudemans, J.A.C. (1873). Bericht über die Beobachtungen, bei Gelegenheit der totalen Sonnenfinsterniss am 12. December 1871 im niederländischen Ostindien angestellt. *Astronomische Nachrichten, 81,* 1–36.

Pearson, J.C. (2009). *The Role of the 40 Foot Schaeberle Camera in the Lick Observatory Investigations of the Solar Corona*. Ph.D. thesis, Centre for Astronomy, James Cook University, Townsville, Australia.

Pearson, J.C., & Orchiston, W. (2008) The 40-foot solar eclipse camera of the Lick Observatory. *Journal of Astronomical History and Heritage, 11,* 25–37.

Pearson, J.C., & Orchiston, W. (2011). The Lick Observatory solar eclipse expedition to Padang (Indonesia) in 1901. In T. Nakamura, et al., pp. 207–216.

Pearson, J.C., Orchiston, W., & Malville, J.McK. (2011). Some highlights of the Lick Observatory's solar eclipse expeditions. In W. Orchiston, T. Nakamura, & R. Strom (Eds.). *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference* (pp. 243–337). New York; Springer.

Perrine, C.D. (1901a). Preliminary report of observations of the total solar eclipse of 1901, May 17–18. *Astrophysical Journal, 14,* 349–359.

Perrine, C.D. (1901b). Preliminary report of observations of the total solar eclipse of 1901, May 17–18. *Lick Observatory University of California Bulletin, 9,* 58–63.

Perrine, C.D. (1901c). The Lick Observatory-Crocker Expedition to observe the total solar eclipse of 1901, May 17–18. *Publications of the Astronomical Society of the Pacific, 13,* 187–204.

Perrine, C.D. (1901d). Bulletin No. 9 – Preliminary report of the observations of the total solar eclipse of 1901, May 17–18. *Lick Observatory Bulletin, 1,* 58–63.

Perrine, C.D. (1902a). Origin of a disturbed region observed in the corona of 1901, May 17–18. *Lick Observatory University of California Bulletin, 18,* 151–152.

Perrine, C.D. (1902b). Results of the search for an intra-mercurial planet at the total eclipse of 1901, May 18. *Lick Observatory University of California Bulletin, 24,* 183–187.

Perrine, C.D. (1902c). Origin of a disturbed region observed in the corona of 1901, May 17–18. *Astrophysical Journal, 15,* 147–149.

Perrine, C.D. (1904). Some total solar eclipse problems. *Astrophysical Journal, 20,* 331–337.

Schaeberle, J.M. (1893). The Dallmeyer lens of the eclipse expedition. *Publications of the Astronomical Society of the Pacific, 5,* 230.

Sheehan, W. (1995). *The Immortal Fire Within: The Life and Work of Edward Emerson Barnard*. Cambridge: Cambridge University Press.

Swisher, C.C. III, Curtis, G.H., Jacob, T., Getty, A.G., Suprijo, A., & Widiasmoro (1994). Age of the earliest known hominids in Java, Indonesia. *Science, 263,* 1118–1121.

Teare, S.W. (2014). Perrine, Charles Dillon. In T. Hockey et al., pp. 1683–1685.

Tyler, D.E., & Sartono, S. (2001). A new *Homo erectus* cranium from Sangiran, Java. *Human Evolution, 16,* 13–25.

van Gent, R.H. (2005). Observations of the 1761 and 1769 transits of Venus from Batavia (Dutch East Indies). In D.W. Kurtz (Ed.), *Transits of Venus: New Views of the Solar System and the Galaxy* (pp. 67–73). Cambridge: Cambridge University Press.

Voûte, J. (1933). Description of the Observatory (with a Dutch Introduction). *Annalen v.d. Bosscha-Sterrenwacht Lembang (Java), 1,* A1–A27.

Whitsell, P.S. (2014). Schaeberle, John Martin. In T. Hockey et al., pp. 1924–1925.

Wright, W.H. (1949). William Wallace Campbell. *Biographical Memoirs, National Academy of Science, 25,* 35–74.

Zuidervaart, H.J., & van Gent, R.H. (2004). "A bare outpost of learned European culture on the edge of the jungles of Java". Johan Maurits Mohr (1716–1775) and the emergence of instrumental and institutional science in Dutch colonial Indonesia. *Isis, 95,* 1–33.

Part VII
Australia

Chapter 17
The Development of Astronomy and the Foundations of Astrophysics in Australia

Wayne Orchiston, Barry A.J. Clark, David Frew, and Jenny Andropoulos

17.1 Introduction

Australia has an indigenous astronomical heritage that extends back more than 50,000 years, and although a number of the European maritime expeditions that visited Australia during the eighteenth century included astronomers, scientific astronomy only anchored itself upon the shores of this giant island continent in 1788 (see Haynes et al. 1996). The following century saw the emergence of government-funded observatories of one kind or another in each of the Australian colonies (Orchiston 1988b), the appearance of a network of notable private observatories maintained by amateur astronomers (Orchiston 1989b), the launching of a local telescope-making tradition (Orchiston 2003), the founding of the nation's earliest astronomical groups and societies (Orchiston 1998a), and a concerted effort both by amateur astronomers and professionals to popularize astronomy (e.g., see Orchiston 1991, 1997). Most of the astronomical research conducted at this time can be classed as positional or descriptive astronomy, and astrophysics—the 'new astronomy'—received little attention.

Astrophysics only began to make a major impact, in the guise of solar physics, following the establishment of the Commonwealth Solar Observatory in 1924

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(Orchiston 1989a). A name change to Mount Stromlo Observatory (Bhathal et al. 2013) more or less coincided with a shift in research emphasis from solar to galactic and extra-galactic targets in the 1940s, and in the emergence of Australia as a leading international player in radio astronomy (see Sullivan 2009; Orchiston and Slee 2017). A little later, from the 1960s, universities throughout Australia began to offer undergraduate and post-graduate programs in astronomy, and contribute to the nation's growing published astronomical output (Haynes et al. 1996).

In this chapter we will briefly review developments that occurred in Australian astronomy during the eighteenth and nineteenth centuries, and then examine various astrophysical investigations carried out by professional *and* amateur astronomers prior to 1924. Subsequent developments have already been nicely summarised in Frame and Faulkner's *Stromlo* (2003), in the classic textbook on the history of Australian astronomy, *Explorers of the Southern Sky*, by Haynes et al. (1996), in Bhathal et al.'s *Stromlo: From Bush Observatory to the Nobel Prize* (2013) and in the web sites of the Australian Astronomical Observatory, CSIRO Astronomy and Space Sciences, the various astronomy-oriented universities and the Astronomical Society of Australia. Therefore, all that we shall do in this chapter is explore the early *emergence* of astrophysics in Australia.

17.2 Scientific Astronomy in the Pre-Astrophysics Era

17.2.1 Dawes Observatory

Australia gained its first permanent scientific astronomical facility in 1788 when Lieutenant William Dawes (1762–1836) established a short-lived observatory at Dawes Point. This location overlooked Sydney Harbour at a spot that is now under the southern approaches to the Sydney Harbour Bridge. Dawes made a few astronomical observations (Laurie 1988) and took regular meteorological readings (McAfee 1981; Orchiston 1989c) before returning to England. Nothing currently remains of his observatory.

17.2.2 Parramatta Observatory

Making a more lasting impression was the privately funded Parramatta Observatory, erected in 1821 by the new Governor of the colony of New South Wales, Sir Thomas Brisbane (1773–1860), just 20 km inland from Sydney at Parramatta (Saunders 2004). Brisbane brought two astronomical assistants with him, Carl Christian Georg Rümker (1788–1862) and James Dunlop (1793–1848), and between them the three men used what they then regarded as 'state-of-the art' astronomical instruments (see Lomb 2004) to plot the positions of more than 3000 stars (Richardson 1835) and

Fig. 17.1 Graeme White posing with the ruined piers of the Parramatta Observatory transit telescope (*Courtesy* Dr. Graeme White)

discover a number of comets. After leaving the Observatory in 1826, Dunlop used a home-made speculum-mirror reflector to observe the sky from his private home, and went on to assemble a pioneering catalogue of southern clusters and nebulae (Cozens et al. 2010). Parramatta Observatory closed in 1847 and today all that remains of this pioneering facility are an obelisk and the ruined piers of the transit telescope (see Fig. 17.1).

Following the closing of the Parramatta Observatory in 1847, a noted amateur astronomer, Philip Parker King (1791–1856), lobbied relentlessly for the establishment of a new government observatory in Sydney (Orchiston 1988a). Despite ongoing opposition from the Astronomer Royal, Sir George Airy (1801–1892), this eventually came to pass in 1858 when Sydney Observatory was founded (Orchiston 1988c; Wood 1958).

17.2.3 The Royal Hobart Observatory

From 1840 to 1854 the British Admiralty maintained a magnetic observatory at Hobart in Tasmania under the direction of Lieutenant Joseph Henry Kay (1815–1875). Although some astronomical instruments there were used for time-keeping purposes (Baracchi 1914), the primary functions of the 'Royal Observatory, Hobart Town', as Kay referred to it, were geophysical and meteorological observations (see Savours and McConnell 1982).

Although this Observatory produced 14 years of high quality magnetic and other observations, it was closed at the end of 1854 following Kay's temporary return to England in 1853. This inspired a local amateur astronomer, Francis Abbott (1799–1883), to establish his own observatory and continue the public meteorological and time-keeping functions that had been a feature of the Royal Observatory. With the passage of time, Abbott became one of Australia's foremost amateur astronomers (see Orchiston 1992), but he received a certain degree of unwarranted international notoriety during the 1860s when he persisted in claiming that the nebula surrounding η Carinae had changed appreciably in the three decades since Sir John Herschel (1792–1871; Evans 2014) first observed it at the Cape of Good Hope (Frew and Orchiston 2003).

17.2.4 Flagstaff Observatory

This Observatory was established in Melbourne at the Flagstaff Hill site of the late Naval Signal Station as a private/community observatory in 1857–1858 by the prominent German scientist, Georg Neumayer (1826–1909; Clark 2015; Gillespie 2011a), but the Colonial Government began contributing towards its funding within a year or so (Home 1991; Neumayer 1859).

The Observatory's roles included geomagnetic, auroral, meteorological and nautical observations. In addition, many sketches of sunspots were made with a 3-in. (76.2-mm) Steinheil refractor using the 'projection method', and in 1860 arrangements were set in place to make 'photographic sketches' of sunspots (see Neumayer 1860: 261–262).

In the early 1860s the Victorian Government made a decision to close Flagstaff Observatory and the nearby Williamstown Observatory and combine their primary functions at a new facility, Melbourne Observatory (see Gillespie 2011a, b).

17.2.5 The Government-Funded Colonial Astronomical Observatories

Sydney Observatory was one of seven different colonial astronomical observatories established in Australia between 1853 and 1896 (see Table 17.1), and their principal roles were to offer a local time service and collect and disseminate meteorological data. Apart from astronomical research, the leading observatories, in Sydney and Melbourne, also were involved in some or all of the following: trigonometrical surveying, seismology, geomagnetism, tidal studies and physical standards (see Haynes et al. 1996 for details), and as we shall see later in this chapter, both institutions experimented with the 'new astronomy', astrophysics, during the last three decades of the nineteenth century.

Table 17.1 Australian government observatories, 1850–1916

Observatory	Founding year	Main telescopes[a]	Reference(s)
Williamstown	1853	4.5-in. OG	Andropoulos (2014); Andropoulos et al. (2011); Ellery (1869a)
Flagstaff	1858	3-in. OG	Gillespie (2011a); Neumayer (1859); Perdrix (1990); Weiderkehr (1988)
Melbourne	1863	48-in. spec	Andropoulos (2014); Gascoigne (1992); Gillespie (2011b); Perdrix (1961, 1970)
		8-in. OG	
		13-in. astr	
Sydney	1858	11.5-in. OG	Lomb (2011); Orchiston (1988c); Wood (1958)
		7.25-in. OG	
		13-in. astr	
Adelaide	1874	8-in. OG	Edwards (1993, 1994)
Brisbane	1879	Small OG	Haynes et al. (1993)
		Small tran	
Hobart	1882	Small tran	Meteorological Department (1900)
Perth	1896	12-in. spec	Hutchison (1980, 1981); Utting (1989, 1992)
		13-in. astr	

Telescope apertures are given in inches (in.), which was the norm in Australia (and Britain) at that time. 1 in. = 25.4 mm

[a] Key: *astr* astrograph, *OG* refractor, *spec* reflector, *tran* transit telescope

Photography, photometry and spectroscopy were the new technologies adopted by astrophysics (see Hearnshaw 1986, 1996; Hughes 2013; Lankford 1984), and as we shall see in Sect. 17.3, below, between them Melbourne and Sydney Observatories were involved in the application of all three, while Perth Observatory only adopted photography as part of its research strategy.

17.2.6 The Role of the Amateur Astronomer

Another prominent feature of late nineteenth century Australian astronomy was the emergence of a national network of active private observatories established by amateur astronomers (see Orchiston 1989b). The owners of some of these facilities pursued active research programs and published in professional journals, and a small number of these astronomers also experimented with astrophysics—albeit on a much more modest scale than some of their illustrious international colleagues, like Ainslie Common (Baum 2014a), Warren De la Rue (Hirschfield 2014), Henry Draper (Gibson 2014), William Huggins (Becker 2011), Isaac Roberts (Abbey 2014) and Lewis Rutherfurd (Baum 2014c). Nonetheless, the tentative forays into astrophysics by these Australian amateur astronomers were important within the context of Australian astronomical history, and are discussed in Sect. 17.4.

17.3 The Genesis of Astrophysics in Australia

17.3.1 Spectroscopic Studies Carried Out at Melbourne Observatory with the 'Great Melbourne Telescope'

During the 1850s, the Australian colony of Victoria was in the throes of a gold rush, and ships swarmed to the port of Williamstown and the nearby ports of the capital city Melbourne. The need for a local time-service soon became urgent, and was solved with the founding of Williamstown Observatory in 1853 (Andropoulos et al. 2011). After a short period in other hands, the directorship of this fledgling facility was accepted by Robert Lewis John Ellery (1827–1908; Fig. 17.2), who went on to make a name for himself as an astronomer, observatory administrator and scientific entrepreneur (see Gascoigne 1992).

In June 1863 Williamstown Observatory and Neumayer's nearby Flagstaff (solar, geomagnetic and meteorological) Observatory were closed down and their activities combined at the newly founded Melbourne Observatory (Fig. 17.3). By this time Melbourne wallowed in the extravagances of the Victorian gold rush, and as one of the richest metropolises in the world could afford the very best of instrumentation for its new scientific institution. Initially the plan was to accept the generous offer by William Lassell (1799–1880) of his 48-in. (1.2-m) equatorially mounted reflector that had been left behind in Malta (Chapman 1988), and although Ellery (1864) familiarized himself with the principles and techniques of stellar spectroscopy so that he could apply them to Lassell's telescope the Colonial Government of the day decided to acquire a new instrument instead. They then commissioned the Irish firm of Thomas Grubb and Sons to manufacture a 48-in. (1.2-m) equatorially mounted Cassegrainian reflector (Gascoigne 1996; Gillespie 2011b; Perdrix 1992).

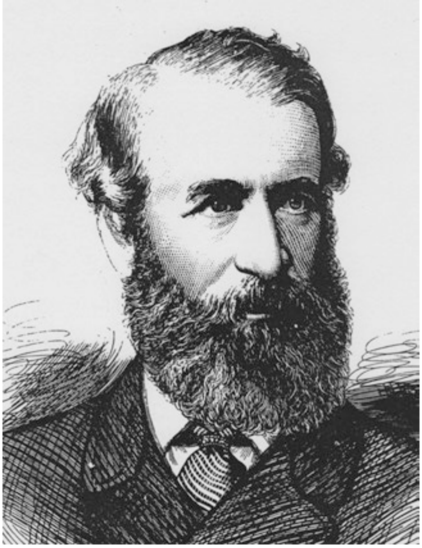

Fig. 17.2 Robert Lewis John Ellery (after Gascoigne 1992)

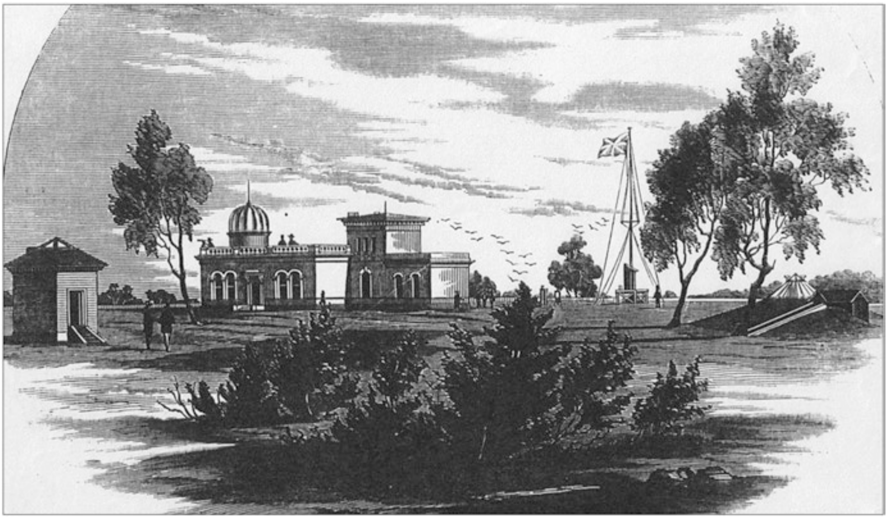

Fig. 17.3 A woodcut showing Melbourne Observatory in 1863 (after New Observatory 1863)

Grubb's most ambitious telescope (see Glass 1997) was the 'Great Melbourne Telescope' (henceforth 'GMT'), which featured two speculum primary mirrors (one for use while the other was being repolished); a primary mirror cell containing two mirror-support mechanisms invented by Grubb; a speculum secondary mirror 8.05-in. (20.45-cm) in aperture; a long steel tube, most of which was an innovative open-lattice construction; a 4-in. (10.2-cm) achromatic finder mounted at the bottom end of the tube; a massive English equatorial mounting, engineered with such precision that the entire telescope could easily be moved by hand; and the all-important clock-drive, complete with slow motion controls (Robinson and Grubb 1869). The completed telescope was an impressive-looking instrument, and is shown in Fig. 17.4.

Once assembled in Melbourne it was housed in a distinctive rectangular observatory building which contained the 'telescope room' or GMT Chamber; a small darkroom in its south-eastern corner for developing the photographic plates; south of the GMT Chamber a room for Grubb's mirror-polishing machine, and then a small adjacent boiler room; a large 'working room'; and an adjoining office for the observer. The GMT Chamber contained a roll-off roof, which allowed the telescope access to the entire sky but also exposed it to any prevailing wind. Fortunately, light pollution from the nearby city of Melbourne was not yet an issue. Gillespie (2011b: 63) remarks that this observatory building "… was a huge step forward from the telescopes of the Herschels, Rosse or Lassell, which had been [completely] exposed to the elements." The completed GMT was Grubb's (1870) pride and joy, and as the largest fully steerable telescope in the world great things were expected of it, especially when used for spectroscopic research.

Fig. 17.4 The Great Melbourne Telescope. The man in the photograph is probably Joseph Turner, the third GMT Observer, and if so the date of the photograph cannot be later than early August 1883 (*Courtesy* Museum Victoria)

The spectroscope supplied by Grubb with the telescope fitted conveniently into drawtube eyepiece adapter in the middle of the primary mirror cell, and was designed to be used for observing nebulae and stars. However, the great image scale of the telescope caused difficulties for the observer when the spectroscope was fitted, but the combination also had unprecedented capabilities:

> For spectroscopic work on objects having a sensible diameter, the great telescope itself labours under some disadvantages; the enormous focal length and consequent magnification of the images is a serious inconvenience in the case of faint objects, and may be only partially remedied by a suitable condenser … [On the other hand] This magnifying of the image may, however, in some cases be advantageous: I allude to the possibility thereby afforded of viewing small definite portions of moderately bright objects … (Le Sueur 1869a: 221).

Note that the optional condenser lens could reduce the image scale by a factor of up to three so that the effective focal ratio could be as fast as f/13.6, similar to the values typically used for large refractors at the time. But the description is not clear and the condenser might have been only a cylindrical lens near the spectroscope slit for broadening the spectrum when looking at stellar spectra.

In his report for 1869, Ellery (1869b) described a new spectroscope made in the Observatory workshop, incorporating a 7-prism train by Browning to give a highly dispersed spectrum. This instrument still exists and has no means of attachment to a telescope. It was intended only for laboratory and sunlight observations, indicating Ellery's resolve to do useful astrophysics. It is clear that only the Grubb spectroscope with its original prism was used by Le Sueur with the GMT but after his time it is difficult for us now to identify which of at least three prisms (one flint and two direct-vision) was used for specific celestial observations.[1]

The official 'Observer' appointed to carry out research with the telescope was Albert Le Sueur, a young mathematics graduate and mathematical tutor at Cambridge University who originally hailed from Jersey in the Channel Islands. Le Sueur accepted the GMT observer's position through the Royal Society of London and saw himself as answerable to the Society, but it was the Victorian Government that owned the telescope and employed him as a public servant. As we shall see, this apparent conflict of interest would later prove to be a problem. After his appointment in September 1866 Le Sueur was trained in astronomy at Cambridge University by Professor John Couch Adams (1819–1892; Kollerstrom 2014) and then moved to Kew Observatory where Warren De la Rue taught him the intricacies of astronomical photography (Gillespie 2011b). Le Sueur also visited William Huggins (1824–1910) to discuss techniques for planned spectroscopic observations with the telescope. By mid-1867 he was at Grubb's works in Dublin, participating in the polishing of the mirrors and assisting in the assembly and testing of the telescope (Gillespie 2011b).

In 1868 Le Sueur made the long ocean-voyage out to Australia, and superintended the telescope's installation at Melbourne Observatory under the eyes of Robert Ellery. It was Ellery who noticed that drawings sent from Dublin for the GMT's massive masonry piers were for Dublin's latitude rather than Melbourne's. By April 1869 the incomplete GMT had a brief first light but the labour of weatherproofing it afterwards with heavy tarpaulins was so great that the GMT was not used again until fully assembled in July 1869, after the building had been completed around it.

Differences of opinion soon emerged between Le Sueur and his employer, the Colonial Government, in relation to allowances in lieu of on-site quarters (*The Argus* 1870), and he was caught in a power struggle between the Government in Melbourne and the Royal Society in London. He also identified a number of embarrassing technical deficiencies of the telescope, most of which Grubb and members of the Southern Telescope Committee back in England attributed at best to Le Sueur's youthful inexperience or at worst to his incompetence. Le Sueur eventually found himself in an impossible position and in mid-1870 he tendered his resignation, which was effective on 31 July (see Gillespie 2011b: 67–75 and *The Argus* 1870, for details). Although he was only 26 years of age at the time, in hindsight he

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[1] Several ex-Melbourne Observatory triangular brass cases, formerly glazed for use as liquid prisms, still exist, and they are fitted with pins for automatic alignment and may therefore have been alternatives for the glass prisms in the Browning spectroscope. Anecdotal evidence is that the liquid prisms were part of an instrument called the 'Great Melbourne Spectroscope' but the absence of any mention of this name in Ellery's Annual Reports suggests that it was a failure, presumably because there was no easy way then of overcoming image blur resulting from schlieren in the fluid used, probably carbon bisulphide, which has a large temperature coefficient of refractive index, as well as the desirable large spectral dispersion. Nevertheless the survival of three of the prism cases adds usefully to knowledge of the instruments used or tried for early astrophysical work in Australia.

was probably the most capable researcher of all of the early users of the Great Melbourne Telescope at Melbourne. Apart from a brief 'first light' in April 1869, Le Sueur's observations took place only between July 1869 and 13 August 1870 (Le Sueur 1869a, 1871), and even then he was an unpaid volunteer for the last 2 weeks of this period. His spectroscopic observations included published accounts of the Orion Nebula (M42), 30 Doradus, η Argus (now η Carinae) and its surrounding nebula and Jupiter. These are discussed below.

17.3.1.1 The Orion Nebula

The (Great) Orion Nebula was the first gaseous nebula to be observed spectroscopically with the GMT, in 1869:

> The three lines are plainly and less conspicuously seen; the hydrogen line is comparatively much fainter than I had anticipated, and disappears in the fainter portions of the nebula. (Le Sueur 1869a: 221–222).

Writing soon after, Le Sueur (1869b: 242–243; his italics) reports that

> In one particular instance the observations of the nebula in Orion are not void of interest; they show distinctly that considerable nebulosity exists *within* and about the trapezium …
>
> [Moreover, visual observations] indicate a positive though comparatively faint nebulosity within and about the trapezium … the spectroscope, however, shows with much force that this nebulosity not only exists, but is comparable in brightness to that surrounding the trapezium at some distance,—the brightest part of the nebula in fact; and therefore that, in ordinary observation, the faintness or apparent complete absence of nebula is mainly due to the disturbing brightness of the four stars, and not to any intrinsic extreme faintness or absolute vacuity.

In a follow-up paper, Le Sueur (1869c) confirmed the existence of nebulous material within the Trapezium, based upon further spectroscopic observations. But countless photographs made subsequently refute his claim that the darkness of the Trapezium area is mostly a visual effect, as nebulosity in and around the Trapezium can be seen on good images with a large plate scale (e.g. see Malin and Frew 1995: 308–309). The claimed brightness of the emission lines from within the Trapezium is probably an artefact, namely the result of stray light arising from microscopic roughness of the speculum metal surfaces and also from reflections by at least ten non-coated lens surfaces in the optical path. Ellery (1885a) stated that the GMT produced enough scattered light to lighten the dark background of the Trapezium. The GMT relied on eyepiece exit pupil stops to exclude direct skylight in direct visual observation, but no equivalent appears to have been present when Grubb's spectroscope was fitted. Furthermore, the spectroscope had f/4 collimator and telescope objectives, so it was readily able to collect image light scattered by the optics and internal surfaces of the drawtube as well as direct skylight from around the secondary obstruction and form it all into an impure veiling spectrum that would nearly always be too faint by itself to show any colour.

Table 17.2 Identification of the various spectral lines observed by Melbourne Observatory astronomers during the nineteenth century (after Humphreys et al. 2008, p. 1256; Walborn and Liller 1977: 183; Young 1902: 206–207)

Spectral line			
Name	Current identification	λ (Å)	Notes
A	Oxygen (O_2)	7593.7	Named by Fraunhofer
B	Oxygen (O_2)	6867.2	Named by Fraunhofer
C	Hydrogen (Hα)	6562.8	Named by Fraunhofer
C_6			"… a dark nebulous band between C, D …"
D_1	Sodium (NaI)	5895.9	Named by Fraunhofer
D_2	Sodium (NaI)	5890.0	Named by Fraunhofer
D_3	Helium (HeI)	5875.6	Yellow line very near sodium D_1 and D_2
E	Iron (FeI)	5269.6	Named by Fraunhofer
b_1	Magnesium (MgI)	5183.6	
b_2	Magnesium (MgI)	5172.7	
b_3	Iron (FeII)	5169.1 + 5168.9	
b_4	Magnesium (MgI)	5167.3	
	Iron [FeII]	5158	Forbidden line
	Iron [FeII]	5018	Forbidden line
	Oxygen [OII]	5007	Green 'nitrogen' line; forbidden line
F	Hydrogen (Hγ)	4861.3	Named by Fraunhofer
	Oxygen [OIII]	4959	Forbidden line
G′	Hydrogen (Hβ)	4340.5	Named by Fraunhofer

17.3.1.2 30 Doradus

When first observed spectroscopically, in 1869, this nebula showed

> … the nitrogen line with facility; the second line certainly, but not in all positions, and always with difficulty; the hydrogen line is suspected only. I can see no trace of a continuous spectrum. (Le Sueur 1869a: 222).

The "nitrogen" line referred to by Le Sueur is actually the stronger of the two forbidden lines of doubly ionized oxygen at 5007 Å, and the second line that he observed is the [OIII] line at 4959 Å (cf. Table 17.2). The element responsible for these lines was unknown at the time, and the mystery of these 'nebulium' lines was only solved about 60 years later (Bowen 1927, 1928). See Hearnshaw (1986) for an account of Bowen's work.

As Hearnshaw (1986: 94) reminds us, this observation is significant in that it "... marks the beginning of extragalactic spectroscopy." Note that Le Sueur's observations were only 5 years after Huggins' pioneering observation of the planetary nebula NGC 6543, and only a year after the first spectroscopic observations of nebulae in the southern hemisphere by Lt. John Herschel in 1868 (Herschel 1869).

17.3.1.3 η Argus

The first time the spectroscope was directed to this object, in November 1869, the seeing was unfavourable and only the ‘nitrogen line’ was obvious, with Le Sueur (1869a: 222) noting that “… of the presence or absence of others [emission lines], or a continuous spectrum, I am unable to speak with certainty.” However, improved viewing revealed that the spectrum was “… crossed by *bright lines*.” (Le Sueur 1869c: 245; his italics). To elaborate:

> The mere fact of a bright-line spectrum is not very difficult to ascertain on a good night; for although from faintness of the light the phenomenon is necessarily delicate, yet the bright lines occasionally flash out so sharply that the character of the spectrum cannot be mistaken. The most marked lines I make out to be, if not coincident with, very near to C, D, *b*, F, and the principal green nitrogen line [see Table 17.2]. There are possibly other lines, but those mentioned are the only ones manageable. (Le Sueur 1869c: 245–246).

Le Sueur (1869c: 246) also mentions the problem of obtaining reliable comparison spectra, the spark spectra being so bright that the spectrum of the star was all but invisible. All attempts to reduce the intensity of the spark emission were unsuccessful.

Le Sueur’s reference here (and elsewhere in this chapter) to specific emission lines (e.g., C, D … F) relates to the scheme introduced years earlier by the German scientist Joseph von Fraunhofer (1787–1826; DeKosky 2014) who identified conspicuous emission lines in the solar spectrum (Fraunhofer 1817). His scheme is summarized in Table 17.2 and illustrated in Fig. 17.5, where the letters indicate Fraunhofer (or, in the case of gaseous nebulae, emission) lines. The challenge now is for us to try and identify the various emission and absorption lines observed by Le Sueur and other Melbourne Observatory astronomers with known elements—which is sometimes a non-trivial task.

Le Sueur soon turned his attention to the nebulosity surrounding η Argus:

> I would remark that the very faint nebulosity (if any) in the immediate neighbourhood of the star *η* is incompetent to give a trace of spectral lines with even a wide slit; for a considerable space s. and f. of *η* no lines are at all visible; the nearest nebula bright enough to show a line (the three usual lines are now easily seen on a good night over the brighter parts) is reached in the direction about 45° n. p. from *η* … is little less than one minute [away]. This remark is of some importance … [and] is mentioned at this point to relieve any impression which might arise that the nitrogen line seen on the star spectrum is merely the chief nebula line crossing it. (Le Sueur 1869c: 246).

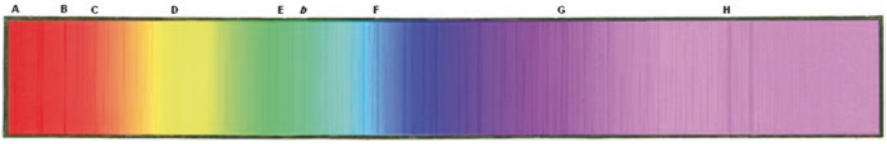

Fig. 17.5 The solar spectrum, and spectral line terminology used by the Melbourne Observatory astronomers (adapted from Pasachoff and Suer 2010: 120)

Returning once more to the star itself, Le Sueur (1872a: 13) provides the following summary: "On the whole, therefore, it would seem that the bright lines seen in the spectrum of *η* Argûs, indicate the presence of hydrogen, nitrogen, sodium, and magnesium." Owing to the faintness of the spectrum, no dark absorption lines were visible, although "… one on the red is strongly suspected, and occasionally there is an appearance as if of a multitude over the spectrum generally, but they refuse to be seen separately and certainly" (Le Sueur 1869c: 247).

In reality, Le Sueur most likely identified Hα, FeII λ5018, FeII λ5169, HeI λ5876 and Hβ in emission (see Walborn and Liller 1977). A sixth line in the blue, possibly Hγ (see Table 17.2), also was strongly suspected (Le Sueur 1872a), as well as a suspicion of numerous absorption lines during good seeing conditions. Further unpublished descriptions by Le Sueur reside in the National Archives of Australia in Canberra (see Frew 2002).

Following Le Sueur's resignation in mid-1870, 33-year old Scottish-born Farie MacGeorge (previously a member of the Victorian Geodetic Survey) took over the post of GMT 'Observer' on 1 August 1870 and for a couple of weeks he used the telescope under Albert Le Sueur's expert guidance "… so that he could learn the intricacies of the instrument and the research program" (Gillespie 2011b: 89).

On 17 January 1871 MacGeorge claimed that a significant change had occurred in the spectrum of η Argus since Le Sueur's earlier observations:

> *Spectrum* of nebula very faint, with usual lines ghostly and fitful.
>
> Spectrum of *η* hazy and unsatisfactory, with diffused light, although other stars appear distinct enough. Could not see the slightest appearance of bright lines, but fancied I detected with [a] wide slit absorption bands in position of nebular lines, but too chaotic and indistinct for measurement although attempted frequently …
>
> Next evening (18th January) Mr. Ellery confirmed my observations and verified sketch. Neither he nor Professor Smith, who was also present, *recognised* the spectrum of *η* when shown in the telescope as the same which they had seen the year before, and could find no bright lines. I again imagined I saw the same ghosts of absorption lines in the positions of the usual bright lines of the nebula (MacGeorge 1872c; 110; his italics).

After carefully reviewing his observing notes and publications, Gillespie (2011b: 89) concludes that MacGeorge "… was a patient and perceptive observer …", so it appears that he really did observe a change in the spectroscopic appearance of η Argus. While it cannot be ruled out that poor transparency or seeing was a contributing factor, it should be emphasized that Ellery, who was a capable observer in his own right, concurred with MacGeorge. There is no evidence to suggest the speculum mirror had deteriorated at this time, and the detailed descriptions and sketches of the η Argus nebula by MacGeorge indicate that the instrument was in good working order. The implications of these observations are discussed by Smith and Frew (2011), and also below (albeit briefly) in Section 17.5.

MacGeorge also had a short incumbency as the GMT Observer, resigning from Melbourne Observatory for private reasons: he was committed to spiritualism and the evening observing sessions at Melbourne Observatory prevented him from attending séances with his wife! Gillespie (2011b: 94) explains that MacGeorge

> … was seeking a greater understanding of the universe than he could find in the eyepiece of the telescope. [Furthermore] … He never seems to have considered himself a fully-fledged astronomer. Even while employed as the observer on the great telescope, he gave his occupation on his marriage certificate as 'civil engineer'.

Nonetheless, on 2 October 1872 he penned a letter to Ellery which included the following remarks about spectroscopic observations of η Argus that he had made:

> … in my notebook … in several places the spectrum of η itself as seen through a newly adapted spectrometer, is described. Several bright lines appear to relieve themselves from the general spectrum. With this spectrometer the lines of the nebula itself are also more distinct and measurable than with the Grubb spectroscopes, on account of the long collimator now used which allows a wider slit with equal definition (MacGeorge 1872a).

This letter is important on two counts. Firstly, MacGeorge's description suggests that emission lines were once again visible. Secondly, the letter indicates that by 1872 a new spectroscope—of unknown origin—was in use, and that prior to this more than one Grubb spectroscope was used with the GMT. We do know that the short collimator of the original Grubb spectroscope was badly mismatched to the GMT's f/41 even when the condenser was used, and this mismatch must have seriously compromised the spectral resolution. But this was some years before Lord Rayleigh's great advances in the theory of spectroscopic resolution, and so was not understood when MacGeorge was writing.

News of the Melbourne Observatory spectroscopic observations of η Argus reached Sydney Observatory Director, Henry Chamberlain Russell (1836–1907; Bhathal 1991), and in September 1871 he tried to observe the spectra of η Argus and its nebula with the Observatory's 7.25-in. (18.4-cm) Merz refractor. He detected the nebula (although he does not describe its spectrum—if indeed one was seen), but was unable to obtain a spectrum of η Argus itself (Russell 1871).[2]

17.3.1.4 The Lunar Crater Aristarchus

Once Farie MacGeorge took over as the GMT 'Observer' it did not take him long to use the telescope also for Solar System spectroscopy. Thus, on 7 December 1870 he observed the lunar crater Aristarchus (see Fig. 17.6) and the

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[2] It is clear from the practical experience of one of the authors (BAJC) in simulating this and other spectroscopic observations of the time with a purpose-built spectroscope on a modern 71.0-cm reflector that the stellar spectrum should have been much easier to observe than the nebular spectrum. The most likely reason for Russell's failure is simply the practical difficulty of getting the star centred on the slit and keeping it there despite the constant tendency for the alignment to be disturbed by shortcomings in the clock drive and mount, and by variations in atmospheric refraction. If the spectroscope is equipped with flat slit jaws that are polished on the input side and there is a means of observing a magnified view of the polished surfaces and the superimposed image, then it is possible to get an initial alignment, but unless a second observer is present to assist, guidance is lost as soon as the observer moves away to the spectroscope eyepiece and regaining alignment quickly becomes unlikely. Of course other techniques are available, such as widening the slit and displacing the slit inside or outside focus. But the guidance problem returns as soon as the system is returned to the optimum settings for observing the stellar spectrum.

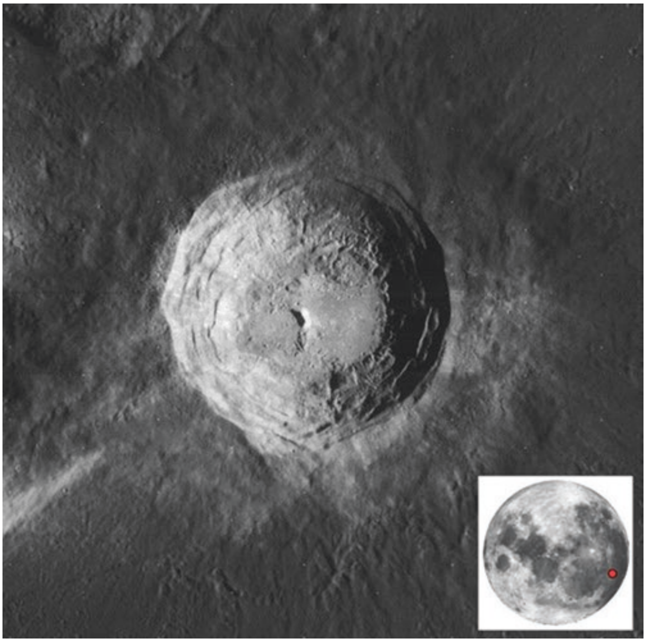

Fig. 17.6 A Lunar Orbiter 4 image of the crater Aristarchus showing the “central hill” and crater rim (“ring”) mentioned by MacGeorge; the *red dot* on the inset photograph shows the location of Aristarchus on the Moon (https://en.wikipedia.org)

> … Spectroscope … shows at same time three spectra—one from the central hill, and one from each side of the ring, side by side, brighter than from rest of moon, yet no lines indicating incandescence, or additional lines beyond those due to the earth’s own atmospheric absorption, as far as I could observe with certainty (MacGeorge 1872b: 68).

17.3.1.5 Jupiter

In reporting for the first time his published spectroscopic observations of Jupiter, which appear to have been made in 1869, Le Sueur (1869b: 243) describes the results as “… if not … important, at least interesting ... the spectrum being considerably bright.” He elaborates:

> The [Fraunhofer absorption] lines G, F, *b*, C, D [see Table 17.2], are seen without the slightest difficulty, C (being near to visible limit) not so readily, but unmistakably, and many other lines with attention. A marked feature is a dark nebulous band between C, D; from measures this turns out to be one of the bands examined by Mr. Huggins, 882 of his scale* (C_6 of Brewster?) (Le Sueur 1869b).

The asterisk in the above quotation mentions that this identification is wrong, as discussed in Le Sueur’s next paper (1869c). Returning to Le Sueur’s 1869b paper, there is further information on the spectrum of Jupiter:

> In the spectrum, G, F, E, D, C_6, C are laid down from the measures on Jupiter. I have called the band between C, D, C_6 for reference purposes [see Table 17.2], subject to rectification … (Le Sueur 1869b: 244).

Le Sueur (1869b: 244–245) continues:

> A point specially aimed at in these observations was to note any peculiarity in the appearance of spectral lines of known atmospheric origin according to the part of the surface viewed.
>
> With the slit perpendicular to Jupiter's equator and the advantage of a large image, an admirable opportunity is afforded of noting the behaviour of the lines as they cross the different parts of the surface, a spectroscopic picture of the planet, as it were, being presented beautifully to the eye.
>
> The nebulous line C_6 was specially and narrowly watched, but without any satisfactory evidence being elicited; as this line crosses the bright band P Q it is perhaps slightly less nebulous …
>
> This almost, if not altogether, complete sameness of the line might perhaps … be accounted for by supposing that the cloud-bands are very near the surface …

Further spectroscopic observations of Jupiter are reported in Le Sueur (1869c: 248–249):

> … the Fraunhofer lines G, F, *b*, E, D are always easily seen, C also easily on a clear night; the lines to which special attention has been directed are the telluric lines 914 and 838 (for convenience of reference I use throughout the numbers in Mr. Huggins's Jupiter and sky diagram). These are the only lines seen with certainty between C and D.

Le Sueur then points out that he earlier misidentified the 914 line with Huggins' 882 line, although he also successfully observed the 882 line on 29 December 1869. In a later paper, Le Sueur (1872b) mentions that observations with the GMT confirmed that Huggins' 838 line was indeed a Jovian absorption line.

17.3.1.6 Saturn

MacGeorge (1872a) is the only one to report spectroscopic observations of Saturn with the Great Melbourne Telescope:

> The new spectroscope shows to me as it does to you [he is addressing his letter to Robert Ellery] a nebulous absorption band on the spectrum of the body of Saturn, which is not visible on the ansae of the ring …

This is the second reference to the "new spectroscope", which appears to be yet another of these instruments, not merely an existing one with a new prism. Clearly there was a degree of enthusiasm for astronomical spectroscopy, judging from the number of spectroscopes already on hand and several more that would be acquired in the decades to come.

17.3.1.7 Comet C/1870 Q1 (Coggia)

Comet (C/1870 Q1 Coggia) was the first comet to appear in Southern skies after erection of the GMT in Melbourne, and in August 1870 spectroscopic observations revealed the usual 'comet lines.' Le Sueur and MacGeorge noted that there was one

Fig. 17.7 A photograph of The Great Comet of 1882 (C/1882 R1) taken at the Royal Observatory, Cape of Good Hope (https://en.wikipedia.org)

faint band about midway between the F line and the b groups (close to the position of the brightest of the 'nitrogen lines'), and on either side of this band they once or twice glimpsed still-fainter bands (MacGeorge 1872b: 65).

17.3.1.8 Comet C/1882 R1 (Great Comet)

Comet C/1882 R1 was one of the most magnificent Great Comets of the nineteenth century, and is famous for the photograph of it—along with images of many stars invisible to the naked eye—obtained at the Royal Observatory, Cape of Good Hope near Cape Town, South Africa (see Fig. 17.7).

The GMT also was used to subject this comet to spectroscopic scrutiny, and the usual carbon lines were clearly visible (Notes from the Observatory 1882). At a meeting of the Royal Society of Victoria, Robert Ellery elaborated:

> The spectrum I found to consist of a moderately bright continuous spectrum, crossed by three broad bright bands, approximate wave lengths of whose centres were 5605, 5070 and 4720, respectively. These bands were very bright in the nucleus itself, and could be well seen anywhere near the head of the comet, and traced faintly over a part of the tail for some distance from the head. In the spectrum of Well's Comet of 1881 several observers saw the well-known D line due to sodium—as far as I know a unique instance in the case of cometic spectra. I examined carefully for any indication of this line in the present comet, but could discover no trace (Royal Society of Victoria 1882).

For spectroscopic observations of comets carried out by other Australian astronomers see Sects. 17.3.4 and 17.4 below.

17.3.1.9 Concluding Remarks

Although Observatory Director Robert Ellery would later carry out spectroscopic observations of γ Argus on two nights towards the end of 1878 (Ellery 1879b), Farie MacGeorge would prove to be the last GMT Observer to conduct on-going serious spectroscopic observations with the GMT. His successor, Joseph Turner (1825–1883), was a professional photographer by trade so it is no surprise that he was committed to using photography rather than spectroscopy with the great telescope. Then Pietro Baracchi (1851–1926; Perdrix 1979) took over following Turner's death in 1883, but the condition of the primary and secondary mirrors continued to deteriorate preventing further spectroscopic work. After several abortive attempts by a noted local amateur telescope-maker, Captain Henry Evans Baker (1816–1890), to repolish the primary mirror, Ellery and Baracchi successfully took on the task themselves, and by the end of 1890 the telescope was once more in excellent working order. Ellery confidently stated in his *Annual Report* for 1890 that the GMT was now "… ready to complete the revision of the southern nebulae *and begin a new project on stellar spectroscopy*." (cited in Gillespie 2011b: 114; our italics). However, this ambitious plan never came to fruition as the Great Depression of the early 1890s impacted drastically on funding and staffing levels at the Observatory. The year 1891 also marked the start of the Observatory's involvement in the international Astrographic Catalogue and Carte du Ciel project, which for years to come would continue to drain the depleted resources of the Observatory. Spectroscopic research with the GMT had come to an end.

17.3.2 Stellar Spectroscopic Studies Carried Out at Melbourne Observatory with the 8-in. Refractor

Melbourne Observatory Director, Robert Ellery, and his ultimate successor, Pietro Baracchi (Fig. 17.8), both embarked on preliminary stellar spectroscopic forays in the late 1880s, but using a Maclean direct-vision on the Observatory's 8-in. (20.3-cm) Troughton and Simms refractor (Fig. 17.9) rather than the GMT.[3] This much

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[3] In his otherwise masterful *The Analysis of Starlight. One Hundred and Fifty Years of Astronomical Spectroscopy*, Hearnshaw (1986: 95) mistakenly assigns these observations by Ellery and Baracchi to the GMT instead of the Observatory's 8-in. refractor, and he then uses the fifth magnitude limit of the observations to denigrate the GMT's performance:

> The spectra of 200 stars were described, but the quality of the results was poor. With such a large telescope the practical limit for spectroscopic work was only about fifth magnitude, which tends to confirm the well-known fact that this telescope was largely a failure.

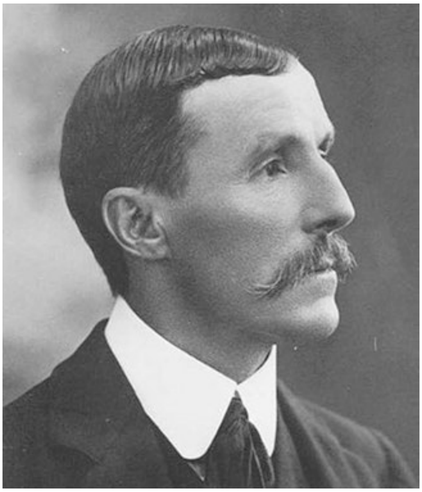

Fig. 17.8 Pietro Baracchi (https://en.wikipedia.org)

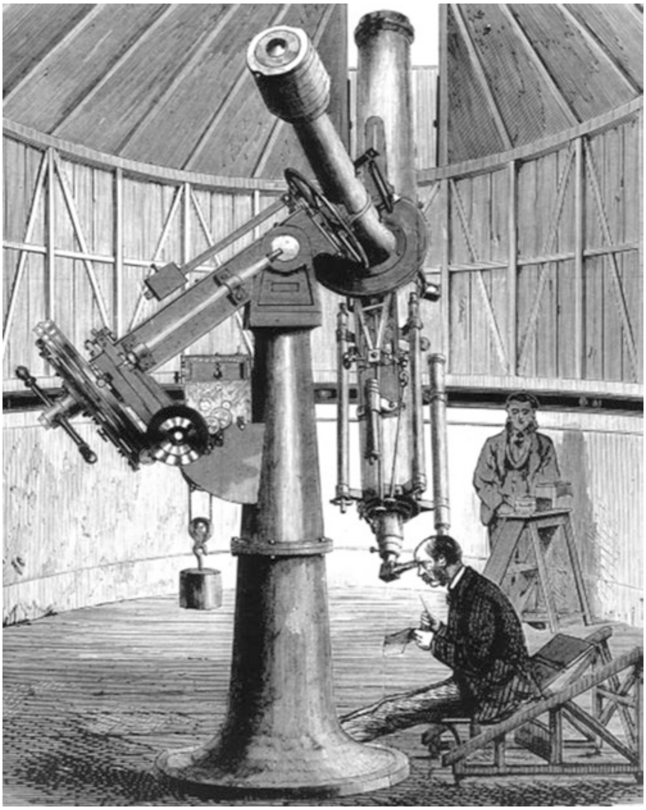

Fig. 17.9 A sketch of Ellery using the 8-in. Troughton & Simms refractor during the observation of the 1874 transit of Venus (*The Australasian Sketcher* 1874)

smaller telescope was chosen because it was (and still is) easy and quick to manoeuvre around the sky and—unlike the GMT—did not need the assistance of an attendant. But as the refractor has an achromatic doublet objective, its secondary spectrum causes the width of stellar spectra to vary with wavelength. At the best setting, the width is greatest at the ends and middle of the spectrum and least at two positions in between, at or near the C and F wavelengths. The effect can be largely overcome by making the spectra broader. This reduces their luminance but has to be done anyway to allow the spectral lines to be seen. Furthermore, the spectra have the variation in angular dispersion found with prism dispersing elements: the width at the violet end made fainter by the increased dispersion and the red end brightened by the reduced dispersion. These artifacts would have increased the difficulty that Baracchi and Ellery encountered in trying to assign spectral classes to the stars they observed.

The surveys conducted independently by Baracchi and Ellery were both completed by 1889 and published in two papers in *Monthly Notices of the Royal Astronomical Society* (see Ellery 1889a; Baracchi 1889). In 2006, two of the authors of this chapter summarized this work in a short paper published in the *Anglo-Australian Observatory Newsletter* (Andropoulos and Orchiston 2006), and the following overview largely is taken from that account.

Collectively, Ellery's and Baracchi's surveys involved 200 stars, but only nine of these were common to both surveys. Seventy-five of the stars showed continuous spectra, and the predominant colours were blue and green; violet was rarely seen, presumably because of the greatly increased dispersion there, along with the tendency of highly dispersive glasses to absorb violet light. About 40 of the remaining stars revealed spectra with some combination of very faint C, D, F and G Fraunhofer lines; many of these stars appeared to be white or yellow. The remaining 85 stars had Fraunhofer lines and bands in their spectra, and Ellery and Baracchi made most frequent mention of the F, G and C lines, but the E, b, H and D lines (Table 17.2) were sometimes referred to. It was also noted that γ Crucis, 20 Librae, η Sagittarii and δ^2 Gruis had 'flutings' towards the red ends of their spectra.

Although nine stars appeared in both surveys, only three of these (β Lupi, π Scorpii and δ^2 Gruis) produced consistent results. Of the others, Ellery did not include any data for β Centauri in his paper, while he and Baracchi described quite different spectra in the case of the other stars. For instance, Baracchi assigned a continuous spectrum to β Scorpii, while Ellery identified faint lines in the blue and violet. In the case of α Pavonis, Baracchi described a spectrum with dark bands and lines, including a very thick dark band or groups of dark lines far in the violet, and with similar bands near the Fraunhofer G line and a dark band or group of dark lines near the F line. In stark contrast, Ellery reported a spectrum with very faint Fraunhofer lines in the blue, violet, orange and red.

Despite the size of their collective sample, all Ellery and Baracchi could do was describe the spectra they observed. What they did not attempt to do was interpret the spectra in any meaningful way, and this merely reflected the confusing state of spectral classification at that time (see Hearnshaw 1986). In a sense, these two Melbourne astronomers launched their stellar spectroscopic 'careers' at just the wrong moment, for had they waited a few short years they would have had access to Wien's Law.

In 1893 Wilhelm Wien (1864–1928) suggested that the wavelength at which the radiated energy reached a maximum is inversely proportional to the absolute temperature of the radiator:

> The colour of a radiating body is thus a function of its surface temperature. *At a stroke, stellar spectral classification became physically meaningful*. Stars of spectral class M appear to be 'red', K orange, G yellow, F creamy, A white and B and O blue-white, with surface temperatures increasing from 3,000 K to 35,000 K. (Hughes 2005: 108; our italics).

As we noted in Sect. 17.3.2 above, the spectral studies undertaken by Ellery and Baracchi initially were planned as forerunners to a more extensive survey using the Great Melbourne Telescope, but during the turbulent 1890s the afore-mentioned problems in interpreting stellar spectra, staffing shortages at the Observatory and the newly adopted Astrographic Catalogue and Carte du Ciel project all conspired to prevent these laudable plans from coming to fruition.

17.3.3 Spectroscopic Studies of Meteors and Aurorae Carried Out at Melbourne Observatory

Not all of the spectroscopic observations made at Melbourne Observatory were accomplished with telescopic aid. Ellery was keen to investigate the spectra of meteors, but realised that this was an observational challenge, the optimal chance of success being during the Leonid meteor storms which only occurred every 33 years Dick (1998). He was too late for the 1866 storm, and the next one, in 1899, lay far in the future.

He chose therefore to investigate the next best option, the August Perseid meteor shower, and in 1879 made many successful observations:

> Many [shower meteors] exhibited the simple continuous spectrum of an incandescent solid; others have shown bright bands, as if from glowing gas; in others again the sharp bright lines of vapourised metals have been noted, especially those of sodium and magnesium, and indeed of many of the known metals. The evidence furnished by the spectroscope of the nature of shooting stars is therefore somewhat inconclusive, although it places beyond a doubt the fact that they are small solid bodies, chiefly if not altogether composed of substances known upon the Earth, and that on entering the outer regions of the Earth's atmosphere its resistance converts their enormous speed into a heat sufficient to render them incandescent, and sometimes even to vapourise them, the various spectra observed being probably due to the fact that they were seen at different stages of combustion (Notes from the Observatory 1880).

At this time meteor spectroscopy was in its infancy (e.g. see Lovell 1954; Olivier 1925), and it is interesting that Ellery chose to reserve these comments for readers of *The Argus* newspaper, rather than sharing them with astronomers and other scientists by publishing them in an academic journal. At about the same time, Professor Alexander Stewart Herschel (1836–1907; Beech 2014) in England, Miklós Konkoly-Thege (1842–1916; Szabados 2014) in Hungary and Father Angelo Secchi (1818–1878; Cenadelli 2014) in Italy also were conducting visual observations of meteor spectra, and Ellery's observations could have added to their combined findings, which subsequently were summarised by Millman (1932). Furthermore, notwithstanding Melbourne Observatory's success with astronomical photography (see Sects. 17.3.5 and 17.3.7 below), what Ellery apparently did not do was attempt to photograph any meteor spectra, an area of meteor astronomy that only was pioneered in the 1930s by the Canadian astronomer Peter Mackenzie Millman (1906–1990; Tors and Orchiston 2009). Thus, Ellery missed a 'golden opportunity'.

Ellery also was interested in the spectra of other atmospheric phenomena, and on 5 April 1870 he observed an aurora with one of Browning's spectroscopes.

Initially, the spectroscope was pointed at the red streamers, and a red line, less obvious than the C hydrogen line, a greenish line about the position of the green calcium lines, and an indistinct band appeared. The spectroscope then was directed towards the green auroral arch and the red band disappeared and only the green lines remained. Ellery (1871: 280) noted that "… the rapid disappearance of the red line as the slit passed across the boundary between the base of the streamers and the green arch, was remarkable." (cf. Royal Society of Victoria 1870).

17.3.4 Spectroscopic Studies of Comets Carried Out at Sydney Observatory

When Henry Russell (Fig. 17.10) accepted the Directorship of Sydney Observatory in 1870 he inherited an institution (Fig. 17.11) steeped in positional astronomy, largely thanks to the charter developed by its hard-working founding Director, William Scott (see Orchiston 1998b).

Whilst adhering to this well-worn path, Russell also decided occasionally to explore selected side-roads that would lead him in new directions. One of these involved the manufacture of silver-on-glass reflecting telescopes and the design of novel mountings for these instruments. Thus, in 1880 he constructed a 15-in. Newtonian reflector and installed this on a novel version of the English equatorial mounting that is very reminiscent of the distinctive 'horseshoe' mounting designed decades later for the 200-in. (5-m) Palomar Telescope (Orchiston 2000).

The other side-road that Russell chose to explore, in 1881, took him in the direction of cometary spectra at a time when these were little understood. Although it is well known that Giovani Battista Donati (1826–1873; Baum 2014b) carried out the first successful visual observation of a cometary spectrum, of C/1864 N1 (Tempel) in 1864, and between that year and the end of 1880 eighteen different comets were observed spectroscopically (Clerke 1893), prior to 1881 all attention had been directed towards the heads of these objects.

All this changed with the appearance of the Great Comet of 1881 (C/1881 K1 (Tebbutt)), which was discovered by the Australian astronomer, John Tebbutt (1834–1916). Despite his amateur status, Tebbutt was Australia's foremost nineteenth century astronomer (Orchiston 2017), his observational programs and publications far surpassing those of his professional colleagues at the government observatories in Sydney, Melbourne and Adelaide (see Orchiston 2004a).

Fig. 17.10 Henry Chamberlain Russell (Orchiston Collection)

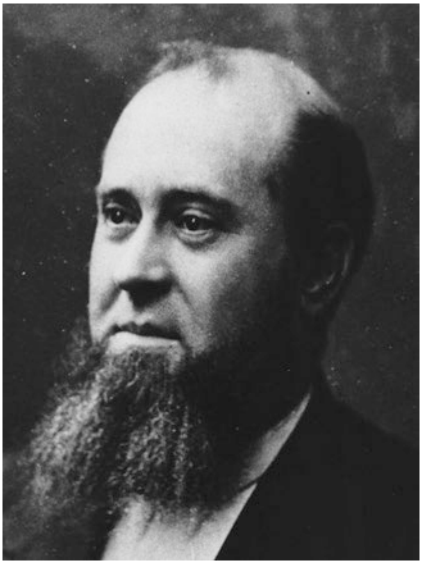

Fig. 17.11 Sydney Observatory in the 1870s (*Courtesy* Dr. Harley Wood)

Tebbutt's well-equipped Windsor Observatory (Orchiston 2001) was located near Sydney, and he and Russell originally were close friends, but the relationship was becoming strained by the time comet C/1881 K1 (Tebbutt) made its presence known (for details see Orchiston 2002b, 2017: Chap. 12). Here was an excellent opportunity for Russell to excel.

The brightest and most majestic comet since the advent of C/1874 H1 (Coggia), C/1881 K1 (Tebbutt) appeared at a particularly fortuitous time, when photography and spectroscopy were making their mark in astronomy (Orchiston 1999). On 6 June 1881 Russell inserted a Browning direct vision spectroscope at the tail end of Sydney Observatory's 11.5-in. (29.2-cm) Schroeder refractor (Fig. 17.12) and pointed the telescope at the new comet. This is what he saw:

> Turning the telescope so that the slit of the spectroscope received light from the tail of the comet, I found it was too faint to give a visible spectrum, and I could not see any until parts near the head were brought upon the slit, when three bright lines became visible. Getting nearer the nucleus a faint continuous spectrum was visible, crossed by three bright lines, but in the faint grey continuous spectrum I could not see any dark lines. The three lines were not sharply defined, but were sufficiently so to admit of good measures of the centre of each. The middle line was by far the brightest; the next in brilliance was in the yellow, and the third and faintest was in the violet. The whole of this spectrum increased in brightness as the slit approached the nucleus, but when the nucleus itself was on the slit all the additional light seemed concentrated in the middle of the B line until it shone almost like a star, and quite as bright as the nucleus itself, proving that its light is monochromatic. Even in the brightest part of the comet I was unable to see any dark lines in the continuous spectrum (Russell 1881: 81).

Fig. 17.12 The 11.5-in. Schroeder refractor at Sydney Observatory (*Courtesy* Dr. Harley Wood)

At this time, Russell was actively promoting the Royal Society of New South Wales and its Astronomical Section (see Orchiston and Bhathal 1991) and so he chose to publish his results in the Society's journal instead of an international astronomical journal. Because of this decision these important observations lacked visibility and never reached the international astronomical audience that they deserved.

After Comet C/1881 K1 (Tebbutt) moved into northern skies it was observed at a number of professional and amateur observatories, but more importantly, it was the first comet for which successful photographs of the spectrum were obtained (all previous spectroscopic observations of comets having been made visually). The photographs in question were taken by the British astronomical pioneer, William Huggins, on 24 and 25 June, and by the American, Dr. Henry Draper (1837–1882), on an unspecified date, or dates, after 24 June.

Huggins (1881a: 233) describes his results obtained after a 1-h exposure in 24 June:

> The spectrum of the comet consists of a pair of bright lines in the ultra-violet region, and a continuous spectrum which can be traced from about F to some distance beyond H.
>
> The bright lines, a little distance beyond H, with an approximate wave-length from 3870 to 3890, appear to belong to the spectrum of carbon [see Table 17.2] …
>
> In the continuous spectrum shown in the photograph, the dark lines of Fraunhofer can be seen.

This spectrogram is reproduced here in Fig. 17.13. The two bright lines and the continuous spectrum seen on 24 June were also visible on the photograph obtained on 25 June, and Huggins (1881b) concluded that "This photographic evidence supports the results I obtained in 1868, showing that comets shine partly by reflected solar light; and partly by their own light …"

Draper's results mirrored those obtained by Huggins. In all, he obtained three photographs of the comet's spectrum, using exposures of 180 min, 196 min and 228 min. In each, "The continuous spectrum of the nucleus was plainly seen … [but] the most striking feature is a heavy band above H which is divisible into lines, one between G and *h* and another between *h* and H [see Table 17.2]" (Draper 1881: 252–253).

It is noteworthy that the spectra depicted in these photographs differ in subtle ways from the spectrum observed visually by Russell several weeks earlier. Whether this is because Russell was a complete novice when it came to cometary spectroscopy or whether it reflected the different spectral state of the comet at this earlier time has yet to be determined.

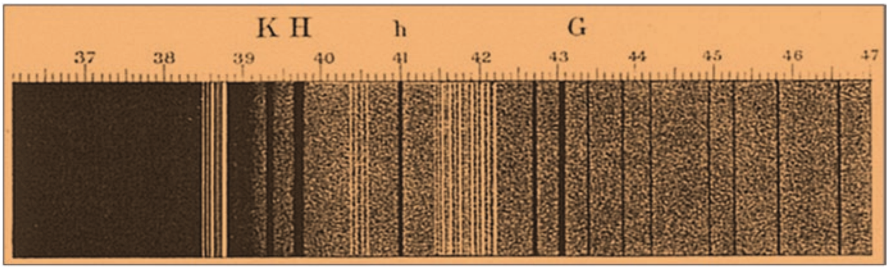

Fig. 17.13 One of Huggins' spectrograms of Comet C/1881 K1 (Tebbutt) (after Huggins 1881b)

Be that as it may, in 1964 Vsekhsvyatskii summarized the various published spectral observations of this comet, starting on 22 June:

> 22 June the nucleus showed an intense continuous spectrum without dark lines (molecular emission); in the envelope, there were traces of bright bands; 25 June, diffuse green and blue bands were observed in the bright continuous background; 29 June, the three common bands were in the intensity ratio 1:5:2; the yellow band was the faintest; 30 June, a well-developed band spectrum of three bands; two additional bands were also reported. Through a high low-power instrument all parts of the comet and the tail over a considerable distance clearly showed a band spectrum. Polarized light emitted by the head. 5 July, the continuous spectrum of the nucleus grew fainter; the bands were quickly visible. (Vsekhsvyatskii 1964: 259, Note 46).

Note that because of the inappropriate journal in which they appeared, Russell's earlier observations were missed by Vsekhsvyatskii and do not form part of his review.

The above account clearly reveals the two major components of most cometary spectra:

1. The continuous spectrum, usually with Fraunhofer lines, which is produced by reflected sunlight; and
2. The bright 'hydrocarbon bands' that are produced by the gases from the comet itself. Only comparatively recently has it been possible to assign specific molecules to the different bands (e.g. see Jackson 1982).

This bipolar classification is taken for granted today, but it was far from obvious in the late nineteenth century. For example, in the first of two papers about Comet C/1881 K1 (Tebbutt) published in *The Observatory* the distinguished US astronomer, Charles Young (1834–1908; Habashi 2014), comments on point 2. above: "We thus have almost overpowering evidence that the gaseous substance of this comet is a hydro-carbon and in a molecular state …" (Young 1881a: 257). However, the state of cometary spectroscopy at this time is revealed when we consider the following comment, which appeared in his second paper, penned less than a week later:

> The spectrum of one of the jets which issue from the nucleus was isolated on June 29th, and found to be continuous. I think this was usually the case with the jets; but it is seldom possible to separate the spectrum of a jet from that of nucleus sufficiently to be perfectly sure (Young 1881b: 284).

Jets should display spectra dominated by hydrocarbon bands, and Sydney Observatory's Henry Russell was merely one of a number of astronomers worldwide who contributed to the confusing status of cometary spectroscopy in the late nineteenth century.

17.3.5 Astronomical Photography Carried Out at Melbourne Observatory with the 'Great Melbourne Telescope'

The Great Melbourne Telescope (GMT) was intended primarily for visual and spectroscopic observations, but one of the members of the Southern Telescope Committee set up by the British Association and Royal Society of London to oversee the development of the GMT was the pioneering celestial photographer Warren De la Rue (1815–1889), and he was particularly keen to see that the telescope also was used for photographic work (De la Rue 1872). However, others perceived the photographic role of the GMT to be limited. For example, Thomas Romney Robinson (1792–1882; Elliott 2014b), Director of Armagh Observatory, and the distinguished Irish amateur and maker of giant reflecting telescopes, Lord William Parsons, the Third Earl of Rosse (1800–1867; Elliott 2014a), both believed

> … that photographic work was a secondary issue. Photography would primarily be used for the Moon, while the main work of the telescope would depend on eyepiece observations of the nebulae, or on spectroscopic analysis. This was where the telescope could make real achievements (Gillespie 2011b: 56).

As we shall see, this would prove to be a somewhat myopic view of the telescope's full potential when applied to photography.

However, the actual design of the telescope created some problems if it was to be used for successful astronomical photography. Firstly, while spectroscopic observations could be conducted conveniently from the secondary (Cassegrainian) focus, all photographic observations had to be made at the primary focus. The problem was that this point was located beyond the upper end of the lattice tube of the telescope, so a specially designed plate assembly had to be constructed and installed. Access to this photographic plate assembly also was an issue, and was achieved via a wooden platform that was erected in 1871 beyond the northern end of the 'telescope room' (see Fig. 17.14). A second problem encountered when attempting photography with the GMT was wind, which was prevalent at Melbourne's southern latitude of 37° 45′. Because the telescope was fully exposed to the elements, the slightest wind caused the lattice tube to vibrate which impacted drastically on the quality of the time-exposure photographic image.

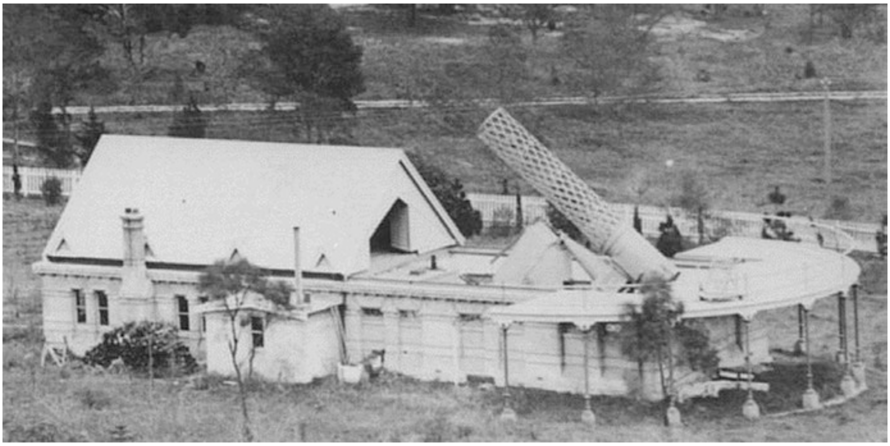

Fig. 17.14 The roll-off roof observatory of the GMT, showing the curved wooden platform erected at the *right-hand* (north) end of the building that allowed access to the camera used during prime focus photography with the GMT (Orchiston Collection)

Therefore, photography could only be accomplished when the atmosphere was still, but even then the accuracy of the drive restricted the efforts of the astronomers to relative short exposures.

Despite these shortcomings, successful photography was achieved with the GMT, but only after Farie MacGeorge succeeded Albert Le Sueur as the 'GMT Observer'. The Royal Society Committee had ordered suitable photographic apparatus from Howard Grubb (Ellery 1872), and this finally reached Melbourne Observatory in late 1871 and was installed atop the great telescope:

> At the top end of the telescope, a steel frame supported a glass plate holder and device for adjusting the focus. The glass photographic plate sat about two feet beyond the mouth of the telescope [but] … The shutter could be operated from the eye end of the telescope (Gillespie 2011b: 94).

Ellery and MacGeorge began by taking a photograph of the Moon, and were so impressed with the result that Ellery sent a copy to De la Rue, who

> … pronounced in *Nature* that it was excellent, although characteristically found it not quite as good as the ones he had taken. [Nonetheless,] The photograph was framed and hung in the meeting rooms of the Royal Astronomical Society (Gillespie 2011b).

In spite of this auspicious start, MacGeorge chose to focus on visual and spectroscopic observations with the GMT, and it was only when Joseph Turner took over as the 'Observer' in the closing months of 1872 that the telescope really came to the fore as a photographic instrument. This was undoubtedly because of Turner's unusual, yet particularly appropriate, background:

> Joseph Turner had been born in southwest Scotland, worked as a lithographer in Glasgow, developed an interest in grinding his own glass specula for small reflecting telescopes, and apparently made a telescope for John Nichol, the professor of astronomy at Glasgow University. In 1852, at the age of 27, he set sail for Victoria, settling in Geelong, where he established a small observatory and seems to have earned an income by regulating ships' chronometers, constructing sundials for wealthy farmers and giving lectures. This may not have been the most lucrative employment, *so Turner established a photographic studio. By the 1860s Turner's Portrait Rooms was one of the main studios in Geelong* … (Gillespie 2011b: 95; our italics).

However, these positive attributes should not blind us to Turner's shortcomings, as he was not highly educated and he lacked any knowledge of mathematics or astronomy. After MacGeorge left, Turner was one of four candidates short-listed for the post of GMT Observer but before they could be evaluated using the GMT the Victoria Chief Secretary intervened and unilaterally appointed Turner (Gillespie 2011b)! Nonetheless, Turner *was* a skilled photographer, and with his involvement the non-visual focus of the GMT observations soon turned from spectroscopy to photography.

After unsuccessful attempts to photograph the Sun with the GMT, Turner turned his attention to the Moon. Since successful photographs of the Moon were first taken in 1840 by John William Draper (1811–1882; Williams 2014), the Professor of Chemistry at the University of New York, the Moon was no new quarry for astronomical photographers by the time that Turner came on the scene. Nonetheless, his

> … photographic skills came to the fore and he continually improved the sharpness of the images … Turner took his best negatives down to his former photographic rooms in Geelong to print large copies of the photos, and Ellery proudly sent prints to De la Rue, asking him to forward them to Robinson, Rosse, Airy and others. Lord Rosse exhibited the large print at the annual meeting of the British Association in August 1874, declaring that it was the equal of or better than the best photos yet taken of the Moon (Gillespie 2011b: 104).

The photograph of the Moon that Ellery sent colleagues in England and elsewhere soon became a classic. Large numbers of Turner's lunar photographs were distributed to schools, mechanics institutes and libraries throughout Victoria and sent to newspapers (Ellery 1873), while enlarged prints were sold to the public. A photograph of the 9-day old Moon taken on 1 September 1873 is shown here in Fig. 17.15.

Even more impressive was a photograph of a 4-day old Moon taken on 4 April 1873, which was described as follows in *The Argus* (1873):

> The photograph … is wonderful sharp and clear in outline. Of course only a small portion of the planet is shown, but we never saw a photograph of the kind in which the volcanic condition of the moon was so distinctly and beautifully depicted.

From time to time copies of these historic photographs come on the market, and they are now highly prized and highly priced.

Not content to rest on his 'lunar laurels', Turner eventually turned his attention to nebulae, and in February 1883 he obtained a number of photographs of the central region of the Orion Nebula (M42) which clearly showed the nebulosity around the Trapezium and nearby stars. One of these images is shown here in Fig. 17.16. Ellery was suitably impressed and one of the photographs was promptly dispatched to the Royal Astronomical Society where it was well received. Meanwhile, Turner (1882, 1883) proudly pointed out that this was the first successful image of a nebula obtained in the Southern Hemisphere. It came less than two and a half years after the New York astronomer Dr. Henry Draper (1880) successfully captured the Orion Nebula using dry gelatine plates and an exposure of 50 min (Gingerich 1982).

Turner's observing notebook and diary (1882–1883, 1883) reveal that he and his son also tried to photograph the nebulosity sounding η Argus, but this required a much longer exposure than the mere 4 min used for the Orion Nebula, and even the gentlest wind coupled with slight irregularities in the telescope drive conspired against them. These observations were to be amongst Turner's last for he was suffering from heart failure, and he died on 25 August 1883 (Gillespie 2011b: 111).

17.3.6 Early Photography of Star Fields and Nebulae Carried Out at Sydney Observatory

In 1890 Sydney's Henry Russell experimented with photography using a 6-in. (15.2-cm) Dallmeyer portrait lens mounted on the tube of the 13-in. (33.0-cm) Carte du Ciel astrograph, and began by taking plates of

Fig. 17.15 A GMT photograph of the 9-day old Moon taken by Joseph Turner on 1 September 1873 (*Courtesy* State Library of New South Wales)

Fig. 17.16 One of Turner's photographs of the Trapezium in M42 taken in February 1883 which shows nebulosity (*Courtesy* Museum Victoria)

> … all the bright parts of the Milky Way from 10 hours to 17 hours RA. Also of the Nubeculae Major and Minor, of the bright region in *Sagittarius*, including 8 Messier, and of several other parts (Russell 1890a: 39; his italics).

Among the successful photographs was a 3 h one of the nebula around η Argus, which

> … shows decided indications of structure, and on the south preceding side of *η*, two parallel wreaths of nebulae are distinctly curved … *η* itself seems to be in another spiral wreath, and the faint markings taken together suggest a structure something like that of the spiral nebula, H 1173 … It is remarkable how slow this nebula [i.e. *η* Argus] is in fixing its image on the sensitive plate. I have often tried before with other instruments, but always failed to get any trace of the nebulous light on the plate (Russell 1890a).

Ellery also commented on this phenomenon, and correctly concluded that the nebula's emission wavelength (which we know now to be Hα) was in a spectral region outside the film's response.

Subsequently, Russell (1891: 494) took an 8 h exposure of the Milky Way in the vicinity of η Argus, where "… the nebula itself is much brighter, and the details more defined, the outlying wreaths of nebula extending over a much wider space than has appeared in any drawing or previous photograph." (see Fig. 17.17). So, Russell was aware that his photograph covered a much larger area than the sketches in question. What he did not do is work out exactly how much larger it was. If he had, he would have realised that his photograph could not and did not show enough detail in the Keyhole region for any valid comparison to be made.

Russell was happy to expound on the apparently clear differences that his photographs revealed when compared with Herschel's drawing from the 1830s, which only served to reinforce the views published earlier by Le Sueur (1869c, 1872a) and MacGeorge (1872c), and documented by Turner (see Gillespie 2011b: 102–103),

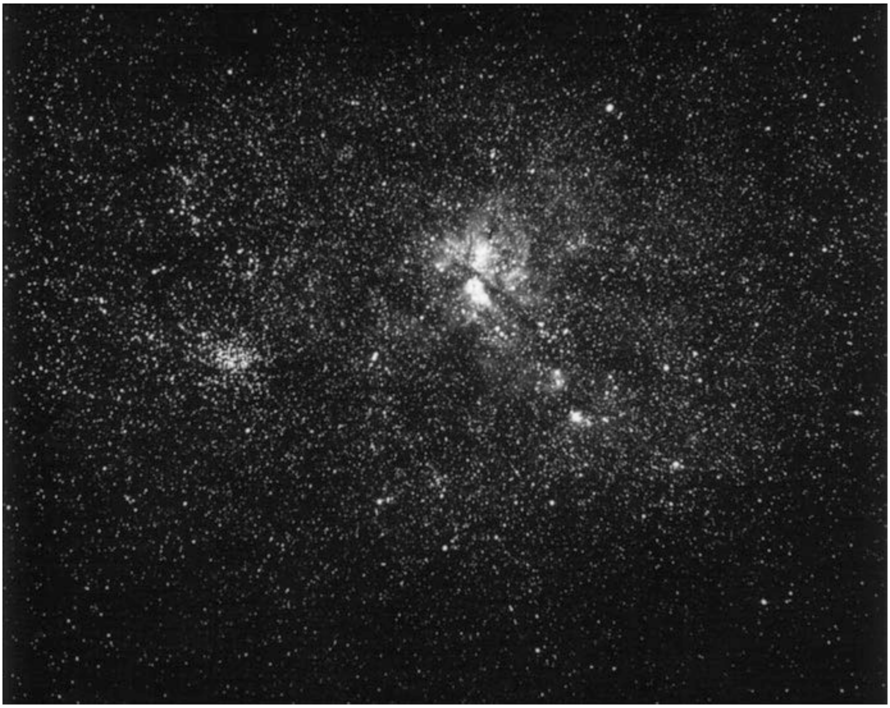

Fig. 17.17 Part of Henry Russell's 1891 photograph of the Milky Way in the vicinity of η Argus (*Courtesy* Dr. Harley Wood)

based on visual observations made with the GMT (see, also, Robinson 1869). Russell's photographs also apparently vindicated Abbott's conviction that the nebula had undergone a change in form, but this seemingly indisputable photographic validation came a little too late as both Abbott and Herschel were dead (see Frew and Orchiston 2003).

From a modern perspective we know that there are effectively no visually detectable changes in nebulae over decades. Those drawing the Keyhole Nebula were working at the limits of human vision, and it appears that Le Sueur's first drawings of the Keyhole were based more on Herschel's earlier quick sketch rather than what must have been visible through the GMT. Meanwhile, MacGeorge's sixth and last sketch of the Keyhole and surrounds is a remarkably accurate portrayal of what a photograph shows when the colour and contrast are manipulated to simulate the overall visual appearance. We believe that if MacGeorge had decided to stay at Melbourne Observatory and kept on making sketches of this quality over several years the case for huge changes would have been dismissed. However, the situation is different for η Argus itself, given the known remarkable growth of the Homunculus since the 1870s.

Russell did not comment on these issues; rather, he was preoccupied with spiral structure, and was convinced that "… a longer exposure will reveal additional evidence of the spiral character of the nebula." (Russell 1890a: 40).

Upon examining other photographs that he took of the southern Milky Way, Russell (1890a; his italics) was again able to emphasize their superiority over even the best of drawings:

> For instance, the boundary, as shown by the two methods, is alike between η and θ *Argûs*, but to the north of η it stretches out far beyond the limit given in drawings. It will be seen, also, that the whole of the stars in the Cross are fully involved in the Milky Way, and the Coal Sack, instead of being a closed space is seen to be open on the south side … It also appears that stars are very numerous over three-fourths of it, and that it is only in the extreme north of it that we find that absence of stars which would justify the name … Altogether, a photograph conveys a picture of the Coal Sack very different from the drawings.
>
> … these pictures present the Milky Way in an entirely new light, quite different from the telescopic or naked-eye view …

It was these sorts of perceptive comments that underpinned the use of photography as an essential tool of astrophysics.

Later in the same paper, Russell returns to the concept of 'spiral structure', but this time in the context of the Large Magellanic Cloud (LMC). In September 1890 he experimented with successively longer exposures and when he examined the negative of a 4.5 h exposure obtained on 18 September he saw

> … the spiral structure of the whole, which became evident as soon as a silver print was made. In fact, the whole of this great cloud is a complex spiral nebula with two centres, if I may so express it. One of these is midway between 30 Doradûs and the 6th mag. star at R.A. $5^h\ 23^m$, and 158° 48′ N.P.D. An examination of the positive and silver prints will show the spiral arrangement of stars and nebula and a dark band surrounding this space. The other centre is about two degrees north of this and in the same R.A.
>
> So far as I am aware the spiral structure of the Nubecula Major is shown for the first time in these photographs (Russell 1890a: 41).

On 17 October Russell was able to obtain an image of the LMC with an exposure of 7 h 3 min, which

> … brings out in a still more remarkable manner the spiral structure of this wonderful object … Each increase in the time of exposure brings out new details … all helping to indicate more and more clearly its spiral character (Russell 1890b: 97).

Part of a photograph of the LMC that Russell took in 1891 is reproduced here as Fig. 17.18.

In marked contrast, the first photographs Russell took of the Small Magellanic Cloud showed no indication of spiral structure, but rather "… a form something like the Dumb-bell nebula." Russell (1890a: 42), but a later image, taken on the night of 14–15 October 1890 with an exposure of 8 h, "… brings out clearly the spiral character of this object, and its general similarity in form to the *Nubecula Major*." (Russell 1890b: 97; his italics).

Another prominent astronomical object that Russell subjected to photographic scrutiny was the Orion Nebula. In October 1890 he exposed a plate for 4 h, and the greatly over-exposed negative revealed

> … folds of the nebula extending to the bright star ι. When developed, and before the intensifying solutions were applied, the negative was full of most beautiful detail of the central

Fig. 17.18 Part of a photograph showing the LMC that Russell took in 1891 (*Courtesy* Dr. Harley Wood)

> part of the nebula … The outer folds of the nebula shown here extend beyond those shown in any other photograph I have seen … (Russell 1890b: 97).

This photograph shows considerably more detail than the image of the Orion Nebula that Turner obtained with the GMT in February 1883, and reveals the intricate nature of the nebulosity.

We see that Russell's initial forays into astronomical photography did contribute to astrophysics by throwing new light on the Orion Nebula, the nebulosity surrounding η Argus and both Magellanic Clouds, but his subsequent use of photography—much like its application during the nineteenth century transits of Venus—was in the service of positional astronomy. This came in the guise of the Carte du Ciel Project, an ambitious program designed to photographically document all stars in the sky down to the 14th magnitude (see Turner 1912). Melbourne and Sydney Observatories were initial participants in this international collaboration from its launch in 1890, and following its founding in 1896 Perth Observatory also joined the program (White 1988). All three observatories used 13-in. (33.0-cm) optically identical astrographs, supplemented in Melbourne and Perth by 10.25-in. (26-cm) telescopes used visually for guiding during photography, mounted side-by-side on the same equatorial mounting. In Sydney, Russell merely ordered the 13-in. objective from Grubb and then assembled the astrograph himself, using the Observatory's old

Mertz 7.25-in. (18.4-cm) refractor as its guide-scope. Because of its perceived non-astrophysical dimensions as seen at the time, the Carte du Ciel program will not be examined here.[4]

17.3.7 Solar Photography

One of the distinctive instruments obtained by Melbourne Observatory specifically for the 1874 transit of Venus was an equatorially mounted clock-driven 4-in. (10.2-cm) f/15 Dallmeyer photoheliograph (see Fig. 17.19).

> After the transit,… the photoheliograph continued in daily use to photograph the Sun, weather permitting, from 1874 to 1895. Dry plates were introduced in 1883. Accumulated negatives were sent to London in 1885 March, arriving with only 13 of the 1712 plates broken … After 1914, surviving records from the Melbourne Observatory are sparse. However, solar photographs from Mauritius, Dehra Dun, Melbourne and Harvard were used to fill gaps in order to get an almost unbroken record for the Greenwich photoheliograph study … that produced the famous 'Butterfly Diagram' showing the change in sunspot latitudes as the 11-year cycle progressed … (Clark and Orchiston 2004: 45–46).

The number of plates successfully exposed in each year is listed in Table 17.3 and depended largely upon weather conditions, staffing levels, research priorities and supplies of photographic plates and chemicals at Melbourne Observatory.

17.3.7.1 The Total Solar Eclipse of 11 December 1871

A total eclipse of the Sun took place on 11 December 1871, which was potentially visible from India, Ceylon, the Dutch East Indies and northern Australia.

Following so closely on the heels of the watershed eclipse of 1868 (see Cottam and Orchiston 2015; Launay 2012; Nath 2013; Orchiston and Orchiston 2017; Orchiston et al. 2017) this was a very important event internationally, and a joint expedition was mounted by Melbourne and Sydney Observatories to 'Eclipse Island' in the Claremont Group, just off the east coast of Cape York. The intention was to photograph the corona and examine its spectral properties and determine whether the light from the corona and chromosphere were polarised, but after all the elaborate preparations inclement weather prevented any meaningful observations being made. For a detailed account of this eclipse expedition see Lomb (2016).

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[4] Now, with the benefit of hindsight, we realise that we can use positional and magnitude data drawn from this Project to derive distances and velocities of stars, and thus the dynamics of stellar systems, as well as determine long-term variations in stellar magnitudes. Thus, the Project now has clear astrophysical applications (e.g., see Jones 2000; Urban and Corbin 1998).

Fig. 17.19 The 4-in. Dallmeyer photoheliograph in 1875 (Clark collection)

17.3.7.2 The Total Solar Eclipse of 9 May 1910

Nearly 30 years later a total solar eclipse was scheduled to take place on 9 May 1910, with the path of totality crossing southern Tasmania (The coming eclipse … 1910b).

Although the weather in southern Tasmania normally was cloudy at this time of the year, the eclipse would occur low in the western sky just before sunset and the duration of totality would be limited to 3.5 min (The coming eclipse … 1910a), Melbourne Observatory decided to mount an expedition on the off chance that they could investigate the solar corona (Lyle 1909; The coming eclipse of the Sun 1910c).

The site Baracchi chose for their eclipse camp was at Alonnah on Bruni Island, 30 miles (48.3 km) from Hobart, and they were joined there by astronomers from Sydney University, Adelaide Observatory and New Zealand.

However, bad weather once again prevented any observations being made (Baracchi 1910a, b; Cheated by clouds 1910; Today’s eclipse 1910), and as in 1871 Australian astronomers were denied the chance to make a useful contribution to solar physics.

Table 17.3 The number of photographs obtained annually between 1875 and 1900 (inclusive) with the Melbourne Observatory Dallmeyer photoheliograph

Period	Number of plates	Comments and/or references
June 1875–June 1876	143	The photographs showed that there was a remarkable absence of sunspots during the year (Ellery 1876)
July 1876–May 1877	168	There was a remarkable absence of sunspots, as in the previous year (Ellery 1877)
June 1877–August 1878	173	Sunspots were seen on 32 of the photographs. There were 14 spots and groups. With the exception of one, they were all small. Since 1 December 1877 only five small groups and sunspots have been seen (Ellery 1878)
September 1878–July 1879	169	There was an almost complete absence of sunspots (Ellery 1879a)
July 1880–June 1881	175	There was a large increase of sunspots during the year (Ellery 1881)
July 1881–June 1882	217	(Ellery 1882)
July 1882–June 1883	170	(Ellery 1883)
July 1883–June 1884	178	(Ellery 1884)
July 1884–August 1885	130	(Ellery 1885b)
September 1885–June 1886	92	Alterations were made to the photoheliograph during the year (Ellery 1886)
July1886–July 1887	121	Photographs were taken with the new large 8-in. plates (Ellery 1887)
August 1887–June 1888	129	(Ellery 1888)
July 1888–June 1889	156	(Ellery 1889b)
July 1889–June 1890	53	The photoheliograph was not used during the year. The photographs were taken with the 'North Equatorial' (Ellery 1890)
July 1890–June 1891	126	(Ellery 1891)
July 1891–June 1892	201	Since February 1892 there was a remarkable prevalence of sunspots and a series of photographs gave an interesting history of their origins and progress (Ellery 1892)
July 1892–August 1893	141	(Ellery 1893)
September 1893–June 1894	134	(Ellery 1895)
July 1894–May 1895	70	(Ellery 1895)
June 1895–June 1896	40	(Baracchi 1896)

(continued)

Table 17.3 (continued)

Period	Number of plates	Comments and/or references
July 1896–June 1897	41	Photographs of the sun were taken only when there were conspicuous spots (Baracchi 1897)
July 1897–June 1898	41	(Baracchi 1898)
July 1898–February 1899	16	A series of photographs showed the phases of a great sunspot of September 1898 (Baracchi 1899)
March 1899–March 1900	29	Solar photographs only were taken on special occasions (Baracchi 1900)

Fig. 17.20 A map showing the path of totality of the 29 April 1911 of the total solar eclipse and the location of Vava'u (the *red dot*) (after Today's eclipse 1911)

17.3.7.3 The Total Solar Eclipse of 29 April 1911

One year later Australian astronomers were offered another total solar eclipse, and this time the old adage "Third time lucky" struck a hopeful chord as Melbourne Observatory chose to base its expedition on the island of Vava'u in the Pacific instead of on the Australian mainland. Vava'u (Fig. 17.20) is in the Kingdom of Tonga and is ~350 km NNE of the main island, Tongatapu.

The expedition was organized by the Australasian Association for the Advancement of Science and subsidized by the Commonwealth Government which granted the sum of £500 towards the expenses (Lyle 1911; Baracchi 1911).

Three staff members from Melbourne Observatory took part in the expedition, including Baracchi (as leader) and the eclipse expert and mathematician C.J. Merfield (see Orchiston 2015). They had to go to Vava'u for at least 3 weeks, in order to set

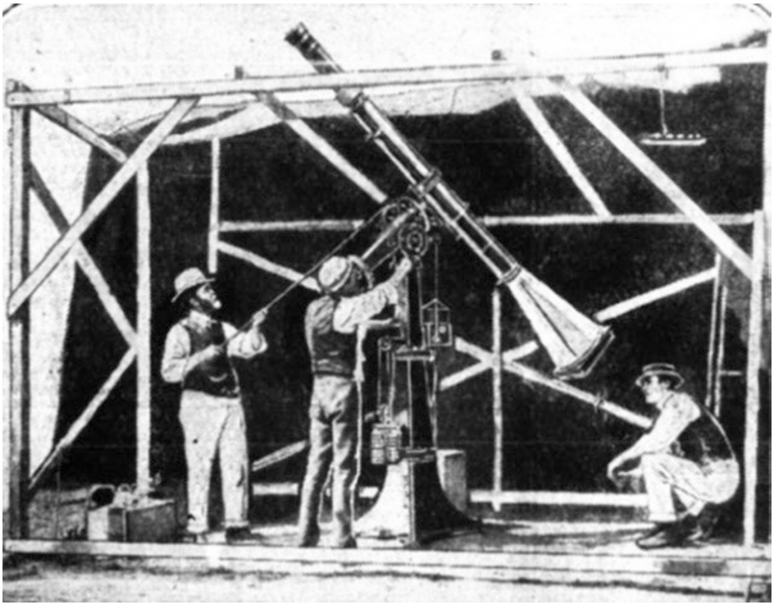

Fig. 17.21 The Melbourne Observatory photoheliograph is prepared for observations of the 29 April 1911 eclipse of the Sun. Merfield is on the *left* (after Today's eclipse 1911)

up temporary observatories, the equipment and the associated huts. Once again coronal photography was the primary research objective (Merfield 1911), and their main instruments were the Dallmeyer photoheliograph with a large plate-holder fitted (see Fig. 17.21), the Observatory's 4.5-in. (11.4-cm) equatorially mounted Cooke refractor and two coronagraphs (Baracchi 1911; Merfield 1911).

Other members of the Australian expedition (see Baracchi 1911; Lyle 1911; Eclipse of the Sun 1911) included people from Sydney University; the Government Astronomer of Western Australia, William Ernest Cooke (1863–1947; Hutchison 1980, 1981); and the Government Astronomer of South Australia, George Frederick Dodwell (1879–1963; Sangster 1964). From Europe there were members of Stonyhurst Observatory, Lancashire; Dr. Joseph Norman Lockyer (1836–1920; Frost 2014) from the South Kensington Solar Observatory; and Dr. Milan Rastislav Štefánik (1880–1919; Gurshtein 2014a) a Slovakian-born French astronomer from Meudon Observatory (Baracchi 1911).

At 0937 h totality commenced. Passing clouds interfered with the observations but 39 photographs of the corona were taken during the 3 min 37 s of totality. According to Merfield (1911) many of the photographs were successful and much detail was seen. Several large prominences were present and coronal streamers were obvious, although they did not appear to extend more than one solar diameter on any of the photographs—probably because of a thin passing cloud. Merfield also succeeded in taking 13 photographs with two coronagraphs attached to the Cooke Telescope (Baracchi 1911; Merfield 1911; The eclipse 1911). Despite these photographic successes, no research papers reporting scientific results from this expedition were ever published.

17.3.7.4 A Comment: Later Total Solar Eclipses and the 1874 and 1882 Transits of Venus

Although the 21 September 1922 total solar eclipse was successfully observed from Western Australia, South Australia, New South Wales and Queensland (e.g. see Orchiston and Pearson 2011; Pearson 2010), it lies outside the chronological scope of this chapter, which deals specifically with the *emergence* rather than the *development* of astrophysics in Australia.

Likewise we have decided not to include a discussion of Australian observations of the 1874 and 1882 transits of Venus (see Lomb 2011; Orchiston 2004b), because these involved the application of solar photography to a major international positional astronomy challenge (determination of the solar parallax and the Astronomical Unit) and not to the emergence of astrophysics in Australia. However, it is of interest to note that experimental dry plates as well as wet plates were used with the Melbourne photoheliograph during the transit of 1874, and that both the Melbourne and Sydney photoheliographs were fitted with De la Rue's versions of Janssen's photographic revolver for that event, allowing temporal resolutions down to several seconds if required. It would be decades before such performance could usefully be employed in astrophysics or solar physics, e.g. in the study of solar flares following Hale's invention of the spectroheliograph.

17.3.8 Sydney Observatory and the Study of Stellar Magnitudes

After spectroscopy and photography, the third analytical technique to feature in the conversion of astronomy to fully fledged astrophysics was photometry, which involved the accurate measurement of stellar (and other) magnitudes.

It appears that Sydney Observatory was the only Australian professional observatory to experiment with photometry when H.C. Russell (1888) used a wedge photometer to measure the brightness of η Argus in May 1888 (Melbourne Observatory had a Pritchard wedge photometer, but apparently it was not used). By this time Eta Argus was a famous variable star that had dropped from a maximum magnitude of about −1 at the end of 1844 to beyond the range of the naked eye by 1865 (see Fig. 17.22).

Initially Russell made occasional visual observations of this star during the decline phase, but from 1874 he observed it more frequently,

> … comparing it with several stars in its own cluster which are not variable. During the years 1875 to 1882 the change seemed to me inappreciable, but in 1883 the estimates varied from 7.5 to 7.8, in 1884 I made it 7.6, in 1885 and 1886 about the same … in 1887 I was away, but the first examination on my return removed all doubt, there was evidently a very decided increase; adopting still Gould's Magnitudes for Stars of Comparison, I find Eta at the end of May, 1888, was of 6.9 magnitude, or almost as great as it was in 1871. These comparisons were made in the usual way, viz., by estimating in the telescope relative brightness of the star images.

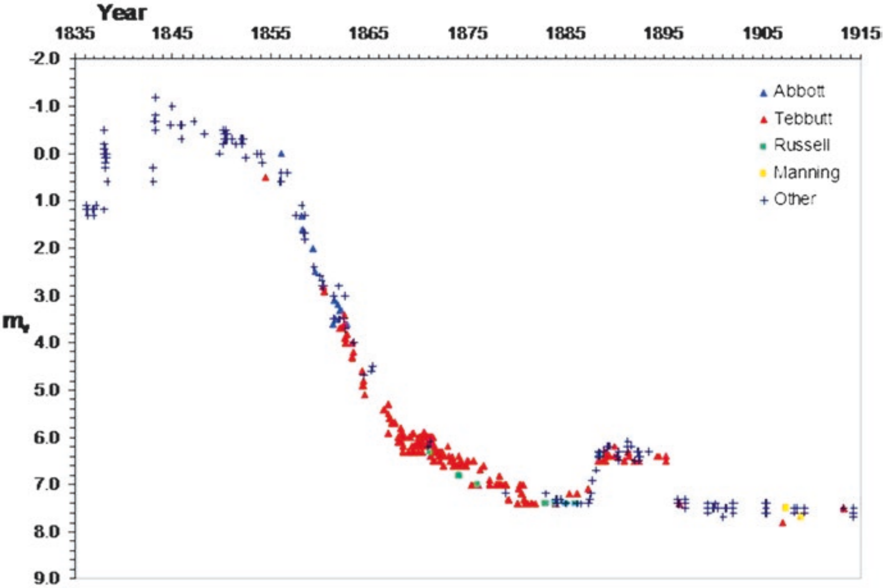

Fig. 17.22 An historic light curve of η Carinae, with Russell's visual observations shown as green squares (after Frew and Orchiston 2003); note that the 1838–1850 section of this light curve has since been superseded by the light curve presented in Smith and Frew (2011)

> *But I have also compared it with six stars in its own cluster (the same stars used by the older method) by means of a wedge photometer*, 180 measures have been made, and give the magnitude 7.24 as a result. *I have also compared it in the same way with six stars in Kappa Crucis cluster*, 90 measures have been made, which give the magnitude 7.42. My experience with the wedge photometer has been that red stars, of which Eta Argus is one, are made to appear smaller than they do by direct vision, or in other words, that red light is more absorbed by the wedge than white light, so that the magnitude of a red star by wedge photometer is smaller than it should be, and as appears in the foregoing, where direct comparison makes it 6.9, and the wedge 7.24. As all my previous comparisons were direct, and I think also those of other observers, we must take 6.9 as its present magnitude … (Russell 1888: 77; our italics).

Wedge photometers operated on the extinction principle, whereby a wedge of dark partially absorbing glass was slowly inserted into the light-path between the telescope objective and the eyepiece until the star under examination disappeared from view. Since the wedge was graduated the magnitude of the star could be calculated. This differed markedly from the other type of nineteenth century visual photometer—the comparison photometer—where a reference light source was adjusted in intensity until it equalled that of the target star (Hearnshaw 1996: 57–58).

Russell (1888) does not describe the wedge photometer that he used for his observations, but it almost certainly was inspired by those developed by Professor Charles Pritchard (1809–1893; Hurn 2014) of Oxford University who championed the wedge photometer at this time (e.g. see Pritchard 1881, 1882, 1885).

As Hearnshaw (1996: 59) relates,

> Oxford wedge photometry had numerous critics for a variety of technical reasons … Pritchard defended his method … yet the results of his work show that the accuracy was disappointing, and could not compete with the comparison photometers being used at Harvard and Potsdam.

In this context, it is interesting that Russell also was critical of his wedge photometer results, and that he chose to favour magnitudes for η Argus obtained from regular visual observations.

It also is interesting that Russell's disappointing experimentation with the wedge photometer came during what Hearnshaw (1996: 105) refers to as the 'hey-days' of visual photometry, which extended 1860–1910, and

> … although the accomplishments of the visual photometrists may well seem extremely meagre … [they] were important nevertheless, in laying the groundwork for the photometry yet to come.

17.4 Explorations in Astrophysics by Australian Amateur Astronomers

As elsewhere in the world, some Australian amateur astronomers were quick to familiarize themselves with new developments in astrophysics. In Hobart, Tasmania's foremost astronomer, Francis Abbott (Orchiston 1992), sought to popularize astronomy by publishing three booklets in 1878, 1879 and 1880, and all of these contained readable up-to-date information about the emerging field of astrophysics (see Abbott, 1878, 1879 and 1880).

Meanwhile, Tasmania's second-ranked nineteenth-century astronomer, Alfred Barrett Biggs (1825–1900; see Fig. 17.23), was primarily a positional astronomer like his mentor, John Tebbutt (Orchiston 1985), but he also was fascinated by the potential that spectroscopy offered astronomers. Thus, in January and February 1884 he carried out observations of Comet 12P/Pons-Brooks using a small direct-vision Browning spectroscope attached to his 3-in. (7.6-cm) refracting telescope, and noted the presence of three different emission bands. These correlated with the three emission lines shown by a common coal gas comparison flame that he set up adjacent to the telescope, and he then went and measured the relative positions of the three 'comets lines' with "… a contrivance of my own, specially designed for double star measurement." (Biggs 1884a: 201). But this is as far as Biggs went, for

> I have contented myself with describing, as carefully as possible, my observation, leaving to others more competent than myself the interpretation of the record. I would venture to remark, however, that my failure to detect continuity in the spectrum would, as I read it, indicate that the self luminosity of the comet must greatly overpower whatever sunlight it reflects (Biggs 1884a).

In February and March 1884, Biggs carried out a second spectroscopic study, but this time his target was terrestrial not celestial: the brilliant red sunsets that then were prevalent. Again Biggs carried out careful observations, and he reported these

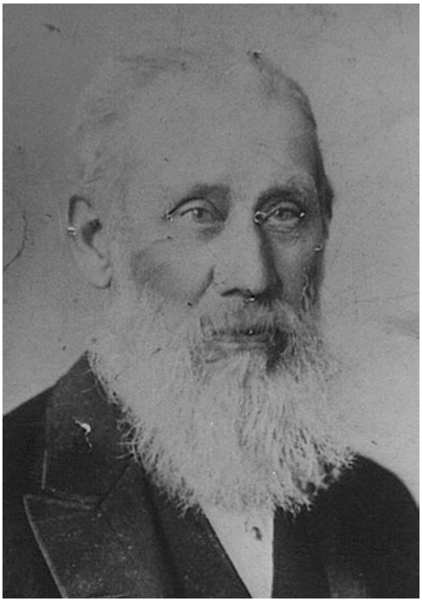

Fig. 17.23 Alfred Barrett Biggs (Orchiston Collection)

in a paper that was read at the 8 April meeting of the Royal Society of Tasmania and was subsequently published in the Society's *Papers and Proceedings* (Biggs 1884b). In presenting his paper, Biggs exhibited a diagram that showed the relative positions of the most prominent solar lines, designated A, B, C, etc., and lines and bands associated with the 'twilight glows,' which he numbered (1), (2), (3), etc. This diagram

> … gives, as nearly as I can show it, the appearance of the spectrum near the horizon when the "glow" is moderately strong. By far the most prominent feature … is the line or band (2) at scale 41. I have noticed that the deeper the glow the broader and deeper does this band become. The line (1) at 37 also comes into great prominence at such times, fully equating, and sometimes exceeding C in intensity. This line (1) is, however, very persistent, continuing more or less conspicuous throughout the day. (3) At about 44 is a faint line, which is scarcely perceptible in the twilight. (4) Is a well-known vapour-band, always more or less conspicuous above the horizon. (5) On the edge of the green is a very broad band, shading off a good way into the green and somewhat resembling a show.
>
> I noted, on the evening of 26th March, when the air was filled with smoke from bush fires that C and 1 [*sic*] were very intense; 2 [sic.] was as usual at times of pretty deep glow. The sunset sky was very red on that occasion, evidently from smoke.
>
> On 31st March (evening), after rain, I noted [in my observing book] "C and 1 [*sic*] very strong; 2 [*sic*] much lighter than usual, being only a little stronger than D." (Biggs 1884b: 202).

Once again Biggs left it to others to interpret his observations. With the benefit of hindsight, we now know this impressive atmospheric phenomenon was associated with tiny airborne ash particles from the spectacular eruption of Krakatoa volcano in what was then the Dutch East Indies.

A further attempt by Australian amateur astronomers to make a meaningful contribution to astrophysics relates to the 'Hoskins Reflector', an 18-in. (46-cm) f/8.2 fork-mounted Newtonian reflector (New South Wales Branch Report 1917) that was assembled in 1917 by the wealthy Sydney amateur astronomer and industrialist George Herbert Hoskins (1883–1953; Hoskins 1969; Orchiston and Bembrick 1997), and installed in an observatory at his home in Beecroft, a far north-western Sydney suburb. The f/8.2 primary mirror was the work of Robert W. Wigmore (New South Wales Branch Report 1921), one of Melbourne's most accomplished telescope-makers (Orchiston and Perdrix 2004), while James Nangle—who later was destined to direct Sydney Observatory—constructed a spectroscope for the telescope (New South Wales Branch Report 1919).

In 1917 Hoskins used the telescope to observe the cluster κ Crucis, and reported on colour changes in some of the stars (New South Wales Branch Report 1917).

Hoskins also allowed other members of the New South Wales Branch of the British Astronomical Association to use the telescope from time to time, and Nova Aquilae 1918, in particular, "... proved a mine of interest." (New South Wales Branch Report 1919: 153). At the 26 June 1918 meeting of the Branch it was reported that

> Mr. G.H. Hoskins, with his 18-in. mirror at Beecroft, obtained photographs of the spectrum, and in conjunction with Messrs. Gale, Nangle and Brown, obtained a series of drawings of the changes in the spectrum, which were plotted and drawn in colour by Mr. J.W. Short, F.R.A.S. [of Sydney Observatory] … The advantage of photographic record of the spectrum was so evident that Mr. Nangle at once offered to construct a camera to be used with Mr. Hoskins' 18-in. mirror … A fine series of photographs has been obtained by this means. At a subsequent meeting Mr. Gale gave an explanation of the spectroscopic work on these objects, and illustrated his remarks by means of photographs supplied by Mr. Hoskins … (New South Wales Branch Report 1919: 153–154).

At yet another meeting of the Branch, Mr. Edward Gardiner exhibited "… some beautiful drawings of the spectrum …" obtained with his 6-in. (15.2-cm) refractor and a Zöllner spectroscope (New South Wales Branch Report 1919: 154).

Despite this flurry of Antipodean interest in the spectrum of Nova Aquila 1918 it is notable that no-one bothered to publish an account of their observations or of their spectrograms. Perhaps they can be excused if they simply found the rapidly changing spectrum too hard to document and too difficult to try and interpret, which would be perfectly understandable in light of Dr. Wyse's (1940) later compilation.

Finally, it is illuminating that although there were at least four other 18-in. reflectors in amateur hands in Australia in 1918 (Orchiston and Bembrick1995), Hoskins' telescope was the only one that is known to have been used for astrophysical observations. The same comment applies to what at that time was Australia's largest 'amateur' reflector, the 26-in. 'Baker equatorial' at the Oddie Observatory in Ballarat, which was committed to astronomy education rather than research (Burk 1986).[5]

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[5] Times have changed markedly in Australian amateur astronomy over the past century, and now there are many telescopes larger than the 'Baker equatorial'. A number of these are used for astrophysics projects, sometimes in collaboration with professional astronomers.

17.5 Discussion

Applied Historical Astronomy is a specialist field of astronomical history where historical data are used to address contemporary astrophysical issues, with particular emphasis on comets, supernovae and solar eclipses (e.g. see Steele 2004; Stephenson 1997; Stephenson and Green 2002). Most applied historical astronomy studies use data gathered before the emergence of the telescope, but there is the potential to expand this concept and accommodate astronomical observations carried out in the nineteenth century (e.g. see Frew 2004; Jones 2000; Orchiston 2002a). For example, pinpointing the times when streamers are emitted from a comet can lead to a calculation of the rotation period of the nucleus (Sekanina 1981), while a long data set for a particular variable star can be used to refine its parameters and model the atmospheric or internal properties of the star.

Frew (2002), Humphreys et al. (2008) and Smith and Frew (2011) show that historic spectral observations of η Carinae have special significance when viewed in the context of contemporary astrophysics. As the archetypal Luminous Blue Variable, η Carinae is one of the most luminous and most massive stars in our part of the Galaxy. It is also "… our closest and best studied example of a "supernova imposter", but there are still numerous unsolved questions about the great eruption and star's subsequent and on-going recovery." (Humphreys et al. 2008: 1249). Walborn and Liller (1977) and Humphreys et al. (2008) have examined historic Harvard spectra of this star, but these only date from the Lesser Eruption of 1887–1895. Spectroscopic observations of η Carinae (= Argus) made with the Great Melbourne Telescope date back further—to the 1870s—and could help to improve our understanding of the dynamics of this unique binary system.

In this light, MacGeorge's observations of an apparent change in the spectrum of η Carinae in 1871 are very interesting. At the time of his observations, the steady decline from the Great Eruption of the 1840s had stalled temporarily (Frew 2004). This brief plateau in the light curve (see Fig. 17.23) may be the signature of a weak brightening event analogous to the Lesser Eruption. We note that MacGeorge's observations were at phase 0.02 using the orbit of Damineli et al. (2000) which assumes an orbital period of 5.53 years, suggesting that the spectroscopic and photometric changes were associated with a periastron passage of the companion star. Similarly, the commencement of the Lesser Eruption was shown by Frew (2004) to be coincident with a periastron passage and was probably triggered by it. In addition, if the modern orbital ephemeris was still applicable as early as 1871, then this places a constraint on the amount of mass loss that occurred during the 1887–1895 event, as a significant loss would change the orbital period. Perhaps the Lesser Eruption was an ordinary S Doradus-type eruption, as suggested by Humphreys et al. (1999) and van Genderen (2001), rather than a major eruption.

17.6 Concluding Remarks

It is now possible for a graduate student in astrophysics with little or no experience in practical astronomy to go to a large telescope, read the manuals, press the buttons and record images or spectra. But during the six or seven decades studied above, success in obtaining such records could hardly be expected, if at all, without substantial prior experience in identifying the constellations and individual stars, checking that the clocks were accurate, operating the telescope and accessories, and using the setting circles and star catalogues. Gaining the requisite skills had to be done then as an amateur astronomer or as a trainee professional astronomer, or both, generally without the insights provided by tertiary education.

Astronomy in nineteenth century Australia was initially done solely for utilitarian purposes such as providing accurate local mean time. By-products of using transit telescopes to do this were star catalogues containing many more stars than were ever likely to be needed for navigation or surveying. These catalogues then provided a convenient precise framework for determining the positions of star clusters and nebulae that could often pass unnoticed in transit telescopes because of their high magnifications. This stage had just barely been reached for the first time in Australia when James Dunlop, observing as an amateur after leaving Parramatta Observatory in 1826, discovered some hundreds of objects that were eventually incorporated into the New General Catalogue, which has often since been the starting point for astrophysical research observations. Of course the bulk of the objects that would make up the NGC had been discovered by William Herschel in England, supplemented by John Herschel's southern sky discoveries at the Cape of Good Hope, South Africa, in the 1830s.

More preparatory work for Australian astrophysics subsequently took place at Williamstown/Melbourne and Sydney Observatories as they ramped up their time services in the 1850s, but nobody involved then would have been aware of that aspect of their work. Contemporaneously, human potential for understanding more about the Universe took a giant stride forward with the application of spectroscopy to astronomy in Europe. Initially Robert Ellery was the only Australian astronomer to be sufficiently intrigued by the possibilities to do something about it. From the beginning at Melbourne Observatory in 1863, and doubtless encouraged by Georg Neumayer who had a laboratory in the basement of his nearby house (Clark 2015), Ellery had a whole room set aside as a laboratory in which to become more familiar with spectral technology as well as the other great technological advances of the time, electricity and electrical telecommunications. In contrast, universities at the time were too busy getting their undergraduates up to the mark to be sidetracked by such hands-on things as laboratories! In the expected course of events, Ellery would have become a substantial contributor in early spectral studies of the Southern skies, but much of his future time would soon be taken up by an unexpected development.

Proposals in mid-nineteenth century England for a Great Southern Telescope to repeat J. Herschel's survey of Southern nebulae grew out of the notions that our Milky Way galaxy was *the* Universe, and the nebulae would be at such distances that changes in their form and positions should be detectable over decades. But politico-economic priorities at the time took precedence and the project remained in limbo until the gold-rich colony of Victoria put up the funds for the Great Melbourne Telescope (GMT) in 1866.

From the outset the GMT had a slit spectroscope attachment. Several papers about spectroscopic observations made by Le Sueur (the inaugural GMT Observer) were published while arguments about the GMT's shortfalls were raging in journals and in the media. Although it would not be known for another half century, the first spectral observations of an extragalactic gaseous nebula had been achieved. Despite a lot of effort to improve the spectroscopic equipment, not much more on the topic from the GMTs first life was published subsequently.

Much of the GMT's usage was for the nebular sketching project instead and it was only towards the end of the first (and final) phase of that project (early 1883) that attempts to do extended exposure dry-plate photography of nebulae showed promise of objectively recording all visible detail and more. However, night sky photography was abandoned for several years after Turner's death in August 1883, and available resources were directed at producing a report on the nebular sketching project. Printed reproductions of a few plates of nebular sketches not only proved very costly but also damaged Melbourne Observatory's standing with the Government. It is estimated that less than 1000 copies of the report were printed and distributed in 1885. Citations of it thereafter in the literature were few and far between, leaving little doubt that a series of papers in astronomical journals would have produced better outcomes. In something of a precedent just 4 years earlier, Russell at Sydney Observatory had consigned his important spectral observations of the Great Comet of 1881 to near oblivion in a local journal instead of publishing them in a far more appropriate international astronomical journal (Orchiston 2017: Chap. 9).

In the 1890s, the Astrographic Catalogue-Carte du Ciel Project to catalogue and map the whole sky was in full swing at Melbourne, Perth and Sydney Observatories. This was resource-demanding to the point that it appears to have stifled any discretionary use of resources for astrophysical research at the three observatories, with the brief but important exception of Russell in 1891 at Sydney who produced a landmark series of Milky Way photographs using a 150-mm aperture camera attached to the Astrograph. On the broader front, the Universe appeared to be running like Newtonian clockwork and the great optical physicist Albert Michelson (1903) thought that all the major discoveries in physics had already been made. Astrophysics appears to have been virtually invisible to Australian governments and voters at the time.

In 1910 a camera with a 150-mm aperture Voigtlander portrait lens was attached to the GMT's boilerplate tube section to photograph Comet 1P/Halley, with the then badly tarnished speculum mirrors restricting the main optical system to the subordinate role of a guide scope. Apparently all of the photographs from this setup and from the Melbourne Astrograph were sent to England for analysis. Then the North Equatorial was modified almost out of recognition to make an astrographic camera, again based on a 150-mm doublet objective. The original 113-mm optical tube assembly became the guide scope for the new camera, but no published results from that instrument have been found.

In 1908, staff and budget reductions occurred at Adelaide, Melbourne, Perth and Sydney Observatories when the new (national) Commonwealth took over responsibility for meteorology and it was removed from the care of the State observatories. WWI (1914–1918) also reduced any limited capacity that might have existed at Melbourne and Sydney Observatories to support astrophysical research. But already a campaign was under way for the Commonwealth to set up its own observatory for solar research. Thus, astrophysics at the professional observatories in Australia stayed at a low ebb for decades from about 1890, broken only by brief flurries of activity connected with solar eclipses and bright comets. However, the seeds for change multiplied, particularly following the demonstration of radioactivity by Marie Curie, and Einstein's extraordinary papers on the photoelectric effect in 1905 and General Relativity in 1915. Such advances, along with the political need to recover from WWI, were reflected in the early 1920s by the formation of what became the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Although mentioning this might appear to be a digression, its importance in context is that a CSIRO group working on radar during WWII formed a nucleus of radio astronomers who gave Australia a fine start after the War in this radically new way of doing astrophysics, as outlined in the next two chapters in this book (see Sullivan 2017; Orchiston and Slee 2017).

On the amateur side, from relatively early days of the colonies there was always some activity in observing variable stars, comets, meteors, planetary features and sunspots. Adelaide Observatory made good use of the limited staff resources at hand and produced a long series of sketches of Jupiter, complementing amateur efforts in this area. The formation of State amateur astronomical societies resulted from the need for individuals to share information, techniques and equipment. In turn, this led to more observers working more systematically.

Overall, the main Australian contribution to nineteenth century astrophysics was undoubtedly that made by the GMT between 1869 and 1895. As Baracchi (1914) put it:

> The great Melbourne telescope was for many years after 1869 employed in the revision of the nebulae and clusters which were observed by Sir John Herschel at the Cape of Good Hope in the years 1834–38, and the results obtained are as satisfactory as the committee of the Royal Society of London, on whose recommendation, supervision, and approval the 4-feet Cassegrain was constructed, could have expected.
>
> Most of Sir John Herschel's southern nebulae have been examined, and many hundreds of drawings of these objects, with notes and micrometric measurements, exist at present in the observer's note books and registers; but there has been no opportunity since 1891 of arranging this material for publication.

More than a century on, most of the GMT's observations still remain unpublished. This is not just the nebulae drawings but virtually all of the other observations made with the GMT as well, such as sketches of the planets and comets, satellite timings, occultations, double star measures and so on. The blame for this breach of scientific method lies completely with the successive State Governments that refused to fund any further publication of GMT results after Part 1 of the planned series of reports, and kept Melbourne Observatory staffing at such low levels that the GMT remained unused for professional astronomy for the rest of its first life at Melbourne. Now it can be seen why the GMT is widely regarded as a failure at Melbourne and why this judgement is wrong (Clark 2015; Gillespie 2011b).

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References

Abbey, L. B (2014). Roberts, Isaac. In T. Hockey et al., pp. 1843–1846.

Abbott, F. (1878). *Modern Astronomy.* Hobart, printed for the author.

Abbott, F. (1879). *Bibliographical Contribution to the Resume on Modern Astronomy*. Hobart, printed for the author.

Abbott, F. (1880). *Sidereal Systems of Modern Astronomy, Multiple Suns and Far-off Worlds*. Hobart, printed for the author.

Andropoulos, J. (2014). *The Astronomical Publications of Melbourne Observatory*. Ph.D. Thesis, Centre for Astronomy, James Cook University, Townsville, Australia.

Andropoulos, J., & Orchiston, W. (2006). Melbourne Observatory and the genesis of astrophysics in Australia. *AAO Newsletter, 109,* 18–20.

Andropoulos, J., Orchiston, W., & Clark, B. (2011). *Williamstown Observatory and the development of professional astronomy in Australia*. Poster paper in the HAD program at the AAS Annual Winter Meeting, Seattle.

Baracchi, P. (1889). Spectra of southern stars observed at the Melbourne Observatory with the McLean Direct-vision Spectroscope attached to the South Equatorial. *Monthly Notices of the Royal Astronomical Society, 50,* 66–71.

Baracchi, P. (1896). *Report of the General State of the Observatory Buildings, Instruments, and Appliances, and on the Work Executed During the Period May 31st, 1895–June 30th, 1896. Dated 21 September 1896. Thirtieth Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 31st May, 1895 to 30th June, 1896*. Melbourne: Government Printer.

Baracchi, P. (1897). *Report of the Melbourne Observatory for the Period 1st July, 1896, to 30th June, 1897. Thirty-first Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st July, 1896, to 30th June, 1897*. Melbourne: Government Printer.

Baracchi, P. (1898). *Report on the General State of the Melbourne Observatory and on the Work Executed During the Period 1st July, 1897–30th June, 1898. Thirty-second Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st July, 1897, to 30th June, 1898*. Melbourne: Government Printer.

Baracchi, P. (1899). *Report of the Work of the Melbourne Observatory for the Period 1st July, 1898, to 28th February, 1899. Thirty-third Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st July, 1898, to 28th February, 1899*. Melbourne: Government Printer.

Baracchi, P. (1900). *Report of the Work of the Melbourne Observatory for the Period Extending From 1st March, 1899, to 31st March, 1900. Thirty-fourth Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st March, 1899, to 31st March, 1900.* Melbourne: Government Printer.

Baracchi, P. (1910a). *Report on the State of the Melbourne Observatory and on the Work Done During the Period 1st June, 1909–30th June, 1910. Forty-third Report of the Board of Visitors to the Observatory; together with the Report of the Government Astronomer for the Period From 1st June, 1909, to 30th June, 1910.* Melbourne: Government Printer.

Baracchi, P. (1910b). *Appendix. Melbourne Observatory Expedition to Bruni Island, Tasmania, for the Observation of the Solar Eclipse of 9th May, 1910. Forty-third Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st June, 1909, to 30th June, 1910*. Melbourne: Government Printer.

Baracchi, P. (1911). *Appendix – The Total Eclipse of the Sun of 29th April 1911. Forty-fourth Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st June, 1910, to 30th June, 1911*. Melbourne: Government Printer.

Baracchi, P. (1914). Astronomy and geodesy in Australia. In G.H. Knibbs (Ed.), *Federal Handbook Prepared in Connection with the Eighty-fourth Meeting of The British Association for the Advancement of Science, Held in Australia, August 1914* (pp. 326–390). Melbourne: Government Printer.

Baum, R. (2014a). Common, Andrew Ainslie. In T. Hockey et al., pp. 447–449.

Baum, R. (2014b). Donati, Giovani Battista. In T. Hockey et al., p. 592.

Baum, R. (2014c). Rutherfurd, Lewis Morris. In T. Hockey, pp. 1886–1888.

Becker, B.J. (2011). *Unravelling Starlight: William and Margaret Huggins and the Rise of the New Astronomy*. Cambridge: Cambridge University Press.

Beech, M. (2014). Herschel, Alexander Stewart. In T. Hockey et al., pp. 945–947.

Bhathal, R. (1991). Henry Chamberlain Russell – astronomer, meteorologist and scientific entrepreneur. *Journal and Proceedings of the Royal Society of New South Wales*, *124*, 1–21.

Bhathal, R., Sutherland, R., & Butcher, H. (2013). *Mt Stromlo Observatory: From Bush Observatory to the Nobel Prize*. Melbourne: CSIRO Publishing.

Biggs, A.B. (1884a). Notes on spectroscopic observations of Comet "Pons," 27th January to 2nd February, 1884. *Papers and Proceedings of the Royal Society of Tasmania,* 200–201.

Biggs, A.B. (1884b). Report on spectroscopic observation of the twilight glows during February and March, 1884. *Papers and Proceedings of the Royal Society of Tasmania,* 202–203.

Bowen, I.S. (1927). The origin of the chief nebular lines. *Publications of the Astronomical Society of the Pacific, 39,* 295–297.

Bowen, I.S. (1928). The origin of the nebular lines and the structure of the planetary nebulae. *Astrophysical Journal, 67,* 1–15.

Burk, K. (1986). A history of James Oddie, Captain Henry Evans Baker and the Ballarat Municipal Observatory. *The Oddie-Baker Bulletin, 8*(4), 3–15.

Cenadelli, D. (2014). Secchi, (Pietro) Angelo. In T. Hockey et al., pp. 1970–1972.

Chapman, A. (1988). William Lassell (1799–1880): practitioner, patron and "grand amateur" of Victorian astronomy. *Vistas in Astronomy, 32,* 341–370.

Cheated by clouds. Disappointed astronomers. The eclipse invisible. *The Argus*, 11 May 1910.

Christie, W.H.M. (1907). *Photo-heliographic Results 1874 to 1885 being Supplementary Results from Photographs of the Sun taken at Greenwich, at Harvard College, U.S.A., at Melbourne, in India, and in Mauritius in the years 1874 to 1885* ... Edinburgh: H.M. Stationery Office.

Clark, B.A.J. (2015). Influences of German science and scientists on Melbourne Observatory. *Proceedings of the Royal Society of Victoria*, *127*, 43–58.

Clark, B.A.J., & Orchiston, W. (2004). The Melbourne Observatory Dallmeyer photoheliograph and the 1874 transit of Venus. *Journal of Astronomical History and Heritage, 7,* 44–49.

Clerke, A. (1893). *A Popular History of Astronomy during the Nineteenth Century*. London: Adam and Charles Black.

Cottam, S., & Orchiston, W. (2015). *Eclipses, Transits, and Comets of the Nineteenth Century: How America's Perception of the Skies Changed*. New York: Springer.

Cozens, G., Walsh, A., & Orchiston, W. (2010). James Dunlop's historical catalogue of southern nebulae and clusters. *Journal of Astronomical History and Heritage, 13,* 59–73.

Damineli, A., Kaufer, A., Wolf, B., Stahl, O., Lopes, D.F., & de Araújo, F.X. (2000). η Carinae: binarity confirmed. *The Astrophysical Journal, 528,* L101–L104.

De la Rue, W. (1872). The Melbourne Telescope. *Nature, 6,* 241.

DeKosky, R.K. (2014). Von Fraunhofer, Joseph. In T. Hockey et al., pp. 2244–2247.

Dick, S.J. (1998). Observation and interpretation of the Leonid meteors over the last millennium. *Journal of Astronomical History and Heritage, 1,* 1–20.

Draper, H. (1880). Photograph of the nebula in Orion. *Nature, 22,* 583.

Draper, H. (1881). Note on photographs of the spectrum of Comet *b* 1881. *The Observatory, 4,* 252–253.

Eclipse of the Sun. News of Australian party. *The Argus*, 28 April 1911.

Edwards, P.G. (1993). Charles Todd and the Adelaide Observatory. *Proceedings of the Astronomical Society of Australia, 10,* 349–354.

Edwards, P.G. (1994). The Adelaide Observatory after Todd. *Proceedings of the Astronomical Society of Australia, 11,* 206–210.

Ellery, R.L.J. (1864). *Report of the Government Astronomer to the Board of Visitors. Read at the Annual Meeting, 15th November, 1864. Fourth Report of the Board of Visitors to the Observatory, with the Report of the Government Astronomer and Correspondence*. Melbourne: Government Printer.

Ellery, R.L.J. (1869a). *Astronomical Observations Made at the Williamstown Observatory in the Years 1861, 1862, and 1863*. Melbourne: Government Printer.

Ellery, R.L.J. (1869b). *Report of the Government Astronomer to the Board of Visitors …* Melbourne: Government Printer.

Ellery, R.L.J. (1871). Spectrum of the aurora. *Nature*, 4, 280.

Ellery, R.L.J. (1872). The photographic apparatus of the Great Melbourne Telescope. *The Australasian Mechanic and Journal of Science, 3*.

Ellery, R.L.J. (1873). *Report of the Government Astronomer, 1873. Ninth Report of the Board of Visitors to the Observatory; with the Annual Reports of the Government Astronomer for the Years 1873 and 1874*. Melbourne: Government Printer.

Ellery, R.L.J. (1876). *Report of the Government Astronomer, 1876. Report of the Board of Visitors to the Observatory; with the Annual Report of the Government Astronomer for the Year Ended 20th June 1876*. Melbourne: Government Printer.

Ellery, R.L.J. (1877). *Report of the Government Astronomer to the Board of Visitors to the Observatory. (Read at the Annual Visitation, 22nd May 1877.) Twelfth Report of the Board of Visitors to the Observatory Together with the Annual Report of the Government Astronomer*. Melbourne: Government Printer.

Ellery, R.L.J. (1878). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Thirteenth Report of the Board of Visitors to the Observatory Together with the Annual Report of the Government Astronomer*. Melbourne: Government Printer.

Ellery, R.L.J. (1879a). *Report of the Government Astronomer to the Board of Visitors to the Observatory, July 1879. Fourteenth Report of the Board of Visitors to the Observatory Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer. Melbourne.

Ellery, R.L.J. (1879b). The spectrum of γ Argûs. *The Observatory, 24,* 418.

Ellery, R.L.J. (1881). *Report of the Government Astronomer to the Board of Visitors to the Observatory, 9th August 1881. Sixteenth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1882). *Report of the Government Astronomer to the Board of Visitors to the Observatory, 15th August 1882. Seventeenth Report of the Board of Visitors to the Observatory; Together with Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1883). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Eighteenth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer*. Melbourne: Government Printer.

Ellery, R.L.J. (1884). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Nineteenth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1885a). *Observations of the Southern Nebulae Made With the Great Melbourne Telescope From 1869 to 1885. Part I.* Melbourne: Government Printer.

Ellery, R.L.J. (1885b). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twentieth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer*. Melbourne: Government Printer.

Ellery, R.L.J. (1886). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-first Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1887). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-second Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1888). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-third Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1889a). Preliminary spectroscopic survey of southern stars, made at the Melbourne Observatory with a McLean Direct-vision Spectroscope on the 8-inch Equatorial. *Monthly Notices of the Royal Astronomical Society, 49,* 349–355.

Ellery, R.L.J. (1889b). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-fourth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer*. Melbourne: Government Printer.

Ellery, R.L.J. (1890). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-fifth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1891). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-sixth Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1892). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-seventh Report of the Board of Visitors to the Observatory; Together with the Annual Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1893). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-eighth Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer.* Melbourne: Government Printer.

Ellery, R.L.J. (1895). *Report of the Government Astronomer to the Board of Visitors to the Observatory. Twenty-ninth Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer.* Melbourne: Government Printer.

Elliott, I. (2014a). Parsons, William. In T. Hockey et al., pp. 1653–1655.

Elliott, I. (2014b). Robinson, Thomas Romney. In T. Hockey et al., pp. 1850–1853.

Evans, D.S. (2014). Herschel, John Frederick William. In T. Hockey et al., pp. 953–956.

Frame, T., & Faulkner, D. (2003). *Stromlo. An Australian Observatory*. Sydney: Allen and Unwin.

Fraunhofer, J. (1817). Bestimmung des Brechungs-und Farbenzerstreuungs-Vermögens verschiedener Glasarten, in Bezug auf die Vervollkommnung achromatischer Fernröhre. *Denkschriften der Königlichen Akademie der Wissenschaften zu München, 5,* 193–226.

Frew, D.J. (2002) Historic observations of the spectrum of η Carinae. In B. Balik (Ed.), *Eta Carine. Reading the Legend. Proceedings of the July 2002 Mt Ranier Symposium*. Seattle: University of Washington.

Frew, D.J. (2004). The historical record of η Carinae I. The visual light curve, 1595–2000. *Journal of Astronomical Data, 10*(6), 1–76.

Frew, D.J., & Orchiston, W. (2003). Nineteenth century Australian observations of *η Carinae*: international controversy and astrophysical implications. Paper presented at the IAU General Assembly, Sydney, Australia.

Frost, M. (2014). Lockyer, Joseph Norman. In T. Hockey et al., pp. 1336–1338.

Gascoigne, S.C.B. (1992). Robert L.J. Ellery, his life and times. *Publications of the Astronomical Society of Australia, 10,* 170–176.

Gascoigne, S.C.B. (1996). The Great Melbourne Telescope and other 19th century reflectors. *Quarterly Journal of the Royal Astronomical Society, 37,* 101–128.

Gibson, S.J. (2014). Draper, Henry. In T. Hockey et al., pp. 607–610.

Gillespie, R. (2011a). George Neumayer and Melbourne Observatory: an institutional legacy. *Proceedings of the Royal Society of Victoria, 123,* 19–26.

Gillespie, R. (2011b). *The Great Melbourne Telescope*. Melbourne: Museum Victoria.

Gingerich, O. (1982). Henry Draper's scientific legacy. [In E.A. Glassgold, P.J. Huggins, & E.L. Schucking (Eds.), *Symposium on the Orion Nebula to Honor Henry Draper*.] *Annals of The New York Academy of Sciences, 395,* 308–320.

Glass, I.S. (1997). *Victorian Telescope Makers. The Lives and Letters of Thomas and Howard Grubb*. Bristol: Institute of Physics.

Grubb, H. (1870). The Great Melbourne Telescope. *Journal of the Royal Dublin Society, 5,* 460–474.

Gurshtein, A.A. (2014a). Štefánik, Milan Rastislav. In T. Hockey et al., pp. 2051–2052.

Habashi, F. (2014). Young, Charles Augustus. In T. Hockey et al., pp. 2400–2401.

Haynes, R.D., Haynes, R.A., & Kitson, W.S. (1993). The history of astronomy in Queensland. *Vistas in Astronomy, 36,* 231–252.

Haynes, R., Haynes, R., Malin, D., & McGee, R. (1996). *Explorers of the Southern Sky. A History of Australian Astronomy*. Cambridge: Cambridge University Press.

Hearnshaw, J. (1986). *The Analysis of Starlight. One Hundred and Fifty Years of Astronomical Spectroscopy*. Cambridge: Cambridge University Press.

Hearnshaw, J. (1996). *The Measurement of Starlight – Two Centuries of Stellar Photometry*. Cambridge: Cambridge University Press.

Herschel, J. (1869). Account of the solar eclipse of 1868, as seen at Jamkandi in the Bombay Presidency. *Proceedings of the Royal Society*, *17*, 103–127.

Hirschfield, A.W. (2014). De la Rue, Warren. In T. Hockey et al., pp. 546–547.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Home, R.W. (1991). George Neumayer and the Flagstaff Observatory, Melbourne. In J. Tampke, & D. Walker (Eds.), *From Berlin to the Burdekin* (pp. 40–53). Sydney: University of New South Wales Press.

Hoskins, Sir Cecil (1969). *The Hoskins Saga*. Sydney: Halstead.

Huggins, W. (1881a). On the photographic spectrum of Comet *b* 1881. *The Observatory, 4,* 233–234.

Huggins, W. (1881b). Photographic spectrum of Comet *b* 1881. *Astronomische Nachrichten, 100,* 143–144.

Hughes, D.W. (2005). The concept and evaluation of temperature in the history of astronomy. *Journal of Astronomical History and Heritage, 8,* 107–121.

Hughes, S. (2013). *Catchers of the Light. The Forgotten Lives of the Men and Women Who First Photographed the Heavens* (2 Vols). Paphos: ArtDeCiel Publishing.

Humphreys, R.M., Davidson, K., & Koppelman, M. (2008). The early spectra of Eta Carinae 1892 to 1941 and the onset of its high excitation emission spectrum. *Astronomical Journa*l*, 135,* 1249–1263.

Humphreys, R.M., Davidson, K., & Smith, N. (1999). Eta Carinae's second eruption and the light curves of the eta Carinae variables. *Publications of the Astronomical Society of the Pacific, 111,* 1124–1131.

Hurn, M. (2014). Pritchard, Charles. In T. Hockey et al., pp. 1762–1763.

Hutchison, D. (1980). William Ernest Cooke: first Government astronomer. *Early Days, 8,* 93–114.

Hutchison, D. (1981). William Ernest Cooke, astronomer 1863–1947. *Historical Records of Australian Science, 5,* 58–77.

Jackson, W.M. (1982). Laboratory studies of photochemical and spectroscopic phenomena related to comets. In L.L. Wilkening (Ed.), *Comets* (pp. 480–495). Tucson: University of Arizona Press.

Jones, D. (2000). The scientific value of the Carte du Ciel. *Astronomy & Geophysics, 41*(5), 5.16–5.20.

Kollerstrom, N. (2014). Adams, John Couch. In T. Hockey et al., pp. 20–21.

Lankford, J. (1984). The impact of photography on astronomy. In O. Gingerich (Ed.), *The General History of Astronomy. Volume 4. Astrophysics and Twentieth Century Astronomy to 1950: Part A* (pp. 16–39). Cambridge: Cambridge University Press.

Launay, F. (2012). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. New York: Springer.

Laurie, P.S. (1988). William Dawes and Australia's first observatory. *Quarterly Journal of the Royal Astronomical Society, 29,* 469–482.

Le Sueur, A. (1869a). Account of the Great Melbourne Telescope from April 1868 to its commencement of operations in Australia in 1869. *Proceedings of the Royal Society of London*, *18*, 216–222.

Le Sueur, A. (1869b). Spectroscopic observations of the nebula of Orion, and of Jupiter, made with the Great Melbourne Telescope. *Proceedings of the Royal Society of London*, *18*, 242–245.

Le Sueur, A. (1869c). On the nebulae of Argo and Orion, and on the spectrum of Jupiter. *Proceedings of the Royal Society of London*, *18*, 245–250.

Le Sueur, A. (1871). Observations with the Great Melbourne Telescope, in a letter to Prof. Stokes. *Proceedings of the Royal Society*, *19*, 18–19.

Le Sueur, A. (1872a). η Argûs and the surrounding nebula. *Transactions and Proceedings of the Royal Society of Victoria*, *10*, 11–16.

Le Sueur, A. (1872b). On η Argus and Jupiter's spectrum. *Transactions and Proceedings of the Royal Society of Victoria*, 10, 23–27.

Lomb, N. (2004). The instruments from the Parramatta Observatory. *Historical Records of Australian Science, 15,* 211–222.

Lomb, N. (2011). *Transit of Venus 1631 to the Present*. Sydney: New South Publishing.

Lomb, N. (2016). Australian solar eclipse expeditions: the voyage to Cape York in 1871. *Journal of Astronomical History and Heritage, 19,* 79–95.

Lovell, A.C.B. (1954). *Meteor Astronomy*. Oxford: Clarendon Press.

Lyle, T.R., 1909. *Forty-second Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st May, 1908, to 31st May, 1909*. Melbourne: Government Printer.

Lyle, T.R., 1911. *Forty-fourth Report of the Board of Visitors to the Observatory; Together with the Report of the Government Astronomer for the Period from 1st June, 1910, to 30th June, 1911*. Melbourne: Government Printer.

McAfee, R.J. (1981). *Dawes Meteorological Journal*. Canberra: Australian Government Publishing Service (Bureau of Meteorology Historical Note No. 2).

MacGeorge, F. (1872a). Letter to R.J.L. Ellery, dated 2 October. In Mt Stromlo Library.

MacGeorge, F. (1872b). Some notes of observation with the Great Melbourne Telescope. *Transactions and Proceedings of the Royal Society of Victoria*, *10*, 65–71.

MacGeorge, F. (1872c). On η Argûs and the nebula. *Transactions and Proceedings of the Royal Society of Victoria*, *10*, 106–113.

Malin, D., & Frew, D. (1995). *Hartung's Astronomical Objects for Southern Telescopes: A Handbook for Amateur Observers.* Cambridge: Cambridge University Press.

Merfield, C.J. (1911). Eclipse expedition. Arrival in Sydney. Details of work. *The Argus*, 18 May.

Meteorological Department (1900). The observatory [Hobart]. In *Cyclopedia of Tasmania …* Hobart: Maitland and Krone.

Michelson, A.A. (1903). *Light Waves and their Uses.* Chicago: University of Chicago Press.

Millman, P.M. (1932). An analysis of meteor spectra. *Annals of the Harvard College Observatory, 82,* 113–147.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nath, B.B. (2013). *The Story of Helium and the Birth of Astrophysics*. New York: Springer.

Neumayer, G. (1859). Description and system of working of the Flagstaff Observatory. *Transactions of the Philosophical Institute of Victoria, 3,* 91–103.

Neumayer, G. (1860). *Results of the Magnetical, Nautical and Meteorological Observations Made and Collected at the Flagstaff Observatory, Melbourne, and at Various Stations in the Colony of Victoria.* Melbourne: Government Printer.

New Observatory, St Kilda Road. *The Illustrated Melbourne Post, 2*(46), 1 (1863).

New South Wales Branch Report. *Journal of the British Astronomical Association, 27,* 284–286 (1917).

New South Wales Branch Report. *Journal of the British Astronomical Association, 29,* 153–154 (1919).

New South Wales Branch Report. *Journal of the British Astronomical Association, 31,* 298–299 (1921).

Notes from the Observatory. *The Argus*, 28 June 1880, page 6.

Notes from the Observatory. *The Argus*, 9 October 1882.

Olivier, C.P. (1925). *Meteors*. Baltimore: Williams and Wilkins.

Orchiston, W. (1985). The contribution of Alfred Barrett Biggs to Australian and Tasmanian Astronomy. *Records of the Queen Victoria Museum*, 89, 1–28.

Orchiston, W. (1988a). Illuminating incidents in Antipodean astronomy: Phillip Parker King and the founding of Sydney Observatory. *Vistas in Astronomy, 32,* 285–321.

Orchiston, W. (1988b). The emergence of professional astronomy in nineteenth century Australia. *Search, 19,* 76–81.

Orchiston, W. (1988c). From research to recreation: the rise and fall of Sydney Observatory. *Vistas in Astronomy, 32,* 49–63.

Orchiston, W. (1989a). Astrophysics and the evolution of twentieth century Australian astronomy. *Search, 20,* 198–202.

Orchiston, W. (1989b). The role of the amateur in early Australian astronomy. *Search, 20,* 16–23.

Orchiston, W. (1989c). William Dawes: Australia's first meteorologist. *Quarterly Journal of the Royal Astronomical Society, 30,* 359–360.

Orchiston, W. (1991). Amateur-professional co-operation in astronomy education: a nineteenth century Australian model. *Proceedings of the Astronomical Society of Australia*, *9*, 186–188.

Orchiston, W. (1992). The contribution of Francis Abbott to Tasmanian and Australian astronomy. *Vistas in Astronomy, 35,* 315–344.

Orchiston, W. (1997). The role of the amateur in popularizing astronomy: an Australian case study. *Australian Journal of Astronomy, 7,* 33–66.

Orchiston, W. (1998a). Amateur-professional collaboration in Australian science: the earliest astronomical groups and societies. *Historical Records of Australian Science, 12,* 163–182.

Orchiston, W. (1998b). Mission impossible: William Scott and the first Sydney Observatory directorship. *Journal of Astronomical History and Heritage, 1,* 21–43.

Orchiston, W. (1999). C/1881 K1: a forgotten 'great comet' of the nineteenth century. *Irish Astronomical Journal, 26,* 33–44.

Orchiston, W. (2000). Illuminating incidents in Antipodean astronomy: H.C. Russell and the origin of the Palomar-type mounting. *Journal of the Antique Telescope Society, 19,* 13–15.

Orchiston, W. (2001). 'Sentinel of the Southern Heavens': the Windsor Observatory of John Tebbutt. *Journal of the Antique Telescope Society, 21,* 11–23.

Orchiston, W. (2002a). [JD6: Applied Historical Astronomy]. Southern Hemisphere observations. In H. Rickman (Ed.), *Highlights of Astronomy as Presented at the XXIVth General Assembly of the IAU* (pp. 322–325). Francisco: Astronomical Society of the Pacific.

Orchiston, W. (2002b). Tebbutt vs Russell: passion, power and politics in nineteenth century Australian astronomy. In S.M.R. Ansari (Ed.), *History of Oriental Astronomy* (pp. 169–201). Dordrecht: Kluwer.

Orchiston, W. (2003). Amateur telescope making in Australia. An historical perspective. In W.J. Cook (Ed.), *The Best of Amateur Telescope Making Journal. Volume 2* (pp. 208–239). Richmond: Willmann-Bell.

Orchiston, W. (2004a). John Tebbutt and observational astronomy at Windsor Observatory. *Journal of the British Astronomical Association, 114,* 141–154.

Orchiston, W. (2004b). The nineteenth century transits of Venus: an Australian and New Zealand overview. *Journal of Astronomical Data, 10,* 219–308.

Orchiston, W. (2015). The amateur-turned-professional syndrome: two Australian case studies. In W. Orchiston, D.A. Green, & R. Strom (Eds.), *New Insights from Recent Studies in Historical Astronomy: Following in the Footsteps of F. Richard Stephenson* (pp. 259–350). New York: Springer.

Orchiston, W. (2017). *John Tebbutt. Rebuilding and Strengthening the Foundations of Australian Astronomy*. Cham: Springer.

Orchiston, W., & Bembrick, C. (1995). The role of the large reflecting telescope in amateur astronomy: an Australian case study. *Australian Journal of Astronomy, 6,* 53–74.

Orchiston, W., & Bembrick, C. (1997). The potency of patronage: George Hoskins and the New South Wales Branch of the British Astronomical Association. *Australian Journal of Astronomy, 7,* 1–15.

Orchiston, W., & Bhathal, R. (1991). Illuminating incidents in Antipodean astronomy: Section A of the Royal Society of New South Wales. *Australian Journal of Astronomy, 4,* 49–67.

Orchiston, W., & Orchiston, D.L. (2017). King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-Koa, Siam. In T. Nakamura, & W. Orchiston.

Orchiston, W., & Perdrix, J. (2004). Who was Robert W. Wigmore? *Crux, 22,* 5, 4–5.

Orchiston, W., & Slee, B. (2017). The early development of Australian radio astronomy: the role of the CSIRO Division of Radiophysics field stations. In T. Nakamura, & W. Orchiston.

Orchiston, W., Lee, E.H., & Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In T. Nakamura, & W. Orchiston.

Pasachoff, J.M., & Suer, T.-A. (2010). The origin and diffusion of the H and K notation. *Journal of Astronomical History and Heritage, 13,* 120–126.

Pearson, J.C. (2010). *The Role of the 40 Foot Schaeberle Camera in the Lick Observatory Investigations of the Solar Corona*. Ph.D. thesis, Centre for Astronomy, James Cook University, Townsville, Australia.

Perdrix, J.L. (1961). The Melbourne Observatory. *Journal of the Astronomical Society of Victoria*, *14*, 19–25, 45–48, 60–64.

Perdrix, J.L. (1970). The Great Melbourne Telescope. *Journal of the Astronomical Society of Victoria, 23,* 54–67.

Perdrix, J.L. (1979). Baracchi, Pietro Paolo Giovanni Ernesto (1851–1926). In B. Nairn, & G. Serle (Eds.), *Australian Dictionary of Biography*, *Volume 7: 1891–1939. A–Ch* (pp. 166–167). Melbourne: Melbourne University Press.

Perdrix, J.L. (1990). Flagstaff Hill and its observatory. *Australian Journal of Astronomy, 3,* 113–124.

Perdrix, J.L. (1992). The last great speculum: the 48 inch Great Melbourne Telescope. *Australian Journal of Astronomy, 4,* 149–163.

Pritchard, C. (1881). On a simple and practicable method of measuring the relative apparent brightnesses or magnitudes of the stars with considerable accuracy. *Monthly Notices of the Royal Astronomical Society, 41,* 1–13.

Pritchard, C. (1882). On certain deviations from the law of apertures in relation to stellar photometry; and on the applicability of a glass wedge to the determination of the magnitudes of coloured stars. *Monthly Notices of the Royal Astronomical Society, 43,* 1–7.

Pritchard, C. (1885). *Uranometria Nova Oxoniensis. A Photometric Determination of the Magnitudes of all Stars Visible to the Naked Eye from the Pole to Ten Degrees South of the Equator.* Oxford: Clarendon Press.

Richardson, W. (1835). *Catalogue of 7385 Stars, Chiefly in the Southern Hemisphere, Prepared from Observations Made in 1822, 1823, 1824, 1825 and 1826 at the Observatory at Paramatta [sic.], New South Wales*. London: His Majesty's Stationery Office.

Robinson, T.R. (1869). On the appearance of the nebula in Argo as seen in the Great Melbourne Telescope. In *Report of the 39th Meeting of the British Association of the Advancement of Science*, [A] (pp. 20–21). London: British Association for the Advancement of Science.

Robinson, T.R., & Grubb, T. (1869). Description of the Great Melbourne Telescope. *Philosophical Transactions of the Royal Society, 159,* 127–161.

Royal Society of Victoria*. The Argus*, 12 April 1870.

Royal Society of Victoria*. The Argus*, 27 October 1882.

Russell, H.C. (1871). *Observations on the Stars and Nebula about η Argus*. Sydney: Government Printer.

Russell, H.C. (1881). Spectrum and appearance of the recent comet. *Journal and Proceedings of the Royal Society of New South Wales*, *15*, 81–86.

Russell, H.C. (1888). On the increasing magnitude of eta Argus. *Journal and Proceedings of the Royal Society of New South Wales*, *22*, 76–78.

Russell, H.C. (1890a). On some celestial photographs recently taken at Sydney Observatory. *Monthly Notices of the Royal Astronomical Society, 51,* 39–43.

Russell, H.C. (1890b). Notes on celestial photographs taken at the Sydney Observatory. *Monthly Notices of the Royal Astronomical Society, 51,* 96–97.

Russell, H.C. (1891). Notes on some star photographs taken at Sydney Observatory. No. 2. *Monthly Notices of the Royal Astronomical Society, 51,* 494–497.

Sangster, R. (1964). Obituary Notices: George Frederick Dodwell. *Quarterly Journal of the Royal Astronomical Society, 5,* 55.

Saunders, S.D. (2004). Sir Thomas Brisbane's legacy to colonial science: colonial astronomy at the Parramatta Observatory, 1822–1848. *Historical Records of Australian Science, 15,* 177–209.

Savours, A., & McConnell, A. (1982). The history of the Rossbank Observatory, Tasmania. *Annals of Science, 39,* 527–564.

Sekanina, Z. (1981). Distribution and activity of discrete emission areas on the nucleus of periodic Comet Swift-Tuttle. *The Astronomical Journal, 86,* 1741–1773.

Smith, N., & Frew, D.J. (2011). A revised historical light curve of Eta Carinae and the timing of close periastron encounters. *Monthly Notices of the Royal Astronomical Society, 415,* 2009–2019.

Steele, J.M. (2004). Applied historical astronomy: an historical perspective. *Journal for the History of Astronomy, 35,* 337–355.

Stephenson, F.R. (1997). *Historical Eclipses and Earth's Rotation*. Cambridge: Cambridge University Press.

Stephenson, F.R., & Green, D.A. (2002). *Historical Supernovae and their Remnants*. Oxford: Oxford University Press.

Sullivan, W.T. III (2009). *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge: Cambridge University Press.

Sullivan, W.T. III (2017). The beginnings of Australian radio astronomy. In T. Nakamura, & W. Orchiston.

Szabados, L. (2014). Konkoly Thege, Miklós. In T. Hockey et al., pp. 1235–1237.

The Argus, 8 July 1870.

The Argus, 14 July 1873.

The Australasian Sketcher, 26 December 1874.

The coming eclipse. The arrangements for observation. The scientists to come. What the public may see. *The Mercury*, 7 April 1910a.

The coming eclipse. The expedition to Bruni. Interview with Mr. Baracchi. Chances of success small. *The Mercury*, 16 April 1910b.

The coming eclipse of the Sun. *The Advertiser*, 15 February 1910c.

The eclipse. How the astronomers fared. Results better than expected. *The Advertiser*, 10 May 1911.

Today's eclipse. Shadow on the Pacific. Scientists at work. *The Argus*, 29 April 1911.

Today's eclipse. Sun almost obscured. *The Argus*, 9 May 1910.

Tors, S., & Orchiston, W. (2009). Peter Millman and the study of meteor spectra at Harvard University. *Journal of Astronomical History and Heritage, 12,* 211–223.

Turner, H.H. (1912). *The Great Star Map: Being a Brief General Account of the International Project Known as the Astrographic Chart.* London: John Murray.

Turner, J. (1882–1883). Work accomplished with Gt Telescope from July 1/182 till June 30/83. Original in the National Archives of Australia (A7798/1, Item 28).

Turner, J. (1883). Dairy. Original in the National Archives of Australia (A7798/1, Item 26).

Urban, S., & Corbin, T. (1998). The Astrographic Catalogue: a century of work pays off. *Sky & Telescope, 95*(6), 40–44.

Utting, M. (1989). *Cooke's Perth Observatory*. Perth: Perth Observatory.

Utting, M. (1992). *Astronomy in Western Australia. Vol. 1: 1896 to 1912*. Perth: Perth Observatory.

van Genderen, A.M. (2001). S Doradus variables in the Galaxy and the Magellanic Clouds. *Astronomy and Astrophysics, 366,* 508–531.

Vsekhsvyatskii, S.K. (1964). *Physical Characteristics of Comets*. Jerusalem: Israel Program for Scientific Translations.

Walborn, N. R., & Liller, M.H. (1977). The earliest spectroscopic observations of Eta Carinae and its interaction with the Carina Nebula. *The Astrophysical Journal, 211,* 181–183.

Weiderkehr, V.H. (1988). Georg Neumayer und die Gründung eines geophysikalisch-nautischen Observatoriums in Melbourne 1857. In W. Schroeder (Ed.), *Past, Present and Future Trends in Geophysical Research* (pp. 111–125). Bremen-Roennebreck: International Committee on History of AIDA.

White, G.L. (1988). The Carte du Ciel – the Australian connection. In S. Débarbat, J.A. Eddy, H.K. Eichhorn, & A.R. Upgren (Eds.), *Mapping the Sky: Past Heritage and Future Directions* (pp. 45–51). Dordrecht: Kluwer.

Williams, T.R. (2014). Draper, John William. In T. Hockey et al., p. 610.

Wood, H.W. (1958). *Sydney Observatory 1858–1958*. Sydney: Government Printer.

Wyse, A.B. (1940). The spectrum of Nova Aquila (1918) right ascension: 18h 43.8m; declination: +0° 28′ (1900). *Publications of the Lick Observatory, 14,* 93–215.

Young, C.A. (1881a). Spectroscopic observations of Comet *b* 1881. *The Observatory, 4,* 256–257.

Young, C.A. (1881b). Spectroscopic observations upon the Comet *b* 1881. *The Observatory, 4,* 282–284.

Young, C.A. (1902). *Manual of Astronomy: A Text Book*. Boston, Ginn & Co.

Chapter 18
The Beginnings of Australian Radio Astronomy

Woodruff T. Sullivan III

18.1 Introduction

Australian radio astronomy has been at the forefront since its foundation during World War II, with imaginative scientists and engineers, innovative equipment, and strong sponsorship. Soon after War's end a multi-faceted program, by far the largest of its kind in the world, was well established at the Radiophysics Laboratory (RP) in Sydney and continually producing pioneering results. The Australians developed fundamental methods of interferometry, discovered the Sun's hot corona, pinpointed the location of solar bursts, and discovered numerous discrete radio sources. By the late 1950s they had produced far more papers in radio astronomy than any other group in the world, and were acknowledged leaders in research on the Sun, Galactic structure, and radio sources. But as new telescope projects became ever more costly, tensions developed over which ones could be funded, resulting in many of the key researchers leaving RP in the 1960s. RP's subsequent work focused on the Parkes Radio Telescope (1961) and Culgoora Radioheliograph (1967), while Sydney University sponsored the Molonglo Cross (1965) and the Fleurs Synthesis Telescope (1973). In subsequent years, these instruments were continually improved, but to remain competitive with the rest of the world eventually a yet larger, national centerpiece was needed—this became known as the Australia Telescope (1988).

How was it that a small, isolated country such as Australia succeeded so impressively in such an arcane field as radio astronomy in the mid-twentieth century? The answers go back to World War II and Australia's relationship with the mother country, as well as the Australian government's policies toward its scientific laboratories. First, a strong community of radio physicists developed in Australia in the 1930s, based on intimate ties with the ionospheric community in England. Second, Britain shared the secret of radar with its Dominions as the War began, nurturing intense

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radar research, development, and manufacture in Australia. Third, the team of scientists and engineers that grew out of that effort, primarily at RP, remained intact at War's end, and soon put their new skills to use in developing peacetime research ventures. And finally, for two decades dynamic and skillful leadership was provided by E.G. 'Taffy' Bowen and Joseph L. Pawsey—two men whose styles of science and complementary personalities produced a favorable mix for exploring and exploiting the most profitable avenues into the radio-sky.

It is impossible to relate the entire story in the allotted space—major published sources for various aspects of the history of Australian radio astronomy are by Bhathal (1996), Collis (2002: Chap. 13), Goddard and Milne (1994), Haynes et al. (1996: Chap. 8), Orchiston and Slee (2005), Robertson (1992), and Sullivan (1988). More general histories, of which major portions cover Australia, are by Edge and Mulkay (1976), Hey (1973), and Sullivan (1982, 1984a, b). This chapter is a direct copy of Sullivan (2005) and is substantially similar to Sullivan (1988). I treat the first decade after World War II in some detail, and only briefly cover the ensuing years, for it was during this period that the technical, scientific and cultural foundations were laid for many decades of success.

18.2 The Radiophysics Laboratory during the Post-war Decade

18.2.1 Transition to Peacetime

The Radiophysics Laboratory (RP) had been established in 1939 in the grounds of Sydney University as a secret branch of the Council of Scientific and Industrial Research (CSIR). Its staff was largely drawn from the strong radio ionospheric community that had been built up during the 1930s by J.P.V. Madsen at Sydney University, T.H. Laby at Melbourne University, and the Sydney research laboratory of Amalgamated Wireless (Australasia), Ltd. (AWA) (Gillmor 1991). During World War II, RP both designed wholly new radar systems and adapted British radars to Australian needs, and by War's end the staff numbered over three hundred, of whom sixty were professionals and fourteen bore names that would later become familiar in radio astronomy.

As the War closed, various memoranda began to circulate on potential peacetime roles for the Laboratory, culminating in an agenda paper put together by Taffy Bowen (1911–1991; Fig. 18.1) for a meeting of the CSIR Council in July 1945 (Bowen 1945a). Bowen, who would soon take over as Divisional Chief, had been working on radar for over a decade (Bowen 1987). He had been trained in physics at the University of Wales and studied atmospheric physics for his Ph.D. under E.V. Appleton at the University of London in 1933. Two years later, Robert Watson-Watt co-opted him into the initial team of four that developed the first operational military radar systems, which soon became vital in the defense of Britain against the

Fig. 18.1 E.G. Bowen (*center*) and J.L. Pawsey (*right*) greet E.V. Appleton on board ship after his arrival in Sydney in 1952 for the URSI General Assembly (*Courtesy* ATNF RAIA)

Luftwaffe. He led the development of 200 MHz airborne radars, for which he flew thousands of hours (often with Robert Hanbury Brown, who would himself later become a central figure in the development of radio astronomy). In 1940 Bowen was a member of the famous Tizard Mission that delivered radar secrets to the United States, including the cavity magnetron, the first source of power sufficient to make microwave radar a feasible proposition. He remained in the USA for three years, eventually developing airborne radar systems at the MIT Radiation Laboratory. In early 1944 he went to RP as its Deputy Chief, and, although still officially on loan from the British, soon took a liking to RP and to Sydney and spent the remainder of his career (until 1971) there as Chief.

Bowen's proposals for RP's peacetime role were warmly received and quickly endorsed by his CSIR bosses A.C.D. Rivett and Frederick G.W. White, a New Zealander who preceded Bowen as RP Chief for three years. Rivett felt strongly that each CSIR division should achieve a roughly even balance between free-running basic research and applied research, a vital element in the culture of CSIRO. RP's proposed program thus emphasized new scientific possibilities as well as areas where Australian commerce and industry would more immediately benefit. Bowen and his staff were clearly as excited about the potential of radar techniques in peace time as they were weary of applying them to warfare. It mattered not that RP's original *raison d'être* had disappeared—fresh directions could now be charted. The agenda paper enthused that the new radar techniques were "… perhaps as far-reaching in themselves as the development of aircraft [during World War I] or the introduction of gunpowder in a previous era." It laid out a long shopping list of possible projects in radio propagation, vacuum research (directed toward generating power at millimeter wavelengths), radar aids to navigation and surveying, and radar study of weather. These topics, along with producing the *Textbook of Radar*, which incorporated RP's knowledge and was edited by Bowen (1947b), were to form the initial postwar program.

At this time, RP was CSIR's glamour Division, arguably containing within its walls the densest concentration of technical talent on the continent, and CSIR was eager to keep this 'winner' intact. As Frank Kerr, one of RP's early staff members, recalled:

> [Basic radio research] … was thought of as a good subject for the Lab to get into, partly in order to keep the Lab in being because it was a collection of good people, well trained in the arts of radio. Especially at that time there was a feeling that it had been a great national value to have had the Lab, and so it was possible to sell the idea to the authorities that the group should be kept in existence as a 'national asset'. (Kerr 1971: 7T).[1]

Keeping the best of the research staff at RP was also immeasurably aided by the fact that research in physics and engineering at Australian universities after the War was minimal; Government funds for university scientific research were thirty times less than for CSIR. In contrast to the situations in England and the United States, the young cadre of RP researchers saw their wartime Laboratory as the best place to continue their peacetime careers. Despite a considerable reduction of staff at War's end, most who left were not oriented toward research. Few researchers had come from the universities (except as recent graduates) and fewer returned. Academia's role in Australian physics research would not strengthen until the 1950s when students were first able to do their postgraduate work at home (Home 1982–1983).

RP's assets included not only its scientists and engineers, but also its significant support staff of technicians, a camaraderie molded during the War, ample laboratory space and workshops, and bulging stores with the latest radio electronics. This last was considerably augmented shortly after the War's end by an extraordinary bonanza. A large amount of American and British equipment (including whole aircraft!) was being discarded by loading it on the decks of aircraft carriers, taking it a few miles offshore, and bulldozing it into the sea. Bowen got wind of this, however, and for two or three weeks was allowed to take RP trucks down to the Sydney docks and load them up with radar and communications equipment, often in unopened original crates. For several years thereafter RP researchers drew on this surfeit.

While RP's continued existence was assured, its direction changed from developing military hardware to a mixture of fundamental research and applications of radio physics and radar to civilian life. This policy was one of the key ingredients of RP's postwar success; in his 1945 strategy document Bowen stated that peacetime military work by CSIR "… stifles research and seldom produces effective assistance to the Armed Forces." In 1949, the CSIR became the CSIRO, or Commonwealth Scientific and Industrial Research Organization, and White became its number-two

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[1] Citations of the form '1971: 7T' refer to page 7 of the transcript of my 1971 interview. The form '1971: 32A' refers to side A of Tape 32 of my (untranscribed) 1971 interview, and 'B' to side B.

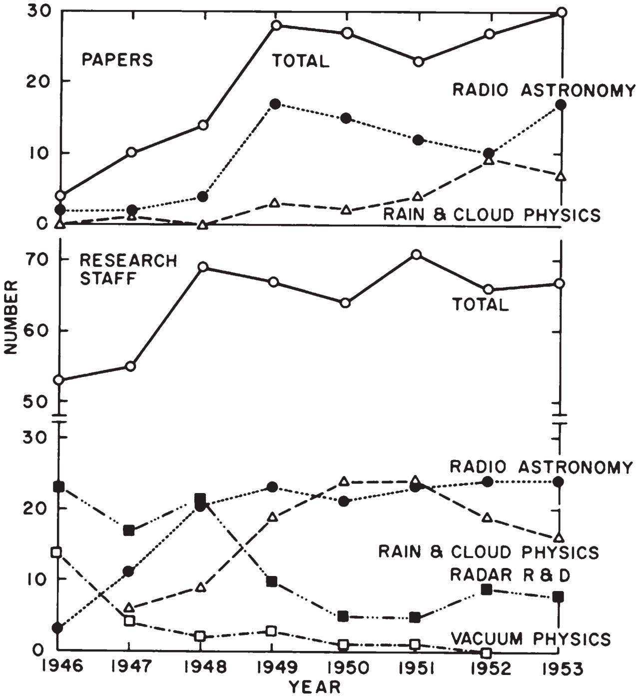

Fig. 18.2 The growth and decline of different research areas at RP over the period 1946–1953, as gauged by the number of published papers per year and the number of research staff. Staff levels not plotted include those for ionosphere (which fell in a similar manner to vacuum physics) and mathematical physics and electronic computing (which rose to a level of about 10 by 1951–1953) (*Plot* Woodruff Sullivan III)

man—over the next two decades he was a major force in fostering the growth of his old division (see Minnett and Robertson 1996).

18.2.2 Overall Research Program

Major programs at RP waxed and waned over the years 1946–1953. The plots of Fig. 18.2 show the bare trends,[2] but one of the leading researchers, namely Paul Wild (1965), more elegantly likened these years to the Biblical parable:

> A sower went out to sow his seed, and as he sowed some fell by the wayside and **it** was trodden down and the fowls of the air devoured it. And some fell upon a rock, and as soon as it sprung up it withered away …And other fell on good ground, and sprang up and bore fruit an hundredfold. (i.e. Luke 8: 5–8).

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[2] The data of Fig. 18.2 come primarily from annual reports and lists of publications issued by the Division of Radiophysics (File D2, RPS).

Vacuum physics work died away within two years and work on radar applications steadily lessened over the first five years. The two research programs that grew were radio astronomy (although note that this term was not used until the 1949 report) and rain and cloud physics. Between 1946 and 1949 these increased their share of the professional staff from 6 to 63%. Because the total staff grew by only one-quarter over this same period, there were clearly many reassignments of personnel. In terms of papers published in the scientific literature, radio astronomy and rain and cloud physics also dominated, accounting for 71% of the papers by 1949 and 65% over the eight-year span. The radio astronomy staff (compared to cloud physics) produced more than double the number of papers per person.

Rain and cloud physics, in which Bowen himself specialized and which he personally oversaw, attempted to understand the way clouds and rain behave. Microwave radar measurement of clouds and rain, often from aircraft, became a central technique. Buoyed by one of the first successes in seeding clouds, the RP group hoped that rainmaking for the dry Australian climate would ultimately become a reliable and economic proposition. Although this never happened, Bowen's group became one of the international leaders in the field (Home 2005). This effort, as well as the development of radar systems for commercial aviation, such as a distance-measuring equipment allowing airliners to locate themselves relative to beacons, were important as practical areas balancing off fundamental research in astronomy, fast becoming RP's most visible sector (Bowen 1984: 105–109; Minnett 1978: 66–68T). But even radio astronomy was sometimes shoe-horned into the role of practicality, as in the 1949 *Annual Report*:

> Radio astronomy has already made important contributions to our knowledge and, like any fundamental branch of science, is likely to lead to practical applications which could not otherwise have been foreseen. For example, attempts to explain how certain types of radio waves arise in the Sun are already leading to new techniques for the generation and amplification of radio waves.

Other projects included a mathematical physics section and (after the late 1940s) a group developing an early electronic computer (CSIRAC). And there were always a few ionospheric radio projects going on. The one example of a major effort that failed was vacuum physics, when costs of a desired particle accelerator became too great.

18.2.3 Growth of Research on Extraterrestrial Radio Noise

Buried in the twenty-four pages describing RP's post-war plan is a fraction of a page under "Radio Propagation" called "Study of extra-thunderstorm sources of noise (thermal and cosmic)":

> Little is known of this noise and a comparatively simple series of observations on radar and short wavelengths might lead to the discovery of new phenomena or to the introduction of new techniques. For example, it is practicable to measure the sensitivity of a radar receiver by the change in output observed when the aerial is pointed in turn at the sky and at a body

> at ambient temperature. The aerial receives correspondingly different amounts of radiant energy (very far infrared) in the two cases. Similarly, the absorption of transmitted energy in a cloud can be estimated in terms of the energy radiated to the receiver by the cloud. None of these techniques is at present in use. (Bowen 1945a).

It was this enigmatic paragraph, with its heading designed primarily to indicate that it was *not* talking about thunderstorm noise (atmospherics), which would develop into RP's radio astronomy program! It surprisingly did not explicitly mention *solar* noise, but instead proposed an exploratory program of "very far infrared" radiometry wherein antennas would be pointed to different parts of the sky.

But when reports of anomalies arrived from radar stations (Sect. 18.3.1), Pawsey and his colleagues jumped on solar observations in October 1945 and never turned back. Joseph L. Pawsey (1908–1962; Fig. 18.1) by this time had become the linchpin and recognized leader of RP's fundamental investigations through his Propagation Research Group. He had studied physics at Melbourne and obtained his Ph.D. in 1934 under J.A. Ratcliffe at Cambridge, with a dissertation on radio waves reflected off the abnormal E layer of the ionosphere. For five years he then developed equipment needed to make television a viable reality at the famous BBC station at Alexandra Palace. Pawsey's main contributions, which involved no fewer than twenty-nine patents, were in designing the transmission lines and antennas necessary for television's broad bandwidth. After the outbreak of WWII he hastened home and joined the RP staff early in 1940. He became the local 'wizard' on antennas and transmission lines, but by War's end he had also gained new skills working on receivers, operational aspects of radar systems, and atmospheric propagation. Just as importantly, the intense wartime environment had cultivated and honed his abilities to lead scientific research teams. For further biographical details of Pawsey, see Christiansen and Mills (1964) and Lovell (1964).

Work on extraterrestrial noise steadily grew, with Bowen as Chief and Pawsey as his right-hand man (in charge of most research activities) willing to shift resources toward those persons showing superior results or great promise. This flexibility was the CSIR style, largely molded by Rivett, who believed that research programs should be based on people, not topics—getting the right people and then letting them loose. As Bowen (1978: 42T) recalled:

> We tried many things, but the criterion for going on with any program was, of course, success. And the things that Pawsey was trying on the Sun and Bolton on point sources were so outstandingly successful that that's the way we went … With our first-rate staff as a handout from the War, we had the freedom and the encouragement to find new projects.

Or as Pawsey (1961: 182) put it:

> [Scientific directors must] … very quickly make decisions and supply facilities for the really promising developments. In all too many cases elsewhere the energies of scientists are taken up in advertising the potentialities of their prospective investigations in order to obtain any support at all.

As the years passed, work on solar and cosmic noise grew in importance at RP and a circle of group leaders emerged (most are pictured in Fig. 18.3). Besides his overall supervision, Pawsey led a large group studying numerous aspects of the

Fig. 18.3 Radio astronomers at Sydney University for the 1952 URSI General Assembly. Left to right, ground level: W.N. Christiansen, F.G. Smith (England), J.P. Wild, B.Y. Mills, J.-L. Steinberg (France), S.F. Smerd, C.A. Shain, R. Hanbury Brown (England), R. Payne-Scott, A.G. Little, M. Laffineur (France), O.B. Slee, J.G. Bolton. First step: C.S. Higgins, J.P. Hagen (USA), J.V. Hindman, H.I. Ewen (USA), F.J. Kerr, C.A. Muller (Netherlands). Second step: J.H. Piddington, E.R. Hill, L.W. Davies (*Courtesy* ATNF RAIA B2842)

radio Sun (Sect. 18.3). In 1947 John G. Bolton began his pioneering work on discrete radio sources (Sect. 18.4) and soon had an active group around him. J. Paul Wild arrived in 1947 and, after a year languishing in the instrument test room, moved into research on solar radio bursts with a swept-frequency receiver. Bernard Y. Mills worked on a variety of projects before permanently switching to radio astronomy in 1948; then he briefly researched the Sun before beginning his own program on discrete sources. W.N. 'Chris' Christiansen arrived at RP in 1948 from AWA and immediately plunged into his own solar research program. He was unique among this group in that, despite his career as an antenna engineer, he had long wanted to be an astronomer (Christiansen 1976, 1: 6T). Jack Piddington and Harry C. Minnett began a program of microwave research in 1948 (for example, measuring the brightness temperatures of the Moon), and Frank J. Kerr and C. Alexander Shain started on lunar radar in 1947 in order to study the ionosphere (Westerhout 2000). Finally, Stefan F. Smerd and Kevin C. Westfold complemented all of the observational work by working on the theory of solar radio emission.

Among all these successes the RP archives also give evidence of at least one important (in retrospect) missed opportunity, that of discovering the 21 cm spectral line arising from interstellar hydrogen. The line had been predicted in 1944 in Holland, and its 1951 discovery at Harvard and Leiden Universities was to be one of the major turning points in early radio astronomy. Pawsey got wind of the idea in early 1948 while on a tour of the United States. His report home triggered two years of intermittent activity at RP. Wild published a full theoretical analysis, Bolton and

Westfold translated a Russian paper and were eager to search for the line, and Mills also gave the hunt serious consideration. But despite all this activity, in the end the decision every time of Bowen, Pawsey and their staff was to not pursue the line. For example, Mills was looking for an independent research area on cosmic noise to pursue in 1949, and he and Pawsey discussed two main avenues:

> One was a search for the hydrogen line. Pawsey was very interested in it at the time. And the other was trying to locate very precisely the positions of radio sources. And it was a difficult decision to make. I eventually chose the precise positioning because I was more familiar with some of the techniques, and it looked as if it was something that would lead to an immediate result, whereas the other was extremely speculative. (Mills 1976: 6–7T).

Mills went on to make vital contributions to knowledge of discrete sources, so the decision in his case not to pursue the hydrogen line can hardly be called a managerial mistake. Nevertheless, given its resources and technical expertise, the fact remains that RP surely would have soon succeeded in detecting the interstellar 21 cm line if it had ever made a serious effort. As it turned out, RP *did* make first-rate contributions to 21 cm hydrogen observations in the early 1950s (starting with Christiansen and Hindman, 1952), but only after others had taken the initiative.

18.3 Early Solar Work

18.3.1 Wartime Efforts

As radar receivers during the War became more sensitive and moved to higher frequencies, concepts of receiver noise, background noise and antenna temperature gained currency:

> Receivers were getting more and more sensitive and we were concerned with the whole thermodynamic theory of their noise level and its relationship, through the antenna, to space—if the antenna were in an enclosure at three hundred degrees, what would be the noise level? This was different from the purely circuit approach that had been worked up by Nyquist and others …And it obviously occurred to Ruby Payne-Scott and Joe Pawsey that radiation from objects might possibly be seen. I remember that Ruby had a small paraboloid poking out a window at certain objects in the sky to see how the noise level varied. (Minnett 1978: 10T).

Ruby V. Payne-Scott (1912–1981; Fig. 18.3), the only woman to make a substantial contribution to radio astronomy during the post-war years, was able to do so only because she kept her marriage secret from 1944 to 1950, when CSIRO changed its policy forbidding married women to join the permanent staff. But the following year she resigned from RP in order to raise a family, and never again participated in research. She trained before the War as a physicist at Sydney University, worked on cancer radiology, spent two years at AWA, and from 1941 on at RP mainly worked on display systems and calibration of receivers. She soon became known around RP for her considerable intellectual and technical prowess, forthright personality, and 'bushwalking' avocation.

It was in March and April 1944 that Pawsey and Payne-Scott (1944) first looked at the microwave sky. In their subsequent RP report they discussed various contributions to the noise power measured by a receiver-antenna combination and cited Karl Jansky's and Grote Reber's (1940) work in the US on cosmic static. But their operating wavelength of 10 cm was far shorter than that of earlier reported work on noise from either terrestrial or extraterrestrial sources. They used a 20 × 30 cm horn connected to a receiver with a system temperature of ~3500 K, one person pointing the horn around the room or out the window in various weather conditions, the other taking readings from a meter. Changes of 20–300 K in antenna temperature were noted, and Pawsey and Payne-Scott were particularly struck by the apparently low absolute temperature of the sky, less than 140 K. Moreover, they noted a "most unusual" consequence of this: inserting attenuation between the horn and receiver actually *increased* the output!

They also tried to detect microwaves from the Milky Way with the same receiver and a 4 ft dish pointing first in the vicinity of Centaurus and then away. There was no detectable difference, that is, less than ¼% (<10 K), "… very much less than that observed by Jansky and Reber." (ibid.). Appealing to Eddington's work in the 1920s (about which they undoubtedly learned from a citation by Reber), they ascribed the low signal to a very low temperature for the material in space.

These Milky Way results were accompanied by a single sentence stating that they did not try for any solar radiation. It would seem that they were then unaware of either J.S. Hey's British or G.C. Southworth's American secret reports on the Sun, but given that they mentioned the Sun at all, why did they not try for it? If they had, they probably would have easily detected a change in power output.[3]

These kinds of ideas were thus in the air around RP and therefore, as already discussed, merited a short paragraph in Bowen's proposed postwar program. But the archival evidence indicates that what really galvanized Bowen and Pawsey into jumping onto solar noise was not this preliminary experiment, nor reports from overseas, nor *ab initio* calculations, but the 'Norfolk Island effect'—solar radio bursts observed by New Zealand military radar stations from as early as March 1945 (Orchiston 2005a). When Bowen learned of this in July 1945, he was entranced:

> These results are remarkable in that while one would expect to receive solar noise radiation on S. or X. band equipment [10 or 3 cm wavelength], a C.O.L. antenna and receiver at 200 Mc/s is quite unlikely to do so. I have heard rumours of the same thing happening in

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[3] If we assume a brightness temperature of the Sun (at solar minimum at 10 cm wavelength) of 35,000 K, then Pawsey and Payne-Scott would have detected an antenna temperature with their 4-ft dish of ~150–200 K, well above their sensitivity to relative changes of ~20–30 K. This type of dish and microwave receiver was in fact very similar to that employed by George Southworth in 1942–1943. Minnett (1986) has speculated, from his memory of the room used, that in March the Sun was not easily observable from any window. Although there is no written record of anyone at RP trying for the Sun before the end of the War, Frank Kerr (1971: 7T, 1976: 53T) recalled a brief attempt he made at a wavelength of 1.5 m with a small antenna. He also recalled that the first RP solar observations were motivated by overseas reported detections of the Sun, and not by the 'Norfolk Island Effect' as I have concluded. Piddington and Martyn also made a brief attempt to observe the Sun in 1939 (Piddington 1978: 1–4T).

> England, but as far as I am aware, the subject has never been followed up. We are therefore going to attempt to repeat the observations here in Sydney to see if we can track down the anomaly. (Bowen 1945b).

This letter testifies that in August 1945 Bowen and Pawsey knew about thermal, microwave radiation from the Sun, presumably from Southworth's restricted report or his early 1945 paper, but were unaware of Hey's low-frequency solar bursts, either from his 1942 report or its later June 1945 version. Instead, their first investigations were triggered by the New Zealand work, which itself was never published as more than a laboratory report and a short paper in an obscure journal (Alexander 1945, 1946; Orchiston 2005a; Orchiston and Slee 2002). Furthermore, the thrust of these investigations was toward monitoring the Sun for non-thermal bursts of radio waves, unlike what was stated in Bowen's proposed program.

18.3.2 Solar Bursts and the sea-Cliff Interferometer

Pawsey swung into action and mounted an observing program on a frequency of 200 MHz using existing Air Force radar installations along the coastline near Sydney. Working with him on this were Payne-Scott and Lindsay L. McCready (1910–1976), a receiver expert, pre-war AWA engineer, and RP veteran who at the time was Pawsey's deputy and eventually head of all engineering services at RP. The first observations were on 3 October from Collaroy, fifteen miles north of Sydney (Fig. 18.4) and one-half mile inland. The antenna was an array of 32 half-wave dipoles (Fig. 18.5), and observations were carried out by Air Force as well as RP personnel. After only a week or two of data, Pawsey (1945) noticed that the general level of "this noise effect" was highly variable and seemed to correlate with the number of visible sunspots. For the latter information he had made contact with Clabon W. (Cla) Allen (1904–1987), a long-time solar astronomer at the Commonwealth Solar Observatory, Mt. Stromlo (near Canberra).

After three weeks of monitoring, Pawsey et al. (1946) sent a letter to *Nature* pointing out the close correspondence between the total area of the Sun covered by sunspots and the daily noise power from the Sun. Because the antenna's elevation angle could not be changed, observations were only possible at dawn or dusk and various corrections had to be made for ground and sea reflections, but it was nevertheless clear that the daily values of solar noise varied by as much as a factor of thirty over the three weeks. They also pointed out that, for a thermally emitting disk the size of the optical Sun, their detected levels implied 'equivalent temperatures' ranging from 0.5 to 15 × 10^6 K, much higher than the Sun's 'actual temperature' of 6000 K. Such incredible signals, they reasoned, could not come from atomic or molecular processes, but more likely from "… gross electrical disturbances analogous to our thunderstorms."

With such a promising start, Bowen and Pawsey decided to increase their efforts on solar noise, and continued monitoring for another ten months. Gradually Air

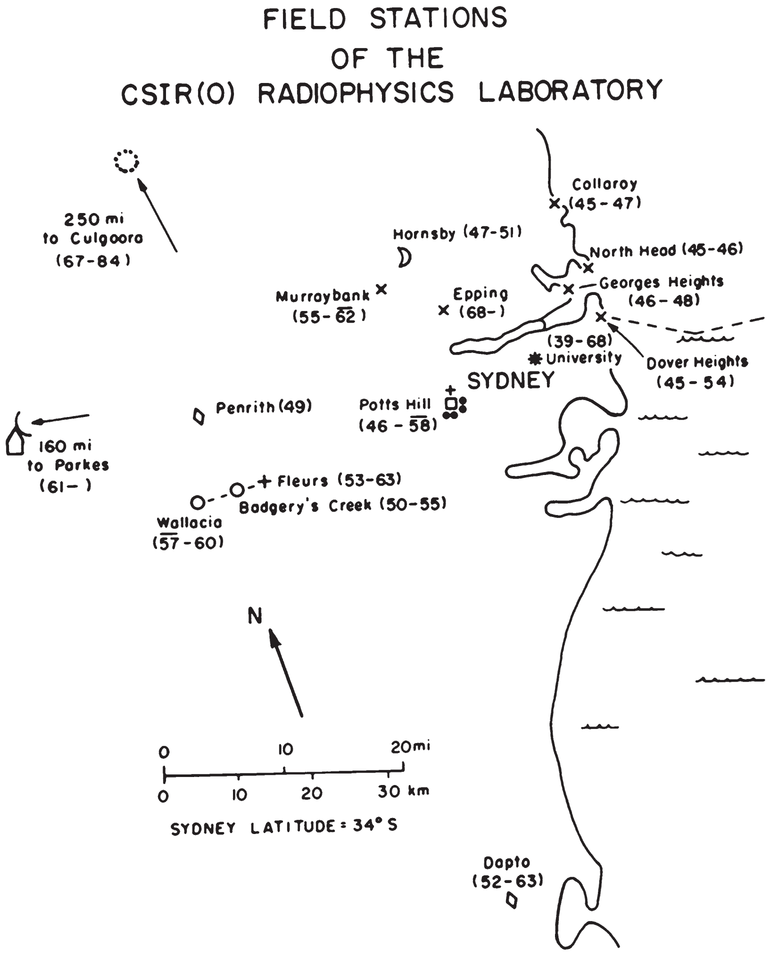

Fig. 18.4 Sites of chief RP field stations and headquarters at Sydney University and at Epping. Each station has the years of operation indicated (years with a bar overhead are uncertain) (*Map* Woodruff Sullivan III)

Force personnel and equipment were phased out as RP took over. Pawsey's group made measurements at a variety of frequencies (but mostly at meter wavelengths), and used antennas (e.g. see Fig. 18.6) located at four different coastal radar sites around Sydney: Collaroy, North Head, Georges Heights, and Dover Heights (Orchiston and Slee 2005) (see Fig. 18.4). And while these data rolled in, they also educated themselves about the solar atmosphere and began thinking about how it might emit radio waves. This led to Payne-Scott's discovery of incorrect calculations by Southworth, and to some changing interpretations. For instance, Bowen wrote to Appleton in January 1946 in order to comment on the latter's letter in *Nature* on radio noise and sunspots. Bowen (1946a) pointed out that RP had now

Fig. 18.5 The 200 MHz wartime radar antenna for shore defense, consisted of a 36-dipole array rotatable only in azimuth, at Dover Heights (1941). This and a similar antenna at Collaroy were used by Pawsey's group in 1945–1946 as sea-cliff interferometers for observations of the rising Sun (*Courtesy* ATNF RAIA B81-16)

obtained the "… first direct experimental verification of this effect … ", and that, unlike in the upcoming *Nature* letter from RP, he now felt that the solar noise was not "electromagnetic", but of thermal origin, either "… from the depths of the sun or in some way from the corona."

The climax of this initial period came in early February 1946 when by good fortune the largest sunspot group ever seen (until then) chose to make its appearance. When Allen phoned with news of the giant group (covering about 1% of the Sun's visible disk), the RP group intensified their monitoring and realized that they now had the opportunity to take advantage of a property of their antenna system that previously had been more bother than help. A single antenna situated on the edge of a cliff or a hilltop, looking near the horizon over a relatively smooth terrain or over the sea, in fact acts as an interferometer and can achieve far better angular resolution than would otherwise be possible. The interference in this case is between that portion of a wave-front directly impinging on the antenna and that portion reflected from the sea, which must travel an additional length equal to twice the cliff height times the sine of the source's elevation angle. In classical optics this arrangement is known as 'Lloyd's mirror', and the fringes obtained are equivalent to those with a conventional interferometer consisting of the antenna and an imaginary mirror image located under the base of

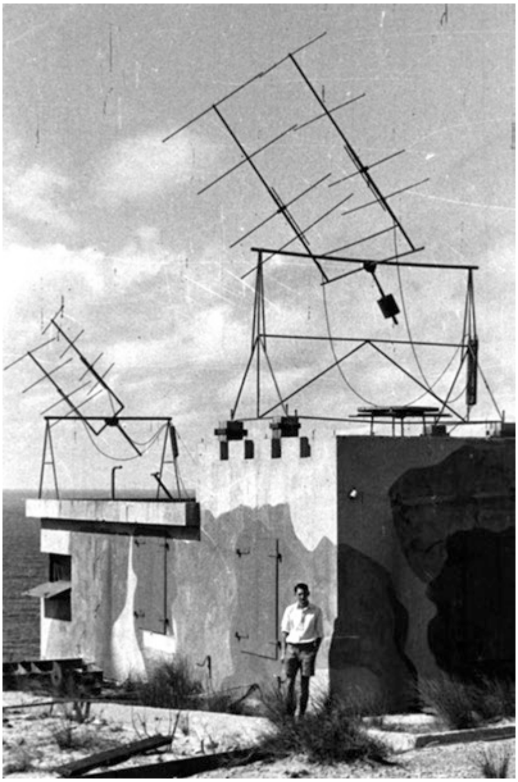

Fig. 18.6 WWII blockhouse, 100 MHz (left) and 60 MHz (right) twin Yagi antennas at Dover Heights (1947). The same pairs, with the Yagi elements parallel and pointing toward the horizon, were used for the first studies and surveys of discrete sources by John Bolton (pictured) and his group (*Courtesy* ATNF RAIA B1031-6)

the cliff. With the antennas at Dover Heights and Collaroy located 85 and 120 m above the sea, the respective fringe lobes at 1.5 m wavelength were spaced by 30′ and 21′. In principle, then, one could locate objects with an accuracy of ~10′, far better than the ~6° beam of the antenna considered by itself.

This phenomenon was nothing new to those who had been developing radar systems, for during the War radar beams often pointed near the horizon, as with search radars on a ship or a coastline. The reflected signal from a distant aircraft was well known to oscillate as it passed through the fringes or lobes of such a radar. This effect was both a blessing and a curse to the radar systems designer, for it could be used to gather precise information on a target's height, but on the other hand it meant that low-flying aircraft could sneak in 'under' a radar, since the first lobe was *not* at the horizon, but above it by a considerable amount, especially if the antenna was not high above its surroundings.

So Pawsey and his colleagues used this sea-cliff interferometer[4] to advantage as the bespotted Sun rose over the ocean. The general level of solar emission was far above normal for several days and often interspersed with bursts. As before, they

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[4] I use the term *sea-cliff interferometer*, although at the time the arrangement was called either a *sea interferometer* or a *cliff interferometer*.

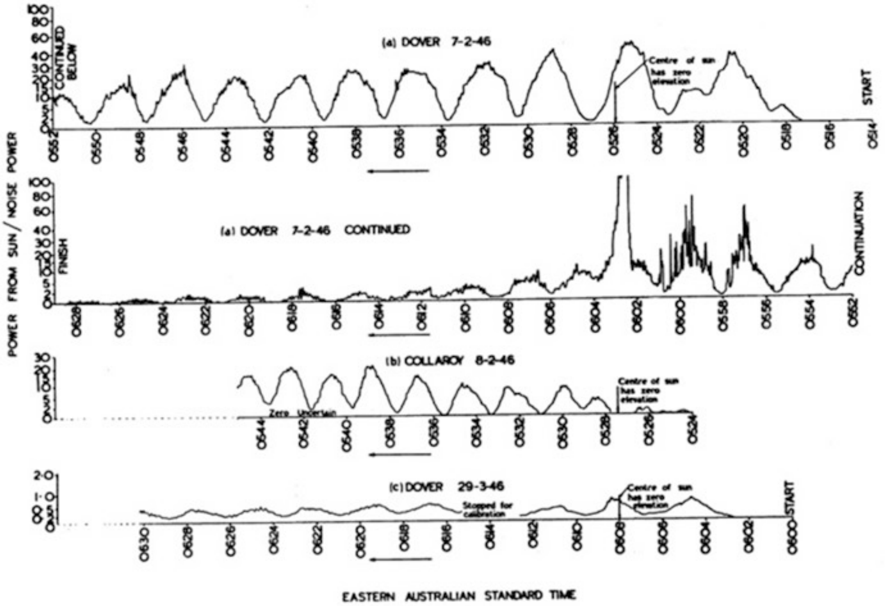

Fig. 18.7 Sea-cliff interferometer interference patterns obtained at 200 MHz in February and March 1946. When the Sun rose, the fringes suddenly appeared (note that 'radio sunrise' came earlier than optical sunrise) and then gradually faded away an hour later as the Sun moved above the antenna beam. Note the greater ratio of fringe maximum to minimum for the top observations, indicating that the radiation originated from a smaller region of the Sun. The very fast variations and intense signals recorded at 0600 on 7 February indicate a solar outburst. Note the closer spacing of the fringes for the Collaroy observations, taken from a higher elevation above the sea (after McCready et al. 1947)

found that the solar signal appeared at sunrise and gradually faded as the Sun rose above the antenna beam, but now superimposed were striking oscillations, the interferometric fringes (Fig. 18.7). And the exciting thing was that the very presence of these oscillations implied that the source of the solar signal was a good bit smaller than the spacing of the fringes (20–30′) and the 30′ size of the optical Sun. Exactly how much smaller the emitting region was, as well as its location, could be worked out through details of the oscillations' amplitudes and phases. This led to Fig. 18.8, where they inferred that the emitting region on any given day had a width of 8–13′ and coincided with the giant sunspot group being carried along by the Sun's rotation. Even though the fringes of the sea-cliff interferometer were oriented parallel to the horizon and thus could give no information about the azimuth of the emitting region, it seemed eminently reasonable that the sunspot group itself originated the enhanced radiation, directly confirming what Hey, Appleton and Alexander had earlier only surmised.

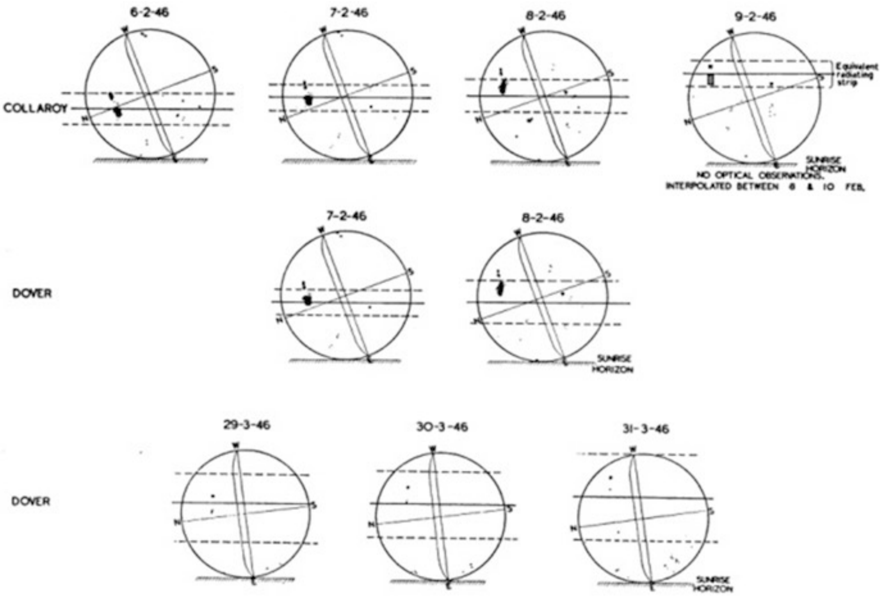

Fig. 18.8 Sketches of optical sunspots visible on the days corresponding to Fig. 18.7. The top two rows are dominated by the great sunspot group, while the March observations show much less activity. 'N–S' indicates the rotation axis of the Sun. The three horizontal lines on each sketch indicate the center and estimated width of the 'equivalent radiating strip' causing the radio fringes (after McCready et al. 1947)

In a paper submitted to the *Proceedings of the Royal Society* in July 1946,[5] McCready, Pawsey and Payne-Scott (1947) reported the above results and much more. They expanded on their first results in *Nature* and now characterized the solar radiation as consisting of two components: (1) a slowly changing type that could vary by a factor of 200 in intensity over many days, and (2) intense bursts, lasting from less than a second up to a minute, that could be tens of times more powerful than the general level on a given day. These results were so unexpected that they worried at length that the ionosphere might somehow induce the bursts, but various arguments, principally the fact that separate sites observed the bursts at the same time (to within a second), convinced them that this indeed was an extraterrestrial "and presumably solar" phenomenon. As in their previous letter to *Nature*, they

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[5] The introduction to this paper (McCready et al. 1947) provides an especially good example of how historical information is usually lost in the formalism of a scientific paper. In this case it appears to have happened because of referee's comments rather than in the initial writing. The submitted manuscript was Report No. RPR 24 (for some reason with a different author order: Pawsey, Payne-Scott and McCready), dated 16 June 1946, and contained historically-interesting material about what the Sydney group knew from overseas reports and when they knew it. The finally-published version, however, was modified in several places to merely recite who published what and what they said. In particular, the phrase "In a prior letter, not available here until our initial work was completed, Appleton (1945) … " was changed to simply "Appleton (1945) …".

pointed out that the equivalent brightness temperatures for these bursts were extraordinarily high, as much as 3×10^9 K.

This seminal paper also explained many basics of the sea-cliff interferometer, considering effects such as refraction (the worst uncertainty), the Earth's curvature, tides and imperfect reflection from a choppy sea. As mentioned above, many of these effects had already been worked out during the War; for instance, in a 1943 RP report by J.C. Jaeger. But Pawsey's group also introduced a vital *new* principle, namely that their interferometer was sensitive to a single Fourier component (in spatial frequency) of the brightness distribution across the Sun, and that in principle a complete Fourier synthesis could be achieved if one had enough observations with interferometers of different effective baselines:

> Since an indefinite number of distributions have identical Fourier components at one [spatial] frequency, measurement of the phase and amplitude of the variation of intensity at one place at dawn cannot in general be used to determine the distribution over the sun without further information. It is possible in principle to determine the actual form of the distribution in a complex case by Fourier synthesis using information derived from a large number of components. In the interference method suggested here … different Fourier components may be obtained by varying the cliff height h or the wave-length λ. Variation of λ is inadvisable, as over the necessary wide range the distribution of radiation may be a function of λ. Variation of h would be feasible but clumsy. A different interference method may be more practicable. (McCready, Pawsey and Payne Scott 1947: 367–368).

Much of the subsequent technical development of radio astronomy was to be concerned with this method of making high-resolution cuts across sources, and eventually complete maps. By the early 1950s their suggested type of Fourier synthesis was indeed central to much of radio astronomy. But the last two sentences of the above quotation were prophetic, for it was not sea-cliff interferometry, but the more tractable and flexible conventional interferometry with separate, movable antennas, that made such mapping a reality.

18.3.3 The Million-Degree Corona

Sometime toward the middle of 1946, Pawsey extracted another jewel from his wealth of data. He noticed that his large set of daily values of the 200 MHz solar flux density had a peculiar distribution (Fig. 18.9), with a sharp lower limit corresponding to an equivalent brightness temperature for the solar disk of about 1×10^6 K. This was drawn from the same data presented earlier, but looked at in a new way: first, with a histogram of values (~150 values over seven months) rather than a plot against time, and second, using single-day values rather than three-day averages. Pawsey had earlier argued that three-day averages were necessary because the solar bursts frequently vitiated daily observations, but now he saw that this averaging had also tended to mask the marked lower limit of intensity, since about two-thirds of all days exhibited enhanced levels.

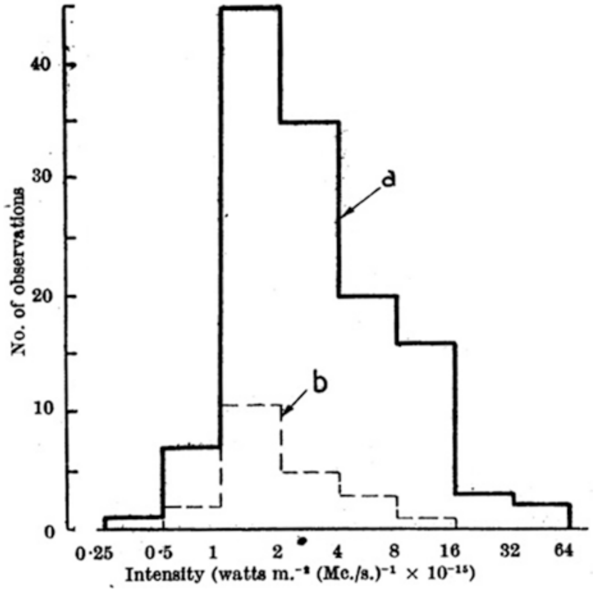

Fig. 18.9 Histograms of daily 200 MHz solar intensity: (**a**) October 1945 to March 1946, observed by Air Force personnel, and (**b**) March–May 1946, RP staff. Note the marked lower limit, corresponding to an effective (brightness) temperature for the solar disk of ~1 × 10^6 K (after Pawsey 1946)

At this same time David F. Martyn (1906–1970), the leading ionospheric theorist in Australia (then at the Commonwealth Solar Observatory, Mt. Stromlo) and a key figure in wartime RP (Sect. 18.3.4), became very interested in this hot new field and introduced a theory that could explain a million-degree base level for the solar radiation. He learnt, undoubtedly from discussions with Allen and Richard v.d.R. Woolley, the Observatory's Director, that recent studies of ionization states and spectral-line widths strongly suggested that the solar corona had a temperature of about 1 × 10^6 K. *Why* the corona was so hot was not at all understood, but the evidence was there. Martyn realized he could apply standard techniques in ionospheric theory to calculate the expected radio emission from the Sun. Once he had adopted likely values for the electron densities in the corona, he found that the corona was opaque at Pawsey's kind of frequencies. The observed radio waves were therefore emanating not at all from the 6000 K optical surface (photosphere) of the Sun, but from well above the photosphere out in the million-degree corona. When the Sun was quiet, this coronal thermal emission constituted the entire solar signal; when active, the coronal emission was dwarfed. Furthermore, at shorter wavelengths, the observed emission would come from deeper in the corona, and eventually even from the chromosphere. This powerful idea thus explained why the measured brightness temperature of the quiet Sun always seemed greater than 6000 K and sharply increased at longer wavelengths. It also meant that one could now study the corona without the inconvenience of having to chase down a total eclipse or resort to a coronagraph. As it turned out, in the Soviet Union a few months earlier Vitaly L. Ginzburg had independently made similar calculations while considering the possibility of reflecting radar off the Sun; and the basic ideas were again independently presented, yet a third time, in the Russian literature in a late 1946 paper by Iosif S. Shklovsky. But Martyn had access to better confirming data and was positioned more in the mainstream of postwar radio astronomy. His paper, in *Nature* for 2 November 1946, had far more influence.

The above description of Pawsey's and Martyn's work seems fairly well established, but there is controversy over whether Martyn first predicted the million-degree corona and then suggested that Pawsey seek it in his data, or whether Pawsey first found it empirically and so instigated Martyn's working on the problem. The archival evidence unfortunately does not speak with certainty. It does show that Pawsey and Martyn were planning a joint publication on this subject in July and August of 1946, but that Martyn then backed out since he and Woolley had decided to do their own theoretical study. Pawsey then persuaded Martyn to change his mind, but in the end Martyn (1946) sent off his own note to *Nature* early in September, apparently without Pawsey's knowledge. Pawsey got wind of this, however, and within a week convinced Martyn to agree that Pawsey (1946b) should send in his own short note and suggest to *Nature*'s editor that it follow Martyn's.[6] The collaboration had clearly gone sour, resulting in two adjacent notes: Martyn's did not mention Pawsey's base-level data at all (citing only Reber's and Southworth's measures of the solar intensity), while Pawsey's acknowledged his indebtedness to Martyn for "… pointing out to me the probable existence of high-level thermal radiation."

Within a few months, however, arguments developed over who had priority over 'the million-degree corona'. In January Bowen (1947a) wrote to Martyn because of "… your insistence on the importance of the written as against the spoken word." Bowen cited a year-old press release, which referred to the RP work as indicating that the usual 'apparent temperature' of the Sun was a million degrees, as clearly antedating Martyn's note in *Nature*, and said that RP knew about million-degree radiation from the Sun long before Martyn came along. Further direct evidence lies in 1948 letters commenting on a draft of a radio astronomy review then being written by Appleton for the International Union of Radio Science (URSI). Martyn (1948) wrote:

> There is a natural tendency now to look on my theory as one designed to explain the observed facts, which followed rapidly upon its heels. In point of fact it was developed (see the internal evidence in Pawsey's *Nature* letter) before the facts were known. It is a theory of prediction rather than explanation, and perhaps has correspondingly greater weight because of that.

And Pawsey (1948d) separately wrote:

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[6] Correspondence between Pawsey, Martyn, Woolley and Bowen, July to September 1946, is all contained in the in RP file B51/14.

> The actual sequence of events … was as follows: (a) observation of considerably high and very variable effective temperatures, 10^6–10^8 degrees on 200Mc/s—J.L.P. and colleagues. (b) Suggestion of high-temperature coronal thermal emission—D.F.M. and colleagues. (c) Successful search for 10^6 degree base level on 200 Mc/s—J.L.P. (d) Detailed theory—D.F.M.

Pawsey (1948c) also wrote from overseas to Bowen about this time:

> I think Martyn might get a mention in [Appleton's] section on the discovery of thermal radiation. I am all for a quiet life and the theory was a vital part of the discovery.

From this evidence it would appear most likely that Pawsey's own recounting of events best tells the story, although it should be noted that he was at times self-effacing. It is clear that Martyn's withdrawal from collaboration and lack of any mention of Pawsey's base-level work upset the RP staff. But this notwithstanding, it seems that Martyn was indeed the one who brought in the previous astronomical evidence of a million-degree corona and who pointed out that the million-degree 'effective' or 'apparent' temperatures cited by the RP group could actually represent *thermal* emission from the solar atmosphere. Pawsey and his colleagues had calculated these temperatures, but thought of them only in a formal sense. In fact, to them these incredibly high values were at first prima facie evidence of *non*-thermal phenomena.

18.3.4 Mt. Stromlo

It is remarkable that the Commonwealth Solar Observatory at Mt. Stromlo worked so closely with RP right from the start—such active collaboration between astronomers and active radio investigators occurred nowhere else in the world in the first few years after the War.[7] Since 1930, however, the Observatory had been doing a small amount of Radio Research Board-funded ionospheric research (in particular by Arthur J. Higgs, who after the War became RP's Technical Secretary). Moreover, during the War, Cla Allen had worked on the effects of sudden solar disturbances on ionospheric conditions and optimum communications frequencies. As we have seen, Allen from as early as October 1945 was feeding optical solar data to RP and indeed over the years his ties with RP remained strong (Smerd 1978: 92A). Since the Commonwealth Solar Observatory was already in the solar-monitoring business at optical wavelengths and RP did not want to maintain a strict daily patrol, the idea soon developed of RP installing a radio system at Mt. Stromlo. From April 1946 onward Allen oversaw regular 200 MHz solar monitoring with a steerable array of four Yagi antennas (similar to the 2-Yagi antennas shown in Fig. 18.6). In early 1949

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[7] The only minor exception was neighboring New Zealand. Both Alexander's group (which Unwin subsequently inherited) and the Burbidge-Kreilsheimer-Maxwell group at the University of Auckland—where Maxwell was doing M.Sc. research on solar radio emission—worked closely with Ivan Thomsen, the Director of Carter Observatory. At the time, Carter Observatory specialized in optical solar work, and Thomsen (1948) eventually published a paper in *Nature* on the correlation between solar radio emission and optical features.

he also used the same array to make a complete map of the Galactic background radiation (Allen and Gum 1950).

In addition to Allen, Martyn worked on extra-terrestrial noise as a sideline to his ionospheric research. Besides his important work on the million-degree corona, he also pointed out in his 1946 *Nature* note that at wavelengths of 60 cm or less the quiet Sun should appear brighter at its edges than in the center. This prediction of 'limb brightening' turned out to be qualitatively correct, although it took more than five years before observations of sufficient detail seemed to settle the question.

This radio activity could not have flourished without the encouragement of the Observatory's Director and Commonwealth Astronomer, Richard Woolley (1906–1986). Woolley was a stellar and dynamical theorist, an Englishman who had come to Australia to take over the Commonwealth Solar Observatory in 1939, and who would return to Britain in 1955 as Astronomer Royal. He had a personal interest in the radio work; for instance, he authored an early paper on the theory of Galactic noise and others on solar models incorporating radio data. In late 1946 Woolley suggested that Bolton should check for radio emission from the nebulosity near the bright star Fomalhaut, and in 1947, after Martyn had speculated that the Cygnus source (Sect. 18.4) might be a distant comet, Woolley searched for such an object. Moreover, relations between Woolley and RP were cordial enough that Bowen first checked with Woolley before sending off the first RP paper on the Cygnus source. Woolley also was elected in 1948 as the first Chairman of the International Astronomical Union's new Commission 40 on Radio Astronomy, and shortly thereafter became Vice-Chairman of Australia's national URSI organization.

Yet despite these fruitful exchanges of ideas, data, and know-how between the astronomers and the radio physicists, tension also existed between Woolley and Martyn on the one hand and Bowen and Pawsey on the other. Much of this stemmed from Martyn and his status as an 'exiled' RP staff member, seconded to the Observatory from Sydney. Martyn had been removed as RP Chief late in 1941 after two years of continual problems—despite his scientific excellence, he did not have the managerial skills or temperament needed to run a large organization developing new technology under the threat of Japanese attack. By 1941 his relations with the military, with industry, and with his own staff were abysmal. On top of this, in early 1941 he was viewed as a security risk because of his liaison with a German woman who had recently emigrated to Australia (Schedvin 1987: 253–259). With this background, one can understand that his post-war relations with RP often went less than smoothly.

Woolley, too, appears to have developed an ambiguous relationship with RP in particular and with radio astronomy in general. For instance, in a major address on the solar corona, he mentioned Allen's and Martyn's work, but none of RP's results (Woolley 1947). In another talk the same year on "Opportunities for astrophysical work in Australia", radio was not mentioned once, although this may have resulted from his definition of *astrophysical* (Woolley 1946b). Several interviewees from RP and from Mt. Stromlo have testified to Woolley's lack of support for radio astronomy. Even as late as 1954, when asked about radio astronomy after a popular talk, Woolley apparently replied that in a gathering of 'real' astronomers it was not considered decent to mention radio astronomy (see Bok 1971; Bowen 1973, 1984; de Vaucouleurs 1976; Kerr 1971, 1987; Mills 1954; Stanley 1974; Wild 1987). On the other hand Woolley was part of a proposal for an independent department of radio astronomy at Mt. Stromlo. The matter culminated in 1951–1952, after the departure of Allen to take up a professorship in England. Professor Mark L. Oliphant (head of physical sciences at the new Australian National University in Canberra) and Woolley made a major thrust to acquire a large radio telescope, but were beaten down by White at CSIRO headquarters and by Bowen and Pawsey (Pawsey 1951; Robertson 1992: 107–113).

18.4 'Radio Stars'

In August 1946 Bowen, then visiting England, excitedly sent Pawsey a reprint of the recent letter in *Nature* by Hey et al. 1946 of the Army Operational Research Group. While mapping the general distribution of Galactic noise, they had accidentally discovered that the noise from one particular spot in the constellation of Cygnus fluctuated in intensity on a time scale of minutes. Although they could measure with their beam only that the fluctuating region was less than two degrees in size, they argued that such rapid changes must originate in a small number of discrete sources, perhaps only one. These sources were taken to be stars, by analogy with the Sun and its radio bursts. Pawsey jumped on this. As he wrote (within a few days of receiving Bowen's letter):

> … we immediately made some confirmatory measurements on 60 and 75 Mc/s, obtaining similar fluctuations, of the same form as the "bursts" observed in solar noise. We have no hint of the source of this surprising phenomenon. (Pawsey 1946a).

This early success, however, was apparently followed by a period of conflicting observations, during which the reality of the Cygnus fluctuations came into question. In the end Pawsey's group gave up, no longer knowing what to make of Hey's claim (Bolton 1976: 3–4T; Stanley 1974: 4–5T).

Cygnus investigations thus lay dormant for several months until resumed by John Bolton (1922–1993), who had joined the RP staff as its second post-war recruit in September 1946 (see Kellermann 1996). Bolton (Fig. 18.3) was a Yorkshireman who had studied undergraduate physics at Cambridge before joining the Royal Navy, where he first developed radar and then served as a radar officer before demobilization in Sydney Harbour. Assigned to the solar noise problem at Dover Heights, Bolton built two 60 MHz Yagi aerials to follow up on Martyn's earlier detection of circular polarization, and was soon joined by technician O. Bruce Slee, a former Air Force radar mechanic who also had just started at RP.[8] But the Sun was not

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[8] Although Slee did not join RP until November 1946, he had made an independent discovery of the radio Sun while operating a radar set near Darwin in late 1945-early 1946, a discovery which he duly reported to RP (Briton 1946; Slee 1946; Sullivan 1988: 342). Orchiston and Slee (2002) recently reported in detail on these observations, and placed them in the public domain. Slee (1994) has published his memories of the years 1946–1954 at Dover Heights, and Orchiston (2004, 2005b) gives details of Slee's career.

co-operating with much activity, and so Bolton decided to check for radio emission at the positions of various well-known astronomical objects, as listed for instance in the venerable *Norton's Star Atlas*. His inattention to solar monitoring, however, got him in trouble:

> After a week or two our efforts were cut short by an unheralded visit from Pawsey, who noted that the aerials were not looking at the sun. Suffice it to say that he was not amused and we were both ordered back to the Lab for reassignment. (Bolton 1982: 349–350).

Notwithstanding this setback, a few months later Bolton managed to resume at Dover Heights, where he was joined by electrical engineer Gordon J. Stanley (1921–2001), a New Zealander who had come to RP upon leaving the infantry three years before (Kellermann et al. 2005). This time the goal was to follow up recent studies by Payne-Scott and Donald E. Yabsley on simultaneous solar burst observations at widely spaced frequencies. On 8 March 1947 the Sun obliged with a remarkable burst exhibiting delays of a few minutes between signals arriving first at 200 MHz, then 100 MHz, and finally 60 MHz. The behavior of this and earlier bursts was taken to arise from emission at various critical frequencies as successively higher coronal layers were excited; with a model of electron densities in the corona, it was even possible to infer a speed of ~600 km/s for the ejected material (Payne-Scott et al. 1947). Here indeed was a dramatic confirmation of Martyn's model of different coronal levels effectively emitting different radio frequencies.

Bolton again grew tired of solar monitoring, however, and together with Stanley returned to the Cygnus phenomenon in June 1947 (see Bolton 1982). The antenna was nothing more than a pair of 100 MHz Yagis (shown in Fig. 18.6) connected to a converted radar receiver and operated as a sea-cliff interferometer. This allowed a three-week reconnaissance of the southern sky, during which they at last reliably found the Cygnus source, as well as hints of two weaker ones (Bolton 1947). They spent several months checking out the Cygnus source, and by the end of the year submitted papers to *Nature* and the very first issue of the *Australian Journal of Scientific Research* (Bolton and Stanley 1948a, b). Cygnus usually gave a workably strong set of fringes as it rose (Fig. 18.10), and this directly implied that the radiation emanated from a very small, single region of the sky. But the source never rose more than 15° above the northern Sydney horizon and observations were continually harassed by the strong intensity fluctuations that had led to Hey's discovery in the first place. By analogy to the Sun, Bolton and Stanley's analysis split the signal into a constant component (which they estimated as 6000 Jy) and a variable component that added (never subtracted) amounts that fluctuated over times of 0.1–1 min. Through auxiliary observations made with other Yagis they found a maximum in the spectrum of the constant component at ~100 MHz, whereas the variable component's intensity increased sharply as frequency was lowered.

The heart of their study was concerned with the size and position of the source. Size came from the solar technique worked out before, namely from measuring the

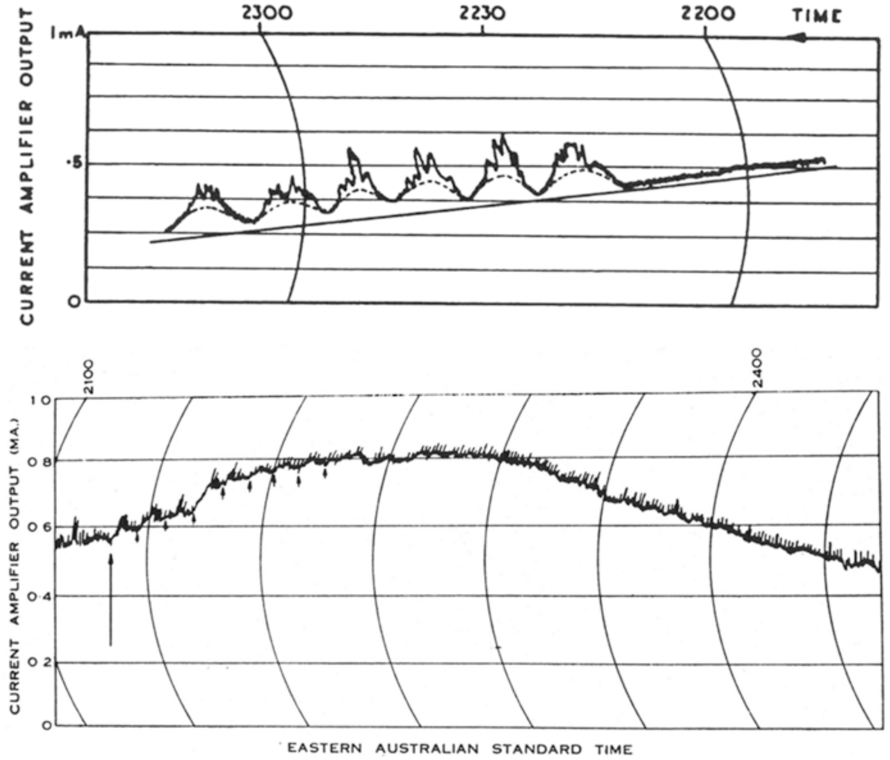

Fig. 18.10 Sea-cliff interference patterns obtained at 100 MHz at Dover Heights for Cygnus-A in June 1947 (top) and for Taurus-A in November 1947 (bottom, discovery recording). Note the ionospheric scintillations superimposed on the Cygnus fringes and the sloping baselines from Galactic background radiation. For the Taurus-A record, the rising point and probable minima of the weak fringes are shown by arrows. Vertical lines on this record are due to interference from a timing mechanism (after Bolton and Stanley 1948b, 1949)

ratio of fringe maximum to minimum. As the ‘equivalent radiating strip’ became broader, the fringes would wash out in a predictable manner. But Cygnus gave difficulties with (1) subtracting off a considerable baseline slope caused by strong galactic noise in the vicinity, (2) isolating the constant component from the variable, and (3) determining a proper upper limit for the fringe minimum, for it appeared that the best records in fact showed minima that were not distinguishable from zero (Fig. 18.10). They estimated that the maximum-to-minimum ratio was at least 50, implying that the source size was <8′ (about one-eighth of the lobe separation). Hey’s group had inferred that the Cygnus fluctuations must arise from a discrete source or collection of sources, perhaps scattered over two degrees of sky, but here was strong evidence for a single, small source. In fact they thought the source even smaller than their published limit:

> Careful examination of the records suggests a much smaller source size than stated above [8′]. Further experiments using improved receiver stability and greater aerial height will probably substantiate the authors' belief that the source is effectively a "point." (Bolton and Stanley 1948b: 64).

With a source size in hand, they moved on to the even trickier task of a position. This involved analyzing the timing and spacing of fringes in terms of sky geometry and radio wave propagation. One had to find the sidereal time when the source was highest in the sky (culmination) and the length of the arc travelled by the source between rising and culmination. But Bolton and Stanley were forced to tie together observations at three different cliffs around Sydney[9] in order to secure reliable data; furthermore, the necessary corrections for refraction were large and, as it turned out, uncertain. In the end, the derived position was 19 h 58 m 47 s ± 10 s, +41° 47′ ± 7′. With this first well-defined position for the enigmatic Cygnus source (Hey's group had been able to give its position only to within 5°), their next step was of course to consult the optical catalogs and photographs. But this was disappointing:

> Reference to star catalogues, in particular the Henry Draper Catalogue, shows that the source is in a region of the galaxy distinguished by the absence of bright stars and objects such as nebulae, double and variable stars, i.e., the radio noise received from this region is out of all proportion to the optical radiation … The determined position lies in a less crowded area of the Milky Way and the only obvious stellar objects close to the stated limits of accuracy are two seventh magnitude stars. (Bolton and Stanley 1948b: 68).

They did, however, request that Woolley take a special photograph of that portion of the sky, and this appeared as a plate in their paper, along with a tracing-paper overlay indicating their source position and error box. It certainly appeared a nondescript patch of sky (but we should note that this initial position for Cygnus-A was a full degree north of the correct position and so there was no chance of finding an optical counterpart, and even positions obtained years later to accuracies of a few arc minutes at first did not disclose an optical identification).

Given that there was no optical counterpart, could one nevertheless put any constraints on the distance to the object? Since they had been observing the source for three months, the changing position of the orbiting Earth might have caused an apparent shift in position if the object were nearby. But they had detected no shift greater than 2.5′ (corresponding to their 10s accuracy in timing the sudden appearance of the source at rising), and this meant the source was at least ten times the 50 light-hour distance to Pluto, that is, well outside the Solar System. But *how* far outside? Bolton and Stanley could only suggest that the farthest imaginable would be if somehow the radio object were a star with total power output similar to that of the Sun, but all channeled into the radio spectrum. That distance worked out to 3000 light years. But no matter what the distance, the cause of the radio radiation was not at all understood. They could only say it had to be a non-thermal mechanism, for the measured effective (brightness) temperature was $>4 \times 10^6$ K.

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[9] Because Dover Heights was not suitably-located to follow Cygnus-A's entire track low across the northern sky, Bolton and Stanley used two other sites in the vicinity of Collaroy, namely Long Reef and West Head (Fig. 18.4 shows Collaroy).

Just as Bolton and Stanley were writing up these results, they received an interesting communication from Pawsey (1947), who was then on the first leg of an around-the-world tour. He had visited Mt. Wilson Observatory in Pasadena and there found Rudolph Minkowski and Seth B. Nicholson "intensely interested" in the Cygnus results and willing to undertake observations directed toward finding an optical counterpart. Pawsey then described optical objects that Minkowski had showed him near the Cygnus position, mentioning that in the process they had had to convert Bolton's derived position to account for "… the change of axes due to 'precession of the equinoxes'."[10] Pawsey's letter (ibid.) ended with a raft of suggestions from Minkowski for possible places to look for radio noise:

> The Magellanic Clouds [are] the nearest external galaxies, abnormal with much dust and blue stars … If we are interested in interstellar dust, etc. the "Crab Nebula", NGC 1952, is a good sample. If white dwarfs are of interest, the companion of Sirius is a convenient sample. The Orion region is a region of emission nebulae. [But] I do not think these ideas get us very far. I should recommend the method of empirical searching; our tools are not too fine to prevent this.

With the Cygnus case temporarily closed, Bolton and Stanley, assisted by Slee, indeed set out in November 1947 to search the sky in Pawsey's 'empirical' fashion. Stanley and Slee had made significant improvements to their receiver's short-term stability, in particular through constructing power supplies able to provide voltages stable to a part in a few thousand. Even weak fringes could now be reliably detected. They methodically took records at different points along the eastern horizon, and were delighted when fringes for several sources appeared over the next few months. As it became clear that the sky had a lot more to offer than just the Cygnus source, Bolton introduced a nomenclature still used today: in the tradition of Bayer's notation for stars, the strongest source in a constellation would be called A, the next B, etc. And so their second source became Taurus-A, one-sixth as strong as Cygnus-A, followed by Coma Berenices-A at a similar level. The uncertainties of this work can be appreciated by noting that Taurus-A appeared nicely on one November night (Fig. 18.10), but it took another three months for confirmation of its existence and measurement of a position good enough to assign a constellation.

By February 1948 Bolton, Stanley and Slee had surveyed about half of the southern sky (man-made interference made daytime observations nearly worthless), and had good cases for six new discrete sources. Bolton (1948) sent a note to *Nature* announcing that a new class of astronomical object existed: Cygnus-A was not unique, either in its existence or in its lack of association with "… outstanding stellar objects". Upper limits on the new sources' sizes were no better than 15–60′, but Bolton was becoming convinced that all these discrete sources were truly stellar, "… distinct 'radio-types' for which a place might have to be found in the sequence of stellar evolution." (Bolton 1948: 141). Since even the most powerful solar-style bursts would not do the trick, he appealed to either pre-Main Sequence, collapsing,

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[10] The phenomenon of precession of co-ordinates, covered at the start of any basic astronomy text, had apparently not been previously known to Pawsey. It also almost slipped the attention of Bolton and Stanley (1948b) when they constructed their photographic overlay (see Stanley 1974: 7–7T).

cool objects or to old, hot objects related to planetary nebulae.[11] He felt, too, that a large portion of the general Galactic noise probably originated from the aggregate effect of solar-burst type emissions.

After this survey Bolton chose to improve his source positions, in particular to eliminate systematic errors, by observing source *setting* as well as rising. High westward- and northward-facing cliffs were needed and so Bolton and Stanley headed off to New Zealand in the southern winter of 1948 (Orchiston 1994). As Bolton (1976: 8T) recalled:

> [Just before the New Zealand trip] … I remember Taffy Bowen asking me what I really thought of the positions of my sources, and I said, "Well, they're the best I can do at the moment, but I'd like to be the first to correct them." And indeed the corrections were absolutely massive when they came in.

The 300 m sea cliffs at Pakiri Hill and Piha (see Fig. 18.11) led to superior observations which put an even tighter limit on Cygnus-A's size (<1.5′), and, together with simultaneous observations by Slee in Sydney, provided strong evidence that most of the intensity fluctuations originated in the Earth's atmosphere, not in the source itself. Many new sources also turned up and it became apparent that incorrect refraction corrections and other problems had thrown most previous positions 5° to 10° off. Some even changed names as when Coma Berenices-A migrated into Virgo! But Cygnus-A was still vexing, as neither its new position (shifted about 1° south from earlier) nor its old one agreed with that measured by Martin Ryle at Cambridge (privately communicated in June 1948). For a while it seemed that the source might actually be moving, but after six months of sorting out, both Hemispheres admitted earlier errors and came to agree on a common position.

The beautiful outcome of the new positions of ~10′ accuracy was that for the first time optical counterparts could be tentatively suggested (Bolton et al. 1949). And these were no ordinary objects. Taurus-A was associated with the Crab Nebula, the expanding shell of a supernova known to have exploded 900 years before (Bolton and Stanley 1949); Centaurus-A was found to coincide well with one of the brightest and strangest nebulosities in the sky, so peculiar that astronomers were not even sure whether or not it was part of our Galaxy; and Virgo-A's position correlated with that of a bright elliptical galaxy six *million* light years away. These associations quickened interest in the study of discrete sources and caused several optical astronomers, among them Minkowski, to take serious note.

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[11] It was only fitting that an ailing Australian star should radiate its Swan song in the form of Cygnus-type radio noise.

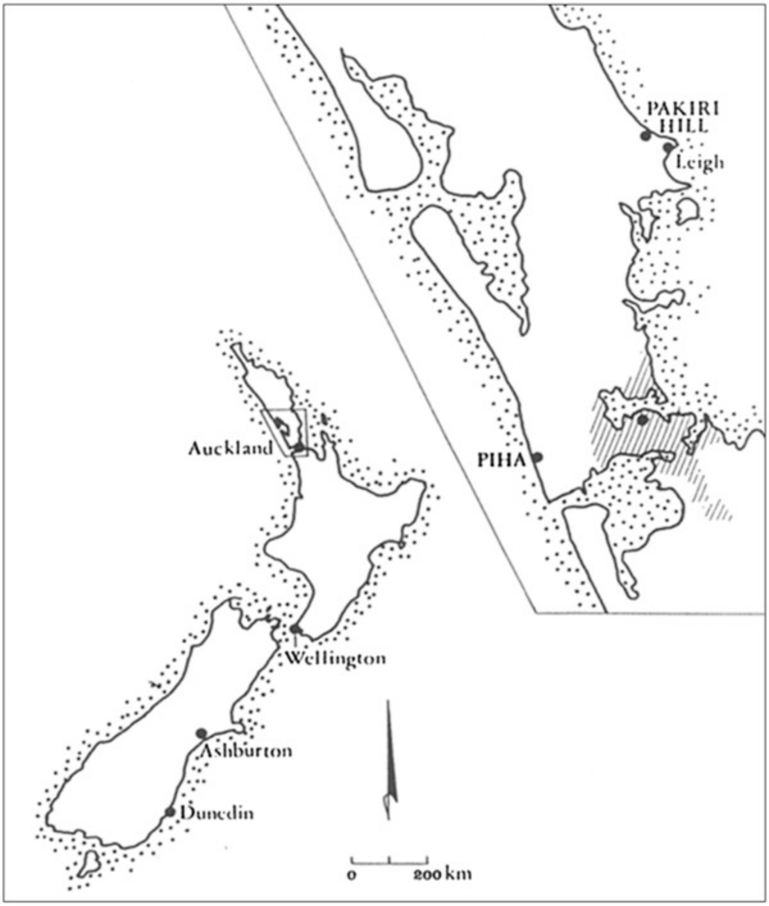

Fig. 18.11 Locations of Pakiri Hill and Piha, near the city of Auckland (hatching), New Zealand (after Orchiston 1994)

18.5 Overview of RP's First Decade

18.5.1 The Isolation Factor

Almost any analysis of things Australian must consider the geographical isolation of Australia from the other centers of Western culture. Geoffrey Blainey (1968) speaks of "… the tyranny of distance … ", that is, the overwhelming importance of distance, isolation, and transport in molding the general history of Australia. In the sciences also, isolation has played a major role. Although the vestiges of a subservient colonial relationship between British and Australian radio science created an asymmetry in status and power that was independent of the distance from London, many problems of Australian science during the postwar years were notably exacerbated by the antipodal separation.

The early RP years are rife with examples of things that would have gone differently if RP had not been located 10,000 miles from its sister institutions, but instead 100 miles, or even 1000. The best airline connections to Europe required a gruelling three days (or a civilized week) and more common passage by ship took about four weeks; moreover, the cost of a ship's berth amounted to one or two months' pay for an RP staff member. The inability to have frequent contact with colleagues from other institutions, the long interval before learning about research conducted elsewhere, the delays in publishing Australian results in the prestigious overseas journals, and the lack of foreign readership of Australian journals—these circumstances constantly bedeviled the RP staff (and Australian science in general). One counterforce was the maintenance of Australian Scientific Research Liaison Offices in London, Washington, and Ottawa. These had been originally set up during the War to coordinate radar research, and served as scientific embassies to increase the flow of information to and fro. But a far better solution was to send an RP researcher on an extended 'jaunt' through North America and Europe. In the six years after the War, the primary overseas stays or trips of importance for the development of Australian radio astronomy were undertaken by Bowen (in 1946), Ronald N. Bracewell (1946–1949), Pawsey (1947–1948), Westfold (1949–1951), Bolton (1950) (see Bolton 1982: 353) and Kerr (1950–1951). The RP correspondence files relating to these trips are particularly good sources for understanding the influence of the isolation factor on RP's work. What emerges is that such trips served five primary purposes: (1) intelligence (in the military and political sense of the term), (2) education, (3) publicity, (4) establishment of personal contacts, and (5) fund-raising for large antennas, which first paid off with American grants in the mid-1950s towards what became the Parkes Radio Telescope (Goddard and Haynes 1994).

The first purpose of the overseas trips was simply to find out what was going on. The RP visitor to an overseas laboratory typically sent back a detailed report of recent and ongoing research, and this report (as evidenced by multitudinous initials on the original documents) was widely circulated back home. Pawsey and Bowen, in particular, were masters at picking up what was being done elsewhere and analyzing its effects on RP's current research program and future plans. To give but two examples: in August 1946 Bowen (1946b) cabled back that British work on the Sun was ahead of RP's at observing frequencies less than 200 MHz and that therefore RP should concentrate on higher frequencies. And in April 1950 Bolton sent word home that the solar work by Hey's group lagged Wild's by at least eighteen months.

A second purpose of the overseas trips was education. Sometimes this was in the formal sense, as when Bracewell took a Ph.D. at Cambridge and Westfold one at Oxford, and Kerr a Master's degree at Harvard; but more often it was simply the wealth of knowledge to be garnered from overseas contacts. The background of the RP staff was of course far weaker in astronomy than in radio physics, and thus it was the visits to observatories that were particularly valuable. As Kerr (1971, 19T) recalled:

> Bolton and also Pawsey did some touring at that time and learned something of what generally were the interesting problems in astronomy, acquiring some of the attitude of astronomers toward astronomy, instead of just the electrical engineers' and physicists' attitudes.

On the other hand, Mills (1976: 20T) points out that the paucity of astronomers in Australia may have helped more than it hindered:

> Our isolation did help us develop with an independent outlook. We had no famous [astronomer] names to tell us what we should believe, and to some extent we just went ahead following our noses.

Overseas voyagers also served to spread the word about RP research—Pawsey called them "… ambassadors for Australian science". The RP archives are full of instances where Bowen and Pawsey sent reprints, complained about Australian work being neglected in reviews overseas, and urged people to subscribe to the *Australian Journal of Scientific Research*, started by CSIR in 1948 and a further sign of the growing independence of Australian science from British hegemony. RP sent thirty full papers to this journal in its first four years, but only eight to British journals (plus eight letters to *Nature*).[12] Although this corpus probably lent more stature to the journal than did any other single field, it took years to foster a world readership, even among radio astronomers. For example, Jodrell Bank did not subscribe until 1950; before then, the only copies they could locate were in London.

Direct word-of-mouth, when possible, was of course also important. After attending a 1948 URSI meeting in Stockholm, Pawsey (1948b) wrote back, "Martyn and I, to put the matter rather bluntly, attempted to put Australia on the map, and I think were fairly successful." And Bracewell (1980: 131A) recalls that while he was at the Cavendish as a postgraduate student, Ryle's group thought Sydney work way behind, but when he returned to RP he found that they thought the same of the Cambridge work—each side was simply acting on dated information. Preprints were not common in those days, and in any case were sent by sea mail (as were journals, even *Nature*), taking two to three months for the passage.[13] Bracewell (1948) also remembers wanting to act as a link between the two groups: "Being young and idealistic, I felt that I should try to close the gap, that a freer flow of information was a blow struck against entropy, as well as my duty." As he wrote to Bowen in early 1948:

> Publication [of Australian work] is slow and the diffusion of advance news by word of mouth does not occur. It results that ideas of priority are fixed before Australian work filters through. This is the case with solar noise. The attitude in the Cavendish Lab. is that nothing much of value is done elsewhere … [Since] I am in an effective position for informal

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[12] One of the factors in the founding of the Australian journal was the well-founded suspicion that letters and research papers sent to British journals in many cases were not being treated fairly, either through premature dissemination of their contents or through delays in publication (Kerr 1987: 8).

[13] A check of accession dates for *Nature* in the Sydney University Library (which was used by RP) revealed that each weekly issue was received fully 5–11 weeks after its date of issue. This situation continued until 1954, when the delay became only one week, presumably because of airmail delivery. I thank J. Threlfall for this information.

> dissemination of news from Radiophysics, I recommend for your consideration the transmission of this news. (ibid.)

Despite his request, it appears that Bracewell himself remained little better informed than others in Cambridge. Upon his return to Australia in late 1949, he wrote back to Ryle:

> There is a lot of good work going on, and the people are very keen. Very little pre-publication news seemed to filter through to me in the Cavendish from Australia … Do not hesitate to let me know if … I can make enquiries which you may think can be better done informally through me. There is a lot of interest in your work—I have had to ward off quite a barrage of minor queries about your set-up since arriving. (Bracewell 1950).

This induced Bracewell over succeeding years to send three short papers to *Observatory* for the purpose of advertising RP's work.

One of the grandest opportunities for interchange and to advertise RP's work was the URSI General Assembly that met in Sydney in August 1952. This was a feather in the hat not only for Australian radio research, but for all of Australian science, as it marked the first time that *any* international scientific union had met outside Europe or North America. In 1948 URSI had created a new Commission V on Extraterrestrial Radio Noise with Martyn as its first President and Pawsey as Secretary. Martyn in particular engineered the General Assembly coming to Sydney and master-minded the organization and funding. Sir Edward Appleton (Fig. 18.1) was the patriarch among the fifty foreigners in attendance, of whom about a third were active in radio astronomy (Fig. 18.3). At last the RP staff could associate faces with names like Jean-Louis Steinberg from France, Robert Hanbury Brown from Jodrell Bank, F. Graham Smith from Cambridge, C. Alexander Muller from Holland and H. I. 'Doc' Ewen from the United States. RP of course put on its best show for the guests with a detailed, glossy *Research Activities* booklet and tours of several of the field stations. The home team was greatly stimulated, and the visitors went away impressed.

18.5.2 The Field Stations

The RP radio astronomy work took place at individual field stations, some as far as 30–50 miles from home base on the grounds of Sydney University (Fig. 18.4). These sites provided sufficient land and isolation for observations free from manmade electrical interference. But why not just one or two sites well removed from Sydney? Many small sites also provided freedom from a second type of 'manmade interference': the RP staff simply preferred to spend most of their time alone at the field stations, not in a central laboratory, and management too found this a productive style of operation. By the late 1940s RP's research in radio astronomy was divided into many teams of two or three: leaders and sites about 1948–1950 were Piddington and Minnett (University grounds), Kerr and Shain (Hornsby), Bolton (Dover Heights), Wild (Penrith), Mills (Badgerys Creek), Payne-Scott and

Christiansen (Potts Hill), and Lehany (Georges Heights). Orchiston and Slee (2005) discuss in detail these field stations and their major research programmes over their lifetimes. Christiansen (1984: 113–114) has evoked the atmosphere of these stations:

> Each morning people set off in open trucks to the field stations where their equipment, mainly salvaged and modified from radar installations, had been installed in ex-army and navy huts … The atmosphere was completely informal and egalitarian, with dirty jobs shared by all. Thermionic valves were in frequent need of replacement and old and well-used coaxial connectors were a constant source of trouble … During this period there was no place for observers who were incapable of repairing and maintaining the equipment. One constantly expected trouble.

Although groups had little day-to-day contact, Pawsey's skill as roving monitor and coordinator gave cohesion to RP's radio noise work. This was achieved first through meetings every two to four weeks of his 'Propagation' Committee (which changed to 'Radio Astronomy' in 1949). These meetings provided a forum for progress reports, discussion of astronomical results and technical problems, floating of new ideas, coordination of experiments, and arguments about priorities. They also served to counter the danger that isolated groups would develop too narrow scientific or organizational perspectives. Several interviewees commented on the value of these sessions; for instance, Christiansen (1976: 19–20T) reported:

> Despite the fact that we were independent groups, we used to have these sessions, sort of what Americans call 'bull sessions', thinking of every conceivable sort of aerial … A really good one would last all day. Joe Pawsey was one to stimulate that.

Pawsey's second device for holding the radio noise research together was to frequently visit the field stations to see for himself what was happening and to give advice. As Wild (1972: 5) recollects:

> On some days he would arrive unexpectedly at one's field station, usually at lunch time (accompanied by a type of sticky cake known as the lamington, which he found irresistible), or else infuriatingly near knock-off time. During all such visits one had to watch him like a hawk because he was a compulsive knob-twiddler. Some experimenters even claimed to have built into their equipment prominent functionless knobs as decoys, especially for Pawsey's benefit … [But] when one ran into problems, half-an-hour's discussion with Joe tended to be both soothing and rewarding.

These visits, however, sometimes led to Pawsey seeing things he did not like:

> Pawsey was in direct linkage with the little isolated groups. He'd try and make sure they didn't clash. And he stopped us working at times when Jack [Piddington] had had some idea and we'd started in a new direction … For instance, one day he found me [working on a radio analogue to a Fabry-Perot interferometer] and I was stopped. He said there are other people already there, and they've got a prior claim. (Minnett 1978: 29–30T).

But although Pawsey usually assigned exclusive turf to each small group, he sometimes encouraged two groups to plow ahead on the same problem if he felt their approaches differed enough. For example, Mills and Bolton for many years both observed discrete sources, albeit with different types of interferometers:

> Bolton's group and mine each felt rather strongly that our own technique was the best. Although we saw each other sometimes, Bolton lived out at Dover Heights and didn't come into the Lab very often and I spent most of my time out at Badgerys Creek. So we didn't actually have very much contact, and there were quite a few arguments about interpretation of the results. (Mills 1976: 26–27T).

18.5.3 Management of the Radio Noise Research

Bowen turned over scientific leadership for radio noise investigations to Pawsey, who was the Division's number-two man from the start (although the office of Assistant Chief was not created until 1951). Pawsey thus had a free hand in running the radio noise side of things while Bowen took on the general administrative burden and concentrated on the rest of RP's program, taking a particular interest in the rain and cloud physics research to which he himself made several contributions. Bowen, however, minimized the number of his collaborations and so through 1951 published only seven papers. His career had seen more than its share of scientific directors (such as Appleton, Watson-Watt and Martyn) who claimed credit for too much of what happened in their laboratory:

> When I became Chief, I was going to be quite certain of one thing … I was not going to jump in and claim credit when somebody else did the work … My previous experience of some pretty hard cases was that the best way to get first class work out of people was to give them the credit. (Bowen 1973: 27–28T).

Along this line, Bolton (1978: 118T) recalled:

> Bowen was on our side in terms of letting people have their head—giving you a pat on the back when you did well and commiserating with you when something failed.

Bowen's philosophy also was expressed in a 1948 letter to Pawsey after the latter had been overseas for eight months:

> It is true that those of us who have had a fair amount of experience can give a lot of help in choosing problems for the younger people, keeping their sights on the target and helping them snatch the odd pearl out of the tangled mass, but I am quite sure that what we are suffering from in the Lab. is not that there is too little of this help but too much. With few exceptions our youngsters have not learnt to stand on their own feet and go for a line of their own … The boys in the Radio Astronomy Group are feeling your absence quite keenly, but I am taking the view that their present gropings are part of their education. (Bowen 1948).

Bowen and Pawsey's leadership styles very much fitted in with Rivett's philosophy discussed earlier: get the best people possible, give them the needed resources, and then let them run free. But there were bounds to this freedom, as we have seen, leading to a creative tension between tight control of the Laboratory's work, as it had necessarily operated during the War, and the kind of individual freedom one might find in a university department. This delicate balance is well illustrated by the juxtaposition of allowing workers to be scattered all over the countryside, while still keeping close tabs on what they did. Other strong limits existed. For example, most scientific correspondence was routed through either Pawsey or Bowen. More significantly, RP maintained a system of rigid internal reviews of all proposed publications, involving one or more of Bowen, Pawsey, and Arthur Higgs (Technical Secretary). The RP archives are replete with internal memoranda shuttling drafts back and forth between authors and management (and sometimes anonymous third-party RP referees), often to the frustration of the authors. But once a paper surmounted this first hurdle, a journal's referees usually seemed easy by comparison. The extent of Pawsey's influence on the radio noise papers can be gauged by the fact that half of them from the 1946–1951 era specifically acknowledge his assistance with either preparation of the paper itself or the project in general. Yet he, like Bowen, published only seven papers through 1951.[14]

Bowen and Pawsey agreed on the basic policies needed to run RP, but their differing temperaments led to differing contributions to RP's success in radio astronomy:

> [Pawsey's scientific style] … set the tone completely … but he was a very, very unworldly fellow … Bowen was the man who got the money, the tough businessman, while Joe was the rather academic scientist. And it was an excellent combination. (Christiansen 1976: 22T).

Bowen knew how to deal with the CSIRO hierarchy, how to pull off the necessary balance of applied and fundamental research, how to use his connections to source funding, and how to manage RP as a whole. On the other hand, interview testimony of numerous RP staff members indicates that Pawsey by nature was not suited for such things. For instance, he abhorred (and avoided) making managerial decisions that he knew would cause upset.

Pawsey played a vital role, however, as scientific father figure and mentor. He was about ten years older than most of the radio noise researchers, who averaged only about thirty years of age, and he quickly gained their respect and confidence. The words of his protégés speak for themselves:

> He had the ability to develop the latent powers in other people. All of the people who came out of that group—Christiansen, Mills, Wild, and so on—I also count myself in it—were made independent and skillful in their subject, experienced and self-reliant, quite largely because of Pawsey's way of drawing people out. He was not the kind of research leader who'd insist on claiming everything himself. But he fed in the ideas that other people developed—he was a teacher as much as anything. In the written record you don't find his name on many papers, but he was the inspiration behind an awful lot. (Kerr 1971: 41–42T).

> There were, and are, few scientific groups of comparable size where the head of the group had such a detailed knowledge of the work of each member and where every paper was criticised in detail by him. Yet this … did not lead to any authoritarian regime. Pawsey's criticisms were usually accepted not only because they were sound but because they were so clearly and intelligibly expressed that acceptance was inevitable. (Christiansen and Mills 1964: 139).

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[14] RP researcher Donald Yabsley (1986) has pointed out a typical example of Pawsey's keeping his name off publications. With regard to the paper by Payne-Scott, Yabsley and Bolton (1947), Pawsey contributed much to the project and to the paper, and originally he was intending to be a co-author. But in the end he withdrew his name because he felt that three authors were quite enough for a letter to *Nature*.

Pawsey's style of science grew out of his training under Ratcliffe in the Cavendish Laboratory of Ernest Rutherford. He inherently loved the simple, inexpensive experiment and distrusted anything coming from complex setups. He also had an innate distrust of theory and mathematics (Westfold 1978: 97B), complemented by a faith in experimentation. As he himself wrote in 1948 (regarding the possibility of solar bursts at frequencies less than a few hundred hertz):

> My present guess is that the theory is wrong in general, and consequently I do not advise any time-consuming observations which are based on the theory. On the contrary, the observation of low-frequency noise is a fundamental scientific observation which is of value independent of the theory. Positive or negative results are of use. Hence this investigation is in order, and it is up to the experimenters to decide how far they go. (Pawsey 1948a).

The experimental style that Pawsey inculcated was particularly striking to H.I. 'Doc' Ewen (1979: 42T), accustomed to much larger American budgets, when he visited Sydney for the 1952 URSI meeting:

> Their equipment was shoestring stuff, but there were a lot of cute tricks … They didn't waste much time with hardware where it wasn't all that important, [or with] trying to make it look pretty. But wherever a part was critical to the operation of a device, they spent a lot of time thinking about it.

And from the other perspective, Christiansen (1976: 31–32T) recalls how Ewen reacted upon seeing his 21 cm hydrogen line receiver:

> Ewen came out and said he had to see how these damn Australians did in three weeks what took other people eighteen months to do. And when he saw our gear, lying all over the room and on the floor, he just about passed out.

Pawsey's scientific style was distinctive and exemplary:

> He had an enormous enthusiasm. It was always a delightful experience to bring to Pawsey some new idea or some interesting new observation. His immediate reaction would be one of intense interest, followed by suspicion as he looked for some mistake or misinterpretation, or what he called 'the inherent cussedness of nature'. Finally, if convinced that all was well, his face would shine with boyish pleasure … He never forced his opinions on a younger colleague; if the matter was open to doubt he was willing to leave it to experiment. He was, in fact, the arch-empiricist. "Suck it and see" was one of his favourite expressions … He did not in general accept theoretical predictions as a guide to experiment; he preferred to investigate the questions that arose from previous experiments. "Following his nose" was how he described this process. (Christiansen and Mills 1964: 139).

> Pawsey had a childlike simplicity about him, a childlike curiosity. He was not a sophisticated man in the least. I find this is a talent that a lot of people who are truly great have in common—retaining a feeling that science is not a business, that it's a game … If Joe had been a businessman, you would have called him a sucker, but [for science] I think that's actually an important characteristic. (Stanley 1974: 25–26T).

> I think you could say Pawsey was a very simple soul … But he could floor a speaker: there'd be a fellow turning up a great piece of astrophysics and Joe would get up at the end and say quite innocently, and it *was* innocent, "I can't reconcile this with Ohm's Law." It would absolutely torpedo the speaker. (Christiansen 1976: 21T).

> Pawsey did not have much of a mathematical background—he once asked me what [statistical] 'variance' meant—but he thought in physical terms … He once proposed what he

> called the Sausage Theorem: "If the error bars on a set of visibility measurements fit inside a certain sausage, then the calculated source distribution [from the Fourier transform of the visibilities] runs down the middle of another sausage." Pawsey very reasonably wanted to know how fat this other sausage was and my job was to find out. It is a very good question. (Bracewell 1984:171).

Finally, a dissenting view has been given by Francis F. Gardner (1986), an RP ionospheric colleague of Pawsey's during these years:

> The impression of Joe as a naive, unworldly type is misleading. To some extent this was a pose, which contributed to his ability to 'draw people out' … Nor was he opposed to theory … In discussions he was able to grasp immediately what was said to him, even if poorly expressed, and he also was able to concentrate one's attention on the problem under consideration. Occasionally he would suggest solutions to some degree with tongue-in-cheek. His suggestions might not be appropriate, but enabled others to see the solutions.

18.5.4 Why was RP so Successful?

When an institution is created for one specific mission and then, because of changed circumstances, tries to adapt to a different role, the results are often less than satisfactory. RP's shift from war to peace, however, was a striking counter to this. Through skillful leadership, scientific expertise, and good fortune (for instance, how might the fledgling solar noise efforts have gone if the 'sunspot group of the century' had not shown up in February 1946?), RP put Australia at the forefront of radio astronomy over the postwar decade. By the early 1950s, RP was also clearly CSIRO's scientific leader (Schedvin 1987: 360). In fact, in no other natural science did such international stature come to Australia during these years—perhaps the closest was the immunology research led by F. MacFarlane Burnet at Melbourne's Walter and Eliza Hall Institute of Medical Research, or the neurophysiology led by J.C. Eccles (see Courtice 1988). Many of the factors important in this achievement have already been discussed, but others deserve mention.

One was the sheer size of the radio noise group, far larger than other institutions in the field—with so many projects going on simultaneously, one is much more likely to have at least one winner at any given time. The radio physicists were also supported by invaluable assistance from the large staff of technicians for electrical and mechanical work. A mild climate also conferred distinct advantages for research involving outdoor construction and experimentation (Bolton 1978: 107T). We can dismiss, however, one possible factor for the Australians' success, namely that they had the southern sky to themselves and therefore had no competition and only needed to mimic northern observers. Although for over a century Australia had been a fertile outpost for research precisely because of its unique flora and fauna and non-European skies, the evidence of this chapter shows that for radio astronomy this notion is patently untenable. After all, the same Sun is shared between north and south. In fact, Bolton took the view that any new setup should work the reachable northern sky first so as to beat the northerners—the southern regions would always be there later (Kerr 1987; cf. Piddington 1959). Witness the trouble Bolton made for himself by observing the notably northern source Cygnus-A as it barely scraped his horizon, although overhead in England.

18.5.5 Transforming Radio Physicists into Radio Astronomers

As work on radio noise developed in the Radiophysics Laboratory over the years, there was a gradual integration of the research into astronomy proper and the transformation of radio physicists into radio astronomers. Even from the beginning, Pawsey recognized that this new radio technique was fundamentally altering *astronomical* knowledge. As he stated during a talk to an August 1946 meeting in Adelaide:

> This [solar noise] work is a new branch of astronomy … New observational tools [in astronomy and astrophysics] have an unusual importance. The last outstanding development in solar instruments was probably the spectroheliograph (developed at the turn of the century). Consequently it is reasonable to expect that the discovery of this radiation will come to be recognised as one of the fundamental advances in astrophysics. (Pawsey 1946c).

Yet although the RP staff realized that they were essentially doing astronomy, albeit of a wholly different type and not well understood by astronomers, their astronomical education proceeded in a checkered manner. Whereas Bolton (1978: 30, 36–37T) chose to plow methodically through volume upon volume of the *Astrophysical Journal* during long observing nights, most just picked up what they deemed necessary as they went along. Books such as George Gamow's *The Birth and Death of the Sun* were read and Bolton undertook a partial translation of Max Waldmeier's 1941 treatise on the Sun. The exposure to Mt. Stromlo, including occasional joint colloquia, was also important. But RP had nary an astronomer on its staff and its orientation during the first postwar years was as often toward the techniques as the astronomy:

> We were simply radio people trying to provide another tool for detecting what these astronomers said was likely to be there … We didn't consider ourselves to be astronomers—our primary interest was in the equipment. In fact we'd just left a wartime situation and we knew that our success in radar stemmed from having people who were very well trained in the techniques. (Hindman 1978: 98B).

By the early 1950s, however, overseas trips, increasing contacts with astronomers, and a gradual accumulation of astronomical knowledge had caused a clearer picture to emerge of how the radio work fitted into astronomy as a whole (cf. Jarrell 2005).

18.5.6 The 1950s as a Watershed

The 1950s represent a watershed from several perspectives. For the first time research on solar noise was overtaken in quantity by that on ‘cosmic’ (non-solar) noise—the percentage of solar papers dropped from ~70% before 1951 to ~40% during 1952–1954. At this time also, Pawsey and Bracewell (1955) wrote a masterful monograph, *Radio Astronomy* (mostly written in 1952). It formed a capstone to the first stage of the field’s development and was to remain the definitive textbook for a decade. And of course the 1952 URSI meeting also happened at this juncture.

A key change during the early 1950s was the shift from a large number of relatively small experiments to a smaller number of projects on a large scale. This was the start of the transition from ‘Little Science’ to ‘Big Science’—or, as Wild (1965) has pungently described it, moving from trailers “… with a characteristic smell … ” to air-conditioned buildings. Progress in the science now demanded huge antennas and arrays, and many of these were beyond the capacity of RP to produce in-house. For example, in 1951 *outside* bids for antennas were sought for the first time for 50 ft and 80 ft dishes (“Tentative specifications … ”, 1951). In 1953 RP funded its last major antenna from its own resources: the 1500 ft Mills Cross array at Fleurs for £2500 (Mills 1953). More costly ventures did not come easily, however, for the Government and CSIRO were not willing to support large capital projects (Bolton 1978: 56T; Bowen 1978: 44T). Eventually, however, the first one emerged in the form of a ‘Giant Radio Telescope’ whose cost and planning dominated the second half of the 1950s (see below).

18.6 The Second Decade and beyond

This section gives a very brief overview of the period beyond 1955, focusing on the major instruments that were built and the personnel changes that led to an entirely different Radiophysics Division.

18.6.1 A Giant Radio Telescope and a Solar Ring

Nascent thoughts about a ‘Giant Radio Telescope’ (GRT) and its funding began as early as 1948. Bowen at that time tried to convince the Royal Australian Air Force to build a huge radar antenna that could do radio astronomy on a part-time basis. Several designs were studied over the next few years, some as large as 500 ft in dimension, but the funding never materialized. By 1951 the search for funds shifted to non-military sources and eventually the key money came from American foundations, starting in 1954 when the Carnegie Foundation made a major grant for a giant dish. But such a facility would represent a wholly different philosophy from that of

RP's small field stations and their concomitant research groups, since it would command such a high fraction of RP's resources that it necessarily had to be all things to all people. In 1961 RP consummated the transition to 'Big Science' with the commissioning of a 210 ft parabolic antenna at Parkes, 260 km west of Sydney. For complete details of the fund-raising, design, construction, and research programme of the Parkes Radio Telescope, see Robertson (1992). Today, after fifty-five years and many upgrades, 'The Dish' remains amazingly productive; it is still the largest stand-alone radio telescope in the Southern Hemisphere, and the only one ever to be the star of a feature film (in 2000).

The other major RP instrument of this period was the pet project of Wild, who later became Division Chief and then Chief Executive of all of CSIRO. In the early 1960s the US Ford Foundation funded the Culgoora Radioheliograph, a 3-km-diameter circle of 96 low-frequency dishes that could produce a detailed, second-by-second 'movie' of the changeable Sun, ultimately at three different frequencies. Over the period 1967–1984 it was the premiere solar radio telescope in the world, and it was only closed down in order to make way for the Australia Telescope Compact Array (see Sect. 18.6.3, below).

18.6.2 Dissension and Exodus

The decision to build the Parkes dish had far more than scientific consequences, for it created dissension among the maturing RP group leaders (most of whom were then in their early 40s). Pawsey had had great success in scientifically rearing his junior colleagues, but RP was not like a university department with its steady stream of students—the RP 'students' had nowhere to go in the first decade, and there were no positions for new ones. Already, in 1951, Pawsey was saying that the outstanding defect in the radio astronomy group was its lack of the 'research student' type with which he worked so well. Through the 1950s the various group leaders became strong-willed, confident individuals, arguing their own particular visions of how radio astronomy at RP should be done. Major disputes centered on two questions: (a) Should the focus continue on small technique-oriented groups or shift to a single major facility? and (b) Which types of antennas would pay off best? Regarding the latter, the cost of major projects was now such that only roughly every decade or so could one be afforded.

The first major figure to leave Pawsey's group was Bolton, who in 1953 switched to cloud physics (after denial of funding for a new type of interferometer) and then in 1955 (assisted by Stanley) founded a new radio observatory at the California Institute of Technology (Kellermann et al. 2005; Stanley 1994: 511–513). In 1960, however, Bolton returned (without Stanley) to become Director of the new Parkes Radio Telescope. Also about this time, Bowen and Pawsey began to work less well as a team and developed significant differences, in particular over the choice of a big dish and how to run it. This led to Pawsey accepting a position to direct the fledgling National Radio Astronomy Observatory in Green Bank, West Virginia, USA, but he died of a brain tumor in 1962 (at age 54) before he could assume his duties. Others who permanently departed in the second decade were Stanley (to Caltech), Bracewell (to Stanford), and Kerr (to the University of Maryland).

Christiansen was also lured away about this time to the University of Sydney (he called the Parkes dish "… the last of the windjammers."), where he continued to develop aperture synthesis techniques at the Fleurs field station (Orchiston and Slee 2005), culminating in the Fleurs Synthesis Telescope, which made continuum maps over the period 1973–1988. Likewise, Mills, after his proposal to RP for a giant (Mills) Cross antenna was passed by (in favor of the Culgoora Radioheliograph), also moved in 1960 to the University of Sydney and built his cross at Molonglo (once again with US funding, this time from the Government's National Science Foundation). It was completed in 1967, and in its first decade catalogued more than 10,000 radio sources at 408 MHz; in 1981 it was transformed into the Molonglo Synthesis Telescope (MOST).

18.6.3 The Australia Telescope

During the 1970s, Australian radio astronomy remained strong, but did not keep up with the major facilities being constructed overseas (e.g., the Westerbork Synthesis Radio Telescope (12 dishes) in the Netherlands, a 100-meter fully-steerable dish in Germany, and the Very Large Array, a 27-dish synthesis array in the US). On the other hand, the pace and scale of worldwide astronomy meant that Australian astronomers (of all stripes, not just radio) wanting any new major facilities needed to act in unison in order to secure funding from the Government. The radio astronomy community had already been supportive of various major optical projects with its expertise and personnel. For example, Bowen and Minnett had contributed to the design of the Anglo-Australian (optical) Telescope at Siding Spring, and Robert Hanbury Brown (a transplant from Jodrell Bank in England) established a specialized optical observatory at Narrabri for measuring stellar diameters (employing his intensity interferometer principle).

Thus in the years around 1980 a (mostly) united front of astronomers sought and eventually secured major funding from the Government for a synthesis array of dishes (final cost was about A$50 million). This eventually became known as the Australia Telescope (AT) when it was accepted as an official Australian Bicentennial Project, which dictated that it had to officially open in 1988—although the first synthesized map (using just three antennas) was not produced until the following year. The AT was centered on a set of six 22-m dishes located at the site of the Culgoora Radioheliograph, near Narrabri, New South Wales. With precision surfaces that could operate at wavelengths as short as 3 mm, it did much to restore Australia's prestige in radio astronomy. A new CSIRO Division, the Australia Telescope National Facility, was set up to operate this major new resource. The inaugural Director was Ronald Ekers, who had trained under Bolton in the 1960s but now came home after two decades overseas.

Australia would never again be as dominant in radio astronomy as it had been in the decade after World War II when the field was brand new, but with the Australia Telescope it was now again fully competitive.

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References[15]

Alexander, E. (1945). Report on the investigation of the "Norfolk Island effect". R.D. 1/518, Radio Development Lab., D.S.I.R., Wellington: New Zealand.

Alexander, F.E.S. (1946). The Sun's radio energy. *Radio & Electronics, 1,* 16–17, 20.

Allen, C.W., & Gum, C.S. (1950). Survey of galactic radio-noise at 200 Mc/s. *Australian Journal of Scientific Research, A3,* 224–233.

Bhathal, R. (1996). *Australian Astronomers: Achievements at the Frontiers of Astronomy*. Canberra: National Library of Australia.

Blainey, G. (1968). *The Tyranny of Distance: How Distance Shaped Australia's History*. Melbourne: Macmillan.

Bok, B. (1971). Taped interview with W. Sullivan.

Bolton, J.G. (1947). Summary of Cygnus Results—4th-25th June, 1947. Undated 1-page report, in File A1/3/1a (RPA).

Bolton, J.G. (1948). Discrete sources of galactic radio frequency noise. *Nature, 162,* 141–142.

Bolton, J.G. (1950). Letter to E.G. Bowen, dated 14 April. In File F1/4/BOL/1 (RPA).

Bolton, J.G. (1982). Radio astronomy at Dover Heights. *Proceedings of the Astronomical Society of Australia, 4,* 349–358.

Bolton, J.G., & Stanley, G.J. (1948a). Variable source of radio frequency radiation in the constellation of Cygnus. *Nature, 161,* 312–313.

Bolton, J.G., & Stanley, G.J. (1948b). Observations on the variable source of cosmic radio frequency radiation in the constellation of Cygnus. *Australian Journal of Scientific Research, A1,* 58–69.

Bolton, J.G., & Stanley, G.J. (1949). The position and probable identification of the source of galactic radio-frequency radiation Taurus-A. *Australian Journal of Scientific Research, A2,* 139–148.

Bolton, J.G., Stanley, G.J., & Slee, O.B. (1949). Positions of three discrete sources of galactic radio-frequency radiation. *Nature, 164,* 101–102.

Bowen, E.G. (1945a). *Future Programme of the Division of Radiophysics*. Report dated 2 July, in File D1/1 (Copy in RPA).

Bowen, E.G. (1945b). Letter to F.G.W. White, dated 1 August. In File A1/3/1a (RPA).

Bowen, E.G. (1946a). Letter to Sir Edward Appleton, dated 23 January. In File A1/3/1a (RPA).

Bowen, E.G. (1946b). Letter to J.L. Pawsey, dated 23 August. In File A1/3/1a (RPA).

Bowen, E.G. (1947a). Letter to D.F. Martyn, dated 28 January. In File A1/3/1a (RPA).

Bowen, E.G. (ed.) (1947b). *A Textbook of Radar*. Sydney: Angus and Robertson.

Bowen, E.G. (1948). Letter to J.L. Pawsey, dated 17 June. (#4). In File F1/4/PAW/1 (RPA).

Bowen, E.G. (1973). Taped interview with W. Sullivan.

Bowen, E.G. (1984). Taped interview with W. Sullivan.

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[15] The following abbreviations are used:
RP = CSIRO Division of Radiophysics.
RPA = CSIRO Division of Radiophysics Archives.

Bowen, E.G. (1987). *Radar Days*. Bristol: Adam Hilger.

Bracewell, R.N. (1948). Letter to E.G. Bowen, dated 19 January. In File F1/4/BRA (RPA).

Bracewell, R.N. (1950). Letter to M. Ryle, dated 6 January. In Box 1/1, RYL.

Bracewell, R.N. (1984). Early work on imaging theory in radio astronomy. In W.T. Sullivan, 1984a, pp. 167–190.

Briton, J.N. (1946). Letter to O.B. Slee, dated 18 March. In File A1/3/1a (RPA).

Christiansen, W.N. (1984). The first decade of solar radio astronomy in Australia. In W.T. Sullivan, 1984a, pp. 113–131.

Christiansen, W.N., & Hindman, J.V. (1952). A preliminary survey of 1420 Mc/s line emission from galactic hydrogen. *Australian Journal of Scientific Research, A5,* 437–455.

Christiansen, W.N., & Mills, B.Y. (1964). Biographical memoir of Joseph Lade Pawsey. *Australian Physicist, 1,* 137–141.

Collis, B. (2002). *Fields of Discovery: Australia's CSIRO*. Crows Nest: Allen & Unwin.

Courtice, F.C. (1988). Research in the medical sciences: the road to national independence. In R. Home, pp. 277–307.

de Vaucouleurs, G. (1976). Taped interview with W. Sullivan.

Edge, D.O., & Mulkay, M.J. (1976). *Astronomy Transformed: The Emergence of Radio Astronomy in Britain*. New York: John Wiley.

Gardner, F.F. (1986). Letter to W. Sullivan, dated 12 November.

Gillmor, C.S. (1991). Ionospheric and radio physics in Australian science since the early days. In R.W. Home, & S.G. Kohlstedt (Eds.), *International Science and National Scientific Identity* (pp. 181–204). Dordrecht: Kluwer.

Goddard, D.E., & Haynes, R.F. (Eds.), (1994). Pioneering a New Astronomy: Papers in Memory of John G. Bolton. *Australian Journal of Physics, 47*(5), 495–680.

Goddard, D.E., & Milne, D.K. (Eds.), (1994). *Parkes: Thirty Years of Radio Astronomy*. Melbourne: CSIRO Publishing.

Haynes, R., Haynes, R., Malin, D., & McGee, R. (1996). *Explorers of the Southern Sky: A History of Australian Astronomy*. Cambridge: Cambridge University Press.

Hey, J.S. (1973). *The Evolution of Radio Astronomy*. London: Elek Science.

Hey, J.S., Parsons, S.J., & Phillips, J.W. (1946). Fluctuations in cosmic radiation at radio-frequencies. *Nature, 158,* 234.

Home, R.W. (Ed.), (1986). *Australian Science in the Making*. Cambridge: Cambridge University Press.

Home, R. (1982–1983). Origins of the Australian physics community. *Historical Studies, 29,* 383–400.

Home, R. (2005). Rainmaking in CSIRO: the science and politics of climate modification. In T. Sherratt, et al. (Eds.), *A Change in the Weather: Climate and Culture in Australia* (pp. 66–79). Canberra: National Museum of Australia Press.

Jaeger, J.C. (1943). *Theory of the Vertical Field Patterns for R.D.F. Stations*. RP Report, No. RP174 (copy in RPA).

Jarrell, R. (2005). "Radio astronomy, whatever that may be." The marginalization of early radio astronomy. In W. Orchiston (Ed.), *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth* (pp. 191–202). Dordrecht: Springer.

Kellermann, K.I. (1996). John Gatenby Bolton (1922–1993). *Publications of the Astronomical Society of the Pacific, 108*, 729–737.

Kellermann, K.I., Orchiston, W., & Slee, B. (2005). Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia, 22*, 1–11.

Kerr, F.J. (1971). Taped interview with W. Sullivan.

Kerr, F.J. (1976). Taped interview with W. Sullivan.

Kerr, F.J. (1987). Letter to W. Sullivan, dated 6 April.

Lovell, A.C.B. (1964). Joseph Lade Pawsey 1908–1962. *Biographical Memoirs of Fellows of the Royal Society, 10,* 229–243.

Martyn, D.F. (1946). Temperature radiation from the quiet sun in the radio spectrum. *Nature, 158,* 632–633.

Martyn, D.F. (1948). Letter to Sir Edward Appleton, dated 27 October. In Appleton Papers, Edinburgh University.

McCready, L.L., Pawsey, J.L., & Payne-Scott, R. (1947). Solar radiation at radio frequencies and its relation to sunspots. *Proceedings of the Royal* Society*, A190,* 357–375.

Mills, B.Y. (1953). Large aerial for meter wavelengths. Report, in File A1/3/10 (RPA).

Mills, B.Y. (1954). Letter to J.L. Pawsey, dated 27 August. In File F1/4/PAW/3 (RPA).

Minnett, H.C. (1986). Letter to W. Sullivan, dated 22 October.

Minnett, H.C., & Sir Rutherford Robertson (1996). Frederick William George White 1905–1994. *Historical Records of Australian Science*, 11, 239–258.

Orchiston, W. (1994). John Bolton, discrete sources, and the New Zealand field-trip of 1948. *Australian Journal of Physics, 47,* 541–547.

Orchiston, W. (2004). From the solar corona to clusters of galaxies: The radio astronomy of Bruce Slee. *Publications of the Astronomical Society of Australia, 21,* 23–71.

Orchiston, W. (2005a). Dr. Elizabeth Alexander: first female radio astronomer. In W. Orchiston (ed.). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth* (pp. 71–92). Dordrecht: Springer.

Orchiston, W. (2005b). Sixty years in radio astronomy: a tribute to Bruce Slee. *Journal of Astronomical History and. Heritage, 8,* 3–10.

Orchiston, W., & Slee, B. (2002). The Australasian discovery of solar radio emission. *AAO. Newsletter, 101,* 25–27.

Orchiston, W., & Slee, B. (2005). The Radiophysics field stations and the early development of radio astronomy. In W. Orchiston (Ed.), *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth* (pp. 119–168). Dordrecht: Springer.

Pawsey, J.L. (1945). Letter to C.W. Allen, dated 15 October. In File A1/3/1a (RPA).

Pawsey, J.L. (1946a). Letter to R. Woolley, dated 11 September. In File B51/14 (RPA).

Pawsey, J.L. (1946b). Observation of million degree thermal radiation from the sun at a wavelength of 1.5 metres. *Nature, 158,* 633–634.

Pawsey, J.L. (1946c). Solar radiation at radio frequencies and its relationship to sunspots: interpretation of results. Paper presented on 19 August at the ANZAAS Meeting. Copy in FileA1/3/1a (RPA).

Pawsey, J.L. (1947). Letter to J. Bolton and G. Stanley, dated 11 November. In File A1/3/1a (RPA).

Pawsey, J.L. (1948a). Letter to E.G. Bowen, dated 13 February. In FileA1/3/1a (RPA).

Pawsey, J.L. (1948b). Letter to E.G. Bowen, dated 12 August. In File F1/4/PAW/1 (RPA),

Pawsey, J.L. (1948c). Letter to E.G. Bowen, dated 15 August. In File F1/4/PAW/1 (RPA).

Pawsey, J.L. (1948d). Letter to Sir Edward Appleton, dated 8 September. In File F1/4/PAW/1 (RPA).

Pawsey, J.L. (1951). Letter to M. Oliphant, dated 10 September. In File A1/3/1n (RPA).

Pawsey, J.L. (1961). Australian radio astronomy. *Australian Scientist, 1,* 181–186.

Pawsey, J.L., & Bracewell, R.N. (1955). *Radio Astronomy*. Oxford: Oxford University Press.

Pawsey, J.L., & Payne-Scott, R. (1944). Measurements of the Noise Level Picked up by an S-band Aerial. Report, No. R.P. 209 (dated 11 April. Confidential). (Copy in RPA).

Pawsey, J.L., Payne-Scott, R., & McCready, L.L. (1946). Radio-frequency energy from the sun. *Nature, 157,* 158–159.

Payne-Scott, R., Yabsley, D.E., & Bolton, J.G. (1947). Relative times of arrival of bursts of solar noise on different radio frequencies. *Nature, 160,* 256–257.

Piddington, J.H. (1959). Proposed early investigations using 210 ft radio telescope. Planning document, dated 16 September. In File A1/3/11/17 (RPA).

Piddington, J.H. (1978). Taped interview with W. Sullivan.

Reber, G. (1940). Cosmic static. *Proceedings of the Institute of Radio Engineers, 28,* 68–70.

Robertson, P. (1992). *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope*. Cambridge: Cambridge University Press.

Schedvin, C.B. (1987). *Shaping Science and Industry: A History of Australia's Council for Scientific and. Industrial Research, 1926–49*. Sydney: Allen & Unwin.

Slee, O.B. (1946). Letter to Radiophysics Division, CSIRO, dated 4 March. In File A1/3/1a (RPA).

Slee, O.B. (1994). Some memories of the Dover Heights field station, 1946–1954. *Australian Journal of Physics, 47,* 517–534.

Stanley, G.J. (1974). Taped interview with W. Sullivan.

Stanley, G.J. (1994). Recollections of John G. Bolton at Dover Heights and Caltech. *Australian Journal of Physics, 47,* 507–516.

Sullivan, W.T. III (1982). *Classics in Radio Astronomy*. Dordrecht: Reidel.

Sullivan, W.T. III (Ed.), (1984a). *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky*. Cambridge: Cambridge University Press.

Sullivan, W.T. III (1984b). Early radio astronomy. In O. Gingerich (Ed.), *Astrophysics and Twentieth-Century Astronomy to 1950* (pp. 190–198). Cambridge: Cambridge University Press.

Sullivan, W.T. III (1988). Early years of Australian radio astronomy. In R. Home, pp. 308–344.

Sullivan, W.T. III (2005). The beginnings of Australian radio astronomy. *Journal of Astronomical History and. Heritage, 8,* 11–32.

Tentative specifications for 80-foot and 50-foot radio astronomy aerials. Document dated 8 August 1951, in File A1/3/1h (RPA).

Thomsen, I.L. (1948). Solar radio emissions and sunspots. *Nature, 161,* 134–136.

Westerhout, G. (2000). Obituary: Frank John Kerr, 1918–2000. *Bulletin of the American Astronomical Society*, 32, 1674–1676.

Wild, J.P. (1965). Origin and growth of radio astronomy in CSIRO. Lecture delivered to CSIRO Division of Plant Industry. Copy in File D/12/1/5 (RPA).

Wild, J.P. (1972). The beginnings of radio astronomy in Australia. *Records of the Australian Academy of. Science, 2*(3), 52–61.

Wild, J.P. (1987). The beginnings of radio astronomy in Australia. *Proceedings of the Astronomical Society of Australia, 7,* 95–102.

Woolley, R. (1947). Opportunities for astronomical work in Australia. [Section A Presidential Address.] In A.G. Ross, (Ed.), *Report of the 26th Meeting of ANZAAS, Perth 1947* (pp. 64–80). Canberra: Government Printer.

Yabsley, D. (1986). Letter to W. Sullivan, dated 10 October.

Chapter 19
The Early Development of Australian Radio Astronomy: The Role of the CSIRO Division of Radiophysics Field Stations

Wayne Orchiston and Bruce Slee

19.1 Introduction

Although radio astronomy was born in the 1930s with the pioneering efforts of Karl Jansky (1905–1950) and Grote Reber (1911–2002) (see Kellermann and Sheets 1983; Kellermann 2005; Sullivan 1984), this new branch of astronomy only blossomed after WWII. Between 1946 and 1961, two nations which established remarkable reputations in radio astronomy were Britain and Australia (Edge and Mulkay 1976; George et al. 2015; Orchiston et al. 2015a, 2017; Stewart et al. 2011c; Sullivan 1984, 1988), the latter largely through the achievements of those employed by the Commonwealth Scientific and Industrial Research Organisation's Division of Radiophysics (henceforth RP). Prior to the opening of the Parkes Radio Telescope in November 1961, most of the observations conducted by RP staff were made at a network of field stations and associated remote sites in and near Sydney (Orchiston and Slee 2005a; Robertson 1992; Sullivan 2005). This chapter examines the contribution that these field stations made to international radio astronomy, and draws freely on the excellent collection of images assembled over the years by the RP Photo Lab (see Orchiston 2001; Orchiston et al. 2004a).

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19.2 The Radiophysics Field Stations

In an unpublished report, Ruby Payne-Scott (1945) reveals that the RP radio astronomy program owes it origin to the more-or-less simultaneous arrival at the Radiophysics Laboratory of three crucial communications: secret reports of war-time detections of solar radio emission by radar units in England and New Zealand, and a copy of Grote Reber's (1944) research paper on 'cosmic static'. The New Zealand research was carried out by Elizabeth Alexander (1908–1958; see Orchiston 2005a, 2016, Chapter 23; Orchiston and Slee 2002a), and this had greatest impact given that Taffy Bowen, Joe Pawsey and others at RP knew her personally, and that they had access to radar antennas similar to the ones used in New Zealand. Thus, RP's initial observations, dating between October 1945 and March 1946, were specifically designed to replicate the New Zealand work. Reports published in *Nature* (Pawsey et al. 1946) and in the *Proceedings of the Royal Society* (McCready et al. 1947) show that they were able to achieve this and to make additional contributions, thereby facilitating Australia's entry into a fascinating yet challenging new field of scientific endeavour.

Between 1945 and 1961, RP staff carried out radio astronomical observations at the Radiophysics building (which was located within the grounds of the University of Sydney), and at nine different field stations in the Sydney area and near Wollongong (see Figs. 19.1 and 19.2 for New South Wales and Victorian localities mentioned in the text). In addition, the Collaroy and North Head WWII radar stations were home briefly to solar radio astronomy projects in 1945–1946, and during the 1950s and 1960s a number of short-lived 'remote' sites were used in conjunction with the regular field stations. In all, research by RP staff was carried out at 21 different sites in the general Newcastle-Sydney-Wollongong region during the early days of Australia radio astronomy, as well as at two solar eclipse sites in Victoria, two further solar eclipse sites in Tasmania, and two temporary field stations in the North Island of New Zealand (for further details see Sullivan 2009). In addition, during the 1940s RP staff members were closely associated with the radio astronomy that was conducted at Mount Stromlo Observatory near Canberra (see Frame and Faulkner 2003; Orchiston et al. 2006).

The bulk of Australia's early radio astronomical observations were made at the nine RP field stations by small close-knit teams of researchers, typically with radio rather than astronomy backgrounds, who at any one time worked on a limited number of specialized research projects. Initially they commandeered surplus WWII receivers and other equipment or built their own primitive instrumentation, but with the passage of the years some amazingly innovative new types of radio telescopes were developed in response to specific research needs.

Field station life was primitive,

> … completely informal and egalitarian, with dirty jobs shared by all. Thermionic valves were in frequent need of replacement and old and well-used co-axial connectors were a constant source of trouble … there was no place for observers who were incapable of repairing or maintaining equipment. (Christiansen 1984: 113, 115).

On the other hand, those of us lucky enough to have lived through this era remember the field stations with genuine affection. There was a freedom not

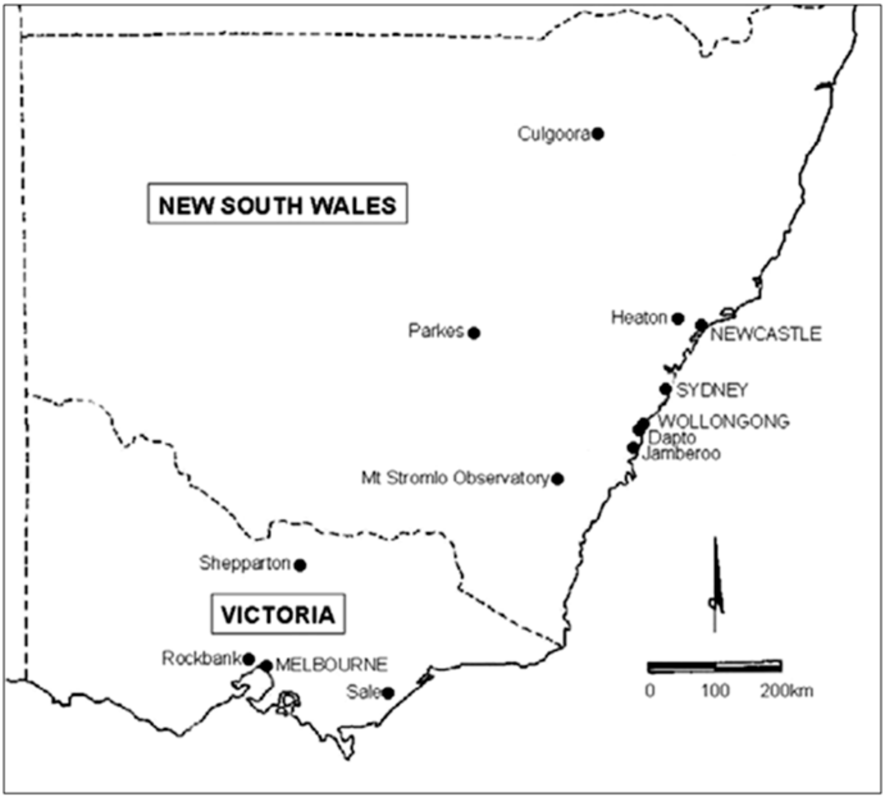

Fig. 19.1 New South Wales and Victorian localities mentioned in the text; for details of the Sydney region see Fig. 19.2 (*Map* Wayne Orchiston)

experienced by those back at the 'Lab' (as the Radiophysics Laboratory was known): the pervading sunshine, the clean fresh air, those incident-packed return trips from home to field station by Commonwealth car, and the sense that we were somehow making history. There were also snakes to contend with, wet days when antennas still had to be aligned and observations made, floods that had to be negotiated, and those times—fortunately they were few and far between—when vehicles became bogged and had to be rescued by a co-operative local farmer (Fig. 19.3). Slide rules were the norm and computers but a future dream. Signal generators, not sources, provided calibrations, and results were displayed in real time on Esterline Angus and other all-too-familiar chart recorders. These were pioneering days.

Overseeing the work at the various field stations was Dr. Joe Pawsey (1908–1962; see Fig. 19.4), a revered father figure and head of the Radio Astronomy Group within the Division of Radiophysics (Chief of the Division, Dr. E.G. (Taffy) Bowen (1911–1991), was responsible for the Division's other major research areas, cloud physics, rain-making and air-navigation aids). Joe liked to make unheralded visits to the field stations, and sometimes turned up for morning or afternoon tea armed with

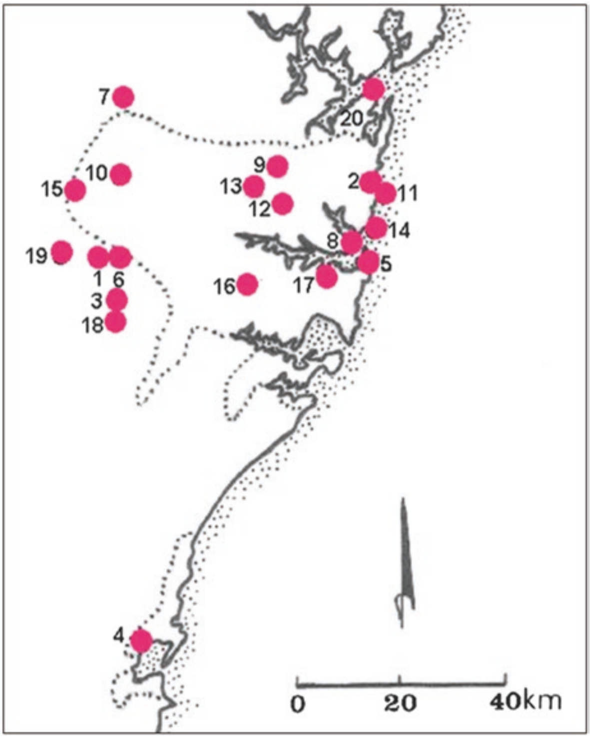

Fig. 19.2 Radio astronomy localities in the Sydney-Wollongong region; the dotted outlines show the current approximate boundaries of the Greater Sydney and Greater Wollongong regions [key to localities: *1* Badgerys Creek, *2* Collaroy, *3* Cumberland Park, *4* Dapto, *5* Dover Heights, *6* Fleurs, *7* Freeman's Reach, *8* Georges Heights, *9* Hornsby Valley, *10* Llandilo, *11* Long Reef, *12* Marsfield (ATNF Headquarters), *13* Murraybank, *14* North Head, *15* Penrith, *16* Potts Hill, *17* Radiophysics Laboratory (Sydney University grounds), *18* Rossmore, *19* Wallacia, *20* West Head] (*Map* Wayne Orchiston)

a supply of his greatest gastronomic weakness, 'lamingtons'—those tasty cubes of sponge cake coated with chocolate icing. Notwithstanding these rather popular 'bribes', Joe was "… very good at getting the best out of people. He had this method whereby when you came to talk to him about some problem, he'd often propose some other way of doing it … he took an interest in everything …" (Gardner 1973). But the downside of Joe's unbridled enthusiasm, Ruby Payne-Scott (1978) recalls, was that "… you were lucky to get home for dinner when he showed up at the end of the day." Yet, through these visits Joe was able to chart progress at the field stations, discuss problems, and keep everyone abreast of relevant developments back at the Lab. Field station staff also got to hear about work at other field stations when they attended seminars and occasional meetings at the Radiophysics Laboratory.

While most of the early observational work was carried out at the field stations, in 1948 and 1949 some important research was achieved using a 1.1 m (44-in.) dish mounted on the 'Eagle's Nest' (Fig. 19.5), a small room and associated flat-roofed area located at the very top of the Radiophysics Laboratory (Fig. 19.2). This recy-

Fig. 19.3 Fleurs' indispensable mobile field laboratory, 'Flo', being extricated from the mud by the radio astronomers and a helpful local farmer (*Courtesy* CSIRO RAIA B3923-4)

Fig. 19.4 John Bolton, Gordon Stanley and Joe Pawsey (left to right) at the Radiophysics Laboratory (*Courtesy* CSIRO RAIA 11833-6)

Fig. 19.5 The 'Eagle's Nest' at the top of the Radiophysics Laboratory, showing the small antenna used by Labrum, Minnett and Piddington (*Courtesy* CSIRO RAIA B1641)

cled WWII searchlight mirror was used by Norman Labrum (1921–2011; Orchiston 2011), Harry Minnett (1917–2003; Orchiston 2014b; Thomas and Robinson 2005) and Jack Piddington (1910–1997; Melrose and Minnett 1998; Orchiston 2014c), in various combinations, to observe the Sun at 9400 and 24,000 MHz and the Moon at 24,000 MHz before being transferred to the Potts Hill field station.

Potts Hill and the other field stations shown in Figs. 19.1 and 19.2 are now considered individually, and for each we indicate the period of existence, the types of instruments and leading scientists found there, and their major research achievements.

19.2.1 Dover Heights

The Dover Heights field station (see Bolton 1982; Robertson et al. 2014; Slee 1994) was at the site of an Australian Army WWII radar station in suburban Sydney, 5 km south of the entrance to Sydney Harbour (Fig. 19.2). Located atop a 79-m high coastal cliff, it soon became known internationally for the solar research carried out by Ruby Payne-Scott (Goss and McGee 2009; Goss 2013) in 1945–1946 and for the pioneering work on discrete sources undertaken mainly by John Bolton (1922–1993; Kellermann 1996; Orchiston and Kellermann 2008; Wild and Radhakrishnan 1994), Gordon Stanley (1921–2001; Kellermann et al. 2005) and Bruce Slee (1924–2016; Orchiston 2004a, 2005b). Bolton and Stanley are both shown in Fig. 19.4. Most of the early observations were conducted with Yagi antennas operating at 60, 85, 100 and 200 MHz, which were mounted on the roof of a cliff-side WWII block-house (see Fig. 19.6). These simple radio telescopes were often used in sea interferometer mode—for a description of the sea interferometer concept see Bolton and Slee (1953).

In 1946 Hey et al. announced the presence of a small, variable radio source in Cygnus, and in mid-1947 Bolton and Stanley confirmed this discovery at Dover Heights and over the next few months observed this enigmatic source at 60, 85, 100 and 200 MHz (Fig. 19.7). Slee joined the team in September 1947, and soon after this the three young researchers conducted what was probably the world's first spaced-antenna experiment, using aerials at Dover Heights and at Long Reef and West Head (about 15 km and 35 km away, respectively, to the north of Sydney Harbour—see Fig. 19.2) in order to measure the degree of correlation between the intensity variations from Cygnus A at the three sites. They found there was a high correlation, showing that the variations were either an intrinsic feature of the source itself or else were caused by an ionospheric, interplanetary or interstellar diffraction

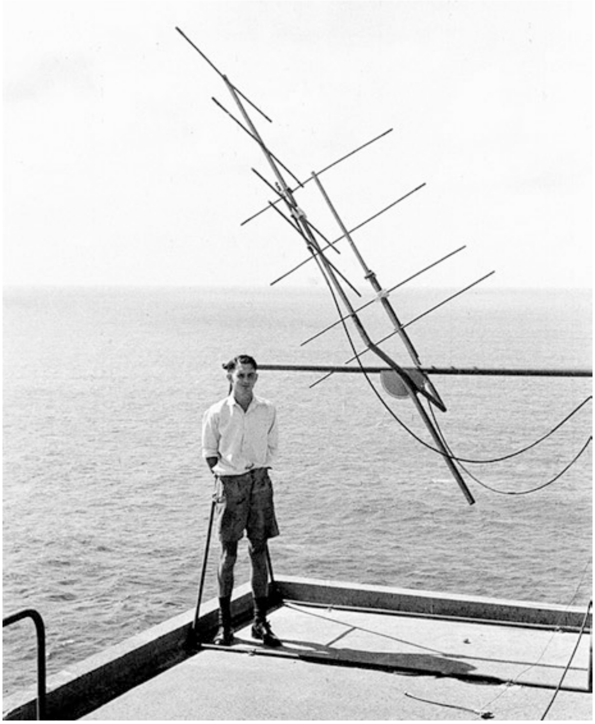

Fig. 19.6 A May 1947 close-up of John Bolton and the 100 MHz twin Yagis mounted on the roof of the cliff-side WWII block-house at Dover Heights (*Courtesy* CSIRO RAIA B1031-7)

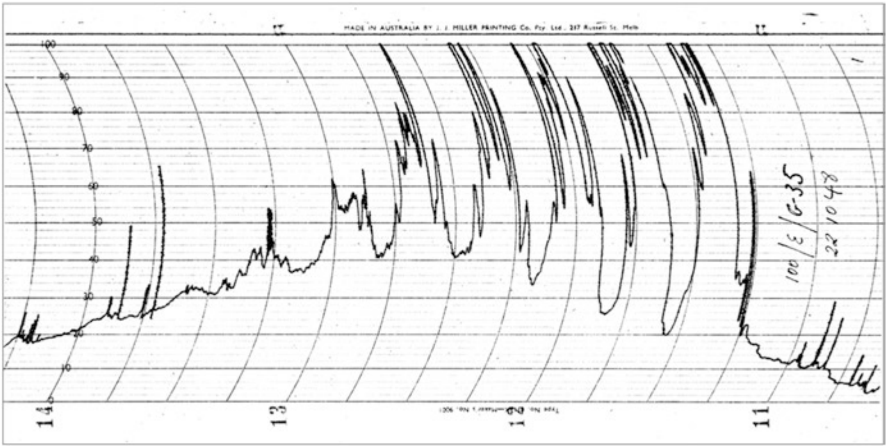

Fig. 19.7 Cygnus A sea interferometer fringes (*Courtesy* CSIRO RAIA 1639-2)

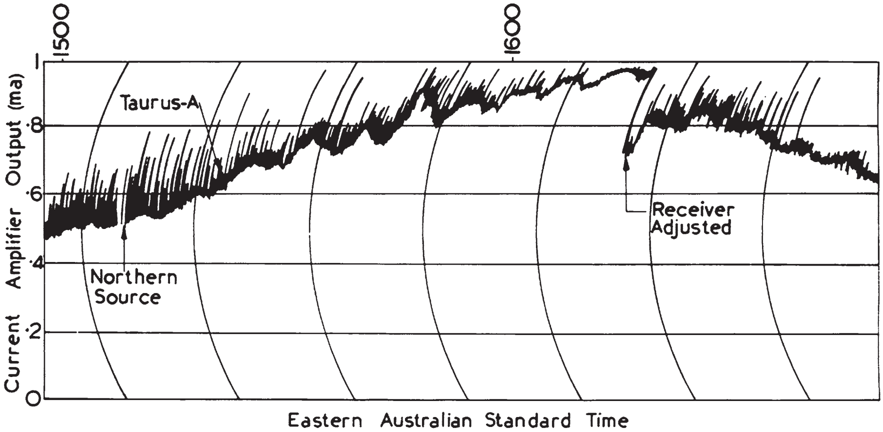

Fig. 19.8 A chart record showing Taurus A interference fringes (*Courtesy* ATNF RAIA B1651-2)

pattern with a scale size less than 15 km sweeping across the Earth. Subsequent observations by British colleagues confirmed their ionospheric origin.

Meanwhile, at Dover Heights the pressure was also on to search for more of these so-called 'radio stars', and this led to a survey with the 100 MHz sea interferometer, starting in November 1947. The first success came on November 6 when Taurus A (Fig. 19.8) was found (Orchiston and Slee 2006), and it was followed over the next few months by two others, Centaurus A (Robertson et al. 2010) and Virgo A. This was quite an achievement given the primitive nature of the equipment, which

> … was very cranky … you got interference patterns one day and wouldn't get them the next. Equipment would fail … The sea interferometer had a lot of nasty habits, like you could get interference wiped out by refraction problems and get sources rising ten minutes of time late and all this sort of crazy stuff … (Stanley 1974).

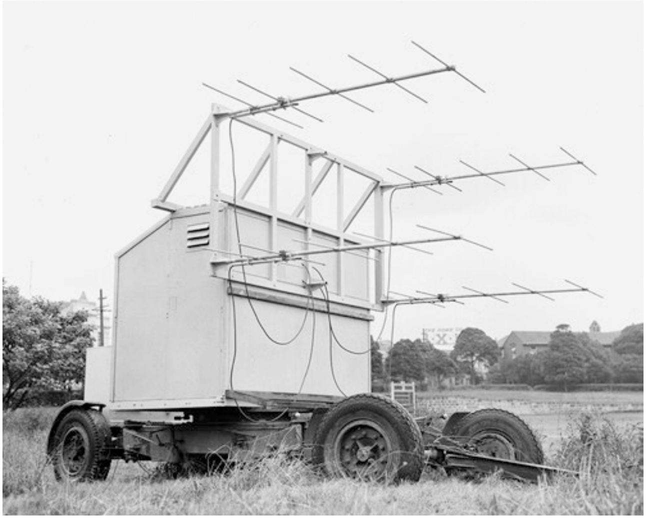

Fig. 19.9 The mobile 4-Yagi radio telescope that was shipped from Sydney to Auckland and used for the New Zealand observations (*Courtesy* CSIRO RAIA 1351-2)

The next priority was to determine accurate positions for these sources so that optical correlates could be sought. This was achieved in mid-1948 when observations made from high coastal cliffs near Auckland, New Zealand (see Fig. 19.9), allowed the identification of Taurus A with the Crab Nebula, and Centaurus A and Virgo A with extragalactic nebulae (Bolton et al. 1949), showing convincingly that the term 'radio star' was a misnomer and that these objects generated almost unbelievable levels of radio energy (see Orchiston 2016, Chapter 24; Robertson et al. 2010, 2014). But more than this, these identifications revealed the potency of radio astronomy to many optical astronomers for the first time, and marked the start of 'bridge-building' between these two disparate groups of scientists (c.f. Jarrell 2005). The New Zealand field trip that led to this remarkable break-through, and to the establishment of RP's two most easterly—albeit temporary—field stations in Stanley's ancestral homeland, is discussed further in Orchiston (1993, 1994, 2016: Chapter 24).

With the realization that 'radio stars' were actually discrete radio sources, the search was on, in earnest, for further sources. In 1948, more sources were discovered with the 2-Yagi antenna, including Fornax A, Hercules A and Hydra A. In 1949 a steerable 9-Yagi array was installed on the roof of the blockhouse (Fig. 19.10) and used to survey Milky Way emission at 100 MHz. When used in sea-interferometer mode, it revealed 14 new sources. At this time, Stanley and Slee also used a number of 2-Yagi antennas to measure the intensities of Centaurus A, Cygnus A, Taurus A and Virgo A at a number of frequencies between 40 and 160 MHz, and published the first acceptable source spectra (see Stanley and Slee 1950; see Fig. 19.11). Except for Taurus A, these spectra strongly suggested that the radio emission was non-thermal in origin.

Fig. 19.10 The 9-Yagi array on the roof of the blockhouse (*Courtesy* CSIRO RAIA 1830-2)

Late in 1951, an 8-Yagi sea interferometer was installed near the blockhouse, and this was soon converted into a 12-Yagi array (Fig. 19.12) which was used at 100 MHz to identify 104 different sources scattered across the entire sky. At that time, this was the most comprehensive survey ever undertaken, and showed that discrete sources were far from rare; in fact, increased sensitivity seemed to bring increasing numbers of them! The celestial distribution of the 104 sources is shown in Fig. 19.13, where the predominance of stronger sources along the plane of the Galaxy and of weaker sources in the southern polar cap is apparent. Meanwhile, new optical identifications suggested by Bolton et al. (1954) only served to reinforce the view that most discrete sources were extragalactic in origin (e.g. Fig. 19.14) and associated with radio galaxies.

The last radio telescope installed at Dover Heights has an interesting history, and one associated with both ingenuity and initiative. When Bolton, Stanley and Slee were unable to obtain funding for a large new radio telescope in 1951 they resorted to building one themselves as a 3 month lunchtime project (Orchiston and Slee 2002c, d). During this period, they excavated a 21.9-m (72-ft.) diameter parabolic hole in the sand just north of the blockhouse, lined the sand with discarded

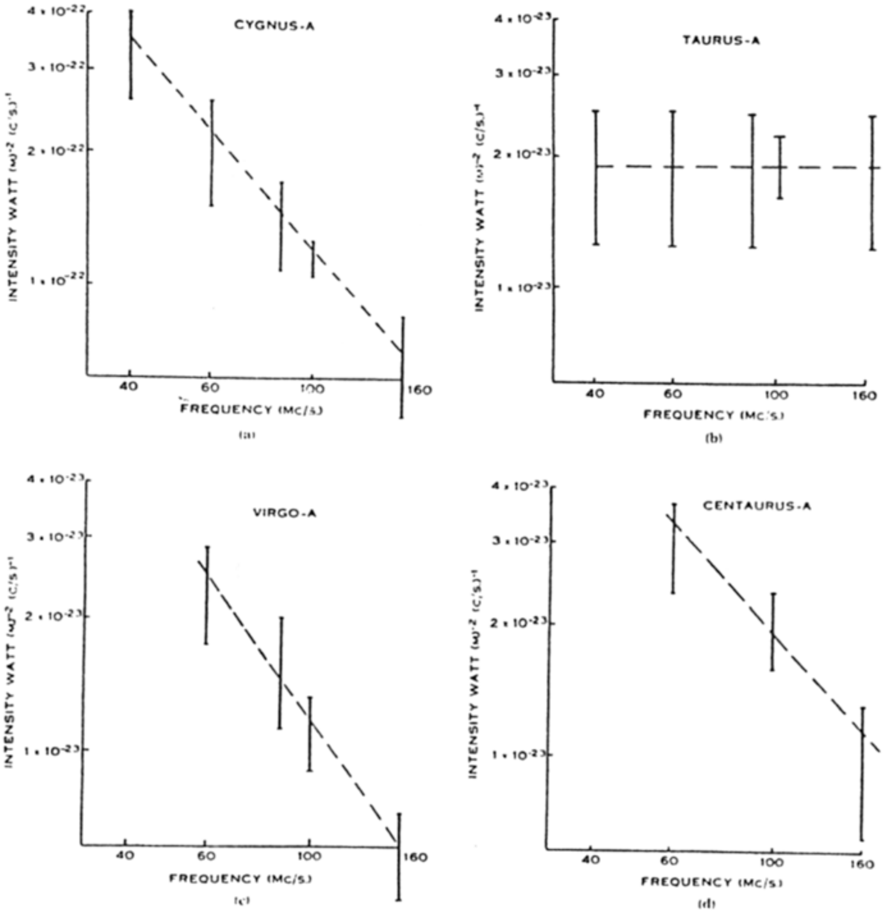

Fig. 19.11 Spectral plots for Centaurus A, Cygnus A, Taurus A and Virgo A (after Slee 1994: 522)

strips of metal from packing cases in order to provide a reflective surface, installed a mast with a dipole, and connected this crude radio telescope up to a 160 MHz receiver. As the Earth rotated, this transit instrument received emission from the sky overhead, in the process revealing a new radio source near the centre of our Galaxy. This initial result inspired Pawsey to assign funds for an expanded 400 MHz hole-in-the-ground antenna (Fig. 19.15), and by altering the position of the aerial mast with strategically placed guy ropes the new concrete-coated 24.4 m (80 ft.) dish was able to map a strip of sky and record 14 different discrete sources (McGee et al. 1955).

The strongest of these was the Galactic Centre source, which was assigned the name Sagittarius A, or Sgr A (Fig. 19.16). At the time, this remarkable radio telescope was only exceeded in aperture by one in England and a slightly larger hole-in-

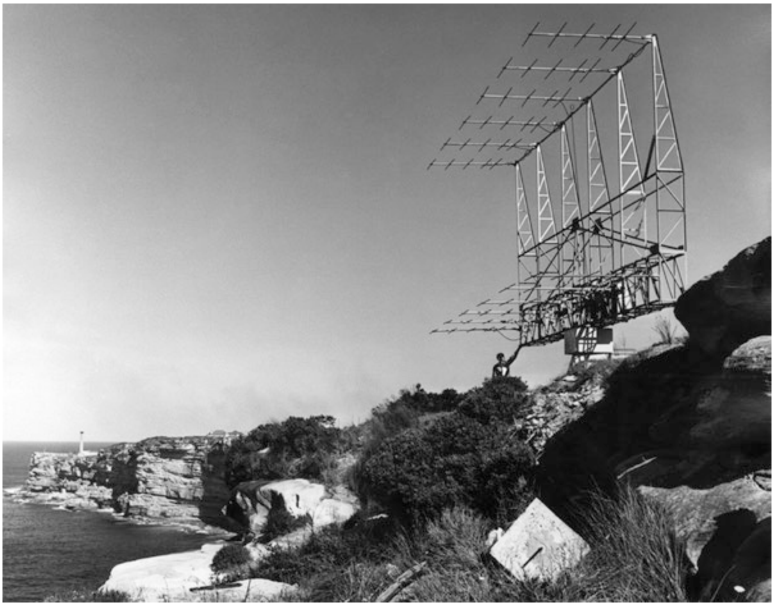

Fig. 19.12 The 12-Yagi sea interferometer (*Courtes*y CSIRO RAIA 2763-8)

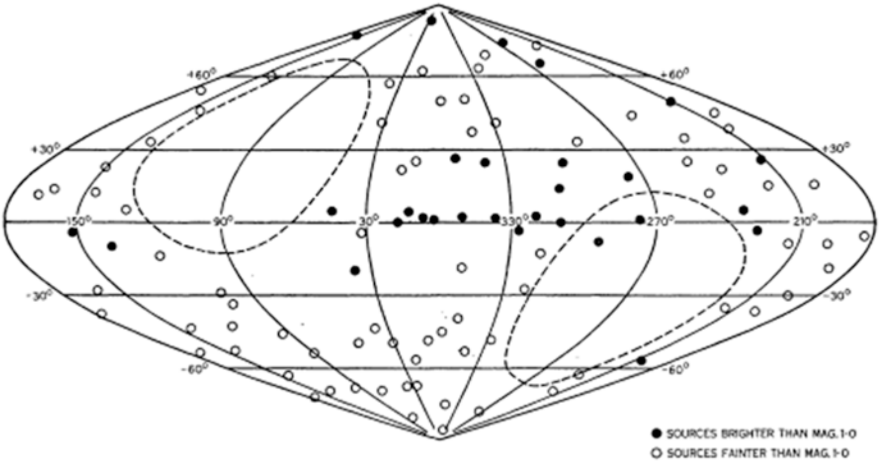

Fig. 19.13 The celestial distribution of the 104 sources detected with the 12-Yagi array (after Bolton et al. 1954: 126)

the-ground antenna in the Netherlands (see Strom 2005), and a detailed account of its construction and research achievements is provided by Orchiston and Slee (2002c).

While most of the research conducted at the Dover Heights field station focused on discrete sources, Bolton and Stanley also made some important solar observations, perhaps the most notable being of a major outburst that occurred on 8 March 1947

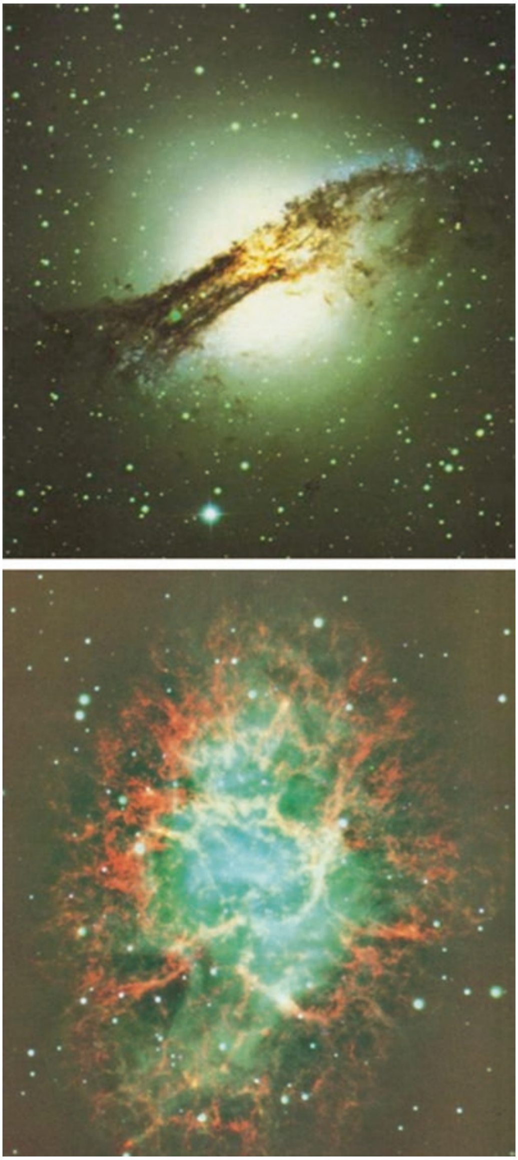

Fig. 19.14 Most of the early discrete sources were identified as extragalactic objects, like NGC 5128 see below, top, with Centaurus A; the most notable exception was Taurus A which turned out to be associated with the Crab Nebula (bottom), an historical supernova remnant

and was recorded at 60 and 100 MHz, with simultaneous 200 MHz observations made at Mount Stromlo. Curiously, the outburst started at different times at the three frequencies, as shown in Fig. 19.17. Later this event would be identified as a typical Type II solar burst (see Sect. 2.6 below).

For a few years—before she transferred to the Hornsby Valley field station—Ruby Payne-Scott (1912–1981; Fig. 19.18) also investigated solar radio emission while based at Dover Heights.

Fig. 19.15 The 24.4 m (80-ft.) hole-in-the-ground radio telescope; Gordon Stanley is using a theodolite to record the angle of tilt of the aerial mast (*Courtesy* CSIRO RAIA B3150-7)

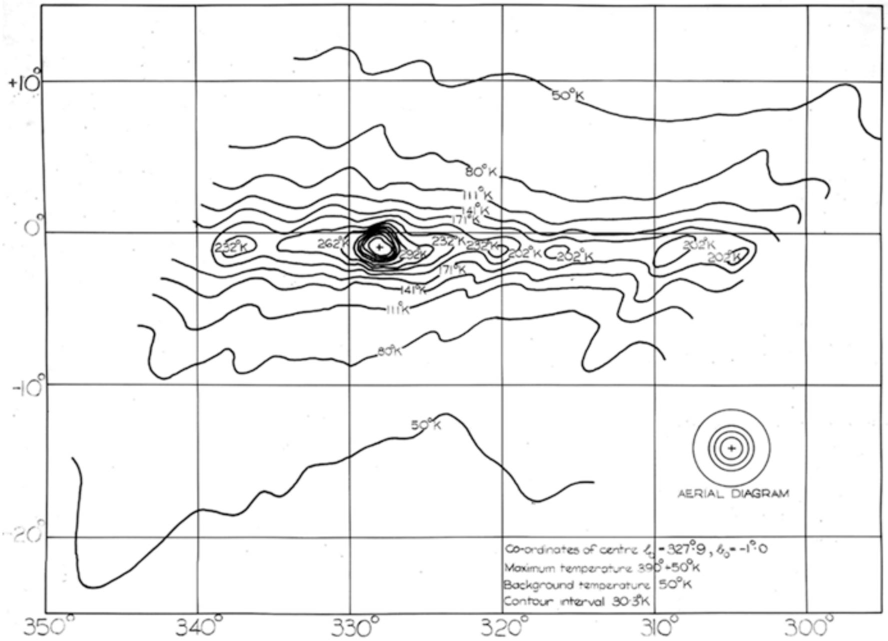

Fig. 19.16 400 MHz radio emission along the Galactic Plane, showing the Galactic Centre (Sgr A) source (*Courtesy* CSIRO RAIA B3761-1)

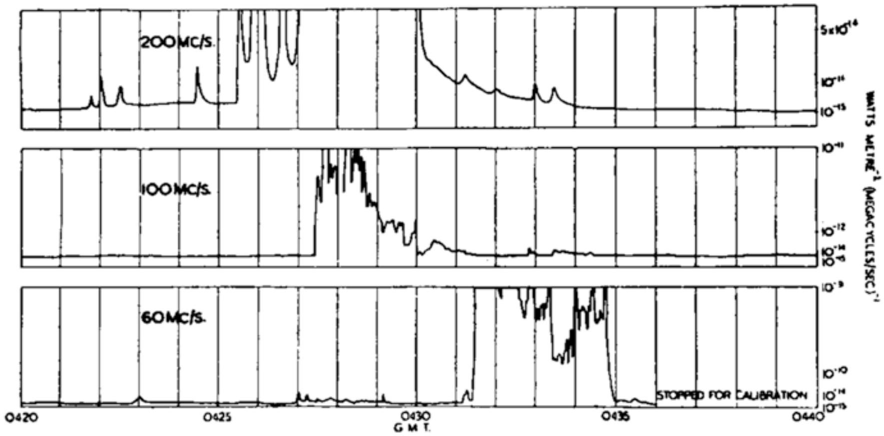

Fig. 19.17 The 8 March 1947 solar outburst; the 60 and 100 MHz observations were made at Dover Heights by Bolton and Stanley, and the 200 MHz observations at Mt. Stromlo Observatory (after Payne-Scott et al. 1947: 256)

Fig. 19.18 Ruby Payne-Scott (*Courtesy* CSIRO RAIA)

In 1954 Stanley was involved in the final research project undertaken at Dover Heights when he and a visiting American radio astronomer used the hole-in-the-ground antenna to search unsuccessfully for emission from the postulated 327 MHz deuterium line. Later that year the Dover Heights field station was closed down, as the Division’s focus shifted to Potts Hill and a new field station at Fleurs.

19.2.2 Georges Heights

The Georges Heights radar station occupied an attractive strategic position on Middle Head, overlooking the entrance to Sydney Harbour (Fig. 19.2), and during the war was home to a number of different radar antennas. In 1947 and 1948, this site was used by RP as a short-lived field station for solar radio astronomy (Orchiston 2004b).

One of the wartime radar antennas at Georges Heights was an experimental unit featuring a 4.9 × 5.5 m (16 × 18 ft) section of a parabola and a cumbersome altazimuth mounting (Fig. 19.19), and from August 1947 this was used to monitor solar radio emission at 200, 600 and 1200 MHz. The only way the antenna could be employed effectively was to place it ahead of the Sun, let the Sun drift through the beam, hand-crank it ahead of the Sun again, and repeat the process throughout the day. This procedure produced a distinctive 'picket fence' chart record.

Assigned to this antenna were two young RP radio engineers, Fred Lehany (1915–1980) and Don Yabsley (ca.1922–2003). Lehany (1978) relates that his

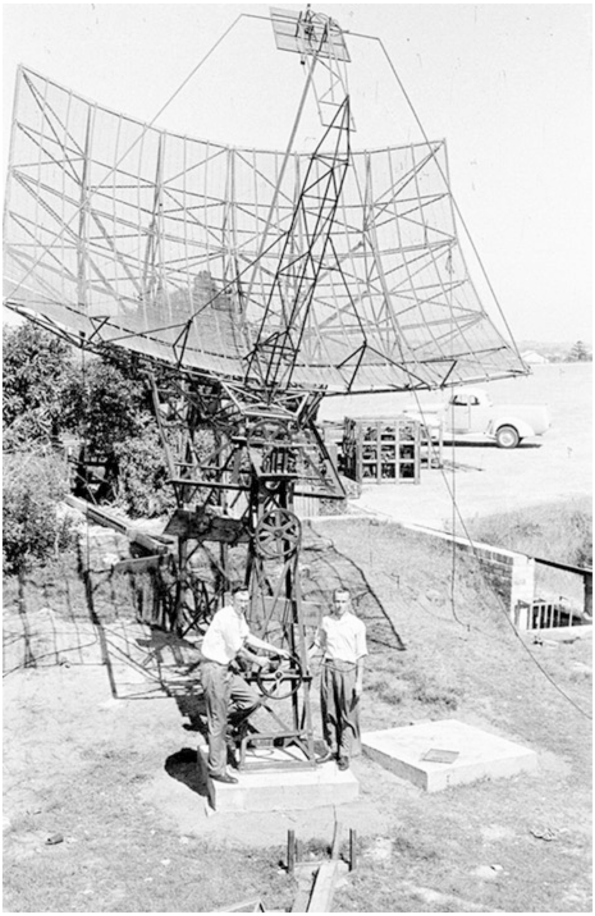

Fig. 19.19 The ex-WWII radar antenna used for solar radio astronomy at Georges Heights; in the photograph (*left to right*) are Joe Pawsey and Don Yabsley (*Courtesy* CSIRO RAIA 1031-9)

involvement with this project: "… came about in a typical 'Pawseyian way', before I knew what was happening … there was an observing program and … Yabsley and I were a suitable pair to share not only the week days but also the weekend duty …" For a few months in 1947, Lehany and Yabsley were assisted by Bruce Slee, before he was re-assigned to Dover Heights.

In the second half of 1947, Ruby Payne-Scott and John Bolton were monitoring solar activity at Dover Heights using 60, 75, 100 and 200 MHz Yagis, and the Georges Heights antenna allowed the frequency-coverage to be extended to up to 1200 MHz. As at Dover Heights, Lehany and Yabsley recorded many bursts at 200 MHz, but they were rare at 600 and 1200 MHz, where the general flux variations with time were correlated with sunspot area (see Fig. 19.20). This research by Lehany and Yabsley helped our understanding of the association of 200 MHz bursts and solar flares, and of the correlation between sunspots and radio emission at 600 and 1200 MHz.

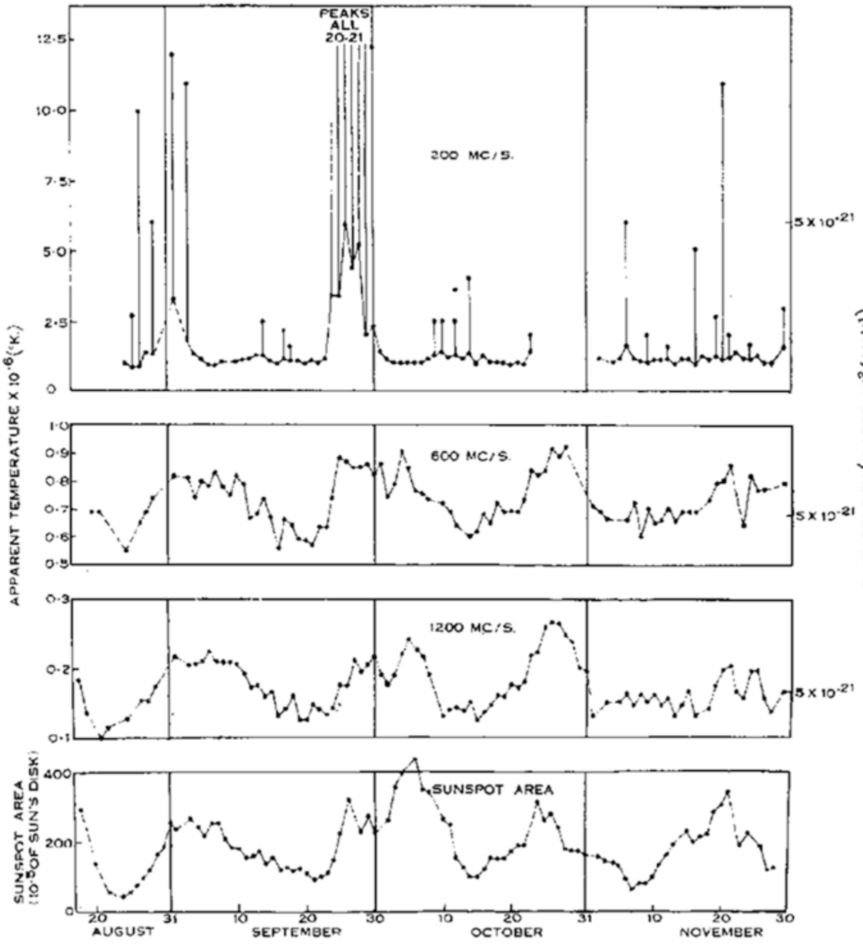

Fig. 19.20 Georges Heights plots showing the correlation between sunspot area and solar emission at 600 and 1200 MHz (after Lehany and Yabsley 1949: 56)

Fig. 19.21 One of the portable 3.05-m dishes set up at Georges Heights (*Courtesy*: CSIRO RAIA 1511)

The final role that the Georges Heights field station played in radio astronomy was to serve as a test-base in mid-1948 for two portable 3.05-m (10-ft.) altazimuth-mounted dishes (see Fig. 19.21) that were erected in order to observe the 1 November 1948 partial solar eclipse from Rockbank in Victoria (Fig. 19.1) and Strahan in Tasmania. Ironically, this eclipse was the death-knell for Georges Heights as a radio astronomy facility, for a decision was made to transfer the ex-radar antenna to the Potts Hill field station, where it would be used to monitor the eclipse. After less than 2 years operation as an RP field station, Georges Heights closed down, but its legacy lived on in the form of the ex-radar antenna. With the passage of time, this historic radio telescope would come to be Georges Heights' greatest contribution to Australian radio astronomy.

19.2.3 Hornsby Valley

This field station (Orchiston and Slee 2005b; Orchiston et al. 2015b) was established in 1946 at what was then one of Sydney's most northerly suburbs (see Fig. 19.2). Hornsby Valley was accessed by train or car, and this radio-quiet site was located on farmland in a picturesque valley that was surrounded by low tree-covered hills (see Fig. 19.22).

The first research conducted at this field station was radar astronomy: in 1947–1948 Frank Kerr (1918–2000) and Alex Shain (1922–1960) spent a year bouncing signals off the Moon in order to investigate the structure of the upper ionosphere (Fig. 19.23). A rhombic aerial linked to a modified communications receiver recorded the bounced signals, which were broadcast at 17.84 and 21.54 MHz by Radio Australia from Shepparton in Victoria (see Fig. 19.1). Thirty different experiments

Fig. 19.22 A picturesque view of the Hornsby Valley field station, showing antennas, instrument huts, and (far *left*) a farm house (*Courtesy* CSIRO RAIA B2802-10)

Fig. 19.23 The assemblage of huts, trailers, poles and wiring associated with the Moon-bounce experiments (*Courtesy* CSIRO RAIA 1266-5)

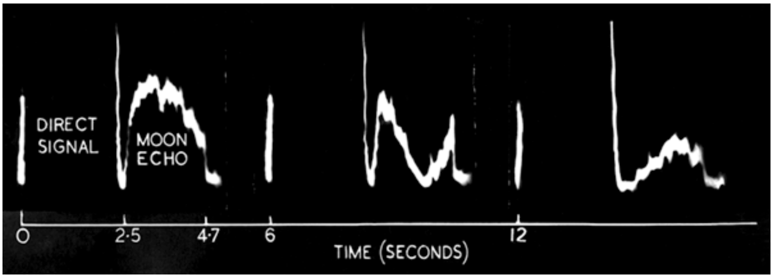

Fig. 19.24 A photographic record showing three successive Moon-bounce echoes (after Kerr and Shain 1951: 232)

Fig. 19.25 Alex Shain in 1952 (adapted from CSIRO RAIA B2842-133)

were carried out, and echoes were received on 24 occasions (e.g. see Fig. 19.24); as expected, these provided further information about the Earth's atmosphere, but from an astronomical viewpoint the interesting conclusion that Kerr and Shain drew was that the nature of the echoes showed the Moon's surface to be "rough" rather than smooth. This project was to be Kerr's sole foray into low frequency research, and he soon transferred to Potts Hill field station where he went on to make a name for himself through his H-line work.

Ruby Payne-Scott was keen to expand the solar work she had begun at Dover Heights, and towards the end of 1947 she moved to the Hornsby Valley field station and set up Yagi antennas for observations at 60, 65 and 85 MHz, together with an 18.3 MHz broadside array. She also made use of Kerr's Moon-bounce rhombic antenna. Her study of solar bursts ran from January through to September 1948, when she too transferred to Potts Hill field station.

After Payne-Scott and Kerr left Alex Shain (Fig. 19.25) stayed on, and he developed Hornsby Valley into RP's forefront low frequency field station (Orchiston et al. 2015b). During 1949 and the early 1950s he and Charlie Higgins (Fig. 19.26)

Fig. 19.26 Charlie Higgins in 1952 (adapted from CSIRO RAIA B2842-132)

Fig. 19.27 A photograph showing part of the second 18.3 MHz array at Hornsby Valley (*Courtesy* CSIRO RAIA B2802-5)

built 9.15 and 18.3 MHz horizontal arrays that were distinguished by their simplicity: ordinary posts were used to support the dipoles, with the ground serving as a reflector (Fig. 19.27). The most ambitious of these radio telescopes was an array of 30 horizontal half-wave dipoles, and by moving the beam electronically a strip of sky extending from declination −12° to −50° could be surveyed. These Hornsby Valley antennas were used to produce the first maps of Galactic emission at low frequencies (e.g. see Fig. 19.28).

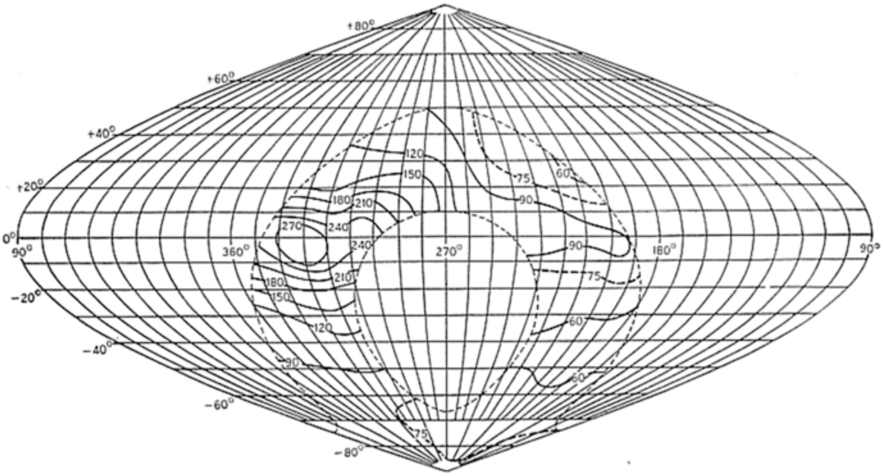

Fig. 19.28 Contours of equivalent aerial temperature at 18.3 MHz plotted in galactic co-ordinates (after Shain and Higgins 1954: 137)

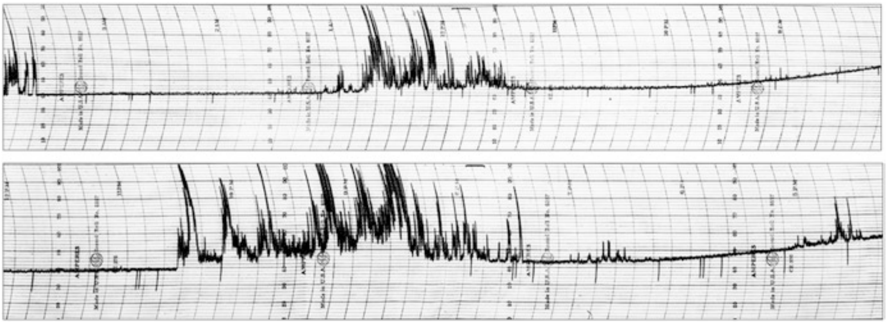

Fig. 19.29 Examples of 18.3 MHz Jovian bursts recorded at Hornsby Valley in 1950–1951; dates of the observations are 17 October 1950 (*top*) and 29 October 1950 (*bottom*) (adapted from CSIRO RAIA B3719-13)

A common problem at low frequencies was terrestrial interference—which Shain tended to dismiss as rather a nuisance—but when Burke and Franklin (1955) reported the discovery of decametric burst emission from Jupiter in 1955 he was forced into a rethink. When he revisited some of those periods of ‘intense static’ recorded at 18.3 MHz in 1950 and 1951 (see Fig. 19.29), Shain found that these were indeed Jovian bursts, and this serendipitous ‘pre-discovery’ proved to be one of RP’s most notable ‘lost opportunities’. Shain (1956) noticed that the bursts were not uniformly distributed in Jovian longitude but tended to cluster between 0° and 135° (Fig. 19.30). In other words, much of the radiation appeared to derive from a localized region on the planet, and its rotation period was timed at 9 h 55 min 13 ± 5 s, very close to Jupiter’s System II rotation period.

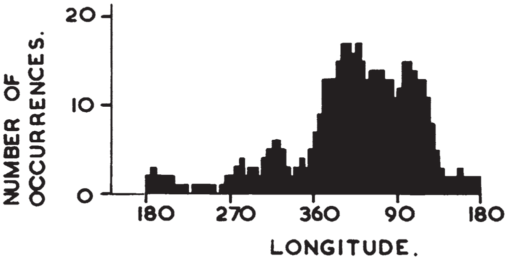

Fig. 19.30 A histogram of the occurrence frequency of 18.3 MHz Jovian emission plotted against System II Joviocentric longitude (after Shain 1956: 68)

Fig. 19.31 An aerial photograph, looking south, of the eastern reservoir at Potts Hill; eventually, radio telescopes and associated huts were located along the southern and western margins of the reservoir, and across the extended area of flat land in the foreground, to the north of the reservoir (*Courtesy* CSIRO RAIA 3475-2)

The Hornsby Valley field station closed in 1955 after contributing pioneering studies in lunar, solar and Galactic astronomy, but not before low frequency research had been taken up in earnest by Ellis and Reber in Tasmania (see George et al. 2015). Shain and Higgins then transferred their low frequency research to RP's Fleurs field station.

19.2.4 Potts Hill

This field station (Fig. 19.31) was situated beside a metropolitan water reservoir in what at that time was an outer Sydney suburb (see Fig. 19.2). Radio astronomy began there is 1948, and Potts Hill quickly developed into one of RP's leading field stations (see Davies 2008; Wendt et al. 2011c). The site appealed because it offered an area of easily accessible flat land in a radio-quiet setting, and as such was ideal for solar and non-solar radio astronomy. A number of radio astronomers built their international reputations at Potts Hill, the most notable of whom were Wilbur Norman (Chris) Christiansen (1913–2007; Davies 2009; Frater and Goss 2011; Swarup 2008; Wendt et al. 2011a), James V. Hindman (b. 1919), Frank Kerr, Harry Minnett, and Jack Piddington. In addition, Rod Davies (1930–2015), Norman Labrum, Alec Little (1925–1985), Don Mathewson (b. 1929), Bernie Mills (1920–2011; Frater et al. 2013; Orchiston 2014a), John Murray, Ruby Payne-Scott, Gil H. Trent, Joseph Aubrey Warburton (1923–2005), Donald E. Yabsley and a rather youthful Brian Robinson (1930–2004; Whiteoak and Sim 2006) all carried out research at this field station.

The first radio telescopes at Potts Hill were situated at the northern end of the reservoir and comprised a single Yagi antenna (used by Little to observe the Sun at 62 MHz), and a 3.05 m (10-ft.) diameter dish (which was employed by Piddington and Minnett to survey radiation from the region of the Galactic Centre at 1210 MHz).

In the second half of 1948 the experimental radar antenna that had previously been used for solar monitoring at Georges Heights was transferred to Potts Hill and mounted equatorially (see Fig. 19.32), so that it could be used to observe the 1 November solar eclipse. The observations were made at 600 MHz by Christiansen, Yabsley and Mills,

Fig. 19.32 The relocated and remounted Georges Heights ex-WWII experimental radar antenna, set up at Potts Hill for radio astronomy (*Courtesy* CSIRO RAIA B2649-3)

in conjunction with 3000 MHz observations made by Piddington and Hindman with a 1.7-m (68-in.) dish. Apart from these two Potts Hill radio telescopes, the eclipse was observed by RP staff at 600 MHz from Rockbank near Melbourne (Fig. 19.1) and Strahan, in Tasmania, using portable 3.05 m (10 ft.) dishes (see Orchiston 2004d; Orchiston et al. 2006). Following the New Zealand 'radio stars' field trip of June–August 1948, this eclipse therefore continued a tradition of establishing radio telescopes at temporary remote sites for special projects. When the various observations of the eclipse were combined they allowed the sources of solar radio emission to be pinpointed with considerable precision (see Fig. 19.33). But more than this, these eclipse observations confirmed the existence of two discrete components of non-burst solar emission: a basic component of thermal origin, which originated from the entire solar disk, and a slowly varying component that was generated in small localized regions that were often associated with sunspots.

In 1949, the small parabola that had been used at the RP Laboratory for lunar and solar work in 1948–1949 was transferred to Potts Hill, and on 22 October it was used in conjunction with other radio telescopes at Potts Hill and the two portable 3.05 m dishes to observe another partial solar eclipse (see Wendt et al. 2008a). These latter radio telescopes were located at Eaglehawk Neck in Tasmania and near Sale, in eastern Victoria (Fig. 19.1).

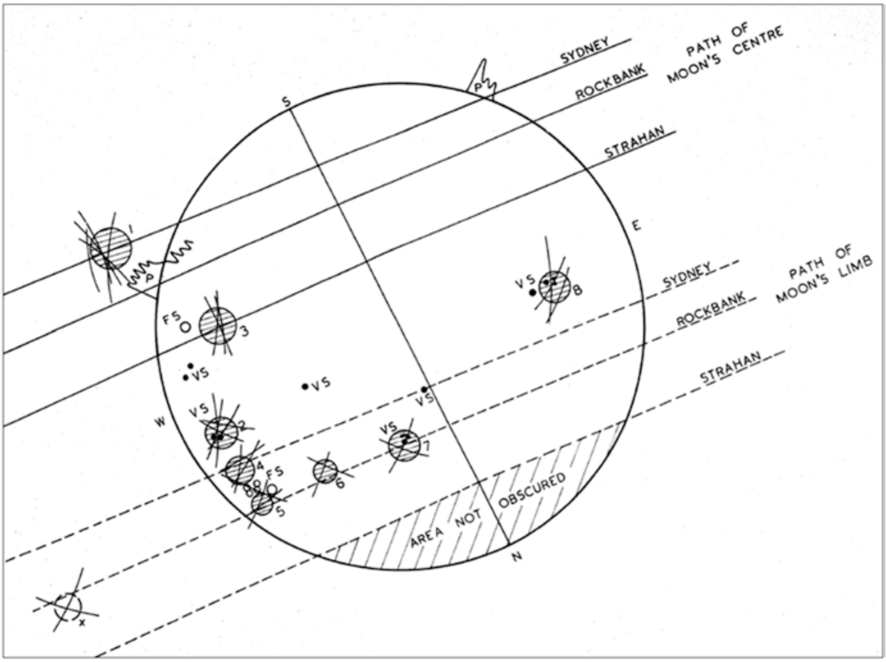

Fig. 19.33 A map of the Sun showing the distribution of sunspots (marked by 'VS') and regions associated with radio emission (hatching); the radio observations were made from Potts Hill, Rockbank (Victoria) and Strahan (Tasmania) during the 1 November 1948 partial solar eclipse (*Courtesy* CSIRO RAIA B1983-3)

Fig. 19.34 Ruby Payne-Scott and Alex Little at Potts Hill (adapted from a CSIRO RAIA image)

Not content with merely detecting solar bursts, Payne-Scott and Little (Fig. 19.34) wanted to record their positions, angular sizes and polarization, so in early 1949 the RP Workshop constructed a new interferometer comprising three 97 MHz Yagi aerials, which were aligned E-W, near the northern edge of the reservoir (and one of these is shown in Fig. 19.35). These were on equatorial mounts and could track the Sun for 4 h daily, centered on midday. Crossed dipoles allowed them to receive left-hand and right-hand circular polarization. The Yagis could be used as either swept-lobe or fixed lobe interferometers, depending on the type of investigation desired (see Little and Payne-Scott 1951). Frank Kerr (1971) has described how this interferometer "… was the first one in the world which could locate a source-position on the sun sufficiently rapidly to be able to operate on the shortlived bursts." Analyses of 30 noise storms, 6 outbursts and 25 randomly polarized bursts detected between May 1949 and August 1950 showed a link between noise storms and the magnetic fields associated with sunspots (even though the noise storms were located in the corona), and between outbursts and solar flares. Outbursts were observed to move away from the Sun at velocities of between 500 and 3000 km/s, and Payne-Scott and Little suggested that they were initiated by corpuscular streams responsible for terrestrial magnetic storms.

During 1949 and through into the 1950s the position interferometer, the ex-Georges Heights antenna, a 62 MHz Yagi and two small parabolas were used to

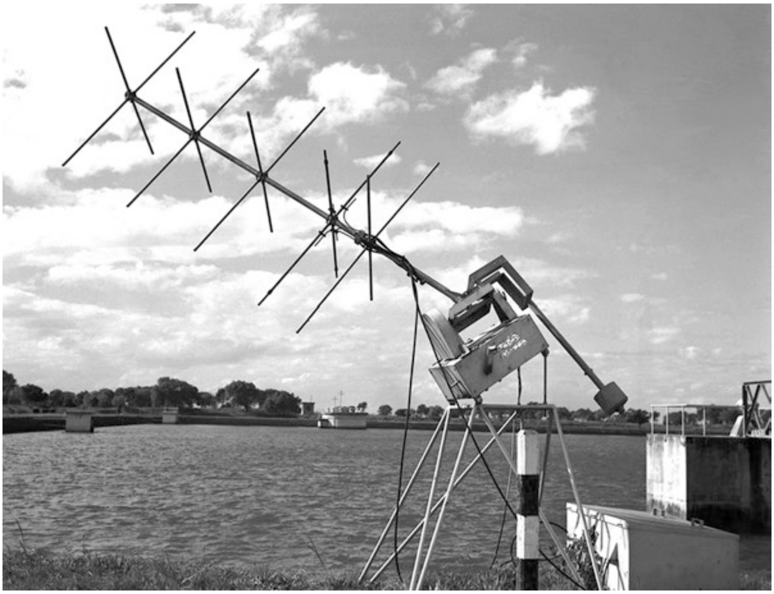

Fig. 19.35 A view looking south across the reservoir, showing one of the 97 MHz position interferometer crossed Yagis (*Courtesy* CSIRO RAIA 2217)

record solar activity at 62, 97, 600, 1200, 3000 and 9400 MHz, with support monitoring from Mount Stromlo Observatory (Fig. 19.1) at 200 MHz. These observations confirmed an earlier discovery, namely that over time intervals of many months variations in the level of solar emission at frequencies above 200 MHz mirrored changes in sunspot area. Many bursts also were detected, and sometimes these were associated with solar flares and terrestrial effects. In his analysis, Davies (1954: 90) suggested that "… there may be two separate components of bursts, one which shows rapid fluctuations and predominates at the lower frequencies, and one which is smooth and is characteristic of the high frequencies (although it may occur at low frequencies also)." He further suggested that these components may be due to plasma oscillations and thermal emission, respectively. Davies' 1954 research paper was published after he had left RP and joined the Jodrell Bank radio astronomers (Davies 2009), and even earlier, in 1951, Ruby Payne-Scott had resigned so that she could start a family. In those days, married women were prevented from accepting permanent positions in the Commonwealth Scientific and Industrial Research Organisation, so Ruby had kept her 1944 marriage secret up to that point.

Further escalation of the solar radio astronomy program took place in 1951 when W.N. (Chris) Christiansen (Fig. 19.36) oversaw the installation of the world's first solar grating array along the southern margin of the reservoir (Davies 2009; Wendt et al. 2008b). Designed to track the Sun at 1420 MHz, this novel radio telescope comprised 32 solid metal parabolic dishes each 1.83 m (72 in.) in diameter and

Fig. 19.36 W.N. ('Chris') Christiansen (adapted from CSIRO RAIA B2842-66)

Fig. 19.37 Chris Christiansen and the first 1420 MHz solar grating array at Potts Hill, looking east (*Courtes*y CSIRO RAIA 2976-1)

spaced at 7 m intervals (see Fig. 19.37). This novel radio telescope (Christiansen and Warburton 1953) provided a series of 3′ fan beams each separated by 1.7°, which meant that the Sun could only be in one beam at any one time. The array was operational from February 1952, and was used daily for ~2 h, centred on midday, to produce E-W scans of the Sun. These showed up the positions of localized active regions situated low in the solar corona and the motion of these as the Sun rotated (Fig. 19.38). Then, by superimposing a succession of strip scans and then deducting the radio plages, Christiansen also was able to determine the level of 'quiet Sun' emission at 1420 MHz (see Fig. 19.39).

A second solar grating array was erected along the eastern margin of the same reservoir in 1953 (Fig. 19.40; Wendt et al. 2008b). This also operated at 1420 MHz, but contained just 16 equatorially mounted mesh dishes each 3.4 m (11 ft.) in diameter. From September 1953 to April 1954 this was used to generate a series of N-S scans of the Sun. By taking many months of observations, allowing for the different

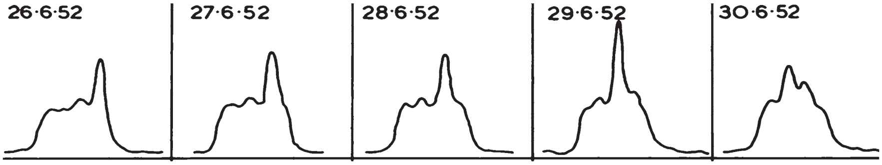

Fig. 19.38 A series of 1420 MHz strip scans of the Sun over a 5-day period in June 1952, showing the existence and motion of a prominent radio plage (adapted from CSIRO RAIA B2849-1)

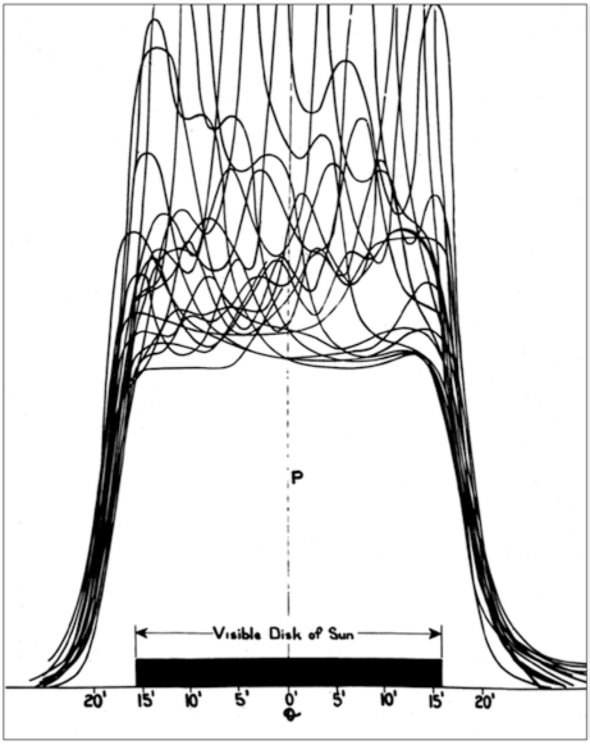

Fig. 19.39 Accumulated Potts Hill strip scans, showing the level of 'quiet Sun' emission at 1420 MHz (*Courtesy* CSIRO RAIA 2851-13)

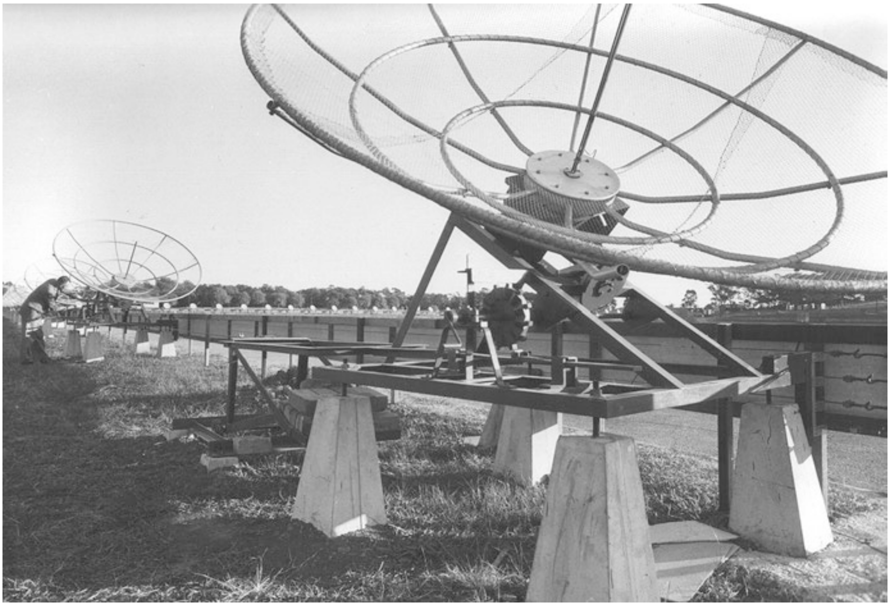

Fig. 19.40 The second 1420 MHz solar grating array, looking south; the antennas of the first solar array are only just visible in the background as a series of small white 'dots' (*Courtesy* CSIRO RAIA 3116-1)

scanning angles involved, and manually deleting all evidence of active regions, Christiansen and Warburton (1955) were able to build up an image of the quiet Sun, and show that this exhibited limb-brightening (Fig. 19.41). Moreover, the radio Sun was seen to be non-circular, with the limb-brightening confined to the near-equatorial regions. Christiansen (1976) would later regard this project as particularly important, given that this was the first time that the concept of Earth-rotational synthesis had been used in radio astronomy.

The final solar radio astronomy project at Potts Hill occurred in 1954–1955 when two Indian visitors to RP, Govind Swarup (b. 1929) and R. Parthasarathy, modified the E-W solar array so it could observe at 500 MHz, and used this instrument to investigate radio emission from the quiet Sun at this new frequency (Swarup 2006). Soon after this research was completed, the 'Chris Cross' was constructed at Fleurs (see Orchiston and Mathewson 2009), and the Potts Hill solar program transferred to that field station. Arrangements were then made to transfer ownership of the redundant Potts Hill grating array and the 500 MHz receiver to the National Physical Laboratory in India (Swarup 2006), and at this time the second solar grating array was also closed down.

Let us now return to non-solar radio astronomy at Potts Hill. Between 1948 and 1950 Piddington (Fig. 19.42) and Minnett used the ex-Georges Heights antenna and one of the smaller radio telescopes for source surveys at a number of different frequencies. Undoubtedly, their most significant discovery—made in 1950—was "… a new, and remarkably powerful, discrete source." close to position of the centre of

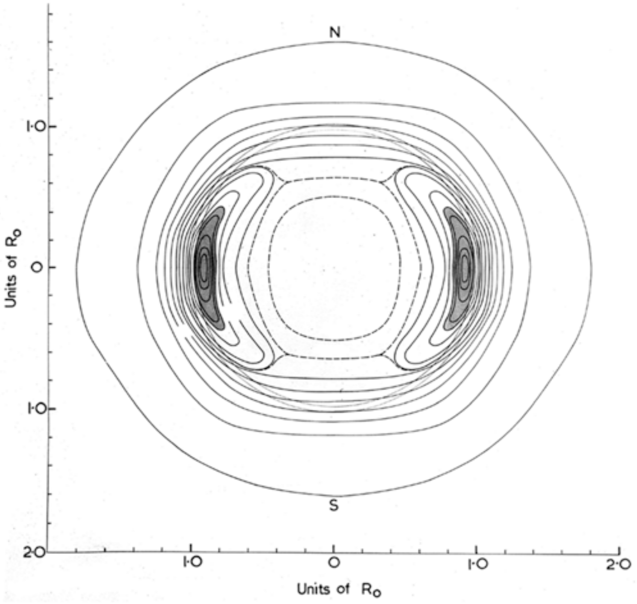

Fig. 19.41 The quiet Sun at 1420 MHz, showing equatorial limb-brightening (*Courtesy* CSIRO RAIA 3400–3)

Fig. 19.42 Jack Piddington (*Courtesy* CSIRO RAIA)

our Galaxy (Piddington and Minnett 1951: 469). This was the first published record of the Sgr A source (see Fig. 19.43) which—as we have seen—was later also detected by McGee, Stanley and Slee at Dover Heights (cf. Fig. 19.16).

Apart from pioneering solar radio astronomy, Potts Hill is famous for its involvement in early H-line work (see Wendt et al. 2008c). Following Ewen and Purcell's pre-publication announcement of their 25 March 1951 detection of the 1421 MHz

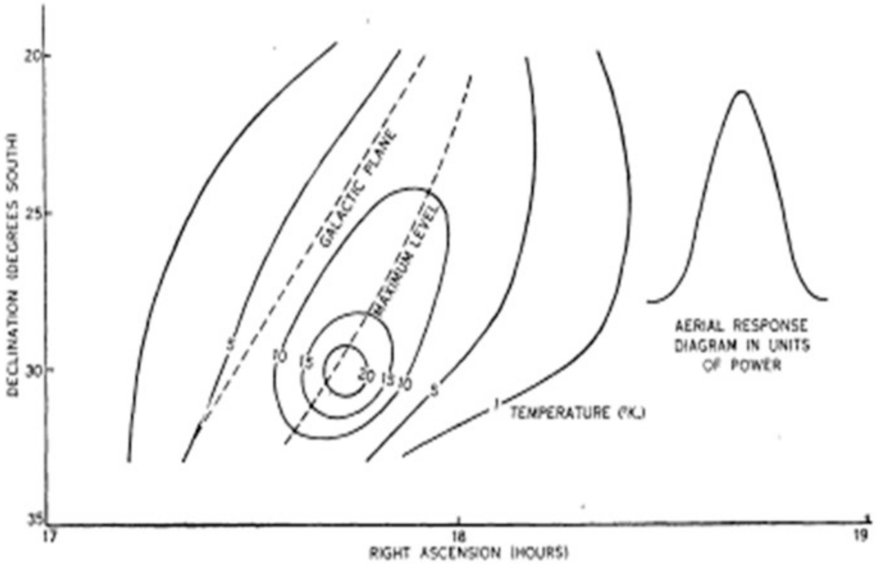

Fig. 19.43 The 1210 MHz isophote plot showing the discovery of the Sagittarius A radio source (after Piddington and Minnett 1951: 465)

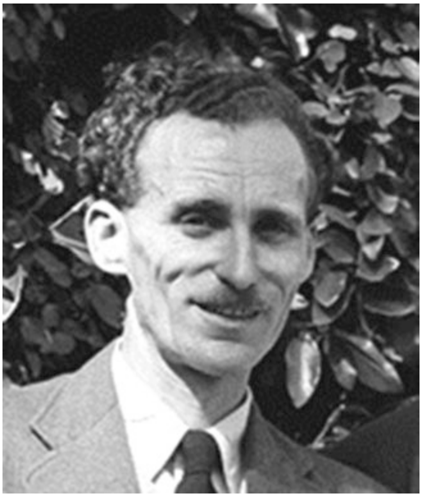

Fig. 19.44 Jim Hindman in 1952 (adapted from CSIRO RAIA B2842-44)

hydrogen line in the USA (see Kerr 1984), Joe Pawsey asked Chris Christiansen and Jim Hindman (Fig. 19.44) to construct H-line receivers. At first they worked away independently and unbeknown to each other in adjacent instrument huts at Potts Hill, and each made significant progress before discovering what the other was up to and deciding to combine their efforts. The result was that in just six short but hectic weeks they were able to cobble together a primitive H-line receiver, which was "… the most terrible piece of equipment I've ever seen in all my life … It was a monster …" (Christiansen 1976). Nonetheless, Christiansen and Hindman proceeded to attach the "monster" to the ex-Georges Heights radar antenna, and soon succeeded in detecting the hydrogen line. Ewen and Purcell's 'discovery' paper appeared in the 1 September 1951 issue of *Nature*, and was immediately followed by a confirmatory paper by the Dutch and a hurriedly composed note by Pawsey, dated 12 July, announcing the initial RP results (see Pawsey 1951). Thus began Australia's assault on the H-line.

From June through September of 1951 Christiansen and Hindman carried out exploratory H-line observations at Potts Hill, and published their results in 1952. Their paper included an isophote map of H-line emission extending over 270° of galactic longitude (including the Galactic Centre) along the Galactic Plane and in galactic latitude from +40° to −50°, and they concluded that "… the source of line radiation occupies roughly the same part of the sky as does the visible Milky Way. Hence it may be assumed that the hydrogen is concentrated near the equatorial plane of the Galaxy." (Christiansen and Hindman 1952: 454–455). The existence of double line profiles over a considerable range of galactic longitudes was interpreted as evidence of spiral arms in our Galaxy. Christiansen (1976) later recalled that when 'Doc' Ewen, the co-discoverer of the H-line, came out to Australia in 1952 in order to attend the Sydney URSI Congress, he especially wanted to examine Christiansen's H-line receiver for himself "… to see how these God damn Australians did in three weeks what took [other] people eighteen months to do." Apparently, when he saw the receiver, "… he just about passed out …" (Christiansen (1976)!

With increasing international interest in hydrogen-line work, a new, more suitable, radio telescope was required *in lieu* of the aging ex-Georges Heights radar antenna, and this came in the form of an 11-m (36-ft.) transit parabola that was constructed in 1952–1953 (see Fig. 19.45), along with "… the world's first "multichannel" receiver, which had all of four 40 kc/s channels!" (Kerr 1984: 139). With Christiansen back on solar work, it was left to Hindman, Kerr (Fig. 19.46) and Robinson to take the H-line work further. They began by making the first H-line observations of extragalactic objects, in this case the Large and Small Magellanic Clouds, and found that the neutral hydrogen extended well beyond the optical boundaries of each Cloud (Fig. 19.47); that the total mass of neutral hydrogen in the Large and Small Clouds was ~$6 \times 10^8 M_\odot$ and ~$4 \times 10^8 M_\odot$ respectively; that the ratio of dust to gas in the two Clouds was very different; and that both Clouds were rotating (Kerr et al. 1954—see Fig. 19.48). Kerr and de Vaucouleurs followed up by studying the three-dimensional distribution of gas density and rotational motion. Radio data supported the view that the Large Magellanic Cloud is a flattened system tilted by ≥65° relative to our line of sight. The tilt angle of the Small Magellanic Cloud is only ~30°, and at 1420 MHz it has "… a large prominence, or wing, extending towards the Large Cloud." (Kerr and de Vaucouleurs 1955: 515).

One of the most fascinating H-line studies carried out at Potts Hill was associated with the collaboration between the Sydney and Dutch groups to map the locations of the spiral arms in our Galaxy. Kerr, Hindman and Martha Starr Carpenter's seminal 1957 paper in *Nature* provided overwhelming pictorial evidence of the

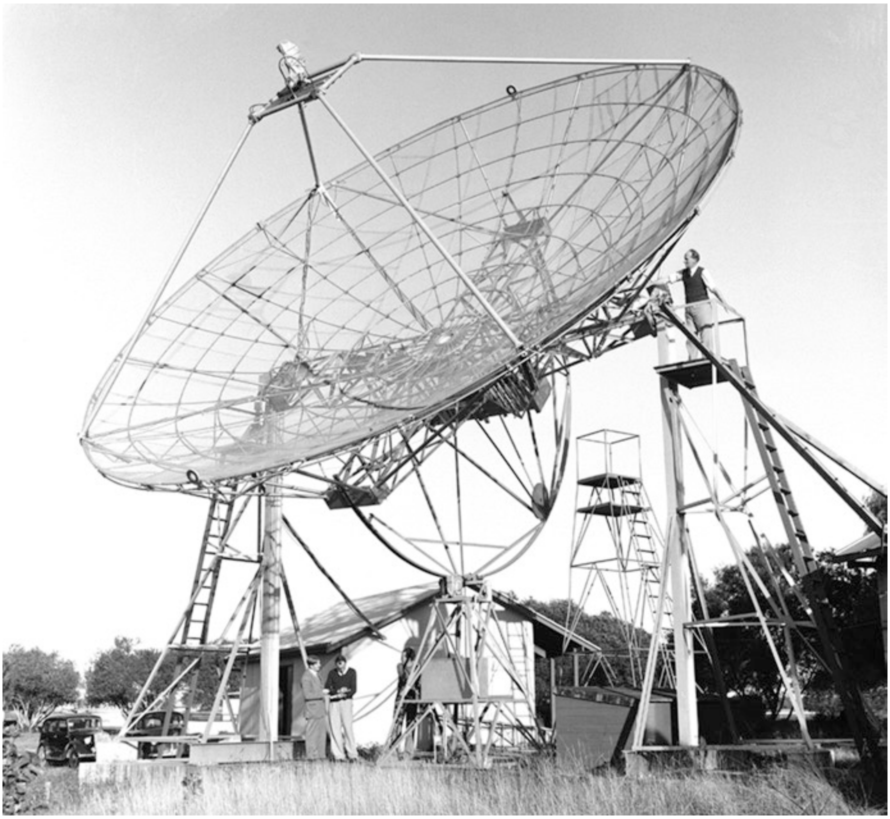

Fig. 19.45 The 11-m parabola constructed for H-line work in 1952–1953, with the receiver hut in the background (*Courtesy* CSIRO RAIA 3679-1)

Fig. 19.46 Frank Kerr in 1952 (adapted from CSIRO RAIA B2842-45)

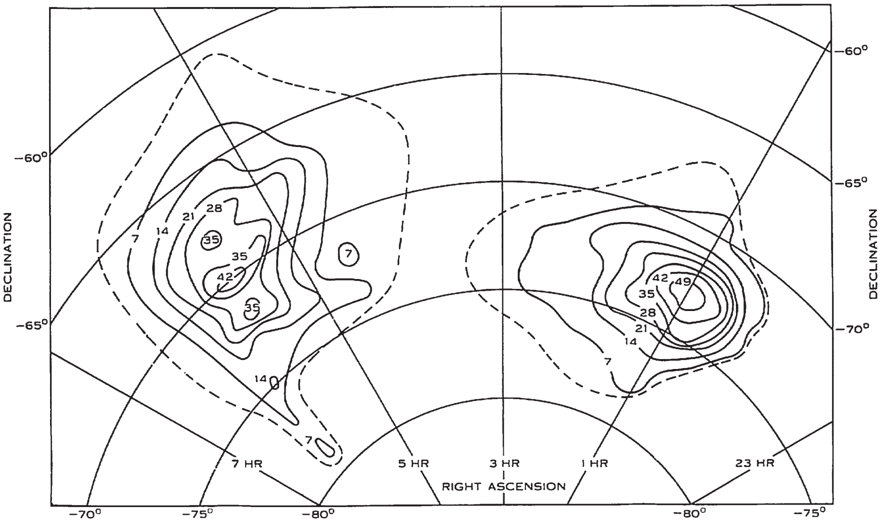

Fig. 19.47 Neutral hydrogen isophotes for the Large and Small Magellanic Clouds (after Kerr, Hindman, and Robinson 1954: Plate 2, Fig. 1)

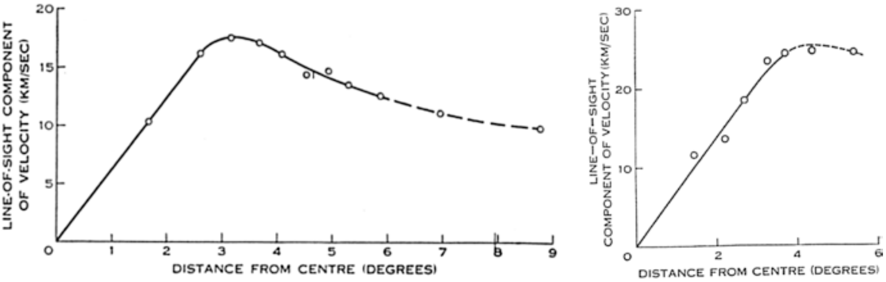

Fig. 19.48 Rotation curves for the Large Magellanic Cloud (*left*) and the Small Magellanic Cloud (*right*) (after Kerr and de Vaucouleurs 1955: 514 and 515 respectively)

spiral nature of our Galaxy (see Fig. 19.49), and the Potts Hill observations yielded evidence of at least four major spiral arms. Their study also produced interesting information on the distribution of hydrogen gas: in the outer regions of the Galaxy it was distorted downwards in the direction of the two Magellanic Clouds, suggesting that this may be evidence of some sort of gravitational tide produced by the Clouds (Kerr et al. 1957: 679). Kerr also summarised these and other Sydney H-line findings in a number of other papers. With the opening of Murraybank in 1956, the Division's H-line research was transferred to this new field station.

Piddington and Trent then took advantage of the vacant 11-m antenna, and used it for an ambitious survey of the whole southern sky and part of the northern sky at 600 MHz (Fig. 19.50). This was one of the most comprehensive all-sky surveys conducted since Reber's pioneering efforts in the 1940s, and its angular

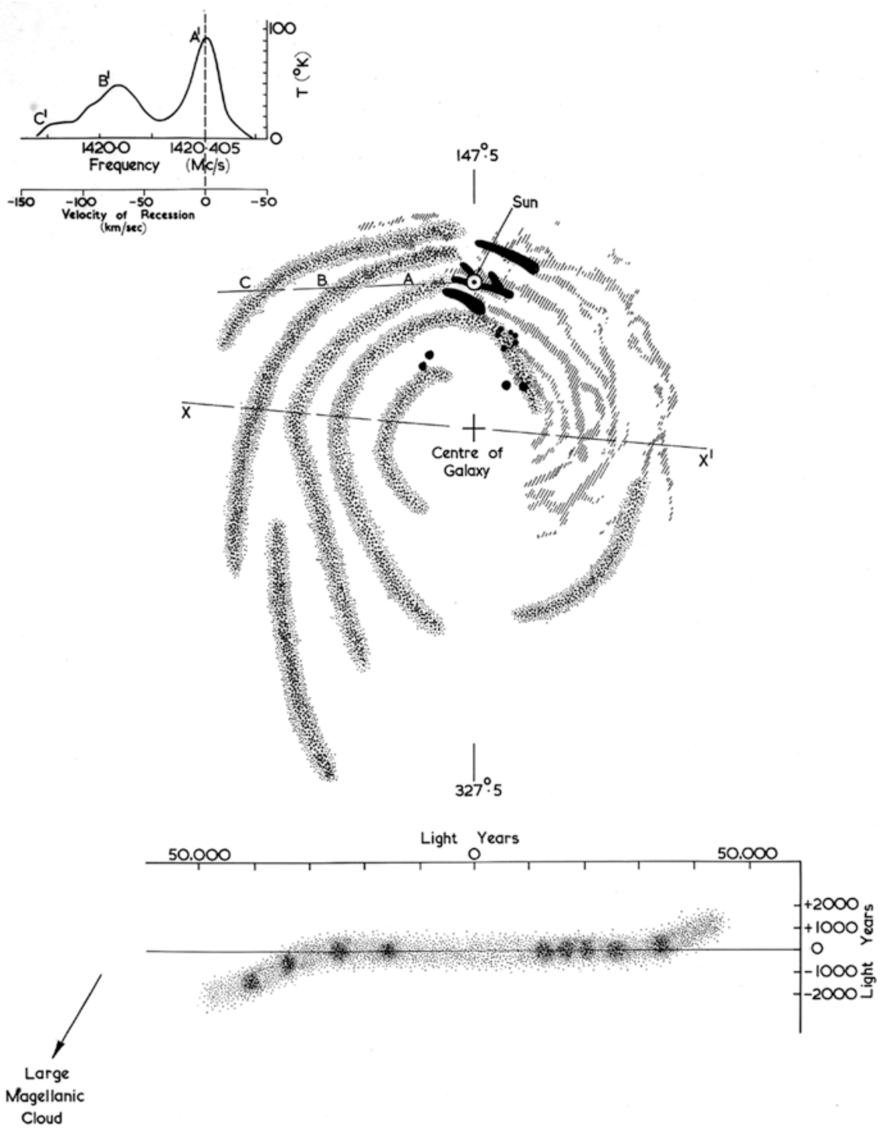

Fig. 19.49 H-line evidence for the spiral nature of our Galaxy, and the distortion of the hydrogen gas away from the plane in the outer reaches of the Galaxy (*Courtesy* CSIRO RAIA B5152)

resolution was an order of magnitude higher than the 100 MHz map produced at Dover Heights.

One of the most interesting radio telescopes erected at Potts Hill was the prototype Mills Cross (Fig. 19.51), built by Bernie Mills and Alec Little in 1952 and early 1953 to test out the cross-type telescope concept. At the time, Mills (1976) felt that he "… had to convince people it would work, and there were also a number of basic

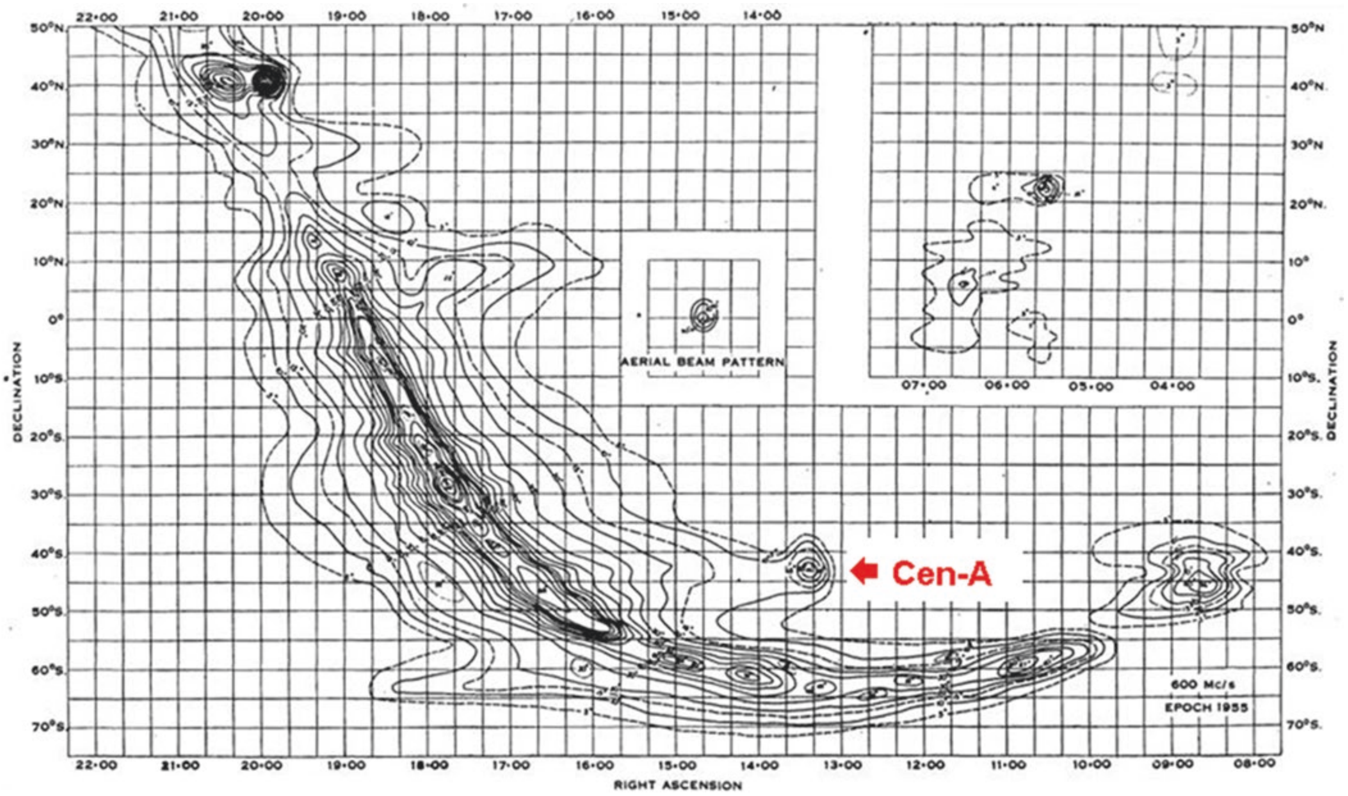

Fig. 19.50 An isophote plot of Galactic emission at 600 MHz, with the position of Centaurus A added (adapted from Piddington and Trent 1956: 483)

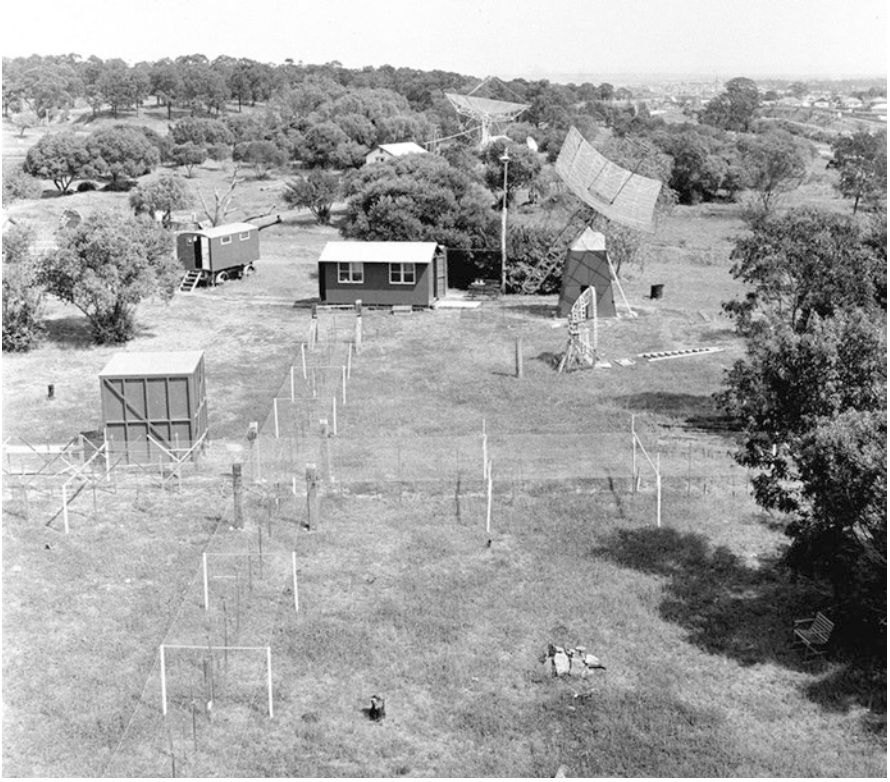

Fig. 19.51 In the foreground is part of the prototype Mills Cross, and in the background are the ex-Georges Heights radar antenna, the 11-m hydrogen-line dish and various instrument huts (*Courtesy* CSIRO RAIA 3171-4)

problems I wasn't quite clear about myself which I wanted to experiment with …" The new radio telescope consisted of N-S and E-W arms, each 36.6 m (120 ft) in length and containing 24 half-wavelength E-W aligned dipoles backed by a wire mesh reflecting screen (Mills and Little 1953). This novel instrument operated at 97 MHz, and had an 8° pencil beam which could be swung in declination by changing the phases of the dipoles in the N-S arm. The success of the 'Potts Hill mini-cross' was to justify the founding of a new RP field station, at Fleurs in 1954.

The final radio telescope erected at Potts Hill was a simple 19.7 MHz antenna that was completed in 1956. The dipoles were suspended between telegraph poles, and the ground served as a reflector. This antenna was used by Shain and Gardner in conjunction with the Shain Cross at Fleurs to carry out simultaneous observations of Jupiter (although no attempt was made to link the two as a long-baseline interferometer).

After making important contributions to solar, galactic and extragalactic radio astronomy, the Potts Hill field station closed in 1963; most of the remaining Galactic and extragalactic programs there were transferred to Parkes.

19.2.5 Badgerys Creek

This field station was located 50 km west-south-west of central Sydney on a Commonwealth Scientific and Industrial Research Organisation cattle research station (Fig. 19.2), and was founded by Bernie Mills (Fig. 19.52; Frater et al. 2013) at the end of 1949 so that he could study discrete sources free from the electrical interference that had plagued him previously at Potts Hill at 101 MHz.

Initially there were three identical radio telescopes at this site: broadside arrays positioned along an E-W line, and mounted so they could be titled about their E-W horizontal axes (see Fig. 19.53). Each antenna contained 24 half-wave dipoles,

Fig. 19.52 Bernard Yarnton (Bernie) Mills (adapted from a CSIRO RAIA image)

Fig. 19.53 A vista showing two of the three 101 MHz broadside antennas at Badgerys Creek (*Courtesy* CSIRO RAIA B2774-52)

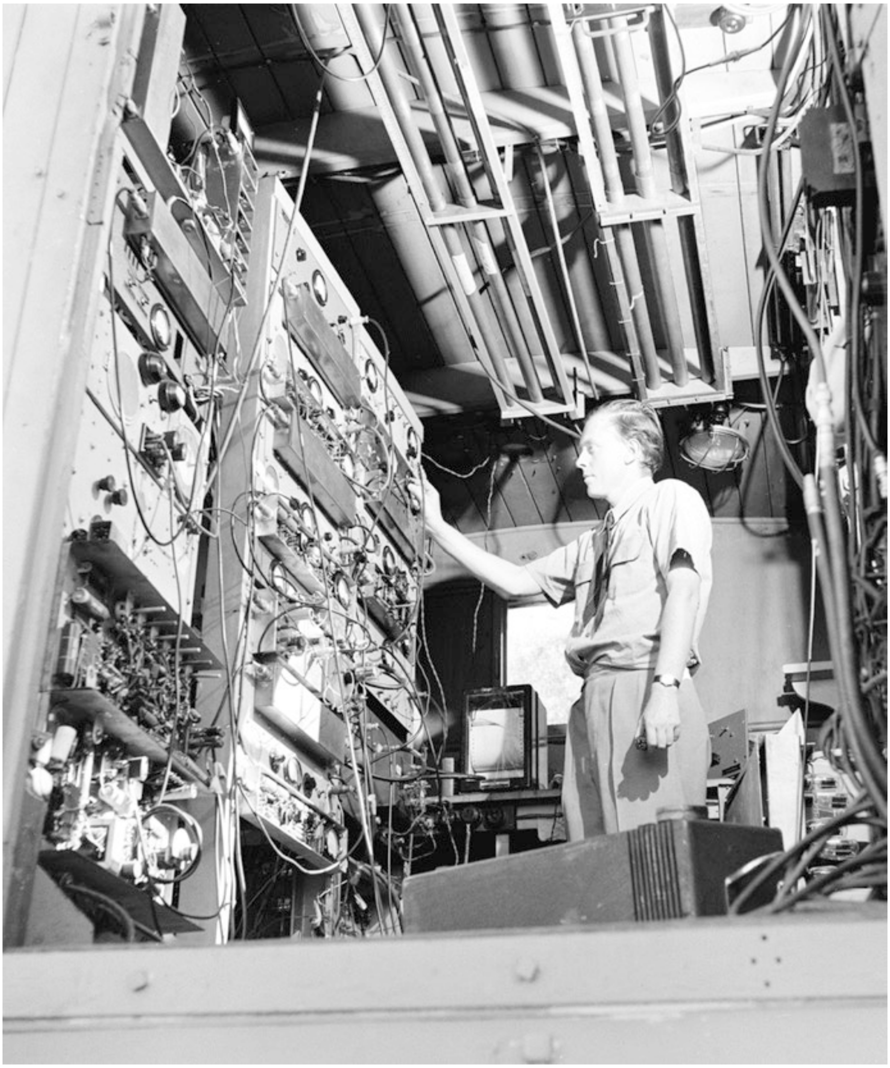

Fig. 19.54 Bernie Mills and the receiver used with the three-element interferometer (*Courtesy* CSIRO RAIA B2774)

backed by a reflecting screen. Antenna 2 was located about 60 m to the east of Antenna 1, with Antenna 3 a further 210 m to the east. Two different receivers (Fig. 19.54) were used with the antennas, so that the outputs of any two aerial spacings could be recorded simultaneously. Between February and December 1950 Mills used this interferometer to conduct a survey of the galactic distributions of discrete sources. The 76 sources that were detected are shown in Fig. 19.55, and fell into two major classes,

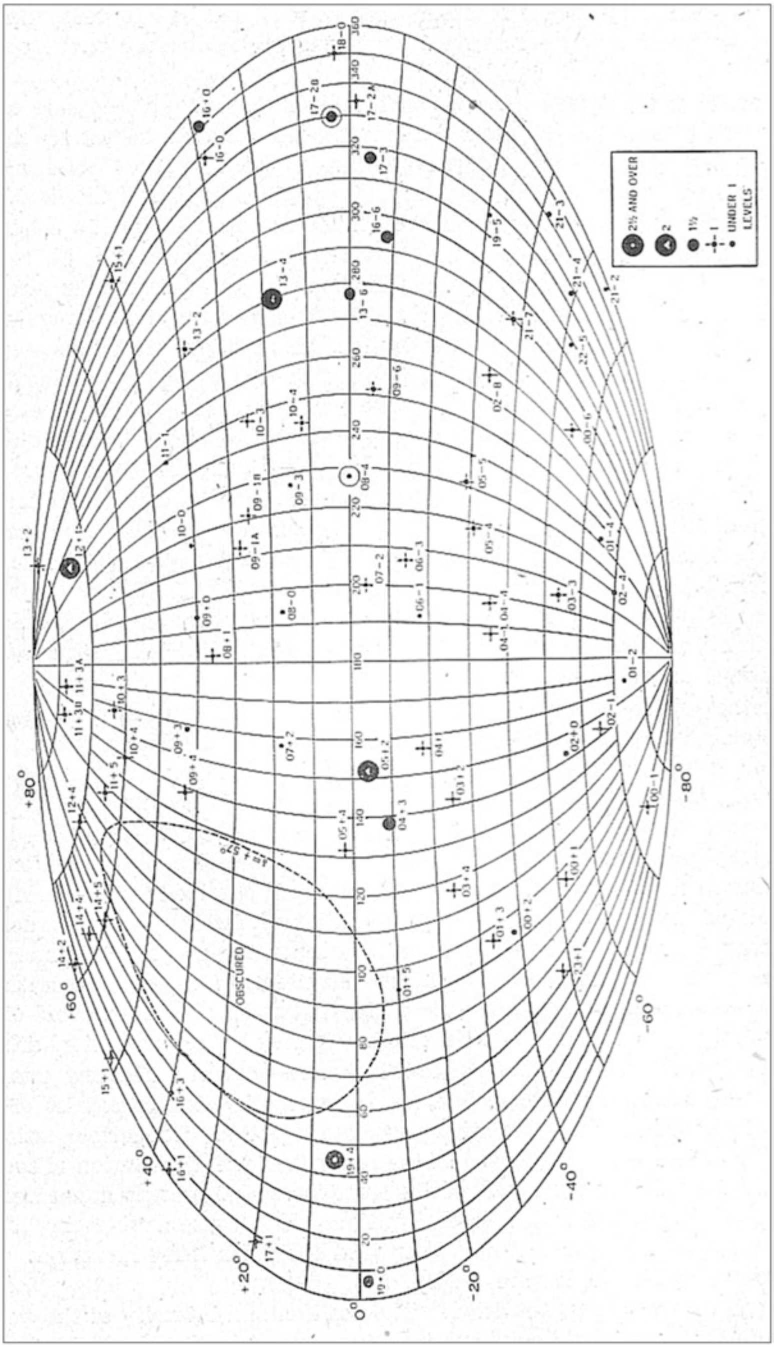

Fig. 19.55 The distribution of discrete sources recorded during the 101 MHz survey (after Mills 1952: 272)

> … the stronger sources being closely confined to the Galactic plane (Class I) and the weaker sources apparently randomly distributed over the sky (Class II) … The latter class included known extra-galactic members, some of which were of appreciable angular size … It could not be determined, however, whether this class was composed entirely of galaxies like those identified, whether it included other classes of extragalactic sources, or, indeed, whether it included a proportion of the conventional "radio stars". (Mills 1984: 150).

Mills then wanted to study the positions and angular sizes of some of the strongest galactic sources (Slee 2005) and to do this a two-element variable baseline interferometer was set up. This used one of the three broadside arrays plus a mobile two-element Yagi array (operating at 101 MHz) and a radio link (see Fig. 19.56). This was the first time such a link had been used in radio astronomy, and to Mills (1976) was simply a matter of logic: "If we wanted to try different spacings and different places, then obviously you couldn't go coiling and uncoiling miles of cables. The radio link was the obvious way of doing it …" During 1952, observations were made of four strong discrete sources at nine different E-W spacings (ranging

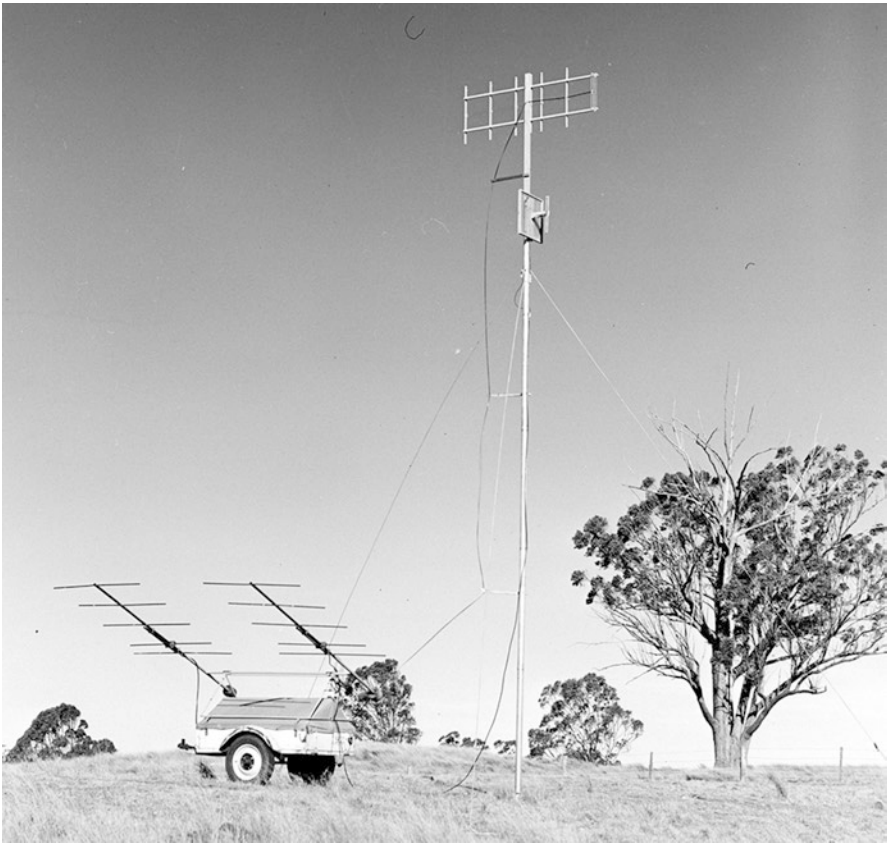

Fig. 19.56 The mobile 2-element Yagi antenna and radio link which was used with one of the broadside antennas for the second Badgerys Creek survey (*Courtesy* CSIRO RAIA 2786-6)

from 0.3 to 10 km), and three spacings in other directions. At the end of this project Mills transferred to Potts Hill, where he would build the world's first cross-type radio telescope. Much later, he explained that

> This [Badgery's Creek] survey was actually the basis for the Cross because I realized that it was necessary in any survey to have an instrument which would respond to close spacings and large angular size structure. Otherwise, one would simply miss it and miss a lot of the information available in the sky. And it was as a result of this survey that I thought of the Cross as being the sort of thing one must use. One must use pencil beams for surveys. That was the basic idea I had in mind. (Mills 1976).

Meanwhile, the Badgerys Creek field station was retained by RP and was subsequently used by some of the radio astronomers based at Fleurs. It was finally closed down in 1956.

19.2.6 Penrith and Dapto

In 1948–1949, Paul Wild (1923–2008; Fig. 19.57; Frater and Ekers 2012; Stewart et al. 2011b) needed a radio-quiet site in the general vicinity of Sydney where he could study the spectra of solar bursts, and this is how the short-lived Penrith field station came into existence. It was located on farm land near Penrith railway station. At that time, Penrith was a small town 50 km west of central Sydney, at the foot of the Blue Mountains (Fig. 19.2); now it marks the western boundary of greater Sydney, with its bustling population of >4 million.

Apart from a motley collection of huts, this field station featured a single rhombic antenna (Fig. 19.58) that was anchored at one end. In order to follow the Sun,

Fig. 19.57 Paul Wild in 1952 (adapted from CSIRO RAIA B2842-45)

Fig. 19.58 The 70–130 MHz rhombic aerial at the short-lived Penrith field station (*Courtesy* CSIRO RAIA B2086-1)

the aerial was moved every 20 min or so by making adjustments to a number of different guy ropes. With this one antenna, solar radio emission was received by sweeping over the frequency range 70–130 MHz, and was displayed on a cathode ray tube where it was photographed. Successive photographs could be taken at intervals of one-third of a second, which allowed the radio astronomers to investigate the ways in which burst intensity changed with frequency and with time (Wild and McCready 1950). Apparently it was Pawsey who suggested using a rhombic aerial for this world's first radio spectrograph (see Stewart et al. 2010a, b), while Bowen came up with the idea of the swept-frequency receiver (as he was familiar with their use in a WWII radar context).

The first serious scientific observations were made in February 1949, and by the end of June spectra of three different types of solar bursts had been constructed from the photographs. Producing these spectra manually was a very trying and time-consuming process—today it would all be done quickly by computer! These bursts were designated Types I, II and III (e.g. see Fig. 19.59) and they were described and discussed in a series of four papers that were written by Wild and published in the *Australian Journal of Scientific Research* in 1950–1951.

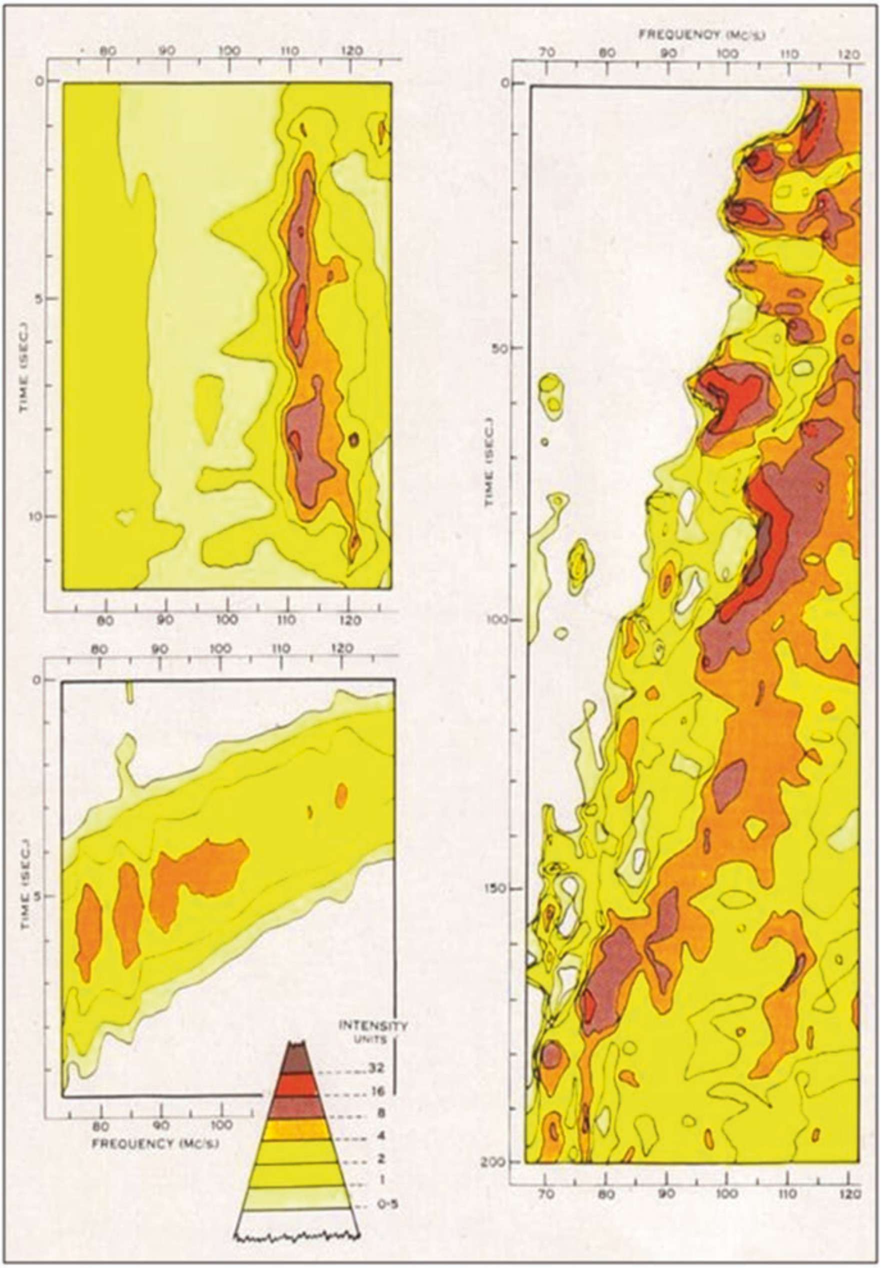

Fig. 19.59 Examples of Type I (*bottom left*), Type III (*top left*) and Type II solar bursts (after Wild 1950: Plate 1)

Type I bursts occurred in large numbers (hundreds, or more typically thousands) during so-called 'noise storms', which usually lasted for many hours, or even days. Bursts normally came in small discrete groups, were strictly localized in frequency (most had bandwidths between 3 and 5 MHz) and in time (typically 1–8 s), and showed strong circular polarization. Type II bursts (more properly, 'outbursts') were major events and were rare. They lasted several minutes, and had clearly defined upper and lower frequency boundaries at any one instant. The emission drifted from higher to lower frequencies with the passage of time at a mean rate of ~0.22 MHz per s. Type II bursts often were associated with solar flares. A third distinct group of bursts belonged to Type III, characterised by narrow-band events that only lasted a few seconds and drifted rapidly from high to low frequencies (at mean rates of ~20 MHz per s). Type III bursts were particularly common, and sometimes occurred in groups near the start of solar flares.

With the potential of the radio spectrograph proven, the search was on for a more 'radio-quiet' site where further antennas could be erected. A reconnaissance trip down the New South Wales south coast revealed Dapto, a sleepy valley with a dairy farm 80 km from Sydney, and shielded from Sydney and Wollongong to the north by surrounding hills (Figs. 19.1 and 19.2). With the passage of the years, Dapto would play a key role in the international development of solar astronomy (Stewart et al. 2011a), and apart from Wild, other notable RP radio astronomers associated with this field station included John Murray (Fig. 19.60), Jim Roberts, Kevin

Fig. 19.60 Paul Wild (*left*) and John Murray (*right*) at Dapto (*Courtesy* CSIRO RAIA 2833-4)

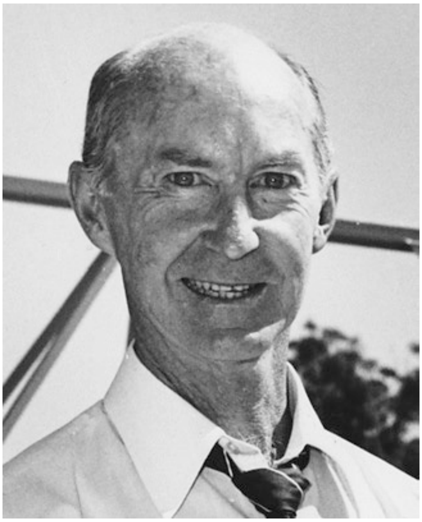

Fig. 19.61 Kevin Sheridan (adapted from a CSIRO RAIA image)

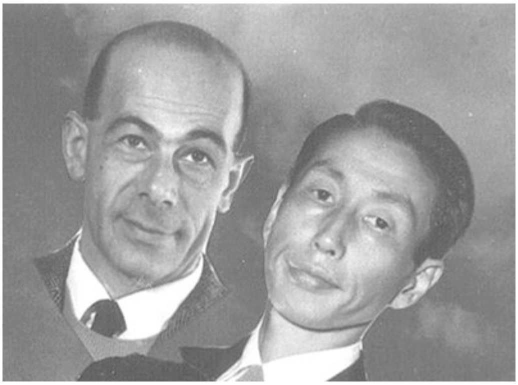

Fig. 19.62 Steve Smerd (*left*) and Shigemasa Suzuki (*right*) in 1968 (adapted from a CSIRO RAIA image)

Sheridan (1918–2010; Fig. 19.61), Steve Smerd (1916–1978; Fig. 19.62; Orchiston 2014d) and, in later years, Shigemasa Suzuki (1920–2012; Fig. 19.62).

Initially, the radio telescopes at Dapto comprised three different crossed-rhombic aerials in a N-S line, which covered the frequency ranges of 40–75, 75–140 and 140–240 MHz, respectively. Each aerial was supported by an equatorial mounting, and could track the Sun. Meanwhile, the crossed-configuration allowed different polarization measurements to be taken. Inside the receiver hut the signals from the three aerials went to three swept-frequency receivers, and then to cathode ray tubes where they were photographed with cine cameras (two of these can be seen in Fig. 19.60). This ingenious system allowed a complete spectrum to be obtained every half-second. Development of the aerials and the supporting receivers took time, so the three solar radio spectrographs only became operational in August 1952 (see Fig. 19.63).

Fig. 19.63 The Dapto field station, showing the three crossed-rhombic antennas and associated buildings (*Courtesy* CSIRO RAIA 12429-1)

Between 1958 and 1963 four new rhombic antennas were added, allowing the lowest frequency received to successively be reduced from 40 MHz to 25 MHz (in 1958), 15 MHz (in 1960) and finally 5 MHz (in 1961). Then in 1963 a 10-m (33-ft.) parabolic dish with a log-periodic feed was installed (Fig. 19.64), and the upper frequency limit was extended from 210 MHz to 2000 MHz.

Soon after the field station became operational, it was noticed that some Type II (e.g. Fig. 19.65) and Type III bursts exhibited harmonic structure, with a near mirror image of the initial burst following in close succession at a frequency separation of 2:1. In addition, by 1958, three further spectral classes of events had been identified: Type IV noise storms, Type V bursts and 'Reverse drift pairs' (or 'Drifting pairs', i.e. DPs). Type IV noise storms, well-documented at Dapto but first described by a French radio astronomer (see Pick et al. 2011), were rare continuum events, characterized by a high-intensity broadband featureless spectrum and linear polarization. They lasted from around half an hour to six hours, and generally occurred after Type II bursts. Type V bursts looked like Type IIIs but with broadband continuum 'tails' that lasted anywhere from half a minute to 3 min and were associated with between 25 and 33% of all Type III bursts. 'Reverse drift pairs' (RDPs, or DPs) were rare very short-duration bursts seen only below 50 MHz, and occurred in pairs separated in time by only 1.5–2 s. The pairs typically drift rapidly from lower to higher frequencies at rates of 2–8 MHz per s. RDPs tended to occur in storms lasting from hours to days, and about 10% were associated with weak Type III bursts. Typical

Fig. 19.64 The 10-m dish and log-periodic feed (*Courtesy* CSIRO RAIA 004032)

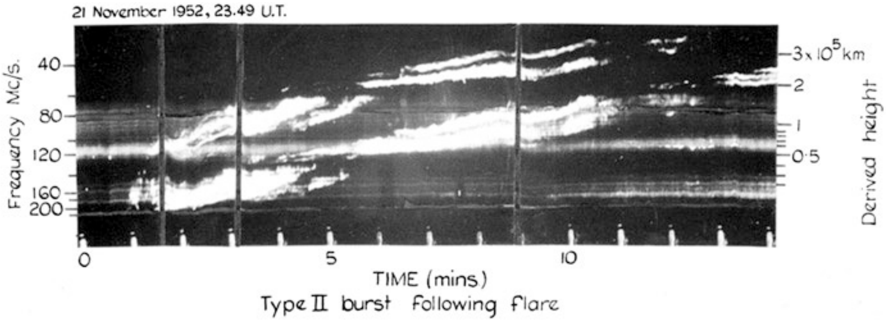

Fig. 19.65 An early example of a Type II burst showing harmonic structure (*Courtesy* CSIRO RAIA 3685-8)

examples of the various Dapto spectral types are illustrated in Fig. 19.66, and this scheme was soon adopted by solar radio astronomers worldwide.

In 1957, three further rhombic antennas were installed at Dapto. Two of these were used as an interferometer to record real-time changes in the positions and sizes of different burst sources over the frequency range 40–70 MHz, while the third antenna

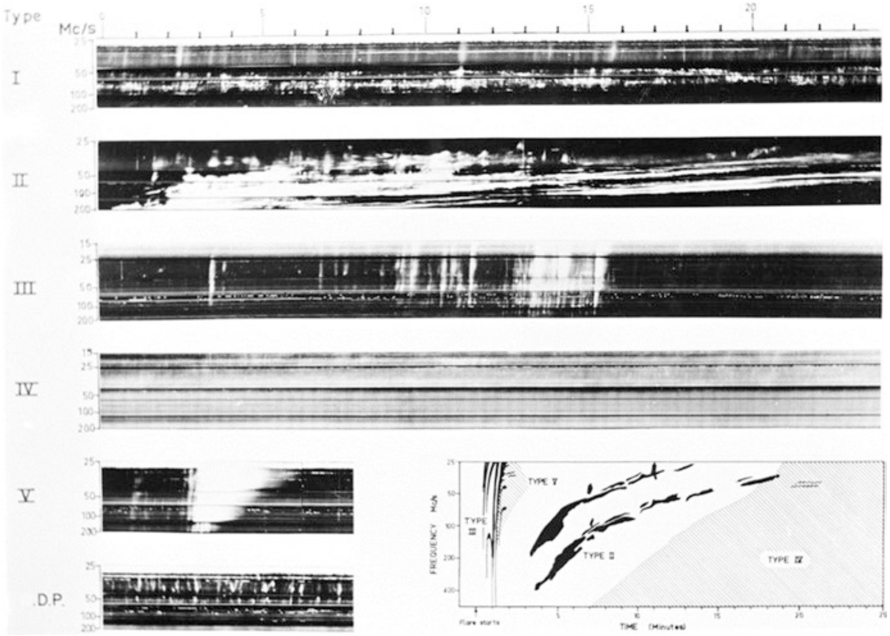

Fig. 19.66 Typical examples of the six different spectral types of solar bursts recorded at Dapto, with a schematic (*bottom right*) that summarizes their relative features (*Courtesy* CSIRO RAIA 6317)

(a crossed-rhombic) could track the Sun and record the polarization of bursts (Wild and Sheridan 1958). The system was set up so that the operator could manually switch between the position interferometer and the polarimeter, as required. After passing through the receivers the signals were initially displayed on a 12-in. cathode ray tube and photographed with a 35-mm cine camera, but in 1959 this arrangement was altered and the results were combined and preserved as a facsimile record (see Fig. 19.67).

Members of RP's illustrious Solar Group then used data from the radio spectrographs, the position interferometer and the polarimeter to produce a succession of seminal research papers on the properties of the different types of solar bursts, and this is surely Dapto's greatest legacy. For more than a decade this field station was at the forefront of international solar radio astronomy, and through its innovative instrumentation (Sheridan 1963) was able to provide important new information on coronal properties, solar burst generation, and the association between solar radio emission and photospheric and chromospheric events and features (see Smerd 1964; Wild et al. 1963). In this, the impact of Wild's leadership cannot be underestimated. When quizzed on this, Steve Smerd (1978) was moved to comment:

> Wild built up a group which was quite unusual compared to all the other research teams that I have seen. I think our solar group under Paul was perhaps the happiest, frictionless collection of people you can imagine. We were keen and dedicated and would have done anything that Paul even half-mentioned or suggested, let alone explicitly asked.

Fig. 19.67 Kevin Sheridan and the position interferometer receiver and facsimile record (*Courtesy* Sullivan, Dapto 02)

The Dapto facility was closed down in 1965, and this sad event also marked the end of a proud tradition at RP: those unforgettable Dapto parties (see Fig. 19.68). Some of the Dapto antennas were relocated to Culgoora, the site of the Division's 'next generation' forefront solar radio telescope, the Culgoora Radioheliograph (Wild 1967), but most remained at Dapto and were inherited by the University of Wollongong when it took over the field station.

19.2.7 Fleurs[1]

One of the last Radiophysics field stations set up in the pre-Parkes era was at Fleurs (Orchiston and Slee 2002b), the site of a WWII airstrip 40 km west-south-west of central Sydney (Fig. 19.2). Situated on an expanse of flattish land between two

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[1] This particular field station has special memories for both authors. W.O. operated the Chris Cross and produced the daily solar maps from 1962 up until the time when Fleurs was handed over to the University of Sydney, while Bruce Slee was closely associated with the Mills Cross and the Shain Cross throughout the life of the field station.

Fig. 19.68 Paul Wild is in front (*in the dark jersey*) and beside him, with the guitar, is Steve Smerd, at one of the famous Dapto parties (*Courtesy* CSIRO RAIA B5865)

streams, Fleurs was home to three different cross-type radio telescopes (Fig. 19.69). Leading radio astronomers associated specifically with this site were Alan W.L. Carter, Chris Christiansen, Eric R. Hill, Norman Labrum (1921–2011; Fig. 19.70), Alec Little, Bernie Mills, Richard F. (Dick) Mullaly (d. 2001; Fig. 19.71), Alex Shain, Kevin Sheridan and Bruce Slee, assisted by people like Frank Gardner (1924–2002; Milne and Whiteoak 2005), Bruce Goddard, Charlie Higgins, Wayne Orchiston (b. 1943; Fig. 19.72) and Arthur Watkinson.

The first radio telescope at Fleurs was the Mills Cross (see Mills et al. 1958), which was constructed during 1953–1954 following the success of the Potts Hill small-scale prototype. The Fleurs Mills Cross had 460 m long N-S and E-W arms, each containing 250 half-wave dipoles (Fig. 19.73). Operating at 85.5 MHz, and with a 49′ beam (in those days regarded as remarkable!), the Mills Cross was effectively a transit instrument that relied on Earth-rotation, but by altering the phasing of the dipoles in the N-S arm it was possible to observe different regions of the sky. Signals from the two arms were channeled to the central hut where the receivers and other equipment were located (see Fig. 19.74).

This unique new radio telescope was used for three different projects. Soon after its inauguration, Mills, Little (Fig. 19.75) and Sheridan searched for radio emission from specific types of celestial objects, including known novae, supernovae and planetary nebulae, but were spectacularly unsuccessful. The only object they could detect was the radio source associated with Kepler's supernova of 1604.

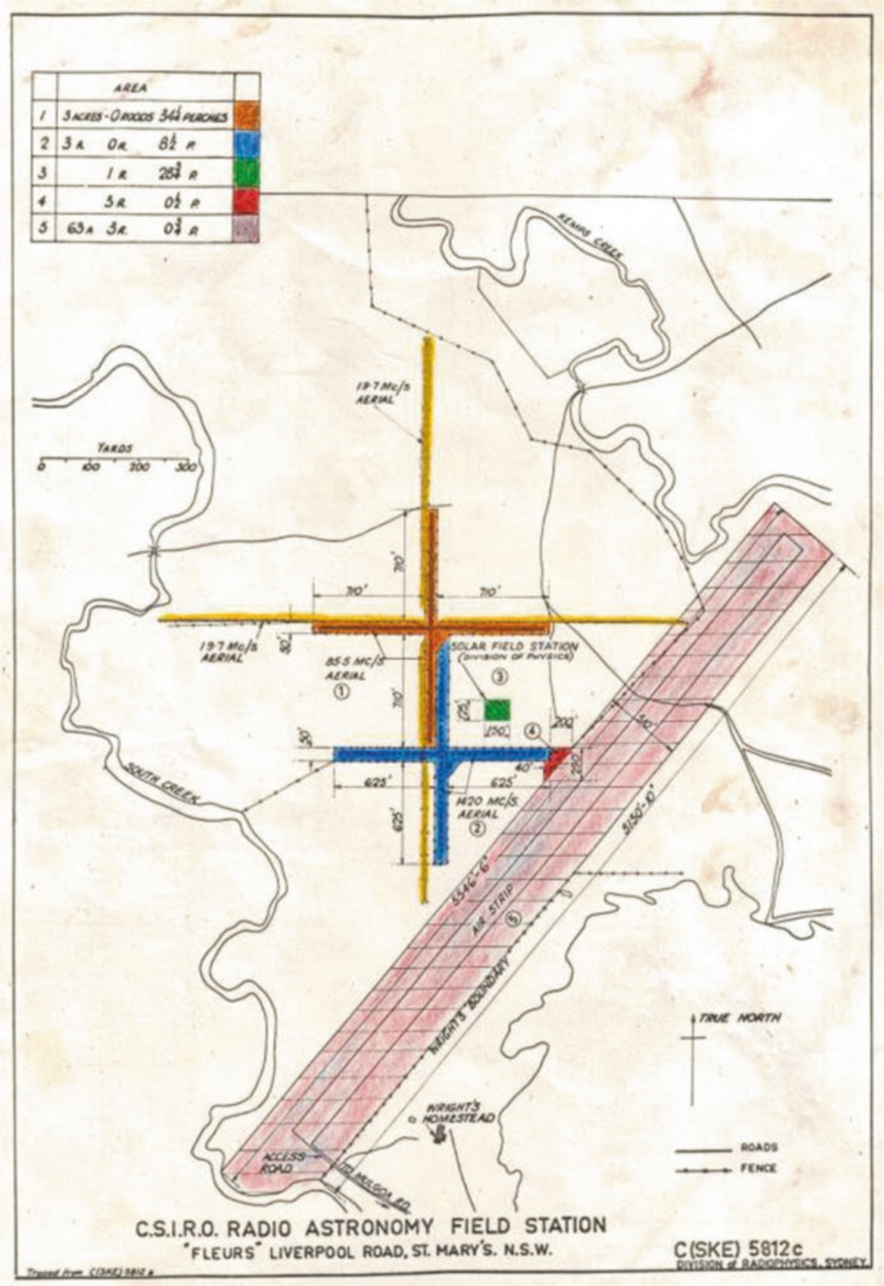


Fig. 19.69 Map showing the Fleurs field station and the three main radio telescopes; the Mills Cross in brown, Chris Cross in blue and Shain Cross in yellow (*Courtesy* CSIRO RAIA)

Fig. 19.70 Norman Labrum in 1968 (adapted from a CSIRO RAIA image)

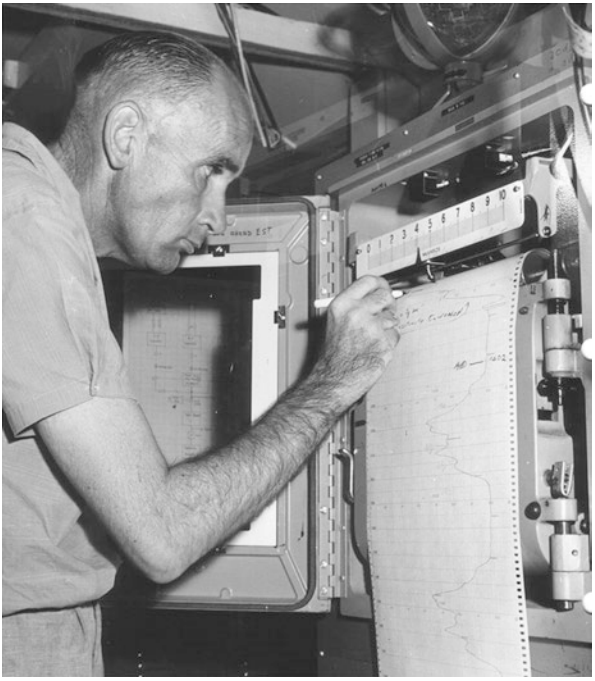


Fig. 19.71 Richard F. (Dick) Mullaly marking the Chris Cross chart record (*Courtesy* CSIRO RAIA 9097-4)

Sheridan also used the Mills Cross to study some of the strongest known radio sources, and was able to produce isophote maps for Centaurus A, Fornax A and Puppis A. By today's standards these are crude, but in 1957–1958 they were regarded as impressive.

Fig. 19.72 Wayne Orchiston in 1968 (adapted from a CSIRO RAIA image)

Fig. 19.73 A close-up of the centre of the Mills Cross, showing individual dipoles, and the receiver hut and microwave link used for long baseline interferometry; in the background are some of the dishes of the Chris Cross (*Courtesy* CSIRO RAIA B5689-8)

Fig. 19.74 A view inside the Mills Cross receiver hut showing Bruce Slee and some of the equipment (*Courtesy* CSIRO RAIA B3868-10)

Fig. 19.75 Alec Little (*left*) and Bernie Mill (*right*) taking some measurements (*Courtesy* CSIRO RAIA B3277-3)

These projects may have been interesting, but they were simply forerunners to the main work of the Mills Cross which was to produce a detailed survey of the sky at 85.5 MHz. The observations for this were carried out by Mills, Hill and Slee between 1954 and 1957, and in the process they recorded about 2000 discrete sources, publishing their results in a series of research papers in the *Australian Journal of Physics*. Although a number of the sources in their famous ‘MSH Catalogue’ were associated with galactic objects, the majority related to extragalactic nebulae, and this had profound cosmological implications in terms of the competing ‘Big Bang’ and ‘Steady State’ theories which were prevalent at the time and led to the notorious ‘Fleurs-2C Controversy’ (see Mills 1984; Sullivan 1990). When they compared the distribution and intensity of the MSH sources with those listed in the Cambridge 2C catalogue, Mills and Slee found there was very little correspondence (see Fig. 19.76). They immediately came up with resolution effects as the explanation, but when Mills tried to raise this with Ryle his letters went unanswered. Later he was to remark: “We were a bit fed up with the Cambridge attitude at this time, I might say … They just ignored us. So we went ahead and did what we felt had to be done.” (Mills 1976). This was to publish a paper reporting the Fleurs-2C discrepancies (Mills and Slee 1957), and explain them away largely in terms of shortcomings associated with the Cambridge interferometer. As might be anticipated, this led to bad blood between British and Australian radio astronomers, and it was some years before the Cambridge scientists finally recognized that their survey had serious shortcomings.

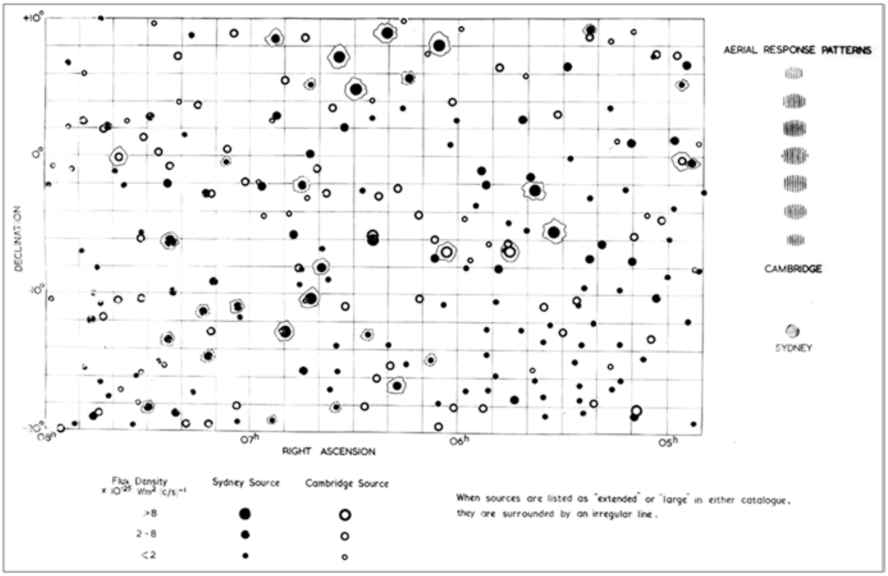


Fig. 19.76 Comparison of sources recorded in the MSH (*filled circles*) and 2C (*open circles*) catalogues (*Courtesy* CSIRO RAIA 5073-12)

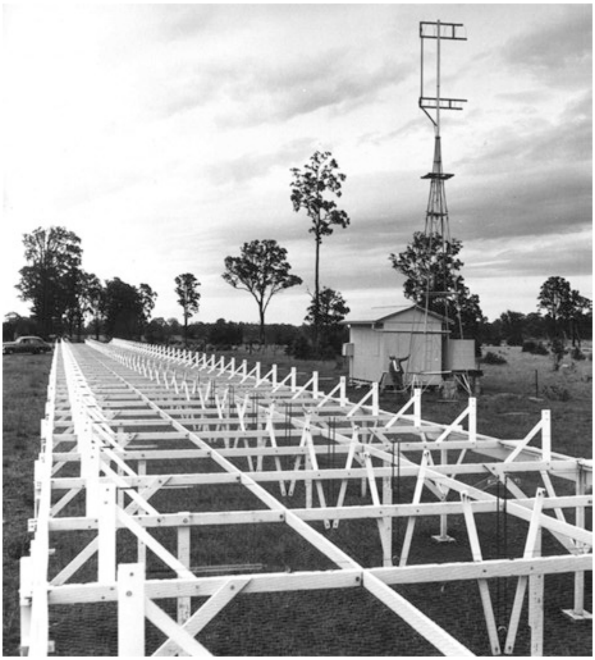


Fig. 19.77 The Wallacia array (*Courtesy* CSIRO RAIA 5689-8)

Evolving out of the Mills Cross survey were a number of other projects that related directly to the MSH Catalogue. In 1954 and 1955, Carter used a 101 MHz broadside array at Fleurs and a similar antenna at Badgerys Creek to investigate the variable radio source, Hydra A, and the sizes of weaker sources in the MSH Catalogue. In 1958 and 1959, Goddard, Watkinson and Mills also used long baseline interferometry to research the sizes of these smaller sources at 85.5 MHz. Their observations were made with the E-W arm of the Mills Cross, a 91.4-m section of the S arm of the Cross, and an identical 50-dipole N-S array at Wallacia (Fig. 19.77), 10 km to the west (Fig. 19.2). Then during 1961 and 1962, Slee (2005) and visiting Cambridge radio astronomer, Peter Scheuer, used the E-W arm of the Mills Cross and barley-sugar arrays erected temporarily at Cumberland Park, Rossmore, Llandilo and Freeman's Reach (respectively 6 and 10 km south, and 17 and 32 km north of Fleurs—see Fig. 19.2) and connected to Fleurs by a radio link to research the sizes of selected sources in the MSH catalogue.

The Mills Cross was also used for a number of other studies involving the use of discrete sources to probe the solar wind. In 1956, 1957, 1958 and 1960 Slee (2005) used elements of the Mills Cross to carry out four different studies relating to electron density irregularities in the solar corona. His fourth, and most ambitious, project took place between June and October 1960 when he used the E-W arm of the Mills Cross and the Wallacia array (mentioned above), to observe different discrete sources as they passed close to the Sun. The results were spectacular: "Sporadic large increases in the scattering first became noticeable when the angular separation was as much as 100 $R_\odot$ and at separations of less than 60 $R_\odot$ the effects of scattering

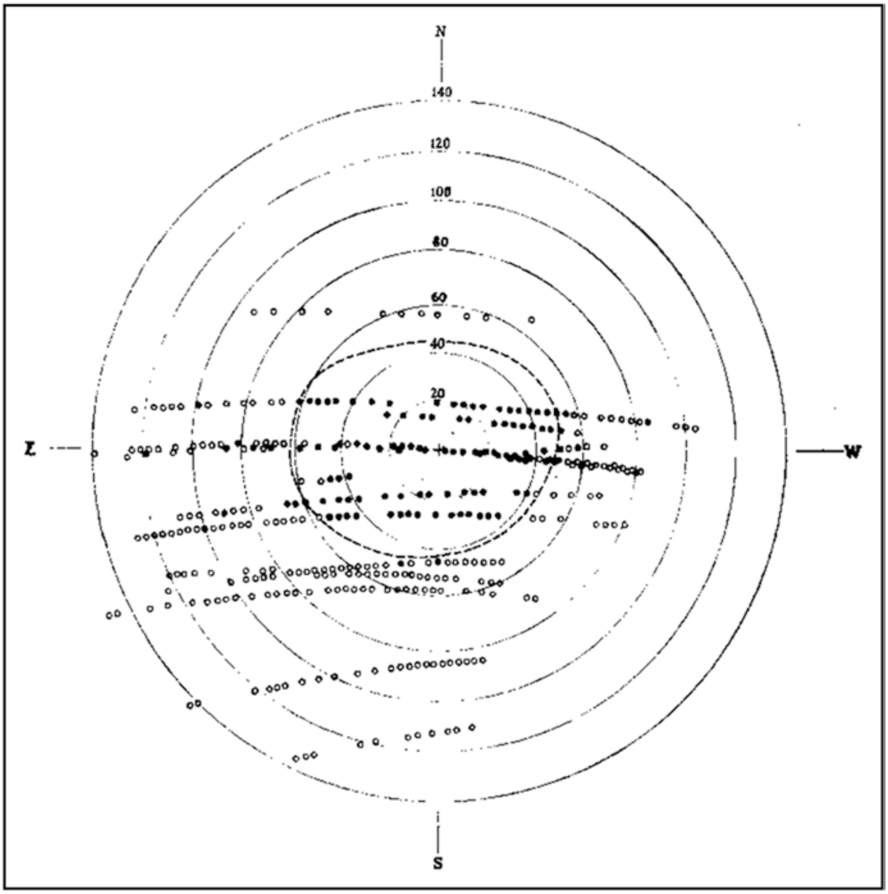


Fig. 19.78 A diagram showing coronal scattering (*filled circles*) suffered by 13 different discrete sources observed in 1960. The Sun is marked by the cross, and coronal scattering is primarily restricted to the region enclosed by the dashed line (*Courtesy* CSIRO RAIA B6328-1)

could be detected on every record." (Slee 1961: 225). Figure 19.78 provides a graphical illustration of this result; open circles indicate days when the source interference fringes appeared to be unaffected by scattering, while filled circles refer to days when fringe amplitudes were greatly reduced. The dashed line indicates the region with the majority of filled circles, where the average scattered distribution exceeded 30″ to half-power points in the E-W direction.

Slee was also involved in the other post-MSH Catalogue observations of considerable significance. Between September 1960 and May 1962 he and Higgins used the N-S arm of the Mills Cross to carry out pioneering observations of radio emission from UV Ceti, a nearby dMe flare star (Slee et al. 1963a). Parallel observations were made with the neighbouring Shain Cross at 19.7 MHz, and with the Parkes Radio Telescope at 408 MHz. Slee and Higgins, plus England's Sir Bernard Lovell, must be credited with the discovery of the first genuine 'radio stars' (see Orchiston 2004a).

During 1955 three low-frequency radio telescopes were constructed at Fleurs, namely a 19.6 MHz two-element E-W interferometer (each aerial consisting of four full-wave dipoles suspended between telegraph poles) and 14 MHz and 27 MHz single in-line arrays of four and eight half-wave dipoles respectively. Gardner and Shain (1958) used these antennas during 1955–1956 to investigate burst emission from Jupiter. Jovian emission was recorded at all three frequencies, but was most common at 19.6 MHz where a rotation period for the source of 9 h 55 min 34 s was derived—close to the earlier result from Hornsby Valley. However, the 19.6 MHz and 27 MHz data tended to indicate the presence of three different sources: the main one at a Jovian longitude in System II of 0° and two much less active secondary sources at longitudes of −100° and +80°. Shain and Gardner (1958) suggested that the bursts resulted from plasma oscillations in an ionized region of the Jovian atmosphere.

In 1956, just 2 years after the Mills Cross was operational, the Shain Cross was completed. Shain was largely responsible for this, but Little helped with the antenna design and Sheridan with the receiving equipment. This large new radio telescope (Shain 1958) was built alongside the Mills Cross, operated at a frequency of 19.7 MHz, and had a beam width of 1.5°. It evolved out of Shain's earlier exploits at the Hornsby Valley and the 19.6 MHz interferometer at Fleurs, and drew inspiration also from the Mills Cross concept. The N-S arm was 1151 m in length and contained 151 dipoles, while the E-W arm was a little shorter, at 1036 m, with 132 dipoles. The dipoles were 4 m above the ground and strung between telegraph poles, with the ground serving as a reflector (Fig. 19.79).

Initially Shain used this new radio telescope to survey 19.7 MHz emission in the Galactic Plane. Observations of a strip of sky extending ±10° from the Galactic Equator, showed a conspicuous dip in the chart records (Fig. 19.80), indicating that "… absorption of 19.7 Mc/s radiation is occurring in a band of HII regions near the galactic plane." (Shain 1957: 198), and when an isophote map was prepared this showed Sgr A in absorption (Fig. 19.81). Shain also investigated selected strong sources, producing 19.7 MHz isophote maps for Centaurus A and Fornax A, which looked rather similar to those generated at 85.5 MHz by Kevin Sheridan.

Shain also planned to observe Jupiter with the new Cross and arrange for simultaneous optical monitoring with a view to identifying any optical features that could conceivably be associated with the radio emission, but his untimely death in 1960 put paid to these plans. Instead, it was left to Slee and Higgins to take up the Jovian challenge (see Slee 2005). In August 1962 they erected a square array of 19.7 MHz dipoles at Fleurs and an identical array at Freemans Reach, 32 km to the north (Fig. 19.2), in order to investigate the size of the region responsible for the Jovian bursts, and in 1963 and 1964 they expanded this project by setting up radio-linked arrays at Dapto and Jamberoo far to the south of Sydney, and at Heaton, near Cessnock, to the north (see Fig. 19.1). Analysis of the observations suggested that the emitting regions were typically 10–15 s of arc in size, but Slee and Higgins concluded that they were probably very much smaller and that scattering in the interplanetary medium gave anomalously large angular sizes.

This conclusion turned the Radiophysics Jovian decametric project in a new direction: what had started as a quest for emission source size now became an

Fig. 19.79 Looking south along the N-S arm of the Shain Cross; on the left is the N-S arm of the Mills Cross, and the broadside antenna used by Alan Carter for his long baseline study of source sizes (*Courtesy* CSIRO RAIAF B3868-19)

investigation of scattering by the interplanetary medium. Slee and Higgins then used their 1963–1964 data on burst arrival times, burst rates, angular position scintillations and apparent angular size to successfully investigate interplanetary diffraction patterns and electron irregularities in the solar wind. This study would mark the final contribution of the Fleurs site to planetary radio astronomy.

Finally, as we have already seen, from September to December 1961 Slee and Higgins used the N-S arm of the Shain Cross to search successfully for 19.7 MHz radio emission from selected flare stars (Slee et al. 1963b).

Fleurs gained its third large radio telescope in 1957—just in time for the International Geophysical Year—when a major new solar array, the Chris Cross (Fig. 19.82), was constructed (Orchiston 2004c; Orchiston and Mathewson 2009). Named, appropriately, after 'Chris' Christiansen, this innovative instrument represented an amalgamation of his Potts Hill solar grating arrays and the Mills Cross concept (Christiansen et al. 1961).

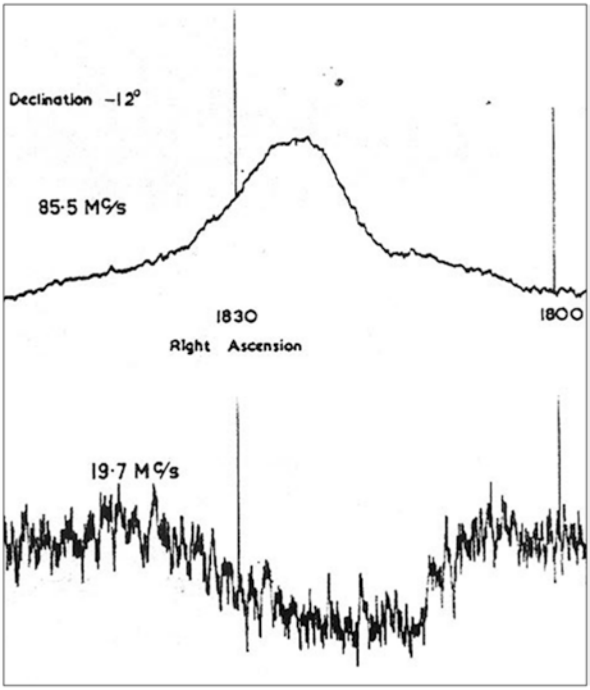


Fig. 19.80 A total power plot showing the dip in Galactic Plane emission at 19.7 MHz, compared to the emission peak at 85.5 MHz (after Shain 1958: 87)

Most visually appealing of all early Australian radio telescopes (Fig. 19.83) this array comprised 433 m long N-S and E-W arms each containing 32 parabolic equatorially mounted dishes 5.8 m (19 ft.) in diameter. Antennas in the E-W arm produced a series of N-S fan beams, and antennas in the N-S arm a series of E-W fan beams. Electronically combining the signals received from the two arms produced a network of pencil beams at the junction points of the fan beams (see Fig. 19.84). Each pencil beam was 3′ in diameter and was separated from its neighbour by 1°, so the Sun could never be in more than one pencil beam at any one time. Thus, the array produced a succession of E-W strip scans which were used to generate daily full-disk solar maps (see Fig. 19.85).

The Chris Cross operated at 1420 MHz, and was built to explore the nature and evolution of radio plages (Fig. 19.86), research those rarely observed bursts seen at this comparatively high frequency, and investigate the distribution across the solar disk of emission from the quiet Sun. It was the first radio telescope in the world to generate daily two-dimensional high resolution radio images of the Sun, and in focusing primarily on non-burst emission was the perfect complement to the Dapto radio spectrographs.

From their accumulated observations, Christiansen and his colleagues found that radio plages had typical diameters of 2–6′ (representing from 10^5 to 3×10^5 km in

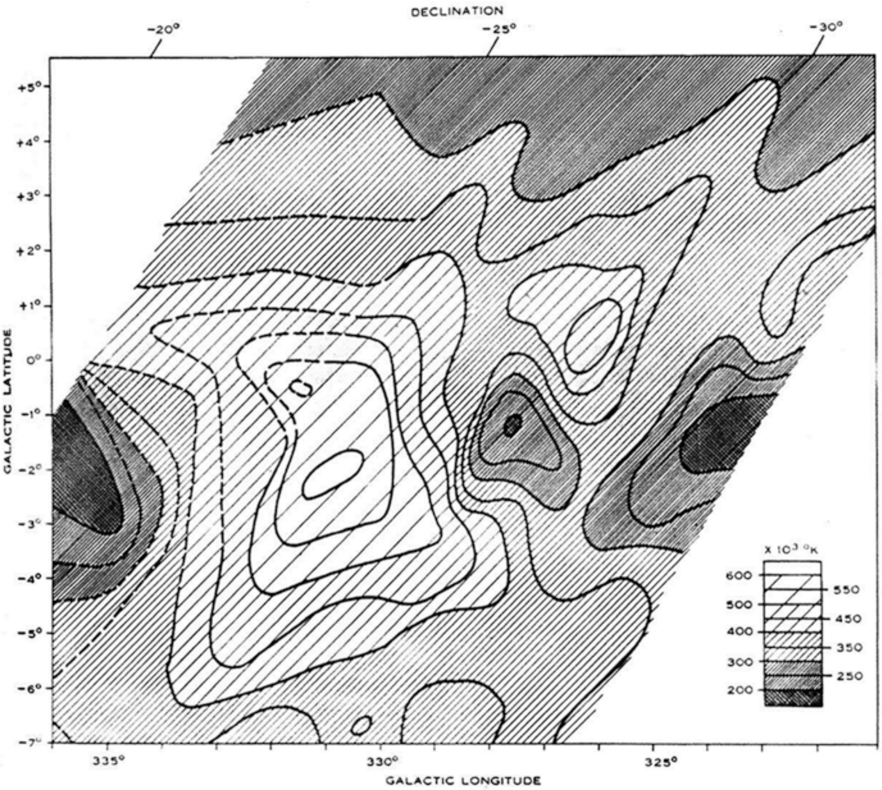


Fig. 19.81 Absorption near the Galactic Centre, caused by ionizing HII regions (after Shain 1957: 197)

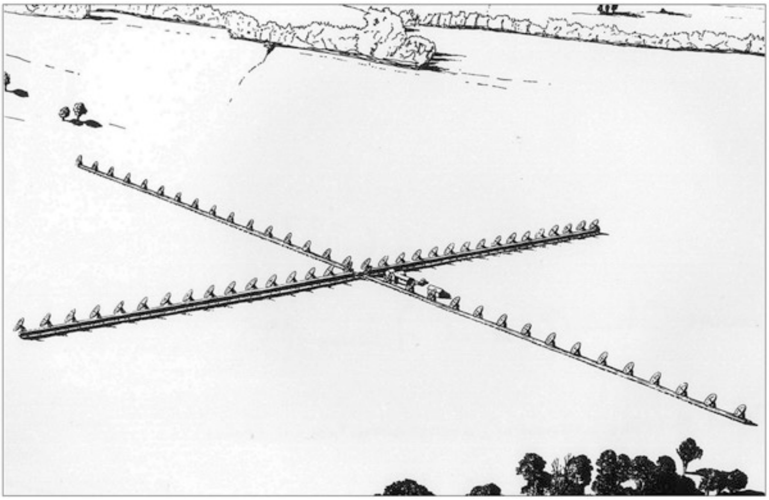
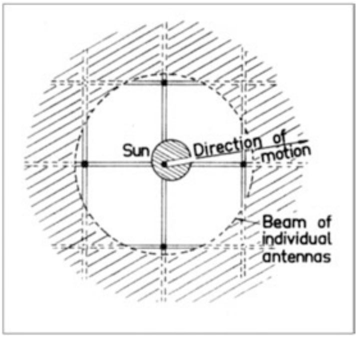


Fig. 19.82 A schematic aerial view of the Chris Cross, looking north-east (after Christiansen et al. 1961: 49)

Fig. 19.83 A view looking south down the N-S arm, from near the centre of the Cross; note the superstructure erected to protect the feeder lines from the elements (*Courtesy* CSIRO RAIA 9097-12)

Fig. 19.84 The network of pencil beams (after Christiansen et al. 1957: 945)



actual areal extent), were situated from 3 × 10^4 to 10^5 km above the photosphere (with an average height of ~4 × 10^4 km), and had peak temperatures of <2 × 10^5 up to ~1.6 × 10^6 K (with a median value of ~6 × 10^5 K). Christiansen and Mullaly (1963: 171) concluded that radio plages "… consist of large clouds of gas (principally hydrogen) … [that are] much denser than the surrounding atmosphere … [and] are prevented from dissipating presumably by magnetic fields …" The virtual absence of circular polarization indicated that the emission was thermal in origin.

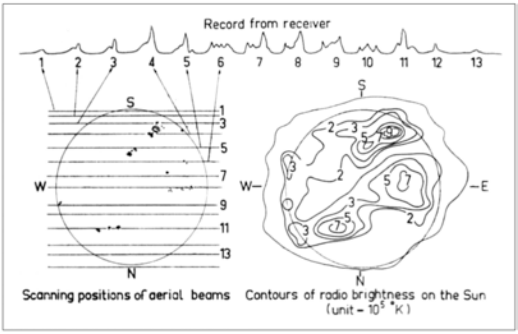


Fig. 19.85 Diagram showing (**top**) a succession of 13 E-W scans, (**bottom left**) their corresponding positions on the solar disk, and (**bottom right**) the resulting isophote map (adapted from Christiansen and Mullaly 1963: 170)

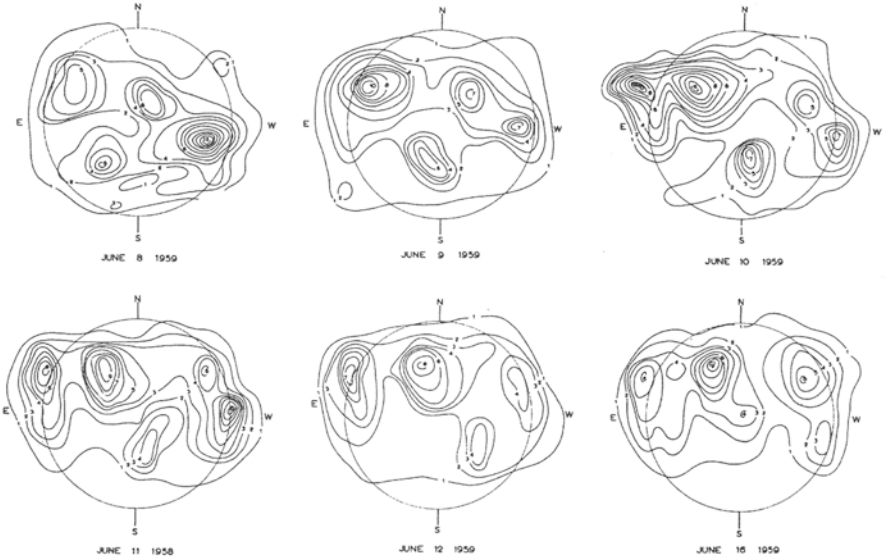


Fig. 19.86 A series of daily 1420 MHz solar maps showing the presence of several radio plage regions (*Courtesy* CSIRO RAIA B6453-3)

The final phase in RP's development of the Fleurs site occurred in 1959 when an 18-m (60-ft.) prefabricated American antenna, known colloquially as the 'Kennedy Dish', was installed at the eastern end of the E-W arm of the Chris Cross (Fig. 19.87). This array, known as the Fleurs Compound Interferometer, had a 1.5′ fan beam, and it was used at times when the Sun was not being observed to investigate 1420 MHz emission from some of the brightest radio sources.

A major change took place at Fleurs at the end of 1962 when the Kennedy Dish was transferred to Parkes (see Fig. 19.1), to be used in conjunction with the 64-m Parkes Radio Telescope. By this time the research programs that justified the construction of the Mills and Shain Crosses had come to an end and Fleurs had

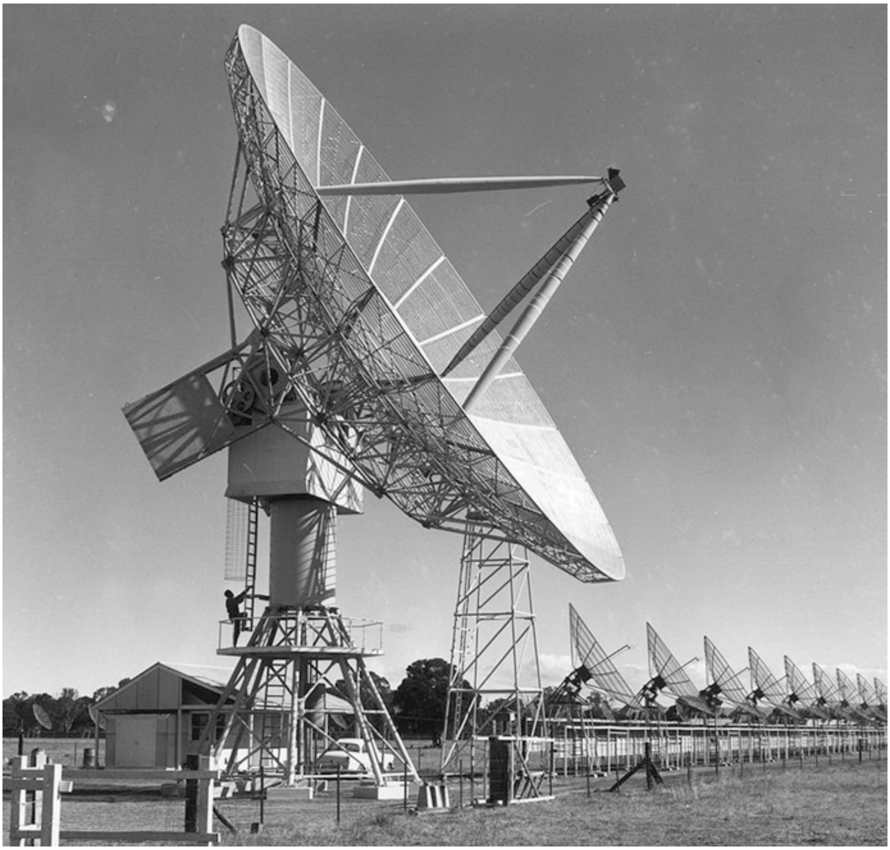


Fig. 19.87 A view looking west along the E-W arm of the Chris Cross, showing the recently installed 'Kennedy Dish' (*Courtesy* CSIRO RAIA B6499-5)

served its purpose. No longer required as a field station, it was handed over to the University of Sydney, and the School of Electrical Engineering (under Professor Christiansen) spent the next decade converting the Chris Cross into the 'Fleurs Synthesis Telescope'.

In summary, during the 10-year interval, 1954–1963, Fleurs was one of the world's foremost radio astronomy sites, and it played an important role in furthering solar and non-solar radio astronomy. Bowen (1984: 97) would go so far as to claim that the three Fleurs cross-type radio telescopes "… were among the great successes of the 1950s and were responsible for a large part of the Division's research output over that period." They consolidated the international standing of Christiansen and Mills, helped build the emerging reputations of people like Shain, Sheridan and Slee, and served as stepping stones to the Division's next major advances in instrumentation: the Parkes Radio Telescope and the Culgoora Radioheliograph.

Fig. 19.88 John Murray at the chart recorder in the receiver hut at Murraybank (*Courtesy* CSIRO RAIA 5695-9)

19.2.8 Murraybank

The Murraybank field station was located in suburban West Pennant Hills (Fig. 19.2), on an orchard ('Rosebank') owned by the father of RP radio astronomer, John Murray, and was set up in 1956 in order to carry out H-line observations with a new purpose-build radio telescope and receiver (see Wendt et al. 2011b). Apart from John Murray (Fig. 19.88), Richard Xavier (Dick) McGee (1921–2012; see Fig. 19.89) was the other radio astronomer who spent time at this field station.

At 6.4 m (21 ft.), the Murraybank radio telescope (Fig. 19.90) was considerably smaller than its Potts Hill predecessor, but its altazimuth mounting meant that interesting areas of the sky could be accessed at will. At 1420 MHz, the beam width was 2.2°.

There was also marked improvement in the ancillary instrumentation, as the old Potts Hill 4-channel unit was replaced by a 48-channel receiver (Fig. 19.91) built mainly by Murray and McGee. This contained 44 separate narrow-band channels, spread at 33 KHz intervals across the H-line frequency of 1420.9 MHz, and four wide-band channels at either end of the range, which were used to obtain reliable zero levels (see McGee and Murray 1963).

Initially the Murraybank facility was used by McGee and Murray to investigate the distribution of neutral hydrogen in the Taurus-Orion region, as a test of the overall system. More than 3500 H-line profiles were obtained (Fig. 19.92), and the level of emission suggested that a large single neutral hydrogen cloud or an association of connected clouds spanned the Taurus-Orion region and that this was rotating as part of the general structure of our Galaxy.

Fig. 19.89 The Radiophysics cricket team included Dick McGee (standing, second from *left*), along with John Bolton (standing, extreme *left*), Joe Warburton (standing, third from *left*), Paul Wild and Kevin Sheridan (seated, second from *left* and second from *right*), all of whom feature in this chapter (*Courtesy* CSIRO RAIA B12718)

Fig. 19.90 The Murraybank field station, showing installation of the 6.4-m dish, and the adjacent building which housed the H-line receiver (*Courtesy* CSIRO RAIA B3973-4)

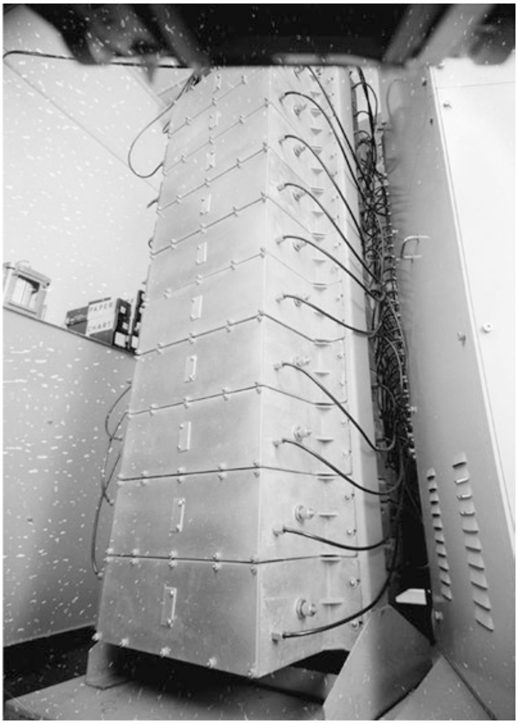


Fig. 19.91 Part of the new 48-channel H-line receiver (*Courtesy* CSIRO RAIA B5985-1)

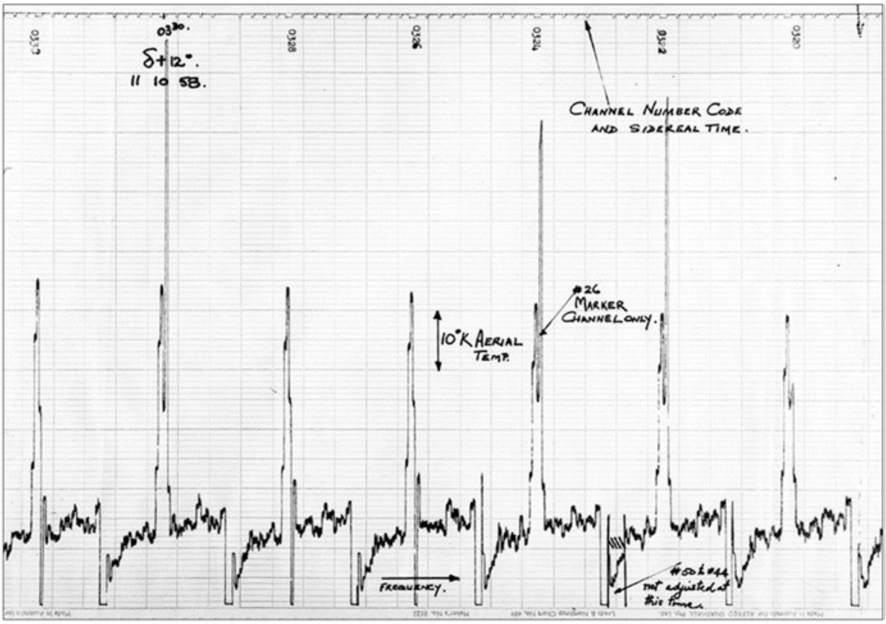


Fig. 19.92 A chart record showing a series of H-line profiles (*Courtesy* CSIRO RAIA B5669)

McGee and Murray followed up this localized study with a survey of the distribution of neutral hydrogen over the whole sky visible from Sydney and found that in general the gas was stratified parallel to the Galactic Plane, and concentrated in a number of massive spiral arms.

One of the problems encountered with the Murraybank receiver was that a complete H-line profile could be obtained in just 2 min, 60 times more quickly than at Potts Hill with the old equipment. Reduction of the large bodies of observational data obtained therefore posed a major challenge, and this prompted the development of a digital data-recording system that would ultimately see extensive use with the Parkes Radio Telescope (Hindman, et al. 1963). However, this innovative system was first trialed at Murraybank during a low resolution H-line survey of the Magellanic Clouds. The digital recording and data handling system successfully converted 250 h of observations to printed profiles in just 8 h of computer time, but more than this, the survey reinforced the earlier finding of Kerr, Hindman and Robinson that an extensive gaseous envelope enclosed both Magellanic Clouds. The total mass of hydrogen in the two Clouds derived in the earlier study also was confirmed. An interesting new discovery was the detection of a tenuous 'bridge' of hydrogen gas between the Large and Small Magellanic Clouds (Fig. 19.93).

For the Radiophysics Division, Murraybank served an important role as the test-bed for the innovative 48-channel H-line receiver, and this field station only closed when the receiver was transferred to the newly opened Parkes Radio Telescope at the end of 1961.

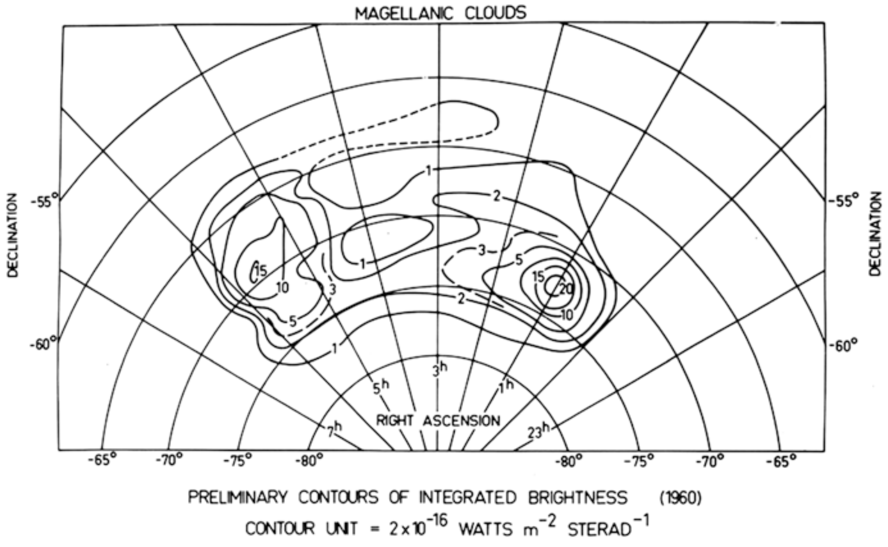


Fig. 19.93 Isophotes of neutral hydrogen, showing the tenuous 'bridge' between the Large and the Small Magellanic Clouds (*Courtesy* CSIRO RAIA B6296-1)

19.3 Concluding Remarks

During the critical 15 years from 1946 to 1961 Australia played a key role in the international development of radio astronomy (Mills 1988; Orchiston et al. 2006; Pawsey 1953, 1961; Robertson 1992; Stewart et al. 2011c; Sullivan 1988, 2009), largely through the research that was carried out at the Radiophysics Laboratory and the nine different field stations located in or near Sydney and Wollongong.

In addition to standard Yagis and parabolic dishes, innovative new types of instruments were invented, including solar radio spectrographs, solar grating arrays, cross-type radio telescopes, H-line multi-channel receivers and an assortment of long baseline interferometers (Christiansen 1959; Mills 1963; Pawsey and Bracewell 1955; Wild 1953).

Collectively, the radio telescopes at the field stations and associated remote sites were used to address a wide range of research problems, and important contributions were made to solar, Jovian, galactic and extra-galactic radio astronomy (e.g. see Bolton 1955; Haynes et al. 1996; Kerr and Westerhout 1965; Mills 1959; Pawsey 1950; Pawsey and Hill 1961; Pawsey and Smerd 1953 Sullivan 1984), largely through the key roles played by such luminaries are John Bolton, Chris Christiansen, Frank Kerr, Bernie Mills, Joe Pawsey, Ruby Payne-Scott, Alex Shain, Bruce Slee, Gordon Stanley and Paul Wild. It is a sad reflection that none of these is still with us today.[2]

Just as the world's pioneering radio astronomers are being taken from us, few of our pioneering radio telescopes have survived. Visits to the sites of the Badgery's Creek, Dapto, Georges Heights, Hornsby Valley, Murraybank, Penrith and Potts Hill field stations quickly reveal an almost total absence of instrumentation, buildings or relevant earthworks, and only Dover Heights, Fleurs and Potts Hill hold any promise.

At Dover Heights the landscape has changed markedly since the field station days, and the site is now a reserve and playing field. However, the badly rusted remains of the mounting that once supported an 8-Yagi and later a 12-Yagi sea interferometer survives, and during the July 2003 IAU General Assembly staff from the Australia Telescope National Facility installed a scaled-down replica of the 8-Yagi array near it (Fig. 19.94), along with a commemorative plaque and historical panel display. Those visiting Dover Heights can now get a feel for the astronomical importance of this famous site.

For its part, Fleurs retains some rusting 13.7-m (45-ft.) antennas that formed part of the Fleurs Synthesis Telescope, and some years ago two of the better-preserved ones were relocated to the CASS antenna range at Marsfield, Sydney, and refurbished (see Fig. 19.95) as part of developments associated with Australia's bid to host the SKA. Back at Fleurs, however, the 12 centrally located original Chris Cross dishes

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[2] The last of these radio astronomers to die was Bruce Slee, the co-author of this chapter, on 18 August 2016. Bruce passed away one week after his 92nd Birthday, but long after we had worked together and drafted this chapter. It is only fitting, therefore, that he should remain a co-author. Earlier in 2016, before he died, Bruce was honoured when the IAU named a minor planet after him, and following his demise he was honoured posthumously in the Australia Day Awards.

Fig. 19.94 The replica 8-Yagi antenna at the site of the Dover Heights field station in 2003, beside its original rusting mount (*Photograph* Wayne Orchiston)

that were preserved and refurbished by University of Western Sydney Engineering staff and students in 1991 (see Orchiston 2004c) deteriorated rapidly after the close-down of the site in 1998, and—unbeknown to the authors of this chapter—were bulldozed. This was a tragic loss for Australian and world radio astronomy.

Until recently, all evidence of radio astronomy at Potts Hill was thought to have gone long ago, so it was a great surprise when Dr. Harry Wendt—who wrote his Ph.D. thesis on the Radiophysics Potts Hill field station while supervised by the two authors of this chapter—received a phone call from Sydney Water early in 2015 and discovered that the original H-line receiver hut still existed, albeit in a vandalised state. This wooden hut has since been refurbished (see Fig. 19.96), and now serves as a fitting reminder of the important contribution that this suburban Sydney site made to international radio astronomy back in the late 1940s and throughout the 1950s.

The only RP sites where historic radio telescopes have survived *in situ* are Parkes and Culgoora. At Parkes there are two: the 64-m Parkes Radio Telescope and the 18-m Kennedy Dish (Fig. 19.97). While the former is still used regularly for forefront research and therefore will be maintained (and preserved), the latter antenna is no longer needed and is now in poor condition. Back in 2003 a policy decision was made by the Australia Telescope National Facility to retain and preserve this historic antenna (see Orchiston 2012), but this has since lapsed (Ron Ekers, pers. comm., 2016).

Fig. 19.95 One of the two refurbished ex-Fleurs Synthesis Telescope antennas at Marsfield in March 2015 (*Photograph* Wayne Orchiston)

Culgoora (Fig. 19.1), near Narrabri in northern New South Wales, is the site of Australia's forefront synthesis instrument, the Australia Telescope Compact Array, but many of the 96 parabolas that once formed the Culgoora Radioheliograph (Fig. 19.98) and some of the antennas associated with the Culgoora radio spectrographs are still there—in varying stages of disintegration. All of these surviving radio telescopes played vital roles in the history of Australian astronomy and deserve to be documented and preserved while such action is still possible. A number of the Radioheliograph antennas have been dismantled (c.f. see Fig. 19.99) and gifted to individuals, schools and other institution, but it is important that some of the remaining parabolic antennas and corner reflectors are retained and used in the historical presentation and interpretation of this site.

Fig. 19.96 Sydney Water's Stephen Iacono and Phil Bennett pose in front of the refurbished Potts Hill H-line receiver hut in May 2015 (after Historic astronomy facility … 2015)

Fig. 19.97 *Left to right*: the Radio Telescope and the Kennedy Dish (*Courtesy* CSIRO RAIA N9706-3)

Fig. 19.98 Part of the original array of 96 antennas that formed the Culgoora Radioheliograph (*Courtesy* CSIRO RAIA 8836-7)

Fig. 19.99 The dismantling of one of the Radioheliograph antennas prior to its removal from the site. In the background on the left is one of the corner reflectors (Orchiston collection)

This then raises an important philosophical issue. We believe that historically significant radio astronomical hardware should be shown the same respect and veneration that is enjoyed by optical instruments that have played a key role in the evolution of astronomy. Historically significant radio telescopes and associated instrumentation (horns, feeds, polarization screens, receivers, chart records, signal generators, etc.) are important objects in their own right and they do deserve to be preserved. This is one of the charters of the IAU Working Group on Historic Radio Astronomy that was formed by the first author of this chapter (W.O.) at the 2003 IAU General Assembly in Sydney with approval from the commissions responsible for radio astronomy and history of astronomy.

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References

Bolton, J.G. (1955). Australian work on radio stars. *Vistas in Astronomy*, *1*, 568–573.

Bolton, J.G. (1982). Radio astronomy at Dover Heights. *Proceedings of the Astronomical Society of Australia*, *4*, 349–358.

Bolton, J.G., & Slee, O.B. (1953). Galactic radiation at radio frequencies. V. The sea interferometer. *Australian Journal of Physics*, *6*, 420–433.

Bolton, J.G., Stanley, G.J., & Slee, O.B. (1949). Positions of three discrete sources of galactic radio-frequency radiation. *Nature*, *164*, 101–102.

Bolton, J.G., Stanley, G.J., & Slee, O.B. (1954). Galactic radiation at radio frequencies. VIII. Discrete sources at 100 Mc/s between declinations +50° and −50°. *Australian Journal of Physics*, *7*, 110–129.

Bowen, E.G. (1984). The origins of radio astronomy in Australia. In W.T. Sullivan, pp. 85–111.

Burke, B.F., & Franklin, K.I. (1955). Observations of a variable radio source associated with the planet Jupiter. *Journal of Geophysical Research*, *60*, 213–217.

Christiansen, W.N. (1959). Development of highly directive aerials in radio astronomy. *Proceedings of the Institution of Radio Engineers Australia*, *20*, 519–528.

Christiansen, W.N. (1976). Taped interview with Woody Sullivan, 27 August. Tape and transcript in the Sullivan Collection, National Radio Astronomy Observatory Archives, Charlottesville (henceforth NRAO).

Christiansen, W.N. (1984). The first decade of solar radio astronomy in Australia. In W.T. Sullivan, pp. 113–131.

Christiansen, W.N., & Hindman, J.V. (1952). A preliminary survey of 1420 Mc/s. line emission from Galactic hydrogen. *Australian Journal of Scientific Research*, *A5*, 437–455.

Christiansen, W.N., Labrum, N.R., McAlister, K.R., & Mathewson, D.S. (1961). The cross-grating interferometer: a new high-resolution radio telescope. *Proceedings of the Institution of Electrical Engineers*, *108B*, 48–55.

Christiansen, W.N., & Mullaly, R.F. (1963). Solar observations at a wavelength of 20 cm with a crossed-grating interferometer. *Proceedings of the Institution of Radio Engineers Australia*, *24*, 165–173.

Christiansen, W.N., & Warburton, J.A. (1953). The distribution of radio brightness over the solar disk at a wavelength of 21 cm. Part I. A new highly directional aerial system. *Australian Journal of Physics*, *6*, 190–202.

Christiansen, W.N., & Warburton, J.A. (1955). The distribution of radio brightness over the solar disk at a wavelength of 21 cm. Part III. The Quiet Sun—two-dimensional observations. *Australian Journal of Physics*, *8*, 474–486.

Davies, R.D. (1954). An analysis of bursts of solar radio emission and their association with solar and terrestrial phenomena. *Monthly Notices of the Royal Astronomical Society*, *114*, 74–92.

Davies, R.D. (2008). A history of the Potts Hill radio astronomy field station. *Journal of Astronomical History and Heritage*, *8*, 87–96.

Davies, R.D. (2009). Recollections of two and a half years with 'Chris' Christiansen. Journal *of Astronomical History and Heritage*, *12*, 4–10.

Edge, D.O., & Mulkay, M.J. (1976). *Astronomy Transformed. The Emergence of Radio Astronomy in Britain*. New York: John Wiley.

Frame, T., & Faulkner, D. (2003). *Stromlo. An Australian Observatory*. Sydney: Allen and Unwin.

Frater, R.H., & Ekers, R.D. (2012). John Paul Wild 1923–2008. *Historical Record of Australian Science*, *23*, 212–227.

Frater, R.H., & Goss, W.M. (2011). Wilbur Norman Christiansen 1913–2007. *Historical Record of Australian Science*, *22*, 215–228.

Frater, R.H., Goss, W.M., & Wendt, H.W. (2013). Bernard Yarnton Mills 1920–2011. *Historical Records of Australian Science*, *24*, 294–315.

Gardner, F. (1973). Taped interview with Woody Sullivan, dated 21 February. Tape and transcript in the Sullivan Collection, NRAO.

Gardner, F.F., & Shain, C.A (1958). Further observations of radio emission from the planet Jupiter. *Australian Journal of Physics*, *11*, 55–69.

George, M., Orchiston, W., Slee, B., & Wielebinski, R. (2015). The history of early low frequency radio astronomy in Australia. 2: Tasmania. *Journal of Astronomical History and Heritage*, *18*, 14–22.

Goss, M. (2013). *Making Waves. The Story of Ruby Payne-Scott: Australian Pioneer Radio Astronomer*. New York: Springer.

Goss, M., & McGee, R.X. (2009). *Under the Radar: The First Woman in Radio Astronomy: Ruby Payne-Scott*. New York: Springer.

Haynes, R., Haynes, R., Malin, D., & McGee, R. (1996). *Explorers of the Southern Sky. A History of Australian Astronomy*. Cambridge: Cambridge University Press.

Hey, J.S., Parsons, S.J., & Phillips, J.W. (1946). Fluctuations in cosmic radiation at radio-frequencies. *Nature*, *158*, 234.

Hindman, J.V., McGee, R.X., Carter, A.W.L., Holmes, E.C.J., & Beard, M. (1963). A low-resolution hydrogen-line survey of the Magellanic system. I. Observations and digital reduction procedures. *Australian Journal of Physics*, *16*, 552–569.

Historic astronomy facility first to see black hole. *Canterbury-Bankstown Torch*, 6 May 2015.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Jarrell, R. (2005). "Radio astronomy, whatever that may be." The marginalization of early radio astronomy. In Orchiston (2005c), pp. 191–202.

Kellermann, K.I. (1996). John Gatenby Bolton (1922–1993). *Publications of the Astronomical Society of the Pacific*, *108*, 729–737.

Kellermann, K. (2005). Grote Reber (1911–2002). A radio astronomy pioneer. In W. Orchiston (2005c), pp. 43–70.

Kellermann, K.I., Orchiston, W., & Slee, B. (2005). Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia*, *22*, 13–23.

Kellermann, K., & Sheets, B. (Eds.), (1983). *Serendipitous Discoveries in Radio Astronomy*. Green Bank: National Radio Astronomy Observatory.

Kerr, F. (1971). Taped interview with Woody Sullivan, 3 October. Tape and transcript in the Sullivan Collection, NRAO.

Kerr, F.J. (1984). The early days in radio and radar astronomy in Australia. In W.T. Sullivan, pp. 133–145.

Kerr, F.J., & Shain, C.A. (1951). Moon echoes and transmission through the ionosphere. *Proceedings of the Institute of Radio Engineers, 39,* 230–242.

Kerr, F.J., & de Vaucouleurs, G. (1955). Rotation and other motions of the Magellanic Clouds from radio observations. *Australian Journal of Physics*, *8*, 508–521.

Kerr, F.J., Hindman, J.V., & Carpenter, M.S. (1957). The large-scale structure of the Galaxy. *Nature*, *180*, 677–679.

Kerr, F.J., Hindman, J.V., & Robinson, B.J. (1954). Observations of the 21 cm line from the Magellanic Clouds. *Australian Journal of Physics*, *7*, 297–314.

Kerr, F.J., & Westerhout, G. (1965). Distribution of interstellar hydrogen. In A. Blaauw, & M. Schmidt (Eds.), *Stars and Stellar Systems. Volume 5* (pp. 167–201). Chicago, University of Chicago Press.

Lehany, F.J. (1978). Taped interview with Woody Sullivan, 13 March. Tape and transcript in the Sullivan Collection, NRAO.

Lehany, F.J., & Yabsley, D.E. (1949). Solar radiation at 1200 Mc/s., 600 Mc/s., and 200 Mc/s. *Australian Journal of Scientific Research, 2,* 48–62.

Little, A.G., & Payne-Scott, R. (1951). The position and movement on the solar disk of sources of radiation at a frequency of 97 Mc/s. I. Equipment. *Australian Journal of Scientific Research*, *A4*, 489–507.

McCready, L.L., Pawsey, J.L., & Payne-Scott, R. (1947). Solar radiation at radio frequencies and its relation to sunspots. *Proceedings of the Royal Society of London*, *A190*, 357–375.

McGee, R.X., & Murray, J.D. (1963). A multi-channel hydrogen line (λ21 cm) receiver. *Proceedings of the Institution of Radio Engineers Australia*, *24*, 191–196.

McGee, R.X., Slee, O.B., & Stanley, G.J. (1955). Galactic survey at 400 Mc/s between declinations $-17°$ and $-49°$. *Australian Journal of Physics*, *8*, 347–367.

Melrose, D.B., & Minnett, H.C. (1998). Jack Hobart Piddington 1910–1997. *Historical Records of Australian Science*, *12*, 229–246.

Mills, B.Y. (1952). The distribution of discrete sources of cosmic radio radiation. *Australian Journal of Scientific Research*, *5*, 266–287.

Mills, B.Y. (1959). The radio continuum radiation from the Galaxy. *Publications of the Astronomical Society of the Pacific*, *71*, 267–291.

Mills, B.Y. (1963). Cross-type radio telescopes. *Proceedings of the Institution of Radio Engineers Australia*, *24*, 132–140.

Mills, B. (1976). Taped interview with Woody Sullivan, 25–26 August. Tape and transcript in the Sullivan Collection, NRAO.

Mills, B.Y. (1984). Radio sources and the log N –log S controversy. In W.T. Sullivan, pp. 147–165.

Mills, B.Y. (1988). Australian contribution to the science of radio astronomy. *Journal of Electrical and Electronic Engineering Australia*, *8*, 12–23.

Mills, B.Y., & Little, A.G. (1953). A high-resolution aerial system of a new type. *Australian Journal of Physics*, *6*, 272–278.

Mills, B.Y., Little, A.G., Sheridan, K.V., & Slee, O.B. (1958). A high resolution radio telescope for use at 3.5m. *Proceedings of the Institute of Radio Engineers*, *46*, 67–84.

Mills, B.Y., & Slee, O.B. (1957). A preliminary survey of radio sources in a limited region of the sky at a wavelength of 3.5m. *Australian Journal of Physics*, *10*, 162–194.

Milne, D.K., & Whiteoak, J.B. (2005). The impact of F.F. Gardner on our early research with the Parkes Radio Telescope. *Journal of Astronomical History and Heritage*, *8*, 33–38.

Orchiston, W. (1993). New Zealand's role in the identification of the first "radio stars". *Southern Stars*, *35*, 46–52.

Orchiston, W. (1994). John Bolton, discrete sources, and the New Zealand field trip of 1948. *Australian Journal of Physics*, *47*, 541–547.

Orchiston, W. (2001). Focus on the history of Australian radio astronomy. *ATNF News*, *45*, 12–15.

Orchiston, W. (2004a). From the solar corona to clusters of galaxies: the radio astronomy of Bruce Slee. *Publications of the Astronomical Society of Australia*, *21*, 23–71.

Orchiston, W. (2004b). Radio astronomy at the short-lived Georges Heights field station. *ATNF News*, *52*, 8–9.

Orchiston, W. (2004c). The rise and fall of the Chris Cross: a pioneering Australian radio telescope. In W. Orchiston et al., pp. 157–162.

Orchiston, W. (2004d). The 1948 solar eclipse and the genesis of radio astronomy in Victoria. *Journal of Astronomical History and Heritage*, 7, 118–121.

Orchiston, W. (2005a). Dr Elizabeth Alexander: first female radio astronomer. In Orchiston (2005c), pp. 71–92 (Reprinted in W. Orchiston 2016: Chapter 23).

Orchiston, W. (2005b). Sixty years in radio astronomy: a tribute to Owen Bruce Slee. *Journal of Astronomical History and Heritage*, *8*, 3–10.

Orchiston, W. (Ed.), (2005c). *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of planet Earth. A Meeting to Honor Woody Sullivan on his 60th Birthday*. Dordrecht: Springer.

Orchiston, W. (2011). Norman Labrum. IAU Historic Radio Astronomy Working Group web site: http://rahist.nrao.edu/labrum_bio-memoir.shtml

Orchiston, W., (2012). The Parkes 18-m Antenna: a brief historical evaluation. *Journal of Astronomical History and Heritage*, *15*, 96–99.

Orchiston, W. (2014a). Mills, Bernard Yarnton. In T. Hockey, et al., pp. 1482–1484.

Orchiston, W. (2014b). Minnett, Harry Clive. In T. Hockey, et al., pp. 1495–1496.

Orchiston, W. (2014c). Piddington, Jack Hobart. In T. Hockey, et al., pp. 1714–1715.

Orchiston, W. (2014d). Smerd, Stefan Friedrich. In T. Hockey, et al., pp. 2019–2020.

Orchiston, W. (2016). *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits*. New York: Springer.

Orchiston, W., & Kellermann, K.I. (2008). Bolton, John Gatenby. In *Dictionary of Scientific Biography* (pp. 332–337). New York: Gale.

Orchiston, W., & Mathewson, D. (2009). Chris Christiansen and the Chris Cross. *Journal of Astronomical History and Heritage*, *12*, 11–32.

Orchiston, W., & Slee, B. (2002a). The Australasian discovery of solar radio emission. *AAO Newsletter*, *101*, 25–27.

Orchiston, W., & Slee, B. (2002b). The flowering of Fleurs: an interesting interlude in Australian radio astronomy. *ATNF News*, *47*, 12–15.

Orchiston, W., & Slee, B. (2002c). Ingenuity and initiative in Australian radio astronomy: the Dover Heights hole-in-the-ground antenna. *Journal of Astronomical History and Heritage*, *5*, 21–34.

Orchiston, W., & Slee, B. (2002d). The Dover Heights 'hole-in-the-ground' radio telescope. *AAO Newsletter*, *99*, 26–27.

Orchiston, W., & Slee, B. (2005a). The Radiophysics field stations and the early development of radio astronomy. In W. Orchiston (2005c), pp. 119–168.

Orchiston, W., & Slee, B. (2005b). Shame about Shain! Early Australian radio astronomy at Hornsby Valley. *ATNF News*, *55*, 14–16.

Orchiston, W., & Slee, B. (2006). Early Australian observations of historic supernova remnants at radio wavelengths. In K.-Y. Chen, W. Orchiston, B. Soonthornthum, & R. Strom (Eds.), *Proceedings of the Fifth International Conference on Oriental Astronomy* (pp. 43–56). Chiang Mai, University of Chiang Mai.

Orchiston, W., Chapman, J., & Norris, B. (2004a). The ATNF Historic Photographic Archive: documenting the history of Australian radio astronomy. In W. Orchiston, et al., pp. 41–48.

Orchiston, W., Nakamura, T., & Strom, R. (Eds.), (2011). *Highlighting the History of Astronomy in the Asia-Pacific Region*. *Proceedings of the ICOA-6 Conference*. New York: Springer.

Orchiston, W., Slee, B., & Burman, R. (2006). The genesis of solar radio astronomy in Australia. *Journal of Astronomical History and History*, *9*, 35–56.

Orchiston, W., George, M., Slee, B., & Wielebinski, R. (2015a). The history of early low frequency radio astronomy in Australia. 1: The CSIRO Division of Radiophysics. *Journal of Astronomical History and Heritage*, *18*, 3–13.

Orchiston, W., George, M., Slee, B., & Wielebinski, R. (2017). Early low frequency radio astronomy in Australia. In Y.-L. Shi (Ed.), *Astronomical Heritages in Asia-Pacific Areas: Proceedings of the Eighth International Conference on Oriental Astronomy*. Hefei: University of Science and Technology of China.

Orchiston, W., Slee, B., George, M., & Wielebinski, R. (2015b). The history of early low frequency radio astronomy in Australia. 4: The Kerr, Shain, Higgins and the Hornsby Valley field station near Sydney. *Journal of Astronomical History and Heritage*, *18*, 285–311.

Orchiston, W., Stephenson, R., Débarbat, S., & Nha, I.-S. (Eds.), (2004b). *Astronomical Instruments and Archives from the Asia-Pacific Region*. Seoul: Yonsei University Press.

Pawsey, J.L. (1950). Solar radio-frequency radiation. *Proceedings of the Institution of Electrical Engineers*, *97*, 290–310.

Pawsey, J.L. (1951). [Note.] *Nature*, *168*, 358.

Pawsey, J.L. (1953). Radio astronomy in Australia. *Journal of the Royal Astronomical Society of Canada*, *47,* 137–152.

Pawsey, J.L, (1961). Australian radio astronomy. *Australian Scientist*, *1*(3), 181–186.

Pawsey, J.L., & Bracewell, R.N. (1955). *Radio Astronomy*. Oxford: Clarendon Press.

Pawsey, J.L., & Hill, E.R. (1961). Cosmic radio waves and their interpretation. *Reports on Progress in Physics*, *24*, 69–115.

Pawsey, J.L., Payne-Scott, R., & McCready, L.L. (1946). Radio-frequency energy from the Sun. *Nature*, *157*, 158–159.

Pawsey, J.L., & Smerd, S.F. (1953). Solar radio emission. In G.P. Kuiper (Ed.), *The Solar System Volume 1. The Sun* (pp. 466–531). Chicago: University of Chicago Press.

Payne-Scott, R. (1945). Solar and cosmic radio frequency radiation. Survey of knowledge available and measurements taken at Radiophysics Lab. to Dec. 1st 1945. Sydney, CSIR, Radiophysics Division (Report SRP 501/27).

Payne-Scott, R. (1978). Taped interview with Woody Sullivan, dated 3 March. Tape and transcript in the Sullivan Collection, NRAO.

Payne-Scott, R., Yabsley, D.E., & Bolton, J.G. (1947). Relative times of arrival of bursts of solar noise at different radio frequencies. *Nature*, *160*, 256–257.

Pick, M., Steinberg, J.-L., Orchiston, W., & Boischot, A. (2011). Highlighting the history of French radio astronomy. 6: The multi-element grating arrays at Nançay. *Journal of Astronomical History and Heritage*, *14*, 57–77.

Piddington, J.H., & Minnett, H.C. (1951). Observations of Galactic radiation at frequencies of 1210 and 3000 Mc/s. *Australian Journal of Scientific Research*, *A4*, 459–475.

Piddington, H.H., & Trent, G.H. (1956). A survey of cosmic radio emission at 600 Mc/s. *Australian Journal of Physics*, *9*, 481–493.

Reber, G., (1944). Cosmic static. *Astrophysical Journal*, *100*, 279–287.

Robertson, P. (1992). *Beyond Southern Skies. Radio Astronomy and the Parkes Radio Telescope*. Cambridge: Cambridge University Press.

Robertson, P., Cozens, G., Orchiston, W., & Slee, B. (2010). Early Australian optical and radio observations of Centaurus A. *Publications of the Astronomical Society of Australia*, *27*, 402–430.

Robertson, P., Orchiston, W., & Slee, B. (2014). John Bolton and the discovery of discrete radio sources. *Journal of Astronomical History and Heritage*, *17*, 283–306.

Shain, C.A. (1956). 18.3 Mc/s radiation from Jupiter. *Australian Journal of Physics*, *9*, 61–73.

Shain, C.A. (1957). Galactic absorption of 19.7 Mc/s radiation. *Australian Journal of Physics*, *10*, 195–203.

Shain, C.A. (1958). The Sydney 19.7 Mc/s radio telescope. *Proceedings of the Institute of Radio Engineers*, *46*, 85–88.

Shain, C.A., & Higgins, C.S. (1954). Observations of the general background and discrete sources of 18.3 Mc/s cosmic noise. *Australian Journal of Physics, 7,* 130–149.

Sheridan, K.V. (1963). Techniques for the investigation of solar radio bursts at metre wavelengths. *Proceedings of the Institution of Radio Engineers Australia*, *24*, 174–184.

Slee, O.B. (1961). Observations of the solar corona out to 100 solar radii. *Monthly Notices of the Royal Astronomical Society*, *123*, 223–231.

Slee, B. (1994). Some memories of the Dover Heights field station, 1946–1954. *Australian Journal of Physics*, *47*, 517–534.

Slee, O.B. (2005). Early Australian measurements of angular structure in discrete radio sources. *Journal of Astronomical History and Heritage*, *8*, 97–116.

Slee, O.B., Higgins, C.S., & Patston, G.E. (1963a). Visual and radio observations of flare stars. *Sky and Telescope*, *25*, 83–86.

Slee, O.B., Solomon, L.H., & Patston, G.E. (1963b). Radio emission from flare star V371 Orionis. *Nature*, *199*, 991–993.

Smerd, S.F. (1964). Solar radio emissions. In *Research in Geophysics. Volume 1: Sun, Upper Atmosphere, and Space* (pp. 65–97). Cambridge: Massachusetts Institute of Technology.

Smerd, S. (1978). Taped interview with Woody Sullivan, dated 6 March. Tape and transcript in Sullivan Collection, NRAO.

Stanley, G.J. (1974). Taped interview with Woody Sullivan, dated 13 June. Tape and transcript in Sullivan Collection, NRAO.

Stanley, G.J., & Slee, O.B. (1950). Galactic radiation at radio frequencies. II. The discrete sources. *Australian Journal of Scientific Research*, *A3*, 234–250.

Stewart, R., Orchiston, W., & Slee, B. (2011b). The contribution of the Division of Radiophysics Dapto field station to solar radio astronomy, 1952–1964. In W. Orchiston et al., pp. 481–526.

Stewart, R., Orchiston, W., & Slee, B. (2011c). The Sun has set on a brilliant mind: Paul Wild (1923–2008). In Orchiston et al., pp. 527–542.

Stewart, R., Wendt, H., Orchiston, W., & Slee, B. (2010a). Highlighting our history: the world's first solar radiospectrograph—Penrith 1948–1949. *ATNF News*, *68*, 8–11.

Stewart, R., Wendt, H., Orchiston, W., & Slee, B. (2010b). The Radiophysics field station at Penrith, New South Wales, and the world's first solar radiospectrograph. *Journal of Astronomical History and Heritage*, *13*, 2–15.

Stewart, R., Wendt, H., Orchiston, W., & Slee, B., (2011a). A retrospective view of Australian solar radio astronomy 1945 to 1960. In Orchiston et al., pp. 589–629.

Strom, R. (2005). Radio astronomy in Holland before 1960: just a bit more than HI. In W. Orchiston (2005c), pp. 93–106.

Sullivan, W.T. III (1984). *The Early Years of Radio Astronomy*. Cambridge: Cambridge University Press.

Sullivan, W.T. III (1988). The early years of Australian radio astronomy. In R. Home (Ed.), *Australian Science in the Making* (pp. 308–344). Cambridge: Cambridge University Press.

Sullivan, W.T. III (2005). The beginnings of Australian radio astronomy. *Journal of Astronomical History and Heritage*, *8*, 11–32.

Sullivan, W.T. III (2009). *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge: Cambridge University Press.

Swarup, G. (2006). From Potts Hill (Australia) to Pune (India): the journey of a radio astronomer. *Journal of Astronomical History and Heritage*, *9*, 21–33.

Swarup, G. (2008). Reminiscences regarding Professor W.N. Christiansen. *Journal of Astronomical History and Heritage*, *11*, 194–202.

Thomas, B.MacA., & Robinson, B.J. (2005). Harry Clive Minnett 1917–2003. *Historical Records of Australian Science*, *16*, 199–220.

Wendt, H., Orchiston, W., & Slee, B. (2008a). The Australian solar eclipse expeditions of 1947 and 1949. *Journal of Astronomical History and Heritage*, *11*, 71–78.

Wendt, H., Orchiston, W., & Slee, B. (2008b). W.N. Christiansen and the development of the solar grating array. *Journal of Astronomical History and Heritage*, *11*, 173–184.

Wendt, H., Orchiston, W., & Slee, B. (2008c). W.N. Christiansen and the initial Australian investigation of the 21cm hydrogen line. *Journal of Astronomical History and Heritage*, *11*, 185–193.

Wendt, H., Orchiston, W., & Slee, B. (2011a). An overview of W.N. Christiansen's contribution to Australian radio astronomy, 1948–1960. In Orchiston et al., pp. 547–587.

Wendt, H., Orchiston, W., & Slee, B. (2011b). The contribution of the Division of Radiophysics Murraybank field station to international radio astronomy. In Orchiston et al., pp. 433–479.

Wendt, H., Orchiston, W., & Slee, B. (2011c). The contribution of the Division of Radiophysics Potts Hill field station to international radio astronomy. In Orchiston et al., pp. 379–431.

Whiteoak, J.B., & Sim, H.L. (2006). Brian John Robinson 1930–2004. *Historical Records of Australian Science*, *17*, 263–281.

Wild, J.P. (1953). Techniques for observation of radio-frequency radiation from the Sun. In G.P. Kuiper (Ed.), *The Solar System. Volume 1. The Sun* (pp. 676–692). Chicago: University of Chicago Press.

Wild, J.P. (Ed.) (1967). The Culgoora Radioheliograph. *Proceedings of the Institution of Radio and Electronic Engineers Australia*, *28*.

Wild, J.P., & McCready, L.L. (1950). Observations of the spectrum of high-intensity solar radiation at metre wavelengths. Part 1. The apparatus and spectral types of solar bursts observed. *Australian Journal of Scientific Research*, *3*, 387–398.

Wild, J.P., & Radhakrishnan, V.R. (1994). John Gatenby Bolton 1922–1993. *Historical Record of Australian Science*, *10*, 381–391.

Wild, J.P., & Sheridan, K.V. (1958). A swept-frequency interferometer for the study of high-intensity solar radiation at meter wavelengths. *Proceedings of the Institute of Radio Engineers*, *46*, 160–171.

Wild, J.P., Smerd, S.F., & Weiss, A.A. (1963). Solar bursts. *Annual Review of Astronomy and Astrophysics*, *1*, 291–366.

Part VIII
New Zealand

Chapter 20
The Development of Astronomy and Emergence of Astrophysics in New Zealand

John Hearnshaw and Wayne Orchiston

20.1 Introduction: New Zealand's Astronomical Heritage

Few nations can claim that astronomy played a pivotal role in their founding and history. But New Zealand can be proud that astronomy was one of the principal motivations which led to the exploration of this land, and its eventual settlement by Europeans. For when Lieutenant James Cook first came to New Zealand in 1769, it was the observation of a transit of Venus that was one of the reasons for his being sent by the Royal Society of London to the south Pacific. Very probably, though less well chronicled, astronomy also played an important role for the Polynesian settlement of New Zealand some hundreds of years before Cook. For astro-navigation may have been an important element that allowed the Māori to make the long sea voyage across the Pacific that ended in their initial settlement of Aotearoa (the Māori name for New Zealand), around 800 years ago.

For New Zealand localities mentioned in this chapter see Fig. 20.1.

20.2 Cook's Voyages and the Transit of Venus

In 1769 the Royal Society organized an expedition to the South Seas for the purpose of making observations of the transit of Venus across the Sun, a rare event which had occurred in 1761 and was to occur again in 1769. Observations of the timing of

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Fig. 20.1 Map of New Zealand showing places mentioned in this chapter (*Map* Wayne Orchiton)

this event at different locations on Earth were known in principle to give the absolute dimensions of the Solar System, including the value of the astronomical unit in miles or kilometres. Lieutenant James Cook (1728–1779) and his fellow-astronomer Charles Green (1734–1771) on the *Endeavour* duly observed the transit from Tahiti on 3 June 1769. Analysis of the data was not however very successful in the aim of calibrating the astronomical unit.

Cook then sailed on to New Zealand, and here the major task of mapping the New Zealand coastline ensued (see Fig. 20.2). With Green he made important observations from Mercury Bay on the Coromandel peninsula, where they observed a transit of Mercury. Cook and Green therefore can be regarded as the first professional astronomers to work in New Zealand. Sadly Green became ill on the return voyage to Cape Town and died in January 1771 before his arrival back in England.

Later, on the second (1773–1774) and third (1777) expeditions, extensive astronomical observations for determining latitude and longitude using precise Kendall chronometers (Fig. 20.3) were made by Cook and his astronomers from Dusky Sound (in the SW of the South Island) and from Ship Cove in Queen Charlotte Sound (the northern tip of the South Island). William Wales (1734–1798; 2nd voyage), William Bayly (1737–1810; 2nd and 3rd voyages) and James King (1750–1784; 3rd voyage) were the accompanying astronomers, and Cook also served as an astronomer on the 3rd voyage (just as he had done on the 1st voyage).

More information on this early nautical astronomical history of New Zealand can be found in the monograph: *Nautical Astronomy in New Zealand*, published by the Carter Observatory Board (Orchiston 1998b) and in the recent book *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits* (Orchiston 2016: Chapters 4, 5 and 6). There also are papers by George Eiby (1970) and Wayne Orchiston (2005, 2017a) on Cook's voyages that discuss the transit of Venus observations in some detail.

20.3 Māori Astronomy

The Māori from early times have developed some astronomical knowledge which is closely entwined with Māori mythology. Certainly the Māori recognized several constellations or stellar patterns in the sky, the brighter planets as well as the Sun and the Moon. The Pleiades, *Matariki* (Fig. 20.4) plays a key role in determining the beginning of the Māori new year when this star cluster is seen to rise just before dawn. The extent to which the Māori used the stars for navigation on their long voyages is uncertain, but may have been of some importance. What is certain is that the Māori have developed a rich mythology based on *Rangi* (sky father), *Papa* (the Earth mother) and their progeny of *Te Ra* (the Sun), *Te Marama* (the Moon) and *Nga Whetu* (the stars), and that they understood the relationship of celestial phenomena to the seasons on the land and the growing of crops.

The standard early reference on Māori astronomy is Elsdon Best's *The Astronomical Knowledge of the Maori* (Best 1922). Also one can refer to a paper by

Fig.20.2 A map of New Zealand based on coastal mapping carried out during Cook's first voyage (after Hawkesworth 1774)

Kingsley-Smith (1967) on Māori star lore, *The Illustrated Encyclopedia of Māori Myth and Legend* by Margaret Orbell (1995), and *Exploring the History of New Zealand Astronomy* … (Orchiston 2016: Chapters 2 and 3).

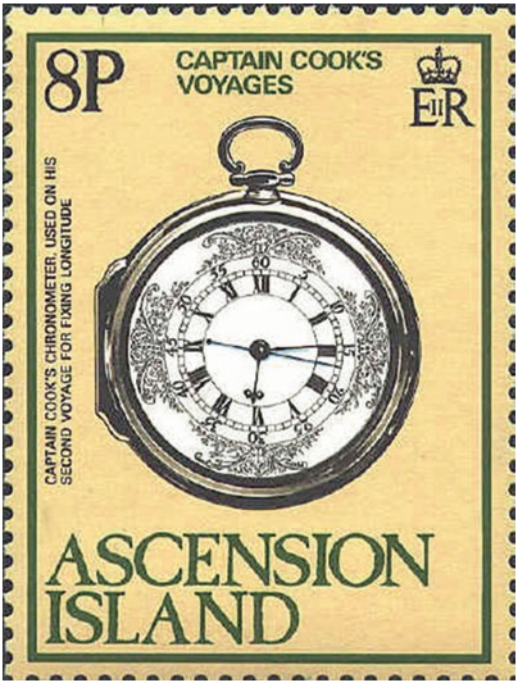


Fig. 20.3 The K1 chronometer by Larcum Kendall, which was used with great success on Cook's second voyage, features on this postage stamp (http://sio.midco.net/dansmapstamps/jamescook2.html)

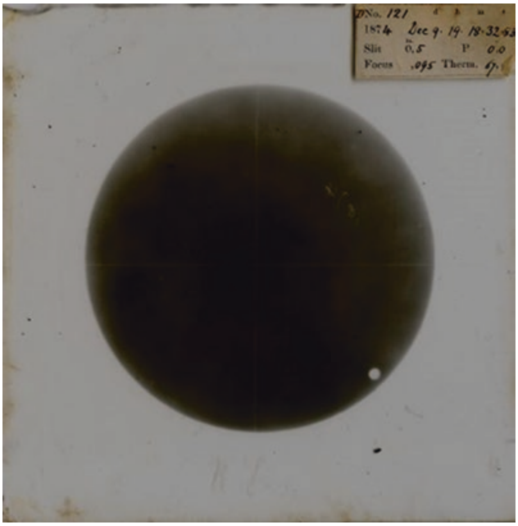
20.4 The Transits of Venus of 1874 and 1882, and the Total Solar Eclipse of 1885

The link between New Zealand and transits of Venus became once again an important part of our astronomical history for the next pair of transits after Cook. These were in December 1874 and December 1882, and in both cases observable from New Zealand. An American expedition to Queenstown in 1874 is well documented, and was one of seven expeditions sent into the Pacific from the U.S. Naval Observatory in Washington (see Dick et al. 1998). A total of 237 photographs were obtained of the transit from Queenstown. Another expedition from USNO went to the Chatham Islands. Once again, the calibration of the scale of the Solar System was the prime motivation. A British expedition to Burnham near Christchurch had cloud for the transit, but did succeed in obtaining a few useful photographs (e.g., see Fig. 20.5).

Further expeditions were mounted for the 1882 transit, the British again going to Burnham and the Americans to Auckland. Several amateur astronomers in New Zealand also observed this event. *Exploring the History of New Zealand Astronomy* (Orchiston 2016: Chapters 14 and 15) has details of all of the New Zealand 1874 and 1882 observations. Also refer to Tobin (2012) and a paper on early New Zealand astronomy by Ronald McIntosh (1970).

Fig. 20.4 This photograph, which was taken by John Drummond of Patutahi, shows *Matariki* (No. 1) and *Tautoro*, the three stars in Orion's Belt (No. 2), the two asterisms that were associated with Māori *kumara* cultivation. Also shown in this photograph are three 'high-born' Māori stars, *Puanga* (Rigel, No. 3), *Putara* (Betelgeuse, No. 4) and *Taumata Kuku* (Aldebaran, No. 5) (*Photograph revision* Wayne Orchiston)

Fig. 20.5 A negative of one of the few successful photographs of the transit taken at Burnham (*Courtesy* STFC and J. Ratcliff)



After the public euphoria generated by the two transits of Venus came the 9 September 1885 total solar eclipse. This was the first total solar eclipse visible from New Zealand following European settlement. By good fortune the sky was clear on the vital day, and since the path of totality fortuitously crossed the middle of the country this allowed those in towns like Collingwood, Motueka, Nelson, Picton, Wellington, Masterton, Woodville, Dannevirke, Otaki, Palmerston North and Wanganui to witness the eclipse. While many thousands enjoyed an unforgettable experience, New Zealand astronomers also observed it in the hope of making a contribution to international solar physics. The 'public face' of this eclipse is reviewed in *Exploring the History of New Zealand Astronomy* … (Orchiston 2016: Chapter 16) while the scientific investigation of it by New Zealand professional and amateur astronomers is discussed in Chap. 22 in this book (Orchiston and Rowe 2017).

20.5 Notable Early Amateur Astronomers

New Zealand has an illustrious history of distinguished amateurs who have made excellent observations at their home observatories. John Grigg (1838–1920; Fig. 20.6) was one such early amateur. He was born in London, migrated to New Zealand in 1863, established a music shop in Thames and built himself an observatory there in 1884 and became an avid comet-hunter. He was the discoverer or co-discoverer of three comets that bear his name, in 1902, 1903 and 1907, and he was one of the first to undertake astro-photography in New Zealand. More details are provided in *Exploring the History of New Zealand Astronomy* … (Orchiston 2016: Chapters 10, 17 and 22).

Fig. 20.6 John Grigg, FRAS (Orchiston Collection)

Fig. 20.7 Joseph Ward and his 20.5-in. (52.1-cm) equatorially mounted reflector, along with a 6-in. (15-cm) reflector that he made for sale (*Courtesy*: Ward (Wanganui) Observatory Archives)

Others followed, taking advantage of the clear unpolluted southern skies and the spirit of do-it-yourself innovation that prevailed in the early colony. Thus Henry Skey (1836–1914) in Dunedin (Campbell 2001), Thomas King (1858–1916) in Wellington (Seymour 1995), Arthur Atkinson (1833–1902) in Nelson, James Townsend (1815–1894) in Christchurch and Arthur Beverly (1822–1907) in Dunedin were all notable amateurs who equipped their private observatories with small telescopes, and many of these were inspired by the 1882 transit of Venus to take up and further pursue astronomy. *Nautical Astronomy in New Zealand* (Orchiston 1998b) provides excellent reference material.

New Zealand even had an accomplished optician and telescope-maker in Joseph Ward (1862–1927), who helped to establish the Ward Observatory in Wanganui, and whose telescopes included a 20.5-in. (52.1-cm) Newtonian reflector (built 1924), which for many years was the largest telescope in New Zealand (Fig. 20.7). Two papers on Ward have appeared in *Southern Stars*: one is by Calder (1978), the other by Orchiston (2002; and a revised version of this is in his 2016 book, *Exploring the History of New Zealand Astronomy* … as Chapter 12).

20.6 The First Professional Astronomers

In 1863 the first 'official' observatory was established by the Wellington Provincial Government. Archdeacon Arthur Stock (1823–1901; Fig. 20.8) was put in charge and, equipped with clocks and a transit telescope, he was able to provide a time service and he operated a time ball from the Custom House on Queen's Wharf. By 1868 this became the Colonial Time-service Observatory with Sir James Hector, the noted geologist, as Director and Stock as the Astronomical Observer. Stock was New Zealand's first resident professional astronomer, and for more on him see *Exploring the History of New Zealand Astronomy* … (Orchiston 2016: Chapter 9) and also Eiby (1977), Hayes (1987) and Orchiston (2017b).

Thomas King (1858–1916) succeeded Stock, and Dr. C.E. Adams (1870–1945; Fig. 20.9) succeeded King in 1911. Adams distinguished himself as a computer of cometary orbits as well as an observer. The Colonial Observatory was resited in Kelburn in 1907 and known then as the Hector Observatory. The Hector Observatory was renamed the Dominion Observatory in 1926.

Professional astronomers were not numerous in early New Zealand, but two other individuals of note deserve mention. Professor Alexander William Bickerton (1842–1929) was foundation Professor of Chemistry and Physics at Canterbury University College in Christchurch from 1874 until he was fired by the College Council in 1902, ostensibly for poor management. Bickerton was a brilliant but unorthodox lecturer, whose star pupil was Ernest Rutherford. But he had a bizarre and largely untenable theory (the 'partial impact theory', as he called it) on stellar collisions as the origin of variable stars, including novae (Fig. 20.10), and for the origin of the Solar System. These theories led to his papers being shunned and discredited by the professional astronomical community in England. More on this

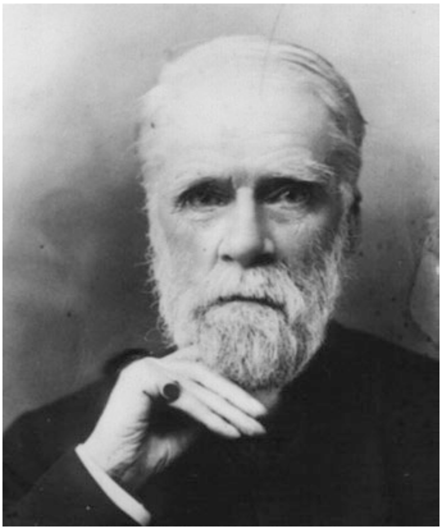


Fig. 20.8 (*left*) Archdeacon Arthur Stock, the Astronomical Observer at the Provincial and later Colonial Observatory (after Eiby 1977)

Fig. 20.9 (*right*) Dr. C.E. Adams, New Zealand's first 'Government Astronomer' (Orchiston Collection)

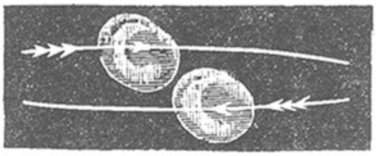
colourful character is to be found in a paper by Gerry Gilmore (1982), and in this book in Chap. 21 (Gilmore 2017). There is also a biography by R.M. Burdon (1956).

A.C. (Charles) Gifford (1861–1948; Fig. 20.11), who studied astronomy at Cambridge University and later taught mathematics at Wellington College, was also a keen astronomer and he had access to one of the best-equipped New Zealand school observatories. His theories of the origin of the lunar craters by meteorite impact were published in 1924 and 1930, and were an early exposition of what is now recognized as the correct interpretation of the lunar landscape (Hoyt 1987). The College acquired a 5-in. (12.7-cm) Zeiss refractor in 1924, and this was fully restored in 2002 after falling into disrepair. For further information about Gifford's astronomical activities see Orchiston (1996, 1998a).

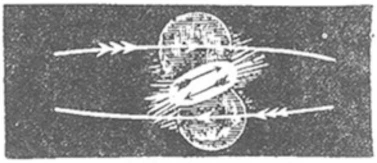
When the Carter Observatory was founded in 1941, Murray Geddes (1909–1944) was appointed the first Director. However he never formally took up this position, being called away on war service and he did not return to New Zealand (Williams 2014). Ivan Thomsen (1910–1969) was his successor from 1946 to 1969. He had previously worked under C.E. Adams at the Dominion Observatory.

20.7 New Zealand Amateur Astronomers in the Twentieth Century

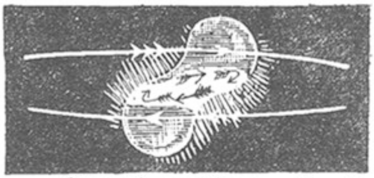
The fine tradition of amateur astronomy in New Zealand continued throughout the twentieth century and up until the present time. This review mentions just three of some distinction among the many who have pursued astronomy as a hobby.



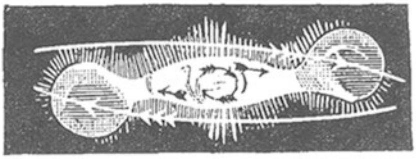
Pair of stars distorted and coming into impact



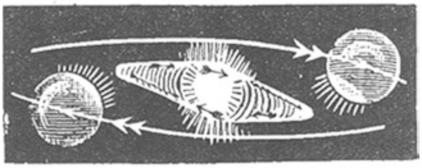
Pair of stars in impact.



Stars passing out of impact, and formation of third body.



Showing entanglement of matter in each body.



Two variables and a temporary star.

Fig. 20.10 The ‘Partial Impact Theory’ that Bickerton used to explain the formation of novae and other variable stars (after Gilmore 1982: 95)

One was Ronald McIntosh (1904–1977; Fig. 20.12), who became a distinguished meteor observer. In 1935 he published his *Index to southern meteor showers* (McIntosh 1935). He also monitored meteor rates and analysed the methods of obtaining meteor orbits from the observed path. McIntosh published mainly in the *Monthly Notices of the Royal Astronomical Society* in London, he directed the Meteor Section of the Royal Astronomical Society of New Zealand, and for a time he also directed the Auckland Planetarium. His achievements in these and various other areas of astronomy are discussed in *Exploring the History of New Zealand Astronomy* … (Orchiston 2016: Chapter 19).

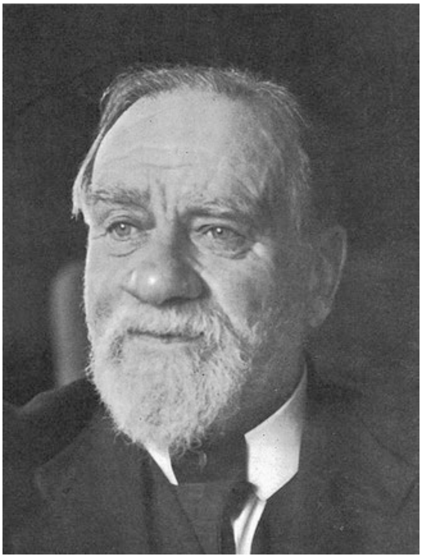


Fig. 20.11 A.C. Gifford (after Jenkinson 1940: f. 136)

Fig. 20.12 (*left*) Ronald McIntosh (Orchiston Collection)

Frank Bateson (1909–2007) in Tauranga was another distinguished New Zealand astronomer. He founded the Variable Star Section (VSS) of the New Zealand Astronomical Society (later the Royal Astronomical Society of New Zealand) in 1927 and directed it from that time almost until his death 80 years later. Not only was he a prodigious observer of variable stars, but his VSS of R.A.S.N.Z. collated observations from dozens of other observers in New Zealand and overseas (Bateson 2001). This great body of material has resulted in the publication of charts, circulars and publications containing visual observations of many stars. Dwarf novae, novae and Mira stars were all studied in much detail, and the fact that many variables had data collected in a continuous record going back six or seven decades has provided an invaluable data resource for many professional astronomers. As a result, Frank Bateson is widely respected amongst professional astronomers world-wide, and he was honoured in New Zealand with an OBE (1970) and an honorary doctorate from Hamilton's Waikato University (1979). Frank Bateson was also instrumental in establishing Mt. John University Observatory in the early 1960s, when he conducted an extensive site-testing campaign on behalf of the University of Pennsylvania to determine the best location for a new professional observatory (Bateson 1964). As a result Mt. John was chosen, and Frank became the first astronomer-in-charge in 1965, and remained there until his retirement in 1970. Tributes to Frank Bateson can be found in an editorial by Ed Budding (1989) in *Southern Stars*, followed by an article by Albert Jones (1989) in the same volume, and in an essay by Grant Christie (2014) in the latest edition of the *Biographical Encyclopedia of Astronomers*. Frank has described the VSS in *Southern Stars* 40, (no. 3), 7 (2001).

Finally Albert Jones (1920–2013; Fig. 20.13), who lived in Nelson, was the world's most prolific observer of variable stars. Since the early 1940s he amassed over half a million visual observations, in some years as many as 13,000 annually, and his magnitude estimates were distinguished by exceptional reliability and precision. Albert Jones was a co-discoverer of the famous supernova 1987A in the Large Magellanic Cloud and he discovered a comet in 1946 and co-discovered another comet in 2000. He too was awarded an OBE (1987), and he received an honorary D.Sc. from Victoria University of Wellington (in 2004) and many international awards for his work. A tribute to Albert Jones is to be found in Rod Austin's paper in *Southern Stars* (Austin 1994), and recently a detailed biographical account of him was published in the *Journal of British Astronomical Association* (Toone 2016).

Fig. 20.13 (*right*) Albert Jones on 15 June 2012 at age 91 (*Photograph* Wayne Orchiston)

20.8 Some Significant Early Telescopes in New Zealand

New Zealand has been fortunate to acquire some remarkable old telescopes by famous manufacturers in America and Great Britain. Most of them came here as a result of the amateur astronomers in New Zealand. A selection based on aperture and pedigree is mentioned here.

One of the oldest astronomical telescope of international importance in New Zealand is a 5-in. (12.7-cm) Gregorian reflector in The Museum of New Zealand Te Papa Tongarewa. This was made during the 1750s or 1760s by the prominent London firm of scientific instrument-makers, Heath and Wing, and has been identified (Orchiston 2016: Chapter 7) as the telescope that Daniel Solander used at Fort Venus, Tahiti, to observe the 1769 transit of Venus, when in the company of Cook and Green.

Thomas Cooke (1807–1868) of York, England, was one of the most famous telescope makers and opticians in Britain in the 1860s. Several New Zealand telescopes are of Cooke manufacture. The largest and oldest of these telescopes in original working order is the Ward Observatory Cooke refractor of 9.5 in. aperture in Wanganui (Fig. 20.14). The telescope's optics were made between 1859 and 1860, and the instrument was purchased for the Wanganui City Observatory (later renamed the Ward Observatory) in 1903. Joseph Ward (1862–1927) was the first observer

Fig. 20.14 The Wanganui Cooke telescope and mounting photographed when it was still in England (*Courtesy*: Ward (Wanganui) Observatory Archives)

with this telescope. The instrument is described in articles by C.T. Harper et al. (1990) and by G.R. Nankivell (1994), while in his *Exploring the History of New Zealand Astronomy* … Orchiston (2016: Chapter 11) draws attention to the international importance of this telescope given that it boasts the first all-metal English equatorial mounting ever made. In museum parlance, this is a 'type specimen'.

Another Cooke telescope of almost the same size (originally 9.33 in. (23.7 cm), later 9 in. (22.9 cm) from 1896) was built in York in 1866–1867 for the well-known English amateur, Edward Crossley (1841–1905; Andrews and Budding 1992). This telescope came to New Zealand in 1907 through the initiative of the Reverend Dr. David Kennedy (1864–1936) and was installed by him in the Meeanee Observatory, at the Roman Catholic seminary near Napier, where it was used to photograph comets and the Sun (e.g. see Fig. 20.15). In the mid-1920s the Wellington City Council purchased it from the Seminary and erected it in a public observatory in the Wellington Botanic Garden. By 1942 the telescope was installed in the newly opened Carter Observatory in Kelburn. It received its third objective lens in 2001, fabricated by New Zealand's outstanding optical engineer, Garry Nankivell (1929–2001). This was 9.75 in. in aperture (24.8 cm), so now slightly exceeds the aperture of the Ward telescope in Wanganui (Nankivell 2002, Rumsey 2002). A detailed account of this historic telescope, including the contributions that it made to astronomical research in England and New Zealand is presented in *Exploring the History of New Zealand Astronomy* … (Orchiston 2016: Chapter 13).

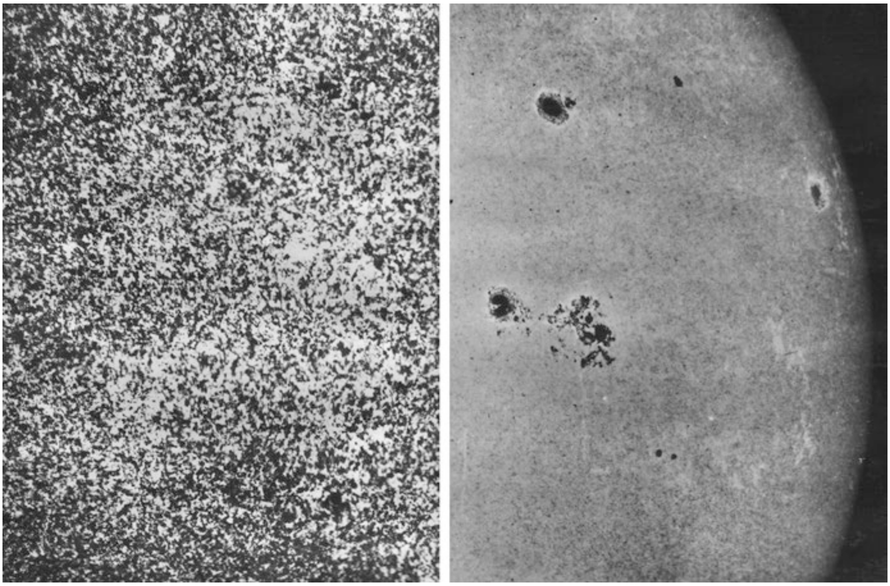


Fig. 20.15 These outstanding photographs of granulation (*left*) and sunspots and faculae (*right*) were taken with the Cooke refractor while it was at Meeanee (after *Astronomical Photographs* … n.d.)

The largest refracting telescope in New Zealand came here in 1963. It is the 18-in. (45.7-cm) refractor by the distinguished American optician John Brashear (1840–1920), which was formerly erected at the Flower Observatory of the University of Pennsylvania (Fig. 20.16). This telescope dates from 1897, though the Brashear optics are a few years older. It was to have been installed at Mt. John, but funds for the building were never realized. Now there are plans to donate this famous old telescope to an astronomy centre near Mt. John at Lake Tekapo for public outreach (Hearnshaw 2009a).

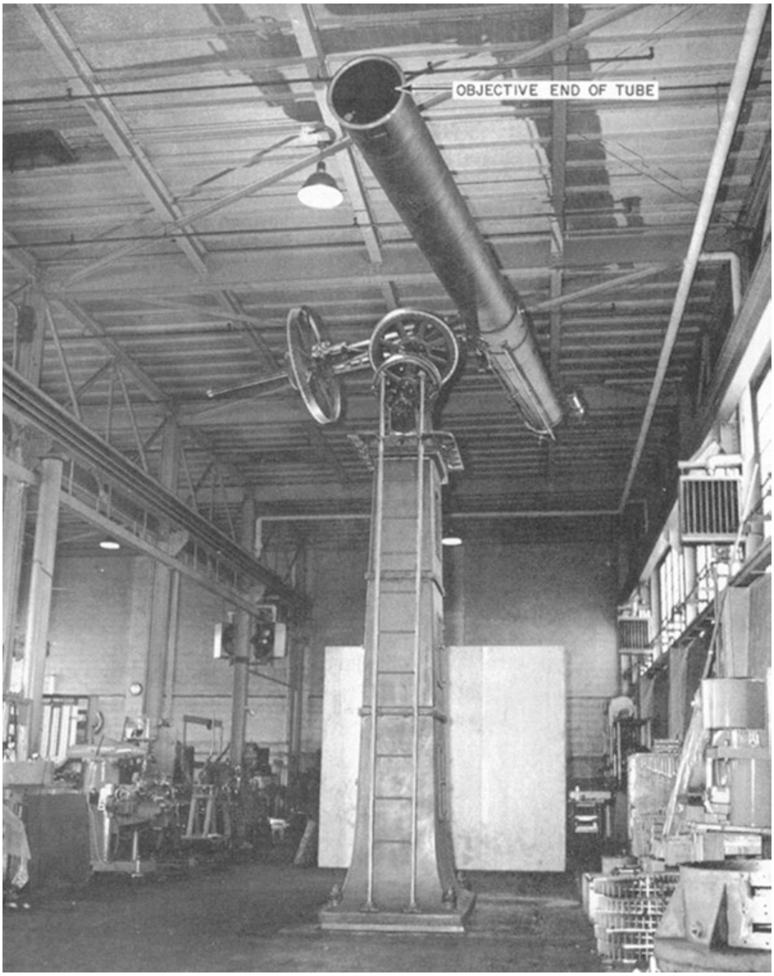


Fig. 20.16 The 18-in Brashear refractor of 1897 being refurbished in Philadelphia in 1963 prior to shipment to New Zealand. There are now plans to mount this telescope near Mt. John and use it for public education in astronomy (*Courtesy* Wilmot Fleming Co., Philadelphia)

Several other smaller telescopes of distinction also date from the late nineteenth century. New Plymouth Observatory acquired a 6-in. (15.2-cm) Alvan Clark refractor in 1920. It dates from 1881, and originally was acquired by Sydney Observatory for observations of the 1882 transit of Venus (Orchiston 1991). Clark was the foremost American optician in the late nineteenth century (Warner and Ariail 1995). Another 6-in. (15.2-cm) refractor was at the Townsend Observatory in Christchurch and was made by Thomas Cooke in 1863. It was acquired by the Canterbury University College in 1891 as a gift from the Christchurch amateur astronomer, James Townsend (Tobin 1996). The telescope was installed at the University in 1896, and was in regular use for public viewing (Hearnshaw 2009b) until the first major Christchurch earthquake in 2010. Fortunately the telescope largely survived when the Observatory collapsed in 2011, and at the present time (2016) it is being renovated it, thanks to a generous bequest from University of Canterbury alumnus Professor David Teece. It will be installed in a new observatory tower at the Christchurch Arts Centre so that it can resume its historic role as an instrument dedicated to astronomical education.

Another refractor of similar aperture was the 5.5-in. (14-cm) Grubb refractor made in Dublin in 1882 that was owned by Thomas King, the observer at the Colonial Observatory in Wellington. After King's death in 1916 it was acquired by the Wellington Philosophical Society and in 1918 erected in their King Edward VII Memorial Observatory in Kelburn (Fig. 20.17). Later this became known as the

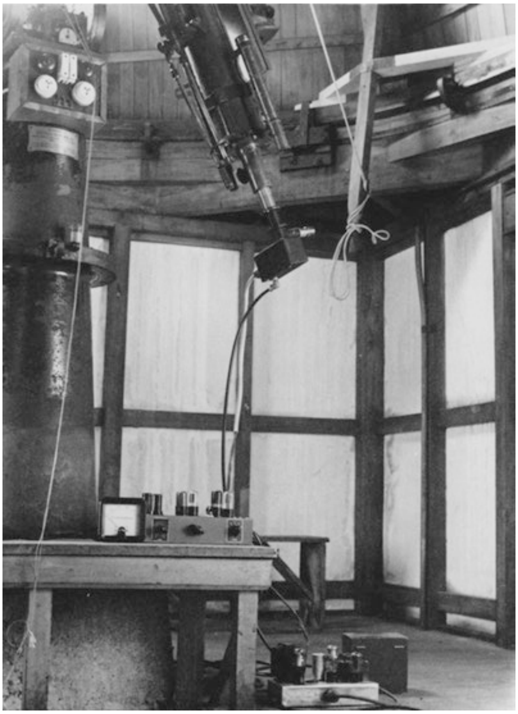


Fig. 20.17 This shows the tail-piece of the 5.5-in. Grubb refractor at the Thomas King Observatory. In the years immediately after WWII this modest telescope was used by Ken Adams from Carter Observatory to carry out New Zealand's first experiments in photoelectric photometry, as shown in this photograph (Orchiston Collection)

Thomas King Observatory and today is part of the Carter Observatory (see Seymour (1995) and Hudson (2003).

One old 8.5-in. (21.6-cm) reflector of note was made by George With and John Browning in England, probably about 1870, and was acquired by J.H. Pope, (1837–1913), an Otago school teacher in about 1871. The subsequent chequered history of this telescope is given by Tony Dodson (1996) in *Southern Stars*. Another With-Browning reflector, of aperture 9.25 in. (23.5 cm), was owned by the amateur observer Henry Skey (1836–1914) in Dunedin. The telescope passed to Skey's son in 1914 and eventually was donated to Ashburton High School in 1925. The telescope was refurbished and housed in a new building between 1974 and 1977. A detailed article was published by Bob Evans and Ken Lucas, who were involved with the refurbishment (Evans and Lucas 1989).

20.9 The Royal Astronomical Society of New Zealand and Other Regional Societies

The New Zealand Astronomical Society was founded in 1920, and formed a nationwide umbrella organization to which the many regional societies have become affiliated. In 1946 the N.Z.A.S. acquired its royal charter, and accordingly became the Royal Astronomical Society of New Zealand. The R.A.S.N.Z. is a rare example of an astronomical society that flourishes with both amateur and professional members, and indeed one of the strengths of the New Zealand astronomical scene has been the healthy interaction between these two communities. The society is run by a Council and President and contains a number of Sections for different interest groups. Of these, the Variable Star Section, directed from 1927 to 2004 by Frank Bateson (Fig. 20.18), is certainly the most famous. It is now known by the name Variable Stars South.

Other R.A.S.N.Z. sections cover aurorae, comets and meteors, occultations, astrophotography, astronomical education and the dark skies group. Sections for photometry and astronomical computing have also existed in the past. The Society holds an annual general meeting and conference, and publishes the journal *Southern Stars* and also a monthly e-newsletter.

More information on R.A.S.N.Z. can be found from the society's website at www.rasnz.org.nz.

Astronomical societies are to be found in all the main centres in New Zealand, with over 600 members for the strong Auckland Astronomical Society founded in 1922 (see www.astronomy.org.nz). As many as 27 regional societies are currently active in New Zealand. Many of these societies now run their own observatories (for example the Joyce Memorial Observatory of the Canterbury Astronomical Society near Christchurch—see www.cas.org.nz).

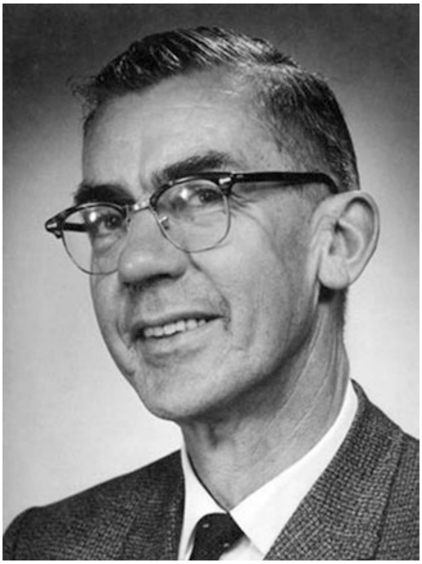


Fig. 20.18 Dr. Frank Bateson, ‘father’ of the R.A.S.N.Z.’s Variable Star Section for more than 70 years (http://taurangahistorical.blogspot.com/2013_10_01_archive.html)

20.10 Carter and Auckland Stardome Observatories

Carter Observatory in Wellington (Fig. 20.19) came into being in 1941 as a result of a generous benefaction by the Wellington businessman, politician and Wairarapa farmer, Charles Rooking Carter on his death in 1896. The original bequest of $2000 was not sufficient to found an observatory, but after many delays, Carter Observatory came into being in December 1941 in the Botanical Gardens in Kelburn. Murray Geddes, a Victoria University College graduate and Southland school teacher and a keen observer of meteors, sunspots, variable stars and aurorae was the first Director from 1939, but WWII prevented him from serving prior to the Observatory’s opening and he died during the war.

Carter Observatory houses the 9.75-in. (24.8-cm) refurbished Cooke refractor, and in 1968 it acquired the 16-in. (40.6-cm) Ruth Crisp reflector. In 1977 Carter Observatory was given the title ‘National Observatory of New Zealand’. A planetarium was built there in 1992 and the role of the Observatory as a regional resource for astronomy education and public outreach was thereby strengthened (e.g. see Leather et al. 1998, Orchiston and Andrews 1995, Orchiston et al. 1998). The observatory was temporarily closed in 2008 and underwent a refurbishment prior to planned reopening early in 2010. At the same time its status as a national observatory was revoked. It is now administered by the Wellington City Council. The Carter website is at www.carterobservatory.org, and for further information about the earlier research role of the Observatory see Orchiston (2016: Chapter 13).

Fig. 20.19 Carter Observatory in 2012 (*Photograph* Wayne Orchiston)

Auckland Observatory on One Tree Hill opened in 1967 after various designs were considered (e.g., see Fig. 20.20) and houses a 20-in. (50.8-cm) Zeiss Cassegrain reflector funded from a donation by Edith Winstone Blackwell (Fig. 20.21). It has been used for photometry of variable stars. The telescope was fully restored in 2003. The Observatory is part of the Auckland Stardome which features a Zeiss Planetarium, completed in 1997. The planetarium installed an advanced digital projector in 2008 (Garner 2009). The Stardome website is www.stardome.org.nz.

20.11 Astronomy in New Zealand Universities

Although at the present time astronomy as a subject for teaching and research is very much concentrated at the University of Canterbury, several of New Zealand's other universities have also had or do have an interest in teaching and researching into astronomy. At present Canterbury's Department of Physics and Astronomy has several academic staff who specialize in optical astronomy, mainly with interests in stars. In addition there is an interest in the Solar System, in particular meteoroid dust particles in the Solar System (observations of their orbits until very recently were made at the meteor radar facility at Birdlings Flat near Christchurch) and near-Earth asteroids. There is also a research group active in cosmology, dark matter theory and astro-particle physics. Two of these individuals are theoreticians specializing in general relativity and gravitation, while another works on problems of neutrino astrophysics, and in particular the opportunity of detecting neutrinos from outer space by the interaction with the ice shelf in Antarctica, the so-called international IceCube project, which is designed to detect high energy neutrino sources.

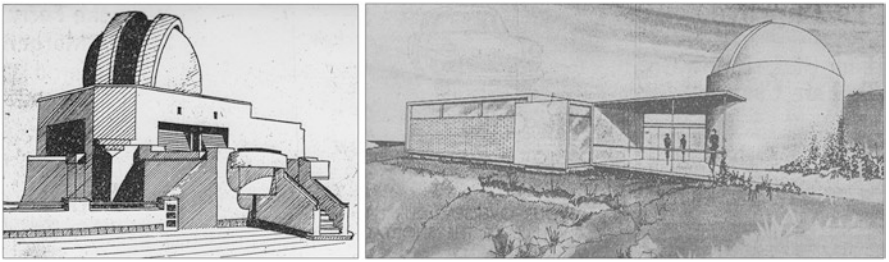
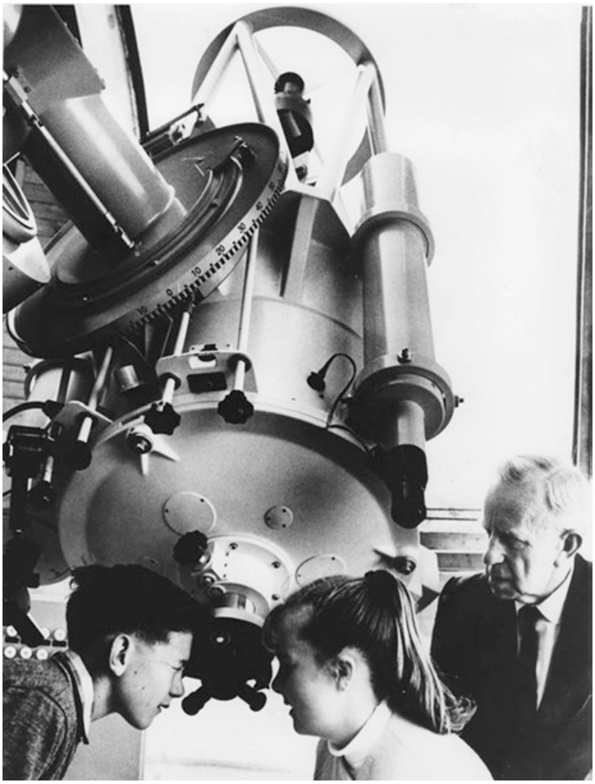


Fig. 20.20 Two different designs suggested for Auckland Observatory, in 1953 and 1959 respectively (after Aries 1953; Observatory design 1959)

Fig. 20.21 Ronald McIntosh and two young visitors with the Auckland Observatory's 20-in. Zeiss reflector in 1978 (Orchiston Collection)



Canterbury also has academic staff with interests in different aspects of astronomy and space science in other departments. Thus, the Department of Electronic and Computer Engineering has an interest in astronomical imaging through a turbulent terrestrial atmosphere and the technique of adaptive optics (a method of producing sharper images by compensating for the blurring of the atmosphere with a very fast computer controlled mirror); the Department of Chemistry has an interest in interstellar chemistry and planetary atmospheres; and the Department of Geological Sciences has an interest in planetary geology and vulcanology. This wide range of expertise makes Canterbury the clear leader in astronomy amongst the New Zealand universities.

Four other universities currently have significant programmes in teaching and research, though each has only two or three academic staff members. Thus Auckland University collaborates in the MOA project (see below), an international programme with Japanese scientists for which the observations are made at Mt. John. Also at Auckland, there is an interest in binary stars and stellar spectra and stellar structure and evolution. Victoria University of Wellington was until recently also part of the MOA project. At Victoria, there has been research on photometry of rapidly oscillating white dwarfs, and there is now a radio astronomy group with a link to the SKA project in Australia and South Africa (www.ska.ac.nz). At Victoria there is also research into astroparticle physics and Māori astronomy.

At Auckland University of Technology, three staff members have an interest in radio astronomy. The recently established Institute for Radio Astronomy and Space Research (IRASR) has as its goal to undertake very-long baseline interferometry across the Tasman and to collaborate with Australia in the Square Kilometre Array (SKA) project. At Massey University's Albany campus on the southern outskirts of Auckland, one staff member is working on data analysis for the MOA microlensing project and another staff member in mathematics has an interest in stellar dynamics.

Otago and Waikato Universities (in Dunedin and Hamilton, respectively) have also employed astronomers in the past, but these astronomical programmes have now lapsed. However, at the University of Otago there is currently an active research group in general relativity and cosmology (in the Department of Mathematics).

Having said that, all New Zealand universities teach physics and most of the physics programmes offer some astronomy, mainly at an introductory level. In 2010 the Auckland University of Technology (AUT) launched a new degree, the Bachelor of Mathematical Sciences in Astronomy as a 3-year major specializing in astronomy, but only at Canterbury can astronomy courses be done at all levels, from years one to three and at honours level (year 4). Canterbury also offers a Master's degree in astronomy. Canterbury, Auckland, Massey and Victoria Universities and Auckland University of Technology have all had recent Ph.D. students in astronomy. Indeed Canterbury typically has had 8–10 graduate students (M.Sc. or Ph.D.) enrolled at any one time.

Information about the teaching and research in astronomy at Canterbury can be obtained from www.phys.canterbury.ac.nz.

20.12 Mt. John University Observatory

Mt. John University Observatory (Fig. 20.22) was founded in 1965, as a joint project between the Universities of Pennsylvania and Canterbury. The observatory is located at Lake Tekapo, in the centre of New Zealand's South Island, at a dark-sky site where there is a maximum chance of clear skies. Although the involvement of Pennsylvania was active for the first 10 years at Mt. John, this is no longer the case and since about 1975 the observatory has been effectively run by the University of Canterbury.

The first major instrument to be installed there was three astrographs used for sky photography, of apertures 100, 125 and 250 mm, and all mounted on a single equatorial mount under a sliding roof. The astrographs came from the University of Pennsylvania and they were used in the late 1960s to produce a photographic atlas of the southern sky, known as the Canterbury Sky Atlas (Doughty et al. 1972). This was in fact a southern extension of a similar northern hemisphere photographic survey made from Lick Observatory in California.

In 1970 Pennsylvania provided a 60-cm (24-in.) aperture Cassegrain reflecting telescope for Mt. John. This telescope is known as the Optical Craftsmen Telescope, and it was equipped with a photoelectric photometer for measuring the brightness of stars. Mainly variable stars were the topic of interest, these being stars that vary in brightness as a result of pulsations, explosive eruptions or eclipses of a binary system. All these types of variable star have been the subject of intense study at Mt. John over the last five decades. In 2007–2009 this telescope was converted to a fully

Fig. 20.22 An aerial view of the summit of Mt. John in October 2004, beside Lake Tekapo. The dome of the 1.8-m MOA telescope is in the centre foreground, the 60-cm Boller & Chivens telescope is to its left and the 60-cm Optical Craftsmen telescope is in the dome on the right. The small dome at the rear on the left houses the 40-cm Earth and Sky telescope used for public viewing. The 1-m McLellan telescope is further to the right, out of the picture (*Courtesy* Tim Rayward)

robotic telescope for CCD photometry of variable stars in a joint venture with the American Association of Variable Star Observers (AAVSO) (www.aavso.org).

In 1975 Mt. John acquired a second telescope, made by the American firm of Boller and Chivens (B&C). This telescope (Fig. 20.23) is also of 60-cm (24-in.) aperture, and it was the first to be used for stellar spectroscopy at Mt. John, from 1976, using the f/13.5 Cassegrain focus. It has also been used for photoelectric photometry and for direct photography of the sky. But in 1995 this telescope was completely refitted and given a new drive and f/6.25 Cassegrain optical system to make it suitable for the MOA project, which involves wide angle CCD imaging of crowded star fields to undertake measurements of stellar brightness. Since 2006 the f/13.5 system has been reinstated and the telescope is now used for MOA follow-up observations of microlensing events. The MOA project is discussed further below.

The 1-m (40-in.) McLellan telescope, currently the largest New Zealand-owned telescope, was designed and built at Canterbury and installed at Mt. John in early 1986. Although it can be used for photometry and imaging, the great majority of all time allocated on it is for high resolution spectroscopy of stars. For this purpose the Hercules spectrograph is used. The data can be used for measuring stellar velocities, the temperatures, pressures, chemical composition, rotation rates and other interesting parameters of stars.

A fourth reflecting telescope at Mt. John is the MOA 1.8-m prime-focus wide-field alt-az telescope which was constructed by the Nishimura Company in Kyoto, Japan (Fig. 20.24). It is now the largest optical telescope in New Zealand (Hearnshaw

Fig. 20.23 Mt. John Observatory in the winter of 2009. The MOA 1.8-m telescope dome is on the left and the B&C 60-cm dome is in the centre. The Southern Alps are in the background. This view is to north-west, towards the 3700-m Aoraki/Mt. Cook, New Zealand's highest mountain (*Courtesy* Fraser Gunn)

Fig. 20.24 The dome of the MOA 1.8-m telescope. This telescope, which was installed in 2004, is a joint project between Nagoya University (Japan) and the University of Canterbury and is used for microlensing observations (*Courtesy* Fraser Gunn)

et al. 2006). The telescope was installed in 2004 and is owned by Nagoya University but operated in the joint MOA project by Nagoya and four NZ universities. A large 80-million-pixel CCD electronic camera is mounted at the prime focus (Sako et al. 2008). This telescope is used primarily for CCD photometry as part of the ongoing MOA project.

In 2004 the University of Canterbury entered into an agreement with Earth and Sky Ltd. (www.earthandsky.co.nz) whereby Earth and Sky would run astronomical tours to Mt. John, both during the day and at night. Since that time Earth and Sky (Director, Graeme Murray) has constructed the popular Astro-Cafe at the summit of Mt. John for day-time visitors. Earth and Sky has also installed a 40-cm Meade telescope for night viewing and public outreach.

Further information about Mt. John can be obtained from the web sites at www.phys.canterbury.ac.nz or www.mjuo.canterbury.ac.nz/mjuo, and from the recent book by Hearnshaw and Gilmore (2015), *Mt. John: The First 50 Years …*

20.12.1 The 1-m McLellan Telescope

The design for the McLellan 1-m telescope was undertaken at Canterbury in the early 1980s, with the assistance of Norman Rumsey and Garry Nankivell working at the Physics and Engineering Laboratory (later known as Industrial Research Ltd.) of the former DSIR in Lower Hutt, near Wellington. The optical design of this Cassegrain telescope is a so-called Dall-Kirkham arrangement, with an ellipsoidal figure for the primary and a spherical secondary. That system has rarely been used in the past because of the significant aberrations as one observes stars off the central axis, which degrade the images. But Rumsey showed that with a suitable system of lenses just before the final focus, sharp images could be achieved even for a 1° field of view. What is more, he argued that the Dall-Kirkham was much easier to make than the more traditional Ritchey-Chrétien arrangement. The optical figuring of the mirrors was undertaken by Garry Nankivell, who was seconded to Canterbury for 6 months in 1981 (Nankivell 1986). Low expansion Zerodur ceramic was used for the mirrors.

The mechanical design and construction was by technical staff at the University of Canterbury. It is a traditional asymmetric single-pier equatorial mounting. The electronics and control system were also a local Canterbury product, including the drive system, encoding and computer control (Hearnshaw 1986). The telescope was completed in late 1985 (Fig. 20.25).

The telescope was installed at Mt. John in early 1986 in a building, which was formerly used by the US Air Force for tracking satellites, but which had become vacant in the early 1980s. This building was completely refitted and modified to accommodate the new telescope, and Canterbury built an 8-m dome for the new installation (Fig. 20.26). The telescope was opened in July 1986 and named after Professor Alistair McLellan, the former head of the Physics Department at Canterbury. It has been in almost uninterrupted operation on clear nights ever since

Fig. 20.25 The 1-m McLellan telescope undergoing tests in a workshop at the University of Canterbury in December 1985, just prior to installation at Mt. John. The Florida spectrograph is at the Cassegrain focus. The entire telescope was designed and built at the University of Canterbury (*Photograph* University of Canterbury)

Fig. 20.26 A view of the building and dome of the 1-m McLellan Telescope at Mt. John, looking towards the Southern Alps. The building also houses the observers' accommodation and dining room (*Courtesy* Fraser Gunn)

1986, with stellar spectroscopy being the main area of research for which it has been used. The photometry of stars with a CCD camera and the tracking of asteroids are other noteworthy projects undertaken with this telescope.

In 2009 the electronics and control system of the telescope were completely redesigned and rebuilt, and installed in 2010.

20.12.2 The Hercules Spectrograph

In 1975–1977 Canterbury built a high dispersion échelle spectrograph for Mt. John based on a design provided by the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. This was at the time a novel kind of instrument using a special type of diffraction grating called an échelle to disperse the light into its component colours. The new échelle spectrograph, which was one of the first of its type in the southern hemisphere, was mounted on the Boller and Chivens 60-cm telescope in 1977 and used for recording the spectra of bright stars (Hearnshaw 1977). At first these were recorded photographically, but later with electronic image intensifier tubes, then with an electronic diode array digital detector and finally with a charge-couple device (CCD). This instrument was retired in 2001.

In 1998 work had begun on a much larger and more powerful spectrograph, the High Efficiency and Resolution Canterbury University Large Échelle Spectrograph (HERCULES) which was designed and built at Canterbury. This is an instrument linked to the telescope by an optical fibre and the whole spectrograph is mounted inside a vacuum tank in a specially insulated room to maintain exceptional stability (Fig. 20.27).

The HERCULES spectrograph was installed in 2001 and had its first light in April of that year. Today it is the main instrument used on the McLellan telescope. It is used to analyse the spectra of variable stars and, for example, to measure precise velocities of stars using the Doppler effect.

In recent years a number of improvements have been made to Hercules, notably the installation of a new 4 k × 4 k CCD camera from Spectral Instruments, the installation of a temperature control system to better than 0.1° C stability, the use of an iodine cell for precise velocities, installation of a new video camera for acqui-

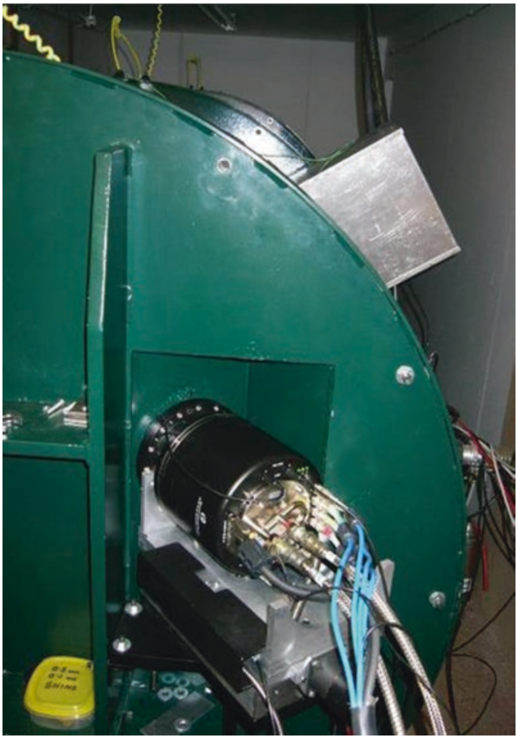


Fig. 20.27 The vacuum tank of the HERCULES fibre-fed spectrograph on the 1-m telescope. The spectrograph receives light from a 25-m length of optical fibre from the telescope's Cassegrain focus. The Spectral Instruments 4 k × 4 k–pixel CCD camera is seen attached to the spectrograph (*Photograph* John Hearnshaw)

sition and guiding and a remote control and readout system for CCD focus. These developments have been described by Hearnshaw et al. (2008). In the first several years of its operation the Hercules spectrograph was used extensively for studies of spectroscopic binary stars. One such study was on the single-lined spectroscopic binary ζ TrA, an F9 V star in a 13-day orbit. More than 200 spectra with a random error of 14 m/s per observation were obtained for a remarkably precise orbital solution (Skuljan et al. 2004). An especially interesting Hercules paper relates to the binary star ν Octantis, a K0III giant in a 2.9-years orbit which apparently has a 2.4 Jupiter-mass planet in a resonant orbit exactly two-fifths of the stellar binary period (Ramm et al. 2009). At present Hercules is being used for extensive programmes on asteroseismology of non-radially pulsating stars (Pollard and collaborators) and the search for Earth-mass planets in α Centauri (Hearnshaw and collaborators).

More information on the Hercules spectrograph can be found in Hearnshaw et al. (2002) and at www.phys.canterbury.ac.nz/research/astronomy/hercules/.

20.12.3 The MOA Project

If by chance a massive object (a star or perhaps a black hole) passes precisely between us and a distant star, then a phenomenon known as gravitational microlensing can take place. This is caused by the bending of light rays by the gravitational field of the intermediate massive object (the lens), with the result that the light from the distant star can be amplified in brightness, typically for a few weeks or a month while the alignment of the source star, lens and Earth is nearly perfect. Although this was predicted many decades ago by Einstein, the first microlensing event was only discovered in the early 1990s. The main reason is that the alignments are so rare, that millions of stars have to be searched to find one undergoing microlensing.

In 1995 a project began at Mt. John, mainly supported by Auckland, Canterbury and Victoria universities and the Carter Observatory in New Zealand and Nagoya University in Japan. About 30 scientists from these four universities and several other institutions are involved in the project. It is known as the MOA project, meaning Microlensing Observations in Astrophysics. All the observations for MOA have so far been made at Mt. John, at first with the 60-cm Boller and Chivens telescope, but since 2005 using the dedicated 1.8-m MOA telescope. The new telescope was installed in 2004 and came from a large grant from Japan's Ministry of Education and Science to Nagoya University's Solar and Terrestrial Environment Laboratory (STELAB) with Yasushi Muraki as principal investigator. The telescope's optics were designed in New Zealand and the four lenses of the aberration corrector were fabricated at IRL (Hearnshaw et al. 2006). The telescope has a Russian-made Astrosital mirror and the mounting is an alt-az mount, in which the two axes are always vertical and horizontal. A very large CCD camera with 80 million pixels and covering a field of view of about 2.0 square degrees is mounted at the prime focus.

The observers for MOA have been from both New Zealand and Japan. The objects viewed are the Magellanic Clouds and the Galactic Bulge near the centre of our Galaxy. In these regions of the sky (which are only easily visible from the southern hemisphere) millions of stars can be observed in one exposure, giving a reasonable chance of finding microlensing events should they occur. At first, 50 or so events were discovered annually by the MOA team. Now with the 1.8-m telescope, the number detected annually in the Galactic Bulge is over 500.

The principal aims of MOA are to discover and make observations of microlensing events in order to learn more about dark matter such as black holes in the Galaxy and to discover planets in orbit around other stars (if the lens is a star, which normally will not be bright enough to be visible, happens to have a planet in orbit around it, then this may influence the way the source star's light is amplified in a characteristic way that can allow new planets to be discovered). To date about two dozen planets have been discovered by microlensing (Fig. 20.28). The MOA astronomers have made a contribution to all these discoveries. The first definitive discovery was MOA-2003-BLG-53 in 2003 (Bond et al. 2004) and other landmarks have been an observational contribution to the detection of one of the first Earth-mass planets in 2005 (Beaulieu et al. 2006), detection of a 3.3 Earth-mass planet in 2007 (Bennett et al. 2008), and observations that led to the first two-planet microlensing system (Gaudi et al. 2008).

More information on the MOA project can be found at www.phys.canterbury.ac.nz/moa/index.html.

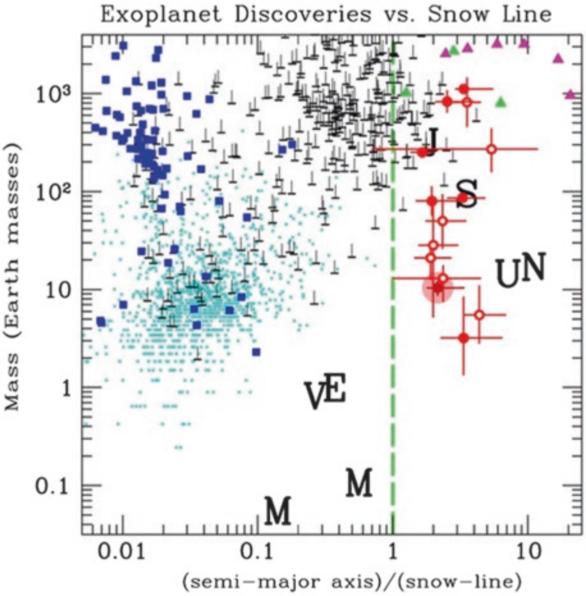


Fig. 20.28 Exoplanets detected by the MOA group using microlensing as of 2011 are shown in red; those discovered using other techniques are shown in other colours (after Muraki et al. 2011)

20.13 Other University of Canterbury Astronomy Initiatives

20.13.1 SALT

SALT is the Southern African Large Telescope (Fig. 20.29). This is a large 10-m class telescope of novel design at the South African Astronomical Observatory at Sutherland some 400 km NE of Cape Town. The telescope had first light in September 2005. In May 2000 the University of Canterbury became a partner in the SALT consortium, being one of about a dozen partner countries or institutions in South Africa, the United States, Poland, Germany and Britain. Canterbury bought a roughly 5% share in SALT in return for funding for the telescope and for the design and construction of one of three major instruments. In Canterbury's case, the instrument bid was for the high resolution échelle spectrograph, similar to but larger than HERCULES now in operation at Mt. John. In the event it was decided to construct the spectrograph at the University of Durham in the U.K.

SALT also has a lower resolution spectrograph (for observing fainter objects) known as PFIS (prime focus imaging camera) or the Robert Stobie spectrograph, which has been built by the University of Wisconsin (which is one of the SALT partners), and a direct imaging CCD camera known as SALTICAM, built at SAAO in Cape Town.

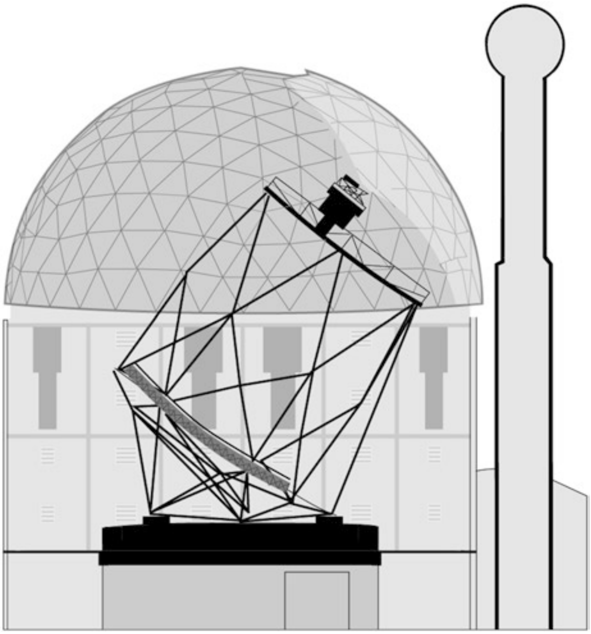


Fig. 20.29 A schematic diagram showing the SALT Telescope and dome (https://www.salt.ac.za/telescope/)

With SALT, Canterbury astronomers have the opportunity to obtain data on one of the world's largest telescopes and to do research into fainter and more distant objects beyond our local region of the universe.

For more information on the SALT project, see www.salt.ac.za.

20.13.2 AMOR

The Department of Physics and Astronomy at the University of Canterbury has an active group working on the dynamics of interplanetary dust grains. Until very recently, the group operated a radar facility (Advanced Meteor Orbit Radar, AMOR—see Fig. 20.30) that determined the trajectories of interplanetary grains near the Earth (Baggaley 2001, Baggaley et al. 1994). The generation of plasma ablation in the atmosphere of such grains (size $\geq 30\ \mu$m) provides a target, the geometry and speed

Fig. 20.30 The University of Canterbury's AMOR radar transmitting antenna sampling in the north-south meridian. The radar facility was at Birdlings Flat, on the spit between Lake Ellesmere and the Pacific Ocean southeast of Christchurch, and was used to detect micrometeroids in the upper atmosphere from radar echoes from their ionization trails (*Courtesy* Jack Baggaley)

of which are sensed by radar. The AMOR group operated the facility as a collaborative programme supported by the European Space Agency via the operation centre (ESOC) situated in Darmstadt. The radar work provided complementary aspects to ESA's spacecraft detections of interplanetary dust by *in-situ* detections via the missions Galileo, Ulysses, Helios and Cassini and the particle collections and Earth-return by the Stardust mission. Whereas present space missions provide very limited dynamical information, the radar tracking can provide heliocentric orbits and sources of the material that makes up the Solar System dust cloud. One aspect of the programme was to provide models for spacecraft impact hazard.

In addition to the near-Sun environment, the radar project was able to detect interstellar grains entering the Solar System from outside (Taylor et al. 1996) and map the inflow of this material (Baggaley and Galligan 2001). Such grains are large enough to penetrate the heliosphere and are undetectable by conventional long sight-line stellar methods. The sources of dust within the solar neighbourhood can also be mapped.

The facility made use of time-of-flight between sites separated by approximately 10 km to gain the velocity components; sensing the ablating grains' speed via the radar signal phase characteristics ensures quality velocity calibration enabling heliocentric orbit uncertainties of $<1°$ and 5% in size elements. The programme was under continuous operation, providing surveillance of the Earth's dust environment with $>10^6$ orbits in the data base. Targeted sources were cometary streams, asteroidal collisional debris material, Earth-orbit space debris and interstellar grains.

In related work, the AMOR group also uses radar data from the ALTAIR (US Air Force) as an additional technique for delineating interstellar grain directions.

The AMOR facility developed from earlier work at Canterbury on the radar detection of meteors by Cliff Ellyett, Walter Roth, Colin Keay and Bob Bennett, which dated from 1952 (Ellyett et al. 1961; Keay 1965).

20.13.3 Neutrino Astrophysics: RICE and IceCube

The particle astrophysics group at the University of Canterbury is currently working on a large neutrino astrophysics experiment located at the South Pole. IceCube is a cubic-kilometre detector that was completed in 2011. It is an international collaboration including researchers from institutes in the United States, Europe, Japan and New Zealand. It consists of 80 strings each holding 60 photomultiplier tubes deployed between 1.4 and 2.4 km below the ice surface. The primary signal will be long range muons from muon-neutrinos interacting with nucleons in the ice. The science goals include the search for transient neutrino sources like gamma-ray bursts or supernova explosions, as well as the study of candidates for steady or variable sources of neutrinos, such as active galactic nuclei and supernova remnants. There will be an effort to search for sources of cosmic rays. The detector can also be used to search for neutrinos from super heavy particles related to topological defects as well as search for magnetic monopoles and any new physics at very high energies. The first IceCube string was deployed in the 2004–2005 austral summer. Deployment of all 80 strings was completed in 2011. More information on the IceCube project is at www.icecube.wisc.edu.

The group at Canterbury was earlier also working on the Radio Ice Cerenkov Experiment (RICE). The lead group is at the University of Kansas in the United States. RICE is also a neutrino detector in Antarctica, and its primary signal was to detect a short burst of radio waves emitted after an electron-neutrino interacts with a nucleon in the ice and the energy is dissipated through an electromagnetic cascade. The science goals were similar to those of IceCube, but RICE probed a higher energy regime and used a different type (or flavour) of neutrino. The RICE detector consisted of about 20 radio antennas at various depths between 100 and 300 m below the ice surface. The detector was sensitive to electron neutrinos of energy above 1 PeV and was sensitive to interactions in the ice up to 1 km away from the antenna array. Analysis of the data revealed no unambiguous ultra-high energy neutrino candidates. This has allowed RICE to place upper limits on various models of cosmic ray neutrino sources (Kravchenko et al. 2006). The experiment operated from 1999 to 2005.

20.14 Radio Astronomy in New Zealand and the SKA

New Zealand played a small but important role in the early history of radio astronomy. In 1945 the New Zealand-based British scientist Dr. Elizabeth Alexander (Fig. 20.31) confirmed that the Sun was an emitter of 200 MHz non-thermal radio bursts. Shortly after, Alan Maxwell studied these solar bursts for the first Masters thesis in radio astronomy completed in New Zealand, and Carter Observatory's Ivan Thomsen examined the relationship between solar radio emission and photospheric optical phenomena. Finally, in 1948 John Bolton and Gordon Stanley (the latter was born in New Zealand) from CSIR's Division of Radiophysics in Sydney used a cliff-interferometer (Fig. 20.32) at Leigh and Piha near Auckland to determine the positions and angular sizes of the radio sources Taurus A, Centaurus A and Virgo A while Bruce Slee carried out parallel observations back in Sydney. They were able to correlate these sources with three optical objects, the Crab Nebula, NGC5128 and M87, respectively. This was an important step forward in the progress of the new science of radio astronomy. Elizabeth Alexander's pioneering discovery, the research by Maxwell and Thomsen and the Bolton-Stanley-Slee experiment are described in *Exploring the History of New Zealand Astronomy …* (Orchiston 2016: Chapters 23 and 24), and summarized in this book in Chap. 23 (Orchiston 2017c).

Various other experiments in radio astronomy have taken place in New Zealand in the last 50 years. The University of Otago under Dick Dowden constructed a dipole array on the Taieri Plains near Dunedin, and observations were made of the

Fig. 20.31 Dr. Elizabeth Alexander (standing at the rear) poses with (*left to right*) Dr. Ernest Marsden (Director of Scientific Developments, DSIR), Sir Cyril Newall (the Governor General of New Zealand), Dr. Ian Stevenson (Director of the Radio Development Laboratory) and the Governor General's Aide de Camp (Orchiston Collection)

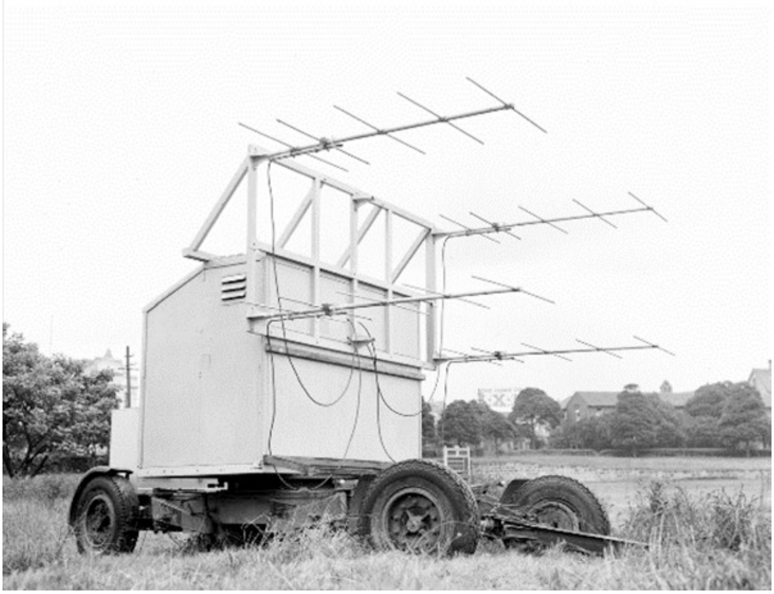


Fig. 20.32 The mobile 4-Yagi interferometer that John Bolton and Gordon Stanley took to New Zealand for the 1948 'radio stars' project (*Courtesy*: CSIRO RAIA: B1351-2)

radio emission from flare stars and T Tauri stars at 120 MHz. Paul Edwards continued this work in the 1970s (Edwards et al. 1974).

Other forays into radio astronomy have included a 10-m radio dish constructed by the Hamilton Astronomical Society in 1985, and a 5-m microwave radio dish installed by Ed Budding at the Central Institute of Technology in the Hutt Valley (just north of Wellington) in 1998. These and other developments are discussed in a review paper on the history of New Zealand radio astronomy by Marilyn Head (2010).

In 2008 the Auckland University of Technology (AUT) erected a 12-m radio astronomy telescope at Warkworth under the direction of Professor Sergei Gulyaev (Gulyaev and Natusch 2008). AUT also established the Institute of Radio Astronomy and Space Research with Gulyaev as its inaugural Director. In 2009 the New Zealand Government announced that it would work with Australia in a bid to host the Square Kilometre Array (SKA) radio telescope in Australia and New Zealand, and the low frequency component of the Array has since been assigned to these trans-Tasman nations. Meanwhile, since 2010 AUT has had access to a 30-m radio telescope at Warkworth (Fig. 20.33), and the Auckland radio astronomers have carried out successful VLBI experiments with Australia.

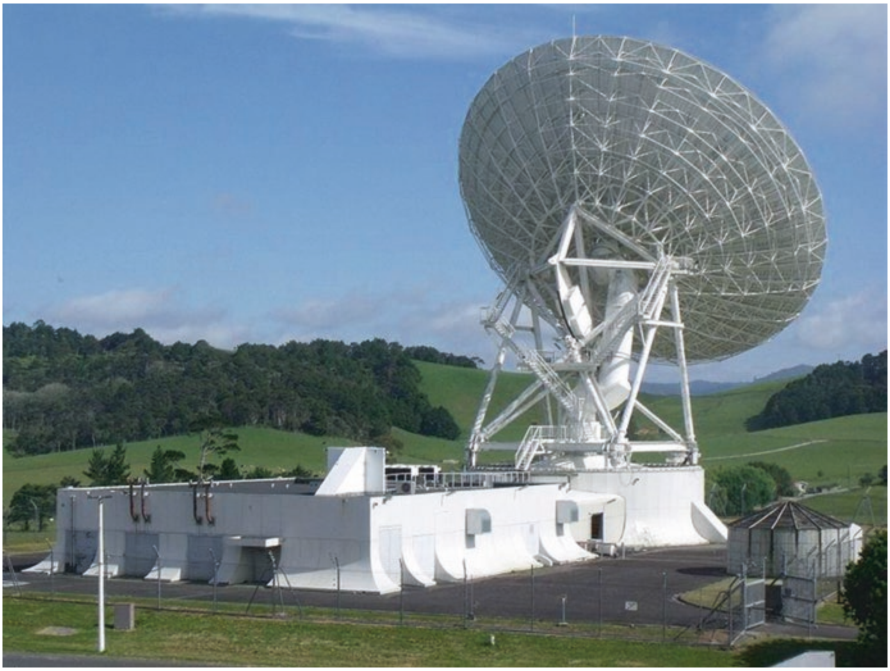


Fig. 20.33 The 30-m antenna at the Warkworth Radio Astronomical Observatory, operated by the Institute of Radio Astronomy and Space Research at the Auckland University of Technology (https://en.wikipedia.org)

20.15 The Future of New Zealand Astronomy

Astronomy world-wide has undergone a fundamental revolution over the last hundred years. That should be evident, even to a casual reader of this account of astronomy in New Zealand. In most of the nineteenth century and before, astronomy was first of all, an aid to maritime navigation and a means of accurate mapping of localities on the Earth. To this end, time-keeping and astrometry, the science of measuring star positions with high precision, were two of the principal tasks undertaken by astronomers.

Starting in the 1860s, changes in the way astronomers in Europe practised their science began to take place. For the first time they began to ask fundamental questions about the physical nature and properties of the Sun, stars and gaseous nebulae. At first physics was hardly advanced enough to provide many answers. But physics also underwent a revolution, and by the early twentieth century astronomers began applying physics to interpret their observations. This revolution was only really successful from the 1920s, when a real understanding of stellar spectra using physics became possible. Thus was born the branch of astronomy called astrophysics (e.g., see Hearnshaw 2014).

The development of New Zealand astronomy mirrors these developments on a world scene. Certainly the first New Zealand astronomers practised time-keeping, navigation, the determination of geographical coordinates and astrometry. Later observers studied meteors and comets and theoreticians speculated on the nature of variable stars (Bickerton) and the origin of lunar craters (Gifford). It is fair to say that New Zealand was slow, however, to embrace astrophysics. The Carter Observatory, established in 1941, undertook some solar physics, and a photoelectric photometer to measure star brightness was used there soon after WWII (Adams 1982; Thomsen 1950). But lack of resources prevented a fully fledged research programme from being developed. Further study of meteors by radar was made at Canterbury in the 1950s and 1960s (Keay 1965). But only when Mt. John Observatory was established with American help in the 1960s can we say that a firm base in observational astrophysics was established in New Zealand. By this time observatories specializing in astrophysics had already celebrated over 50 years or more of existence in many European countries and in North America, and the Commonwealth Solar Observatory in Canberra, Australia, was founded in 1924. In this sense, New Zealand has had a late start in astrophysical research.

With Mt. John now a high-tech and successful research observatory, with astronomy and astrophysics being taught and researched in at least four if not five New Zealand universities, and with important contributions to astronomy from a thriving amateur community, and New Zealand's participation in international astronomy projects such as MOA, IceCube and SALT, the future of astronomy in New Zealand now looks bright. In spite of a late start, there is no doubt that we are now making a significant mark on the world scene in selected areas of astronomy and astrophysics. Perhaps only about a dozen professional astronomers actually work in New Zealand (the number depends on how one defines an 'astronomer'), mainly in our universities.

On the other hand, about four dozen New Zealanders are professional astronomers overseas, and many have been or are astronomers of international distinction. If we add these people to the tally of astronomers in New Zealand, including a dozen or more amateur astronomers who make valuable research contributions, there is no doubt that in proportion to our total population, New Zealand is making a huge contribution to the world of discovery in astrophysics and space science. And it is a contribution of which New Zealanders—living in a nation with an astronomical birth—can justifiably be proud.

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References

Adams, K.D. (1982). Some aspects of the development of instrumentation for astronomical photometry [in New Zealand]. *Southern Stars, 30,* 3–11.

Andrews, F.P, & Budding, E. (1992). Carter Observatory's 9-inch refractor: the Crossley connection. *Southern Stars, 34,* 358–366.

Aries (i.e. McIntosh, R.A.) (1953). Observatory for Auckland. In 'The Newest in Science', newspaper article dated 28 April (copy in Orchiston Collection).

Astronomical Photographs Taken at the Meeanee Observatory Napier, N.Z. (n.d.). Carter Observatory Library.

Austin, R.R.D. (1994). Albert Jones – the quiet achiever. *Southern Stars, 36,* 36–42.

Baggaley, W.J. (2001). The AMOR radar: an efficient tool for meteoroid research. *Advances in Space Research, 28,* 1277–1282.

Baggaley, W.J., & Galligan, G.P. (2001). Mapping the interstellar dust flow into the Solar System. ESA Special Report SP-495, 703.

Baggaley, W.J., Bennett, R.G.T., Steel, D.I., & Taylor, A.D. (1994). The Advanced Meteor Orbit Radar: AMOR. *Quarterly Journal of the Royal Astronomical Society, 35,* 293–320.

Bateson, F.M. (1964). Final report on the site selection survey of new Zealand. *Publications of the University of Pennsylvania, Astronomy. Series, X,* pp. iv + 139.

Bateson, F.M. (2001). The Variable Star Section, RASNZ. *Southern Stars, 40,* 7–11.

Beaulieu, J.-P., Bennett, D.P., Fouqué, P., Williams, A., Dominik, M., and 68 coauthors (2006). Discovery of the distant cool sub-Neptune mass planet OGLE 2005-BLG-390Lb by microlensing. *Nature, 439,* 437–440.

Bennett, D.P., Bond, I.A., Udalski, A., Sumi, T., Abe, F., and 41 coauthors (2008). A low-mass planet with a possible sub-stellar-mass host in microlensing event MOA-2007-BLG-192. *Astrophysical Journal, 684,* 663–683.

Best, E. (1922). *The Astronomical Knowledge of the Maori*. First published 1922; new edition published as Dominion Museum Monograph No. 3 (1955).

Bond, I.A., Udalski, A., Jaroszynski, M., Rattenbury, N.J., Paczynski, B., and 27 coauthors (2004). OGLE 2003-BLG-235/MOA 2003-BLG-53: a planetary microlensing event. *Astrophysical Journal, 606,* L155–L158.

Budding, E. (1989). Eightieth birthday of Dr Frank M. Bateson. *Southern Stars, 33,* 169.

Burdon, R.M. (1956). *Scholar Errant*. Christchurch: Pegasus Press.

Calder, D. (1978). Joseph Ward: pioneer astronomer and telescope maker. *Southern Stars, 27,* 104–108.

Campbell, R.N. (2001). Henry Skey 1836–1914. *Southern Stars,* 40, 2, 11–12.

Christie, G. (2014). Baterson, Frank Maine. In T. Hockey et al., pp. 171–172.

Dick, S.J., Orchiston, W., & Love, T. (1998). Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy, 29,* 221–255.

Dodson, A. (1996). The With-Browning telescope at Pauatahanui. *Southern Stars, 37,* 45–51.

Doughty, N.A., Shane, C.D., & Wood, F.B. (1972). *The Canterbury Sky Atlas*. Christchurch: Deptment of Physics, University of Canterbury, New Zealand.

Edwards, P.J., Hurst, R.B., & McQueen, M.P.C. (1974). Correlation search for dispersed radio emission from the Galactic Centre. *Nature, 247,* 444–446.

Eiby, G. (1970). Captain James Cook and the Universe. *Southern Stars, 23,* 140–152.

Eiby, G. (1977). The New Zealand Government time-service: an informal history. *Southern Stars, 27,* 15–34.

Ellyett, C., Keay, C.S.L., Roth, K.W., & Bennett, R.G.T. (1961). The identification of meteor showers with application to southern hemisphere results. *Monthly Notices of the Royal Astronomical Society, 123,* 37–50.

Evans, R.W., & Lucas, K.J. (1989). The Skey-Asburton College telescope. *Southern Stars,* 33, 178–187.

Garner, C. (2009). Stardome planetarium goes digital. In *New Zealand Astronomical Yearbook 2009* (pp. 24–25). Auckland: Auckland Stardome.

Gaudi, B.S., Bennett, D.P., Udalski, A., Gould, A., Christie, G.W., and 64 coauthors (2008). Discovery of a Jupiter/Saturn analog with gravitational microlensing. *Science* 319, 927–930.

Gilmore, G.F. (1982). Alexander William Bickerton: New Zealand's colourful astronomer. *Southern Stars, 29,* 87–108.

Gilmore, G.F. (2017). Alexander William Bickerton: New Zealand's first astrophysicist? In T. Nakamura, & W. Orchiston.

Gouguenheim, L., McNally, D., & Percy, J. (Eds.), 1998. *New Trends in Astronomy Teaching*. Cambridge: Cambridge University Press.

Gulyaev, S., & Natusch, T. (2008). Introducing the AUT 12-m radio telescope. *Southern Stars, 47,* 15–17.

Harper, C.T., Warren, O., & Austin, R. (1990). J.T. Ward and the NZO double stars. *Southern Stars, 33,* 281–294.

Hawkesworth, J. (1774). *Relation des Voyages Entrepris par Ordre de Sa Majesté Britannique …* Paris: Saillant et Nyon.

Hayes, M. (1987). *In Spite of his Time, a Biography of R.C. Hayes*. Wellington: N.Z. Geophysical Society.

Head, M. (2010). A brief history of radio astronomy in Aotearoa New Zealand. *Southern Stars, 49,* 7–19.

Hearnshaw, J.B. (1977). The Cassegrain échelle spectrograph at Mt John Observatory. *Proceedings of the Astronomical Society of Australia, 3,* 102–103.

Hearnshaw, J.B. (1986). The Mt John 1-metre telescope project. *Astrophysics and Space Science, 118,* 79–81.

Hearnshaw, J.B. (2009a). A pedigree old telescope in New Zealand awaits a new home. http://cosmicdiary.org/blogs/john hearnshaw/

Hearnshaw, J.B. (2009b). The Townsend Observatory and the Cooke refractor of 1864. http://cosmicdiary.org/blogs/john hearnshaw/?p=544

Hearnshaw, J.B. (2014). *The Analysis of Starlight. Two Centuries of Astronomical Spectroscopy*. Cambridge: Cambridge University Press.

Hearnshaw, J., & Gilmore, A. (2015). *Mt John: The First 50 Years. A Celebration of Half a Century of Optical Astronomy at the University of Canterbury*. Christchurch: Canterbury University Press.

Hearnshaw, J.B., Barnes, S.I., & Endl, M. (2008). Latest results and developments with the Hercules spectrograph at Mt John Observatory. In S.N. Zhang, Y. Li, & Q.J. Yu (Eds.), *Proc*eedings of the *10th Asia-Pacific IAU Regional Meeting* (pp. 350–353). Kunming: National Observatories of China Press.

Hearnshaw, J.B., Barnes, S.I., Kershaw, G.M., Frost, N., Graham, G., Ritchie, R., & Nankivell, G.R. (2002). The Hercules Échelle Spectrograph at Mt. John *Experimental Astronomy, 13,* 59–76.

Hearnshaw, J.B., Abe, F., Bond, I.A., Gilmore, A.C., Itow, Y., and 10 coauthors (2006). The MOA 1.8-metre alt-az wide-field survey telescope and the MOA project. In W. Sutantyo, & P. Premadi (Eds.), *Proceedings of the IAU 9th Asian-Pacific Regional Meeting, Bali, Indonesia, July 2005 (272–273)*. Bandung: Boschha Observatory.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hoyt, W.G. (1987). *Coon Mountain Controversies: Meteor Crater and the Development of Impact Theory*. Tucson: University of Arizona Press.

Hudson, G. (2003). Refurbishment of the Thomas King telescope at Carter Observatory. *Southern Stars, 42*(4), 4–6.

Jenkinson, S.H. (1940). *New Zealanders and Science*. Wellington: Department of Internal Affairs.

Jones, A.F. (1989). F.M. Bateson: a tribute from an observer. *Southern Stars, 33,* 170–171.

Keay, C.S., 1965. Meteor research in New Zealand. *Southern Stars, 21,* 9–19.

Kingsley-Smith, C. (1967). Maori star lore. *Southern Stars, 22,* 5–10.

Kravchenko, I., Cooley, C., Hussain, S., Seckel, D., Wahrlich, P., and 16 coauthors (2006). RICE limits on the diffuse ultrahigh energy neutrino flux. *Physical Review, D73,* 082002–082020.

Leather, K., Andrews, F., Hall, R., & Orchiston, W. (1998). Coping with a new curriculum: the evolving schools program at the Carter Observatory, New Zealand. In L. Gouguenheim et al., pp. 267–272.

McIntosh, R.A. (1935). Index to southern meteor showers. *Monthly Notices of the Royal Astronomical Society, 95,* 709–718.

McIntosh, R.A. (1970). Early New Zealand astronomy. *Southern Stars, 23,* 101–108.

Muraki, Y., Han, C., Bennett, D.P., Suzuki, D., and 125 coauthors (2011). Discovery and mass measurements of a cold, 10 Earth mass planet and its host star. *Astrophysical Journal, 741,* article id. 22, 15 pp.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nankivell, G.R. (1986). The primary mirror for the Mt John 1-metre telescope. DSIR Physics and Engineering Laboratory Report No. 932.

Nankivell, G.R. (1994). The 9.5-inch Cooke objective in the Wanganui Observatory. *Southern Stars,* 36, 1–9.

Nankivell, G., 2002. The Cooke photovisual objective and the 22.9cm refractor at the Carter Observatory, New Zealand. *Journal of the Antique Telescope Society, 24,* 4–8.

Orbell, M. (1995). *The Illustrated Encyclopedia of Māori Myth and Legend*. Christchurch: Canterbury University Press.

Observatory design. *New Zealand Herald*, 24 January 1959.

Orchiston, W. (1991). The ancient history of the New Plymouth 6-inch refractor. *Southern Stars, 34,* 277–284.

Orchiston, W. (1996). *The Enigmatic "Uncle Charlie": Algernon Charles Gifford*. Wellington: Carter Observatory (Information Sheet No. 8).

Orchiston, W. (1998a). A.C. Gifford. In C. Orange et al. (Eds.), *The Dictionary of New Zealand Biography*. *Volume Four. 1921–1940*. (pp. 194–195). Auckland: Auckland University Press and Department of Internal Affairs.

Orchiston, W. (1998b). *Nautical Astronomy in New Zealand*. Wellington: Carter Observatory.

Orchiston, W. (2005). James Cook's 1769 transit of Venus expedition to Tahiti. In D.W. Kurtz (Ed.), *Transits of Venus: New Views of the Solar System and Galaxy* (pp. 52–66). Cambridge: Cambridge University Press.

Orchiston, W. (2016). *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits*. Cham: Springer.

Orchiston, W. (2017a). Cook, Green, Maskelyne and the 1769 transit of Venus: the legacy of the Tahitian observations. *Journal of Astronomical History and Heritage, 20,* 35–68.

Orchiston, W. (2017b). James Hector, Arthur Stock and early astronomy in Wellington. *Journal of the Royal Society of New Zealand, 47,* 88–93.

Orchiston, W. (2017c). The early development of radio astronomy in New Zealand. In T. Nakamura, & W. Orchiston.

Orchiston, W., & Andrews, F. (1995). A cloudy night under the stars: "Overnight Extravaganzas" at the Carter Observatory. *The Planetarian, 24,* 15–19.

Orchiston, W., & Rowe, G. (2017). New Zealand astronomy and the 9 September 1885 total solar eclipse. In T. Nakamura, & W. Orchiston.

Orchiston, W. Carter, B., Dodd, R., & Hall, R. (1998). Selling our southern skies: recent public astronomy developments at the Carter Observatory, New Zealand. In L. Gouguenheim et al., pp. 214–219.

Ramm, D.J., Pourbaix, D., Hearnshaw, J.B., & Komonjinda, S. (2009). Spectroscopic orbits for K giants β Reticuli and ν Octantis: what is causing a low-amplitude RV-resonant perturbation in ν Oct? *Monthly Notices of the Royal Astronomical Society, 394,* 1695–1710.

Rumsey, N. (2002). Garry Nankivell: perfectionist. *Southern Stars, 41,* 14–16.

Sako, T., Sekiguchi, T., Sasaki, M., Okajima, K., Abe, F., and 14 coauthors (2008). MOA-cam3: a wide-field mosaic CCD camera for a gravitational microlensing survey in New Zealand. *Experimental Astronomy, 22,* 51–66.

Seymour, J.B. (1995). The history of the Thomas King Observatory, Wellington. *Southern Stars, 36,* 102–114.

Skuljan, J., Ramm, D.J., & Hearnshaw, J.B. (2004). Accurate orbital parameters for the bright southern spectroscopic binary ζ Trainguli Australis – an interesting case of a near-circular orbit. *Monthly Notices of the Royal Astronomical Society, 352,* 975–983.

Taylor, A.D., Baggaley, W.J., & Steel, D.I. (1996). Discovery of interstellar dust entering the Earth's atmosphere. *Nature, 380,* 323–325.

Thomsen, I. (1950). Proceedings of observatories: Report from Carter Observatory, Wellington, NZ. *Monthly Notices of the Royal Astronomical Society, 110,* 163.

Tobin, W. (1996). The Townsend Telescope—A century of university stargazing. In W. Tobin, & G.M. Evans (Eds.), *Stars in a Cluster* (pp. 78–83). Christchurch: Department of Physics and Astronomy, University of Canterbury.

Tobin, W. (2012). A transit of Venus primer. *Southern Stars, 51,* 3–18.

Toone, J. (2016). Albert Francis Arthur Lofley Jones, D.Sc., OBE, FRAS, FRASNZ (1920–2013). *Journal of the British Astronomical Association, 126,* 83–93.

Warner, D.J., & Ariail, R.B. (1995). *Alvan Clark & Sons, Artists in Optics. 2nd Edition.* Richmond: Willmann-Bell,

Williams, T.R. (2014). Geddes, Murray. In T. Hockey et al., pp. 791–792.

Chapter 21
Alexander William Bickerton: New Zealand's First Astrophysicist?

Gerard F. Gilmore

21.1 Introduction: The Early Years

Alexander William Bickerton (Fig. 21.1; Burdon 1956; Parton 2013) was born in Hampshire, England, in 1842. Perhaps surprisingly for a successful academic, he was a total failure at school. This he later ascribed to his poor memory as his rather cynical impression of current educational techniques convinced him that this was the only attribute necessary for success at school. Whatever the reason, the only things he seems to have retained from his formal education were a strong dislike for the study of classics and a remarkable inability to spell. Both of these skills he retained for life.

Bickerton's reaction to this schooling appeared much later when, in New Zealand, he repeatedly attempted to reorganise the school system to be, as he termed it, in line with the laws of nature. What the relevant laws were is unsure, but it seems that they included a law requiring a scientific and technical education for all, a law banning the teaching of any subjects by rote, and a specific law prohibiting classics. This desire to influence the social and educational system in a country young enough to allow substantial modification was a major motivation behind Bickerton's later decision to come to New Zealand, and was a direct consequence of his early education.

In any event, after working for a time in an engineering office, he set up in business (unsuccessfully) and, at the age of 21, began his scientific education at night classes. He was so successful at these that in 1856, at the age of 24, be began teaching science classes himself, in Birmingham. At the end of his first year he passed the entry examination for the Royal School of Mines with considerable distinction. His record in this examination illustrates both his range of interests and his depth of ability, and is as follows:

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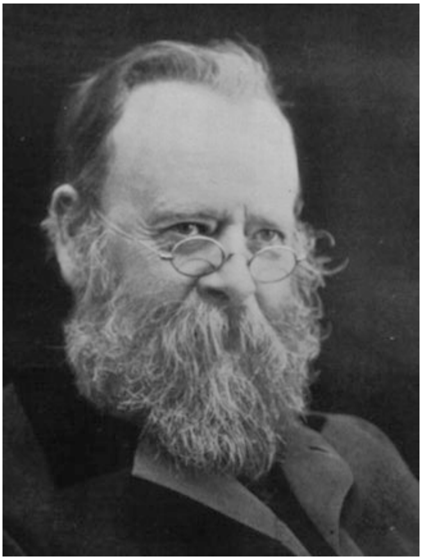

Fig. 21.1 A photograph of Professor Alexander William Bickerton by Hemus Sarony, published in the *Canterbury Times* on 15 June 1910 (*Courtesy* Canterbury Museum, Bishop Collection, ref. 1923.53.500)

National Silver Medal: Applied Mechanics.
National Bronze Medal: Plane and Descriptive Geometry; Mechanical and Machine Drawing.
First Class Queen's Prizes: Building Construction; Acoustics, Light and Heat; Practical, Plane and Descriptive Geometry; Inorganic Chemistry; Mechanical and Machine Drawing; Applied Mechanics.
Second Class Queen's Prizes: Geology; Organic Chemistry; Magnetism and Electricity; Physical Geography.
Third Class Queen's Prizes: Steam; Zoology; Vegetable Physiology; Economic Botany.

While at the Royal School of Mines, Bickerton again presented a series of public lectures, with such success that, when pressure of space threatened his classes, his students voluntarily rebuilt an old factory as a classroom for him. He was in fact the first person to succeed with such classes anywhere in London, a success which was a direct consequence of his realization that he would achieve his aim only by making his classes "… as entertaining as a music hall and as sensational as a circus." In addition he was careful always to discuss only general principles and not delve into detail. He remained a brilliantly successful public lecturer throughout his life, and also took care, judging from published reports of his New Zealand lectures, to arrange a continual series of practical demonstrations, to distract any in his audience whose interest might be waning.

At the Royal School of Mines, in spite of his teaching duties, Bickerton won the Senior Royal Scholarship, with examination marks of 100% in both Geometrical and Mechanical Drawing, 100% in two of the Chemistry papers and 98% in the third, and averaging 98% in his other subjects.

21.2 The Canterbury University College Appointment

In 1874, after teaching for 3 more years at the Hartley Institute he was offered the first Professorship in Chemistry at Canterbury University College, Christchurch. He accepted this post, although also being offered professorships in Australia, Canada, Japan and South America. The terms of his appointment required him to teach Chemistry and its applications to Agriculture, Arts and Manufactures students; to undertake chemical analyses; and also to teach Minerology and Electricity and its applications.

Bickerton arrived in Christchurch in June 1874, at the age of 32, with all the enthusiasm of the dedicated educator and with a new university to mould. Fifty students enrolled for the College's first teaching term of 1874, eleven of whom were female. Canterbury College was co-educational from its origin, partly due to Bickerton's influence. His first chemistry class for 1875 contained his wife and three other females. His first task though was to change the education system by writing a science book for primary school teachers *Materials for Lessons in Elementary Science* in which he exhorted teachers to "… let the pupils assist in experiments and to encourage them in private." (cited in Campbell 1999: 74). He also arranged for science to be introduced into secondary schools.

To increase public knowledge of, and enthusiasm for, scientific subjects, Bickerton began his always popular public lectures, and also arranged public demonstrations whenever possible. One such opportunity was the opening of a new wing of the Canterbury Museum by the Governor, Lord Normanby, in 1877. The occasion was utilised by Bickerton for technological propaganda, by demonstrating the first use of electricity in public lighting in Christchurch. A powerful searchlight was erected, which succeeded in illuminating the Cathedral, half a mile away. Many other experiments were demonstrated, including a large container of water, which had been thoughtfully electrified by the Professor, as an aid to the teaching of practical electricity to the crowd. It was typical of Bickerton's inability to conform to expected patterns of behaviour that he neglected to warn the audience of this modification.

At this time Bickerton was an active campaigner for educational reform in New Zealand, and on several occasions illustrated his displeasure with the attitudes of the University Council by public comment. The only effect of this was to confirm the dislike which the more conservative Council members held for Bickerton as a consequence of his social opinions.

As with the educational system, Bickerton wished to reorganise society, and was a convinced socialist. Such opinions were, to say the least, not socially acceptable in the Christchurch of the 1870s to the social classes which populated the University Council.

At this time, Bickerton had his only direct involvement in the political system, when elected to the City Council in September 1877. He immediately took an active interest, joining several committees and proposing many motions. Included among these was a recommendation to the Government that the unemployed be paid a benefit, a remarkably liberal concept for the time. However, his only practical success as a Councillor was a by-law which restricted horse traffic turning into Colombo and Hereford Street at no more than walking pace. His initial enthusiasm for public service soon waned, and by mid-1878 his attendance at Council meetings was very irregular. This seems to have afflicted most of the Councillors of the time, for in September 1878, four consecutive meetings were postponed due to a lack of a quorum. The quorum at the time was two Councillors! Eventually seven of the eight Councillors, including Bickerton, resigned, and his involvement with public politics ceased.

At the same time, and perhaps as a cause of the lack of enthusiasm for city affairs, Bickerton was active in University politics, and he campaigned for professorial involvement in University policy making. As a result of these conflicts with the University Council, a Professorial Board was established, in 1878, with Bickerton as its first Chairman, and its role was to advise the Council on matters of academic importance.

In spite of this considerable success, Bickerton was becoming less and less popular with those in authority, including his companions on the Professorial Board, and it was only the substantial weight of public opinion in his support which enabled him to survive his incompetence as his own advocate. The support was due in part to his success as a public teacher *cum* entertainer, in part to his outspoken support for the 'common man' and defiance of society's esteem, and in part to the popularity of his 'Partial Impact Theory' (see Sect. 21.3, below) which was developed at this time.

He became popular with the students by setting up his home in the sandhills near New Brighton, and establishing this as an undergraduate centre of social life. Meanwhile, he named his property Wainoni (meaning 'a bend in the water'), as his home was close to a bend in the Avon River.

Meanwhile, Bickerton became continually less popular with established society by his unorthodox manners, his outspoken socialism (he is the only university professor to have been President of the Tailoresses and Pressers Union, at least to date) and his refusal to accept biblical authority as absolute. He was a convinced evolutionist, itself a heinous offence in Christchurch at the time, and regularly clashed with established religion. On one such occasion, an Anglican minister demanded that Bickerton reread the bible, and then decide if he still refused to accept its authority. After he had done so, Bickerton informed the minister that he was so impressed with the gospels that in the next census he would register as a Christian. The outraged minister promptly demanded to know what he had registered as previously. Bickerton replied, 'The Church of England'. Such a lack of tact did little to endear him to established authority.

This situation continued until, in 1894, when he requested the services of an additional assistant, the opportunity was taken to launch a full enquiry into the management of the Department of Chemistry and Physics. A special committee interviewed Bickerton, Cook (the Professor of Mathematics), and several current and former students in the Department. Among these were J.A. Erskine and Ernest Rutherford (Fig. 21.2), who at the time were conducting research in Bickerton's laboratory.

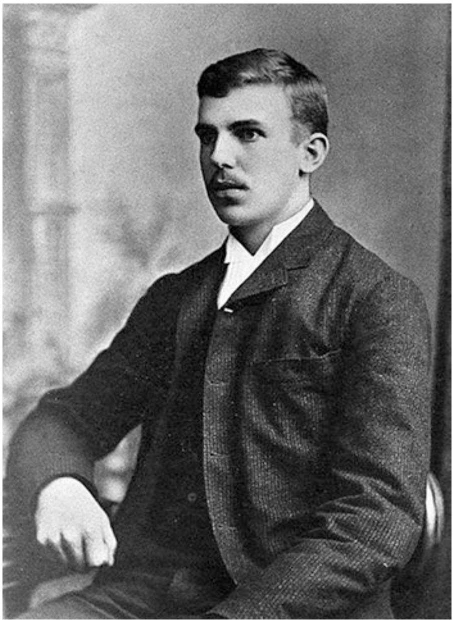

Fig. 21.2 Ernest Rutherford, ca 1892, when he was a student and researcher under Bickerton (*Courtesy* John Campbell)

The almost unanimous opinion of these people was that Bickerton was doing a good job under difficult conditions. (It is interesting to speculate how many university staff would be rated so highly by their students today!) In spite of this, and Bickerton's teaching record (his students took more Senior Scholarships and First Class Honours degrees than did all other science students in New Zealand in the 1890s) the committee of inquiry in a bound and printed 108-page report, recommended that he be relieved of the teaching of Physics. The justification was that the Laboratory was untidy (this was the reason for the request for additional staff) and that his graphical calculation technique (see below) was unsuitable for Honours level students. Again, public opinion intervened to save Bickerton.

In 1898 Bickerton, convinced that a life-style that was in harmony with the laws of nature was the only way to live, set up a 'Federative Home' at Wainoni. Those living there who went out to work brought money in, while some of the women stayed home, to cook, clean and raise the children (Campbell 1999). To further outrage society Bickerton gave the 1898 degree day speech, in his capacity as Chairman of the Professorial Board, on the desirability of this way of life. The reaction of the Council followed in 1899, when Bickerton applied for a 1 year leave of absence to further his astronomical research. He was informed not only that his leave was granted, but that upon his return the care of the Department of Physics would be taken from him.

Bickerton spent 1900 in England, promoting his theory of the partial impact of two stars as an explanation for novae, the formation of Solar Systems, and galactic evolution. His theory had practically no impact on the astronomical world, but received substantial publicity in newspapers and popular science journals. As today, such publications were prepared to listen to one who claimed to know it all, in preference to the qualified hypotheses advanced by the more scientifically reputable who were interviewed.

Bickerton's fall at the hands of the group on the University Council who were most outraged by his behaviour occurred upon his return. In 1902 he was relieved of his duties for alleged poor management of the Department, but it is more likely, given that there was no apparently major change in the Department since the 1895 enquiry, that hostility to his opinions was the true reason.

In order to make a living, Bickerton converted the Wainoni commune—which had failed in the interim—into an amusement park (see Baker 2004). This was for some time the highlight of the Christchurch entertainment scene (Fig. 21.3), gate takings being up to £400 on a good day. It included an art gallery, aquarium, Punch and Judy show, merry-go-round, sideshows, fireworks displays and dramatic theatre. The high point of this was a mock naval battle on a small pond which concluded with the eruption of the 'Wainoni geyser'. This geyser was based on an explosive called Splitlite, which Bickerton had invented, and spouted 50 ft. into the air when triggered. A zoo was later added, but Mrs. Bickerton complained about the roaring of the lions at night.

The popularity of this park waned as the cinema became more common, and Bickerton was again in need of money. He nominated himself for an Emeritus Professorship, without success, in spite of a glowing testimonial from Rutherford,

Fig. 21.3 A popular Punch and Judy Show at Wainoni Park in 1906 (*Weekly Press* 1906)

who had just received his Nobel Prize. He then decided that another trip to England would ensure acceptance of his Partial Impact Theory, and the solution to all his problems. The expenses for this trip were raised by a public subscription organised by the Canterbury Trades Council, subsidised by the New Zealand Government and supported by the Governor-General of Australia. If nothing else this illustrated Bickerton's imaginative attitude to public funding of pure science, and his remarkable gift of persuasion.

There is a (possibly apocryphal) story told by John A. Lee that Edwin John (Ted) Howard (1868–1939; Fig. 21.4), who was Chairman of the Trades Council at that time, and later a Labour M.P., had care of these funds. To prevent their being seized by creditors, he tied a wallet with the money to a long stick, and handed it to Bickerton when the ship was too far from the wharf to be reached by the creditors.

In London, under Rutherford's patronage, Bickerton lectured on his Partial Impact Theory at all of the important institutions, except the Royal Astronomical Society. This organization consistently declined his applications for membership and refused him permission to present his theories at their meetings.

The reaction of the other scientific societies, while more polite, was not much more enthusiastic. It was repeatedly pointed out that the probability of stellar collisions was extremely small, that even if they did collide, there was no evidence or rigorous support for the consequences predicted by the theory (see below), and that Bickerton's theory of Cosmic Evolution was, at best, wild speculation. Bickerton presented his theory in a series of papers to the British Astronomical Association, none of which, however, contained more than vague generalities and unsupported assertions. The likely reason for this is discussed below.

Fig. 21.4 Ted Howard (https://en.wikipedia.org)

Shunned by both professionals and amateurs alike, Bickerton established his own organization, the London Astronomical Society, to propagate his theories. The resolutions of this society received a similar response in the astronomical community to those of Immanuel Velikovsky today, with a small group of converts, and a considerably larger group of sceptics.

Bickerton's reaction to the massive yawn which greeted his organization is typical of his inability to accept disbelief in his audience. In 1914 the London Astronomical Society circulated a protest at the neglect of the theory of Partial Impact by astronomers. Bickerton noted that "… over 100 of these protests were sent to observatories, and no objection was raised." A less biased observer might conclude that each protest was suitably filed when received.

In spite of Bickerton's efforts, very little notice was taken of his theories. Every time a new nova was observed he, with considerable newspaper publicity, claimed that his Partial Impact Theory was proven. However, he made no effort to relate new spectroscopic information to his theory or carry out detailed calculations of the physical consequences of the theory. The only change in his life was his remarriage, in 1920, at the age of 79.

In 1928 Nova Pictoris (1925) was observed to have split into two stars, and was hailed as conclusive proof of Bickerton's Partial Impact Theory. While the more conservative waited for confirmation (which contradicted the observation), Bickerton was hailed as a prophet. The New Zealand Government granted him an annuity, while a repentant—or at least, different—Canterbury University Council, under the influence of Ted Howard, made him an Emeritus Professor. He died 4 months later on 21 January 1929 and was cremated. A few days before Bickerton's death, Sir Ernest Rutherford was moved to describe him as a "… most lovable character … [and] unusually clear and stimulating, whose enthusiasm and versatility were of great value in promoting an interest in science in a young community." (*The Times* 1929).

However the story does not end there. His ashes were forwarded to Ted Howard, with a request that he be buried in the wall of the Great Hall at the University. This was opposed by one of the Councillors, the Bishop of Christchurch, who did not want the ashes of an unrepentant Bickerton to lie in 'his' Hall. Ted Howard therefore buried them in a sandhill, but fearing that they might be discovered by a scavenging dog he later dug them up and deposited them, for 2d per day, in the railway left luggage lockers. Howard was of the opinion that this was the only time Bickerton's rent was ever paid in advance!

Eventually, because of the Bishop's continuing opposition, Howard threatened to deliver the ashes to the Bishop's palace to dispose of. It seems that the Bishop was even less enthusiastic about having a Bickerton in his garden than in his Hall, so he relented. The ashes of Alexander William Bickerton, first Professor of Canterbury University College, were interred in the Great Hall on 23 June 1929. Meanwhile, a portrait by Petrus van der Velden is housed in the Christchurch Art Gallery Te Puna o Waiwhetu (Fig. 21.5) and another Petrus van der Velden oil, owned by the University of Canterbury, originally was displayed in the Physical Sciences Library when the University was still at the old town campus site.

Fig. 21.5 The oil painting of Bickerton by Petrus Van der Velden that is now in the Christchurch Art Gallery (https://en.wikipedia.org)

21.3 Bickerton's Partial Impact Theory

21.3.1 Novae and Variable Stars

Bickerton's theory of the consequences of the collision of two stars can be appreciated only in terms of astronomical knowledge of the time. He pictured a star as a large solid body, with a cool crust and incandescent core, much more like modern pictures of the Earth than the Sun. The collision of two stars was then expected to be a large-scale analogue of the collision of two dense solid objects, rather than two gaseous spheres. Bickerton's favourite analogy was with the collision of two cannon balls in flight.

The essential feature of Bickerton's hypothesis was that, in such a collision, the two stars would neither elastically rebound (like billiard balls) nor would they totally disintegrate. Rather, he expected those parts of the star which directly collided to be sheared off from the remaining mass, which would be relatively unaffected and would continue its motion as a single body. The portions of the two original stars which did collide were postulated to form a discrete 'Third Body', whose evolution led to a variety of observed phenomena. A more accurate analogy is then the slicing of a pat of butter with a hot knife, while Bickerton's illustration of the process is shown is Fig. 20.10 (in the previous chapter).

The Third Body is formed from equal masses of each of the two original stars and remains exactly halfway between them (and technically at rest at the position of the centre of mass). The initial orbital velocity of that part of the two stars which has formed the Third Body is converted into heat, so that the Third Body becomes a very hot ball of gas. It is straightforward to calculate what this temperature would be for a given velocity of the stars before collision. For example, if an object were dropped into the Sun from infinity (or any suitably large distance), it will hit the Sun with a velocity of about 300 miles per second (there being no metric units in Bickerton's day). The collision of two balls of lead at this velocity would heat them to a temperature ~ 9×10^8 °C. Now a characteristic of the motion of particles in a hot gas is that a particle typically has a velocity which is inversely related to its atomic weight, that is, lighter elements have faster molecules at a given temperature than do heavy elements of the same temperature.

Bickerton used this property to develop his theory of Selective Molecular Escape, which determines the evolution of his Third Body. As the Third Body expands, due to the pressure of its high temperature, he expected that the dominant direction of motion of each atom would become directed away from the centre of the hot gas. Therefore, the fastest (lightest) atoms will move away from the less fast atoms. This, according to Bickerton, then results in a shell of hydrogen at the outer surface, followed by a shell of helium, and so on. The heaviest elements (iron) need not escape at all, but may remain behind as a solid remnant.

The remaining heavy elements then oxidize, coalesce into droplets, and grow by accretion. These can then form any of the following sequence (which are listed in order of increasing mass):

1. comets
2. meteor swarms
3. star clusters
4. nebulous stars
5. Wolf-Rayet stars

The presence of star clusters in this list was justified by Bickerton because he believed that the stars in these clusters were unlike other stars as they were of very small mass.

Outside this core, the expanding shells of gas form a planetary nebula, and dissipate into space, while the initial luminosity of the Third Body after impact forms a nova outburst.

While Bickerton's Selective Molecular Escape process is nowadays easily shown to be totally incorrect,[1] in view of the knowledge of his time it would have been of interest to calculate its properties in some detail. Bickerton, however, lacked the necessary mathematical skills to do this, and was forced to state it as a 'reasonable' possibility, rather than to justify it. By accepting both this process and his expectation of the shearing off of slices of each star during a collision, Bickerton was able to 'explain' a wide variety of phenomena. He estimated that, where the impact involved the coalescence of more than about one-third of the mass of the original stars, the two fuse together into a single rotating gaseous nebula. If the impact involves a smaller fraction than this, the remaining segments of the stars carry on

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[1] For the molecules to attain the velocity distribution appropriate to a high temperature, a very large number of collisions of each molecule with others is necessary. In this case, all molecules will expand together, with faster molecules undergoing more collisions rather than escaping preferentially. Bickerton's conclusion is therefore inconsistent with his assumptions.

unaffected, apart from a large scar which reveals their hot core, and a consequent rotation (see Fig. 20.10). If their velocities exceed the escape velocity of the system, allowing for the gravitational effect of the third body, they will drift apart and form two independently variable stars.

The varieties of variable stars are then all explainable with combinations of rotating scarred stars, stars interacting with remnant meteoritic swarms, or collisions of massive stars with much smaller bodies. An example of Bickerton's ingenuity is his model for the irregular variable SS Cygni. This was postulated to be a double star partially and varyingly eclipsed by a meteor swarm. At various times one or both of the stars are seen behind or through the swarm.

The spectroscopic properties of the model predict the superposition of narrow absorption lines on broad emission bands, with both gradually dying away without change of width. The emission is broad because of the wide range of velocities of atoms visible in the expanding nebula, while the absorption is caused only by those atoms in the line of sight to the central source. It is therefore narrow.

21.3.2 Theory of the Solar System

Bickerton had two theories for the origin of the Solar System. The first (Bickerton 1879a, b, c, d, 1880a, b, c) concerned the near head-on collision of two massive objects to form a spindle-shaped rotating nebula. This nebula condensed to form the Sun, while the bulk of the two original masses escaped into space. Many solid fragments were thrown off in the collision, into approximately coplanar orbits. As these orbit through the nebula, gas drag affects the orbit in several ways. The drag due to outward motion of the nebula slows the motion, making the orbit more circular. Stationary gas drag, which is maximized at perihelion, tends to decrease the aphelion distance without affecting the perihelion, thus reducing eccentricity.

When the orbit is nearly circular, the body will tend to spiral in until the (dissipating) nebular density is insignificant.

Because the resistance per unit mass is greater for light objects, these spiral in farthest and orbit nearer the Sun. So the inner planets are less massive than the outer ones. The orbiting fragments will accrete all material inside their aphelia, which will lead to a uniform direction of rotation, in the direction of orbital motion. Capture of satellites will also occur at this time.

This theory was discarded by 1880, and replaced by the complete impact of two stars, each of which was presumed to already have a family of randomly orbiting planets. The impact led to the coalescence of the two original stars to form the Sun, and threw the planets into orbits which all rotated in the same direction in the same plane. These orbits would be circularized as in the former theory.

This second theory, as it requires the previous existence of *two* families of planets, is in fact a theory of the present orbital properties of the Solar System, and not of its origin. In addition it is incorrect. Bickerton's first theory, which he rejected, was certainly ahead of its time, and contained all of the fundamental ideas of the theory proposed by the Americans Thomas Chrowder Chamberlin (1843–1928; Chamberlin 1932) and Forest Moulton (1872–1952; Gasteyer 1970), which later became of considerable importance (Brush 1978; Hetherington 1994). Had Bickerton carried out a detailed analysis of his first theory of the Solar System in 1879, he could have made a substantial contribution to the astronomical knowledge of the time.

21.3.3 Origin of the Milky Way and Nebulae

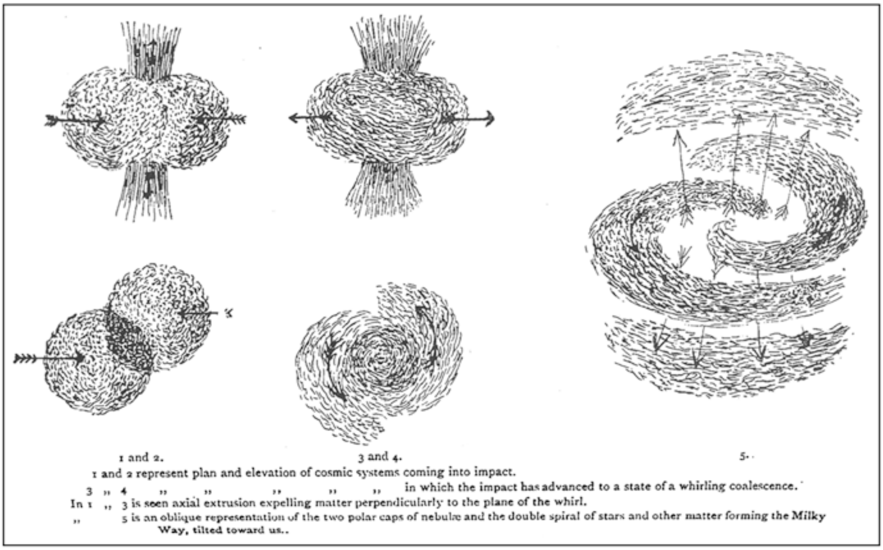
Around 1890, Bickerton extended his Partial Impact theory to the collision of two galaxies. This theory however differs from his theories of the Solar System and variable stars in that, even with the knowledge of the time, it contains many major and obvious errors and inconsistencies.

Two systems of stars (elliptical galaxies, clusters?) each of approximately the same mass as our Galaxy, are assumed to collide. As they do, the rate of stellar collisions increases, especially near the galactic nuclei, and a large and hot nebula is formed. This is prevented from expanding in the plane of the collisions by the pressure of the infalling system, which leads to gas expulsion to the new galactic poles. The remainder of the system becomes a disc of stars, eventually forming a ring with a near-empty centre as the gas dissipates, forming a nebulous cap at the poles. Collisions of smaller bodies lead to substantial interstellar dust, and consequent obscuration. Thus we cannot see other galactic systems (extragalactic nebulae were not recognised as such at that time). This is shown in Fig. 21.6.

This theory was then extended to a model of an infinite Universe. In this, stars radiate light which is eventually all absorbed by dust, which is consequently heated. Stars collide, and, by selective molecular escape, hydrogen escapes at high velocity. This velocity is converted to a potential energy as the atoms leave the galactic system and the hydrogen cools. Collisions of the hydrogen gas with the interstellar dust transfer energy to the hydrogen atoms. This energy was originally radiated by the star as the hydrogen cloud contracted (nuclear fusion models of stellar energy being unknown at the time) and is now reabsorbed by the hydrogen as velocity of escape from the galaxy.

This principle was the basis of Bickerton's perpetual motion machine for the Universe. In this theory, the process above continues until significant amounts of hydrogen have collected away from the galaxy in regions of low gravitational potential. Eventually there is sufficient hydrogen to form a new galaxy and so on. The process then involves the collapse of a gas cloud to form a star, with release of gravitational potential energy as light and heat. Two stars collide, releasing hydrogen, which (via the interstellar medium) reabsorbs the energy and transfers it back to gravitational potential. Sufficient hydrogen is processed in this way to allow new star formation and so on.

This theory contains so many inconsistencies that Bickerton's true meaning is not clear. Certainly however, none of his postulated events could occur, even if we



1 and 2 represent plan and elevation of cosmic systems coming into impact.
3 " 4 " " " " " in which the impact has advanced to a state of a whirling coalescence.
In 1 " 3 is seen axial extrusion expelling matter perpendicularly to the plane of the whirl.
" 5 is an oblique representation of the two polar caps of nebulæ and the double spiral of stars and other matter forming the Milky Way, tilted toward us..

Fig. 21.6 A diagram illustrating the evolution of the galactic system (after Bickerton 1894a)

accept a high rate of stellar collisions and the Selective Molecular Escape mechanism. For example, the volume of space between stars is so great compared to the size of a single star that the gas from remnant Third Bodies would fill all of space, not only a small area. In fact, the gas would fill a shape defined by the gravitational field of all the stars in the system. This property also rules out his postulated collection of cool hydrogen in regions of low gravitational potential. These regions occupy almost the whole of space, which is the region that any such mass of cool hydrogen would spread over, and not a narrow volume above the Galactic poles.

21.4 Discussion

21.4.1 The Significance of Bickerton's Theories

Bickerton's Partial Impact Theories had effectively no impact on the scientific community at the time. The main reason for this is undoubtedly his inability to present detailed calculations supporting his many assertions, and this is discussed briefly below in Sect. 21.4.2.

In terms of the physics of the time however, Bickerton's total neglect of, for example, thermodynamics and ionization properties, and many other obvious branches of chemistry and physics with which he should have been familiar, was inexcusable. It was regularly explained to him that the stellar number densities known, even with the distance scales of the time, made stellar collisions exceedingly unlikely. Similarly, any person with even a general concept of gravitational potentials dismissed his theory of perpetual Cosmic Evolution. There can be no doubt that the Royal Astronomical Society, and the hundreds of observatories who ignored his pamphlets, were scientifically justified in doing so. In those few cases when distinguished scientists (Sir James Jeans among then) did suggest that his ideas needed to be made specific and analyzed more carefully, Bickerton ignored their reasoned remarks as blind bigotry. The true zealot repeatedly had recourse to the popular press and became systematically ignored by knowledgeable and reputable scientists.

As so often however, the wheat went with the chaff though, ironically, it was Bickerton himself who rejected what was probably his only worthwhile contribution to pure research. Bickerton's first theory of the formation of the Solar System was certainly ahead of its time, and did contain the important features of the Chamberlain-Moulton Theory, which later had considerable impact. The historical significance of both this theory, and Bickerton's, have been briefly discussed by Jaki (1978) to whom the reader is referred for further details.

21.4.2 The Graphics of Partial Impact

The method that Bickerton used to calculate the consequences of a stellar impact, as well as other physical problems, was graphical rather than analytical. This method was described in a series of articles in *Knowledge* (Volume 38, 201–206, 246–249, 262–267, 1915) and is simply a graphical presentation of Newton's laws.

By the graphical representation of various physical relations (e.g. an hyperbola represents an inverse square law), he was able to investigate kinematical interactions by careful geometrical construction, without recourse to the equations which his curves represented. By considering all variables in terms of unit mass, he was then able to estimate other parameters from the areas of curves. An example of this is his use of the five curves of gravitation, representing force, kinetic energy per unit mass (designated kinetol), velocity, duration, and of time.

The curve of force, being related to the gravitational law, is an inverse square relationship. The kinetic energy/unit mass is the product of gravitational force and the distance travelled. This is therefore a rectangular hyperbola, and its value at any point is the area under the gravitational curve between that point and infinity. The velocity curve is readily deduced from the kinetic energy curve, and represents the momentum of unit mass. The inverse of the velocity curve is the curve of duration, and is therefore a parabola. The area under this curve between zero and any point then represents elapsed time.

This process is simply the graphical representation of simple calculus, as Bickerton realised. His technique of evaluating the areas under his curves, and the relations between less obvious parameters was ingenious rather than rigorous. He carefully cut out the required figure from his diagrams, and weighed the paper on a chemical balance. By comparison with the weight of the corresponding figure for a unit mass, he derived the value required.

His attitude to more rigorous mathematical techniques is given in his paper in *Knowledge*:

> All these curves have been treated with the calculus by different mathematicians, but this mode is rarely of value in cosmological problems.
>
> In these articles the problems will only be treated geometrically. The whole of the vast number of problems involved in the new cyclic cosmology have been solved geometrically. They have frequently been checked by the calculus, and by weighing the tracing-paper of the curve area with a chemical balance.

Bickerton's tendency to avoid mathematical analysis in favour of geometry is no doubt a consequence of his undoubted ability as a draughtsman, coupled with an apparently total ignorance of calculus. His adherence to such at best approximate methods of calculation was one of the chief criticisms (the other being the dirty state of the laboratory) of the committee of enquiry into the teaching of physics and chemistry in 1895.

The lack of support for any conclusions derived from such a method also seems to be the main reservation voiced by two other noted New Zealand astronomers, Arthur Beverly (1822–1907; Campbell 2001) and Charlie Gifford (1861–1948; Jenkinson 1940), in their letters to Bickerton on the subject (as quoted by him). It seems likely that Bickerton's mathematical incapacity was the real justification for his determination to force the general principles of Partial Impact on the scientific world by means of popular lectures and newspaper articles. He repeatedly failed to submit any description of his theory containing more than vague generalities for publication in the scientific literature. These were of course refused, with the advice that a more scientific analysis would be acceptable.

In 1917 Sir James Jeans advised Bickerton that "… what is needed is more exact mathematical knowledge as to what masses of matter actually do, rather than speculations as to what they might do." (cited in Gilmore 1982: 103). While in the same year Professor Alfred Fowler, Secretary of the Royal Astronomical Society, wrote:

> I am sorry that you have not adopted my suggestion that you should write a paper dealing with some of the features of the recent nova. I feel sure that this would give you the best chance of a hearing. It is but little use to talk of generalities, as the main points of your theory are well known. (Gilmore 1982: 103).

The neglect of such advice from the very people he most wished to impress is explicable only if Bickerton's knowledge was insufficient for him to heed it, as indeed it was.

It should not be imagined however that the graphical method was entirely unsuitable for the teaching or understanding of physics. In his evidence to the commission of enquiry, Rutherford noted that the graphic method was useful in many cases, and was underrated. He agreed however that analytical techniques were more appropriate for research purposes.

21.5 Conclusion

Alexander Bickerton led a most interesting life and career. He was undoubtedly extremely intellectually capable, but suffered from a lack of adequate formal education. As a result, his research was superficial, and suffered from fundamental weaknesses which prevented its serious discussion by those qualified to comment. His frustration in his attempts to modify society in line with his beliefs led him to a fixation with his astronomical theories, to the detriment of his teaching career.

In spite of the failure of both of the major tasks of his life, he certainly had a significant effect on the intellectual life of the Canterbury settlement. It is reasonable to assume that without Bickerton's approach and popularity, technical and scientific education in Canterbury would have been delayed for many years.

Bickerton's greatest success was undoubtedly as a teacher, and the inspiration of a Rutherford is undisputable proof of this. The best summary of his career and impact is perhaps given by the review of his *Romance of the Heavens* in the *Pall Mall Gazette* (18 June 1901): "The practical astronomer will perhaps condemn the (Partial Impact) theory as being too wildly speculative … However, those of us who enjoyed Jules Verne in boyhood will enjoy Professor Bickerton in middle age."

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References

Baker, T.D. (2004). *Professor Bickerton's Wainoni*. Christchurch: printed by the author.

Bickerton, A.W. (n.d.-a). *Atoms, Suns, and Systems*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-b). *Genesis of Worlds and Systems*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-c). *Partial Impact Theory of Cosmic Evolution - A Summary*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-d). *Reply to Critics*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-e). *The Birth of Worlds*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-f). *The Evidence and Scope of the Theory of Impact*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-g). *The Latest Astronomical Heresy*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (n.d.-h). *The Theory of Cosmic Evolution*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (1874). *Report of a Lecture on Matter (Six Lectures)*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (1878a). On temporary and variable stars. *Transactions of the New Zealand Institute, 11,* 118–124.

Bickerton, A.W. (1878b). Partial Impact: a possible explanation of the origin of the Solar System, comets, and other phenomena of the Universe. *Transactions of the New Zealand Institute, 11,* 125–132.

Bickerton, A.W. (1879a). Partial Impact (Paper No. 3): on the origin of the visible Universe. *Transactions of the New Zealand Institute, 12,* 175–181.

Bickerton, A.W. (1879b). Partial Impact (Paper No. 4): on the general problem of stellar collision. *Transactions of the New Zealand Institute, 12,* 181–186.

Bickerton, A.W. (1879c). On the genesis of worlds and systems. Presidential Address, April 3, 1879. *Transactions of the New Zealand Institute, 12,* 187–197.

Bickerton, A.W. (1879d). On the birth of nebulae. *Transactions of the New Zealand Institute, 12,* 197–205.

Bickerton, A.W. (1880a). On the causes tending to alter the eccentricity of planetary orbits. *Transactions of the New Zealand Institute, 13,* 149–154.

Bickerton, A.W. (1880b). The origin of the Solar System. *Transactions of the New Zealand Institute, 13,* 154–159.

Bickerton, A.W. (1880c). The origin of double stars. *Transactions of the New Zealand Institute, 13,* 160–164.

Bickerton, A.W. (1880d). On a simple method of illustrating the motions of the Earth. *Transactions of the New Zealand Institute, 13,* 164–166.

Bickerton, A.W. (1880e). Probability of impact. *Transactions of the New Zealand Institute, 13,* 166–169.

Bickerton, A.W. (1893). Some recent evidence in favour of impact. *Transactions of the New Zealand Institute, 26,* 464–476.

Bickerton, A.W. (1894a). *A New Story of the Stars*. London, Swan-Sonnenschein and Co. [Reprinted in 1896, 1900.]

Bickerton, A.W. (1894b). The immortality of the cosmos: being an attempt to show that the theory of dissipation of energy is limited to finite portions of space. *Transactions of the New Zealand Institute, 27,* 538–545.

Bickerton, A.W. (1894c). Synoptic statement of the principles and phenomena of cosmic impact: prepared for the criticism of scientific men and societies. *Transactions of the New Zealand Institute, 27,* 545–558.

Bickerton, A.W. (1894d). On an oversight of Croll's mode of lengthening the age of the Sun's heat. *Transactions of the New Zealand Institute, 27,* 558–559.

Bickerton, A.W. (1898). *The Romance of the Earth*. London, Swan-Sonnenschein and Co.

Bickerton, A.W. (1900). Cosmic evolution. *Philosophical Magazine, 50,* 216–223.

Bickerton, A.W. (1901). *The Romance of the Heavens*. London, Swan-Sonnenschein and Co.

Bickerton, A.W. (1902). *The Perils of a Pioneer*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (1907). *The Epic of Creation*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (1908a). *COSMOPHYSICS: Journal of International Astrophysics:-Progress Special - the Birth of Worlds.* Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (1908b). *COSMOPHYSICS: Journal of International Astrophysics:-Progress Special – Cosmic Evolution*. Christchurch: Wainoni Postal Publishing Co.

Bickerton, A.W. (1911a*). The Birth of Worlds and Systems*. London, Swan-Sonnenschein and Co.

Bickerton, A.W. (1911b). The new astronomy. *Knowledge, 34,* 362–367, 379–383, 413–418, 453–459.

Bickerton, A.W. (1915). The Graphics of Gravitation. *Knowledge*, 38, 201–206, 246–249, 262–267, 317–324.

Brush, S.G. (1978). A geologist amongst astronomers: the rise and fall of the Chamberlin-Moulton cosmogony. *Journal for the History of Astronomy, 9,* 1–41, 77–104.

Burdon, R.M. (1956). *Scholar Errant*. Christchurch: Pegasus Press.

Campbell, J. (1999). *Rutherford Scientist Supreme*. Christchurch: AAS Publications.

Campbell, R.N. (2001). Arthur Beverly 1822–1907. *Southern Stars, 40*(3), 23–24.

Chamberlin, R.T. (1932). Biographical Memoir of Thomas Chrowder Chamberlin. *Biographical Memoirs, National Academy of Sciences, 15,* 307–407.

Gasteyer, C.E. (1970). Forest Ray Moulton. *Biographical Memoirs, National Academy of Sciences, 41,* 341–355.

Gilmore, G. (1982). Alexander William Bickerton: New Zealand's colourful astronomer. *Southern Stars, 29,* 87–108.

Hetherington, N.S. (1994). Converting an hypothesis into a research program: T.C. Chamberlin, his planetesimal hypothesis, and its effect on research at the Mt. Wilson Observatory. In G.A. Good (Ed.), *The Earth, the Heavens and the Carnegie Institution of Washington: Historical Perspectives After Ninety Years* (pp. 113–123). Washington: American Geophysical Union.

Jaki, S. (1978). *Planets and Planetarians*. Edinburgh, Scottish Academic Press.

Jenkinson, S.H. (1940). *New Zealanders and Science*. Wellington: Department of Internal Affairs.

Parton, H.N. (2013). Bickerton, Alexander William. In *Dictionary of New Zealand Biography. Te Ara – the Encyclopedia of New Zealand*, updated 5 June 2013 (http://www.TeAra.govt.nz/en/biographies/2b23/bickerton-alexander-william)

The Times, 25 January 1929.

Weekly Press, 17 January 1906.

Chapter 22
New Zealand Astronomy and the 9 September 1885 Total Solar Eclipse

Wayne Orchiston and Glen Rowe

22.1 Introduction

For those of us who have witnessed a total solar eclipse, it remains an unforgettable spectacle and one of the most remarkable astronomical events open to naked eye observation, yet for centuries these eclipses were viewed by many as portends of death or destruction (Zirker 1984), or were interpreted in terms of terms of heroic conflicts between major mythological characters. To the Māori of New Zealand, the Sun was *Te Ra*, one of the grandchildren of *Ranginui* (the Sky Father) and *Papatuanuku* (the Earth Mother), and an eclipse of the Sun, termed *Ra Kutia*, occurred when *Te Ra* was "… being attacked and devoured by demons, from which attacks, however, it invariably recovers." (Best 1955: 20).

Why observe total solar eclipses? As Sir Robert Ball (1840–1913; Marché 2014) points out:

> It may seem strange to say that a great part of our knowledge of Solar phenomena has been derived with the assistance of the Moon. The Sun-spots, no doubt, can be observed and studied without any help from our satellite; but for our knowledge of the appendages outside the photosphere of the Sun, we are primarily indebted to assistance rendered by the Moon. In fact, it was by such help that the existence of those flames which leap from the Solar surface, and of the glorious halo known as the corona, were discovered. (Ball 1910: 122).

This was written in 1910, and Ball (1910: 122) went on to note that it was by then possible to observe the chromosphere and prominences without the aid of an eclipse—thanks to the invention, by George Ellery Hale (1868–1938; Florence 2014), of the

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spectrohelioscope (see Abetti 1957: 55–56). However, the corona remained the exclusive preserve of the total eclipse observer until Bernard Lyot (1897–1952; Baum 2014a) perfected the coronagraph in 1930 (Abetti 1957: 194–196). Even though the importance of total solar eclipses has diminished since these innovative instruments were introduced, Pasachoff and other professional astronomers still find viable research programs to conduct during eclipses (e.g. see Golub and Pasachoff 2009), and these spectacular astronomical events also continue to captivate a growing band of avid amateur ‘eclipse-chasers’.

Between Māori settlement of Aotearoa/New Zealand in about AD 1200 (see Lowe 2008) and the arrival of Cook in 1769 there were ten total solar eclipses that were potentially visible from the North Island or South Island of New Zealand (Orchiston 2016: 47), but the first to occur following the European settlement of New Zealand was in 1885 (An earlier eclipse 1936).

This chapter documents the individuals who successfully observed the 1885 total solar eclipse, their instruments and their observations, discusses the place of the 1885 eclipse in the overall pattern of professional and amateur astronomy in New Zealand between 1874 and 1885, and examines the contribution that this particular eclipse made to our international understanding of solar physics. But first, let us provide a context within which to view this eclipse by examining the development of coronal science during the nineteenth century.

22.2 Coronal and Chromospheric Science Prior to the 1885 Eclipse

By 1885 rapid advances had been made in solar science thanks to a succession of earlier well-observed total solar eclipses (e.g. see Golub and Pasachoff 2009; Pearson 2009; Ranyard 1879). The most significant of these are discussed below.

The 7 July 1842 eclipse (Fig. 22.1) was visible from Europe and Russia and was the first to be subjected to intense scientific scrutiny. It was the Royal Astronomical Society’s Francis Baily (1774–1844; Luminet 2014) who assigned the term ‘corona’ (meaning ‘bright glory’) to the whitish light surrounding the Sun’s disk at the time of totality (Mitchell 1923: 133). Meanwhile Astronomer Royal George Biddell Airy (1801–1892; Satterthwaite 2014) observed ‘saw-tooth’ prominences and named the thin red layer surrounding the black disk of the Sun the ‘sierrra’. The Frenchman François Arago (1786–1853; Ten 2014) noted structure within the corona and tried to calculate the heights of the prominences, while Russia’s Otto Struve (1819–1905; Batten 1988) estimated the height of the corona and coronal streamers (see Proctor 1871: 322–323; Ranyard 1879: 508; Young 1895: 254). Although it was noted that the corona first appeared on the side of the Moon opposite the vanishing crescent, at the time observers did not realize that this was proof that the corona was a solar as opposed to lunar or terrestrial feature. This realization would only come later (see Chambers 1902: 57).

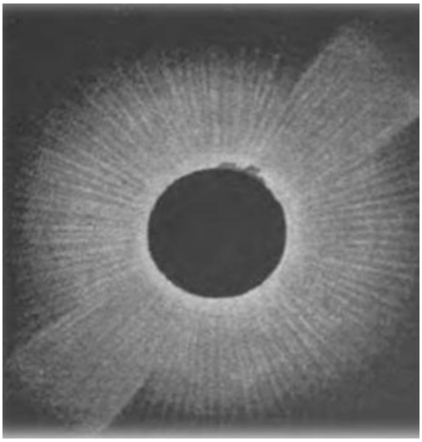

Fig. 22.1 A drawing by François Arago of the 1842 eclipse showing prominences, the 'sierra' and a prominent corona (https://en.wikipedia.org)

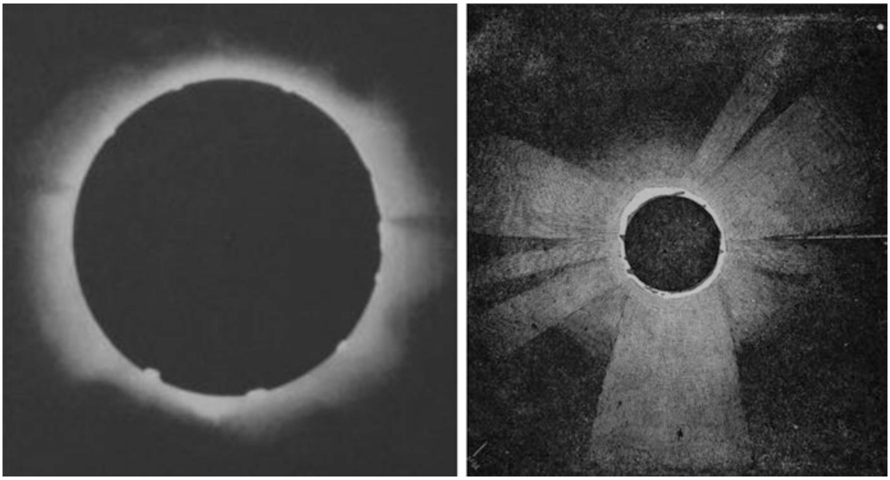

Fig. 22.2 On the left is a composite photograph of the 1860 eclipse obtained by superimposing several different images obtained by Secchi which shows the inner corona, and on the right is a sketch of the same eclipse, also made by Secchi, which shows the extent of the coronal rays as seen with the naked eye (after Ranyard 1879: plates)

On 18 July 1860 the first successful photographs of a total solar eclipse were obtained (Abetti 1957: 197) by England's Warren De la Rue (1815–1889; Hirschfield 2014) and Italy's Father Angelo Secchi (1818–1878; Cenadelli 2014), but as Fig. 22.2 indicates these preserved little evidence of the corona. However, this eclipse was the first to produce conclusive evidence that the prominences were definitely solar features.

From a research standpoint, undoubtedly the most important nineteenth century total solar eclipse was the event of 18 August 1868, which was visible from Aden, India (see Launay 2011: 35ff.; Nath 2013; Orchiston et al. 2017), Siam (see Orchiston and Orchiston 2017) and the Dutch East Indies (Mumpuni et al. 2017). It was at this time that the British solar specialist, Joseph Norman Lockyer (1836–1920; Meadows 1972) renamed the 'sierra' the 'chromosphere' (Lockyer 1874). This was the first eclipse that was investigated spectroscopically (Clerke 1893), and Lieutenant John Herschel (1837–1921; Shylaja 2006), Jules Janssen, Norman Robert Pogson (1829–1891; Fig. 24.14; Dreyer 1892), Georges-Antoine-Pons Rayet (1839–1906; Baum 2014c) and James Francis Tennant (1829–1915; Hollis 1916) recorded a number of emission lines (see Fig. 22.3) which showed that the corona and chromosphere were composed mainly of hydrogen, some iron and an unidentified element that Janssen later named 'helium', which was represented by the D3 line (see Lockyer 1896). A conspicuous feature of the chromosphere on this occasion was an enormous prominence dubbed 'The Great Horn' (Fig. 22.4), which spectroscopic observations revealed to be composed principally of hydrogen (Orchiston et al. 2017).

The following year offered another observable total solar eclipse, on 7 August 1869, when further spectroscopic observations of the corona were a priority. On

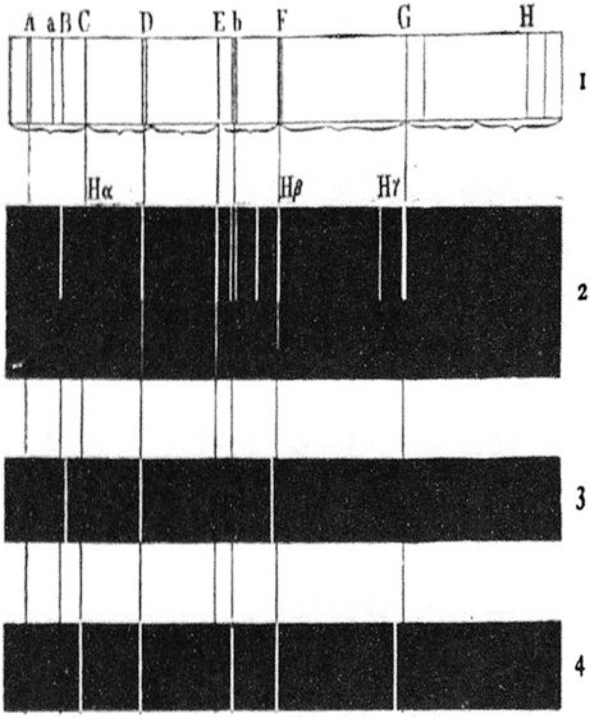

Fig. 22.3 The main emission lines in the solar spectrum (*1*), and the specific lines detected by Rayet (*2*), Herschel (*3*) and Tennant (*4*) during the 1868 total solar eclipse (Orchiston Collection)

Fig. 22.4 A drawing of 'The Great Horn' (after Tennant 1869)

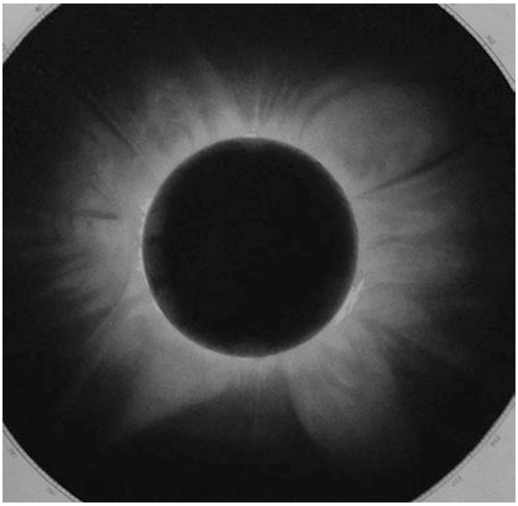

Fig. 22.5 A combination of images of the 1871 eclipse obtained by Tennant and Davis showing fine coronal detail (after Ranyard 1879: plates)

this occasion 11 emission lines were detected, six of which were new ones (Cottam et al. 2011: 350, 352). One of these, dubbed the 'green emission line', was at 1474 K and in 1887 was assigned to the new element 'coronium'. Only much later would this be identified as a highly ionised 'forbidden' line of iron, Fe^{13+} (Golub and Pasachoff 1999). This eclipse was also important because spectroscopic observations showed clearly that the corona was a highly rarefied self-luminous atmosphere surrounding the Sun, and was not associated with the Moon or with the Earth.

The eclipse of 12 December 1871, which also was visible from India was the first in which a realistic representation of the corona, as seen visually was recorded photographically and details of coronal form were apparent on the photographs (e.g. see Fig. 22.5).

Subsequent eclipses offered astronomers further opportunities to investigate the nature and composition of prominences and the solar corona. As Pearson (2009: 14) has noted:

> Photography, of the 1878 corona, gained over drawing in earnest in its role of making permanent coronal records. Large aperture short focal length portrait lenses were used to record significantly more detail within the inner and outer corona. General coronal form was photographed to one lunar diameter. The photographic process was still not of sufficient sensitivity to record the longer-fainter coronal streamers and rays … [while] At the 1883 eclipse, the extensions of the streamers were photographed beyond that visible to the naked eye or telescopic observer …

During the 17 May 1882 eclipse, the British astronomer, Professor Arthur Schuster (1852–1934; Knill 2014) obtained the highest quality coronal photographs taken to that date, which revealed more fine structure within the inner and outer corona. He also recorded a great coronal rift out to 1.5 lunar diameters (Mitchell 1923: 157).

At the 6 May 1883 eclipse, extensions of the streamers were photographed by Janssen beyond those visible to the naked eye or telescopic observer. This was made possible by using large-aperture lenses 6–8 in. in diameter, and taking long photographic exposures (Clerke 1893).

So by the 1885 solar eclipse the principal research questions asked internationally revolved around

1. The form and structural detail of the inner and outer corona, and the relationship between coronal features and photospheric phenomena such as sunspots, faculae and flares;
2. The precise gaseous composition of and particle-gas distribution within the inner and outer corona; and
3. The precise location and the identity of the green coronal line.

If observations of the New Zealand eclipse were to play a major role in coronal science these were the sorts of topics that they had to address.

22.3 New Zealand Astronomy 1874–1885

What was the status of astronomy in New Zealand in September 1885, a mere 116 years after scientific astronomy was introduced by James Cook and Charles Green (see Orchiston 1998)? Although Hearnshaw and Orchiston (2017) provide a useful summary of the nineteenth century in Chap. 20 in this book, their account is not specific to 1885, so let us look in detail at developments in New Zealand astronomy that occurred in the 11 years leading up to the eclipse.

By 1885 the Government's Colonial Observatory in Wellington provided a national time-service (Eiby 1977; Orchiston 2016: Chapter 8); Christchurch's Professor A.W. Bickerton (Fig. 21.1) was championing his remarkable 'partial impact theory' (Gilmore 2017); Auckland boasted the nation's first fledgling astronomical society (McIntosh 1959); and amateur astronomers of note were beginning to make their presence felt in cities and towns across the country (see Hearnshaw and Orchiston 2017; Mackrell 1985; Orchiston 2016). Auckland had J.T. Stevenson (McIntosh 1958); Thames, J. Grigg (Orchiston 2016: Chapters 10, 17 and 22); Wellington, A. Stock (Fig. 20.8), who also worked part-time at the Colonial Observatory (Orchiston 2016: Chapter 9, 2017a); Nelson, A.S. Atkinson (Gibbs n.d.); Christchurch, J. Townsend (Tobin 1996); and Dunedin, A. Beverly (Orchiston 1998: 114; Pettit 1965) and H. Skey (Campbell 2001b; Orchiston 1998: 101, 113). As we shall see in Sect. 22.4, a number of these individuals would attempt to observe the 1885 total solar eclipse.

There were several reasons for the flowering of amateur astronomy during the 1870s and 1880s. The famous British astronomer and author, Richard Anthony Proctor (1837–1888, Fig. 22.6; Baum 2014b), toured New Zealand in 1880 and 1881 delivering popular public lectures (e.g. see Gibbs n.d.), and Bickerton was starting to do the same thing in Christchurch.

The 1870s and early 1880s also offered a wealth of impressive naked eyed comets, which could not fail to attract the notice of even the most disinterested of individuals. These were: Coggia's Comet (C/1874 H1 Coggia) in 1874 (Fig. 22.7), the Great Comets of 1880 (C/1880 C1; Fig. 22.8), 1881 (C/1881 K1; Fig. 22.9) and 1882 (C/1882 R1′; Fig. 22.10), we well as Comets Schaeberle (C/1881 N1) and Wells (C/1882 F1) in 1881 and 1882 respectively.

And in addition to this amazing cometary opulence there were two transits of Venus, in 1874 and 1882, both of which were visible from New Zealand and its offshore islands (see Fig. 22.11). The 9 December 1874 event

Fig. 22.6 Richard Proctor (https://en.wikipedia.org)

Fig. 22.7 Coggia's Comet, C/1874 H1 (adapted from Ball 1893)

Fig. 22.8 The Great Comet of 1880, C/1880 C1 (Orchiston Collection)

Fig. 22.9 The Great Comet of 1881, C/1881 K1 (Tebbutt) (https://en.wikipedia.org)

Fig. 22.10 The Great Comet of 1882, C/1882 R1′ (https://en.wikipedia.org)

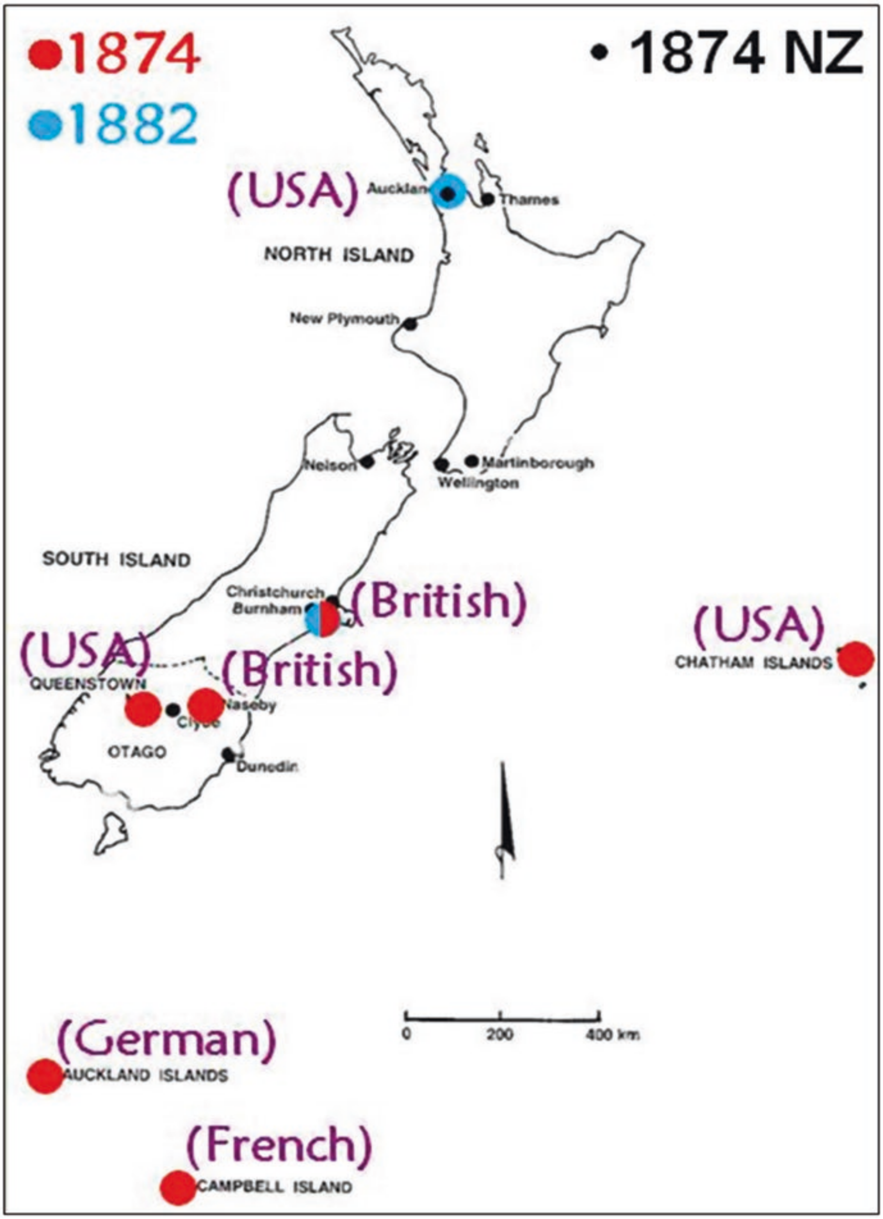

Fig. 22.11 New Zealand and the 1874 and 1882 transits of Venus. The sites of international observing stations are marked by red and/or blue dots (*Map* Wayne Orchiston)

> … promised to be the most important astronomical event in New Zealand since the European settlement of the country, and it attracted enormous public attention. Not only did the Government plan transit observations, but amateur astronomers throughout the nation readied themselves for this once-in-a-lifetime event which promised views of the entire transit and all four contacts … (Orchiston 2016: 372).

International parties from England, France, Germany and the USA also were based in the South Island of New Zealand or on surrounding islands to the east and to the south. The public, meanwhile, was alerted to the forthcoming spectacle thanks to a little book titled *December 9, 1874. The Transit of Venus and How to Observe It*, which was penned by Arthur Stock (1874) of Wellington. Despite extensive preparations, most of New Zealand was clouded out on the vital day and only some of those in Auckland, the British at Burnham, the Americans at Queenstown, and the German and American parties based on the Auckland Islands and Chatham Islands respectively saw the transit (Orchiston 2016: Chapters 14 and 15).

The focus then shifted to the all-important 1882 transit, which was the last chance for astronomers from around the world to use these transits to refine the value of the Astronomical Unit (see Dick et al. 1998). Even though only a part of the transit was to be visible from New Zealand, on this occasion the weather was more cooperative and local observers in Auckland, Thames, New Plymouth, Martinborough, Wellington, Nelson, Christchurch, Dunedin and Clyde, plus transit teams from Britain and the United States stationed at Auckland and Burnham respectively, all saw the transit (see Orchiston 2016: Chapter 16 for details).

Thus by 1885 New Zealand astronomers had gained some experience in the application of photography to astronomy, but they were still novices when it came to astronomical spectroscopy which, it was anticipated, would play an important role in the investigation of the 9 September total solar eclipse.

22.4 The 1885 Total Solar Eclipse

22.4.1 Introduction

The eclipse occurred on 9 September 1885 local time, and as Hind (1885) stressed in his announcement of the eclipse in *Monthly Notices of the Royal Astronomical Society*, "The only land traversed by the central line … will be the southern part of the north island and the northern part of the south island of New Zealand …", as is indicated in Fig. 22.12.

The central line of totality passed through West Wanganui Inlet, Collingwood, D'Urville Island, the Wairarapa and Castle Point. Settlements lying within the northern and southern limits that would witness a total solar eclipse included Waipawa, Waipukurau, Wanganui, Dannevirke, Feilding, Palmerston North, Otaki, Masterton, Wellington, Motueka, Picton and Nelson (see Fig. 22.13). Blenheim was on the very southern limit, with those in some areas of the town seeing a total eclipse and others just missing out (see Orchiston 2016: Chapter 16). The northern and southern limits were separated by about 145 km (Meeson et al. 1886: 375–376).

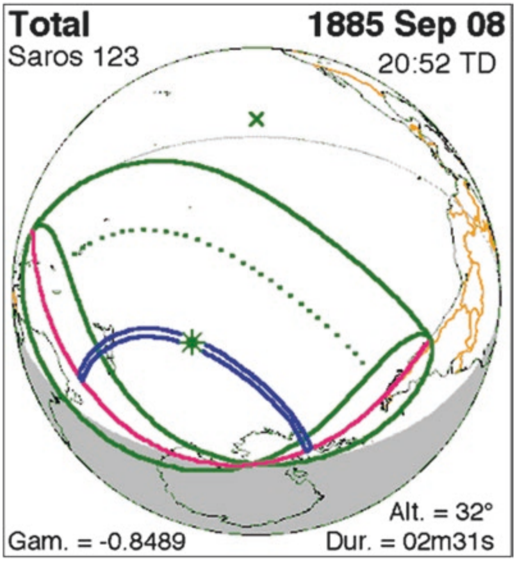

Fig. 22.12 The path of totality of the total solar eclipse of 8 September 1885 (after Espenak and Meeus 2006)

Fig. 22.13 A map showing locations mentioned in this chapter that lay within the path of totality of the 9 September 1885 eclipse. Those located at or very close to the centre line are shown in black, while locations at or very near the northern and southern limits are shown in blue. All other localities are in red (*Map* Wayne Orchiston)

As total solar eclipses go, totality was of comparatively short duration, lasting just 2 min. Moreover, the eclipse occurred in New Zealand early in the morning, with the Sun low in the eastern sky. At Castlepoint, first contact began at 07 h 35 min 12 s New Zealand mean time; at Wellington, at 07 h 35 min 04 s; and at Nelson, at 07 h 34 min 14 s (Meeson et al. 1886).

The Eclipse Committee of the Royal Society in London identified specific research objectives for this particular eclipse and these were circulated widely in New Zealand among those who planned to carry out scientific observations. There were four primary objectives (e.g. see Atkinson 1885: 212):

1. To conduct a spectroscopic analysis of the corona;
2. To measure the mean lateral extension of the corona;
3. To record the positions and extent of any coronal steamers; and
4. To ascertain whether the corona exhibited a line of 'approximate symmetry'.

22.4.2 *The Astronomers, Their Instruments and Their Observations*

The following general account by Lieutenant Herbert Russell (1886; his italics), who observed from Palmerston North, is an excellent example of the spectacle afforded members of the public with no specific knowledge of astronomy:

> We had a magnificent view this morning of the total eclipse of the sun. The totality lasted one minute-and-a-half, when the corona was visible in all its glory. It was one of the grandest, sublimest sights I ever saw. There were some beautiful dark pink flames (or rather small clouds) floating on either side of the sun, besides other flames of a white colour. I was looking through the telescope … but they were just as easily seen with the naked eye. It was not *quite* dark, as the corona was so brilliant that it gave a certain amount of light; but many of the stars were distinctly visible, especially one quite close to the sun. There was hardly a cloud in the sky. I would not have missed it for anything.

But even experienced astronomers could not help but be moved by the spectacle:

> … a sight grander and more unique than the whole eclipse it is impossible to conceive. Even as the wind falls when the shades of evening close around, the very light breeze which had been blowing in the early morning gradually died away, and darkness increased. Birds ceased their twittering, all—at all events, except some paraquets, which were evidently much startled, and broke into the most noisy chattering as the sun disappeared, and flew away, it may be supposed, to their usual night haunts. Everything else became hushed; even the human voice had, or seemed to have, an unnatural sound. All nature seemed to bow its head, and stand in mute silence as the awful spectacle passed, and until the God of Day should again emerge from his temporary seclusion. The general appearance of things at the moment of totality, which was certainly not a period of complete darkness—for a soft and 'dim, religious light' was always present—was such as the observer can surely never forget. It was decidedly uncanny. The human face looked ghastly. The colours on mountain and field, on sea and sky, were weird, unearthly, and indescribable, such as one had never seen before. They had gradually deepened in hue as the eclipse proceeded, and just before total-

> ity the sky around the sun was of a dirty yellow, and quivering beams, of the colour of electric light, shot out from above and below the moon, giving it somewhat the appearance of a St. Andrew's cross with a circular centre.
>
> Generally speaking, during the sun's complete obscuration, the sky was of a mauve colour, except round about the luminary itself, where the intense brilliance of the silvery protuberances or the golden glory of the coronal rays diffused tints of dirty red and grey. The sea became black, the mountains across the bay iron-grey, while the sky above the latter assumed shades of dirty, ghastly yellow. A few patches of fleecy clouds hanging low over the sea took on the appearance of black cumulus heaps, and afterwards, on the emergence of the sun, donned garbs of varied colours. (Meeson et al. 1886: 377).

Most of those situated along the path of totality were treated to uninterrupted views of the eclipse, and for the general public this would turn out to be an unforgettable experience (for details, see Orchiston 2016: Chapter 16).

Scottish-born James McKerrow (1834–1919; Fig. 22.14; Obituaries 1920), the efficient Surveyor-General of New Zealand and Secretary of Lands and Mines, was one of those charged with assembling the data provided by various observers of the eclipse, and his approach was laudable:

> In a matter pertaining to science it is important to record information from every trustworthy source, and, consequently, every sketch and report deemed worthy has been recorded in the appendix [i.e. in McKerrow 1886b], with the name of the officer or contributor. (McKerrow 1886a: vi).

When we combine the names listed by McKerrow (1886a, b), Meeson et al. (1886), Hector (1885) and mentioned in a few other published sources we discover that at least 33 people obtained scientifically useful photographs, descriptions or sketches of the eclipse. These are listed in Table 22.1, and collectively they provided a wealth of information about the corona and prominences.

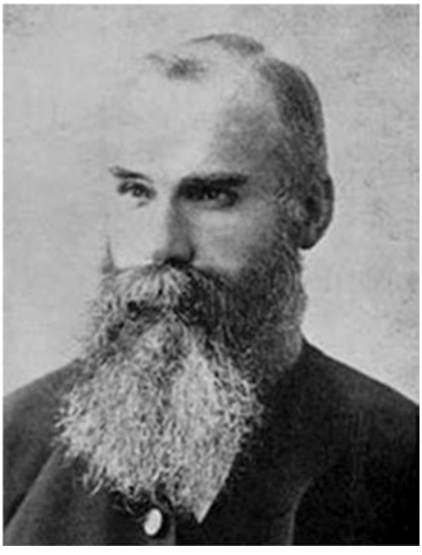

Fig. 22.14 James McKerrow (jamesmckerrowsurveyor.blogspot.com/)

Table 22.1 A list of those who successfully photographed, described or sketched the eclipse

Observer	Location	Type of Observation[a]	Instrument	References
J.R. Akersten	Nelson	Photographs	Telescope	Atkinson (1885: 212–213)
A.S. Atkinson	Nelson	Description	Telescope; naked eye	Atkinson (1885)
A. Barron	Wellington	Photograph (c & p)	Telescope	McKerrow (1886b: 19–20)
A. Beverly	Masterton	Sketch (p)	Telescope	McKerrow (1886b: 18–19)
Bishop Suter	Nelson	Sketch	Naked eye; binoculars	Meeson et al. (1886: 378–379)
A. de B. Brandon	?	Sketch	Naked eye	Hector (1885: 210)
J. Buchanan	?	Sketch		Hector (1885: 209)
F. Bull	Wellington	Sketch (c)	Naked eye	McKerrow (1886b: 21)
M. Cazneau	Wellington	Photograph	Camera	Hector (1885: 209)
H.A.R. Farquhar	Wellington	Sketches (c & p)	Theodolite	McKerrow (1886b: 21)
E. Gell	Wellington	Photograph (c & p)	Camera	Meeson et al. (1886: 394); McKerrow (1886b: 20)
J. Goodall	Tahoraite	Sketch	Telescope	Meeson et al. (1886: 379–380)
S. Goodbehere	Taonui	Photograph		Meeson et al. (1886: 394)
H.A. Gordon	Wellington	Sketches (c & p)	Theodolite	McKerrow (1886b: 19–20)
E.J. Graham	?	Sketch (c)		McKerrow (1886b)
T.M. Grant	Wellington	Sketches (c & p)		McKerrow (1886b: 19–20)
Mr. Harding	Dannevirke	Sketch	Naked eye	Meeson et al. (1886: 394)
N. Heath	Tahoraite	Photograph		*Hawkes Bay Herald* (1885)
Captain J.D.R. Hewitt	Wellington	Sketch (c & p)		McKerrow (1886b: 21)
H.P. Higginson	Wellington	Sketches	Binoculars	Hector (1885: 209–210); Meeson et al. (1886: 394)
Mr. Holmes	Wellington	Photographs		Meeson et al. (1886: 394)
Dr J. Hudson	Wellington	Sketch	Telescope	Meeson et al. (1886: 394)

(continued)

Table 22.1 (continued)

Observer	Location	Type of Observation[a]	Instrument	References
T. Humphries	Masterton	Photograph (c & p)	Telescope	McKerrow (1886b: 19)
I. Jones	Nelson	Sketch	Naked eye	Meeson et al. (1886: 394)
T.W. Kirk	Wellington	Sketches	Naked eye	Hector (1885: 209); Meeson et al. (1886: 394)
A. McKay	Dannevirke	Sketches	Naked eye	Meeson et al. (1886: 394)
W.H. Macey	Blenheim	Photographs	Telescope	The eclipse (1885).
J.M. Malings	Wellington	Sketch (c & p)	Theodolite	McKerrow (1886b: 21)
C.R. Marten	Wellington	Description	Binoculars	Marten (1885)
J. Meeson	Stoke	Sketch	Naked eye	Meeson et al. (1886: 376–378)
Mr. Parsons	Wellington	Sketch	Telescope	Meeson et al. (1886: 394)
Lieutenant H. Russell	Palmerston North	Description	Telescope	Russell (1886)
Mr. Seymour	Picton	Sketch	Telescope	Meeson et al. (1886: 394)
H.E. Taylor	Wellington	Sketch (c)	Naked eye	McKerrow (1886b)
Mr. Tyree	Nelson	Photograph	Camera	Meeson et al. (1886: 394)

[a] *c* corona, *p* prominences

However, we must be aware of the limitations of visual descriptions and sketches, even when the astronomers in question were skilled artists. Pang (2002: 84–95), Ranyard (1879: 484–485, 489) and Young (1895: 241) list the following factors that affected the rendition and accuracy of an artist's drawing(s):

1. First impressions at the beginning of totality.
2. Extreme excitement and confusion at the moment of totality.
3. The shortness of the totality event.
4. The weather and climatic conditions present during totality.
5. Social and political influences of the expedition's participants.
6. The specific instructions the artist received regarding which segment of totality they were assigned to record (e.g. coronal form, internal coronal structure, color notations, delicate light shadings, and other specific notations required).
7. The tools and materials used to make the drawings and their preparation.
8. The ability of the artist to remember what they saw, for the later finishing of their drawing(s).
9. The methodology that the artist used to make the actual drawings.

10. Identifying the furthest extension and general form of the corona.
11. Using contour lines to denote brightness levels within the corona.
12. Outlining the largest features within the corona.
13. The use of rays to denote bright features of the corona.
14. The use of other symbols to denote brightness within the corona.

Ranyard (1879: 489) defined two classes of coronal drawings: those in which the observer attempted to represent the structures within the corona that caught his eye during totality, and those in which the observer attempted to indicate the areal extent and limits of the corona. Furthermore, he noted that there were great differences in coronal form on drawings made during the same eclipse by different artists, even by those standing side by side. This was certainly a factor in interpreting the coronal drawings made during the 1885 eclipse. One of the observers, Captain Dudley Hewitt (1840–1913) from the Survey Department, also specifically mentioned two other factors that would complicate the comparison of coronal drawings (1) even during the short interval of totality, "… the shape of [the] corona varied a good deal." (McKerrow 1886b: 21) and (2) the existence of

> … two classes of coronal light, the inner very white light extending about a quarter of the sun's diameter all round, and fading into the outer [corona] which gave the idea of a light reflected by a vapoury mass, and the marked changes in its shape giving more the idea of a varying amount of light falling on it at different parts than any change in the shape of the material itself. (McKerrow 1886b: 21).

The variations in the appearance of the corona during totality mentioned above by Hewitt are well illustrated in Fig. 22.15, which shows three different sketches prepared in Wellington by Thomas William Kirk (1856–1936; Fig. 22.16) from the Geological Survey (but who later would become very well known as a biologist and botanist).

Some observers ignored these variations by focusing on the conspicuous and unchanging inner corona in their drawings, whilst others attempted to define the outer corona and identify coronal streamers. Then it was left to Wellington's Dr. (later Sir) James Hector (1834–1907; Fig. 22.17; Nathan 2015; Orchiston 2017a), Director of the Colonial Observatory, and of the Geological Survey (amongst many other responsibilities), to attempt to synthesize the various solar eclipse descriptions and sketches:

> … the corona had a very irregular outline, and was most continuous and vivid close to the sun's limb, having the longest expansion reaching to nearly two diameters from the western equatorial region. This large expansion appears to have had a strongly marked spirally twisted structure … No laminated structures appear to have been observed in any part of the corona. (Hector 1885: 209).

Marten (1885: 24) also provides a clear description of the corona, as viewed from Wellington:

> The corona presented a splendid spectacle surrounding the jet-black lunar disc. It was deeply serrated, or rather "rayed," pearly white with rays streaming out to a distance of fully two lunar diameters, and in the case of one on the upper left quadrant, more. Another long ray proceeded from the lower right quadrant, and there was an apparent equatorial protuberance.

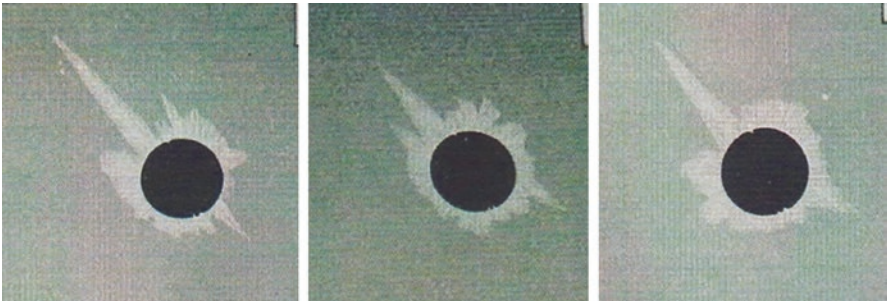

Fig. 22.15 Three different sketches of the corona made by T.W. Kirk during totality (after Meeson et al. 1886: Plate XV, images IX, X and XI)

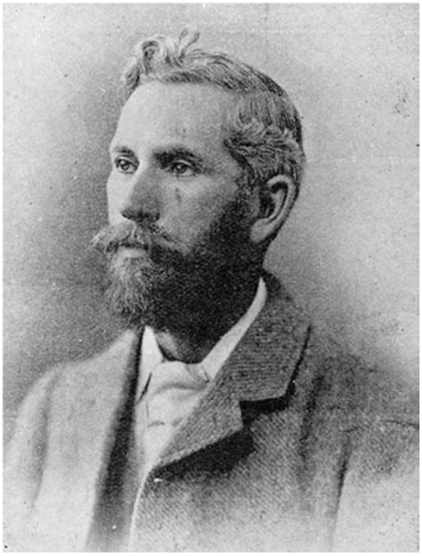

Fig. 22.16 T.W. Kirk (www.teara.govt.nz)

Figure 22.18 contains a selection of coronal drawings by different observers, and highlights Ranyard's comment about the great variations in drawings, even with astronomers observing from the same city.

Some observers provided information that specifically addressed the Royal Society Eclipse Committee research objectives. Thus the natural historian J.T. Meeson from Stoke, near Nelson, wrote about the extent and symmetry of the corona:

> The general outline of the corona, towards the latter part of the period of totality, was, as it appeared to me, pretty much as represented in the accompanying chart, though there must have been other leading features which I had not time to observe. Generally its shape was irregular, and there was little or no four-cornered appearance. If there was any symmetry at all, it was as regards the place of the longest streamers (*x* and *y*), which were exactly on opposite sides, and at those parts of the sun's rim which were respectively the first and last to disappear behind the moon. Some of these streamers, particularly those from the upper western limb, and at an angle of about 30° from the perpendicular, could not have been less in length than 1½ times the moon's or sun's apparent diameter, *i.e.*, not less than

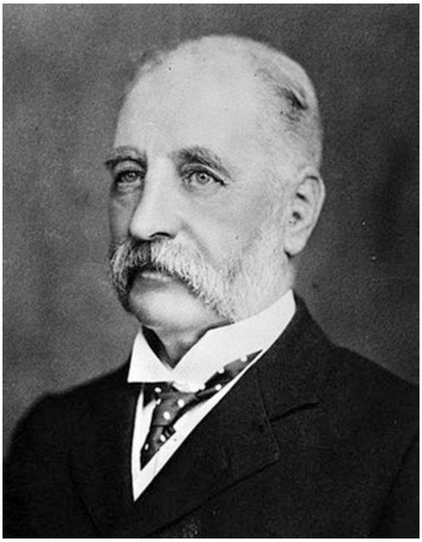

Fig. 22.17 Sir James Hector in about 1900 (https://en.wikipedia.org)

> 1,275,000 miles. The greatest effulgence of light was in the neighbourhood of the longest streamers, and particularly round about the highest part of the upper limb. The least was in the lower western and upper eastern limbs—in the former of which the breadth was not more than ¼th of the moon's diameter, and in the latter, certainly as small as 1/12th, if not smaller. Although, for the most part, the streamers seemed to radiate as from a common centre—that is, the centre of the sun or moon—yet this was not universally the case; for some (particularly the ray marked *z*) seemed to proceed as from another centre, and interlaced with the more normal gleams … The corona in our eclipse was certainly not very sharply defined, for it was very difficult to say where the faint coronal tints ended and the abnormal hues of the sky began … Upon the whole, the picture which I present seems to agree pretty well with what others, with whom I have compared notes, observed. I noticed no rotatory motion of the beams, such as, I believe, has been sometimes previously observed, nor any flickering or quivering, except as before stated, just before and after totality. (Meeson et al. 1886: 385–386).

Nelson's well-known amateur astronomer, Arthur Samuel Atkinson (1833–1902; Fig. 22.19) also addressed the Committee's queries:

> The following are my answers to the questions of the committee:
>
> (a) I estimated the greatest distance from the moon's limb to which I could trace the corona as from two-thirds to three-fourths of a diameter.
>
> (b) The corona extended much farther in one direction than in any other. By far the greatest feature in the corona was a broad-based but hollow-sided cone of white light, with well-marked edges, and a rather sharp point, the axis of which I judged to be from 40° to 45° from the perpendicular towards the west. The "least extent" of the corona, as I saw it, was the same in several places, where there was only a narrow rim of light round the moon's limb. There were other smaller but more or less similar prominences of pure white light, all of which, I may say, gave me the idea of radiating from the sun's centre.
>
> (c) There was, in my opinion, no line of "approximate symmetry" in the corona. I looked right round the sun with a view to answer this question, and that was the conclusion I came to without hesitation. As there was nothing to balance the large "cone," the nearest approach to symmetry would have been obtained by taking its axis as the line, but I should not have called the result of this division "approximately symmetrical. (Atkinson 1885: 212).

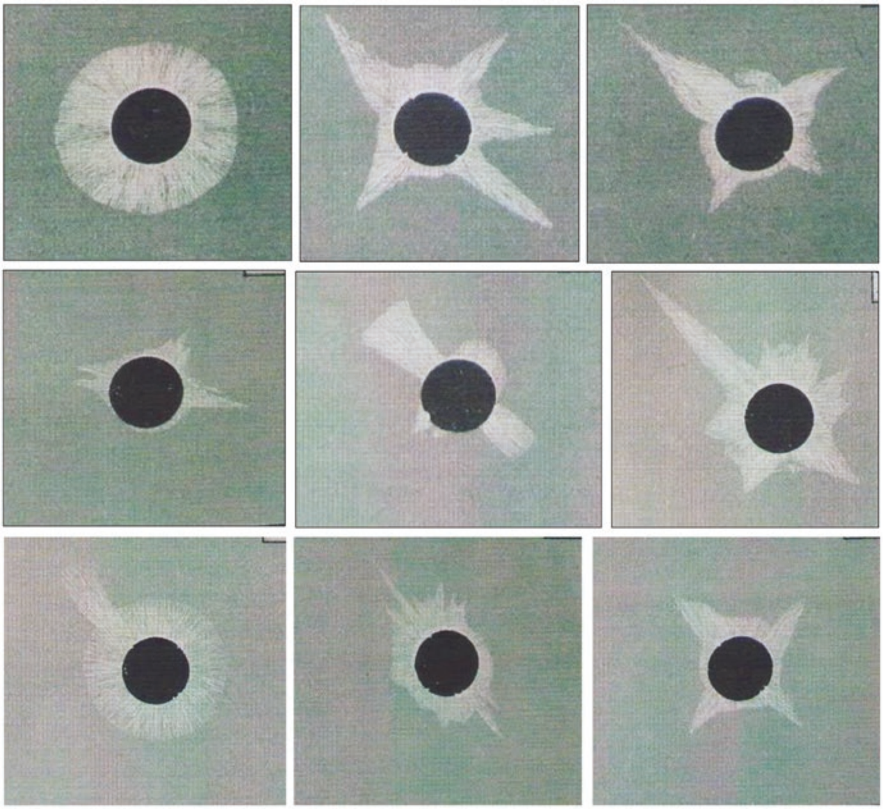

Fig. 22.18 Coronal drawings from Wellington by Parsons, Higginson and Hudson (*top row*, *left to right*); from Dannevirke by Harding and McKay and from nearby Tahoraite by Goodall (*middle row, left to right*); and from Nelson by Bishop Suter, Meeson and Jones (*bottom row, left to right*) (after Meeson et al. 1886: Plate XIV, images VI, VII and VIII (*top row*); Plate XV, images XIV, XV and XIII (*middle row*); and Plate XVI, images XIX, XX and XXI (*bottom row*))

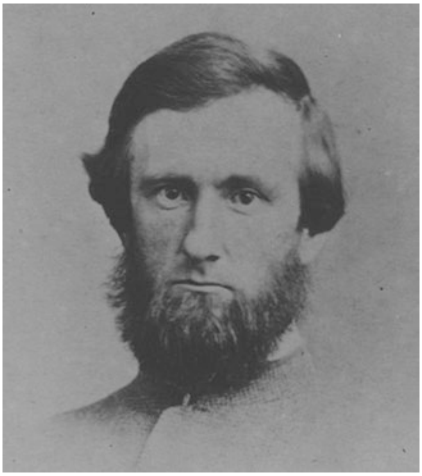

Fig. 22.19 A.S. Atkinson (https://en.wikipedia.org)

By 1885 it was known that coronal form was connected with sunspots (see Pearson 2009: 26–27). During eclipses that occurred at sunspot minimum, such as in 1867 and 1878, the corona displayed a long faint equatorial extension and distinctly defined diverging polar rays referred to as 'brushes', whereas at sunspot maxima the corona displayed a star-like circular form with equatorial wings, and brushes were nearly absent. Between sunspot maximum and minimum, as in 1885, an intermediate form was expected, with coronal structure concentrated above areas with sunspots. This is precisely what was witnessed in 1885.

Hector (1885: 209) also tried to summarize the various accounts of the prominences: "Scarlet prominences were only moderately developed, and were clustered chiefly at the equatorial and polar regions of the sun." Meeson provides more specific information:

> As to the so-called red protuberances, I saw distinctly prominences, but they, one and all, seemed to me intensely white or pearly in colour—such as those described by Professor Airy in the eclipse of 1851—rather than red.
>
> Perhaps my sense of colour was temporarily impaired by the unwonted and unearthly hues which prevailed on everything at the time. I could persuade myself, perhaps, that one or two of the smaller prominences, situated on the eastward of D. in the chart, were of a faint rose-colour, but not red. Whatever their colour, and whatever their real nature—mountains, clouds, or flames—they were exceedingly beautiful and wonderful; but, as they can be, and are now, studied at any time when the sun can be seen, whether he be eclipsed or not—or rather, perhaps, as the sun can be by modern astronomical contrivances so artificially eclipsed that the prominences are rendered visible—*it is very improbable that any observations of ours as to them can have any scientific value* … At the commencement of totality the largest prominences visible were those on the lower eastern or right limb; and towards the close they were those on the upper western, or left limb. During the passage of the moon across the sun's face, the prominences near where the sun was last visible diminished in size, while those directly opposite considerably increased. In astronomical books these prominences are said to be heaps, jets, or flames. Those which we saw were heaps, I think, and they were less serrated and fantastic in shape than some of us perhaps expected. Decidedly the largest prominences, towards the close of the total obscuration, appeared over the moon's left upper limb, at an angle of about 30° from the perpendicular, directly below the point where I observed the longest and most vivid coronal ray. Its apparent height above the limb of the moon could not have been less than 70,000 miles, for it reached to nearly 1/12th of the moon's apparent or angular diameter. (Meeson et al. 1886: 382–383; our italics).

The following account of prominences by C.R. Marten (1885: 24–25), who observed from The Terrace near central Wellington, also is illuminating:

> The red prominences were visible in remarkable brilliancy to a far greater extent than I have ever seen described in accounts of other total eclipses. To describe their extent very roughly, I should say that, taking a clock face and its minutes as the gauge, one serrated series of prominences on the upper limb of the Sun, resembling a mountain range of red flames, extended from $0^h\ 54^m$ to $0^h\ 3^m$ in full brilliancy, and that red traces extended on the left hand to $0^h\ 52^m$, and on the right to $0^h\ 4^m$. Other large but narrow red prominences were at $0^h\ 39^m$ and at $0^h\ 20^m$. I fancied I saw a fourth momentarily at $0^h\ 30^m$. These "times" will be distinctly understood to indicate merely the position—regarding the Sun's disc as a clock-face … The prominences were very rich in colour and seemed, like the corona, to vary in intensity. They also seemed to vary in depth of hue, ranging from pink or rose to scarlet and almost to crimson. They had a markedly transparent appearance, like a light shining through coloured glass. I found I could see them quite plainly with my naked eye, after once having ascertained their position by means of the glass.

In addition, Meeson noticed two unusual prominences:

> Of two prominences I wish specially to speak. They do not seem to have been generally observed, but were clearly seen by other members of my household beside myself. One of them was also observed from the Hospital, by Dr. Boor. They were like tiny clouds, of a heapy character, and differed entirely from the other prominences, inasmuch as they were of a dun, or dark-smoke, nearly black colour. Their positions were, one at an angle of about 40° from the perpendicular towards the east, and the other at about 10° below the horizontal line on the lower western limb. Their position and relative size were recorded at the moment of observation. They were entirely different in appearance from the silvery or white, or rose-coloured prominences; and were no optical illusion, for I was so surprised to see them that I looked at them again and again with the binocular or coloured glass, and with the naked eye alternately. While I observed them, they seemed to undergo no change. What were they? (Meeson et al. 1886: 383).

Dunedin's noted amateur astronomer Arthur Beverly (1822–1907; Fig. 22.20; Campbell 2001a) and Wellington-based Captain Hewitt provided nice sketches of the prominences that they saw (see Fig. 22.21). Beverley was observing from near Masterton with his own 3-in. (7.6-cm) refractor, using a 36× eyepiece (Meeson et al. 1886), but McKerrow (1886b) and Meeson et al. (1886) do not provide any information on Hewitt's instrumentation. The sketches of both observers highlight the three main areas of prominence activity during the eclipse.

By 1885 it was well established that sunspots were associated with prominences and that prominences were connected to the corona (Proctor 1876: 319).

Bailey's Beads also were noted by some observers. Here is an account by British-born and Cambridge educated Andrew Burn Suter (1830–1895; Fig. 22.22), who in 1866 was appointed the Bishop of Nelson but believed in the compatibility of religion and science:

> As totality came near, and one's attention was confined almost exclusively to the sun, it seemed to me that the crescent was divided into one or two elongated portions of light, and then, subsequently, that these elongated portions were divided up into what reminded me of

Fig. 22.20 A. Beverly (Orchiston Collection)

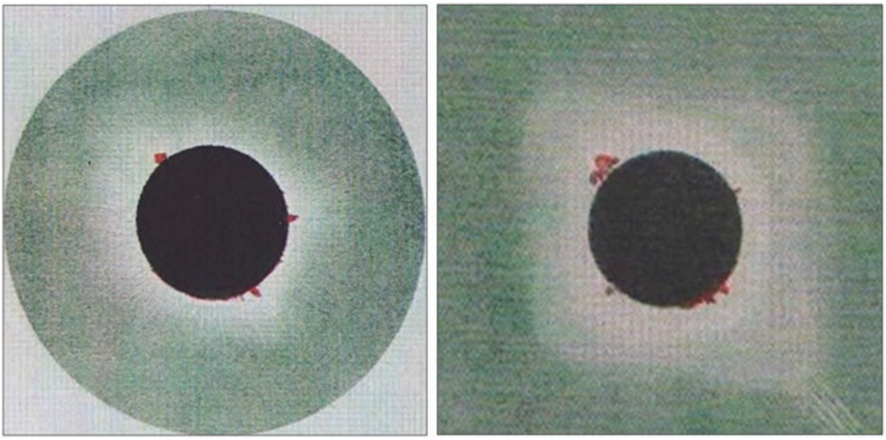

Fig. 22.21 Drawings of prominences made by Beverly (*left*) and Hewitt (*right*) (after Meeson et al. 1886: Plates)

Fig. 22.22 A photograph of Andrew Burn Suter, taken later, when he was Bishop of Dunedin, by James Weaver. Allen (Courtesy Alexander Turnbull Library, PA2–0019/records/23015702)

> the cogs of a wheel, or rather the little blocks of different metal that are planted in the rim of the compensating balance of a good watch or chronometer. I suppose this appearance to be that described as "Bailey's beads." They appeared to me to exist for only a very short time indeed, but they were distinct cogs of light, over little more than a third of the edge of the sun, on the eastern or lower side. (Meeson et al. 1886: 378).

This description of several distinct Bailey's beads differs somewhat Hector's (1885: 209) generalised comment that "Most observers [saw] an intensely brilliant flash … lasting for two seconds, at the commencement of totality … At the close of totality another flash … was seen on the western limb of the sun …"

22.4.3 The Planned Spectroscopic Observations

While the numerous published descriptions and drawings of the eclipse did throw valuable light on the nature and extent of the corona, this eclipse contributed nothing on the first objective of the Royal Society's Eclipse Committee: the chemical composition of the corona. This was because the two parties equipped by Government to carry out spectroscopic observations selected two different hills near Masterton. McKerrow and Beverly proceeded to the top of Otahoua Hill (altitude 352 m above mean sea level) but

> … unfortunately, the weather was very bad – dense masses of cloud, driven before a cold southerly gale, obscured the Sun to within a few minutes of totality. Just then a clear patch of sky enabled the near approach of totality, its completion, and duration for rather more than a minute to be distinctly seen, when clouds again intervened … (McKerrow 1886a: v).

This atrocious weather was in marked contrast to the beautiful clear skies enjoyed throughout much of the band of totality, and certainly was totally out of character for 'sunny' Wairarapa—where the eclipse was seen from most places—but those on top of Otahoua Hill could not make any spectroscopic observations (Hector 1885: 208–209). Meanwhile, the third member of McKerrow's team, the Chief Surveyor of Taranaki, Thomas Humphries (1841–1928; Fig. 22.23; Scholefield 1940(1): 420), observed from about 122 m below the summit of Otahoua Hill (The solar eclipse 1885), where he took some photographs, but he did not attempt to make any spectroscopic observations.

A second research party in Masterton, which was led by New Zealand's premier nineteenth century scientist Dr. Hector, with two assistants, was to have observed from Rangitumau, a nearby even higher hill (The solar eclipse 1885), but inclement weather forced them to settle on Dryertown, where "They had fair views at intervals. [But] *It is expected that the observations will not prove of great scientific value* …" Eclipse of the Sun 1885; our italics). There is no mention of any spectroscopic observations.

Fig. 22.23 Thomas Humphries (after Ward 1928: Fig. 295)

Indeed, of all the observers listed in Table 22.1, the only one who specifically mentions attaching a spectroscope to his telescope is J. Goodall, who was at Tahoraite, but his description of the eclipse contains no spectral data (Meeson et al. 1886: 379–380).

22.4.4 Photographs of the Eclipse

If spectroscopy was not in a position to make any contribution to the scientific investigation of the 9 September 1885 total solar eclipse what of photography, that other hand-maiden of astrophysics (or, in this case, solar physics)?

According to the assorted written accounts mentioned above and contemporary newspapers, at least ten different individuals attempted to photograph the eclipse—with varying degrees of success—and relevant documentation is listed in Table 22.2.

Akersten and Tyree were both professional photographers who observed (separately) from Nelson, where they lived; Humphries (Chief Surveyor of Taranaki Province) lived in New Plymouth but was based near Masterton for the eclipse; Heath was a Napier Headmaster who led a party of school boys to Tahoraite in order to observe a total eclipse (it would only be partial in Napier); Goodbehere was a solicitor with an amateur passion for astronomy, who lived at Taonui near Feilding; and all of the others observed from Wellington.

Of the 32 photographs listed in Table 22.2, the only originals we have been able to trace are two of the three images that Atkinson (1885: 212–213) describes, expressly taken for him by James Raglan Akersten (1855–1928; Fig. 22.24):

> Mr. J.R. Akersten obtained for me two photographs during totality, one immediately after it began with an exposure of probably a little less than a second; the other a few seconds later, with about double the exposure. A third plate was all but ready when the sun reappeared; it was taken just afterwards, but still shows some of the "red flames".

These are in the Cawthron Institute Library in Nelson, and one of these photographs is reproduced here as Fig. 22.25. Given that it only shows the corona, this is probably a copy of the first of the two exposures taken by Akersten during totality. Note that only the inner corona is apparent in Fig. 22.25, and there is no indication of coronal structure—which was one of the research priorities for this eclipse. The corona on the second surviving Akersten photograph shows clear evidence of retouching and consequently is not reproduced here.

Because of the technical challenge associated with successfully printing small images of the Sun and the tenuous corona, Meeson et al. (1886) and McKerrow (1886b) chose to illustrate the salient features of some of the photographs listed in Table 22.2 by including drawings of them in their reports. Two examples are shown in Fig. 22.26, which provide excellent information on the prominences, but no detail of the corona.

In the course of our research we located four original photographs of the 9 September 1885 total solar eclipse that are not mentioned in the publications by

Table 22.2 Photographs taken of the 1885 eclipse

Observer	No.	Comments and References
J.R. Akersten	3	Three "… small photographs …" were taken (Atkinson 1885: 211), two at totality and one immediately after it. (1885: 212–213)
A. Barron	3	Used a 2.75-in. f/17.7 Elliott refractor owned by T. Humphries (McKerrow 1886b: 19). The three photographs were taken before, during and after totality, but only the one of totality, a 1-second exposure, "… was worth preserving … [It] clearly shows the form and position of the largest prominences, and the general form of the corona …" (McKerrow 1886b: 20)
M. Cazneau	1	Hector (1885)
Mr. Gell	1	Used an ordinary camera (McKerrow 1886b: 20). The negative contained an image of the Sun just one-eighth of an inch in diameter (Hector 1885: 209)
S. Goodbehere	1	Meeson et al. (1886: 394)
N. Heath	1	Mr Heath went to Tahoraite and took one photograph during totality, which showed "… the corona as an immense halo of irregular form." (*Hawkes Bay Herald* 1885)
Mr. Holmes	3	Meeson et al. (1886: 394)
T. Humphries	8	Used a 5-in. refractor loaned by G.V. Shannon, with a prime-focus astrocamera that took 4.75-in. square plates. This gave an image of the Sun half an inch in diameter. Three photographs were taken during totality (with exposures of 1, 3 and 4 s), but—given the gale force winds at the time—none of them was really successful, although the 1-s exposure "… shows the positions of the prominences, and also the extension of the corona at the equator more so than at the poles". Five other photographs were taken before or after totality, but they were unsuccessful (McKerrow 1886b: 19)
W.H. Macey	10	Macey, working together with the engineer Alfred Dodson, took the photographs using a telescope. The photographs "… contain valuable records of the eclipse at different stages." But since Blenheim was right on the southern limit of the path of totality a total eclipse was not photographed (The eclipse 1885)
Mr. Tyree	1	Meeson et al. (1886: 394)

Hector (1885), McKerrow (1886b) or Meeson et al. (1886). One of these was taken from Wellington by William Williams (1859–1948), and currently is lodged in the Alexander Turnbull Library in Wellington, New Zealand. It is reproduced here in Fig. 22.27, but only shows the inner corona and no detail of coronal structure.

The other three photographs are in the archives of the Royal Astronomical Society (RAS), London (File A2 Solar Eclipses) and also were taken from Wellington, by a Mr. Radford. One photograph (a 2-s exposure) was taken during totality, and the other two after totality. All three photographs were purchased for the RAS by James Hector, and it is interesting that he does not mention them (or Radford) in his report on the eclipse (Hector 1885). Presumably he became aware of these photographs only after he had written his paper.

Fig. 22.24 J.R. Akersten (http://www.theprow.org/)

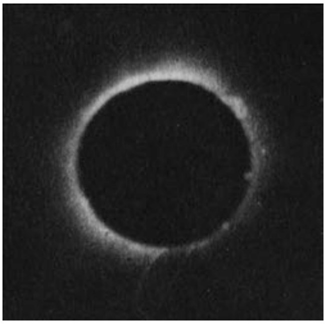

Fig. 22.25 The photograph of the 1885 solar eclipse taken by J.R. Akersten from A.S. Atkinson's Observatory during totality (*Courtesy* Cawthron Institute, img518, 2114 1/4 pl)

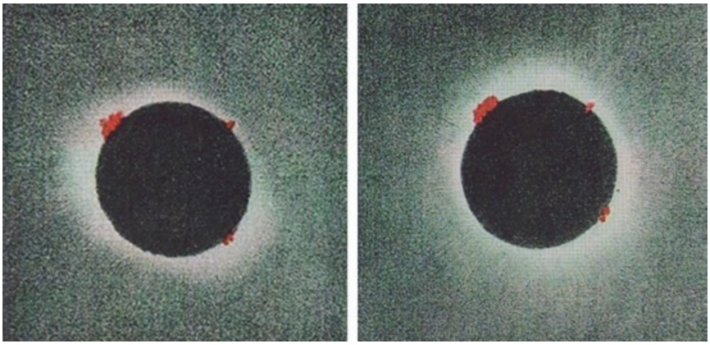

Fig. 22.26 Drawings of enlarged photographs of the 9 September 1885 solar eclipse taken by A. Barron (*left*) and E. Gell (*right*) (after Meeson et al. 1886: Plates)

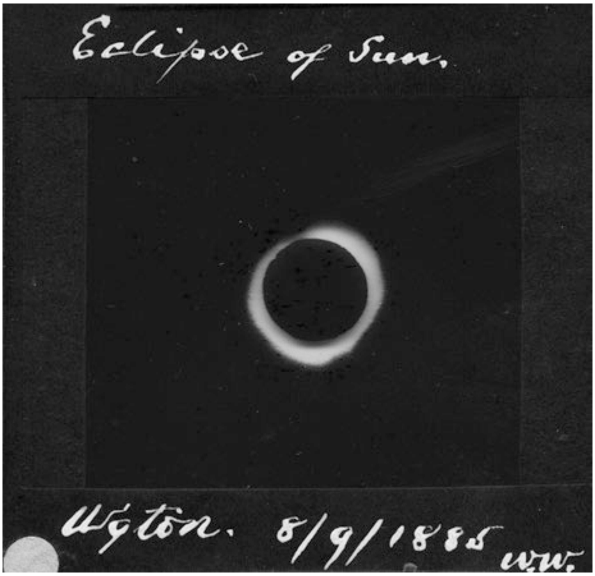

Fig. 22.27 A photograph taken from Wellington by William Williams of the 9 September 1885 total solar eclipse. Note that Williams' annotations include a wrong date for the eclipse (Courtesy Alexander Turnbull Library, E.R. Williams Collection, PA11–255-1)

22.5 Discussion

22.5.1 The Absence of Overseas Expeditions

In 1868 and 1871 the total solar eclipses visible from India both attracted European observing teams (see Kochhar and Orchiston 2017; Orchiston et al. 2017), so by 1885 the concept of sending international expeditions to the far 'corners' of the globe in order to address the principal problems of coronal science and solar physics was well established. The 1885 eclipse therefore offered those overseas nations involved in solar research an opportunity to make further contributions, and after the successful observations of the 1874 and 1882 transits of Venus by foreign teams based in the South Island and on off-shore islands to the east and south, New Zealand had clearly proved itself to be an excellent site from which to view important transient astronomical events.

The 1885 solar eclipse therefore provided yet another chance for overseas astronomers to station themselves in New Zealand, but because of the travel distances involved for the serious contenders (Britain and the United States) and the option of other more accessible up-coming eclipses this was not seen as a viable option. Australia, though, was another story.

In Australia there were total solar eclipses in 1857 and 1871. The central line of the earlier eclipse passed through Sydney and Windsor (Orchiston 2017b: Chap. 7), while the latter event was visible from far north Queensland and attracted a joint expedition mounted by Sydney and Melbourne Observatories (Lomb 2016). Unfortunately, cloudy weather prevented observations being made of either eclipse, and since the next one visible from Australian soil would not occur until 1910 the 1885 New Zealand eclipse offered the next nearby opportunity for the professional astronomers in Sydney, Melbourne and Adelaide to observe one of these rare events. Yet only Russell, in Sydney, seriously considered this option, but in the end decided against it. He later reported to Wesley of the Royal Astronomical Society:

> I felt so uncertain about the weather at this time of the year that I would not risk the loss of time & cost of going to New Zealand to observe it and it turned out that the weather was unfavourable. (Russell 1885).

22.5.2 Other Astronomical Observations Made During the Eclipse

Nelson's A.S. Atkinson (1885) tells us that when was using his 5-in Cooke telescope prior to the start of the eclipse,

> … in finding my way with the telescope to the moon's following limb, I chanced upon Jupiter, the appearance of which surprised me greatly. It was, of course, "boiling" a good deal [due to the low altitude of the Sun], but at the moment I caught sight of it, it seemed to have one broad uniform equatorial belt, with at least its northern edge rather sharply marked; in breadth it seemed about one-third of the planet's (polar) diameter, and in colour distinctly pink. This belt disappeared and reappeared with the motion of the air. I shifted my eye in the telescope, but the breadth and colour seemed constant on each reappearance, so long as I looked, which was not, however, very long.

The extent and colour of the various Jovian belts and of the 'Great Red Spot' was of great interest to astronomers during the 1870s and 1880s, as documented by Hockey (1992).

22.5.3 Non-Astronomical Observations Made During the Eclipse

Atkinson (1885: 212) also recorded the following account:

> As the sun was just disappearing, the most striking phenomenon I noticed, looking straight at it, was a strongly marked pulsation in its light; those who were looking away from it saw waves of shadow passing rather rapidly over the ground. This also, I supposed, was from the unsteadiness of the air, but to me it seemed not the least striking part of the great spectacle to see the sun flickering as it were before it went out.

22.6 Concluding Remarks

Thanks to clear skies, the 9 September 1885 total solar eclipse was a spectacular event that was widely observed across much of the band of totality, and especially by those residing in Nelson, Picton, Wellington, Palmerston North, Wanganui and localities in the Wairarapa. Yet the observing sites in the Wairarapa selected by the official Government research parties were clouded out and because these astronomers could not carry out their spectroscopic observations, as planned, this limited the research potential of the eclipse. Yet not all was lost for the photographs and naked eye observations that were published by successful observers stationed elsewhere did provide useful information on the form and extent of the corona, which was one of the topics of special interest to members of the Eclipse Committee of the Royal Society of London.

So in this context the New Zealand eclipse was a success, and by following as it did 'hot on the heals' of the 1880, 1881 and 1882 Great Comets and the 1882 transit of Venus, it also served as a catalyst for the further development of New Zealand astronomy during the late 1880s and through to the turn of the century, and the involvement of New Zealand astronomers in overseas solar eclipse expeditions during the twentieth century (e.g. see Michie, 1938).

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References

Abetti, G. (1957). *The Sun*. London: Faber and Faber.
An earlier eclipse. *Southern Stars, 2,* 158–160 (1936).
Atkinson, A.S. (1885). On the total solar eclipse of September 9, 1885 (in a letter to J.N. Lockyer, F.R.S.). Proceedings of the Royal Society of London, 39, 211–212.

Ball, Sir Robert (1893). *The Story of the Heavens*. London: Cassell and Company.

Ball, Sir Robert (1910). *The Story of the Sun*. London: Cassell and Company.

Batten, A. (1988). *Resolute and Undertaking Characters: The Lives of Wilhelm and Otto Struve*. Dordrecht: Reidel.

Baum, R. (2014a). Lyot, Bernard. In T. Hockey et al., pp. 1366–1367.

Baum, R. (2014b). Proctor, Richard Anthony. In T. Hockey et al., pp. 1768–1769.

Baum, R. (2014c). Rayet, Georges-Antoine-Pons. In T. Hockey et al., 1803–1804.

Best, E. (1955). *The Astronomical Knowledge of the Maori*. Wellington: Government Printer (Dominion Museum Monograph No. 3).

Campbell, R.N. (2001a). Arthur Beverly 1822–1907. *Southern Stars, 40*(3), 23–24.

Campbell, R.N. (2001b). Henry Skey 1836–1914. *Southern Stars, 40*(2), 11–12.

Cenadelli, D. (2014). Secchi, (Pietro) Angelo. In T. Hockey et al., pp. 1970–1972.

Chambers, G.F. (1902). The *Story of Eclipses.* New York: McClure, Phillips.

Clerke, A. (1893). *A Popular History of Astronomy During the Nineteenth Century*. London: Adam and Charles Black.

Cottam, S., Pearson, J., Orchiston, W. & Stephenson, R. (2011). The total solar eclipses of 7 August 1869 and 29 July 1878 and the popularization of astronomy in the USA as reflected in the *New York Times*. In W. Orchiston, T. Nakamura, & R. Strom (Eds.). *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference* (pp. 339–375). New York: Springer.

Dick, S.J., Orchiston, W., & Love, T. (1998). Simon Newcomb, William Harkness and the nineteenth century American transit of Venus expeditions. *Journal for the History of Astronomy, 29,* 221–255.

Dreyer, J.L.E., (1892). Obituary: Norman R. Pogson. *Monthly Notices of the Royal Astronomical Society, 52,* 235–238.

Eclipse of the Sun. *Daily Telegraph*, 9 September 1885 (p. 3).

Eiby, G. (1977). The New Zealand Government time-service: an informal history. *Southern Stars, 27,* 15–34.

Espenak, F., & Meeus, J. (2006*). Five Millennium Canon of Solar Eclipses: −1999 to +3000*. Greenbelt: NASA (Technical Publication TP-2006-214141).

Florence, R. (2014). Gale, George Ellery. In T. Hockey et al., pp. 886–888.

Gibbs, F.G. (n.d.). Notes on the history of astronomy in Nelson. MS, Nelson Provincial Museum (MSS 289).

Gilmore, G. (2017). Alexander William Bickerton: New Zealand's first astrophysicist? In T. Nakamura, & W. Orchiston.

Golub, L., & Pasachoff, J.M. (2009). *The Solar Corona*. Cambridge: Cambridge University Press.

Hawkes Bay Herald, 10 October 1885 (p. 2).

Hearnshaw, J.B., & Orchiston, W. (2017). The development of astronomy and emergence of astrophysics in New Zealand. In T. Nakamura & W. Orchiston.

Hector, J. (1885). On the total solar eclipse of September 9, 1885 (in a letter to Professor Stokes, Sec. R.S.). *Proceedings of the Royal Society of London, 39,* 208–211.

Hind, J.R. (1885). Note on the track of the total phase on the solar eclipse of 1885, Sept. 8, in its passage across New Zealand. *Monthly Notices of the Royal Astronomical Society, 45,* 126–127.

Hirschfield, A.W. (2014). De La Rue, Warren. In T. Hockey et al., pp. 546–547.

Hockey, T.A. (1992). Seeing red - observations of colour in Jupiter's Equatorial Zone on the eve of the modern discovery of the Great Red-Spot. *Journal for the History of Astronomy, 23,* 93–105.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hollis, H.P. (1916). Obituary Notices. Lieutenant-General James Francis Tennant. *Monthly Notices of the Royal Astronomical Society, 76,* 272–276.

Knill, O. (2014). Schuster, Arthur. In T. Hockey, et al., pp. 1957–1959.

Kochhar, R., & Orchiston, W. (2017). The development of modern astronomy and emergence of astrophysics in India. In T. Nakamura, & W. Orchiston.

Launay, F. (2011). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. Cham: Springer.

Lockyer, J.N. (1874). *Contributions to Solar Physics*. London: MacMillan and Co.

Lockyer, J.N. (1896). The story of helium. *Nature, 53,* 319–322, 342–346.

Lomb, N. (2016). Australian solar eclipse expeditions: the voyage to Cape York in 1871. *Journal of Astronomical History and Heritage, 19,* 79–95.

Lowe, D.J. (2008). Polynesian settlement of New Zealand and the impacts of volcanism on early Maori society: an update. In D.J. Lowe (Ed.), *Guidebook for Pre-Conference New Zealand Field Trip A1 'Ashes and Issues'* (pp. 142–147). Palmerston North: New Zealand Society of Soil Science (Australian & New Zealand 4th Joint Soils Conference, Palmerston North, 1–5 December 2008).

Luminet, J.-P. (2014). Baily, Francis. In T. Hockey et al., pp. 143–144.

McIntosh, R.A. (1958). The astronomical history of the Auckland Province. Part III: Nineteenth century. *Amateur Astronomer, 18,* 3–6.

McIntosh, R.A. (1959). The astronomical history of the Auckland Province. Part V - first astronomical society. *Amateur Astronomer, 19,* 46–48.

McKerrow, J. (1886a). Surveys of New Zealand (Report for 1885–86). Eclipse of the Sun. In *Appendix to the Journals of the House of Representatives of New Zealand 1886* (pp. v–vi). Wellington: Government Printer.

McKerrow, J. (1886b). Surveys of New Zealand (Report for 1885–86). Appendix No. 8. The total eclipse of the Sun, 9th September, 1885. In *Appendix to the Journals of the House of Representatives of New Zealand 1886* (pp. 18–21). Wellington: Government Printer.

Mackrell, B. (1985). *Halley's Comet over New Zealand*. Auckland: Reid/Methuen.

Marché, J.D. (2014). Ball, Robert Stawell. In T. Hockey et al., pp. 151–152.

Marten, C.R. (1885). Notes on the total solar eclipse of September 9, 1885, viewed at The Terrace, Wellington, New Zealand. *Monthly Notices of the Royal Astronomical Society, 46,* 23–25.

Meadows, A.J. (1972). *Science and Controversy: a Biography of Sir Norman Lockyer*. Cambridge (Mass.): MIT Press.

Meeson, J., Suter, Right Reverend Dr., Goodall, J., Atkinson, A.S., Hudson, Dr., & Coleman, A. (1886). The total eclipse of the Sun of the 9th September, 1885 … *Transactions and Proceedings of the New Zealand Institute, 18,* 375–394.

Michie, C.B. (1938). Report of the New Zealand total solar eclipse expedition to Canton Island, 1937 June 8. *Monthly Notices of the Royal Astronomical Society, 99,* 132–135.

Mitchell, S.A. (1923). *Eclipses of the Sun*. New York: Columbia University Press.

Mumpuni, E.S., Orchiston, W., & Steinicke, W. (2017). J.A.C. Oudemans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In S. Nakamura, & W. Orchiston.

Nakamura, S., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Nath, B.B. (2013). *The Story of Helium and the Birth of Astrophysics*. New York: Springer.

Nathan, S. (2015). *James Hector: Explorer, Scientist, Leader*. Lower Hutt: Geoscience Society of New Zealand.

Obituaries. James McKerrow. *Monthly Notices of the Royal Astronomical Society, 80,* 348 (1920).

Orchiston, W. (1998). *Nautical Astronomy in New Zealand. The Voyages of James Cook*. Wellington: Carter Observatory.

Orchiston, W. (2016). *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits.* Cham: Springer.

Orchiston, W. (2017a). James Hector, Arthur Stock and early astronomy in Wellington. *Journal of the Royal Society of New Zealand, 47,* 88–93.

Orchiston, W. (2017b). *John Tebbutt: Rebuilding and Strengthening the Foundations of Australian Astronomy*. Cham: Springer.

Orchiston, W., and Orchiston, D.L. (2017). King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-koa, Siam. In S. Nakamura, & W. Orchiston.

Orchiston, W., Lee, E.-H., & Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In S. Nakamura, & W. Orchiston.

Pang, A.S.-K. (2002). *Empire and the Sun, Victorian Solar Eclipse Expeditions*. Stanford: Stanford University Press.

Pearson, J. (2009). *The Role of the 40 Foot Schaeberle Camera in the Lick Observatory Investigations of the Solar Corona*. Ph.D. Thesis, James Cook University, Townsville, Australia.

Pettit, J. (1965). Mr Arthur Beverly (1822–1907). MS (copy in Orchiston Collection).

Proctor, R.A. (1871). *The Sun: Ruler, Fire, Light, and Life of the Planetary System.* London: Longmans, Green.

Proctor, R.A. (1876). *The Sun: Ruler, Fire, Light, and Life of the Planetary System*. London: Longmans, Green

Ranyard, A.C. (1879). Observations made during total solar eclipses. *Memoirs of the Royal Astronomical Society, 41*.

Russell, H.C. (1885). Letter to W.H. Wesley, dated 29 September. In RAS Archives.

Russell, H (1886). Account of the total eclipse of the Sun of September 9th, 1885 … *Astronomical Register, 24,* 20.

Satterthwaite, G.E. (2014). Airy, George Biddell. In T. Hockey, et al., pp. 32–35.

Scholefield, G.H. (Ed.), (1940). *Dictionary of New Zealand Biography* (2 vols.). Wellington: Department of Internal Affairs.

Shylaja, B.S. (2006). John Herschel's astronomical observations from Bangalore. *Current Science, 90,* 259–260.

Stock, A. (1874). *December 9, 1874. The Transit of Venus, and How to Observe It.* Wellington: Boweden.

Ten, A.E. (2014). Arago, Dominique-François-Jean. In T. Hockey, et al., pp. 92–94.

Tennant, J.F. (1869). Report on the total eclipse of the Sun, August 17–18, 1868 … *Memoirs of the Royal Astronomical Society, 37,* 1–55.

The eclipse. *Marlborough Express*, 9 September 1885 (p. 2).

The solar eclipse. *Poverty Bay Herald*, 9 September 1885 (p. 2).

Tobin, W. (1996). The Townsend Telescope – a century of university stargazing. In W. Tobin, & G.M. Evans (Eds.), *Stars in a Cluster* (pp. 78–83). Christchurch: Department of Physics and Astronomy, University of Canterbury.

Ward, L.E. (1928). *Early Wellington*. Auckland: Whitcombe & Tombs.

Young, C.A. (1895). *The Sun*. New York: Appleton

Zirker, J.B. (1984). *Total Eclipses of the Sun*. New York: Van Nostrand Reinhold.

Chapter 23
The Early Development of New Zealand Radio Astronomy

Wayne Orchiston

23.1 Introduction

Although radio astronomy had its origins in the 1930s through the pioneering efforts of Karl Jansky and Grote Reber (Kellermann and Sheets 1983; Sullivan 1984), it blossomed as an emerging scientific discipline only after WWII. Part of the reason for this was the technological developments that occurred during the war, particularly those relating to radar (e.g. see Lovell 1977, 1983).

One of the wartime discoveries that provided an impetus for the post-war focus on radio astronomy was the independent detection of solar radio emission in Denmark (Schott 1947), the United States (Reber 1944; Southworth 1945), England (Hey 1946), Australia (Orchiston and Slee 2002) and New Zealand (Orchiston 1994b).

This chapter (which draws freely on Chapters 23 and 24 in Orchiston 2016) discusses various solar and non-solar radio astronomy projects carried out in New Zealand between 1945 and 1948, during the formative years of international radio astronomy (see Sullivan 2009).

23.2 Dr. Elizabeth Alexander and the Enigmatic ‘Norfolk Island Effect’

Frances Elizabeth Somerville Alexander, neé Caldwell (1908–1958; Fig. 23.1; Harris 2017a, b; Orchiston 2005, 2016; Orchiston and Slee 2002), was born in England, studied physics and geology at Cambridge, graduated with a Ph.D. in geology in 1934, married New Zealand physicist Dr. (later Sir) Norman Stanley

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Fig. 23.1 Dr. Elizabeth Alexander in about 1943 (*Courtesy* Mary Harris)

Alexander (1907–1997) in 1935, and moved with him to Singapore when he accepted the Chair of Physics at Raffles College. There she worked on radar research at the Singapore Naval Base.

In early 1942 when the Japanese invasion of Singapore became imminent, Elizabeth Alexander and her three children (born in 1937, 1939 and 1941) escaped to New Zealand (for localities mentioned in this chapter see Fig. 23.2), where she was appointed head of the Operational Research Section of the Radio Development Laboratory in the nation's capital, Wellington, and continued to research and develop radar (see Fraser 2005; Unwin 1992; *World War II …* 1948).

Elizabeth Alexander was particularly interested in studying propagational effects and developing fundamental theory so that radar performance could be predicted from meteorological data, and vice versa, so any examples of 'anomalous propagation' were of special interest. An example of this occurred between 27 March and 1 April 1945, when a very striking increase in 'radio noise' was noted by the officer in charge of the Royal New Zealand Air Force 200 MHz COL radar unit located on Norfolk Island in the Tasman Sea between New Zealand and Australia. This enhancement, dubbed the 'Norfolk Island Effect,' originated from outside the radar antenna, the turning gear and the receiver, and occurred only within half an hour of the rising or setting of the Sun. Furthermore,

> The maximum increase of noise was on the bearing of the sun and rotation of the aerial showed noise fluctuations corresponding fairly closely to the radiation diagram of the aerial. At its maximum the noise reached saturation on the azimuth of the sun and peaks of noise were also observed on azimuths corresponding to the first and second pair of side lobes. Switching off the Transmitter had no effect on the noise … (Alexander 1945d: 1).

Elizabeth Alexander then arranged for the Sun to be monitored within an hour of sunrise and sunset at the Norfolk Island, North Cape, Whangaroa, Maunganui Bluff

Fig. 23.2 New Zealand localities mentioned in this chapter are shown in red (*Map* Wayne Orchiston)

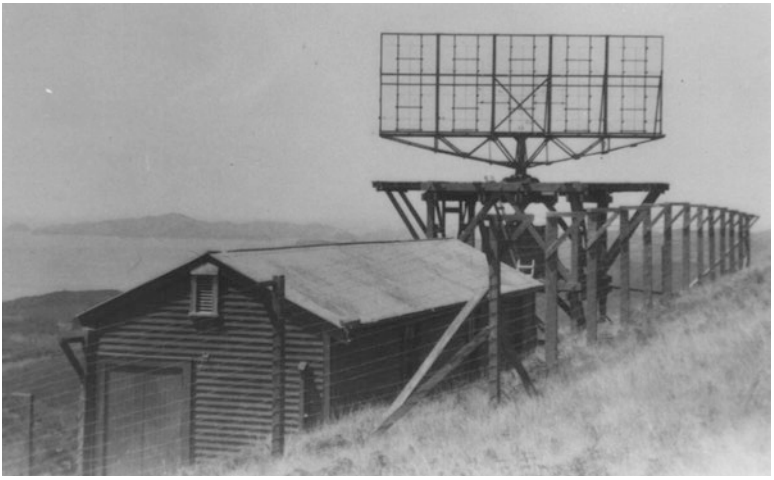

Fig. 23.3 The Whangaroa Radar station, showing the 200 MHz broadside array and associated technical building (Orchiston Collection)

and Piha RNZAF radar stations (see Fig. 23.2 for these locations). A contemporary photograph of the Whangaroa radar station is reproduced below in Fig. 23.3.

The monitoring took place between 10 and 23 April, although few stations were able to continue with this project past 18 April, but solar detections were made at all five stations (see Table 23.1). Part of the reason for the inconsistent results indicated in Table 23.1 lay with the design of the COL radar antennas, which could only rotate in azimuth and detect solar radio emission as the Sun rose or set through the antenna beam. The output, meanwhile, was displayed as 'grass' on a cathode ray tube, and it was a matter of making a subjective assessment as to whether the amplitude of this 'grass' exhibited a meaningful increase. Because the increase was often marginal, this was a problem. To counter this, the Commanding Officer at the Whangaroa radar station installed a microammeter between the receiver output and the diode limiter, and "Immediately a change was apparent and results [were] obtained." (Marsden 1945: 1). Meter readings of 'normal noise' were taken either side of the Sun as the radar antenna was slowly swept across the azimuth of the Sun, and up to five sweeps were made when solar noise was detected. Following this altered *modus operandi*, solar radio emission was detected at both sunrise and sunset on five successive days (see Table 23.1).

Elizabeth Alexander analysed the April observations made at the five radar stations, and concluded that "… at sunrise and sunset a detectable amount of noise over and above normal noise is received from a direction roughly that of the sun." (Alexander 1945d: 4). She stressed that while the observations were crude "… they do seem to indicate that more energy is sometimes radiated from the sun on 200 Mc/s than would be expected on black body theory." (Alexander 1945d: 4); in other words, the emission was non-thermal.

Table 23.1 Days when solar monitoring took place (●) and when solar radio emission was detected (⦿) at the different RNZAF radar stations

Radar station	Date (April 1945)														Detection days
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Norfolk Island			⦿	●	⦿	●	●	●	●	●	⦿	⦿	●	⦿	5
North Cape		⦿	●	⦿	●	●	●	●							2
Whangaroa			●	●	⦿	⦿	⦿	⦿	⦿						5
Maunganui Bluff		●	⦿	●	⦿	⦿	⦿	⦿							5
Piha	●	●	●	⦿	●	●	●	●	⦿	⦿					3
Monitoring Stations	1	3	5	5	5	5	5	5	3	2	1	1	1	1	
Station Detections	0	1	2	2	3	2	2	2	2	1	1	1	0	1	

On the basis of this result, Elizabeth Alexander planned an elaborate solar monitoring program for the second half of 1945, which would involve the original five Air Force radar stations, "… and any Army and Navy stations that can take the observations …" (Alexander 1945d: 5). Two unfortunate factors combined to prevent widespread adoption of this program: (1) an early, successful, outcome of the War was anticipated, so there was ongoing reduction of staff at the various radar stations, but despite this (2) there was "… the necessity of keeping up operational watches [which] placed considerable obstacles in the way of a regular observation programme." (Millar 1946a: 1). Nonetheless, the five original RNZAF radar stations were able to carry out some solar monitoring. The Norfolk Island station began observations on 24 July, but the other radar units were not in a position to join the program until September, and all continued through into December 1945 (Alexander 1945c).

Sadly, this monitoring revealed just the one short-lived period when the Sun was particularly active at 200 MHz, centred on 5 October (Millar 1946a) when "… violent surges of noise were observed at irregular intervals. These surges were of momentary duration and sent the noise meter needle hard over." (Alexander 1945c). When this occurred, the officer in charge of the Piha radar station installed a simple Yagi aerial that could track the Sun, and although the gain was much less than that of the adjacent radar antenna, "… the noise could still be observed, its intensity remaining the same throughout the day whenever the aerial was directed towards the sun …" (Alexander 1946: 16). Elizabeth Alexander (1945c) also reported that "… The signals fluctuated rapidly but did not completely disappear until sunset." However, a plot of the solar noise observations made at this time (Fig. 23.4) reveals that solar radio emission also was detected on 21 October, and that both periods of solar activity correlated with enhancements in sunspot numbers. Elizabeth Alexander (1945c) concluded:

> Such evidence as we have so far in New Zealand points to a direct correlation between sunspot number and solar noise … Though we have no absolute measure of the power received, there is strong evidence that during the periods of intense activity … Long wave Solar radiation is far removed from black body radiation.

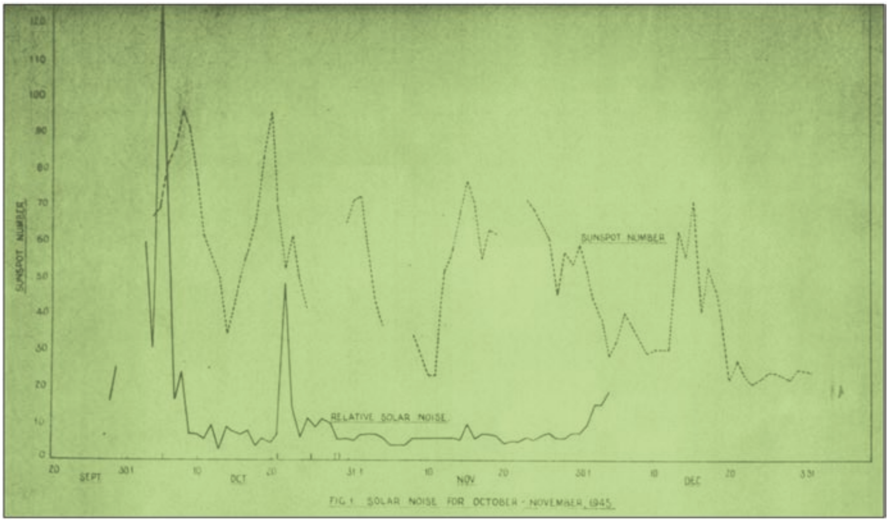

Fig. 23.4 Plots of sunspot numbers (the upper dotted curve), and 200 MHz solar noise recorded at Norfolk Island and Piha, September–December 1945 (after Millar 1946b: 5)

The October activity reinforced her view that she was again dealing with non-thermal emission.

At the end of 1945, most of the RNZAF radar stations were closed down, and at the end of January 1946 the Radio Development Laboratory was disbanded and most of the staff returned to their previous positions or to interrupted university studies (Galbreath 1998; *World War II* … 1948). But before Elizabeth Alexander and her children sailed for England in July 1946 (Mary Harris, pers. comm. 2002), she had one final radar-related task: to write up an account of her 1945 solar research project.

This appeared as a 3-page research paper titled "The Sun's radio energy" (Alexander 1946),[1] and reported the March–April and October activity. The association between sunspots and solar noise—first put forward in her brief December 1945 report—was repeated, and it was noted that both March–April and

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[1] Elizabeth Alexander's daughter, the London academic Mary Harris, has carried out a detailed investigation of her mother's research on the 'Norfolk Island Effect' and thinks

> ... it is very likely that [in addition to the short paper published in *Radio and Electronics*] Elizabeth would have written up the work formally for DSIR, but that her report did not survive the writing of the Narrative and the destruction of the reports that became part of it. (Mary Harris, pers. comm., 2014).

The 'Narrative' to which she refers is the unpublished official history of New Zealand's war-time involvement in radar (see *World War II* ... 1948), and many classified documents were destroyed during and following its preparation. Given her professional approach to research and her meticulous attention to detail, I also am convinced that Elizabeth Alexander prepared a detailed report on the 'Norfolk Island Effect' for the DSIR.

October 1945 were periods of notable sunspot activity. She also mentioned the non-thermal nature of the 200 MHz emission, but thought that "To deduce solar temperatures of millions of degrees from this radiation, as has been suggested in some press reports, is absurd." (Alexander 1946: 20). However, later that same year, the Australian radio astronomers David Forbes Martyn (1906–1970) and Joseph Lade Pawsey (1908–1962) published papers in *Nature* in which evidence of a coronal temperature of one million degrees was presented (see Martyn 1946; Pawsey 1946).

In her paper, Elizabeth Alexander (1946) also discussed wartime observations of solar radio emission made by other researchers in England, Australia and the USA; it is telling that the Australian research (Orchiston et al. 2006; Payne-Scott 1945) was undertaken only after receipt of her reports on the 'Norfolk Island Effect'.

Elizabeth Alexander ended her 1946 paper by stressing the need for further observations, and suggesting that this could be a fruitful field for amateur astronomers and radio enthusiasts:

> What is required at the moment is more experimental evidence on the following aspects:–
>
> 1. The way the received power varies with wavelength, over the whole band of the shortest microwaves up to the largest wavelengths (15-m) which will penetrate the ionosphere (it almost looks at present as if the power might be greater at longer wavelengths).
> 2. The variation, at all wavelengths, with angle of elevation of the sun. This will permit evaluation of atmospheric absorption.
> 3. Exact times of onset, cessation, or change in character. This will permit correlation either with visible changes in the sun, or with other associated phenomena, magnetic storms, etc., and might lead to methods of predicting radio fadeouts.
> 4. Seasonal fluctuations, and variation with geographical position, particularly latitude.
>
> *In observations of this type, amateurs can play an important part. Anyone who cares to build an ultra-shortwave receiver can be fairly sure of collecting useful information. The time is appropriate, since the sun is just entering a new phase of activity, and sunspots may be expected with increasing frequency over the next few years*. (Alexander 1946: 20; my italics).

The tragedy is that Elizabeth Alexander's interesting little paper appeared in the inaugural issue of a New Zealand-based journal titled *Radio and Electronics*, which at the time had virtually no international visibility, and certain never came to the attention of radio astronomers—or indeed those researching the history of radio astronomy—until recently. Nor did Elizabeth send out reprints (if indeed any were issued), or have time to correspond with colleagues she had met who were involved in the formative days of British and Australian radio astronomy. As her daughter Mary Harris (pers. comm. 2014) points out, to Elizabeth Alexander her DSIR job was simply that—a job—even if it did just happen to take her on an interesting excursion into what would soon become radio astronomy. So when the war was over and she had completed her investigation of the 'Norfolk Island Effect' she simply "… wrote it up, signed off and left, rarely to speak of it again." (Alexander 1946).

As a result, her pioneering research was soon forgotten, only to be rescued from obscurity when Woody Sullivan (1988) came upon an archival reference to the 'Norfolk Island Effect' in the course of his research on the world-wide development of radio astronomy (see Sullivan 2009).

23.3 Solar Radio Astronomy and the 'Canterbury Project'

During WWII Elizabeth Alexander was a key participant in an ambitious international radio-meteorological project to investigate 'anomalous propagation', radiation that appeared to originate from over the horizon (Harris 2017a). Towards the end of the War, this would evolve into a joint British-New Zealand research study known as the 'Canterbury Project'. Government funding for this was approved in 1945, but the end of the War delayed its launch as funding had to be re-negotiated under civilian peacetime conditions (see Alexander 1945b).

When Elizabeth Alexander left New Zealand in 1946 the Canterbury Project came under the direction of Dr. Robert S. Unwin (Fig. 23.5), who in 1942 had been appointed as Elizabeth Alexander's assistant (Mary Harris, pers. comm. 2014).

Early in 1947 an ex-WWII radar antenna and field trucks were set up at Wakanui Beach on the Canterbury coast, 85 km southwest of Christchurch (Fig. 23.6), but in October 1947 the antenna was transferred to a more accessible site at Ashburton Airport (Unwin 1947). Although this equipment was intended for the study of radio propagation across the Canterbury Plains under varying meteorological conditions, Dr. Unwin arranged for his staff to observe the Sun at 97.5 MHz for an hour and a half after sunrise and before sunset from March to December 1947, and "… a large number of solar bursts of short duration were detected. On many occasions these occurred when sunspots and other visual signs of solar activity were in evidence." (Orchiston 1994b: 68).

The radio observations were forwarded to Ivan Thomsen at the Carter Observatory in Wellington, but there is no indication that he analysed these, and no publications resulted from what could have been an interesting and valuable study.

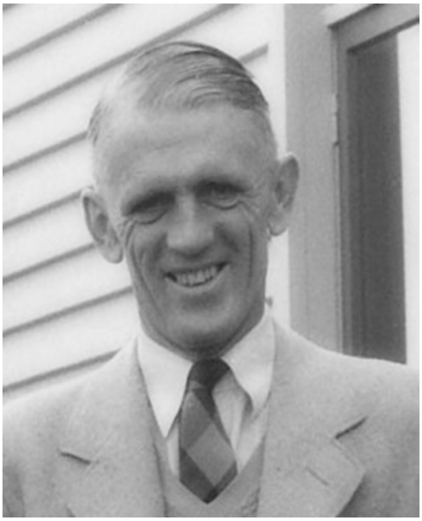

Fig. 23.5 Dr. Bob Unwin (www.niwa.co.nz/atmopshere/facilities/lauder-atmospheric-research-station/lauder-photo-gallery)

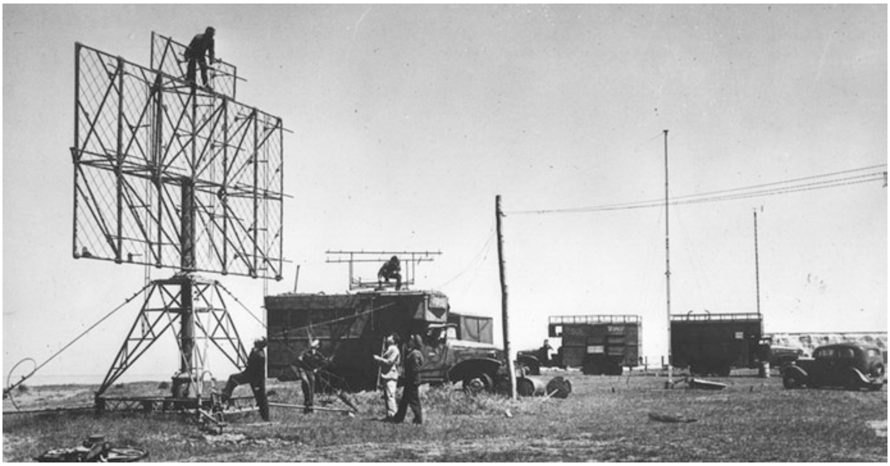

Fig. 23.6 Installation of the ‘Canterbury Project’ 97.5 MHz radar antenna and instrument huts at Wakanui Beach near Ashburton (Orchiston Collection)

23.4 Alan Maxwell and Solar Radio Astronomy at Auckland University College

While the Canterbury Project was in progress, a graduate student named Alan Maxwell (b. 1926) was engaged in a solar radio astronomy project for his M.Sc. degree at what is now the University of Auckland (see Maxwell 1948). His supervisor was Dr. Karl S. Kreielsheimer, and he also found ready support from Professor Percy William Burbidge (1891–1984), both of whom were interested in astronomy, radiophysics and upper atmospheric physics.

In mid-1947 Maxwell erected twin Yagis on the roof of the Biology Department (Fig. 23.7), and tracked the Sun at 100 MHz for the remainder of the year and into the second half of 1948. Maxwell (1948: 82) found that “In general, when solar noise was received there were sunspots on or near the sun’s meridian.” Of special interest was “… a period of solar activity between 1948 August 5–9, when there were numerous small-scale bursts of radio noise.” (Orchiston 1994b: 69), and “On at least two days an indication of a general solar noise background was noticed by pointing the array into and away from the sun … [Furthermore] A rough correlation of bursts with those observed in Canterbury [at Ashburton] has been established on several occasions.” (Burbidge and Kreielsheimer 1947).

Despite this being one of the first post-graduate theses on solar radio astronomy ever written anywhere in the world, Maxwell failed to publish his work—it simply was not the custom at this time—and soon after completing his Auckland studies he moved to the dynamic astronomical environment of Jodrell Bank (at the University of Manchester) where he was quickly immersed in new research for a Ph.D. (Alan Maxwell, pers. comm. 1993).

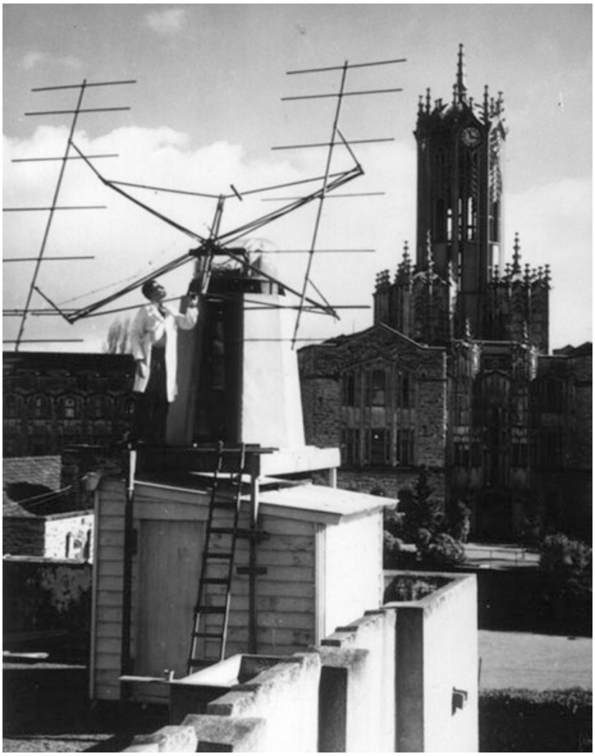

Fig. 23.7 Alan Maxwell adjusting the 100 MHz twin Yagi antenna set up on the roof of the Biology Building at Auckland University College in 1947. The small hut below that antenna and mounting housed the receiver (*Courtesy* Alan Maxwell)

Later he would go on to build an international reputation in solar radio astronomy while at Harvard College Observatory and develop the Radio Astronomy Station at Fort Davis, Texas (see Thompson 2010).

23.5 Ivan Thomsen and the Relationship Between Radio Emission and Optical Features on the Sun

Carter Observatory in Wellington (see Orchiston 2016: Chapter 13) specialised in optical solar monitoring, and from the start its Director, Ivan Leslie Thomsen (1910–1969; Fig. 23.8), was vitally interested in the projects carried out by Elizabeth Alexander and Alan Maxwell and supplied both with relevant optical data. While his involvement in the solar radio monitoring associated with the Canterbury Project was disappointing (in that no results were published), he did in fact publish one paper pertaining to solar radio astronomy.

Thomsen (Co-ordination … 1947) was particularly interested in the relationship between solar emission, sunspots and solar-terrestrial effects—such as short-wave radio fadeouts—and the 24 January 1948 issue of *Nature* features a paper where he

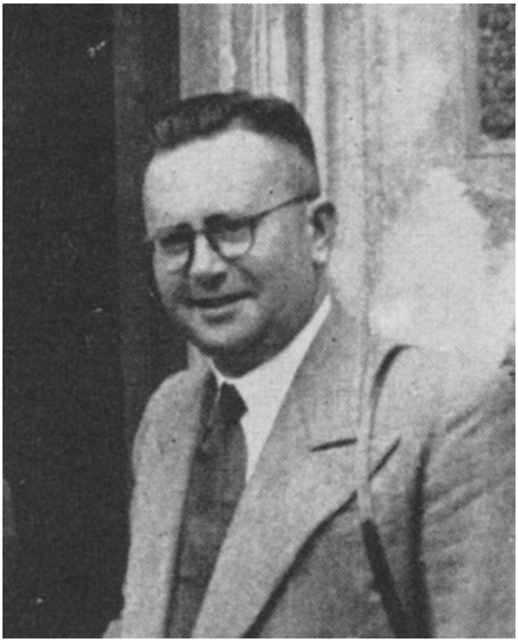

Fig. 23.8 An undated photograph of Ivan Thomsen (adapted from Eiby 1971: 19)

compares Ryle and Vonberg's (1947) radio data for December 1946–April 1947 with sunspot records and finds "… a surprisingly general agreement." (Thomsen 1948: 134). Looking more closely, when the general level of radio emission for February–March 1947 was plotted against the position of photospheric features recorded at the Carter Observatory (Fig. 23.9), "… it was nearly always possible to ascribe some significant sunspot group to each of the maxima of the [radio] curve …" (Thomsen 1948: 134–135). Furthermore, the radio emission tended to coincide with the central meridian passage of the associated spot group, and "… in general, groups in the early stages of vigorous development, or showing activity by large umbral movements and changes and accompanied by flares, give the greatest emission." (Thomsen 1948: 135).

23.6 Robert Francis Joyce: New Zealand's First Amateur Radio Astronomer

Surprisingly, New Zealand can boast a fourth solar radio astronomy project dating to the immediate post-War years. Perhaps inspired by Elizabeth Alexander's 1946 'call to arms', Kaiapoi's Robert Francis Joyce (1886–1961; Fig. 23.10; Orchiston 2016: Chapters 22 and 23) constructed a corner reflector that could track the Sun, obtained an ex-WWII radar receiver, and from mid-1949 carried out solar monitoring at 515 MHz, sending his records to Ivan Thomsen at the Carter Observatory. Although energetic Type II and III solar bursts would have been present at 515 MHz

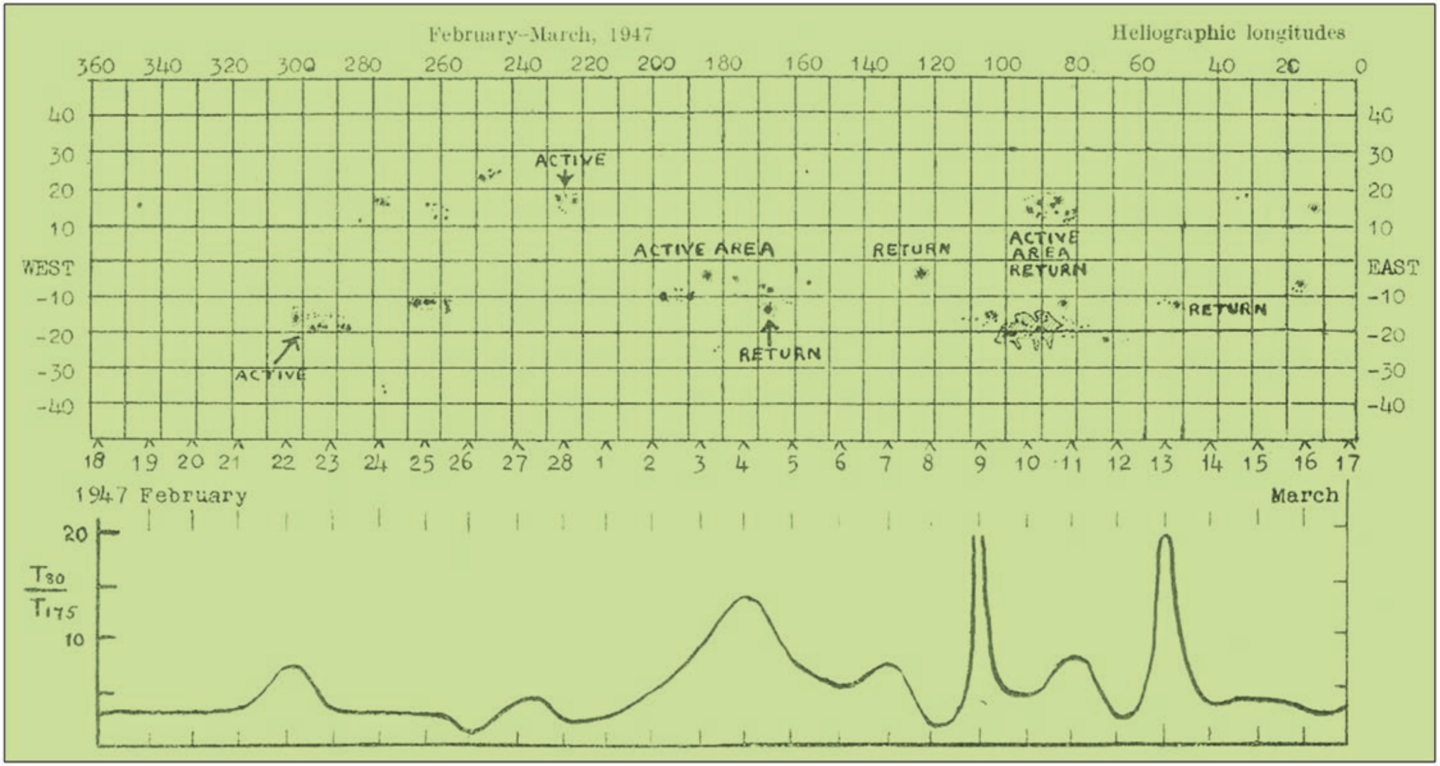

Fig. 23.9 Plot of solar radio emission in February–March 1947 and associated photospheric features (after Thomsen 1948: 135)

Fig. 23.10 Kaiapoi amateur radio astronomer R.F. Joyce (Orchiston Collection)

and presumably were recorded by Joyce, there is no evidence that Thomsen (or anyone else) made any research use of Joyce's data.

By avocation Joyce was a well-known amateur astronomer, whose Neptune Observatory boasted a much-used 11.4-cm (4.5-in.) Wray refractor, and he was an ardent astronomical photographer (see Howell 1967; Murray Geddes … 1956). Meanwhile, by vocation he ran a radio manufacturing and repair business. Thus, he was in an ideal position to tap into the newly emerging field of solar radio astronomy.

23.7 John Bolton, Gordon Stanley, Bruce Slee and the Riddle of the 'Radio Stars'

Thus far New Zealand's romance with early radio astronomy has focused on solar emission, but this section examines a totally different type of radio emitter, which originally was known as a 'radio star' (see Orchiston 1993 1994a).

As Sullivan (1982) points out, the discovery of the first of these discrete radio sources was an accident. In 1946, Hey et al. (1946b) were conducting a sky survey at 60 MHz and discovered a 'radio star' in Cygnus, which subsequenrly was named Cygnus A. Further observations disclosed "… short-period irregular fluctuations." (Hey et al. 1946a).

Although these source variations were later attributed to ionospheric scintillations, at the time they were not understood and attracted the curiosity of radio astronomers John Gatenby Bolton (1922–1993; Orchiston and Kellermann 2008; Robertson 2015), Gordon John Stanley (1921–2001; Kellermann et al. 2005) and Owen Bruce Slee (1924–2016; Orchiston 2004) from the Division of Radiophysics, C.S.I.R. (as it then was) in Australia, who were based at the Dover Heights field station near the entrance to Sydney Harbour. The Radiophysics field stations and associated remote sites in or near Sydney (see Orchiston and Slee 2017; Robertson 1992) were a distinctive feature of post-war radio astronomy in Sydney up to the mid-1960s, and were largely responsible for Australia's rapid emergence as one of the world's leading nations in the fledgling new field of radio astronomy (Sullivan 2009).

During 1947 Bolton, Stanley and Slee not only detected Cygnus A (Bolton and Stanley 1948a, b), but also discovered a number of other 'radio stars' (Bolton 1948) and by the end of January 1948 the tally stood at five (Bolton 1982). The radio telescopes used for these observations were 'cliff interferometers' (Bolton and Slee 1953), which operated on the principle of a Lloyd's Mirror:

> The technique employed was to observe the region [of Cygnus A in this case] rising over the sea with the aerials situated on a high high cliff … Due to interference between the direct ray and the ray reflected from the sea, a lobe pattern is obtained, which gives rise to a succession of maxima and minima. An estimate of the size of the source can be made from the relative heights of maxima and minima, and an accurate position found from the times of occurrence of minima. (Bolton and Stanley 1948b).

Most of the cliff interferometer observations were carried out at 100 MHz, and indicated that sources less than 8 arcminutes in size were involved. These concentrated sources of radio emission, or 'radio stars', were an entirely unknown phenomenon to optical astronomers, and their explanation therefore posed a major challenge to the radio astronomers.

The fundamental problem was to establish accurate source positions so that optical correlates of the radio sources could be sought, and it would be possible to achieve this with the instrumentation at hand only if rising *and* setting times of the sources were determined. Such observations could not be carried out in Sydney (where only the rising of the sources could be observed), but they were possible from near Auckland in New Zealand. The east coast and west coast of Northland not only offered ideal readily-accessible observing sites, but much higher cliffs than at Dover Heights, which would allow lower limits to be set on the sizes of the emitting sources. In addition, as we have seen, Auckland also was home to a university with physics staff who were interested in radio astronomy.

Bolton and Stanley (Fig. 23.11) therefore proposed an expedition to New Zealand, and Dr. 'Taffy' Bowen, Chief of the Division, gave this his enthusiastic support. Meanwhile, the third member of the research team, Bruce Slee (Fig. 23.12), would remain in Sydney and conduct parallel observations at Dover Heights. Partly this was in order to investigate the nature of the variable emission from Cygnus A: parallel observations from these widely separated trans-Tasman locations hopefully would indicate whether the variations were intrinsic to the source itself, or were imposed on the signal by the Earth's ionosphere or the interplanetary medium.

The field trip was approved and at the end of May 1948 an ex-Army-WWII gun-laying radar trailer (Fig. 20.32) containing a 100 MHz 4-Yagi array, a new receiver, recorders, chronometers and weather-recording equipment was shipped to Auckland. Bowen had arranged with New Zealand's Department of Scientific and Industrial Research for logistical support for the expedition, which resulted in the New Zealand Army supplying a truck that was used to haul the little mobile radio telescope to the two different observing sites.

Fig. 23.11 John Bolton (*left*) and Gordon Stanley (*centre*), together with Dr. Joe Pawsey, the head of the radio astronomy group within the Division of Radiophysics (*Courtesy* CSIRO Radio Astronomy Image Archive)

Fig. 23.12 Bruce Slee just before he joined the CSIR Division of Radiophysics in 1946 (*Courtesy* Bruce Slee)

Fig. 23.13 The mobile radio telescope on the Greenwood farm at Pakiri Hill in June 1948 (*Courtesy* Stanley Family)

The first observing station was at ‘Pakiri Hill’, a farm about 10 km from the township of Leigh and 70 km north of Auckland (see Fig. 23.1). The site was at an altitude of about 300 m above mean sea level, and the coastline ran roughly east-west so that Cygnus A could be observed rising in the north-east, culminating at just 15°, and then setting in the north-west. Taurus A also was visible from this location, but Centaurus A and Virgo A were too far south. The Yagi array (Fig. 23.13) had a horizontal beamwidth of 12° and a vertical beamwidth of 30°. In later years, Bolton (1982) was to reminisce:

> We spent nearly two months at Leigh, in periods of working 10 nights and then having four days’ rest as tourists. Conditions were far from ideal; we had a long extension from an already overloaded power line and frequency variations caused variations in the recorder chart speed of at least 10%. The weather was sometimes appalling … Nevertheless we obtained about 30 nights’ usable data on Cygnus-A and in mid-July five observations of Taurus-A …

At the end of July, Bolton and Stanley moved the mobile radio telescope to the deserted WWII radar station at Piha on the adjacent west coast of the Auckland Peninsula 30 km due west of the centre of Auckland (where successful observations of solar radio emission had been made in 1945). This also offered 300-metre-high cliffs, and an uninterrupted view of the western horizon. Conditions here were vastly superior to those encountered at Pakiri Hill: “The diesel plant for the radar provided a supply of electricity stable in both voltage and frequency, our receivers performed faultlessly and the weather was perfect.” (Bolton 1982). Over the next 2 weeks successful observations were made of Cygnus A, Centaurus A, Taurus A and Virgo A as they set.

While these observations were underway in New Zealand, the third member of the ‘radio sources’ team, Bruce Slee, continued to observe these same sources from Dover Heights. He also succeeded in discovering one new source, Fornax A.

In August 1948 Bolton and Stanley returned to Sydney and Bolton began the laborious reduction of the observations. The eventual outcome was outstanding:

> The expedition had been a major success on a number of levels. A further six discrete sources had been discovered, bringing the known number to 13, and there was strong evidence that there might be up to fifty more. The sources were far too faint to examine in any detail during the expedition, but could be followed up later at Dover Heights. (Robertson et al. 2014: 298).

Furthermore, because of the higher New Zealand cliffs, the stronger sources were far more obvious on the chart records than when seen at Dover Heights (e.g. see Fig. 23.14).

The first source Bolton worked on the position of was Taurus A, and after making the appropriate corrections for minor differences in latitude of the observing sites, curvature of the Earth's surface, and atmospheric refraction, he derived the following celestial coordinates:

Right Ascension (1948)	5 h 31 min 20 ± 30s
Declination (1948)	22° 02 ± 8′

Lying within the 'position box' provided by the above co-ordinates was NGC 1952, the Crab Nebula (Fig. 23.15), and Bolton and Stanley (1949) had no hesitation in associating Taurus A with this object (Orchiston and Slee 2006). This identification showed that discrete radio sources could be related to known astronomical objects, in this case a remnant of a supernova that erupted in AD 1054, and was recorded by Arab, Chinese, Japanese and Korean astronomers (see Stephenson and Green 2002), but seems not to have been mentioned by European astronomers (Stephenson and Green 2003).

Four months later, Bolton, Stanley and Slee (1949) completed their pioneering paper "Positions of three discrete sources of galactic radio-frequency radiation" which was published in the leading English scientific journal, *Nature*. They found that "… all three sources correspond within limits of experimental error to positions of certain nebulous objects …", and they were able to identify Centaurus A with NGC 5128 (see Robertson et al. 2010), Virgo A with NGC 4486 (M87), and confirm the Taurus A Crab Nebula association (see Fig. 23.15). A much more detailed account of this work, which included the first radio spectra, was subsequently published in Australia (Stanley and Slee 1950). However, as Sullivan (pers. comm. 1992) has observed, these 'identifications' were regarded by many astronomers with suspicion, especially when "… other likely optical objects of the same classes turned out *not* to be radio sources." This issue was finally resolved by Wilhelm Heinrich Walter Baade (1893–1960; Osterbrock 2001) and Rudolph Minkowski (1895–1976; Osterbrock 1983) with the publication in the *Astrophysical Journal* of their landmark paper titled "Identification of the radio sourcres in Cassiopeia, Cygnus A and Puppis A" (Baade and Minkowski 1954).

The other notable result deriving from the 1948 New Zealand field trip involved the enigmatic Cygnus A source fluctuations first report by Hey et al. (1946a). Thanks to the parallel Australian and New Zealand observing session it was revealed that these

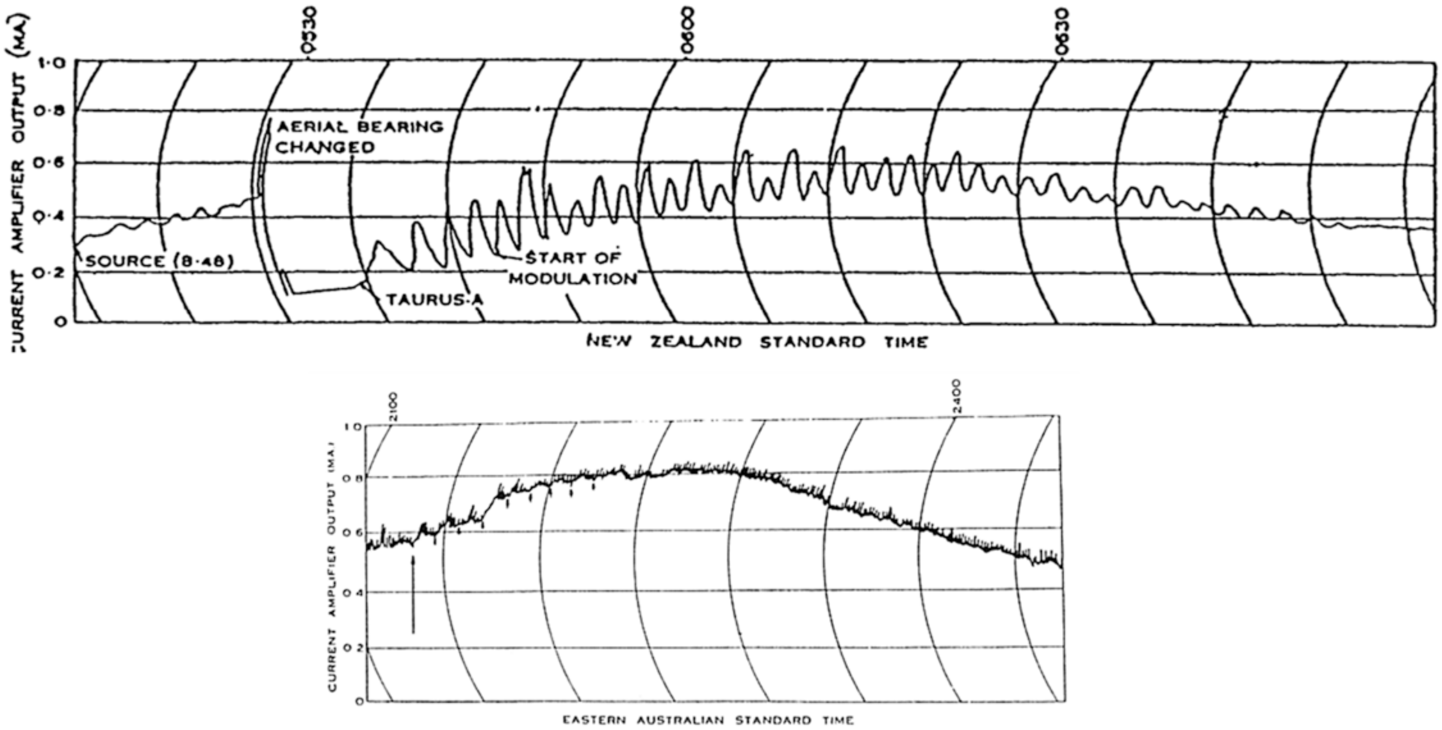

Fig. 23.14 Chart records, to the same scale, showing the Taurus A interference fringes as seen at Pakiri Hill, New Zealand (*top*) and Dover Heights (*bottom*) (after Bolton and Stanley 1949: 140–141)

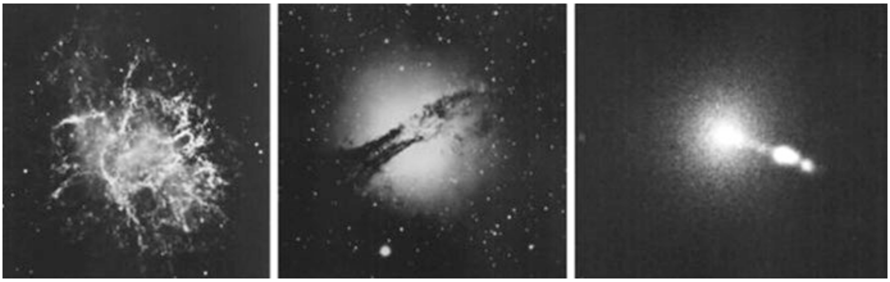

Fig. 23.15 The first three radio sources identified with optical objects by Bolton, Stanley and Slee. Left: Taurus A with the Crab Nebula; centre: Centaurus A with NGC 5128; right: Virgo A with NGC 4486 (*Courtesy* CSIRO Radio Astronomy Image Archive)

Table 23.2 Radio positions of Cygnus A used in identifying its optical correlate (based on Baade and Minkowski 1954: 265)

R.A. (1950)	Dec. (1950)	Reference
19 h 58 min 47 ± 10s	+41° 47 ± 07′	Bolton and Stanley (1948a, b)
19 h 58 min 14 ± 60s	+40° 36 ± 10′	Stanley and Slee (1950)
19 h 57 min 46 ± 05 s	+40° 30 ± 07′	Ryle et al. (1950)
19 h 57 min 37 ± 06 s	+40° 34 ± 03′	Mills and Thomas (1951)
19 h 57 min 44 ± 2.5 s	+40° 35 ± 1.5′	Mills (1952)
19 h 57 min 22 ± 25 s	+40° 22 ± 16′	Hanbury Brown and Hazard (1951)
19 h 57 min 44.3 ± 1 s	+40° 35 ± 01′	Smith (1951)

puzzling source amplitude fluctuations were caused by terrestrial atmospheric scintillations and therefore were not intrinsic to the source itself (Stanley and Slee 1950).

From all accounts the New Zealand expedition of 1948 was a great success. Once optical identifications were published it was clear that the term ‘radio star’ was a misnomer, as these sources were in no way associated with individual stars. In retrospect, Bolton (1982) felt the Taurus A work was a personal milestone: “The identification of the Crab Nebula was a turning point in my own career and for non-solar radio astronomy. Both gained respectability as far as the ‘conventional’ astronomers were concerned.”

The New Zealand work therefore demonstrated that research into discrete radio sources was justified (see Bolton 1955), and led eventually to the various Cambridge and Sydney source catalogues, which, with their associated cosmological implications, were to generate considerable international controversy and even animosity (e.g. see Mills 1984; Smith 1984). Before this took place, however, there was the problem of Cygnus A, which the New Zealand observations had not resolved.

In contrast to Centaurus A, Taurus A and Virgo A, which were associated with obvious optical objects, the Cygnus A source proved far more difficult to explain. Table 23.2 shows the way in which British and Australian radio astronomers gradually pinned down the position of this source until Baade and Minkowski (1954) finally were able to publish an optical identification after subjecting the relevant region of sky to intensive scrutiny with the 5-m (200-in.) Palomar Telescope. The Cygnus A source proved to be associated with a faint (15th magnitude) elliptical galaxy.

As fate would have it, Bernard Yarnton Mills (1920–2011; Mills 2006) and Adin B. Thomas from the Radiophysics Laboratory in Sydney actually made this very optical identification several year earlier, in 1949. After observing Cygnus A from May to December 1949 with the 97 MHz Swept-lobe Interferometer at the Laboratory's Potts Hill field station (Wendt et al. 2011), Mills examined a photograph of the region that Minkowski had sent to Bolton and in the error box of their observations he noticed a faint extragalactic nebula. He felt that this could be the source of the emission and wrote to Minkowski suggesting this (Mills 1949). However, Minkowski (1949) advised Mills against claiming the identification, so when their paper on Cygnus A finally appeared Mills and Thomas (1951) concluded that this faint galaxy was unlikely to be responsible for the emission. Ironically, the more precise position obtained in 1951 by Cambridge University's Francis (later Sir Francis) Graham Smith (b. 1923) confirmed that this galaxy was indeed responsible for the Cygnus A emission.

23.8 Concluding Remarks

23.8.1 New Zealand's Contribution to Early Radio Astronomy

During the formative years of radio astronomy immediately after WWII, Australia and England were forging international reputations, while France, Germany, Japan, the Netherlands, the USA and New Zealand also were active research nations. Radio astronomy continued to thrive in all of these countries except for New Zealand, which has only begun to gain some international visibility in the past decade (see Gulyaev et al. 2005; Head 2010).

This is an ironic situation given that between 1945 and 1949 New Zealand initiated or hosted no fewer than five different radio astronomy projects, and also saw the emergence of the nation's first amateur radio astronomer.

British-born Dr. Elizabeth Alexander must be credited with the independent discovery of metre-wave burst emission from the Sun in 1945, and although she established a link between this emission and sunspots and determined that the emission was non-thermal, circumstances prevented her from publishing her results in *Nature* or some other internationally visible outlet. Instead, her single publication was a 3-page summary of her research that appeared in the first issue of a new New Zealand journal, *Radio and Electronics*, which was virtually invisible to the emerging international radio astronomical fraternity. What is particularly disappointing, though, is the fact that when Sir Edward Appleton (1945) wrote about solar radio emission in *Nature* in 1945 he failed to mention Elizabeth Alexander's work and the non-thermal nature of the emission—even though he was fully aware of it. Instead he claimed her discoveries for himself, but by this time Sir Edward was beginning to gain a reputation for claiming credit for other people's work and delaying the publication of papers submitted to *Nature* by those he viewed as competitors (see Bowen 1946, 1985; Kerr 1987). Be that as it may, it is clear that Elizabeth Alexander made an important contribution to solar radio astronomy under trying personal circumstances (with three young children to support and mistakenly believing that her husband had perished during the Japanese occupation of Singapore). Elsewhere (Orchiston 2005) I have suggested that by being in the right place at the right time she ended up being the first woman in the world to conduct research in the fledging new discipline of 'radio astronomy' (although it would take another 5 years of intensive research—mainly in England and Australia—before this term would begin to find common usage). It is known that Australia's Ruby Violet Payne-Scott (1912–1981) and the head of the Radiophysics Division's radio astronomy group, Dr. Joe Pawsey, made an earlier unsuccessful attempt to detect solar radio emission, but archival records (including those provided by Payne-Scott herself) indicate that her first successful solar research project was inspired by Elizabeth Alexander's 1 August 1945 report on the 'Norfolk Island Effect" and the accompanying letter (Alexander 1945a) that she sent to Joe Pawsey. These facts notwithstanding it has been suggested (Goss and McGee 2009; Goss 2013) that Ruby Payne-Scott should be identified as the world's first female radio astronomer. Woody Sullivan (2009) has examined the credentials of both women and he assigns priority to Dr. Alexander, but it is clear to me that both deserve due recognition for their pioneering efforts in solar radio astronomy in 1945.

New Zealand's second solar radio astronomy project was associated with the 'Canterbury Project', and although numerous solar bursts were detected at 97.5 MHz between March and December 1947, unfortunately these observations were sent to Carter Observatory Director Ivan Thomsen for analysis. I say 'unfortunately', for Thomsen was known by Board members of the Observatory for his reluctance to write papers of international repute, although—as we shall see shortly—he would soon make one key exception to this rule. Nonetheless, if Thomsen had found the inclination and the time to subject the Canterbury Project solar observations to careful scrutiny and written up this work, his paper would undoubtedly have made a valuable contribution to our understanding at that time of the association between solar bursts of different intensities and duration and various photospheric and chromospheric features present on the Sun.

New Zealand's third solar radio project was undertaken by Alan Maxwell at Auckland University College, and resulted in an M.Sc. thesis, which was certainly the first radio astronomy graduate thesis in New Zealand—and possibly in the world. But, reminiscent of the ill-fated solar research associated with the Canterbury Project, Maxwell had neither the time nor the necessity of writing up his research for publication, as he moved to England in 1948 and was soon immersed in doctoral research at Jodrell Bank. Later he would build an international reputation in solar radio astronomy whilst living in the USA (e.g. see Thompson 2010).

Ivan Thomsen may have ignored his obligation to analyse the Canterbury Project solar data but as if to make amends he did compare and contrast observational data published by two British radio astronomers with optical data gathered at the Carter

Observatory. His resulting paper was the first (and only one) he published in *Nature*, and was the first publication in this prestigious journal by a New Zealand-based astronomer.[2] As such, it occupies an important place in the annals of New Zealand, and, indeed, international solar radio astronomy. It is to be regretted that Ivan Thomsen never saw fit (or found the time) to build on this excellent beginning.

Finally we come to the Australian 'radio stars' project, where New Zealand was merely a means to an end: to provide observations made from high cliffs on the eastern and western coasts of the North Island, near Auckland, to pin down the positions of the first four 'radio stars'. As we have seen, this project was an outstanding success and let to the identification of optical correlates for three of the four radio sources and showed that the term 'radio star' was a misnomer. The research was a collaboration between three young Sydney-based scientists, John Bolton, Gordon Stanley and Bruce Slee, but this team had a particular international flavour, for Bolton hailed from England, while Stanley was born in Cambridge, New Zealand. Only Slee was a native Australian. Unlike the various New Zealand solar radio astronomy projects mentioned above, the Australian 'radio stars' project was well publicised through papers published in *Nature* and the *Australian Journal of Scientific Research*. As Robertson et al. (2014: 302) have observed,

> The youthful trio of Bolton, Stanley and Slee would all go on to carve out distinguished careers in radio astronomy, but none would produce another paper to rival the importance of their 1949 *Nature* letter. A new branch of astronomy had been founded—extra-galactic radio astronomy …
>
> This new branch would revolutionise astronomy in the second half of the twentieth century.

Meanwhile, I find it a little strange that the media did not make anything of Stanley's New Zealand origins. I have suggested elsewhere that "Obviously the ANZAC tradition was still prevalent, and issues of nationalism had yet to emerge. To all intents and purposes Stanley was an 'Australian' scientist—as was Bolton." (Orchiston 2016: 666).

23.8.2 Why did New Zealand Radio Astronomy die in 1948?

Ignoring for a moment the 'radio stars' project, it is clear that Elizabeth Alexander's work in 1945 was the catalyst that led to several other New Zealand research projects in solar radio astronomy in the immediate post-War years. Yet unlike in neighbouring Australia, this discipline did not succeed in gaining a sustained foothold in New Zealand at the time. Why was this?

The radio astronomy research on both sides of the Tasman Sea was led by highly trained, respected radar experts with British doctorates (Elizabeth Alexander and Joe

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[2] Note that I specifically say 'New Zealand-based astronomer' because in 1946 expatriate New Zealander Congreve John Banwell (1908–1983; Fraser 2016) published a paper jointly with Bernard Lovell on solar radio emission while teaching and carrying out graduate research in radio astronomy at Jodrell Bank (see Lovell and Banwell 1946).

Pawsey), and each managed a sizeable research team. At war's end there were ~300 staff in the CSIRO's Division of Radiophysics in Sydney (see Sullivan 2017), while in New Zealand, collectively there were more than 100 technical and research staff in the Auckland, Wellington and Christchurch branches of the Government's Department of Scientific and Industrial Research Radio Development Laboratory (Galbreath 1998). But, apart from the numerical disparity, there were two key differences.

Firstly, Joe Pawsey was committed to radar and to radio astronomy (Christiansen and Mills 1964), and while Elizabeth Alexander was certainly interested in radar the Wellington job was a stop-gap measure imposed on her by the War, and her principal research love was geology. Moreover, as a mother with young children, her allegiance lay with her family, her husband, and his career. Unlike Pawsey (whom she knew well from their pre-War days in England), she had no long-term commitment to the new field of radio astronomy. Nor was she interested in remaining in New Zealand so long as her husband had employment in Singapore (and later in Nigeria—which is where she died).

Secondly, the New Zealand DSIR and Australia's CSIRO were structured quite differently. In New Zealand the Radio Development Laboratory was part of the Public Service, so at the end of the War staff there were expected to return to their pre-war posts, or undertake university studies (if this was an option). There was no possibility of maintaining the Radio Development Laboratory and redirecting its research efforts to peacetime objectives—as occurred with the Division of Radiophysics in Australia (see Sullivan 2017). Elizabeth Alexander was well aware of this, and on 23 November 1945 she wrote Joe Pawsey warning that New Zealand's solar radio astronomical future looked bleak after the close-down of the COL radar stations at the end of the year:

> I doubt that New Zealand will be able to put sufficient effort into building aerials adequate to investigate the phenomenon. It is a large scale job, if it is to be done properly, and the Canterbury Project is taking all available men and cash. (Alexander 1945b).

This forecast proved remarkably accurate, and although Ernest Marsden (Director of Scientific Developments in the DSIR) succeeded in forming a Radar Section within the Dominion Physical Laboratory on 21 February 1946 (*World War II …* 1948), this began with a staff of just 13 (Atkinson 1976: 66) and would always be a small-scale operation with limited funding and even more limited research capability. Within post-War Government-funded science, there simply was no place for radio astronomy in New Zealand.

But radio astronomical research was not just about viable research projects and adequate financial resources. It was also about people. With access to the right people, research opportunities could open up that otherwise might remain closed. There is no doubt that had Elizabeth Alexander and/or Alan Maxwell remained in New Zealand after WWII and retained an interest in solar radio astronomy, then New Zealand could have built on its 1945–1948 achievements and become a major international player. Indeed, John Bolton specifically alluded to this when he gave a lecture at Auckland University College in August 1948. Bolton's lecture was written up by a local newspaper, in an article with the ominous title "New Zealand Lost Opportunity. Study of Radiations" (1948):

> New Zealand missed one of its greatest opportunities of leading in a scientific field by not following up observations of solar radiation obtained by radar operators in the Dominion in 1942 [in fact the observations were made in 1945]. This opinion was expressed by Mr. J.G. Bolton the young scientist of the Australian Scientific and Industrial Research Council who has been studying cosmic noise at Leigh and Piha, in an address to a scientific gathering at the Auckland University College last night.

As we have seen, history dictated that this would not happen, but if we ignore Alexander and Maxwell for the moment and agree that Thomsen had neither the time nor the right academic background to lead a major collaborative New Zealand solar research project (he did not even possess a university degree), there were two other individuals who could have played key roles in such a development. One was the aforementioned John Banwell (who was a WWII radar expert and had published a paper on solar radio emission in 1946), but when he returned to New Zealand from England in 1947 he chose to redirect his research acumen to geophysics, and

> … enter the new field of geothermal research established to investigate the possible generation of electric power from natural steam bores … Although it was a new line of research for both him and the country, he showed the same originality and high quality of research as in his preceding career. (Fraser 2016: 16.

He went on to became a key participant in the development of the Wairakei geothermal complex (see Dawson 1989).

The other possible participant was Clifton Darfield Ellyett (1915–2006; Keay 2006), like Banwell a Canterbury University College physics graduate and Ph.D. student at the University of Manchester (Jodrell Bank). However, Ellyett chose to emulate Lovell's lead and use radar techniques to research meteors rather than the Sun, and when he returned to New Zealand in 1950 he proceeded to establish a University meteor field station at Rolleston to the southwest of Christchurch. Ellyett was able to attract funding and graduate students and quickly built up a research team that achieved international eminence (see Fraser 2016; Head 2010; Keay 1965). Given that Banwell also published two papers on meteors while at Jodrell Bank, it is illuminating to imagine what might have happened at Canterbury had he joined forces with Ellyett instead of choosing to remain in geophysics.

In ending this chapter I can do no better than to quote from an earlier piece that I wrote about the emergence of radio astronomy in New Zealand:

> We can say, therefore, that from 1945 until the end of 1948 radio astronomy flourished in New Zealand, but it was like a supernova: it made a sudden short-lived appearance, rose rapidly to prominence, attracted much attention, and then quietly subsided. Despite this promising start in the 1940s, radio astronomy would remain the 'poor cousin' of optical astronomy in New Zealand for decades, until the emergence of Professor Sergei Gulyaev and the Institute of Radio Astronomy and Space Research at the Auckland University of Technology … (Orchiston 2016: 668).

We have finally entered a new era in the development of radio astronomy in New Zealand (see Hearnshaw and Orchiston 2017).

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References

Alexander, F.E.S. (1945a). Letter to J.L. Pawsey, dated 1 August. Copy in Sullivan Collection.

Alexander, F.E.S. (1945b). Letter to J.L. Pawsey, dated 23 November. Copy in Sullivan Collection.

Alexander, F.E.S. (1945c). Long wave solar radiation. DSIR, Radio Development Laboratory (Report).

Alexander, F.E.S. (1945d). Report on the investigation of the "Norfolk Island Effect". DSIR, Radio Development Laboratory Report dated 1 August (R.D. 1/518).

Alexander, F.E.S. (1946). The Sun's radio energy. *Radio and Electronics, 1* (1), 16–17, 20.

Appleton, E.V. (1945). Departure of long-wave solar radiation from black-body intensity. *Nature, 156,* 534–535.

Atkinson, J.D. (1976). *DSIR's First Fifty Years*. Wellington: Department of Scientifc and Industrial Research.

Baade, W., & Minkowski, R. (1954). Identification of the radio sources in Cassiopeia, Cygnus A and Puppis A. *Astrophysical Journal, 119,* 206–214.

Bolton, J.C. (1948). Discrete sources of galactic radio frequency noise. *Nature, 162,* 141–142.

Bolton, J.C. (1955). Australian work on radio stars. *Vistas in Astronomy, 1,* 568–573.

Bolton, J.G. (1982). Radio astronomy at Dover Heights. *Proceedings of the Astronomical Society of Australia, 4,* 349–358.

Bolton, J.G., & Stanley, G.J. (1948a). Observations of the variable source of cosmic radio frequency radiation in the constellation of Cygnus. *Australian Journal of Scientific Research, A1,* 58–69.

Bolton, J.G., & Stanley, G.J. (1948b). Variable source of radio frequency radiation in the constellation of Cygnus. *Nature, 161,* 312–313.

Bolton, J.G., & Stanley, G.J. (1949). The position and probable identification of the source of the galactic radio-frequency radiation Taurus-A. *Australian Journal of Scientific Research, A2,* 139–148.

Bolton, J.G., Stanley, G.J., & Slee, O.B. (1949). Positions of three discrete sources of galactic radio-frequency radiation. *Nature, 164,* 101–102.

Bolton, J.G., & Slee, O.B. (1953). Galactic radiation at radio frequencies. V. The sea interferometer. *Australian Journal of Physics, 6,* 420–433.

Bowen, E.G. (1946). Letter to Dr. F.W.G. White, dated 26 April. Copy in Sullivan Collection.

Bowen, E.G. (1985). Letter to Woody Sullivan, dated 7 August. In Sullivan Collection.

Burbidge, P.W., & Kreielsheimer, K.S. (1947). Report on solar noise measurements carried out at the Physics Department, Auckland University College. Unpublished report prepared for a DSIR meeting on 6 November 1947. Copy in National Archives, Wellington.

Christiansen, W.N., & Mills, B.Y. (1964). Biographical memoir of Joseph Lade Pawsey. *Australian Physicist, 1,* 137–141.

Co-ordination of research on auroral, solar, ionospheric, geophysical and radio phenomena. Memorandum to interested parties (1947). Report prepared for a DSIR meeting on 6 November 1947. Copy in National Archives, Wellington.

Dawson, G. (1989). With the DSIR at Wairakei the first year, March 1950 to February 1951. In *Proceedings of the 11th New Zealand Geothermal Workshop* (pp. 255–260). Auckland: University of Auckland.

Eiby, G. (1971). Astronomy in New Zealand. *Sky and Telescope, July,* 18–20.

Fraser, G.J. (2005). The antecedents and subsequent development of scientific radar in New Zealand. *Journal of Atmospheric and Solar-terrestrial Physics, 67,* 1411–1418.

Fraser, G. (2016). Early meteor radar astronomy at Jodrell Bank and Canterbury. *Southern Stars, 55*(4), 11–20.

Galbreath, R. (1998). *DSIR. Making Science Work for New Zealand. Themes From the History of the Department of Scientific and Industrial Research*. Wellington: Victoria University of Wellington Press, in association with the Historical Branch, Department of Internal Affairs.

Gulyaev, S., Natusch, T., Addis, B., Tingay, S., & Deller, A. (2005). Development of radio astronomy and trans-Tasman long baseline array. *Southern Stars, 44*(4), 12–16.

Hanbury Brown, R., & Hazard, C. (1951). A radio survey of the Cygnus region. I. The localized source Cygnus (I). *Monthly Notices of the Royal Astronomical Society, 111,* 576–584.

Harris, M. (2017a). Rocks, radio and radar: Elizabeth Alexander and the DSIR Radio Development Laboratory, 1942–1945. *Journal of the Royal Society of New Zealand, 47*.

Harris, M. (2017b). *Rocks, Radio and Radar: The Extraordinary Scientific, Social and Military History of Elizabeth Alexander*. London: Imperial College Press.

Head, M. (2010). A brief history of radio astronomy in Aotearoa New Zealand. *Southern Stars, 49,* 7–19.

Hearnshaw, J., & Orchiston, W. (2017). The development of astronomy and emergence of astrophysics in New Zealand. In T. Nakamura & W. Orchiston.

Hey, J.S. (1946). Solar radiations in the 4-6 metre radio wave-length band. *Nature, 157,* 47–48.

Hey, J.S., Parsons, S.J., & Phillips, J.W. (1946a). Fluctuations in cosmic radiation at radio-frequencies. *Nature, 158,* 234.

Hey, J.S., Phillips, J.W., & Parsons, S.J. (1946b). Cosmic radiations at 5 metres wave-length. *Nature, 157,* 296–297.

Howell, P. (1967). Robert Francis Joyce. An appreciation. *Southern Stars, 22,* 51–53.

Keay, C.S. (1965). Meteor research in New Zealand. *Southern Stars, 21,* 9–19.

Keay, C. (2006). Clifton Darfield Ellyett. Royal Society of New Zealand, Academy Yearbook (http://royalsociety.org.nz/publications/reports/yearbooks/year2006/obituaries/ellyett/).

Kellermann, K., & Sheets, B. (Eds.), (1983). *Serendipitous Discoveries in Radio Astronomy*. Green Bank: National Radio Astronomy Observatory.

Kellermann, K.I., Orchiston, W., & Slee, B. (2005). Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publications of the Astronomical Society of Australia, 22*, 13–23.

Kerr, F. (1987). Letter to Woody Sullivan, dated 6 April. In Sullivan Collection.

Lovell, B. (1977). The effects of defence science on the advance of astronomy. *Journal for the History of Astronomy, 8,* 151–173.

Lovell, B. (1983). Impact of World War II on radio astronomy. In K.I. Kellermann & B. Sheets, pp. 89–104.

Marsden, E.D.L. (1945). Report on radio sunset-sunrise observations taken at No. 7 radar unit for the period 14th until 18th April, 1945. DSIR (Report).

Martyn, D.F. (1946). Temperature radiation from the quiet Sun in the radio spectrum. *Nature, 158,* 632–633.

Maxwell, A. (1948). *Enhanced Solar Radiation at 3 Metre Wavelengths*. M.Sc. Thesis, Physics Department, Auckland University College, Auckland, New Zealand.

Millar, J.G. (1946a). Long wave solar research. DSIR Report dated 15 January.

Millar, J.G. (1946b). Observations of noise from the Sun at metre wavelengths on Norfolk Island and in New Zealand. DSIR, Radar Section, Dominion Physical Laboratory (Report 1/536).

Mills, B.Y. (1949). Letter to R. Minkowski, dated 16 December. National Archives of Australia, 972099—C3830—A1/1/1 Part 4 Box 1.

Mills, B.Y. (1952). The positions of six discrete sources of cosmic radio radiation. *Australian Journal of Scientific Research, A5,* 456–463.

Mills, B.Y. (1984). Radio sources and the log N–log S controversy. In W.T. Sullivan, pp. 146–165.

Mills, B.Y. (2006). An engineer becomes astronomer. *Annual Review of Astronomy and Astrophysics, 44,* 1–15.

Mills, B.Y., & Thomas, A.B. (1951). Observations of the sources of radio frequency radiation in the constellation of Cygnus. *Australian Journal of Scientific Research, A4,* 158–171.

Minkowski, R. (1949). Letter to B.Y. Mills, dated 25 December. National Archives of Australia, 972099–C3830–A1/1/1 Part 4 Box 1.

Murray Geddes Prize Award—1955. Mr. R. Francis Joyce. *Southern Stars, 17,* 6 (1956).

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

New Zealand Lost Opportunity. Study of Radiations. Newspaper article dated 11 August 1948 (source unspecified, but probably the *New Zealand Herald*). In: Bolton Papers, Series 3, Folder 1, Newspaper cuttings 1948–93, National Library of Australia, Canberra.

Orchiston, W. (1993). New Zealand's role in the identification of the first 'radio stars'. *Southern Stars, 35,* 46–52.

Orchiston, W. (1994a). John Bolton, discrete sources, and the New Zealand field-trip of 1948. *Australian Journal of Physics, 47,* 541–547.

Orchiston, W. (1994b). Radio waves from the Sun: the New Zealand connection. In W. Orchiston, R. Dodd, & R. Hall (Eds.), *Astronomical Handbook for 1995* (pp. 65–69). Wellington: Carter Observatory.

Orchiston, W. (2004). From the solar corona to clusters of galaxies: the radio astronomy of Bruce Slee. *Publications of the Astronomical Society of Australia, 21,* 23–71.

Orchiston, W. (2005). Dr Elizabeth Alexander: first female radio astronomer. In W. Orchiston (Ed.), *The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth* (pp. 71–92). Dordrecht: Springer.

Orchiston, W. (2016). *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits*. Cham: Springer.

Orchiston, W., & Kellermann, K.I. (2008). Bolton, John Gatenby. In *Dictionary of Scientific Biography* (pp. 332–337). New York: Gale.

Orchiston, W., & Slee, B. (2002). The Australasian discovery of solar radio emission. *Anglo-Australian Observatory Newsletter, November,* 25–27.

Orchiston, W., & Slee, B. (2006). Early Australian observations of historic supernova remnants at radio wavelengths. In K.-Y. Chen, W. Orchiston, B. Soonthornthum, & R. Strom (Eds.), *Proceedings of the Fifth International Conference on Oriental Astronomy* (pp. 43–56). Chiang Mai: Chiang Mai University.

Orchiston, W., & Slee, B. (2017). The early development of Australian radio astronomy: the role of the CSIRO Division of Radiophysics field stations. In T. Nakamura & W. Orchiston.

Orchiston, W., Slee, B., & Burman, R. (2006). The genesis of solar radio astronomy in Australia. *Journal of Astronomical History and Heritage, 9,* 35–56.

Osterbrock, D.E. (1983). *Biographical Memoir. Rudolph Minkowski 1895–1976*. Washington: National Academy of Science.

Osterbrock, D.E. (2001). *Walter Baade – A Life in Astrophysics*. Princeton: Princeton University Press.

Pawsey, J.L. (1946). Observation of million degree thermal radiation from the Sun at a wavelength of 1.5 metres. *Nature, 158,* 633–634.

Payne-Scott, R. (1945). Solar and cosmic radio frequency radiation. Survey of knowledge available and measurements taken at Radiophysics Lab. to Dec. 1st 1945. Sydney, CSIR, Radiophysics Division (Report SRP 501/27).

Reber, G. (1944). Cosmic static. *Astrophysical Journal, 100,* 279–287.

Robertson, P. (1992). *Beyond Southern Skies: Radio Astronomy and the Parkes Radio Telescope*. Cambridge: Cambridge University Press.

Robertson, P. (2015). *John Bolton and the Nature of Discrete Radio Sources*. Ph.D. Thesis, University of Southern Queensland, Toowoomba, Australia.

Robertson, P., Orchiston, W., & Slee, B. (2014). John Bolton and the discovery of discrete radio sources. *Journal of Astronomical History and Heritage, 17,* 283–306.

Robertson, P., Cozens, G., Orchiston, B., Slee, B., & Wendt, H. (2010). Early Australian optical and radio observations of Centaurus A. *Publications of the Astronomical Society of Australia, 27,* 402–430.

Ryle, M., & Vonberg, D.D. (1947). Relation between the intensity of solar radiation on 175 Mc./s. and 80 Mc./s. *Nature, 160,* 157–159.

Ryle, M., Smith, F.G., & Elmore, B. (1950). A preliminary survey of the radio stars in the Northern Hemisphere. *Monthly Notices of the Royal Astronomical Society, 110,* 508–523.

Schott, E. (1947). 175 MHz emission of the Sun. *Physikalische Blätter, 3,* 159–160.

Smith, F.G. (1951). An accurate determination of the positons of four radio stars. *Nature, 168,* 555.

Smith, F.G. (1984). Early work on radio stars at Cambridge. In W.T. Sullivan, pp. 236–248.

Southworth, G.C. (1945). Microwave radiation from the Sun. *Journal of the Franklin Institute, 239,* 285–297.

Stanley, G.J., & Slee, O.B. (1950). Galactic radiation at radio frequencies. II. The discrete sources. *Australian Journal of Scientific Research, A3,* 234–250.

Stephenson, F.R., & Green, D.A. (2002). *Historical Supernovae and their Remnants*. Oxford: Oxford University Press.

Stephenson, F.R., & Green, D.A. (2003). Was the supernova of AD1054 recorded in European history? *Journal of Astronomical History and Heritage, 6,* 46–52.

Sullivan, W.T. III (Ed.), (1982). *Classics in Radio Astronomy*. Dordrecht: Reidel.

Sullivan, W.T. III (Ed.), (1984). *The Early Years of Radio Astronomy*. Cambridge: Cambridge University Press.

Sullivan, W. III (1988). Early days of Australian radio astronomy. In R. Home (Ed.), *Australian Science in the Making* (pp. 308–344). Cambridge: Cambridge University Press.

Sullivan, W.T. III (2009). *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge: Cambridge University Press.

Sullivan, W.T. III (2017). The beginnings of Australian radio astronomy. In T. Nakamura & W. Orchiston.

Thompson, A.R. (2010). The Harvard radio astronomy station at Fort Davis, Texas. *Journal of Astronomical History and Heritage, 13,* 17–27.

Thomsen, I.L. (1948). Solar radio emissions and sunspots. *Nature, 161,* 134–136.

Unwin, R.S. (1947). Notes on observations of solar noise at 3 metres wavelength made at Canterbury Project, Ashburton. DSIR Report dated 29 October (original in National Archives, Wellington).

Unwin, R.S. (1992). The development of radar in New Zealand in World War II. *The Radioscientist, 3* (1), 8–18.

Wendt, H., Orchiston, W., & Slee, B. (2011). The contribution of the Division of Radiophysics Potts Hill field station to international radio astronomy. In W. Orchiston, T. Nakamura, & R. Strom (Eds.), *Highlighting the History of Astronomy in the Asia-Pacific Region* (pp. 379–431). New York: Springer.

World War II Narrative No. 3. Radar. Wellington, DSIR (1948). Original Manuscript in National Archives, Wellington (W3424, Box 16).

Part IX
India

Chapter 24
The Development of Modern Astronomy and Emergence of Astrophysics in India

Rajesh Kochhar and Wayne Orchiston

24.1 Introduction

Modern astronomy came to India in tow with the Europeans, as a geographical and navigational aid, and as part of Anglo-French geo-political rivalry. The first recorded use of the telescope on Indian soil however is atypical, as it was in the field of pure astronomy rather than applied astronomy. The observer was a Bohemian-born Portuguese Jesuit missionary-astronomer, Father Venceslaus Pantaleon Kirwitzer (1588–1626), who observed the two Great Comets of 1618 (C/1618 V1 and W1) from Goa (for Indian Subcontinent localities mentioned in this chapter see Fig. 24.1) using what he referred to as a *tubo optico*, namely a telescope (Kapoor 2016: 282–290). Later that century, one of the earliest followers of Kepler, an Englishman named Jeremiah Shakerley (1625–ca.1655), viewed the 1651 transit of Mercury from Surat in West India. He could however neither time the ingress nor the egress. His observation therefore was of no scientific value, and it remains a curiosity. Shakerley was the first modern astronomer to die in India (Kochhar 1989).

More representative of things to come was the work of the Jesuit priest Jean Richaud (1633–1699) who, observing from the French enclave of Pondicherry, in 1689 discovered that the bright southern star α Centauri was in fact a double star (Kameswara Rao et al. 1984). This was the second binary discovered in the southern skies, after α Crucis, which was discovered in 1685 from the Cape of Good Hope by the China-bound Jesuit Fr Jean de Fontenay (1643–1710). While Abū'l Fazl independently discovered the Great Comet of 1577 (C/1577 V1) (Kapoor 2015) and

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Fig. 24.1 Indian Subcontinent localities mentioned in the text (*Base map* www.d-maps.com/carte.php?num_car=284&lang=en; *Map modifications* Wayne Orchiston)

both Nūr ud-Din Jahāngīr and the afore-mentioned Father Kirwitzer both discovered the two November Great Comets of 1618 (Kapoor 2016), Richaud's was the first recorded *telescopic* astronomical discovery from India. Yet, "These telescopic swallows … did not make an astronomical Indian summer." (Kochhar 1991c: 72).

Jesuits were the first systematic users of the telescope in India who had the intellect, time, scientific training and the opportunity to criss-cross the country (Kochhar 1991b). They collected valuable and reliable geographical data, partly out of curiosity and partly on instructions from France (Udias 2003). Thanks to the work carried out by the Jesuits, the French were more successful in India on the scientific front than they were on the colonial front. Early use of (modern) astronomy in India by the Europeans was desultory, sporadic and very often driven by personal curiosity.

The East India Company became a territorial power in Bengal in 1757 and completed the conquest and control of India by 1818 (Keay 2010; Lawson 1993). Its geographical and navigational needs became clear very early on:

1. To survey the territories it already held;
2. To increase revenue earnings;
3. To ensure safety of sea passage to and from India; and
4. To learn about Indian geography, for the sake of administration and future conquests.

Observation of the 1761 and 1769 transits of Venus was perceived as a continuation of the on-going rivalry between France and England, and brought many instruments and a general awareness of astronomy to British India. The Seven Years War between the two nations and their allies was still in progress when the 1761 transit occurred (Baugh 2011; Marston 2001) and this had a profound influence on who eventually would be able observe the transit. Undoubtedly best known is the sad saga of the French astronomer Guillaume Joseph Hyacinthe Jean-Baptiste Le Gentil (1725–1792) whose plan to observe the transit from the French port of Pondicherry was thwarted when the British occupied the port. Instead, he had to observe the event from a moving ship in the Indian Ocean, and consequently his observations had no scientific value.

The British had more luck. Observing from the Governor's house at Fort St George in Madras (present-day Chennai), the Reverend William Hirst (d. 1774; Goodwin 1891) used a 2-ft. long reflector that recently was donated to Muhammed Ali, the Nawab of Arcot, by Sir George Pigot (the Governor) on behalf of the East India Company, and was kindly made available for the transit (Hirst 1761–1762). William Magee, a notary public in Calcutta, also observed the transit, and some Jesuit priests observed it from near Madras. Details of these observations, and others made in the Subcontinent, are provided by Kapoor (2013).

Observations of the 1761 transit that were made worldwide produced an unacceptably large range of values for the solar parallax and hence the Astronomical Unit (Orchiston 2005), so the focus then became the 1769 transit, which also would be visible from the Indian Subcontinent. On 22 January 1768, the Secretary of the Royal Society wrote:

> The honor of this Nation seems particularly concerned in not yielding the palm to their Neighbours, and the Royal Society intends to exert all its strength and influence in order to have this observation [1769 transit] made … (cited in Love 1913: 591).

On this occasion, however, the weather was less co-operative: there were cloudy skies over both Madras and Pondicherry, but useful observations were made from Dinapoor and nearby Phesabad in north-eastern India (again, for details see Kapoor 2013).

One of those frustrated by the cloudy skies over Pondicherry was Le Gentil, who after making abortive observations of the 1761 transit had decided to stay in Asia and wait for the 1769 event. He holds the record for the longest scientific expedition in recorded world history: he only returned to France after 11 years, and without accomplishing his mission. In a four-part 'essay', Helen Sawyer Hogg (1951)

> … presents us with a wonderful peek into the life and travails of Le Gentil, based on his memoirs, *Voyages dans les Mers de l'Inde fait par Ordre du Roi, à l'Occasion du Passage de Vénus sur le Disque du Soleil le 6 Juin 1761, & le 3 du Même Mois 1769*, which was published in two volumes in 1782. (Kapoor 2013: 276).

By the eighteenth century, astronomical expeditions and instruments were seen as symbols of a superior, science-driven culture. Thus, instruments were presented as official gifts to native rulers as status items, even when the rulers had no interest in them or use for them. But sometimes they did prove useful: we have seen how the telescope that had been presented to the Nawab of Arcot was borrowed back for the 1761 transit.

At this time, many East India Company officers started making astronomical observations for longitude and latitude for their own amusement (Kochhar 1991c). Thus, surveying instruments were in great demand, and they could be purchased from England or from the captains and crew members of visiting European ships. When an officer died or left India his surveying instruments quickly found ready buyers. In the early days it was not the Company's policy to supply surveying instruments to its officers, but over time a small stock of sextants, quadrants, theodolites, clocks, telescopes etc. was gradually built up through purchases from England or within India (Kochhar 1991c).

Two early British observers were Colonel Thomas Dean Pearse (1741/2–1789) and Reuben Burrow (1747–1792). Pearse, who was probably the first professionally educated artillery officer in the Company's service, made observations for longitude and latitude from 1774 to 1779 (Kochhar 1991c; Phillimore 1945). Burrow was a former assistant to the Astronomer Royal Nevil Maskelyne, and in 1787 he was provided with a chronometer, astronomical quadrant and a Dollond refracting telescope so that he could carry out survey work (Phillimore 1945). His suggestion for a permanent astronomical observatory was, however, rudely turned down (Phillimore 1945), so that these individual efforts at Calcutta did not produce any cumulative effect.

In contrast, Madras turned out to be more congenial for matters scientific, but what led to the institutionalization of modern astronomy in India was not a love of the stars but a fear of death. The Bay of Bengal is visited by monsoons twice a year, and the east coast of India—the Coromandel—was rocky and full of shoals. In addition, Madras—unlike Bombay (present-day Mumbai)—did not have a natural harbour. A survey of the coast was thus literally a matter of life and death. Accordingly,

Fig. 24.2 Michael Topping (https://en.wikipedia.org)

Fig. 24.3 William Petrie (http://www.indianetzone.com/63/william_petrie.htm)

in 1785 a trained surveyor-astronomer, Michael Topping (1747–1796; Fig. 24.2), was sent to Madras by the East India Company, passage paid and equipped with surveying instruments.

24.2 Madras Observatory (1787)

Topping received valuable scientific and administrative support from William Petrie (1747–1816; Fig. 24.3), an influential Madras civil servant. Petrie (Kochhar 2011; Prinsep 1885) was in India from 1765 until 1812, but with some breaks, and even officiated as the Madras Governor for a few months in 1807. Later, from 1812 to 1816, he held the office of the Governor of Prince of Wales Island, which is now known as Penang, in Malaysia.

Back in India, longitude observations would make sense only if they were made with respect to a reference meridian. This need was fulfilled by Petrie in 1787 when he established a private iron-and-timber observatory on his 11-acre property at Egmore, Madras, and equipped it with a "… small but invaluable …" transit telescope "…of exquisite workmanship …" The year (1787) and the foregoing quotations were taken from a manuscript description of the observatory dated 24 December 1792, which is preserved in the Royal Greenwich Observatory Archives (Topping 1792).[1]

When Greenwich Observatory was established it had no instruments. The East India Company, on the other hand, had accumulated instruments, but had no place in which to use them. They were made serviceable and gathered together in Madras, but it was only when Petrie's Observatory was erected that they could be used effectively. Their primary use, Petrie explained, would be "… to provide navigational assistance to the company ships, and help determine the longitudes and latitudes of the company territories." (Kochhar 1985a: 163).

One of the most interesting instruments in the Company's 'collection' was a gridiron pendulum clock by John Shelton (1712–1777), which was identical to the one used by Captain James Cook (see Howse and Hutchison 1769) on his voyages to the South Seas and one used by Charles Mason and Jeremiah Dixon in North America during 1763–1767 to lay down the 'Mason-Dixon Line'.[2] This historic clock is shown in Fig. 24.4, and is still ticking at Kodaikanal Observatory, a witness to the advent and growth of modern astronomy in India (Kochhar 1987).

A young man from England named John Goldingham (1766–1849; Fig. 24.5) arrived at Madras in 1787, and with future employment in mind started making corresponding observations in Petrie's Observatory while Topping was out in the field surveying the east coast of India. In 1788 Goldingham was officially appointed Topping's assistant. In 1789, when Petrie was about to go to England on leave, he offered the Observatory to the Government which then took it over and appointed Topping as Astronomer. Rather grandiosely, the Government arranged for a granite tablet with the following inscription to be installed over the western doorway of the Observatory: "Posterity may be informed a Thousand years hence of the period when the Mathematical Sciences were first planted by British liberality in India." Although there were marginally older observatories in the Americas (e.g., see Shy 2002) Madras Observatory was the earliest modern astronomical institution in Asia. Yet India would have done well without this distinction, because the Observatory was there to serve British colonial interests (cf. Kochhar 1991a).

Quite apart from the Shelton clock, at this time the main instruments at the Observatory were a small 20-in. (50.8-cm) long transit instrument by Stancliffe, a

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[1] In earlier publications Kochhar (1985a, 2016) listed the date as 1786.

[2] We learn this from Topping's (1792) manuscript. In an earlier work, Kochhar (1985b) wrongly stated that the clock belonged to Petrie. To date we have been unable to find any details as to how the clock ended up in India.

Fig. 24.4 This pendulum clock by John Shelton was made for the British eighteenth century transit of Venus expeditions and was in use at Madras Observatory throughout the nineteenth century. It is now at Kodaikanal Observatory, as an ordinary timekeeper (after Kochhar 1987)

Fig. 24.5 John Goldingham (https://en.wikipedia.org)

12-in. (30.5-cm) quadrant by Bird, and three identical 2.75-in. (7-cm) f/15.3 Dollond achromatic refractors—all kindly donated by Petrie (Kochhar 1985a). Then a little later (i.e. in or before 1792) it acquired a 12-in. (30.5-cm) altazimuth instrument by Troughton. This latter instrument and the ex-Petrie transit telescope would remain the observational mainstay of the Observatory for more than half a century.

In 1791, a garden house that once belonged to a Mayor of Madras, Edward Garrow, was purchased in the Nungambakkam area of Madras as the Observatory campus (Kochhar 1991c). Another floor was added to the existing single-storey building to serve as the library, Astronomer's residence and offices. In 1792 a separate 20-ft. × 40-ft. building was constructed on the banks of the Cooum River 120 yards southwest of the Astronomer's residence to serve as the Observatory proper (see Fig. 24.6).

The Observatory was rebuilt in 1850 to accommodate a magnetic and meteorological department (which had been functioning as a separate entity), following Humboldtian directions emanating from the Royal Society, and the Astronomer's residence was added in 1869 (Fig. 24.7). In 1899, all of the astronomical activities were shifted to Kodaikanal Observatory and Madras Observatory became a purely meteorological station. The Madras Observatory site now houses the offices of the India Meteorology Department.

Regrettably, none of the original Madras Observatory buildings has survived, but some old granite remnants from within the Observatory which supported the instruments can still be seen (see Fig. 24.8). The top of an 18-ft. (5.49-m) high conical pillar at the centre of the Observatory accommodated a small telescope, while a stone slab supported a clock. Two further slabs supported the transit instrument and later a transit circle, and defined the meridian at the Observatory.

Although the East India Company had grandiosely declared that "… the establishment of an Observatory at Madras would be of great advantage to Science." (Phillimore 1945: 280), astronomy was only a small part of the Astronomer's duties. Topping received 192 pagodas a month as Astronomer (Phillimore 1945: 280),[3] but his salary as the superintendent of tank repairs and water courses was more than

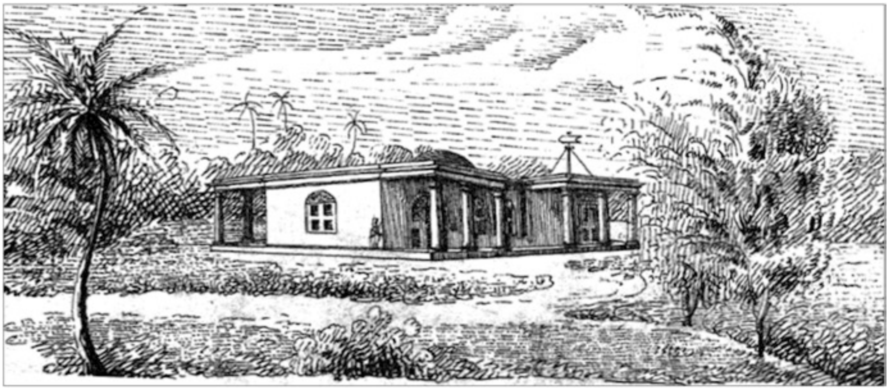

Fig. 24.6 An undated woodcut of the original Madras Observatory building (after Taylor 1848: cover)

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[3] Note that 1 pagoda equalled three and a half rupees, while eight rupees were equivalent to one pound sterling.

Fig. 24.7 Madras Observatory as it stood in 1880. The building no longer exists (https://en.wikipedia.org)

double this at 400 pagodas (Phillimore 1945: 280). He persuaded the Government to set up a surveying school. Kochhar (1991c) and others have wrongly stated that Topping was the Superintendent of the surveying school but, actually, the school's superintendence was placed in the hands of his assistant, John Goldingham. This school, maintained from 1794 till 1810 was, contrary to the popular perception, meant exclusively for half-caste or Eurasian boys—that is the offspring of Protestant European fathers and local Hindu, Muslim or Roman Catholic women (Kochhar 1991c). The Company made optimum use of the available manpower. While submitting a report on his astronomical survey, Topping also gave an account of the cultivation of pepper (Dalrymple 1793: 451), and during the 1790 war against Tipu Sultan of Mysore he was engaged in making gun carriages (Phillimore 1945: 391)!

Topping was succeeded by Goldingham as Astronomer in 1796. During 1800–1801 Goldingham doubled as Chief Engineer for 2 years, earning a (legitimate) commission of the substantial sum of 22,507 pagodas. Goldingham returned to England in 1805 on prolonged leave, and in 1808 he was elected a Fellow of the Royal Society for no particular distinction. He was "… desirous of having the honour of becoming a Fellow of the Royal society … [and was] likely to be an useful and valuable Member." (Royal Society Archives). His certificate of nomination was signed, among others, by Nevil Maskelyne and his ultimate successor at Greenwich,

GOVERNMENT OF INDIA
METEOROLOGICAL DEPARTMENT

MONUMENT 1

THIS GRANITE SLAB WITH THE INSCRIPTION IN LATIN WAS FIXED IN 1792 ON THE SOUTHERN WALL OF THE OBSERVATORY ROOM. IT WAS SHIFTED TO ITS PRESENT POSITION NEAR ABOUT 1948.

MONUMENT 2

THIS GRANITE PILLAR WEIGHING MORE THAN 10 TONS WAS ERECTED IN 1792 BY SIR CHARLES OAKLEY, THEN GOVERNOR OF MADRAS. ON THE TOP OF THIS PILLAR, THERE WAS A TWELVE INCH ALTITUDE AND AZIMUTH INSTRUMENT BY TROUGHTON. THE NAME, MICHAEL TOPPING, ON THE PILLAR REFERS TO THE CHIEF SURVEYOR RESPONSIBLE FOR THE ARCHITECTURAL DESIGN OF THE OBSERVATORY. THE BENCH MARK REFERRED TO IN THE INSCRIPTION IS PRESUMABLY THE OLDEST ONE IN INDIA WITH REFERENCE TO WHICH ALL GEODETIC SURVEY MEASUREMENTS WERE MADE. THE INSCRIPTIONS IN TAMIL, TELUGU AND URDU DATE BACK TO 1792. THEY MORE OR LESS CORRESPOND TO THE LATIN INSCRIPTION ON MONUMENT 1.

MONUMENTS 3 & 4

THESE GRANITE PILLARS WERE CONSTRUCTED IN 1860 FOR MOUNTING A NEW TRANSIT CIRCLE.

MONUMENTS 5 & 6

ONE OF THESE PILLARS WAS CONSTRUCTED IN 1792 AND THE OTHER PRESUMABLY IN 1860 FOR THE STANDARD CLOCKS AT THE OBSERVATORY.

Fig. 24.8 The interpretive panel at the site of the original Madras Observatory building (http://www.rohinidevasher.com/old-madras-observatory-field-notes-1/img_20160901_115544/)

John Pond. At that time, the Royal Society was more a club of well-off, well-connected gentlemen than the learned body that it became later. From 1805 until 1812 Goldingham was in England, and the Italian-born Frenchman Jean-Baptiste Francois Joseph de John Warren (1769–1830; Kochhar 1991b), better known simply as John Warren, served as the Acting Astronomer at the Madras Observatory.

Goldingham resumed duties when he returned to Madras in 1812, and he continued in office until 1830.

With the defeat of Tipu Sultan, the East India Company's territorial control extended from the Indian east coast to the west. A trigonometrical survey of peninsular India was immediately ordered, in 1800, under Major William Lambton (ca 1753–1823; Warren 1830) along the lines of the recently started Ordnance Survey in Britain. Actual work began in 1802, from Madras Observatory, but from 1 January 1818 the survey was extended to cover the whole of India (and even beyond), under the Governor General, with the designation of the 'Great Trigonometrical Survey of India' (or GTS). This name is often retrospectively applied, and the history of the GTS (see Strahan 1903) is also the story of the step-wise entrenchment of the British in India.

The GTS began with second-hand instruments purchased from Dr. James Dinwiddie (b. 1746) of Calcutta. Originally, they had been meant as a gift to the Emperor of China, but he refused them (Proudfoot 1868). In the early years, both the Survey and the Observatory were engaged in similar work, and up to 1810 the Madras Astronomer even carried the additional designation of 'Surveyor'. The Observatory provided the reference meridian for the survey work, and Warren's 1807 value for its longitude continued to be used in the maps until 1905. Both the Observatory and the Survey were short of instruments and freely borrowed from each other.

The Observatory also provided time signals for ships, and repaired private as well as public scientific instruments. Whenever repairs were required, the Survey officers had to carry them out themselves with the help of local mechanics employed at the Company ordnance depots. This was because to send the instruments to England via the Cape of Good Hope took several years, and there was always the added risk of the loss of the ships. Thus, in 1808 when the great theodolite was damaged in a fall at Tanjore, Lambton brought it to Bangalore, and repaired it himself, after 6 weeks of dedicated labour (Phillimore 1950).

24.3 The Great Trigonometrical Survey of India

In 1818 Welsh-born George Everest (1790–1866; Fig. 24.9) joined the GTS as Lambton's assistant and succeeded him in 1823. The GTS came into its own in 1830 when Everest became Surveyor General in addition to being Superintendent of the Trigonometrical Survey, and continued until he relinquished both positions in 1843. The GTS was a monumental scientific endeavour, unparalleled in the world by virtue of its vastness (Fig. 24.10) and logistical problems (see Keay 2000). It took precedence over all other surveys in India and was equipped with the best of manpower and equipment (Edney 1997). Strahan (1903: 146) would go further: he felt that Everest "… was a creative genius; the whole conception of the trigonometrical survey as it now exists was the creation of his brain." The East India Company's support for research in the geography, geodesy and natural history of the colony won appreciation from the European scientific community, and helped divert attention from its other activities.

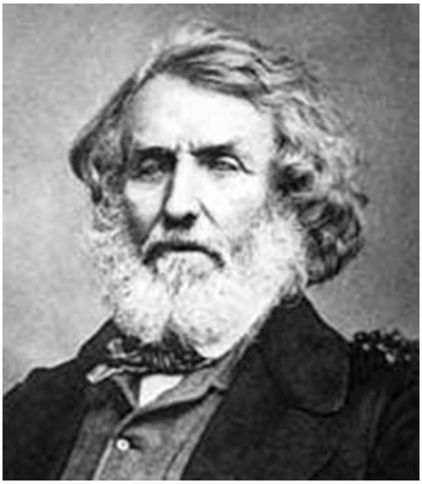

Fig. 24.9 A photograph of George Everest taken some years after he had left India and returned to live in Britain (https://en.wikipedia.org)

Fig. 24.10 A map showing regions surveyed during the Great Trigonometrical Survey of India (https://en.wikipedia.org)

24.3.1 GTS Instrumentation

In 1830 the GTS got some new instruments and, more importantly, a repair workshop. When Everest returned from England after a 5-year stay, he brought with him Henry Barrow (1790–1870), later a FRS, who had earlier done contract work for Troughton, Dollond, Jones, Wilkins, etc. Everest was introduced to Barrow by an Assistant at Royal Greenwich Observatory (RGO), William Richardson (1797–1872), who on medical grounds had refused the Madras Observatory Directorship that then went to another RGO Assistant, Thomas Glanville Taylor (1804–1848; McConnell n.d.). Barrow was appointed as the Mathematical Instrument Maker to the East India Company at a monthly salary of Rs 500, and a workshop was set up for him at Calcutta (which is now known as the National Instrument Factory). The instrument department was busy modernizing old instruments, and even modifying new instruments to Everest's exacting standards (Strahan 1903). Gifted but headstrong, Barrow fell out with Everest and was discharged from service in 1839. Upon returning to England he set up his own manufactory, and then supplied instruments to the GTS.

24.3.2 Syed Mir Mohsin Hussain

An example of how Indian talent was spotted and utilized by colonial scientists is best illustrated by the case of Syed Mir Mohsin Hussain (d. 1864). He was born near Madras, and was described as of partial 'Arab descent', and from a good family, that had connections to the Nawab of Arcot. He came to Madras and found employment at a well-known European jeweller's shop run by George Gordon. Here he was spotted by Colonel Valentine Blacker (1778–1826), the Quarter Master General, who "… was stuck by his uncommon intelligence and acuteness." (Phillimore 1954: 485). Blacker got some instruments repaired by him and when Blacker moved to Calcutta as Surveyor General in 1823 he brought Mohsin with him as a substitute for the local *siclegur* (polisher; sword or knife grinder). In 1824, Mohsin was appointed instrument-maker at the Surveyor General's office with a salary of Rs 25 a month. Between 1826 and 1829, Blacker's successor, Major General John Anthony Hodgson (1777–1848), taught Mohsin how to take astronomical observations and found him "… a most respectable man and steady observer." (Phillimore 1954: 485).

Mohsin's rise began when Everest took over as Surveyor General. During field trips Everest took Mohsin along to make repairs to the instruments. By 1832 Mohsin was drawing a salary of Rs 90 a month, and in 1836 while recommending him for appointment as sub-assistant, Everest reported him as "… particularly remarkable for his inventive talent, the facility with which he comprehends all mechanical arrangements, and the readiness with which he enters into all new ideas of others." (Phillimore 1955: 458). Everest went on to declare that "Without the valuable aid … rendered to me, it would … have been utterly out of my power to carry into effect my various projects for the remodelment of the instruments …" (Phillimore 1955: 458). On Everest's recommendation the East India Company's Court of Directors appointed Mohsin to succeed Barrow, but with the lowered designation of 'Head Artificer to the Department of Scientific Instruments'. Overcoming prejudice in high quarters, in 1843 Everest finally got Mohsin the same official designation as enjoyed by his English predecessor, if not the same salary. Instead, Mohsin received a monthly salary of Rs 250, and in 1854 he was given a personal monthly allowance of Rs 150. It was said of Mohsin that "… though he could not read English, he would have taken a leading place even among European instrument makers." (Markham 1878: 200). However, Mohsin was unique: no other Indian reached his level of achievement.

24.4 Madras Observatory in the Nineteenth Century

The paths of the Madras Observatory and the GTS diverged from the beginning of the Everest era. Until 1830, the Observatory was wholly engaged in survey-related astronomy, its chief instrumental assets being the 20-in. (50.8-cm) transit and 12-in. (30.5-cm) altazimuth, "… neither of them bearing an object glass of so much as an inch and a half in aperture." (Pogson 1887). The ever-expanding British colonial interests depended on safe navigation which in turn required familiarity with the southern skies. *Madras Astronomical Observations, Volume 1* (Taylor 1832a) reveals that three complementary state-of-the art instruments were ordered from Dollond of London in 1826: (1) a 3.75-in. (9.5-cm) 61-in. (1.55-m) focal length transit instrument; (2) a 4-ft. (1.22-m) diameter mural circle with a 3.75-in. (9.5-cm) f/13.1 telescope; and (3) a 3.5-in. (8.9-cm) 5-ft. (1.52-m) long equatorially mounted refractor. They arrived in 1829, but the task of unpacking and installing them fell to T.G. Taylor, a former Assistant at Greenwich, who joined Madras Observatory as Astronomer in 1830 and held that post until his death in 1848.

Had India been part of the Western communication network, Taylor would have been credited with the discovery of the Great Comet of 1831 (C/1831 A1), which he first saw with the unaided eye on 7 January 1831, a few hours before the declared discoverer, the British physicist John Herapath (1790–1868). Next day Taylor converted the transit telescope into an equatorial and continuously monitored the comet until 20 February 1831 (Taylor 1832b). A full account of Taylor's discovery and observations is given by Kapoor (2011).[4]

However, Taylor's scientific reputation rests on prolonged systematic work which remained valuable for a long time. Between 1830 and 1843, he used the Madras Observatory instruments to prepare his famed *A General Catalogue of the Principal Fixed Stars* … (Taylor 1844; Fig. 24.11), which contained observations of

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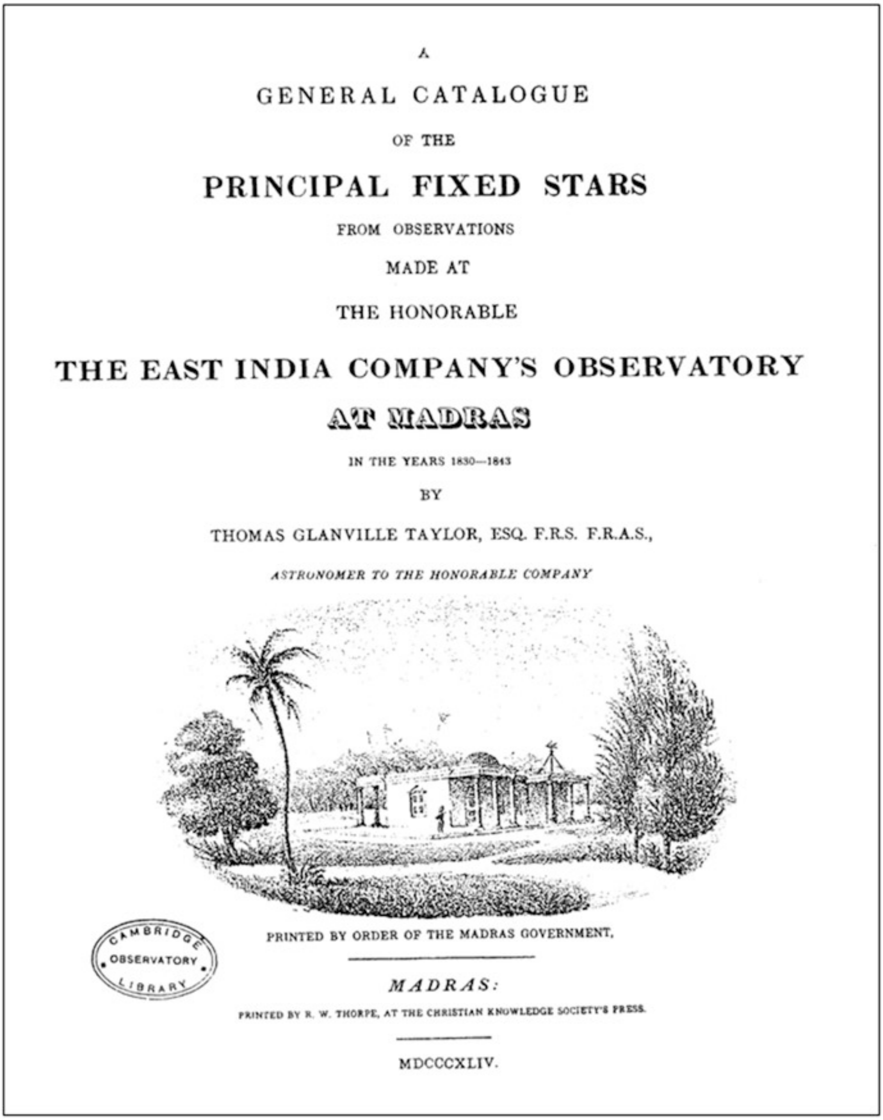
[4] This is yet another instance of the so-called 'tyranny of distance', where discoveries—particularly of comets—made in the 'colonies' were not assigned due credit because of the difficulty in communicating with Britain and Europe. Australian examples are discussed in Orchiston (1997).



A
GENERAL CATALOGUE
OF THE
PRINCIPAL FIXED STARS
FROM OBSERVATIONS
MADE AT
THE HONORABLE
THE EAST INDIA COMPANY'S OBSERVATORY
AT MADRAS
IN THE YEARS 1830—1843
BY
THOMAS GLANVILLE TAYLOR, ESQ. F.R.S. F.R.A.S.,
ASTRONOMER TO THE HONORABLE COMPANY

PRINTED BY ORDER OF THE MADRAS GOVERNMENT.

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MDCCCXLIV.

Fig. 24.11 The cover of Taylor's *General Catalogue of the Principal Fixed Stars …* (after Kochhar 1991c: 85)

no fewer than 11,015 stars (epoch 1835). Ten years after it was published and 6 years after Taylor's death, this remarkable publication was lauded by the Astronomer Royal George Biddell Airy (1801–1892; Fig. 24.12):

> In spite, then, of some defects arising from instrumental imperfections, I must characterise the Madras Catalogue of our late member. T. G. Taylor, as the greatest catalogue of modern times. In the number of observations and the number and distribution of the stars, and in the

Fig. 24.12 Astronomer Royal, G.B. Airy, was very impressed with Taylor's Catalogue (https://en.wikipedia.org)

> circumstance that the observations were made, reduced, combined, and printed, at the same place and under the same superintendence, it bears the palm from all others. (Airy 1854: 145).

In 1842, even before the Catalogue was published, Taylor was elected a Fellow of the Royal Society. Interestingly, although his citation refers to his five volumes of astronomical observations, it also makes a point of drawing attention to his series of observations of the magnetic dip and intensity every 20 miles between Ongol and Cape Comorin (present-day Kanyakumari). This is perhaps not surprising given that the distance by road between these two locations is 997 km!

Later, Taylor's star catalogue was revised between 1893 and 1901 by Dr. Arthur Matthew Weld Downing (1850–1917), Superintendent of the Nautical Almanac, with financial assistance from the India Office and the Royal Society. The revised catalogue contained 10,988 stars (Rambaut 1901).

In 1836, the distinguished German scientist, Baron Alexander von Humboldt (1769–1859; Wulf 2015) wrote to the President of the Royal Society suggesting the establishment of a network of geomagnetic observatories in British colonies (Christie and Airy 1837). Following up on this idea, a number of leading British physicists recommended launching a 'Magnetic Crusade', that is, a magnetic survey of the entire globe (Malin and Barraclough 1991). Note the employment of a term from religious history, but employed in a new context. The Government accepted the proposal and left it to the East India Company to identify stations in its domain. One of the stations chosen was Madras where a Magnetic Observatory was established in 1840 as an independent institution (Report … 1841). Just 5 years later, the magnetic and astronomical observatories was merged, and in 1850 the Madras Observatory building was expanded accordingly. Astronomy, meteorology *and* geomagnetism were now all official functions of Madras Observatory.

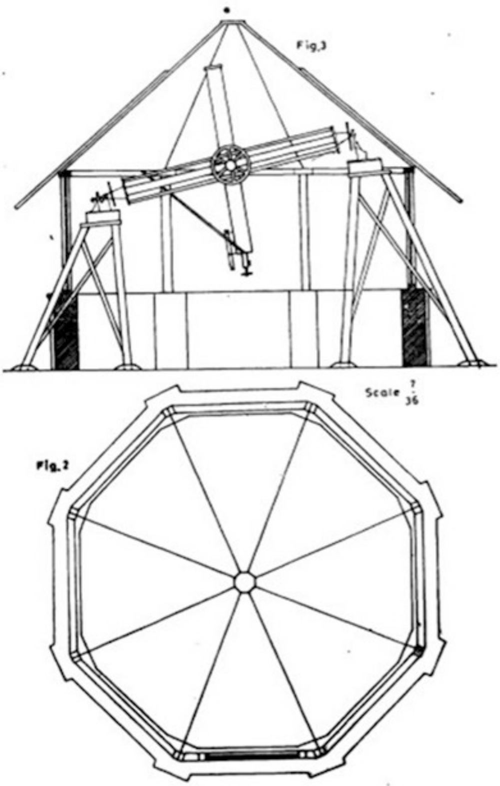

Fig. 24.13 A cut-away section (*top*) and plan (*below*) showing the Lerebours and Secretan 6-in. refractor and its octagonal observatory (after Kochhar 1985b: 297)

The Observatory also acquired its first fixed telescope in 1850, which came as the personal property of the new Astronomer, and which the Government bought from him. William Stephen Jacob (1813–1862; Obituary … 1863) arrived in India in 1831 as an engineer in the Bombay presidency and worked on the longitudinal series when his mathematical abilities made a good impression on Everest (Phillimore 1955). Sometime after 1845 he resigned his job and settled in Poona (present-day Pune) in western India. There he set up his own observatory, and focused on the observation of double stars. On the basis of his numerous publications in *Monthly Notices of the Royal Astronomical Society* Jacob was offered the Astronomer's position at Madras Observatory, which he accepted in 1849. Jacob was always dogged by ill health. He went to England on leave in 1858, and resigned later that year.

Jacob's telescope, acquired by Madras Observatory, was a 6-in (15.2-cm) Lerebours and Secretan refractor with an English equatorial mounting. Jacob's Scottish friend Charles Piazzi Smyth (1819–1900; Brück and Brück 1988) inspected the telescope when it was being made, and he drew a colour sketch of it which is now in the Royal Observatory Edinburgh. Fig. 24.13 is a black and white rendition, based on this sketch. The telescope was mounted on the roof of the Astronomer's residence, and "Instead of a rotatory [conical] roof, a folding roof (made of teak wood) was erected." (Kochhar 1985b: 297–298). This was modelled on one that Jacob (1843) had designed for his observatory in Poona.

In 1852 the telescope's defective objective was replaced by the manufacturers with a new one of 6 in. (15.2 cm) aperture and 88 in. (5.3 m) focal length. Using it, Jacob showed in 1852 that the recently discovered crepe ring of Saturn was translucent (Jacob 1853). This discovery was made independently by William Lassell (1799–1880) from Malta using a 20-in. (50.8-cm) reflector, and provided convincing proof that the rings of Saturn were not solid. Norman Pogson, who was Director of the Observatory from 1861 to 1891, discovered his first minor planet with the 'Jacob Telescope' in 1861, aptly naming it 'Asia' (Pogson 1861). Finally, the telescope was 'reconstructed' by Sir Howard Grubb (1844–1931; Glass 1997) in 1898, who also mounted a 5-in. (12.7-cm) Grubb astrograph on it.[5] The only other research telescope at Madras Observatory was an 8-in. (20.3-cm) Troughton & Simms equatorial refractor, which was ordered in 1861 and commissioned in 1864 (Kochhar 1985b).

It was no easy matter to maintain an observatory situated so far from Europe. A 5.5-in. (14-cm) f/9.1 transit circle was ordered in 1855, and constructed by Troughton & Simms in 1857 under the supervision of Richard Christopher Carrington (1826–1875; Obituary … 1876) who had a similar one made in 1852 and therefore could suggest "… improvements in the light of his own experience." (Kochhar 1985b: 299). The transit circle only reached Madras in 1858, the delay being caused by the uncertainties due to the 1857 Indian Uprising. In the process, the instrument either arrived without the booklet of instructions or this was subsequently lost, so there were difficulties with its installation. This only was achieved in 1862, when the services of an expert German mechanic, Frederick Doderet, were available.

By this time, Madras Observatory had already become redundant as far as utilitarian astronomy was concerned: when observatories were established at the Cape of Good Hope in South Africa (1820) and Williamstown (1854) and Sydney (1858) in Australia (Evans 1988), British astronomers largely lost interest in India. Those were the days when the Sun never set on the British Empire, but if it did the Astronomer Royal took over. Thus, in 1866 the Secretary of State for India wrote to the Governor of Madras:

> From the information with which Professor Airy has furnished me, I have come to the conclusion that it is not necessary, in the interests of science, to maintain permanently in India any observatory for the purpose of general astronomical investigation. In his opinion, systematic observations may be more advantageously taken at other observatories in the Northern and Southern Hemispheres. (Kochhar 1991a: 126).

The Secretary of State went on to suggest, upon the advice of the Astronomer Royal, that Madras Observatory be closed down, that astronomical activity at Bombay be restricted to the determination of local time, and that the Bombay Astronomer report to the Astronomer Royal.

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[5] This telescope has been in Kodaikanal Observatory since 1899, and in use as a photoheliograph since 1912.

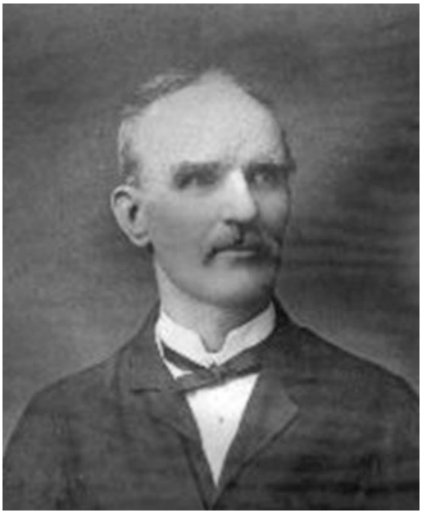

Fig. 24.14 Norman Robert Pogson (*Courtesy* Indian Institute of Astrophysics)

The threat to Madras Observatory from 'back home' launched an outpouring of local British pride, with the Director of Public Instruction spiritedly writing to the Chief Secretary, Madras, on 16 January 1867:

> I earnestly hope that the Rulers of India will take a higher and more extended view of the matter, and consider what is due to this country … I earnestly hope … that India should have at least one well-equipped and well-officered Astronomical Observatory, and that the Astronomer … should not be made a subordinate of another Astronomer. (Kochhar 1991a: 126).

The Observatory survived, but only just.

Norman Robert Pogson (1829–1891; Fig. 24.14; Dreyer 1892) took over as the Madras Observatory Astronomer on 8 February 1861, and remained in office until his death. His uninterrupted 30-year stint is a tragic testimony to wasted opportunity at Madras, with his own neuroses matching the Astronomer Royal's imperiousness. Pogson was the first Madras Astronomer without any surveying background, but he came to Madras with a well-established scientific reputation as an observer of variable stars and of minor planets. Furthermore, he was already well known as the propounder (see Jones 1967) of the universally accepted logarithmic magnitude scale (where a difference of five in magnitude corresponded exactly to a difference of 100 in brightness). Attracted no doubt by the good salary, Pogson hoped to make full use of his ready access to the southern skies, and if left to his own devices he would have worked on his variable star atlas and extended Friedrich Wilhelm August Argelander's (1799–1875) Bonn star survey of 1863 to southern skies (Hagen 1898). But he was not permitted to do so. The course of observations at Madras was determined by the Board of Directors, and Pogson was forced to carry on routine drab irrelevant transit observations year after year, which he most obstinately refused to reduce and publish (Sen 1989). However, while at Madras Pogson (Reddy et al. 2007) did discover five minor planets, Asia (1861), Sappho (1864), Sylvia (1866), Camilla (1866) and Vera (1886), bringing his total discoveries to eight, and during his entire career he discovered 14 variable stars (Reddy et al. 2007), including the first eruption of the recurrent nova, U Scorpii, in 1863 (a remarkable observation considering its very brief appearance). Regrettably, Pogson's *Atlas of Variable Stars* was only published after his death—by his sister's husband, Joseph Baxendall (1815–1887; Baum 2014a), himself a well-known observer of variable stars.

24.4.1 Maintenance and Instrumentation

In September 1861, the German mechanic Frederick Doderet was appointed to start a workshop under the Public Works Department in Madras, and his services were immediately loaned to the Observatory. Captain (later Lieutenant General) James Francis Tennant (1829–1915; Hollis 1916), who was the Director of the Observatory for a year, from October 1859, purchased an excellent lathe, by Holtzaffel. Using this, and other instruments borrowed from the arsenal, Doderet finally could accomplish the long-delayed task of commissioning the transit circle. The object glass of the mural circle was reportedly stolen in 1861 (Kochhar 1991c: 81). For the 1868 eclipse, "… Doderet made handy telescopes out of the parts of the historical 1830 transit and mural circle, thus proving that history is a luxury poorly-equipped observatories can ill afford." (Kochhar 1991c: 83).

With the introduction of the telegraph and the railway the scientific content of the administration increased, and workshop facilities became available at an administrative as well as commercial level. Thanks to these, the Observatory could remain active even though it did not acquire any new instrument after 1864. There is an important contemporary lesson here: a culture can sustain astronomical research only if other activity at a similar technical level also takes place.

24.4.2 The Case of Chintamani Ragoonatha Charry

Of all the Indian Assistants at Madras Observatory in Pogson's time, the most outstanding was Chintamani Ragoonatha Charry [Raghunath Acharya] (1828–1880; Fig. 24.15; Shylaja 2012). The son of an assistant at the Observatory, he started working there as a young boy and stayed for 35 years, the last 17 of them as the Head Assistant. He discovered a variable star, R Reticuli, in 1867, the first recorded modern astronomical discovery by an Indian (see Kameswara Rao et al. 2009), and was elected a Fellow of the Royal Astronomical Society 5 years later, in 1872 (Obituary … 1881).

Charry edited the astronomical pages of the *Madras Asylum Press Almanac*, and he brought out an explanatory pamphlet about the 1874 transit of Venus in various languages, including English, Urdu and Telugu (Ragoonatha Chary 2012; cf. Shylaja 2012). He was obviously encouraged by the Government to do so, because a large number of copies were purchased by various Government departments throughout the country. Charry also brought out a Sanskrit almanac (*panchanga*) incorporating elements from modern astronomy.

Fig. 24.15 Chintamani Ragoonatha Charry (after Kameswara Rao et al. 2009: Fig. 1)

To his European mentors, Charry was proof of their success in improving the indigenes, and it was noted in his obituary—which probably was written by Pogson—that

> … he latterly took great interest in delivering public lectures on Astronomy, with a view to enlighten his countrymen upon the subject, and to convince them of the absurdity of their notions in regard to celestial phenomena, by familiar explanations, in simple terms, of the true principles of the science, as opposed to the ignorant superstitions and rough predictions of Hindu astrologers and empirics of the old school. (Obituary … 1881: 182–183).

Despite this, Ragoonatha Charry however does not seem to have had any lasting effect on his countrymen.

24.5 The Royal Observatory at Lucknow

The King of Oudh [Avadh, corresponding to Eastern Uttar Pradesh] Nasiruddin Haider (reigned 1827–1837), founded a modern ‘Royal Observatory’ in his capital city of Lucknow in 1832. This was known colloquially as the Lucknow Observatory,

Fig. 24.16 Lucknow Observatory, later known as 'the star house' (after Alli 1874: Plate 18)

and is shown in Fig. 24.16. It is a beautiful example of classical-style architecture, but Alli (1874: 30) notes that "It forms a kind of set-off to the general extravagance for which the Kings of Oudh were notorious."

On 28 October 1831 Nasiruddin Haider sent a letter to Lord William Bentick (1774–1839), the Governor-General of India, indicating why he wished to establish an observatory:

> As my mind is always bent on promoting diverse enlighted [*sic*] arts and sciences, which are replete with good and possess salutary advantages to the wise and to the public at large, it is my wish to establish an observatory in the metropolis of Lucknow … (cited in Ansari 2011: 359–360).

The King wanted an observatory that would reflect the wealth and importance of the Government, but also would have a major educational function "… amongst the inhabitants of India." (Ansari 2011: 359–360).

Although the Observatory belonged to the King, its scientific control was in the hands of the British, the Astronomer's appointment being made by the Governor General. Major James Dowling Herbert (1791–1833) came to Lucknow with good credentials. At the time he occupied the number two position in Calcutta as the Deputy Surveyor General and Superintendent of Revenue Survey, with a salary of Rs 750 per month. He had earlier officiated as the Surveyor General, and his name had even been mentioned to take over Everest's responsibilities as Superintendent of the GTS if Everest relinquished charge on the grounds of ill health (Phillimore 1954). Herbert reached Lucknow in December 1831, and promptly ordered the best available instruments for the Observatory. However he died prematurely in September 1833.

Herbert was succeeded by Lieutenant Colonel Richard Wilcox (1802–1848); the lure of a high salary (Rs 1000) had again attracted a capable man to Lucknow. Herbert had earlier described Wilcox as "… one of the cleverest young men we have." (Phillimore 1955: 474). Everest, in turn, described him as "… a person highly able, and likely to qualify himself in a shorter time than any person in the Department." (Phillimore 1955: 474). He was, in addition, a distinguished oriental scholar (Phillimore 1955: 115).

Wilcox came to Lucknow in September 1835, and his place at the GTS was taken by Andrew Scott Waugh (1810–1878) who subsequently succeeded Everest. It was Wilcox who oversaw the construction of Lucknow Observatory, so we have to wonder about his input in deciding on the architectural style. He also oversaw the installation of the instruments, and brought the Observatory to a state of high efficiency, so that it was ready for use in 1841. At that time it was the best-equipped observatory in India—certainly better than Madras Observatory—and was on fact on a par with Greenwich and Cambridge in that it boasted (1) a mural circle of 6-ft. (1.83-m) diameter, (2) an 8-ft. (2.44-m) long transit telescope, and (3) an equatorial of more than 5 in. (12.7-cm) aperture, all made by Troughton & Simms (see McConnell 1992). There also were astronomical clocks, made by Molyneaux.

Wilcox set out to emulate Taylor at Madras Observatory, who was working on his monumental Madras Catalogue. Wilcox observed with the mural circle, and commented that 'I believe my transit observations—in which I take no part myself (being left to the 'Hindoo lads')—will compete with those of any observatory." (Phillimore 1955: 116). Meanwhile, the equatorial was used for observing eclipses of the Jovian satellites, but Wilcox (Kochhar 1991c: 91) remarked that he had only observed a few occultations, "… on account of their requiring time for the previous computations." Wilcox died in October 1848, and these excellent observations were never published. The following year, the King abandoned the Observatory on the grounds that the great outlay incurred in maintaining it had produced no advantage whatever to the State or to the people of Oudh, whereas a memorandum to the King asserted that "… the Europeans and not Indians are benefited by this observatory." (Hadyar 1896: 44). Alli (1874: 22) also suggests that "… the King always thought more of astrology than of astronomy. So much for the enlightenment of the Monarchs of Oudh."

When Avadh was annexed by the British in 1856 there was a move by Surveyor General Waugh to use these instruments for an Observatory in Calcutta, but before this could happen the Observatory was ransacked. In March 1858 Lieutenant J.F. Tennant was part of the British force that re-captured Lucknow, and he reported that although the Observatory building itself was undamaged, all of the instruments had perished during the Indian Uprising of 1857–1858. In the meantime, all the records of the Observatory—reduced as well as unreduced—were eaten by insects. Thus ended a first class observatory which was not needed in the first place and whose results would never see the light of day.

For further details of the Lucknow Observatory see Ansari (1977: 29–33; 1985: 385–389).

24.6 Trivandrum Observatory (1837–1852)

In 1837 the learned King of the South Indian princely state of Travancore, Raja Varma, better known as Svati Tirunal (1813–1846, who ruled from 1829), established Trivandrum Observatory (Fig. 24.17), "… with the double view of affording his aid to the advancement of astronomical science, and of introducing by its means correct ideas of the principles of this science amongst the rising generation under his government …" (Caldecott 1837a: 56). He also was eager that "… his country should partake with European nations in scientific investigations." (Menon 1878: 416). As it turned out, astronomy met the same fate here as in Lucknow, but Trivandrum's proximity to the magnetic equator at least ensured a successful future for the institution as a magnetic (rather than astronomical) observatory.[6]

The first Director was London-born former amateur astronomer John Caldecott (1800–1849; John Caldecott n.d.; Fig. 24.18). He came to Bombay in 1821 to take up commercial appointments, and in August 1831 he was appointed Commercial Agent and Master Attendant at the port of Alleppey (now Alappuzha), as an employee of the Travancore Government (Menon 1878).

At the time, the young King was quite familiar with ancient Indian astronomy, and was keen to compare it with modern Western astronomy. He often discussed the subject with Caldecott,

> … who being well versed in that science, used to make astronomical observations with several portable instruments of his own. Mr. Caldecott's descriptions of his observations of the various movements of the heavenly bodies, closely corresponding with the calculations and observations of the Hindu Astronomers, *the Maha Rajah was most anxious for a thorough investigation of this science*. (Menon 1878: 415; our italics).

In 1834, when on tour of the northern districts, the King visited Alleppey and took the opportunity to inspect Caldecott's astronomical instruments, while Caldecott, for his part, took the opportunity to suggest that the King establish "… a

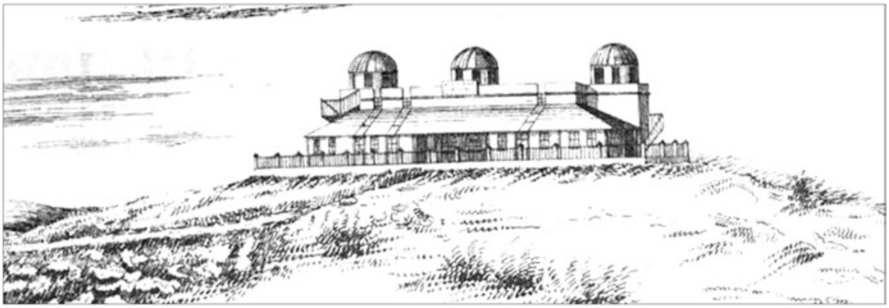

Fig. 24.17 A panoramic view of Trivandrum Observatory from the northwest (after Caldecott 1837a: facing 57)

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[6] The present-day name of Trivandrum is Thiruvananthapuram, and it is the capital of the Indian State of Kerala. In Raja Varma's era it was the capital of the State of Travancore.

Fig. 24.18 An undated painting of John Caldecott (after Walding n.d.)

small Observatory, at Alleppey; but the Maha Rajah wished to have a good building erected at Trevandrum." (Menon 1878: 415–416). The King asked Caldecott to send a formal proposal to the British Resident, Colonel (later Lieutenant General) Stuart Fraser. The King promptly accepted the proposal, appointed Caldecott as his Astronomer, and "… gave him power to furnish it with the best instruments to be obtained in Europe." (Menon 1878: 416). In return, Caldecott placed his own astronomical instruments at the disposal of the Government. These are listed by Walding (n.d.): (1) A fine Troughton & Simms mounted equatorial telescope; (2) a mounted 46-in. (1.8-m) refracting telescope; (3) a 30-in. (76.2-cm) long transit telescope by Dollond; (4) a portable altitude and azimuth with 18-in. (45.7-cm) and 15-in. (38.1-cm) circles; (5) a portable Troughton & Simms reflecting circle; and (6) three chronometers. Dollond (King 1979) and Troughton & Simms (McConnell 1992) were top British manufacturers of astronomical instruments.

The construction of the Observatory began in October 1836, and it was completed in mid-1837 (see Fig. 24.19)—it measured 78 ft. × 38 ft., i.e. 23.8 m × 11.6 m (Caldecott 1837a: 57). At the same time, instruments were ordered from England.

Available evidence suggests that the agenda which Caldecott described to the King was different from what he set for himself, keeping in mind his own European aspirations. Taking note of the recommendation by the British Association for the Advancement of Science that "… a set of hourly meteorological observations within the tropics … [was] highly desirable …" (Report … 1841: 28), Caldecott used the King's permission to order astronomical *and* meteorological instruments, and in June 1837 he began making systematic meteorological observations (Caldecott 1837b).

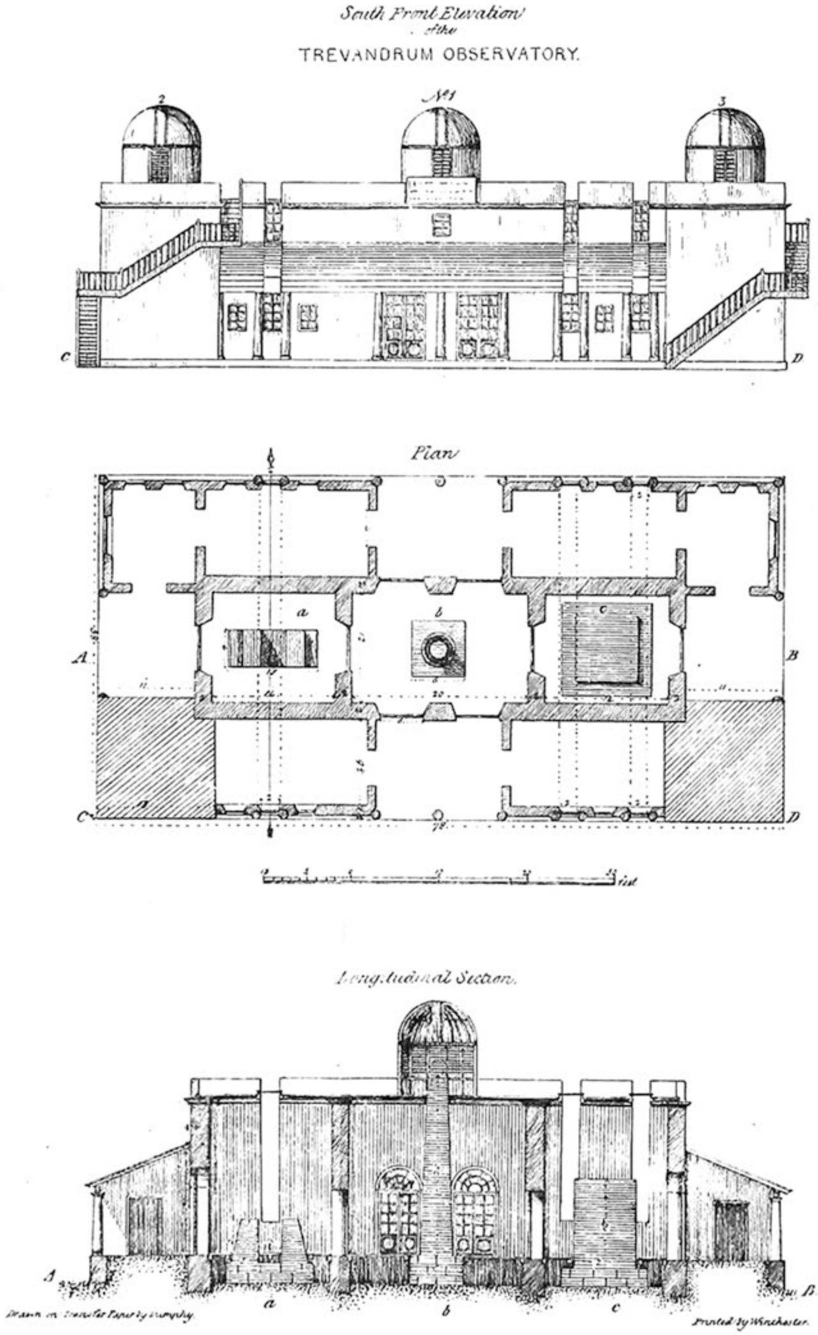

Fig. 24.19 Drawings made in 1837 of the section, plan and elevation of Trivandrum Observatory (https://en.wikipedia.org)

Caldecott also begun a collaboration with Taylor on the magnetic survey already referred to, and the first results were published in 1839 in the *Madras Journal of Literature and Science* (Taylor and Caldecott 1839); they were part of an international campaign (see Cawood 1977). To superintend the construction of the instruments, Caldecott went to England in December 1838 and returned in April 1841.

While in England Caldecott extracted full mileage out of his rather exotic designation as an Astronomer to an eastern King. He was elected a Fellow of the Royal Astronomical Society on 10 January 1840 and of the more prestigious Royal Society on 20 February 1840. His citation for the latter introduces him as "The author of annual astrono[mica]l Ephemeris of the Observatory at Trevandrum …" and specifically draws attention to his "Observation on the direction & Intensity of the Terrestrial magnetic force in Southern India." (Royal Society Archives). Later, the same year, Caldecott spoke at the Glasgow meeting of the British Association on the meteorological observations that he had made at Trivandrum, and he pointed out that he "… was about to return to his post in India amply furnished with meteorological, magnetical, and astronomical instruments …" (note the order) and invited instructions on the programmes "… in meteorology, or any other branch of the physical sciences …" which he could pursue (*Literary Gazette* 1840). At this same meeting, Sir David Brewster proposed "The health of his Highness the Rajah of Travancore, the great promoter of science in the East …" and "… along with his name, coupled that of Mr. Caldecott." (*Literary Gazette* 1840).

The Observatory that the Rajah built for Caldecott was well equipped (Caldecott 1837a: 58–59), containing (1) A 5-in. (12.7-cm) aperture, 7-ft. (2.13-m) focal length refractor by Dollond on an English equatorial mounting; (2) A 4.2-in. (10.7-cm) aperture, 5-ft. (1.63-m) focal length equatorially mounted refractor; (3) A 3.75-in. (9.5-cm) aperture transit instrument by Dollond; (4) A 5-ft. (1.63-m) diameter mural circle by Troughton & Simms, with a 4-in. (10.2-cm) aperture telescope; (5) A mural circle by T. Jones; (6) Two portable altazimuths by Troughton & Simms; (7) A transit clock by E. J. Dent; and (8) A mean time clock by E. Wrench. The two refractors came "… with micrometers and all appurtenances for observations on the double stars, &c. …" (Caldecott 1837a: 59). When it came to the allocation of funds for these instruments and the Observatory building itself Caldecott (1837a: 56) was very clear about where his priorities lay:

> I very soon came to the conclusion that no outlay, beyond what was absolutely necessary to effectiveness, should be made on the building, but that no expense should be spared in procuring instruments of such a size and quality as would ensure to an Observatory, when they were judiciously and actively made use of, a rank second to none in the world.

By "… judiciously and actively …" using the instruments at the Observatory, Caldecott accumulated a large mass of astronomical, geomagnetic (Ratcliff 2016) and meteorological data, and forwarded complete copies to the Court of Directors of the East India Company. In 1846 he visited England again, but was unable to persuade any scientific society to aid in the publication of his observations, but when he returned to India in 1847 he arranged for them to be published at the Raja's own printing works (Walding n.d.). Caldecott apparently was busy preparing his observations for publication when he fell ill, and he died about 1 year later, on 17 December 1849.

Dr. Josiah Sperschneider (1825–1882) temporarily took charge of the Observatory until the Scottish scientist John Allan Broun (1817–1879; McConnell 2004) came out from Britain to take over. He "… left Europe on 11th November, and arrived at Trivandrum on the 11th January 1852 …" (Menon 1878: 462). He soon discovered that some of the scientific instruments had not been properly installed, and he decided to abandon astronomy and focus on geomagnetism and meteorology (see Broun 1857). Broun returned to England in 1865 and then the Rajah of Travancore decided to close down the Observatory.

24.7 Juggarow's Observatory, Vizagapatam (1840–Post 1911)

An Observatory was established in 1840 at Vizagapatam (a coastal town that is now in Andhra Pradesh) by a scion of an influential pro-British land-holding family as a non-official Indian initiative and was maintained by three generations of the family for more than 70 years before it faded away.

In the initial years, the Observatory operated at two distinct levels: while it served as a vehicle for satisfying the celestial curiosity of the owners, it also formed an important part of Government apparatus as far as timekeeping and meteorology were concerned. Since this was a most atypical case, it would be instructive to examine it in some detail and within a wider context. It should be kept in mind that names are spelt variously, and the first name denotes the family which therefore is repeated from father to son. There are three Juggarow's in four generations, so it is important to keep track of their initials.

The natural starting point for the narrative is Gode Jagga Rao (also spelt Godde or Goday Jugga Row, etc.) who had the good fortune of attaching himself as *dubash* (interpreter *cum* commercial agent, etc.) to John Andrews, a Madras civil servant. In 1769 Andrews was appointed as the administrative head of the Vizagapatam District, and Jagga Row came with him (Francis 1915), only to emerge in the course of time as the second biggest land-holder (*zamindar*) in the area. His zeal for the East India Company's interests, which was "… manifested on various occasions …", was recognized by the Company's Court of Directors in 1779 (Lethbridge 1893: 139).

Jagga Rao had two sons, Surya Prakash Rao and Surya Narayan Rao (1782–1863). The later was the father of Goday Vencat Juggarow (1817–1856) and Goday Naraen Gujputee Rao [Narayana Gajpati Rao] (1828–1903). Gujputee enjoyed a high public profile and was given the title of Raja by the Viceroy in 1881 and Maharaja in 1898 (Lethbridge 1893: 139). Our primary interest, however, is in the elder brother G.V. Jugga Row (Kameswara Rao et al. 2011), who in mid-1833 had "… selected the divine science of Astronomy as the study and pursuit most suited to my disposition and best calculated fully to occupy my attention." Accordingly, he came to Madras to take tuition from T.G. Taylor, the Madras Astronomer (Francis 1915), whom he considered a friend. When Taylor observed Comet 1P/Halley in 1836, Juggarow assisted him with mathematical calculations (Taylor 1836). The Secretary of the Madras Literary Society, J.C. Morris, FRS, inserted with a great sense of colonial satisfaction the following editorial note in a paper by Jugga Row: "We hail this display of talent as bright specimen of 'the march of mind' among the members of the native community of Southern India." (Juggarow 1835: 93n).

Juggarow returned to Vizagapatam in July 1838 and set up his own Observatory 2 years later at his residence in Daba Gardens (Francis 1915). At this time the Observatory did not house a telescope; even though he obtained the optics of a 4.8-in. (12.2-cm) aperture refractor of 5 ft. 8 in. (1.73 m) focal length telescope by W.S. Jones, he was unable to install it (Kameswara Rao et al. 2011). However, the Observatory was equipped with a transit circle by Troughton, and a chronometer (Kameswara Rao et al. 2011). Vizagapatam's coastline is broken by a headland called Dolphin's Nose, which is 1174 ft. (358 m) high above sea level (Fig. 24.20). Juggarow established a flagstaff here, and arranged for the flag to be lowered precisely at 9 a.m. in order to provide a local time service. Whatever research papers Juggarow published were during his Madras days, and they were in mathematical astronomy. At Vizagapatam, he did set up a meteorological station, and he even invented a pluviometer (or rain gauge; see Vadivelu 1903: 156–157).

When Juggarow died in 1856 his estate and the Observatory passed to his daughter and her husband Ankitam Venkata Narsinga Rao (1827–1898; Fig. 24.21)—also known by his Anglicized name of Nursing Row—who had earlier been employed by the Government as a Deputy Collector and Magistrate. Nursing Row rose to these positions "… through sheer dint of energy, good character, and perseverance." (Vadivelu 1903: 153). His earlier astronomical work, like his father-in-law's, was utilitarian, and dealt with time-keeping and time signals, but the 1868 solar eclipse—which was partially visible from Vizagapatam—was used as the incentive to set up the old 4.8-in. (12.2-cm) telescope.

In 1874 Nursing Row decided to furnish the Observatory with a 6-in. (15.2-cm) Cooke equatorial, a 3-in. (7.6-cm) transit circle and a sidereal clock (Nursing Row 1875). The Observatory is shown here in Fig. 24.22. Nursing Row communicated his observations of solar eclipses, transits of Mercury and Venus, and comets, to British astronomers and the Royal Astronomical Society. When the Government of India set up the India Meteorological Department in 1875, the private Vizagapatam

Fig. 24.20 The Dolphin's Nose was clearly visible from Vizagapatam (http://tourmet.com/dolphins-nose-visakhapatnam/)

Fig. 24.21 A.V. Nursing Row (www.avncollege.ac.in/)

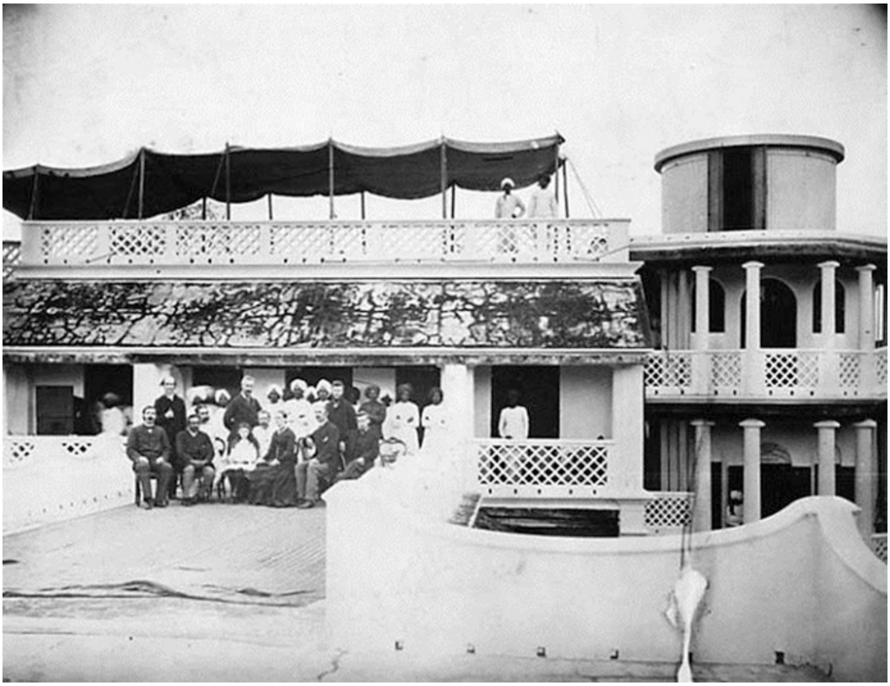

Fig. 24.22 A photograph showing Jugga Rao's observatory, and people gathered to observe the 1874 transit of Venus (after Ramani 2010)

Observatory was integrated into the official network, and Nursing Row was designated the Honorary Meteorological Reporter for Vizagapatam. Nursing Row welcomed "… the help of a number of well trained native assistants …" in making his meteorological observations (Vadivelu 1903: 160).

In 1871, when the Madras Government decided to discontinue the firing of the evening gun, Nursing Row offered to pay the expenses and the practice was resumed (see Vadivelu 1903: 161–164). The flagstaff and the evening gun were also symbols of the prestige that the Ankitam family enjoyed in the eyes of the Government. Nursing Row was elected a Fellow of the Royal Astronomical Society in 1871 and of the Royal Geographical Society in 1872 (Vadivelu 1903). He obtained equipment for celestial photography but died in 1898 before he could install it, and this task was accomplished by his wife. The instruments then included (1) the 6-in. Cooke equatorial; (2) the transit instrument; (3) a sidereal clock, and (4) the new astrograph (Francis 1915: 332).

In November 1894, Mrs. Ankitam Achayyamma Nursing Row, "In accordance with the wishes of her father as well as her husband …" handed over the Observatory and an endowment of Rs 300,000 to the Government of India (Results … 1894: 1). The Government in turn appointed a Committee under the chairmanship of the Collector for the "… immediate management of the institution." The Committee included the Madras and Bengal Meteorological Reporters and the Madras Astronomer. The Committee then appointed Walter Arnold Bion as the Director of the Observatory.

Subsequently Nursing Row's son Ank[h]itam Venkata Jugga Row (1866–1921) regained control of the observatory. It is recorded elsewhere (Vadivelu 1903: 163) that Jugga Row succeeded to the management of the estate in October 1898, presumably on the death of his mother, and "Till then he was engaged in scientific pursuits." (Vadivelu 1903: 163). While the astronomical activity was kept at the level his father and his mother had left, new meteorological instruments were ordered, and magnetic and seismic instruments were installed.

In 1900 Jugga Row went to England, where he called on Queen Victoria. During his stay in England he was elected a Fellow of the Royal Astronomical Society, and of the Royal Meteorological Society, the Royal Colonial Institute and the Society of Arts. "While in England he visited various Observatories, and studied their working …" (Vadivelu 1903:164).

Back in Vizagapatam Jugga Row had "… a beautiful library of more than 10,000 volumes, treating on science, English literature, and Indian subjects, among them being many rare books …" (Vadivelu 1903: 165). Although he served as the Vice-President of the short-lived Calcutta-based Astronomical Society of India for a year 1911–1912 (Kochhar and Narlikar 1995: 23), he does not seem to have ever made any astronomical observations himself and the Observatory later was closed (Kochhar 1993). It was demolished in the 1960s, and the site is now occupied by the Dolphin Hotel.

No astronomical instruments from the Observatory seem to have survived. At a recent but unspecified date Mrs. Ankitam Indrani Jagga Rao presented a 'photo theodolite' and a 'photo transit' to the Visakahapatam Municipal Museum, but the instruments are not on display. What is displayed is a T. Cooke and Sons magnetometer, a standard instrument that was used by the Indian Magnetic Survey (pers. comm., David Lee Ingram, 2012).

In Europe, scientific facilities created privately by the aristocracy were used as valuable training grounds by professional astronomers (e.g., see numerous examples in Hockey et al. 2014). But here we have little information about who assisted at this observatory. We also have little idea about who advised on the purchase of scientific instruments, etc. To sum up, during the seven decades that the observatory was in existence, it is only during Nursing Row's time that any useful astronomical results were produced. This facility did more for colonial administration and weather science than it did for astronomy.

24.8 W.S. Jacob and Poona non-Observatory

There was an observatory that was not to be. In 1859, the former Madras Astronomer, W.S. Jacob, who was then in England, wrote the following letter to R.C. Carrington, the Secretary of the Royal Astronomical Society:

> The East India Company has extended large sums in the promotion of science, witness the Trigonometrical Survey, and the Magnetic and Meteorological Observatories, but though astronomy has not been altogether neglected, it has scarcely been allowed the prominence that it merits both by its intrinsic importance and from the advantages offered by the Climate. (Jacob 1859).

As a result, the British Parliament gave a grant of £1000 to the Royal Astronomical Society "… in aid of the proposed temporary maintenance of an Observatory near Poona." (Phillimore 1958: 448). Jacob then went and bought a T. Cooke and Sons 9-in. (22.9-cm) refractor at his own expense (it cost £550), and he was given £100 for the purchase of a chronometer and other minor instruments and another £400 for packaging and freighting the telescope to India (payable upon arrival). Jacob was to remain in charge of the observatory for 3 years, but he never got to use the remaining grant or the telescope as he arrived in Poona in August 1862 and died 2 days later (Obituary 1863). Subsequently the telescope was put on sale in England (Phillimore 1958: 449).

24.9 Nineteenth Century Positional Astronomy: A Summary

We have seen that astronomical activity in India in the nineteenth century followed two distinct channels: pure astronomy as represented by the Madras Observatory, and practical astronomy as represented by the Great Trigonometrical Survey of India (Ansari 2000). In the early years, prior to 1829, there was hardly a distinction between the activities of the Observatory and the Survey. Madras Observatory was the reference meridian for all survey work, and the early astronomers (Michael Topping, John Goldingham and John Warren) actively participated in the GTS work, being officially co-designated (till 1810) 'Madras surveyors'. Between 1794 and 1810 the Observatory ran a surveying school to train half-caste or Eurasian boys as assistant surveyors.

The last Madras Observatory astronomer to do survey work was Thomas Glanville Taylor who assisted George Everest at Calcutta in 1831 (Phillimore 1958:

115). The first astronomer without any surveying connection whatsoever was Norman Pogson who joined Madras Observatory in 1861. After this, the two streams, pure astronomy (Madras Observatory) and practical astronomy (the Great Trigonometrical Survey of India), increasingly separated. For reasons of state, practical astronomy received all the favours, while pure astronomy emerged as a poor cousin. The relative importance of the two streams of astronomy is best brought out by the economics. In 1801 the Survey Superintendent's monthly salary was fixed at Rs 980, while the Madras Astronomer received Rs 672 (Phillimore 1958: 115). Seven decades later, in 1877, the Superintendent's salary had gone up to Rs 2565, whereas the Madras Astronomer received a paltry Rs 800. Fifteen officers of the Survey were drawing more than the Astronomer, three of them being Fellows of the Royal Society (Kochhar 1991a: 126). Significantly, while military officers were permitted to serve on the GTS, they were not allowed to take up a 'civil' appointment at Madras Observatory.

The Trigonometrical Survey's attitude towards pure astronomy is best brought out by a little-known incident. In 1834, on orders from the Government, instruments were issued to John Cumin (1793–1848; Schaffer 2012: 152–153) for the observation of the opposition of Mars, but the Surveyor General, George Everest, made a strong protest against the loan, sayings: "The discoveries which the late astronomer of Bombay is likely to make in science would hardly repay the inconvenience occasioned by retarding the operations of the Great Trigonometrical Survey …" (Kochhar 1991a: 126). Cumin had been the first Director of Colaba Observatory (in Bombay), and he was dismissed in 1828 (see Schaffer 2012). Therefore, his stock would not have been very high in British India. Yet, this incident sums up where pure astronomy stood vis-a-vis practical astronomy.

24.10 Solar Eclipses and Transit of Venus: The Advent of Physical Astronomy

While positional astronomy was struggling at Madras Observatory, astrophysics—a new type of physical astronomy that relied on spectroscopy and photography—was emerging in Europe (e.g., see Clerke 1903a). During the late 1860s and early 1870s both of these techniques were employed in India, which was host to no fewer than three total solar eclipses (in 1868, 1871 and 1872) and a transit of Venus (in 1874).

24.10.1 The 1868, 1871 and 1872 Solar Eclipses

Elsewhere in this book the 18 August 1868 total solar eclipse is referred to as a 'watershed event' that led to a major breakthrough in solar physics (Orchiston and Orchiston 2017). As Fig. 12.1 reveals, the path of totality extended from Aden, across India, Siam (present-day Thailand) and the Dutch East Indies (present-day Indonesia), and observations were made in all of these places (Fig. 24.23), but the

Fig. 24.23 The red bulls-eyes mark locations where observing parties were based for the 18 August 1868 total solar eclipse (*Map* Wayne Orchiston)

Table 24.1 Indian-based observers of the 18 August 1868 total solar eclipse

Team Leader	Institution	Observing Site	References
British Teams			
Captain Haig RE	GTS?	Bijapur	Haig (1869)
Lieutenant Herschel	GRT (Royal Society)	Jamkandi	Herschel (1869)
Pogson	Madras Observatory	Masulipatam	Pogson (n.d.)
Ragoonatha Chary	Madras Observatory	Vunpurthy	Pogson (n.d.)
Major Tennant	Government of India (RAS)	Guntoor	Tennant (1869)
French Team			
Janssen	[National]	Guntoor	Janssen (1869)
German Team			
Professor Tietjen	[National]	Mulwar	

most important observations—the ones that led to the aforementioned ‘major breakthrough’—came predominantly from India.

The 1868 eclipse would have one of the longest intervals of totality of all eclipses, thus offering astronomers ample opportunity to make spectroscopic observations, take photographs, and examine the corona with the polariscope. A new understanding of the nature of the chromosphere, prominences and the corona was anticipated.

Because of its ideal location and Britain’s strong astronomical tradition, India attracted visiting teams of British, French and German astronomers, as well as local teams from Madras Observatory and the Great Trigonometrical Survey of India. As Table 24.1 shows, both the French astrophysicist Pierre Jules Cesar Janssen (1824–1907; Launay 2012) and the British expedition mounted by the Royal Astronomical Society and led by the soldier-astronomer Colonel James Francis Tennant (1829–1915; Fig. 24.24; Obituary 1915) were based at Guntoor. One of Sir

Fig. 24.24 Major J.F. Tennant (*Courtesy* Indian Institute of Astrophysics Archives)

John Herschel's sons, Lieutenant John Herschel (1837–1921; Shylaja 2006) and his team from the Great Trigonometrical Survey of India (with instruments provided by the Royal Society of London) was based at Jamkandi. Another 'local' team, led by Captain C.T. Haig, Royal Engineers (1837–1921) and also from the Great Trigonometrical Survey of India, was at Bijapur, while Madras Observatory arranged two different observing teams (Ranyard 1879), one led by Ragoonatha Charry (at Vunpurthy) and the other by Norman Pogson, at Masulipatam. Finally, there was a German team, led by Astronomisches Rechen-Institut Director Professor Friedrich Tietjen (1834–1895; Fig. 24.25; Obituary … 1895), at Mulwar near Bijapur.[7] Most of these localities are shown in Fig. 24.1.

All of the Indian-based teams succeeded in observing the eclipse, but the most scientifically valuable observations were made by the teams led by Janssen, Pogson and Tennant (and to gain some insight into the types of instruments used and range of observations made see the next chapter in this book, by Orchiston et al. 2017). Suffice it to say that the chemical composition of the chromosphere, prominences and the corona was clearly established, while Pogson was the first to notice an unidentified spectral line that later was shown to be due to a new element (Nath 2013). This was aptly name helium by Janssen and Norman Lockyer. Meanwhile, during his post-eclipse stay at Simla, Janssen created the first spectrohelioscope, which facilitated daily examination of prominences and the chromosphere without the aid of an eclipse.

Soon after the momentous 1868 event, India was specially favoured with yet another total solar eclipse, on 12 December 1871. On this occasion, the path of

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[7] The Germans sent two teams to observe this eclipse—the second one was based in Aden. The French also sent two teams, and the other one was in Siam (Orchiston and Orchiston 2017). The Dutch only had one observing team in SE Asia, and this was based in the Dutch East Indies—now Indonesia (see Mumpuni et al. 2017).

Fig. 24.25 Professor F. Tietjen (*Vierteljahresschrift der Astronomischen Gesellschaft* 1895)

totality (see Fig. 15.7) crossed southern India, Ceylon (now Sri Lanka) and the Dutch East Indies, and observations were made from all three areas. Because of the momentum generated by the 1868 eclipse, the Indian Subcontinent again was host to overseas eclipse teams, bent on learning more about prominences and the corona, and the mysterious coronal green spectral line that was discovered in 1869. Thus, Britain's Norman Lockyer led a large Government-funded expedition, members of which carried out successful observations from Bekul (see Fig. 26.10), Manatoddy and Poodocottah in India and from two sites in Ceylon. Herschel and Tennant also were back, but on this occasion they teamed up and observed together from a site near Ootacamund, while at neighbouring observing sites were their French colleague Jules Janssen and Pogson's Madras Observatory party. Rounding out the overseas visitors was the Italian Professor of Astronomy, Lorenzo Respighi (1824–1889; Fig. 24.26; Bònoli 2014), who set up his observing camp much further to the east, at Poodocottah, near one of Lockyer's parties. Although the skies were kind on 12 December 1871 and India once more contributed successful observations (e.g. see Janssen 1873; Lockyer 1874; Tennant 1875c), particularly of the corona (Fig. 26.11), understandably these did not lead to a major breakthrough in solar physics—as experienced in 1868.

Less than a year later India was favoured with yet another solar eclipse, on 15 August 1872. However, because it was an annular eclipse and the path of totality crossed Ceylon and the very southern tip of India (Fig. 24.27), this event did not offer the research opportunities enjoyed by astronomers in 1868 and 1871. As such, it need not detain us here.

However, the success of the international expeditions in 1868 and 1871 and the important role that India had played in furthering solar physics was largely respon-

Fig. 24.26 Professor L. Respighi (https://en.wikipedia.org)

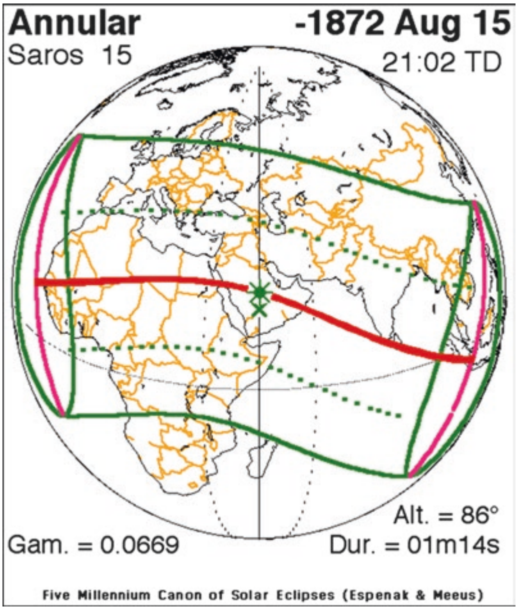

Fig. 24.27 A map showing the path of totality of the annular solar eclipse of 15 August 1872 (after Espenak and Meeus 2006)

sible for the decisions made by Britain, Japan and the USA to send parties out to India to observe the 22 January 1898 total solar eclipse (Nakamura and Orchiston 2017: Section 2.2.3; Strahan 1903: 155). India again favoured the observers with clear skies, and successful photographic and spectroscopic campaigns were mounted. By way of example, the Lick Observatory expedition to Jeur is discussed in Chap. 26 in this book (see Orchiston and Pearson 2017).

24.10.2 The 1874 Transit of Venus

As we saw in Sect. 24.1, transits of Venus were thought to offer a particularly elegant way of measuring the solar parallax—hence the Astronomical Unit—and establishing the scale of the Solar System. When compared with the 1761 transit, the 1769 event did provide "… an improved value for the solar parallax, but a divergence of results remained that implied a not so exact value for the distance to the Sun." (Kapoor 2014: 113). A detailed discussion of this issue is provided in Dick et al. (1998) and in Orchiston (2005). Thus, the focus shifted to the 1874 and 1882 transits.

Moreover, the world of astronomy had changed markedly since the previous transit:

> … a century had passed, the techniques for angular measurements and geo-positions and instrumentation had improved greatly, and more observatories had been built. On the other hand, the Solar System itself had grown larger with the discovery by Sir William Herschel (1738–1822) of Uranus on 13 March 1781 and of Neptune by Johann Gottfried Galle (1812–1910) and Heinrich Louis d'Arrest (1822–1875) on 23 September 1846. [Furthermore,] The science of astrophysics came into being in the nineteenth century with the introduction of spectroscopy and photography to astronomy. (Kapoor 2014: 113).

In 1874—for the first time in history—nations of the world would subject a transit of Venus to intensive spectroscopic and photographic scrutiny, and in this regard India would be no different.

Because of its fortuitous location, India was favourably placed to offer a view of the entire 9 December 1874 transit. Accordingly, several overseas nations decided to mount Indian 'transit expeditions', and Indian-based astronomers also were eager to take up the challenge.

However, for some of the scientists the agenda ran deeper than the transit itself. What was advertised was the momentary passage of Venus in front of the solar disc, but what was planned was a long-term study of the solar disc itself. The British Association for the Advancement of Science even passed a resolution asking the Government of India to make arrangements for the observation of the transit, and that the associated instruments should afterwards be transferred to a solar observatory (Tennant 1877: 1). Such was the prestige enjoyed by science and scientists in Europe at the time that the British Empire, as the 'owner' of most of the world's sunshine, could not but respond favourably, albeit only partially. For its part, the Indian Government was interested in the concept that a study of the Sun would help predict the failure of monsoons (India meteorology 1883), which were—and still are—India's economic life-line.

The 1874 transit of Venus would be viewed from many different sites across the Indian Subcontinent, and the most important transit campaigns are summarized here. As per international convention, in this chapter the terms 'contact 1' and 'contact 2' refer to the first and second ingress contacts, and 'contact 3' and 'contact 4' to the first and second egress contacts, respectively.

As part of its international transit campaign (see Ratcliff 2008), Britain was keen to send an official expedition to India, and at the initiative of the Astronomer Royal,

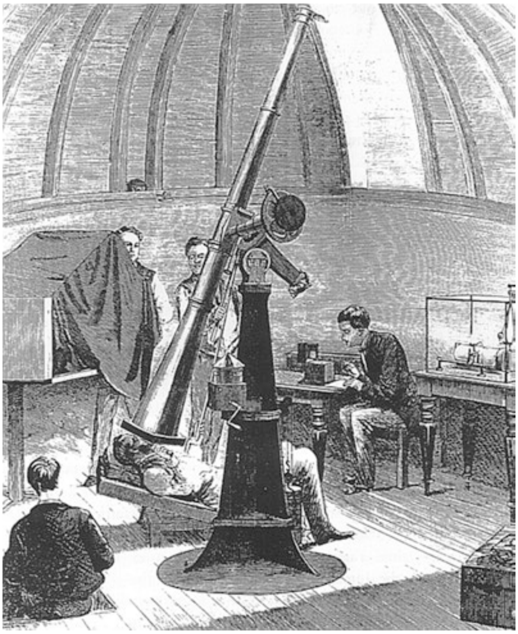

Fig. 24.28 A woodcut showing the Dallmeyer photoheliograph that was made in 1874 for Melbourne Observatory and its transit of Venus program; the one used in India was similar in design (Orchiston Collection)

Sir George Airy, observations were planned for Roorkee and Lahore, under the supervision of a familiar figure in Indian astronomy, Colonel James Francis Tennant (Fig. 24.24). We should note that it was Tennant, and not Airy's *bete noire*, the Madras Astronomer Norman Pogson, who was asked to supervise this work.

The following instruments were sent out from England for the transit observations: (1) A 4-in. Dallmeyer Photoheliograph (similar to five others made for the British transit of Venus expeditions—see Fig. 24.28) that produced a 4-in. diameter solar image on 6-in. square photographic plates; (2) a 6-in. f/13.7 Cooke equatorially mounted refractor with a double image micrometer;[8] (3) a small portable Cooke transit telescope; (4) one standard and two journeyman clocks, all made by Thomas Cooke & Sons, and (5) a Cooke chronograph.[9] Various other instruments were provided (mainly) by the Great Trigonometrical Survey of India.

Tennant elected to observe from Roorkee, and he sent Captain George Strahan R.E. to Lahore. Assisting Tennant at Roorkee were (amongst others) Captain William M. Campbell R.E. (from the Great Trigonometrical Survey of India), Captain James Waterhouse, R.E. (Superintendent of the Mathematical Instrument

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[8] Eventually this telescope reached Kodaikanal (via South Kensington and Poona), and its mounting now supports Pogson's 8-in refractor at Kodaikanal Observatory.

[9] Thomas Cooke & Sons would later amalgamate with the equally well-known British scientific instrument-makers, Troughton and Simms (see McConnell 1992).

Department in Calcutta)[10] and Sergeant J. Harrold R.E. Their instruments were the Dallmeyer photoheliograph, the 6-in. Cooke refractor, an altazimuth-mounted refractor, the portable transit instrument and a chronograph. Later Captain William James Heaviside R.E. joined the team, bringing with him the Royal Society's 'Slater Telescope'.

During the transit, Tennant missed the first contact, but did record the other three; there was no sign of the notorious 'black drop'. He also made a series of micrometric measures, while Waterhouse and Harrold took "… 107 six-inch photographs and 6 Janssen plates …" (*Proceedings* … 1875: 244n).

Tennant's colleague Captain C. Strahan R.E. (see Strahan 1903) was based at Lahore, and furnished with a 6-in. (15.2-cm) Simms refractor and solar and sidereal chronometers. Although he also could not see the ingress, he was able to view the rest of the transit. While he did not notice the 'black drop', he did see a luminous ring round part of Venus at egress. Tennant (1877) wrote a report on observations he and others under his charge made during the transit (but see, also, Tennant 1875a, b, 1882).

As might be expected, Madras Observatory was well prepared for the transit, but clouds prevented any useful observations being made:

> Venus was briefly seen once or twice during the transit, but only through thick clouds which rendered photographs or measurement of any kind impossible. The second internal contact, noted by Miss E. Isis Pogson and C. Ragoonatha Charry, was the only record obtainable … (Pogson 1874).

In the above quotation we see one of only two Madras Observatory staff who actually saw the transit was C. Ragoonatha Charry (Fig. 24.15). The transit was of particular interest to him, and he prepared a 38-page pamphlet titled *Transit of Venus* that was published in English, Kannada, Urdu and other languages (e.g. see Fig. 24.29). One of these was reprinted in time for the 2012 transit (Ragoonatha Charry 2012) and Bengalaru Planetarium Director, Dr. B.S. Shylaja (2012) has written a book about it.

The Great Trigonometrical Survey of India's main observing program centred on John Babonau Nickterlein Hennessey (1829–1910; Fig. 24.30; Hollis 1910), who was based in northern India at Mussoorie (now Masauri) in the Shivalik Hills, 6765 ft. above mean sea level. He had access to two telescope, one of which was loaned by the Royal Society through Captain John Herschel. Hennessey enjoyed a fine view of the transit and accurately timed the first three contacts. Eight and a half minutes before second contact he saw a thin luminous ring around Venus, but there was no sign of the notorious 'black-drop' (Hennessey 1874–1875, 1879). Hennessey also "… obtained some interesting results with the spectroscope …" (*Proceedings* … 1875: 244n).

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[10] We wonder if this is in fact the Survey's foremost photographic expert, James Waterhouse (1842–1922) who in 1866 moved to Calcutta to take charge of the Photolithography Department, and built a considerable reputation as a photographer. Our searches revealed no Captain James Waterhouse associated with the Mathematical Instrument Department in Calcutta. Note that the James Waterhouse who accompanied Tennant was responsible for the photographic component of the project, using the Dallmeyer photoheliograph.

فتبارک الله فی حسن تقویم

TRANSIT OF VENUS

BY

قران زہرہ

۱۲۹۱

مدراس کے مطبع ہاشمی میں چھپوایا

Fig. 24.29 The cover page of the *Urdu* version of Ragoonatha Charry's booklet about the 1874 transit of Venus (*Courtesy* Kochhar 1991c: 87)

Fig. 24.30 J.B.N. Hennessey, F.R.S. (after Phillimore, 1968: Plate 23)

Colonel James Thomas Walker (1826–1896; Markham 1896), the Superintendent of the Great Trigonometrical Survey of India, was based at Dehra Dun, 16 km south of Hennessey, but at a much lower altitude (2200 ft.), and he saw the 'black-drop' during the transit.

Observations of the transit also were made at the Surveyor General's Office in Calcutta, "… where 39 photographs and several eye observations were made …" (*Proceedings* … 1875: 244n).

Meanwhile, back in northern India, the Reverend H.D. James was based at Chakratae (altitude 7300 ft.) in the Shivalik Hills, 80 km by road to the west of Mussoorie. Assisted by his son, James used his own telescope, a 3.5-in. (8.9-cm) Smith and Beck refractor and a pocket-watch. James briefed Hennessey on his observations:

> When she [Venus] was about halfway on (at ingress) the sun we both noticed a fringe of white light illuminating that rim of the planet which was yet on the dark sky. When she went off we noticed the same fringe of light, but for a much shorter time, and when only about one eighth of her had passed the sun's disk. (Hennessey 1874–1875: 382).

Captain A.C. Bigg-Wither (1844–1913), an engineer with the Indus Valley Railway, observed the transit from his observatory at Mooltan (present-day Multan, which is now in Pakistan), using a 4-in. (10.2-cm) f/15 equatorially mounted Cooke refractor and a transit telescope. He timed the second contact and noticed the black drop', but it was absent during the egress. Instead he saw a ring of light round part of Venus (Bigg-Wither 1883).

The Italians also mounted an ambitious transit of Venus expedition, based on a spectroscopic analysis of the transit (which they hoped would yield precise contact timings). Pietro Tacchini (1838–1905; Fig. 24.31; Gariboldi 2014), the Director of Palermo Astronomical Observatory, led the expedition to Muddapore in Bengal. Accompanying him were Alesandro Dorna (1825–1886) from the Observatory of Torino, Antonio Abetti (1846–1928), two other Italians, and the Belgian, Father Eugene Lafont S.J. (1837–1908), from St Xavier's College in Calcutta. Tacchini, Abetti, Dorna and Lafont all had access to chronometers and equatorially mounted refractors furnished with spectroscopes, and they succeeded in making contact timings. Tacchini and Abetti also found spectroscopic evidence of water vapour in Venus' atmosphere (Biswas 2003), proving beyond any doubt that Venus had an atmosphere. For further information about this important Italian campaign see Pigatto and Zanini (2001).

For details of the above-mentioned and other observations made from India during the 1874 transit of Venus see Kapoor (2014).

The year 1874 was the last time that India would play a role in elucidating the AU, as the 1882 transit was not visible from the Subcontinent. Meanwhile, data provided by all British observers in 1874 produced parallax values between 8.82″ and 8.88″ (Tupman 1878). Then in 1895 the U.S. Naval Observatory's Simon Newcomb (1835–1909; Trudel 2014) re-analysed the observations made during the 1761, 1769, 1874 and 1882 transits and produced a value of 8.794″ (Newcomb 1895), which is remarkably close to the modern value of 8.794148″ that was adopted by the IAU in 1976 (for details see Dick et al. 1998).

Fig. 24.31 Pietro Tacchini (after Macpherson 1905: facing page 77)

24.11 Dehra Dun Observatory (1878–1925)

When he was in Simla after the 1874 transit Tennant suggested that the Government establish a solar physics observatory there using some of the instruments already in India for the 1874 transit. The laudable role of this new observatory would be to make a spectroscopic and photographic study of the Sun, and carry out observations of Jupiter's satellites, but the Government turned Tennant down.

However, the Government was more responsive when Lockyer used his influence with Lord Salisbury (1830–1903), the Secretary of State for India. On 28 September 1877, Salisbury wrote to the Viceroy:

> Having considered the suggestions made by Mr. Lockyer, and viewing that a study of the conditions of the sun's disc in relation to terrestrial phenomenon has become an important part of physical investigation, I have thought it desirable to assent to the employment for a limited period of a person qualified to obtain photographs of the sun's disc by the aid of the instrument now in India [for the transit]. The stand of the photoheliograph will be retained in India, and a fresh tube will be sent there to replace that used by Colonel Tennant (which had been found defective) … The other instruments may also be sent to England, and will be placed in the custody of the Science and Art Department which has offered to take charge of them. (*Report* … 1882).

It is clear that Lockyer either drafted Salisbury's letter or else supplied him with the relevant technical details.

Accordingly, starting from early 1878 daily solar photographs (weather permitting) were taken at Dehra Dun with the Dallmeyer photoheliograph under the auspices of the Survey of India (the new title of the Great Trigonometrical Survey, following Government restructuring); this is how Dehra Dun Observatory came into existence. Initially the photographic plates were sent to England every week. In 1884 the Hennessey Observatory was built at Dehra Dun. This Observatory contin-

Fig. 24.32 The Hennessey Observatory at Dehra Dun in February 2013 (*Photograph* Ramesh Kapoor)

ued solar photography till 1925, but more out of a sense of duty than enthusiasm. The larger of the two photoheliographs eventually fell into disuse, and in 1898 Lockyer was stung by an on-the-spot discovery that "… the dome has been taken possession of by bees." (Lockyer 1898).

On a more modern tone, Kapoor (2014: 119) notes that

> At the compound of the Survey of India's Geodetic Branch Office in Dehra Dun the Hennessy Observatory still exists … [see Fig. 24.32] all the instruments are gone, but the dome remains … it and the building require conservation.

24.12 St Xavier's College Observatory, Calcutta (1879)

Sunny India caught the attention of astronomers in Europe also. As we saw in Sect. 24.10.2 above, one of those co-opted by Pietro Tacchini into the 1874 Italian transit of Venus team was Father Eugene Lafont (Fig. 24.33), the Professor of Science at St. Xavier's College in Calcutta and an inspiring educator and science communicator (Biswas 1994). The College provided education for sons of Europeans, Anglo-Indians, rajas, *zamindars* and Indian men of note. Lafont therefore "… secured great influence among these classes …" (*Nature* 1908: 35), which he put to good use in the service of science.

Tacchini suggested to Lafont "… the advisability of erecting a Solar Observatory in Calcutta, in order to supplement the Observations made in Europe, by filling up the gaps caused in the series of solar records by bad weather." (Kochhar and Narlikar 1995: 16). Lafont soon collected a sum of Rs 21,000 through donations, including Rs 7000 from the Lieut.-Governor or Bengal,

Fig. 24.33 Father Eugene Lafont (https://en.wikipedia.org)

> … and in a couple of years the present spacious dome was constructed and fitted with a splendid 9" Refractor by Steinhill of Munich to which was adapted a large striking work, thanks to the customary thoroughness and dedication of the Jesuit men of science. (Kochhar and Narlikar 1995: 16).

Soon the Steinheil telescope was joined by a 7-in Merz refractor, and a Browning spectroscope (Udias 2003). This was the first astrophysical observatory established at a school in India but, unfortunately, little research was carried out at this facility, and the last Director, Father Edward Francottee, turned the focus from astronomy to meteorology.

For further details of this Observatory see Chinnici (1995/96) and Narlikar (2003).

At about the same time a research observatory emerged in Poona, but for entirely different reasons.

24.13 Takhtasinghji's Observatory, Poona (1888–1912)

This was the first modern astrophysical observatory in the country, and resulted from the efforts of Kavāsjī Dādābhāī Naegamvālā (1857–1938) a Lecturer in Physics at Elphinstone College in Bombay, who had been a brilliant graduate student in physics and chemistry at the College (winning the Chancellor's Gold Medal in 1878). Armed with a Rs 5000 grant from Maharaja Takhtasinghji of Bhavnagar (in Gujarat) and a matching amount from the Bombay Government, Naegamvālā established an observatory in 1888 at the Government College of Science (now College of Engineering) in Poona (Fig. 24.34), where he had shifted in the meantime as the Professor of Astrophysics (Narlikar 2003).

The main instrument at 'Poona Observatory' (as it colloquially was known) was a 16.5-in. Newtonian reflector with a 4-in. finder. This telescope by Grubb along

Fig. 24.34 A photograph of part of the Government College of Science in Poona (http://educrib.com/college/4310/college-of-engineering-coep-pune)

with its £250 observatory dome was inspected at the Indian Government's Lambeth Observatory in 1887 or 1888 before being sent to Poona, where it was installed in 1890, although the building had been ready since 1888.

Back in 1874 the Government of India had purchased a 6-in. Cooke equatorial for the transit of Venus. Some years after the transit (in 1879) it was loaned to Sir Norman Lockyer at South Kensington. The India office also purchased two-spectroscopes from Hilger (one solar, the other stellar) for Lockyer's use. In 1885 the telescope and spectroscopes were sent to India for Poona Observatory.

Ironically, Naegamvālā's first use of the large reflecting telescope was to prove his mentor, Lockyer, wrong. Naegamvālā (1891) showed that the chief nebular line in Orion was sharp under all circumstances and therefore could not be the remnant of a magnesium band as Lockyer had suggested. In other words William Huggins (1824–1910; Brück 2014) and James E. Keeler (1857–1900; Walsh 2014) were right. Lockyer's bland reaction is amusing. Describing Poona Observatory, he wrote in 1898 "Some spectroscopic work of preliminary character was done during 1891, but it was found that the instrument used was altogether lacking in stability and was very weak in its driving parts …" (Lockyer 1898). However, this was a biased evaluation, for the large reflecting telescope had been sent to Grubb for modifications, and was received back in 1894. It was then a Cassegrain reflector of 16½ in. aperture and 127 in. focus, adapted both for visual and photographic work, and supplied with an electric drive. Attached to the reflector was a 6-in. achromatic finder with filar micrometer and solar eye piece. The telescope underwent yet another change when in 1897 the mirror was replaced by a 20-in. aperture, 11 ft. 3 in. focus mirror made by Dr. Andrew Ainslie Common (1841–1903; Baum 2014b). As an aside, we should mention that this refurbished telescope would remain the largest reflector in India for the next eight decades, and it has been described by Kameswara Rao et al. (2014: 618) as "… the most widely travelled telescope in the country."

In 1898 the newly knighted Sir Norman Lockyer and the Astronomer Royal Sir W.H.M. Christie (1845–1922; Fig. 24.35; Dewhirst 2014) visited India in order to report on observatories in the Subcontinent *and* observe the total solar eclipse of 22

Fig. 24.35 Astronomer Royal Sir W.H.M. Christie (https://en.wikipedia.org)

January 1898. Whilst there they met Naegamvālā, who was at Jeur (see Fig. 26.14) and successfully observed the eclipse (see Naegamvala 1902). The best thing

> … that could have happened to Naegamvala was his discovery by Lockyer. Lockyer in his report paid glowing tributes to Naegamvala, 'who as far as I know is the only person in India practically familiar with solar physics work'. On Lockyer's recommendation, Naegamvala was relieved of teaching duties, appointed full-time director of the observatory and asked to send data regularly to Lockyer. If Lockyer had had his way, he would have appointed Naegamvala the director of the proposed Solar Physics Observatory at Kodaikanal. (Kochhar and Narlikar 1995: 18).

Unfortunately this did not happen as the founding Directorship went to Madras Observatory Director, Charles Michie Smith. Instead, Naegamvālā remained in Poona, but from that time on he appears to have made little use of the excellent research facilities at Takhtasinghji's Observatory since no papers were published reporting observations made with the 20-in. telescope.

Naegamvālā retired in 1912, the Observatory was closed down, and the following instruments were transferred to Kodaikanal: (1) the 20-in. reflecting telescope by Grubb with the mirror by Common (now called the Bhavnagar Telescope); (2) the 6-in. Cooke photo-visual equatorial telescope; (3) two prisms of 6-in. aperture for use with the above telescopes; (4) a 12-in. Cooke siderostat; (5) an 8-in. horizontal telescope; (6) a large grating spectroscope by Hilger; (7) an ultraviolet spectrograph by Grubb; (8) a sidereal clock by Cooke, and (9) a mean time chronometer by Frodsham (No 3476).

The Poona Observatory was a clear case of history repeating itself. Even though it was the best equipped in the country when it was set up, Maharaja Takhtasinghji's Observatory turned out to be a one-astronomer observatory, closing down with Naegamvālā's retirement.

For further information about Naegamvālā and Takhtasinghji's Observatory see Ansari (1985: 390–394; 2011: 364–368).

By way of contrast, after a shaky start Kodaikanal Observatory rose to great heights, and was intact when the time came for modernization.

24.14 Kodaikanal Observatory (1899)

24.14.1 Introduction

Although the need for a modern observatory as a successor to the one at Madras for research in the emerging field of physical astronomy had been felt for many decades, it was only in 1891 on the death of Pogson—after a 30 year uninterrupted stint as the Director of Madras Observatory—that the question of a new observatory was taken up in earnest.

The severe famine in the Madras Presidency in 1876–1877 was taken to underline the need for a study of the Sun in the hope that monsoon patterns would be better understood. Thanks to the efforts of John (later Sir John) Eliot (1839–1908; Fig. 24.36), Meteorological Reporter to the Government of India (and later the Director General of Observatories), it was finally decided in 1893 to establish a solar physics observatory at Kodaikanal in the Palani Hills of South India; to transfer all astronomical activity from Madras to Kodaikanal; and to place the new Observatory under the control of the Central Government. Kodaikanal Observatory came into existence on 1 April 1899 (Kochhar 2009).

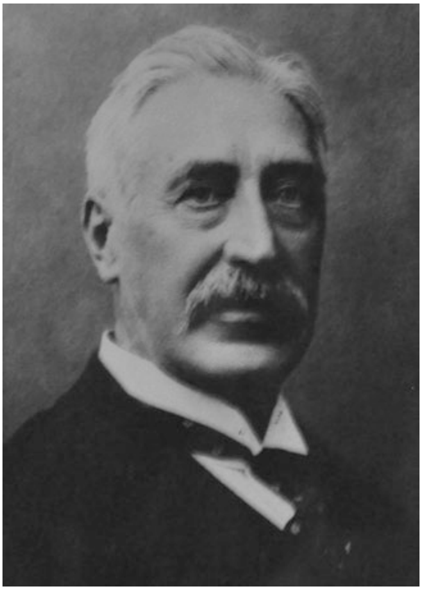

Fig. 24.36 John Eliot Meteorological Reporter (http://www.imd.gov.in/pages/about_ex_dgms.php)

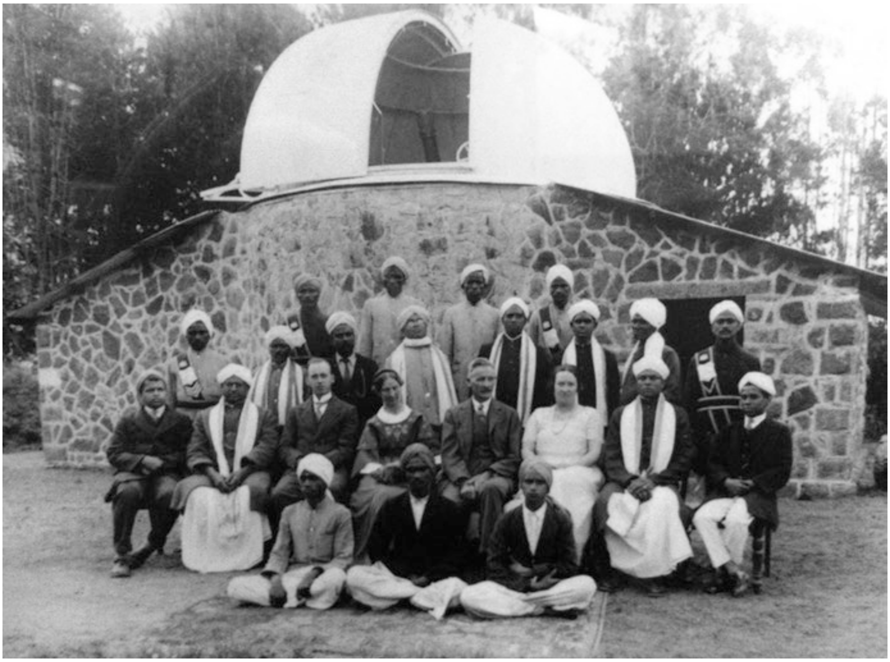

Fig. 24.37 A photograph of the Kodaikanal staff in about 1907. John Evershed and his wife Mary (also an astronomer) are in the centre of the second row (http://astronomy.snjr.net/blog/wp-content/uploads/2013/03/Kodaikanal.jpg)

Then there was a tussle between two English power centres as to who should head the Observatory. As we have seen, Norman Lockyer supported Naegamvālā, but the appointment was offered to Astronomer Royal Christie's protégé, the Madras Astronomer Charles Michie Smith (1854–1922; Fig. 24.37). Smith was born near Aberdeen in Scotland and after graduating B.Sc. in 1876 accepted the Chair of Physics at the Christian College in Madras. There he showed a particular interest in meteor astronomy. In 1891 he succeeded Norman Pogson as Director of Madras Observatory, and apart from observing two solar eclipses during the 1890s there was no hint that he was interested in solar astronomy, or that it would become his future research forté (Obituary … 1923).

In 1895 the plans for buildings and instruments were approved by the London-based Indian Observatories Committee, chaired by Lord Kelvin, and the formal Government sanction followed as a matter of course. The same year, the 100-acre mountaintop site, known locally as Nadingipuram, was acquired, and a road opened to the top of the hill. In October the foundation stone was laid by the Madras Governor, Baron Wenlock (1849–1912). In July 1897, a north-south line was laid out atop the hill for the main building, then known simply as 'the observatory'. While he was in India for the 22 January 1898 total solar eclipse, the Astronomer

Royal visited Kodaikanal on instructions from the Secretary of State. At the time he found that the foundations of the Director's residence and of the main building were being dug. Plans were modified on Christie's suggestion. Instead of three dome as originally envisaged, the main building would only have two, each 18 ft. in diameter instead of 15 ft. While the local artisans were capable of conventional construction, domes were beyond their competence, so these offered a special challenge.

The first building to be completed was the Director's house, and Michie Smith took up residence in February 1899, in time to personally receive and handle more than a thousand coolie loads of books and instruments. Once on site, Michie Smith personally undertook the erection of the domes, doing with his own hands "… all the work that could not be done by a common native village carpenter or blacksmith. This included the driving of some 2,300 rivets." By December 1899 the two domes were finally almost finished. A recent view of the original building is shown in Fig. 26.16.

24.14.2 The Initial Instruments

The early scientific instrumentation at Kodaikanal came from four sources: (1) original Madras Observatory equipment; (2) instruments that had been sent out to India for the 1874 transit; (3) telescopes and other equipment expressly designed and constructed for Kodaikanal and assembled in Madras, and (4) instrumentation sent from other Indian Government observatories.

The old (1850s) ex-Madras Observatory 6-in. Lerebours and Secretan refractor on an English equatorial mounting was installed in the north dome, after being remodelled by Sir Howard Grubb in 1898 and supplied with a new drive. In 1912 it was adapted for white light photography of the Sun and (weather permitting) has been used continuously daily to take 20-cm photographs of the Sun.

The south dome has seen in succession three different telescopes. First to be installed was the ex-transit of Venus 6-in Cooke equatorial (which after Roorkee went to Lockyer at South Kensington, England, then to Poona in 1885, Madras Observatory in 1893, and finally to Kodaikanal). In 1912 this Cooke telescope was replaced by the 6-in. Cooke received from Poona when Takhtasinghji's Observatory was closed. This Cooke telescope remained intact until 1960 when the mounting was retained but the telescope tube assembly was replaced by an 8-in. Troughton & Simms refractor that was renovated for photoelectric work (this telescope had been installed at Madras Observatory in 1862, and was only sent to Kodaikanal in 1931). It is now used for observing comets and for the Observatory's public astronomy programs.

Construction of the transit room began in 1900–1901. It was completed in 1903, and housed the 5-in. Cooke transit telescope used first for the Great Trigonometrical Survey of India, and then at Madras. Madras Observatory sent it to Kodaikanal, along with an accompanying galvanic drum chronograph made by Eichen & Hardy of Paris.

The Observatory's potential to conduct 'cutting edge' solar physics was enhanced in 1897 when it received a spectrograph comprising a polar siderostat with an 11-in. plane mirror, a 6-in. 40-ft. focal length collimator lens and a concave diffraction grating. The siderostat and lens were made by Sir Howard Grubb, and the rest of the instrument by Adam Hilger. The siderostat still exists and is at Bangalore.

In order for it to more effectively pursue this solar agenda, Greenwich Observatory gave Kodaikanal Observatory a photoheliograph on permanent loan. Called 'Dallmeyer No 4', it was one of the five identical photoheliographs made by John Henry Dallmeyer (1830–1833) for the British 1874 transit of Venus expeditions, and had been used (sparingly given the weather) at Burnham in New Zealand (Hughes 2013: 298; Orchiston 2016: 374–378). With an original 4-in. f/15 objective, it was modified in 1884 to give an 8 in. diameter solar image—similar to the photoheliographs in use at Greenwich and Dehra Dun—and it was sent to Madras in 1895. It then moved to Kodaikanal, and at first it was set up in an iron shed and then, in 1907, housed in a domed building. It was used for daily solar photography till August 1912 when—as already noted—the Lerebours and Secretan telescope was substituted for this purpose. The Dallmeyer photoheliograph was removed from the dome in 1912 to make way for the ex-transit of Venus Cooke refractor that had been in the south dome, and is now at Bangalore, minus its optics.

The Observatory's potential to carry solar physics research was further enhanced in 1902 when a calcium K-line spectroheliograph was ordered from the Cambridge Scientific Instruments Company in England, at a cost of £1300. Its construction was supervised by Hugh Frank Newall (1857–1944; Hearnshaw 2014) from Cambridge University Observatory, and it arrived at Kodaikanal in August 1904. It comprised a 12-in. aperture 20-ft. focal length solar telescope used in conjunction with a Foucault siderostat incorporating an 18-in. diameter plane silver-on-glass mirror made by T. Cooke & Sons. In 1903, a dividing engine was received from the same company. The spectroheliograph was used to photograph the Sun in the calcium K line.

In 1912 Kodaikanal Observatory received the last of the early suite of major astronomical instruments, and one with an interesting history. This was the ex-Poona Observatory Grubb reflector with a 20-in. Common mirror. After a very long delay, a dome finally was erected for it at Kodaikanal in 1951, and it was named the 'Bhavnagar Telescope' to commemorate its past associations.

Despite its primary focus as a solar physics facility, Kodaikanal Observatory could not neglect entirely other physical sciences. Because it was barely half a degree north of the magnetic equator, a magnetic laboratory was erected at the Observatory in 1902 as part of the Indian Magnetic Survey. It was under the charge of the Survey of India from 1904 until 1918, when it was returned to the Observatory. It was closed in 1923 and restarted in 1948. The laboratory is no longer in use.

Most of the 100-acre grounds of the Observatory was either rock or grass-covered slopes. In order to reduce the disturbing effect of sunshine on the bare ground and to modify the strength of the winds to which the Observatory was exposed, Michie Smith decided to cover the ground with trees and shrubs, and in 1899 alone some 1500 trees were planted. In 1904 seeds of various types of pines were received from Lick Observatory and Pasadena in southern California from which a large number of saplings were raised and planted. Because there was always danger of forest fires, wild grass was replaced by short grass and wide fire trails were kept in good order.

24.14.3 John Evershed and Solar Research

Although some Kodaikanal Observatory instruments were used at Shahdol (now in Madhya Pradesh) to successfully photograph the 22 February 1898 total solar eclipse, solar research *par excellence* only began at the Observatory on 21 January 1907 when the British solar expert, John Evershed (1864–1956; Fig. 24.37; Stratton 1957), became the Director.

He made a prismatic camera using the prisms he had brought with him, and got the spectroheliograph into working order. He also designed and constructed a number of spectrographs, and from a study of the photographs of the solar spectra taken with one of these on 9 January 1909 he detected the radial outflow of gases in a sunspot (now known as the 'Evershed Effect'). Two years later (in 1911) he built a new spectroheliograph and bolted it to the framework of the original spectroheliograph so that he could photograph the Sun in calcium K *and* Hα light. This was the first time that a state-of-the-art astronomical instrument was built in India.

We could say, then, that John Evershed's arrival in 1907 launched the Observatory's 'golden age' in solar astronomy, but that was not the end of the acquisitions. In 1933 a Hale spectrohelioscope was received as a gift from Mount Wilson Observatory, and in the 1960s a new spectroheliograph was build that could photograph the Sun in any chosen spectral line.

Kodaikanal Observatory now has an uninterrupted record of solar activity with the same equipment that extends for about a century and, as an interesting aside, the spectroheliograph building also houses the historic clock by John Shelton (Fig. 24.4) that we met near the beginning of this Chapter.

24.15 Nizamiah Observatory (1901)

The positional astronomy slot that fell vacant in 1899 with the winding up of the Madras Observatory was filled by Nizamiah (Nizam's) Observatory at Hyderabad. Its founder was a rich British-educated nobleman, Nawab Zafar Jung (Fig. 24.38).

The Nawab purchased a small telescope and set up an Observatory at his estate at Phisalbanda in Hyderabad. Very far-sightedly, in 1901, he took the Nizam's permission to name the Observatory the Nizamiah and made sure that it would be taken over by the Government on his own death. He subsequently acquired a 15-in. Grubb refractor (Fig. 24.39). Curiously, he also obtained an 8-in. Cooke astrograph, which later became the Observatory's chief instrument.

Fig. 24.38 Nawab Zafar Jung (http://kamalp.blogspot.com/com/2013/09/28th-september-1908-deluge-of-hyderabad.html)

Zafar Jung died in 1907 and as planned his Observatory was taken over by the Government. Thus, ironically, the formal establishment of the Observatory had to await its founder's death. The following year the Observatory was formally inducted into the ambitious, on-going Carte du Ciel (astrographic chart and catalogue) programme. The aim of this international programme was to photographically map the whole sky by assigning various celestial zones to 18 different observatories around the world (Turner 1912). The Nizamiah was asked to take over from Santiago Observatory in Chile, which had defaulted on the 17°–23° S zone assigned to it. Finally the Observatory also ended up doing the Potsdam zone, 36°–39° N. Meanwhile, in March 1908 Arthur Brunel Chatwood (1866–1915) was brought from England as the Director on a monthly salary of Rs 1000 (about £1200 a year). Chatwood's tenure was far from a success: he did not go beyond the installation of the astrograph at the new site of Begumpet, and quit in 1914. The following year he died prematurely in Colombo.

Astrographic work would be taken up in earnest only in 1914 with the arrival of Robert John Pocock (1889–1918; Obituary 1919). Pocock was the protégé of the influential Oxford Professor Herbert Hall Turner (1861–1930) and came direct from Oxford, armed with a special grant. The first usable astrographic plate was taken on 9 December 1914, and the first volume of results was published in 1917. When the work finally ended in 1946, a total of 463,542 stars had been observed, and 12 vol-

Fig. 24.39 Nawab Zafar Jung and two visiting astronomers posing beside the 15-in. Grubb refractor (commons.wikimedia.org)

umes published. These data were in turn used by the Observatory astronomers to extract information on proper motion of stars and on double stars. Pocock was the last European Director of the Observatory. After his untimely death in 1918 he was succeeded by his erstwhile Assistant [Rao Sahib] Theralandoor Panchapagesha Bhaskaran (1889–1950), who however had to wait 4 years before getting the formal appointment. Bhaskaran was a foundation Fellow of the Indian National Science Academy (INSA), which was established in 1935 under the name National Institute of Science of India (the current name was only adopted in 1970). In the Academy records his name appears as T.P. Bhaskara Shastri.

Apart from the astrographic work, Nizamiah Observatory was involved in other research. In 1922 the 15-in. Grubb refractor was at long last operational, and it was used for visual observations of variable stars and lunar occultations. The Sun also received some attention, thanks to a Hale spectrohelioscope which was acquired in 1939. The Observatory also was involved in community service: it provided a standard time service and prepared Government calendars in Urdu and English.

24.16 Indian Responses to the Development of Astronomy in the Subcontinent

Just as the British needed (modern) science in India, they needed Indians also. Accordingly, the 'natives' were introduced to English education. As the scientific content to administration increased, Indians graduated from being clerks and writers to become doctors and engineers, and finally scientists. In January 1876 Dr. Mahendra Lal Sircar (1833–1904; Biswas 2003) collaborated with Father Lafont (Fig. 24.33), generating support among Indians as well as in Government for setting up at Calcutta the rather oddly named Indian Association for the Cultivation of Science (IACS). It was the scientific wing of the Indian Association, which was a political organization of educated Indians and a precursor of the Indian National Congress. Its aim was to enable the "Natives of India to cultivate Science in all its departments with a view to its advancement by original research." (Biswas 2003: 126). A rich benefactor (Kumar Kanti Chandra Singh Bahadur) presented the IACS with a valuable 7-in. Merz-Browning equatorial telescope in 1880. However, it had to wait for more than 30 years to find a user.

Observational astronomy simply failed to develop under Indian auspices. The appearance of Comet 1P/Halley in 1910 activated astronomy buffs at Calcutta, who set up the Astronomical Society of India. There were 192 original members including not only men of science but also informed laypersons and Christian missionaries. In addition, there were some rich Indian patrons. The first President was Bengal's Accountant General Herbert Gerald Tomkins (1869–1934; see Appleton et al. 2016), who remained the Society's driving force during its decade-long exis-

Fig. 24.40 Chandrasekhar Venkata Raman (https://en.wikipedia.org)

tence. It is not clear whether the Society was formally wound up or simply became defunct. The last available issue of the Society's *Journal* is dated June 1920.[11]

An active member of the Society was Chandrasekhar Venkata Raman (1888–1970; Fig. 24.40; Venkataraman 1988), the young Deputy Accountant General and part-time researcher at the IACS who in 1917 quit his lucrative Government job in order to take up the newly created Palit Professorship of Physics at Calcutta University. He served the Society variously as its Business Secretary, Librarian and Director of the Variable Star Section, and contributed to the *Journal* as well as to the discussions at Society meetings. He installed the Society's 7-in. telescope and put it to use. Raman maintained a life-long interest in, and enthusiasm for, astronomy. Another member of the Society was a subjudge, Nagendra Nath Dhar (1857–1929), who made optics for telescopes at his workshop at Hooghly near Calcutta.

The most dedicated observer of the time worked outside the pale of the Astronomical Society. Born in a *zamindar* family at the small village of Bagchar in Jessore district (now in Bangladesh), Radha Gobinda Chandra (1878–1975; Fig. 24.41) left school after failing the matriculation examination three times, and he took a job as a *poddar* (coin tester) at the Collectorate at a salary of Rs 15 monthly. His introduction to astronomy came from a Bengali text and practical acquaintance with the sky from his scientific apprenticeship to a lawyer (Kalinath Mukherjee) who was editing a star atlas. Chandra observed Comet 1P/Halley through binoculars and in 1912 purchased a 3-in. refractor from London for £13. He then became a regular observer of variable stars and a member of the American Association of Variable Star Observers (AAVSO), which in 1926 gave him a 6-in. telescope that originally belonged to the AAVSO's patron and friend, amateur

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[11] This same name was used more than half a century later when the present Astronomical Society of India was set up at Hyderabad in 1973.

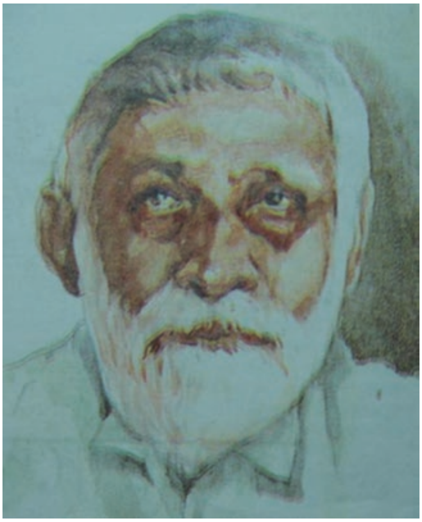

Fig. 24.41 Radha Gobinda Chandra (https://en.wikipedia.org)

Fig. 24.42 Meghnad Saha (https://en.wikipedia.org)

astronomer Charles W. Elmer (1872–1954). Chandra certainly made very good use of it, contributing a total of 37,215 naked-eye observations up to 1954, when he finally retired from observing. His observations were particularly valuable because he was sited at a longitude that was far from that of most other observers. Chandra also was one of those amateur astronomers who independently discovered Nova Aquila in June 1918. After his 'retirement', Chandra passed the AAVSO telescope to Manali Kallat Vainu Bappu (1927–1982), who was then at the Astronomical Observatory at Nainital. The Elmer-Chandra telescope, one of very few American telescopes in India (if not the only one), is now at Kavalur.

Although the Indian response to observational astronomy was rather lackluster, it was path-breaking in the field of theoretical astrophysics. While the well-placed Calcuttan astronomy enthusiasts were forming their Society, unknown to them a bright lad in the backwaters of east Bengal was making his acquaintance with astronomy. Meghnad Saha (1893–1956; Fig. 24.42; Kothari 1959) wrote an essay on Comet Halley in Bengali for the Dacca College magazine. In 1920, two lecturers in physics at Calcutta University, Meghnad Saha and Satyendranath Bose (1894–1974), brought out an English translation of Einstein's papers on relativity. Reviewing it, the science magazine *Nature* wrote on 26 August 1922: "Provided it is studied with care, the translation will nevertheless be of service to those who are unfamiliar with German, and wish to grapple with the pioneer works on these subjects, some of which are rather inaccessible." Stimulated in part by Agnes Clerke's authoritative books *Problems in Astrophysics* (Clerke 1903a) and *The System of the Stars* (Clerke 1903b), in 1920 Saha published his epoch-making work on the theory of high temperature ionization and its application to stellar atmospheres. Saha's demonstration that the spectra of far-off celestial objects can be simply understood in terms of laws of nature as we know them on Earth transformed the whole Universe into a terrestrial laboratory and laid the foundation of modern astrophysics. In 1923, Saha moved to Allahabad University as Professor of Physics

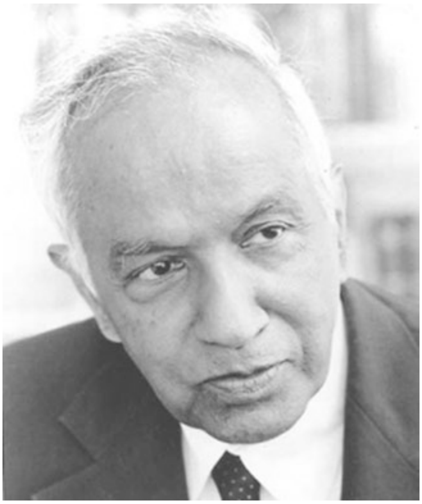

Fig. 24.43 Subrahmanyan Chandrasekhar (https://en.wikipedia.org)

where he set up a school of astrophysics, training outstanding students like Daulat Singh Kothari (1906–1993). Saha was the first one to point out (in 1937) the need to make astronomical observations from outside the Earth's atmosphere. He returned to Calcutta University in 1938 as Palit Professor of Physics. Saha and Bose, like Raman, were the foundation fellows of the INSA. Saha became its President during 1937–1938, Bose during 1949–1950, whereas Kothari held the post during 1973–1974. For details of Saha's contributions to international astrophysics, and the friction that existed between him and C.V. Raman, see DeVorkin (1993, 1994, 1996).

At Madras, Subrahmanyan Chandrasekhar (1910–1995; Kameshwar 1997; Fig. 24.43) for the first time applied the theory of special relativity to the problems of stellar structure and obtained preliminary results on what after his rigorous work at University of Cambridge came to be known as the Chandrasekhar mass limit. Chandrasekhar belatedly received the Nobel Prize for Physics in 1983 (jointly with William A. Fowler).

Curiously, unlike the physicists, India's pioneering relativists were trained abroad. Nikhil Ranjan Sen (1894–1963), a class-mate of Saha and Bose, joined Calcutta University in 1917 as a Lecturer in Applied Mathematics. He obtained his D.Sc. in 1921, but went to Berlin where he obtained his Ph.D. under the supervision of Professor Von Laue. Sen's was the first Indian doctorate in relativity, and he joined the INSA as a Foundation Fellow.

Vishnu Vasudeva Narlikar (1908–1991) obtained his B.Sc. in 1928 from the Royal Institute of Science in Bombay. He left to carry out graduate studies at Cambridge University, thanks to financial assistance from Bombay University, Kolhapur State, and the J.N. Tata Endowment. He passed the Mathematics Tripos with distinction in 1930 and went on to win the Rayleigh Prize for his astronomical researches. Spurning an offer to go to Caltech, in 1932 he accepted an invitation from Pandit Madan Mohan Malaviya, the Vice-Chancellor of Banaras Hindu

University, and came to Banaras as the Head of the Mathematics Department, where he remained for the next 28 years. He trained and guided a large number of students, including Prahlad Chunilal Vaidya (b. 1918), the author of the well-known Vaidya metric (1943) for the gravitational field of a radiating star. In 1955 Amal Kumar Raychaudhuri (b. 1923) derived his equation that has played a crucial role in the investigation of singularity in relativistic cosmology.

In 1938, B. Datt from Sen's group gave the solution for a gravitationally collapsing spherical ball of dust. This solution was published in *Zeitschrift für Physik* in 1938, and pre-dates the more commonly known solution of Oppenheimer and Snyder. In 1947, S. Datta Majumdar (University of Calcutta) published a class of exact solutions of Einstein's equations for the case of an electrostatic field with or without spherical symmetry; these are now known as the Datta Majumdar-Papapetrou solutions.

By the time the WWII came to an end it was clear that the British rule in India would soon be over. Plans were therefore afoot to set the scientific agenda for the future. It is not very well known that between 1943 and 1945 the Indian Government made sincere efforts to bring Subrahmanyan Chandrasekhar back from Chicago as the Director of Kodaikanal Observatory. The official files of the India Meteorological Department show that he even was offered a salary three times the usual in order to match his US salary—but all to no avail. The history of Indian astronomy and astrophysics would have been very different if Chandrasekhar had come to Kodaikanal, or any other place in India for that matter.

Twenty years earlier the British Director General of Observatories had offered Saha the number two position at Kodaikanal, under Evershed. Now, in December 1945, Saha led a five-member Committee (which included the Indian Director General of Observatories) to Kodaikanal so that they could prepare a plan for 'Astronomical and astrophysical observatories in India'. The Saha Committee proposed updating existing astronomical facilities, and as a part of a long-range plan, "… the establishment in Northern India of an astronomical observatory provided with a large sized telescope for special stellar work."

The year 1945 also saw the establishment of the Tata Institute of Fundamental Research at Bombay. Its founder was Homi Jahangir Bhabha (1909–1966), a brilliant physicist who shared Jawaharlal Nehru's vision of a scientific India, as well as Nehru's aristocratic background. Additionally, he was related to the wealthy and enlightened Tata Family of industrialists (in 1898 Sir Dorab Tata had married Bhabha's paternal aunt, Meharbai). An important item on Tata Institute's agenda was experimental research on cosmic rays, in which Bhabha was personally interested, and the associated scientific ballooning, in the course of time, led to the advent of space astronomies in India.

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References

Airy, G.B. (1854). Address by the President, G.B. Airy, Esq., F.R.S., Astronomer Royal, on presenting the Gold Medal of the Society to Mr. Charles Rumker. *Monthly Notices of the Royal Astronomical Society, 14,* 142–147.

Alli, P.U. (1874). *The Lucknow Album. Containing a Series of Fifty Photographic Views of Lucknow and its Environs Together with a Large Sized Plan of the City*. Calcutta: Printed by G.H. Rouse, Baptist Mission Press.

Ansari, S.M.R. (1977). On the early development of Western astronomy in India and the role of the Royal Greenwich Observatory. *Archives Internationales d'Histoire des Sciences, 27,* 237–262.

Ansari, S.M.R. (1985). Introduction of modern Western astronomy in Indian during 18th–19th centuries. *Indian Journal of History of Science, 20*, 363–402.

Ansari, S.M.R. (2000). Introduction of modern Western astronomy in India during 18th–19th centuries. In S.N. Sen, & K.S. Shukla (Eds.), *History of Astronomy in India* (pp. 395–453). New Delhi: Indian National Science Academy.

Ansari, S.M.R. (2011). Early modern observatories in India, 1792–1900. In U. Das Gupta (Ed.), *History of Science, Philosophy and Culture in Indian Civilization. Volume XV, Part 4. Science and Modern India: An Institutional History, c.1784–1947* (pp. 349–379). Delhi: Pearson Longman.

Appleton, J., Goward, K., & Barton, B. (2016). Herbert Gerard Tomkins (1869–1934). Orwell Astronomical Society (Ipswich) web site (www.oasi.org.uk/HGT/HGT.php).

Baugh, D. (2011). *The Global Seven Years War, 1754–1763: Britain and France in a Great Power Contest*. Abingdon: Taylor Francis.

Baum, R. (2014a). Baxendall, Joseph. In T. Hockey et al., pp. 177–179.

Baum, R. (2014b). Common, Andrew Anslie. In T. Hockey et al., pp. 447–449.

Bigg-Wither, A.C. (1883). Observation of the transit of Venus, 1874, December 8–9, as observed at Mooltan, Punjab, India. *Memoirs of the Royal Astronomical Society, 47,* 97–99.

Biswas, A.K. (1994). Reverend Father Eugene Lafont and the scientific activity of St. Xavier's College. *Indian Journal of History of Science, 29,* 77–88.

Biswas, A.K. (ed.) (2003). *Collected Works of Mahendralal Sircar, Eugene Lafont and the Science Movement (1860–1910)*. Kolkata: The Asiatic Society.

Bònoli, F. (2014). Respighi, Lorenzo. In T. Hockey et al., pp. 1818–1820.

Broun, J.A. (1857). *Report on the Observatories of His Highness the Rajah of Travancore*. Trevandrum: Sircar Press.

Brück, H.A., & Brück, M.T. (1988). T*he Peripatetic Astronomer: The Life of Charles Piazzi Smyth*. Bristol: Adam Hilger.

Brück, M.T. (2014). Huggins, William. In T. Hockey et al., pp. 1026–1027.

Caldecott, J. (1837a). Description of an Observatory lately established at Trevandrum, by His Highness the Rajah of Travancore. *The Madras Journal of Literature and Science, 6,* 56–60.

Caldecott, J. (1837b). Horary meteorological observations made at the equinoxes and solstices, agreeably with the suggestion of Sir John Herschel. 1. At the Trevandrum Observatory. *The Madras Journal of Literature and Science, 6,* 339–340.

Cawood, J., 1977. Terrestrial magnetism and the development of international collaboration in the early nineteenth century. *Annals of Science*, 34, 551–587.

Chinnici, I. (1995/96). An "Italian" observatory in Calcutta: the history of the Calcutta Observatory. *Studies in History of Medicine and Science, 16,* 91–115.

Christie, S.H., & Airy, G.B. (1837). Report upon a letter addressed by M. Le Baron de Humboldt to His Royal Highness the President of the Royal Society, and communicated by His Royal Highness to the Council. *The Madras Journal of Literature and Science, 6,* 224–236.

Clerke, A. (1903a). *Problems in Astrophysics*. London: Adam and Charles Black.

Clerke, A. (1903b). *The System of the Stars*. London: Longmans, Green, & Co.

Dalrymple, A. (1793). *Oriental Repertory. Volume 1*. London: G. Biggs.

DeVorkin, D.H. (1993). Saha's influence in the West: a preliminary account. In S.B. Karmohapatro (Ed.), *Meghnad Saha Birth Centenary Commemoration Volume* (pp. 154–202). Calcutta: Saha Institute of Nuclear Physics.

DeVorkin, D.H. (1994). Quantum physics and the stars (IV): Meghnad Saha's fate. *Journal for the History of Astronomy, 25,* 156–188.

DeVorkin, D.H. (1996). The development of Meghnad Saha's ionization equilibrium theory and its reception in the West. In B. Sinha, & M. Bhattacharya (Eds.), *From Astronomy to Astrophysics. Proceedings of a Symposium on Astronomy and Astrophysics* (pp. 3–34). Calcutta: Saha Institute of Nuclear Physics.

Dewhirst, D.W. (2014). Christie, William Henry Mahony. In T. Hockey et al., pp. 422–424.

Dick, S., Orchiston, W., & Love, T. (1998). Simon Newcomb, William Harkness and the nineteenth-century American transit of Venus expeditions. *Journal for the History of Astronomy, 29,* 221–255.

Dreyer, J.L.E., (1892). Obituary: Norman R. Pogson. *Monthly Notices of the Royal Astronomical Society, 52,* 235–238.

Edney, M.H. (1997). *Mapping an Empire: The Geographical Construction of British India, 1765–1843*. Chicago: University of Chicago Press.

Espenak, F., & Meeus, J. (2006). *Five Millennium Canon of Solar Eclipses: −1999 to +3000*. Greenbelt: NASA (Technical Publication TP-2006-214141).

Evans, D.S. (1988). *Under Capricorn: A History of Southern Hemisphere Astronomy*. Bristol: Adam Hilger.

Francis, W. (1915). *Vizagapatam*. Madras: Government Press.

Gariboldi, L. (2014). Tacchini, Pietro. In T. Hockey et al., pp. 2120–2122.

Glass, I.S. (1997). *Victorian Telescope Makers: The Lives and Letters of Thomas and Howard Grubb*. Bristol: Institute of Physics.

Goodwin, G. (1891). Hirst, William. In *Dictionary of National Biography, Volume 27*. London: Smith, Elder & Co.

Hadyar, K. (1896). *History of Oudh. Volume II. Second Edition*. Lucknow: Navil Kishore Press (in Urdu).

Hagen, J.G. (1898). Note on Pogson's manuscripts, relating to his proposed *Atlas of Variable Stars. Monthly Notices of the Royal Astronomical Society, 59,* 57–61.

Haig, C.T. (1869). Account of spectroscopic observations of the eclipse of the Sun, August 18, 1868. *Proceedings of the Royal Society of London, 17,* 74–80.

Hearnshaw, J. (2014). Newall, Hugh Frank. In T. Hockey et al., pp. 1561–1563.

Hennessey, J.B.N. (1874–1875). Some particulars of the transit of Venus across the Sun, December 9, 1874, observed on the Himalaya Mountains Mussourie, at Mary-Villa. Note II, with Appendix. *Proceedings of the Royal Society of London, 23,* 379–384.

Hennessey, J.B.N. (1879). Further particulars of the transit of Venus across the Sun, December 9, 1874; observed on the Himalaya Mountains, Mussourie, at Mary-Villa Station, Lat. 30° 28′ N., Long. 78° 3′ E., height above sea 6,765 feet, with the Royal Society's 5-inch Equatorial. Note III. *Proceedings of the Royal Society of London, 29,* 297–302.

Herschel, J. (1869). Account of the solar eclipse of 1868, as seen at Jamkandi, in the Bombay Presidency. *Proceedings of the Royal Society, 17,* 104–120.

Hirst, W. The Rev. (1761–1762). An account of an observation of the transit of Venus over the Sun, on the 6th of June 1861, at Madrass … *Philosophical Transactions of the Royal Society, 52,* 396–398.

Hockey, T. et al. (Eds.), (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Hollis, H.P. (1910). J.B.N. Hennessey. *The Observatory, 33,* 315–316.

Hollis, H.P. (1916). Obituary Notices. Lieutenant-General James Francis Tennant. *Monthly Notices of the Royal Astronomical Society, 76,* 272–276.

Hogg, H.S., (1951). Le Gentil and the transits of Venus, 1761 and 1769. *Journal of the Royal Astronomical Society of Canada, 45,* 37–44; 89–92; 127–134; 173–178.

Howse, D., & Hutchinson, B. (1769). The saga of the Shelton clocks. In D. Howse, & B. Hutchinson (Eds.), *The Clocks and Watches of Captain James Cook 1769–1969* (pp. 281–299). London: The Antiquarian Horological Society.

Hughes, S. (2013). *Catchers of the Light. The Forgotten Lives of the Men and Women Who First Photographed the Heavens. Two Volumes*. Paphos: ArtDeCiel Publishing.

India meteorology. *Nature, 28,* 428–430 (1883).

Jacob, W.S. (1843). Description of a small observatory at Poona. *Monthly Notices of the Royal Astronomical Society, 6,* 1.

Jacob, W.S. (1853). Remarks on Saturn as seen with the Madras Equatoreal (by Lerebours and Secretan; focus, 89 in., aperture, 6.2 in.). *Monthly Notices of the Royal Astronomical Society, 13,* 240–241.

Jacob, W.S. (1859). Letter to R.C. Carrrington, Royal Astronomical Society. In RAS Papers 49.

Janssen, J. (1869). Spectroscopic observations made during the eclipse of 18 August 1868, and a method of observing prominences outside of an eclipse. *Comptes Rendus de l'Académie des Sciences, 68,* 367–376 (in French).

Janssen, J. (1873). An account relating to the observation of the eclipse of 12 December 1871 … *Journal Officiel de la République Française, Jan. 16,* 312–313; *Jan. 19,* 392–394; *Jan. 20,* 408–409 (in French).

John Caldecott (n.d.). Wikipedia entry (en.wikipedia.org/wiki/John_Caldecott).

Jones, N. (1967). Norman Pogson and the definition of stellar magnitude. *Astronomical Society of the Pacific Leaflet, 469,* 145–152.

Juggarow, G.V. (1835). Astronomical tables and observations. *The Madras Journal of Literature and Science, 2,* 92–95.

Kameshwar, C.W. (Ed.), (1997*). Chandrsekhar: The Man Behind the Legend. Chandra Remembered*. London: Imperial College Press.

Kameswara Rao, N., Vagiswari, A., & Louis, C. (1984). Father J. Richaud and early telescope observations in India. *Bulletin of the Astronomical Society of India, 12,* 81–85.

Kameswara Rao, N., Birdie, C., & Vagiswari, A. (2014). Bhavnagar Telescope: the most widely travelled telescope in the country. *Current Science, 106,* 618–620.

Kameswara Rao, N., Vagiswari, A., & Birdie, C. (2011). Early pioneers of telescopic astronomy in India: G.V. Jugga Rao and his observatory. *Current Science, 100,* 1575–1581.

Kameswara Rao, N., Vagiswari, A., Thakur, P., & Birdie, C. (2009). Ragoonatha Charry and variable star astronomy. *Journal of Astronomical History and Heritage, 12,* 201–210.

Kapoor, R.C. (2011). Madras Observatory and the discovery of C/1831 A1 (The Great Comet of 1831). *Journal of Astronomical History and Heritage, 14,* 93–102.

Kapoor, R.C (2013). Indian astronomy and the transits of Venus. 1: the early observations. *Journal of Astronomical History and Heritage, 16,* 269–286.

Kapoor, R.C. (2014). Indian astronomy and the transits of Venus. 2: the 1874 event. *Journal of Astronomical History and Heritage, 17,* 113–135.

Kapoor, R.C. (2015). Abū'l Faẓl, independent discoverer of the Great Comet of 1577. *Journal of Astronomical History and Heritage, 18,* 249–260.

Kapoor, R. (2016). Nūr ud-Dīn Jahāngīr and Father Kirwitzer: the independent discovery of the Great Comets of November 1618 and the first astronomical use of the telescope in India. *Journal of Astronomical History and Heritage, 19,* 264–297.

Keay, J. (2000). *The Great Arc*: *The Dramatic Tale of How India was Mapped and Everest was Named*. London: Harper Collins.

Keay, J. (2010). *The Honourable Company: A History of the English East India Company*. London: Harper Collins.

King, H.C. (1979). *The History of the Telescope*. New York: Dover.

Kochhar, R.K. (1985a). Madras Observatory: the beginning. *Bulletin of the Astronomical Society of India, 13,* 162–168.

Kochhar, R.K. (1985b). Madras Observatory – buildings and instruments. *Bulletin of the Astronomical Society of India, 13,* 287–302.

Kochhar, R.K. (1987). The Shelton clock at Kodaikanal. *Antiquarian Horology, 17,* 181–184.

Kochhar, R.K. (1989). Transit of Mercury 1651: the earliest telescopic observation in India. *Indian Journal of History of Science, 24,* 186–192.

Kochhar, R.K. (1991a). Astronomy in British India: science in the service of the state. *Current Science, 60,* 120–129.

Kochhar, R.K. (1991b). French astronomers in India during 17–19 centuries. *Journal of the British Astronomical Association, 101*, 95–100.

Kochhar, R.K. (1991c). Growth of modern astronomy in India 1651–1960. *Vistas in Astronomy, 34,* 69–105.

Kochhar, R.K. (1993). Historical perspective. In R.K. Kochhar, & J. Narlikar (Eds.), *Astronomy in India: Past, Present and Future* (pp. 1–42). Pune; IUCAA.

Kochhar, R. (2009). Kodaikanal Observatory. In G. Wolfschmidt (Ed.), *Cultural Heritage of Astronomical Observatories; Proceedings of International ICOMOS Symposium, Hamburg* (pp. 255–260). Berlin: Hendrik Balker Verlag.

Kochhar, R. (2011). William Petrie (d.1816), Madras civil servant 1765-1812 and Governor, Penang 1812-1816. Blog (rajeshkochhar.com/william-petrie-d1816madras-civil-servant-1765-1812-and-governorpenang-1812-1816/)

Kochhar, R., & Narlikar, J. (1995). *Astronomy in India*. New Delhi: Indian National Science Academy.

Kothari, D.S. (1959). Meghnad Saha. *Biographical Memoirs of the Fellows of the Royal Society, 5,* 217–236.

Launay, F. (2012). *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics.* New York: Springer.

Lawson, P. (1993). *The East India Company: A History*. London: Longman.

Lethbridge, R. (1893). *The Golden Book of India*. London: Macmillan.

Literary Gazette, p. 705 (1840).

Lockyer, N. (1874). *Contributions in Solar Physics.* London: Macmillan.

Lockyer, N. (1898). Report on Indian Observatories and their Organisation. Printed report dated 15 May.

Love, H.D. (1913). *Vestiges of Old Madras, 1640–1800. Volume II*. London: John Murray.

McConnell, A. (n.d.). Taylor, Thomas Glanville (1804–1848). *Oxford Dictionary of National Biography* (online ed.). Oxford: Oxford University Press. doi:10.1093/ref:odnb/27089.

McConnell, A. (1992). *Instrument Makers to the World: History of Cooke, Troughton and Simms*. York: William Sessions.

McConnell, A. (2004). Broun, John Allan (1817–1879). In *Oxford Dictionary of National Biography*. Oxford: Oxford University Press.

Macpherson, H. (1905). *Astronomers of Today*. London: Gall & Inglis.

Malin, S.R.C., & Barraclough, D.R. (1991). Humboldt and the Earth's magnetic field. *Quarterly Journal of the Royal Astronomical Society, 32,* 279–293.

Markham, C.R. (1878). *A Memoir of the Indian Surveys. Second Edition*. London: W.H. Allen & Co.

Markham, C.R. (1896). Obituary: General James Thomas Walker, R.E., C.B., F.R.S. *The Geographical Journal, 7,* 320–323.

Marston, D. (2001). *The Seven Years' War*. Essential Histories. Oxford: Osprey.

Menon, P.S. (1878). *History of Travancore from the Earliest Times.* Madras: Higginbothams and Co.

Mumpuni, E.S., Orchiston W., & Steinicke, W. (2017). J.A.C. Oudemans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In T. Nakamura, & W. Orchiston.

Naegamvala, K.D. (1891). On the character of the chief line of the nebula in Orion. *Monthly Notices of the Royal Astronomical Society, 51,* 442–443.

Naegamvala, K.D. (1902). *Report on the Total Solar Eclipse of January 21–22 1898, as Observed at Jeur in Western India*. Bombay: Government Central Press.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Narlikar, J.M. (2003). *The Indian Scientist from Vedic to Modern Times: The Scientific Edge*. Harmondsworth: Penguin.

Nath, B.B. (2013). *The Story of Helium and the Birth of Astrophysics*. New York: Springer.

Nature, 78, 35 (1908).

Newcomb, S. (1895). *The Elements of the Four Inner Planets and the Fundamental Constants of Astronomy*. Washington: Government Printing Office.

Nursing Row, A.V. (1875). Observation of the transit of Venus at Vizagapatam. *Monthly Notices of the Royal Astronomical Society, 29,* 278.

Obituary: Capt. William Stephen Jacob. *Monthly Notices of the Royal Astronomical Society, 23,* 127–128 (1863).

Obituary: Richard Christopher Carrington. *Monthly Notices of the Royal Astronomical Society, 36,* 137–142 (1876).

Obituary: Chintamanny Ragoonatha Chary. *Monthly Notices of the Royal Astronomical Society, 41,* 180–183 (1881).

Obituary: Dr Friedrich Tietjen. *The Observatory, 18,* 308–309 (1895).

Obituary: Lieut.-General James Francis Tennant. *Journal of the British Astronomical Association, 25,* 240 (1915).

Obituary: Robert John Pocock. *Monthly Notices of the Royal Astronomical Society, 79,* 230–231 (1919).

Obituary: Professor Charles Michie Smith. *Monthly Notices of the Royal Astronomical Society, 83,* 245–246 (1923).

Orchiston, W. (1997). The 'tyranny of distance' and Antipodean cometary astronomy. *Australian Journal of Astronomy, 5,* 115–126.

Orchiston, W. (2005). James Cook's transit of Venus expedition to Tahiti. In D.W. Kurtz (Ed.), *Transits of Venus: New Views of the Solar System and the Galaxy* (pp. 52–66). Cambridge: Cambridge University Press.

Orchiston, W. (2016). *Exploring the History of New Zealand Astronomy: Trials, Tribulations, Telescopes and Transits*. Cham: Springer.

Orchiston, W., & Orchiston, D.L. (2017). King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-koa, Siam. In T. Nakamura, & W. Orchiston.

Orchiston, W., and Pearson, J. (2017). American observations of the 22 January 1898 total solar eclipse from Jeur, India. In T. Nakamura, & W. Orchiston.

Orchiston, W., Lee, E-H., and Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In T. Nakamura, & W. Orchiston.

Phillimore, R.H. (1945–1968). *Historical Records of Survey of India. Five Volumes*. Dehra Dun: Survey of India. [1945: *Volume I*; 1950: *Volume 2*; 1954: *Volume III*; 1955: *Volume IV*; 1968: *Volume V*.]

Pigatto, L., & Zanini, V. (2001). Spectroscopic observations of the 1874 transit of Venus: the Italian party at Muddapur, eastern India. *Journal of Astronomical History and Heritage, 4,* 43–58.

Pogson, N.R. (n.d.). *Report of the Government Astronomer upon the Proceedings of the Observatory, in Connexion with the Total Eclipse of the Sun on August 18th, 1868, as Observed at Masulipatam, Vunpurthy, Madras, and other Stations in Southern India*. IOR V/27/430/8, BL.

Pogson, N.R. (1861). Discovery and observations of a new planet (Asia). *Astronomische Nachrichten, 55,* 283–286.

Pogson, N.R. (1874). Administration Report of the Madras Observatory for the year 1874 (Indian Institute of Astrophysics Archives).

Pogson, N.R. (1887). *Madras Meridian Circle Observations in 1862–4*. Madras: Government of Madras.

Prinsep, C.C. (1885). *Record of Services of the Honourable East India Company's Civil Servants in the Madras Presidency, from 1741 to 1858*. London: Trübner.

Proceedings of the Asiatic Society of Bengal January to December 1874, Calcutta, Baptist Mission Press (1875). (Internet Archives: https://archive.org).

Proudfoot, W.J. (1868). *Biographical Memoir of James Dinwiddie, LL.D., Astronomer in the British Embassy to China* … Liverpool, Edward Howell.

Ragoonatha Chary, C. (2012). *Transit of Venus*. Bangalore: Indian Institute of Astrophysics Archives (reprint of the 1874 original).

Ramani, M. (2010). The Jugga Rao Observatory. The History of Vizag (http://heavydutytravel.blogspot.com/2010/01/jugga-rao-observatory.html)

Rambaut, A.A. (1901). Dr. Downing's revision of Taylor's Madras Catalogue and the policy of reducing old observations. *The Observatory, 24,* 453–458.

Ranyard, A.C. (1879). The solar corona. *Memoirs of the Royal Astronomical Society, XLI,* 1–791.

Ratcliff, J. (2008). *The Transit of Venus Enterprise in Victorian Britain*. London: Pickering & Chatto.

Ratcliff, J. (2016). Travancore's magnetic crusade: geomagnetism and the geography of scientific production in a princely state. *The British Journal for the History of Science, 49,* 325–352. doi:10.1017/S0007087416000340.

Reddy, V., Snedegar, K., & Balasubramanian, R.K. (2007). Scaling the magnitude: the rise and fall of N.R. Pogson. *Journal of the British Astronomical Association, 117,* 237–245.

Report of the Committee of Solar Physics. London: H.M. Stationary Office (1882).

Report on the 10th Meeting of the British Association for the Advancement of Science (pp. 28–31). Glasgow: BAAS (1841).

Results of Meteorological Observations, G.V. Juggarow Observatory. Vizagapatam: General Committee (1894).

Schaffer, S. (2012). The Bombay case: astronomers, instrument makers and the East India Company. *Journal for the History of Astronomy, 43,* 151–180.

Sen, S.N. (1989). Madras meridian circle observations of fixed stars during 1862 to 1887. *Indian Journal of History of Science, 24,* 257–283.

Shy, J. (2002). Early astronomy in America: the role of the College of William and Mary. *Journal of Astronomical History and Heritage, 5,* 41–64.

Shylaja, B.S. (2006). John Herschel's astronomical observations from Bangalore. *Current Science, 90,* 259–260.

Shylaja, B.S. (2012). *Chintamani Ragoonatha Charry and Contemporary Indian Astronomy,* Bangalore: Bangalore Association for Science Education and Navakarnataka Publications Private Limited.

Strahan, C. (1903). The Survey of India. *Professional Papers of the Corps of Royal Engineers, 28,* 141–171.

Stratton, F.J.M. (1957). John Evershed. *Biographical Memoirs of Fellows of the Royal Society, 3,* 41–51.

Taylor, T.G. (1832b). *Madras Astronomical Observations, Vol. 1 (for 1831)*. Madras, Madras Observatory.

Taylor, T.G. (1832a). Observations of the comet of January 1831. In *Results of Astronomical Observations made at the Honourable The East India Company's Observatory of Madras. Vol. 1. For the Year 1831* (pp. 95–100). Madras: Madras Observatory.

Taylor, T.G. (1836). Observations respecting Halley's Comet. *The Madras Journal of Literature and Science, 3,* 59–62.

Taylor, T.G. (1844). *A General Catalogue of the Principal Fixed stars from Observations made at the Honourable The East India Company's Observatory at Madras in the Years 1830–1843. Volume 6*. Madras: Madras Observatory.

Taylor, T.G. (1848). *Madras Astronomical Observations. Volume 7 (for 1843–47)*. Madras: Madras Observatory.

Taylor, T.G., & Caldecott, J. (1839). Observations on the direction and intensity of the terrestrial magnetic force in southern India. *Madras Journal of Literature and Science, 9,* 221–273.

Tennant, J.F. (1869). Report on the total eclipse of the Sun, August 17–18, 1868 … *Memoirs of the Royal Astronomical Society, 37,* 1–55.

Tennant, J.F. (1875a). Letter dated Roorkee, December 11, 1874. *Monthly Notices of the Royal Astronomical Society, 35,* 209–210.

Tennant, J.F. (1875b). On the dimensions of Venus as determined during the recent transit. *Monthly Notices of the Royal Astronomical Society, 35,* 345–347.

Tennant, J.F. (1875c). Report of observations of the total eclipse of the Sun on December 11–12, 1871, made by order of the Government of India, at Dodabetta, near Ootacamund. *Memoirs of the Royal Astronomical Society, 42,* 1–33.

Tennant, J.F. (1877). *Report on the Preparations for, and Observations of the Transit of Venus, as Seen at Roorkee and Lahore, on December 8, 1874*. Calcutta: Office of the Superintendent of Government Printing.

Tennant, J.F. (1882). An examination of the Roorkee observations of the transit of Venus, 1874, December 8. *Monthly Notices of the Royal Astronomical Society, 42,* 352–355.

Topping, M. (1792). Description of an Astronomical Observatory erected at Madras in 1792 by Order of the East India Company, Madras, 24th December 1792. MS, Royal Greenwich Observatory Archives, Cambridge.

Trudel, J.-L. (2014). Newcomb, Simon. In T. Hockey et al., pp. 1563–1565.

Tupman, G.L. (1878). On the mean solar parallax as derived from the observations of the transit of Venus, 1874. *Monthly Notices of the Royal Astronomical Society, 38,* 429–456.

Turner, H.H. (1912). *The Great Star Map. Being a General Account of the International Project Known as the Astrographic Chart*. London: Murray.

Udias, A. (2003). *Searching the Earth and the Sky. The History of Jesuit Observatories*. Dordrecht: Kluwer.

Vadivelu, A. (1903). *The Aristocracy of Southern India*. Madras, Vesy and Com.

Venkataraman, G. (1988). *Journey into Light: Life and Science of C.V. Raman*. Oxford: Oxford University Press.

Vierteljahresschrift der Astronomischen Gesellschaft, 30, 205 (1895).

Walding, R. (n.d.). John Caldecott FRS (indicatorloops.com/Caldecott.htm).

Walsh, G.A. (2014). Keeler, James Edward. In T. Hockey et al., pp. 1169–1172.

Warren, J. (1830). Biographical sketch of the late Col. Lambton, Superintendent of the Trigonometrical Survey of India. *Gleanings in Science, 15,* 73–82.

Wulf, A. (2015). *The Invention of Nature: How Alexander Von Humboldt Revolutionized Our World*. London: Hodder and Stoughton.

Chapter 25
British Observations of the 18 August 1868 Total Solar Eclipse from Guntoor, India

Wayne Orchiston, Eun-Hee Lee, and Young-Sook Ahn

25.1 Introduction

During the nineteenth century—before the invention of the spectrohelioscope and coronagraph—total solar eclipses provided an important means of studying the chromosphere and its prominences, and the enigmatic corona. While an association of the chromosphere with the Sun was accepted by most astronomers, the true nature of prominences and the corona was under intense debate. Some saw both as solar phenomena, while to others they were a feature of the Earth's upper atmosphere or were connected with the postulated atmosphere of the Moon. During the second half of the nineteenth century, two new research tools came to the aid of astronomy, and both were applied, with excellent effect, to solar eclipses. They were astronomical photography and astronomical spectroscopy, those hand-maidens of the emerging 'new astronomy', astrophysics (see Clerke 1893). Astronomical photography offered a permanent record, and took the onus away from that remarkably unreliable photon discriminator, the human eye (Lankford 1984), while astronomical spectroscopy probed the elemental composition of the solar atmosphere to reveal its secrets (Lockyer 1887; Meadows 1970).

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Consequently, solar eclipse expeditions were an important element of professional and amateur astronomy at this time. The first such expedition mounted by the Royal Astronomical Society was to Spain to observe the eclipse of 28 July 1851. This began a pattern whereby the Society or leading members of it, mounted eclipse expeditions to geographically accessible sites, so long as these were not embroiled in political instability that would pose a security threat to expedition members. One such expedition, to India in 1868, is the subject of this study, and was chosen because of the special place of this particular eclipse in astronomical history:

> In the year 1868 *the history of eclipse spectroscopy virtually began* … On the 18th of August 1868, the Indian and Malayan peninsulas were traversed by a lunar shadow producing total obscuration during five minutes and thirty-eight seconds. Two English and two French expeditions were dispatched to the distant regions favoured by an event so propitious to the advance of knowledge, chiefly to obtain the verdict of the prism as to the composition of prominences. (Clerke 1893: 209; our italics).

25.2 The 1868 Eclipse

The path of totality of this eclipse extended from Aden in the Arabian Peninsula, across India, Thailand (or Siam, as it was known in 1868), Borneo, Sulawesi (then known as the Celebes), the well-known Indonesian Spice Islands of Ambon and Ceram, through the extreme southern part of New Guinea and on to islands in the New Hebrides. The map for this eclipse is shown in Fig. 25.1. Sunset took place at those localities within the right hand ellipse, so the end of the eclipse was not visible; conversely, the start of the eclipse could not be observed from places within the left hand ellipse, for the eclipse was already in progress there at sunrise. Meanwhile, the dashed lines to the north and south of the path of totality indicate maximum eclipse magnitudes of 80, 60, 40 and 20%.

Weiss (1867: 307) reported that the maximum duration of totality "… takes place in the Gulf of Siam where it reaches on the central line 6 min 50 s …", an unusually long interval for a total solar eclipse. This chapter (cf. Orchiston et al., 2006) discusses the Royal Astronomical Society's expedition to Guntoor in India, where totality lasted 5 min 45 s (Tennant 1869: 46). Guntoor and other Indian Subcontinent localities mentioned in the text are indicated in Fig. 25.2.

25.2.1 Preparations for the Eclipse

In a letter dated 2 January 1866 and published subsequently in *Monthly Notices of the Royal Astronomical Society*, Major J.F. Tennant drew the attention of the RAS Council to the up-coming 1868, total solar eclipse, and suggested an expedition should be mounted to observe the event from what is now known as Machilipatam:

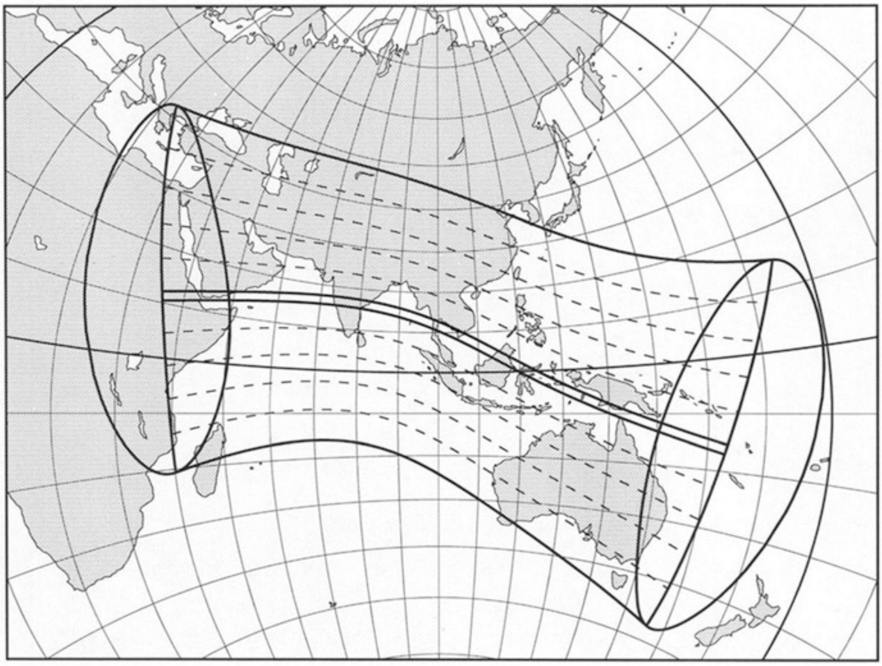


Fig. 25.1 Map for the 17/18 August 1868 eclipse (*Courtesy* Jan Meeus and Salvo de Meis)

> Mr. Pogson [at Madras Observatory] will doubtless do his part, but Masulipatam is readily accessible from both Calcutta and Madras by steamer, and is itself a port at which they call. It will be quite in the power of the Government, if so disposed, to collect at that place a corps of practiced observers; and even if they will not do this, I have little doubt that, if their officers are permitted to go, there will be some (probably enough) observers who would form a party for the occasion …
>
> The season is favourable, being a time when the officers of the Indian [Trigonometrical] Survey will be in quarters, and when they could be best spared. (Tennant 1867a: 79).

Tennant followed up with a longer communication, where he provided details of the eclipse and advocated that the Society organize two expeditions,

> One to be stationed near the sea in the neighbourhood of Masulipatam and Guntoor in such position as may be found best, and the second inland on the central line about 60 miles south of Hyderabad. One or other of these parties would, I think, be certain to obtain observations … (Tennant 1867b: 175–176).

The Society responded by appointing Tennant as leader of one of the expeditions. Meanwhile, the Astronomer Royal (George Airy) arranged to provide two telescopes from the Royal Observatory, and submitted a successful request to the Secretary of State for India for funds to purchase other necessary instruments. In the end, expenses would be shared by the British Government and the Government of India (Tennant 1869: 1).

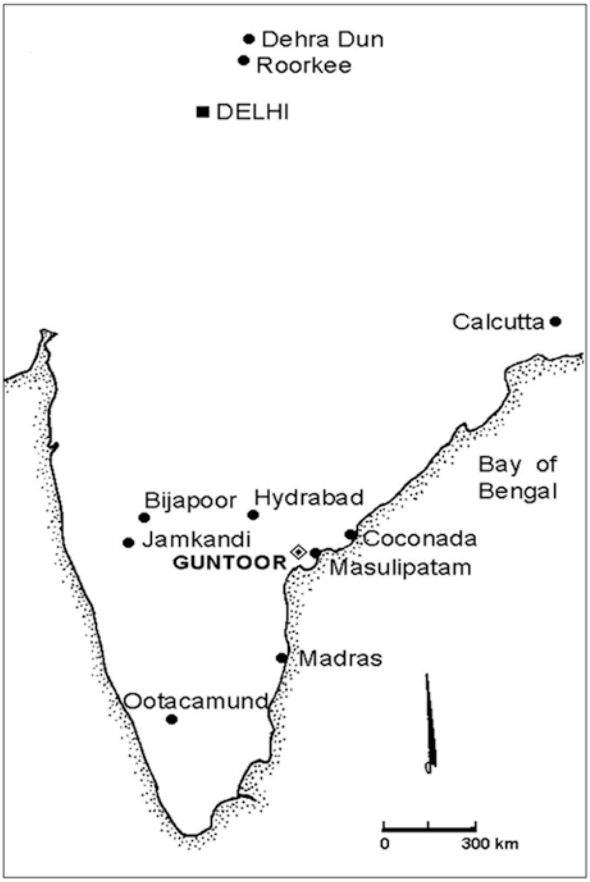


Fig. 25.2 Map showing Guntoor, and other Indian localities mentioned in the text (*Map* Wayne Orchiston) (Although some of the place names were changed during the twentieth century, the nineteenth century spellings have been retained for this map)

Those who eventually joined Tennant in the observing team were Captain Branfill from the Indian Trigonometrical Survey, Sergeant Henry Phillips from the Royal Engineers, Mr. W.F. Grahame from the Madras Civil Service, Major Hearn from the Madras Police (who happened to be passing through Guntoor at the time of the eclipse), Mr. Wilson (the Sub-collector of Guntoor, on whose property the expedition was based), and two sappers. James Francis Tennant was born in England in 1829, and was in an excellent position to negotiate such secondments given his Indian connections. As an engineering officer he first served in the Indian Mutiny, and then joined the Indian Survey and was involved in the trigonometrical survey of India—which is how he developed a catholic taste for astronomy. In 1859–1860, he also served for a year as Director of Madras Observatory. Apart from the 1868 eclipse expedition, he led two other Indian-based British expeditions, to observe the 1871

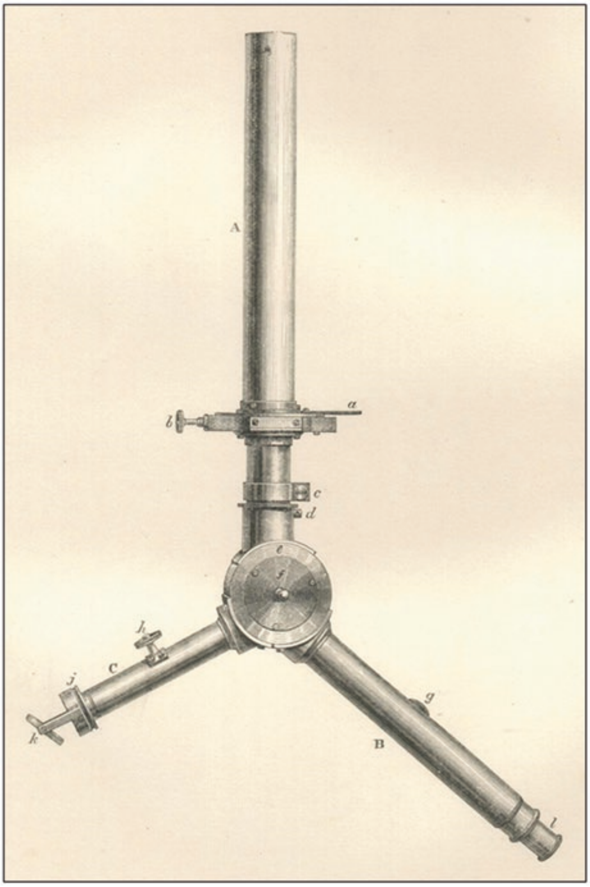


Fig. 25.3 The spectroscope (Key: *A* = the tube passing into the telescope, *B* = small telescope for viewing the spectrum, *C* = collimator for showing the scale, *a* = the handle, used to adjust the length of the slit, *b* = the screw, used to adjust the width of the slit, *c* = a capstan-headed screw, used for clamping the instrument, *d* = small screw which must be taken out before the collimating lens is removed, *e* = cylindrical drum containing the prism, *f* = plate to which the prism is attached, *g* = milled head used to focus the small telescope, *h* = milled head used to make the scale visible, *j* = cell containing the scale, *k* = mirror that reflects light along *C*, *l* = telescope eyepiece) (after Tennant 1869: 53, 55)

total solar eclipse and the 1874 transit of Venus. After leaving the Indian Survey he became Master of the Mint in Calcutta, a position he retired from in 1884. He then returned to England, where he maintained his astronomical interests. A Fellow of the Royal Society from 1869, Tennant served as President of the Royal Astronomical Society from 1890 to 1892. He died in 1915 (Kochhar 1991: 83; Obituary 1915a, b).

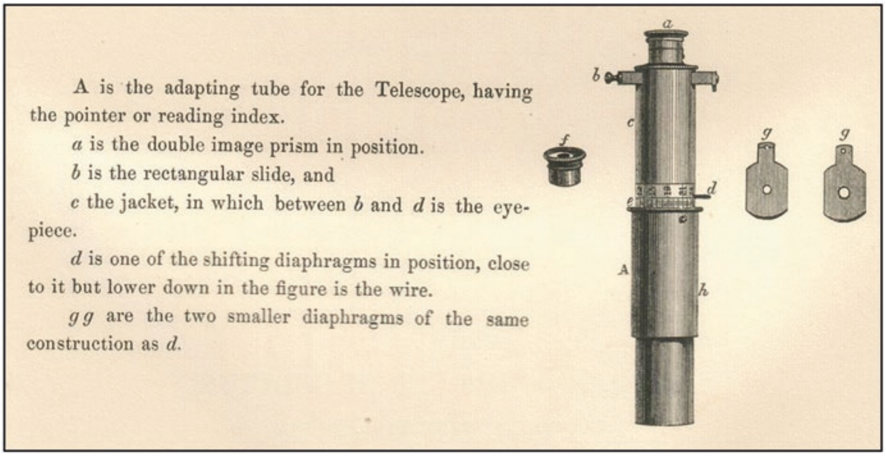
In planning the expedition, a decision was made to conduct visual, spectroscopic, polarization and photographic observations during the eclipse. This was an ambitious program and demanded suitable and reliable instruments. These are now described.

The spectroscopic observations were conducted with the Troughton and Simms spectroscope shown in Fig. 25.3, which was attached to The Royal Astronomical Society's Sheepshanks' Telescope No. 3. This was an 4.6-in. (11.7-cm) aperture f/13 refractor, mounted equatorially by Cooke. To examine the solar spectrum in the absence of a comparison spectrum

> … a scale of equal parts was reduced by photography to a small size. This was illuminated by a swinging lamp, and the rays from it having been rendered parallel by an object-glass, were reflected from the surface of the prism up the small telescope (see Fig. 25.3). They thus became visible at the same time as the spectrum. An arrangement was also provided … so that the length of the slit and breadth of the spectrum could be adjusted with the touch of a finger … (Tennant 1869: 15).

Used for the polarization observations was a 3.75-in. (9.5-cm) f/16 refractor loaned by the Royal Observatory. This instrument had originally served as one of the old collimators of the Greenwich Transit Circle, and was fitted with an equatorial mounting manufactured for the eclipse expedition by Simms. The 'polariscope' comprised a Ramsden eyepiece made by a Mr. Ladd but specially adapted for the eclipse expedition by Mr. Simms. Details of its design are shown in Fig. 25.4, and Tennant (1869: 22) describes how it

> … was of RAMSDEN'S construction, having a positive focus, and was contained inside an outer jacket into which it slipped till a wire came into focus; close to this wire was an opening in the jacket, through which perforated plates (similar to the WATERHOUSE diaphragms of photographic lenses) could be inserted in order to limit the field of view. Inclosing the whole eye-piece, and passing beyond it, the jacket carried at the eye-end a small piece of tube, into which fitted two cells carrying the prisms; between these prisms and the lens nearest to it, there traversed backwards and forwards a right-angled prism of ebony, having in it two holes, one plain, the other carrying the compound quartz plate of a SAVART'S polariscope. In one of the prism cells is a NICOL'S prism, in the other a Double-image prism and quartz plate … There were thus four combinations of the slide and



A is the adapting tube for the Telescope, having the pointer or reading index.

a is the double image prism in position.

b is the rectangular slide, and

c the jacket, in which between *b* and *d* is the eye-piece.

d is one of the shifting diaphragms in position, close to it but lower down in the figure is the wire.

gg are the two smaller diaphragms of the same construction as *d*.

Fig. 25.4 The 'polariscope' (after Tennant 1869: 55)

> prisms, which could be readily changed one for another, and which showed the existence of polarized light by differing phenomena … If polarized light is absent then the phenomena are so too.

A 9-in. (22.9-cm) clear aperture f/8 Newtonian reflector was chosen for the photography, with the camera positioned at the eyepiece assembly. Tennant (1867c: 324) relates that

> Unfortunately there have been very great and unavoidable delays with this instrument. The low latitude [16° 18′ N] in which it has to be used, and the arrangements for Photography, have rendered a new design of almost every part necessary, and have, of course, entailed new patterns for all the castings. In making these changes, decisions have had to be made on various points of detail …

Despite various delays and misgivings, the final product was a particularly attractive, solidly mounted silver-on-glass reflector (see Fig. 25.5), which was manufactured by John Browning, with optics by George With (Tennant, 1869: 28). Working in collaboration, their telescopes were popular with British and overseas astronomers during the last quarter of the nineteenth century (see King 1979: 271–273).

Tennant (1869: 29) has provided a detailed description of the photographic attachment:

> … the tube to carry the eye-pieces was 3½ inches in diameter. On to this screwed the frame, into which the dark slides slipped. This frame carried two wires at right angles to each other … placed as near as possible to the surface of the sensitive plate. There were six dark slides for glass plates, 4 in. × 4 in., all fitting into the same place. They were entirely of brass, except that the corners on which the plates were to rest were of silver; of course, both for lightness, and to avoid increasing the distance of the wires from the sensitive plate, the sheet metal was very thin. These answered extremely well; the fitting was very good, and they worked with hardly a difficulty … the only mistake in it was, that there was no means of defining the position of the wires with respect to the axis of the telescope; and that they could not, therefore, be taken off with their frame, so as to allow ordinary eye-pieces to be used with their adapter. If they were removed, they could not be returned to the same position.

With the instruments for the eclipse finalised, Tennant left London on 12 January 1868, bound for Calcutta. *En route* he stopped briefly in Aden, the first port of call where a total eclipse would be visible, and encouraged a number of British officers stationed there to make polarization and spectroscopic observations and to sketch the form of the solar corona. From Aden, he sailed to Madras, where he spent a few days considering possible Indian observing sites, and from there took the next steamer to Calcutta, arriving on 29 February.

It was during a stay of 4 months in Calcutta that Tennant decided to base the expedition at Guntoor, a town about 1070 km to the southwest (as the crow flies), 90 km from the east coast of India, and accessed by sea, river and road (see Fig. 25.2). With preparations underway, the Royal Astronomical Society's Sheepshanks' Telescope and refractor loaned by the Royal Observatory arrived in Calcutta at the end of March, and the Browning-With reflector in early May. The crates containing all three instruments were badly damaged, but only the first two telescopes needed minor repairs, and Tennant's old friend, the Surveyor General "… placed the resources of

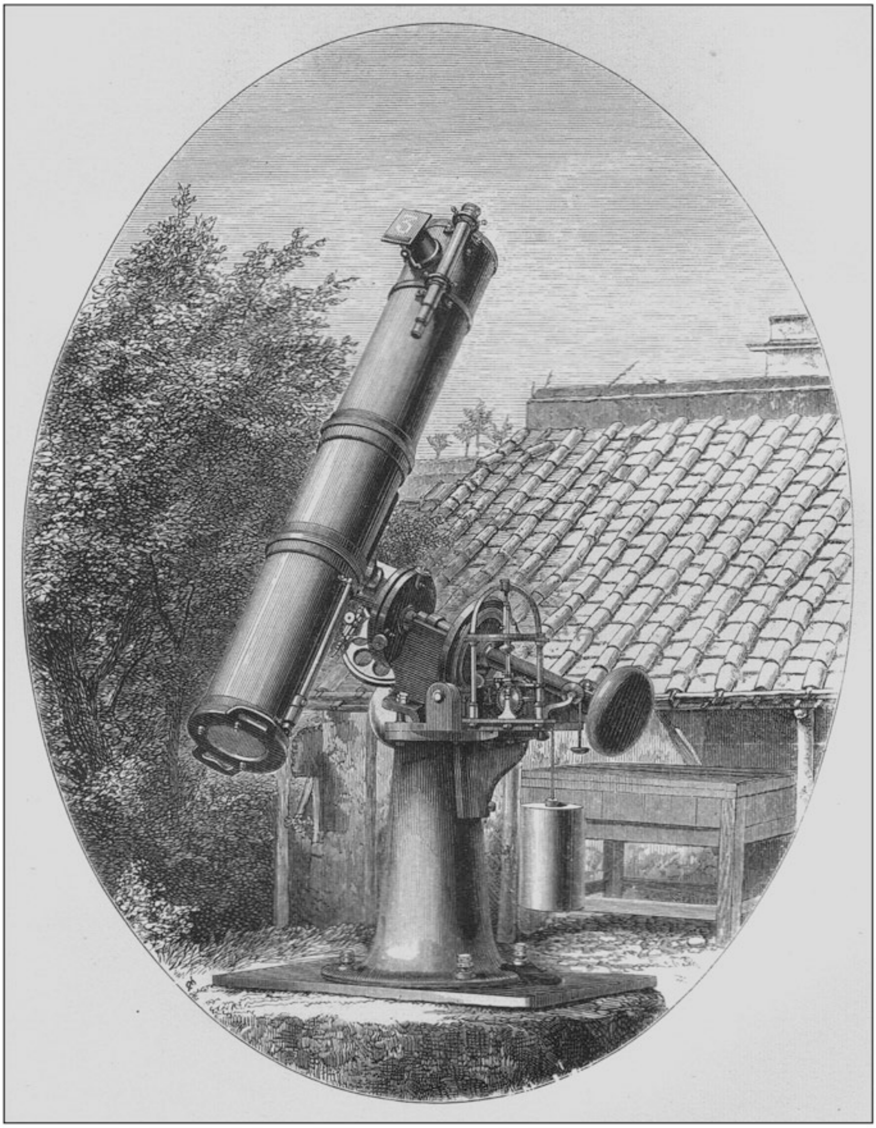


Fig. 25.5 The equatorially mounted 9-in. (22.9 cm) Browning-With reflector used for the photographic observations (after Tennant 1869: 51)

his mathematical-instrument workshop at my disposal as far as urgent calls on it would admit." (Tennant 1869: 5). Meanwhile, Tennant (1869: 8) reports that

> During my detention at Calcutta waiting for the first installment of instruments, I had selected from the stores of the Mathematical Instrument Department two chronometers, DENT No. 2071, and BARRAUD No. 1659, a Repeating Circle by TROUGHTON, and a

> Mercurial barometer … As a precaution in case the Repeating Circle should fail, I also borrowed a TROUGHTON's Circle, but it never was used.

Tennant also took advantage of the presence of scientific instrument dealers in Calcutta, and purchased two thermometers by Negretti and Zambra, and an aneroid barometer by the same manufacturer.

On 15 June, Tennant and the photographers took the steamer down the coast, accompanied by "… all our apparatus." (Tennant 1869: 6), and after a slight delay due to inclement weather anchored at Coconada on June 22. The crates were then transferred to a barge and shipped to Bezwada, but the expedition members followed in a small steamer. From Bezwada, there was only a 30-km trip by road to Guntoor, and the expedition party arrived there safely on 3 July—more than 6 weeks before the much-anticipated eclipse. A Mr. Wilson, the Sub-collector of Guntoor, invited Tennant to stay at his house, and the enclosure in which it stood proved an ideal observing station.

The first task was to set up the various instruments. The Sheepshanks' Telescope was installed on a foundation, inside a tent observatory that had been made to measure in Bezwada:

> The iron pillar of the Equatorial-stand rested on a stone 2 ft. 6 in. in diameter, forming the top of a brick pillar of the same diameter, and 4 feet deep, standing on compact gravel. The surface of the stone was level with that of the ground, and the whole instrument was enclosed in an octagonal tent, 10 feet in diameter, with a pyramidal roof … When the instrument was not in use, a waterproof sheet protected it from leakage which, in heavy rain, is almost unavoidable in a shelter of this sort. (Tennant 1869: 15–16).

In erecting and testing the telescope Tennant encountered various problems. Because of the low latitude of Guntoor, the mounting had to be modified, but when it still proved defective the clock drive was removed. He also had trouble with the balance of the telescope, and the only way it could be precisely corrected for when the spectroscope was installed or removed was to shift the telescope in the collars that attached it to the equatorial head. As may be anticipated, "…it was impossible to do so, and this prevented the free use of the telescope …" (Tennant 1869: 15). He also discovered that there were problems with the spectroscope:

> No cylindrical lens was provided for viewing stellar spectra; this proved a very serious want, for I soon found I could not stand the exposure to the Sun's rays, which were unavoidable when using the spectroscope on it. A trial on *Saturn* showed me a spectrum, but so narrow and fading so much at the ends, that I could not work on it. The only preparation I could make, therefore, for the Eclipse, was to accustom myself to find the adjustments of the slit quickly, and to experiment on illumination of the scale. Eventually, I disliked the illumination from the swinging lamp so much, that I gave it up, and substituted a common bull's eye lantern, which was fixed to a swinging frame fastened to one of the angles of the Observatory tent. (Tennant 1869: 15).

The refractor used for the polarization studies was set up nearby in one of the Trigonometrical Survey's tent observatories (Tennant 1869: 24). To provide a sturdy foundation for the telescope, "The stump of a tree was firmly planted in the ground, and its upper end so cut off that the plane of section nearly passed through the pole.

To this inclined surface the bed-plate was bolted by four coach-screws …" (Tennant, 1869: 21).

Another tent observatory manufactured in Bezwada and delivered to Guntoor on 20 July housed the Browning-With reflector, which was installed on

> … a solid brick foundation capped by stone, precisely similar to what has been described for the Sheepshanks' telescope, save that to allow the clock-weight to pass down, a cast-iron pipe, 12 inches in diameter, and closed at the bottom, was sunk, and of course, its upper end partly imbedded in the pillar. The tent … was 12 feet in diameter …" (Tennant 1869: 29–30).

In order to process the photographic plates, a 'dark tent' was set up nearby. Tennant (1869: 30) describes this:

> The dark tent was 12 ft. × 6 ft., a strong wooden frame braced with hoop iron, and covered with cotton cloth and felt, and as a further security against light (for we had to make experiments in the day), country blankets covered it. There was a curtain capable of dividing it into two parts, one of which was used for preparing the plates, and the other for developing them, but practically the curtain was not used, though the practice of separating the operations was.

Figure 25.6 shows the locations of the various instruments in relation to Wilson's house, while a rather quaint sketch of the 'Observatory Tents' is reproduced here as Fig. 25.7.

One of the first challenges after they set up the instruments was for the astronomers to determine the co-ordinates of the observing station. Table 25.1 lists the

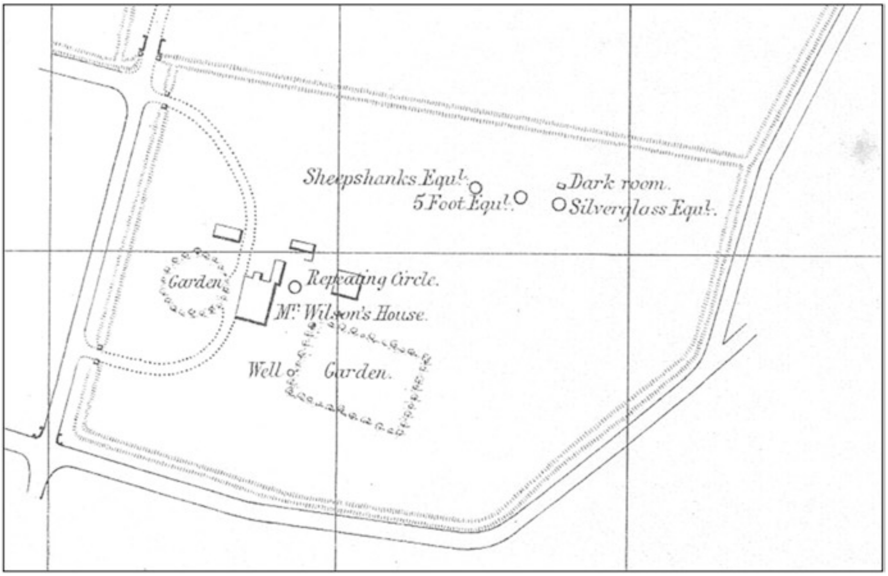


Fig. 25.6 Plan showing Mr. Wilson's property and the locations of the astronomical instruments (adapted from Tennant 1869: frontispiece)

Fig. 25.7 View by Sergeant Phillips of the observatory tents (after Tennant 1869: 49)

Table 25.1 Observations made to determine latitude

Star	Observing dates	Total observations	Derived latitude __° __′ __″
α Scorpii	18 July, 9 August	26	16 17 27.7
α Cassiopae	13 August	8	16 17 29.2
ζ Draconis	19 July	10	16 17 29.6
δ Draconis	14 August	14	16 17 32.4
Polaris	19 July	10	16 17 28.4

values of latitude derived from 68 observations of five different stars made with the repeating circle during July and August. When weighted according to the number of observations, these give a mean value of 16° 17′ 29.23″ N (Tennant 1869: 12). The station was then connected to the Trigonometrical Survey, producing a value of 16° 17′ 34.3″ N, but this result depended upon accepting an assumed latitude for Calcutta (Tennant, 1869: 13–14).

As might be expected, determining the longitude was a more difficult exercise. Listed in Table 25.2 are results derived from observations of lunar occultations and phases of the solar eclipse made with the Browning-With reflector, and equal altitude measurements of the Moon and stars made with the repeating circle. These produced a mean longitude of 05 h 21 min 43.9 s, similar to the figure of 05 h 21 min 46.6 s arrived at when the site was connected to the Trigonometrical Survey (Tennant 1869: 13).

Table 25.2 Observations made to determine longitude

Type of event	Star	Obs'g dates	Total obsns	Derived longitude __h __min __s
Solar eclipse, first contact		18 Aug	1	05 21 43.9
Solar eclipse, start of totality		18 Aug	1	05 21 45.3
Solar eclipse, last contact		18 Aug	1	05 21 51.2
Occultation, ingress	33 Ceti	08 Aug	1	05 21 48.8
Occultation, ingress	α Tauri	12 Aug	1	05 21 53.1
Occultation, egress	α Tauri	12 Aug	1	05 21 50.3
Equal altitudes Moon/stars	γ Virginis	24 July	4	05 21 53.4
Equal altitudes Moon/stars	τ Sagittarii	01 Aug	2	05 21 46.6
Equal altitudes Moon/stars	α Arietis	09 Aug	2	05 21 43.3
Equal altitudes Moon/stars	ζ Persei	11 Aug	2	05 21 53.3
Equal altitudes Moon/stars	Z Tauri	13 Aug	3	05 21 47.9
Equal altitudes Moon/stars	γ Geminorum	14 Aug	2	05 21 45.5

25.2.2 Observations of the Eclipse

When the expedition party arrived in Guntoor the prevailing weather pattern was alternating winds from the west and south, producing fine mornings, cloudy afternoons, and rain in the evenings. Occasional gaps in the clouds allowed some astronomical observations, but these opportunities were few and far between (as indicated by the paucity of July dates in Tables 25.1 and 25.2).

Eventually the west winds became very light, and the days and evenings were characterised by a rarely broken grey sky and frequent rain. This did not bode well for eclipse day, but eventually the wind blew strongly from the west for 3 or 4 days, and on 8 August all of the clouds finally cleared away, and fine weather greeted the astronomers. It then remained hot and dry right through to the day before the eclipse, surely a promise of clear skies on 18 August.

We can therefore imagine the disappointment experienced by Tennant and other expedition members when they woke on the morning of the 18th to find the sky clouded over. Totality was expected to commence at about 09:30 local time, and fortunately

> … these clouds soon cleared and we had every promise of a fine day. [But] By 8 A.M. a wedge-shaped mass of light cumulo-stratus had formed to my east, having its vertex above the Sun, and extending later to the horizon. (Tennant 1869: 7).

To Tennant's dismay (Tennant 1869: 7), this cloud covering remained over the Sun until nearly 10 min after totality, but it did prove thin enough for observations to be possible.

Spectroscopic observations were carried out in order to "… examine the Corona and prominences, as to their source of light." (Tennant 1869: 1). This was achieved by comparing the spectrum "… with a scale of equal parts, by means of which its peculiarities can be referred to the lines of the solar spectrum." (Tennant 1867c:

325). On the morning of 18 August, prior to the eclipse, Tennant (1869: 16–18) directed the Sheepshanks' Telescope to the brightest part of the sky (the Sun then being invisible), and was able to see the solar Fraunhofer lines and assign readings to them from the spectroscope's comparison scale. Most prominent were lines that he designated respectively C, D, *b*, F and G, in order of decreasing wavelength.

During the partial phase of the eclipse the Sun was sufficiently visible for him to use the repeating circle, and at one stage the finder of the Browning-With reflector, to observe the passage of the lunar limb across various sunspots. Then towards totality he closed the entrance to the tent observatory and readied himself for the spectacle. Mr. Wilson had agreed to serve as recorder, and he "… took his seat with his back to the Sun, and we awaited the disappearance of the Solar disk." (Tennant 1869: 18). At the moment of totality, Tennant pointed the telescope at the corona, and when he looked through the small viewing telescope of the spectroscope he saw

> … a very faint continuous spectrum. Thinking that want of light prevented my seeing the bright lines, which I had fully expected to see in the lower strata of the corona, I opened the jaws of the slit … but without effect. What I saw was undoubtedly a continuous spectrum, and I saw no lines. There may have been dark lines, of course, but with so faint a spectrum and with the jaws of the slit wide apart, they might escape notice. I then searched for the remarkable horn [a large prominence], projecting apparently upwards from the Moon's limb … [which suddenly] burst into sight, a glorious brilliant linear spectrum. I closed the jaws of the slit as fast as I could, and hastily cast my eyes over the field. One line in the red was so beautiful that it needed an effort to turn my attention to anything else; there was a line in the orange not so well defined, and one in the green which seemed multiple … beyond, I saw a line just defined, which, as will be seen from the measures before given, must have been near to F, and still further off in the blue I saw a hazy light probably beyond G. (Tennant 1869: 18–19).

Tennant was busy reading the positions of these lines on the comparison scale when totality ended and the spectrum faded, but not before he had identified the bright prominence lines with C (in the red), D (in the yellow), *b* (in the green), and F. As for the hazy line beyond G, in the blue, "… it is useless from my data to speculate upon, [and] I must hope that some one else has identified it." (Tennant 1869: 20). Given the threatening sky at sunrise, Tennant must have judged the spectroscopic observations a resounding success (although he does not pronounce on this matter).

When it came to the polarization observations, Tennant (1867c: 324) noted that those made during previous eclipses "… have been so contradictory, that I have been anxious to obtain some simple test which shall not be liable to be misinterpreted, and to provide the means besides of verifying its indications." If polarized light was present, then the construction of the polarizing eyepiece allowed the plane of polarization to be determined in three ways:

> 1st. By the extinction of the polarized portion of the light by means of a Nicol's prism, reducing the intensity of the image to a minimum.
> 2nd. By Savart's test where parallel fringes are formed by the interference of the polarized rays, the centre one being either dark or light as its plane is in or perpendicular to the plane of polarization.
> 3rd. By a Double-image Prism and Analysing Plate, giving images of complementary colours with polarized light, in using which the field of view is bounded by a stop in the common focus of object-glass and eye-piece. (Tennant 1867c: 324).

It took just 2 min to make all three tests in succession (Tennant 1867c: 324).

Captain Branfill was responsible for the polarization observations, and after arriving in Guntoor and setting up the equipment "… he then set to work to familiarize himself with the phenomena produced by polarized light in the telescope." (Tennant 1869: 24). When the eclipse began, Branfill and Hearn watched the partial phase with interest, then just before totality commenced Branfill

> … noticed the cusp I was watching (the apparent left) break into beads and short lines of light, and suddenly, with the palest dark glass on, caught sight of a group of red prominences … Immediately after the commencement of totality my attention was caught by a tall, narrow, brilliantly-lighted, rose-coloured, horn-like protuberance. With the Nichol and crossed quartz in, and the largest shifting diaphragm, I turned the centre of the small field on this; I received a very vivid impression of the beautifully clear features and colour of this protuberance. The background gave SAVART'S bands, but the horn did not. With the finder I then sought the brightest part of the corona, and directed the instrument upon it (viz. The left upper quarter), when the first-mentioned group of protuberances was just disappearing … I found this part clearly polarized in a plane passing through the Sun's centre. I determined a position by a reading of the graduated arc on the eye-piece tube taken when a wire in the eye-piece was a tangent to the Moon's limb at the spot …
>
> The double-image prism with two diaphragms gave the same result — plentiful polarization in the plane passing through the Sun's centre. (cited in Tennant 1869: 25–26).

After examining various parts of the corona and always detecting polarized light, Branfill then turned his attention back to the horn-like prominence, and subjected it to further scrutiny:

> I used the smallest diaphragm and the Nicol with and without the crossed quartz; and also the double image with the largest diaphragm; but could not detect any trace of polarized light in it, any bands, or any changes of colour or relative brilliancy. (cited in Tennant 1869: 26).

In planning the expedition, Tennant (Tennant 1869: 26) anticipated that Savart's test would be the most effective one in determining the polarization, and this indeed proved to be the case. For his part, Tennant (1869: 21) was particularly impressed by Branfill's performance, whose notes on the observations

> … bear evidence, not only that the writer of them saw many things to which his attention was not especially directed, and noted them, but also that small phenomena impressed themselves so accurately on his mind, that he saw during the total phase appearances, which certainly neither of us expected, and whose explanation proves the accuracy and freedom from bias of his mind.

Apart from his record of the polarization observations, Branfill carefully examined the horn-like prominence and provided a detailed description of it:

> … the tint … was a beautiful bright rose pink, with veins of silver light. The definition was very good, the outline clear, but irregular; a detached cloud of the same tint, with a distinct gap between, hung over the top. The tint was slightly deeper here and there on the body of the protuberance, and curved silver-lined streaks pervaded it generally in the direction of its length and height. Near the centre and lower part there appeared to be a rent, or place of no colour, like a small opening or hole in a cloud. (cited in Tennant 1869: 26–27).

This impressive prominence, affectionately termed the 'Great Horn', is clearly visible in Fig. 25.8.

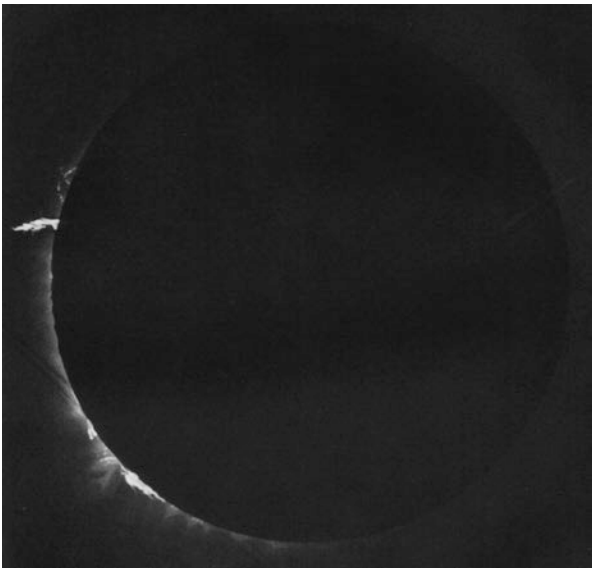


Fig. 25.8 Copy of Photograph 2, showing prominences, including the Great Horn. North is at the top and west to the right (after Tennant 1869: Plate 5B)

Table 25.3 Photographs of the total solar eclipse obtained at Guntoor (data after Tennant 1869: 33–36)

Photo	Time (local time) (__h __min __s)	Exposure	Comments
1	09 29 51.5	<1 sec	Many prominences and the Great Horn visible
2	09 30 49.75	5	Ditto (see Fig. 25.8, here)
3	09 31 57	10	Only the Great Horn and one other prominence visible. Possibly taken through slightly heavier cloud
4	09 32 49	5	Only the Great Horn visible
5	09 33 52	<1	Only the Great Horn and one other prominence visible
6	09 35 22.5	<1	Many prominences and the Great Horn visible (see Fig. 25.9)

The third element in the expedition's research arsenal was photography, and the Browning-With reflector was used to take images of the eclipse "… in the hope that some traces of the structure of the corona may be obtained …" (Tennant 1867c: 324). During their training runs prior to the eclipse, Sergeant Phillips and the two sappers involved in the photographic project encountered difficulties with the telescope drive and with the test photographs, which lacked definition (Phillips attributed this to the quality of the distilled water used and also to problems in precisely focussing the image on the photographic plates).

On the day of the eclipse, Phillips was also assisted by a Mr. Grahame, who noted the times of the various exposures. Six different photographs were taken during the 5 min and 45 s of totality, and these are summarised in Table 25.3.

In Photographs 1, 2 and 3, the only prominences visible were within the 90° sector exhibiting activity in Fig. 25.8 (i.e. approximately from the east to the southeast). Most conspicuous of these was undoubtedly the ‘Great Horn’, the height of which in Photograph 1 was measured at $3' \, 18''$, corresponding to 88,900 miles (Tennant 1869: 33)—more than 11 times the diameter of the Earth! It exhibited a similar appearance and height in Photograph 2, which is reproduced here as Fig. 25.8. Tennant (1869: 35) notes that the neighbourhood of the Great Horn and the other distinctive prominence in this Photograph “… is marked by light flaring into the Corona in irregularly curved lines, and this corresponds to that part of the Corona which has been described by Captain BRANFILL and others as most bright.” Tennant also comments on the spiral structure of the Great Horn, which is best evidenced in Photographs 2, 3 and 4. In this last photograph, “Nothing is seen but the Great Horn, but that picture is of singular beauty. The continually varying intensity of the light and its markedly spiral structure are the material points.” (Tennant 1869: 35). With Photograph 5, taken just 1 min after Photograph 4, a new area of prominence activity is emerging from behind the Moon’s limb just as the Great Horn is being hidden by it, and when the final photograph was taken, just before the end of totality at Guntoor, this new area of activity displayed an impressive assemblage of prominences—as clearly illustrated in Fig. 25.9. As Lockyer (1874: 112) reminds us, “Nothing could be more complete … proof … that these appendages belonged to the sun: the prominences were eclipsed and uncovered exactly as the sun itself was.” Upon reviewing these newly visible prominences, Tennant (1869: 36) especially wanted to draw attention to “… the appearance of a strong current of air (so to speak) blowing from north to south, and bending over and even detaching

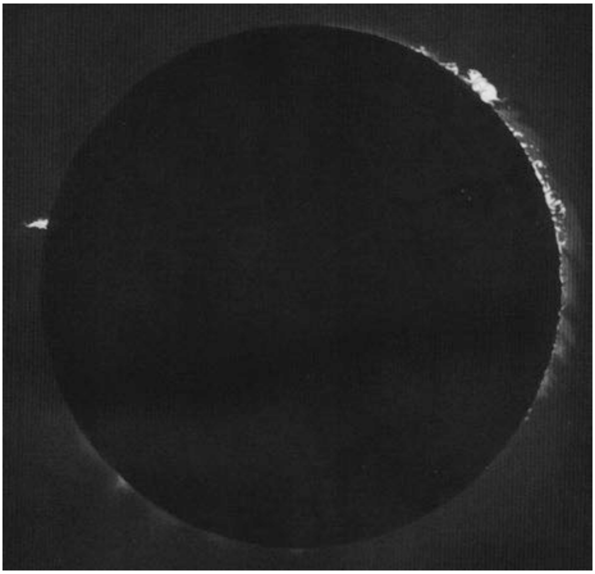


Fig. 25.9 Copy of Photograph 6, showing numerous prominences, and a slowly disappearing Great Horn (after Tennant 1869: Plate 5F)

and carrying away the tops of prominences." This feature is very apparent in Fig. 25.9. Despite the virtual absence of the corona in the published photographs, the expedition's photographic work must be judged a resounding success.

Following what was undoubtedly an eventful expedition, Tennant and his team packed the crates of equipment, which left for Bezwada on 2 September. Tennant followed on the 5th, and he and Phillips reached Coconada 4 days later and sailed on the 17 September steamer, arriving in Calcutta—along with the instruments—on the 23rd (Tennant 1869: 7).

25.2.3 Reduction and Publication of the Observations

In reviewing the observations made during the expedition, Tennant (1869: 37, his italics) concluded that the following new knowledge was in evidence:

> *First. The Corona is the atmosphere of the Sun not self-luminous, but shining by reflected light*. It is evidenced both by the Spectroscope and Polariscope that this is the case …
>
> *Secondly. The Great Horn certainly was composed of incandescent vapours, and probably all brilliant protuberances are the same.* In the Great Horn these vapours were hydrogen, sodium, and magnesium.

Addressing the first of these: Tennant's identification of the corona as an outer atmosphere of the Sun merely confirmed a view that was first expressed by Grant back in 1852 in his classical *History of Physical Astronomy* (see pp. 400–401). Regarding Tennant's second item of "new knowledge", while the C emission line was undoubtedly associated with hydrogen, spectroscopic observations of the eclipse made by other international teams would later force Tennant (1869: 43–45) to cast doubt on the sodium and magnesium identifications. Of greatest significance was the correct identification of the D line, and Young (1902: 344) discusses this:

> Most of the observers [of the 1868 eclipse] supposed it to be the D line of sodium, but Janssen noted its non-coincidence; and very soon, when Lockyer and Frankland took up the study of the chromosphere spectrum, they found that the line could not be ascribed to hydrogen or to any then known terrestrial element. As a matter of convenient reference, Frankland proposed for the unknown substance the provisional name of "helium" (from the Greek "helios," the sun), and this ultimately, though rather slowly, gained universal acceptance.

Pogson from Madras Observatory also observed this eclipse, and in fact he was the first to draw attention to this anomalous line, which was later dubbed 'helium' (for details, see Nath 2013).

Helium was finally detected in the laboratory, by Ramsay, in 1895 (see Young 1902: 345–346). Meanwhile, we now know that Tennant's multiple *b* emission lines were associated with iron and magnesium, and the emission lines in the green (F) and in the blue, near G, with hydrogen (see Table 25.4 for details). But at the time of the eclipse, such identifications were in no way straightforward, as Lockyer (1874: 122–123) relates:

Table 25.4 Identification of the emission lines noted by Tennant (after Young 1902: 206–207)

Line	Element	Wavelength (Å)
C	Hydrogen (Hα)	6563.05
D	Helium	5875.98
b_1	Magnesium	5183.8
b_2	Magnesium	5172.9
b_3	Iron	5169.2
b_4	Magnesium	5167.6
F	Hydrogen (Hβ)	4861.50
Near G	Hydrogen (Hγ)	4340.66

> It is obvious from these discrepancies [comparing observations by Herschel and Tennant in India and Rayet in Siam], which we hold to be entirely unavoidable in such a delicate investigation, carried on under difficulties of weather and under conditions so out of the common, that the question as to the nature of the red flames—our knowledge of which depended upon a rigorous determination of the position of the lines—was left open …

Apart from the two aforementioned items of "new knowledge", Tennant felt that he also made an important discovery in regard to the spiral structure of the Great Horn, which was apparent in all six of his photographs:

> I believe I have the good fortune to be the first person to recognise such a phenomenon. In the facsimile of Mr. DE LA RUE'S Photograph No. 25, and in the enlarged and touched copies, there is evidently an appearance of a spiral structure in the floating cloud he calls C; but he does not seem to have recognised this … (Tennant 1869: 38).

This spiral appearance was also reported by a Captain Tanner and Professor Keru Luximon Chatrey, who observed the eclipse from Bijapoor (see Fig. 25.2) in company with a Captain Haig, R.E. (Tennant 1869: 38).

While the original photographs taken at Guntoor showed little trace of the corona, it was clearly visible during totality and was commented on by Tennant. For instance, when Photograph 6 was exposed, "… the whole limb from N. to S.W. shows a trace of Corona …" (Tennant 1869: 36). Tennant was able to capture this tenuous outer atmosphere of the Sun in a number of drawings, one of which is reproduced here in Fig. 25.10. Meanwhile, we should not forget that

> … haze covered the sky at Major Tennant's station during totality … [and] on account of the extent of the eclipse, the Moon shut off the brightest part of the corona, except at the commencement and end of the total phase near the points of first and last internal contacts. (de la Rue; cited in Tennant 1869: 47).

The August 1868 eclipse occurred when the Sun was about half way between sunspot minimum and maximum (see Fig. 25.11), and the form of the corona shown in Fig. 25.10 reflects this: a comparatively uniform halo, with small extensions to the south-east, south-west and north-west. This is in contrast to the typical corona associated with sunspot maxima, "… a great irregular halo, sending out its rays

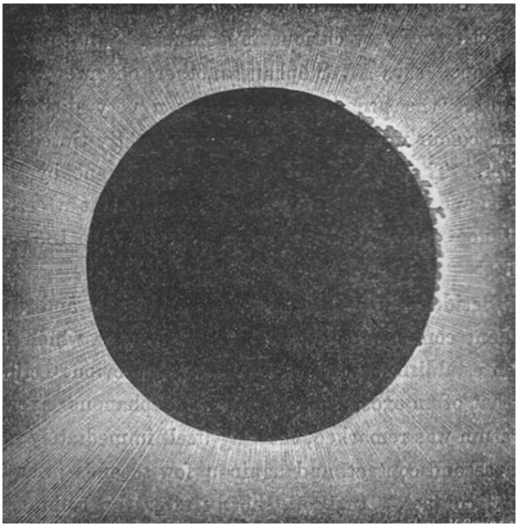


Fig. 25.10 Tennant's drawing of the eclipsed Sun and corona, made at about the time Photograph 6 was exposed (after Guillemin 1870: 251)

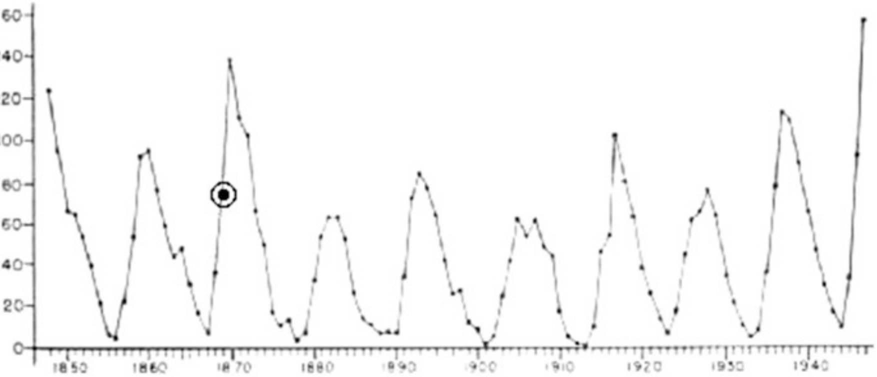


Fig. 25.11 Sunspot numbers, 1848–1947, with 1868 indicated by the larger circle (adapted from Menzel 1949: Fig. 70)

indiscriminately in almost every direction …" (Maunder, 1899: 88). It also differs markedly from the corona seen at sunspot minima, when "… the equatorial wings and polar rays were much less striking, the corona was more nearly circular, and its principal development was over the sun-spot zones." (Young 1902: 256–257). Of course, this association between coronal form and the sunspot cycle was not clearly understood in 1868. It only became apparent a decade later, when astronomers were able to compare and contrast photographs and drawings of the corona that spanned nearly two complete solar cycles, and since 1878 "… a correspondence between the general form of the corona and development of spots upon the sun has always been looked for." (Maunder 1899: 88, 91).

Tennant eventually wrote up the expedition, and his long well-illustrated paper was published in the *Memoirs of the Royal Astronomical Society* in 1869. Details are provided of the instruments used and of the observations, and reproductions are included of all six photographs. In his concluding paragraph, Tennant (1869: 41) states:

> I have now completed the narrative of my proceedings of all sorts. It was an anxious time for me, from the long delays which reduced the time available for preliminary arrangements in Guntoor … Nevertheless, I have I trust added somewhat to previous knowledge.

We feel that he did indeed achieve this.

25.3 Solar Studies, and Other Indian Observations of the 1868 Eclipse

Apart from Tennant's Guntoor expedition, there was a second British eclipse party in India, which was led by Lieutenant John Herschel (1837–1921) from the Indian Trigonometrical Survey and was supplied with instruments by the Royal Society. Herschel's team was based at Jamkandi near the Western Ghats (see Fig. 25.2) and on 18 August was plagued by cloud, "… but during the lapse of the critical five and a half minutes the clouds broke, and a "long, finger-like projection" jutted out over the margin of the black lunar globe." (Clerke 1893: 209). Spectroscopic observations instantly revealed three emission lines (Herschel 1869: 116), as in Guntoor disclosing the gaseous nature of the Great Horn and its obvious solar association.

A third professional British observing party in India was led by Madras Observatory Director, Norman Pogson (1829–1891; Fig. 25.12), and was based at Masulipatam (on the east coast, near Guntoor). Pogson also successfully observed the eclipse (Ranyard 1879), and as we have already noted, was the first to remark on the anomalous emission line that we now associate with helium—although he is generally not given the credit for this discovery (see Nath 2013).

One French expedition led by Professor Jules Janssen was in India for the 1868 eclipse, and was also based at Guntoor, just under a kilometre to the west of Tennant's compound. Clerke (1893: 210) relates how this eclipse "… is chiefly memorable for having taught astronomers to do without eclipses, so far, at least, as one particular branch of solar inquiry is concerned." Inspired by his spectral observations of prominences (including the Great Horn) during totality, it occurred to Janssen that he should be able to replicate these observations outside of eclipse,

> … and this he realised at 10 A.M. next morning, August 19, 1868—the date of the beginning of spectroscopic work at the margin of the unobscured sun. During the whole of that day and many subsequent ones, he enjoyed, as he said, the advantage of a prolonged eclipse. (Clerke 1893: 210).

By a happy coincidence, at very much the same time, the two British astronomers, Norman Lockyer and William Huggins, independently came up with the same idea (see Meadows 1970).

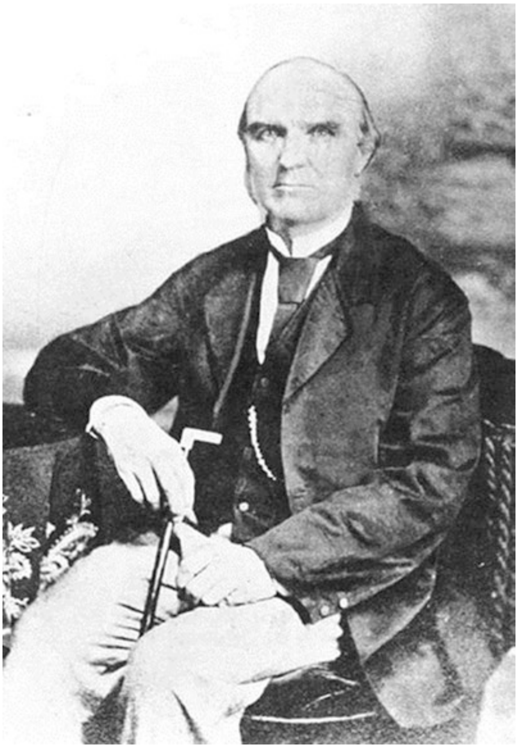


Fig. 25.12 Norman Robert Pogson (after *Popular Astronomy* 1913)

25.4 Concluding Remarks

The 1868 total solar eclipse occupies an important place in the history of solar physics and spectroscopic studies in astronomy. One of the two British expeditions in India to observe this eclipse was led by John Francis Tennant, and was based at Guntoor, to the south of Madras. Tennant and his colleagues carried out successful spectroscopic, polarization and photographic observations and were able to confirm the solar nature of the corona and to show that it shone by reflected sunlight. They also established the gaseous composition of the prominences and detected emission lines associated with hydrogen, magnesium and helium—although this last-mentioned identification only came later. The French astronomer Jules Janssen also was based in Guntoor and made valuable spectroscopic observations. During the eclipse he realized that spectroscopic investigation of prominences should be possible outside of eclipse, thereby initiating an important new methodology in solar observational astronomy.

India has a tradition in scientific astronomy that dates back to 1618 (see Kochhar and Orchiston 2017), but prospered during the eighteenth century through the East India Company and founding of the Madras Observatory (e.g. see Kochhar 1991).

With such sympathy for astronomy and a scientific infrastructure in place, it is no surprise that the 1868 eclipse was not the first transient astronomical event to attract foreign expeditions to Indian shores. Overseas observers successfully observed or attempted to observe the 1761, 1769 and 1874 transits of Venus (e.g. see Kapoor 2013, 2014), while the total solar eclipses of 1871 and 1898 each attracted numerous foreign expeditions (Maunder 1899; Orchiston and Pearson 2017; Ranyard 1879).

Tennant led two other Indian astronomical expeditions after his 1868 venture. In 1871 his team successfully observed the solar eclipse from Dodabetta near Ootacamund (Tennant 1875) in southern India, and in 1874 he and his colleagues recorded the transit of Venus while based in Roorkee, near Delhi and the foothills of the Himalayan mountain range (Tupman 1878: 432). It is significant that the telescopes sent out from England for the 1874 transit became the founding instruments of the solar observatory set up at nearby Dehra Dun in 1878 (Kochhar 1991).

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References

Clerke, A.M. (1893). *A Popular History of Astronomy During the Nineteenth Century*. London: Adam & Charles Black.

Grant, R. (1852). *History of Physical Astronomy, From the Earliest Ages to the Middle of the Nineteenth Century*. London: Baldwin.

Guillemin, A. (1870). *The Sun*. London: Bentley.

Herschel, J. (1869). Account of the solar eclipse of 1868, as seen at Jamkandi, in the Bombay Presidency. *Proceedings of the Royal Society, 17,* 104–120.

Kapoor, R. (2013). Indian astronomy and the transits of Venus. 1: The early observations. *Journal of Astronomical History and Heritage, 16,* 269–286.

Kapoor, R. (2014). Indian astronomy and the transits of Venus. 2: The 1874 event. *Journal of Astronomical History and Heritage, 17,* 113–135.

King, H.C. (1979). *The History of the Telescope*. New York: Dover.

Kochhar, R.K. (1991). The growth of modern astronomy in India, 1651–1960. *Vistas in Astronomy, 34,* 69–105.

Kochhar, R., & Orchiston, W. (2017). The development of modern astronomy and emergence of astrophysics in India. In T. Nakamura, & W. Orchiston.

Lankford, J. (1984). The impact of photography on astronomy. In O. Gingerich (Ed.), *The General History of Astronomy. Volume 4. Astrophysics and Twentieth-Century Astronomy to 1950: Part A* (pp.16–39). Cambridge: Cambridge University Press.

Lockyer, J.N. (1874). *Contributions to Solar Physics*. London: Macmillan and Co.

Lockyer, J.N. (1887). *The Chemistry of the Sun*. London: Macmillan and Co.

Maunder, E.W. (Ed.), (1899). *The Indian Eclipse 1898. Report of the Expeditions Organized by the British Astronomical Association to Observe the Total Solar Eclipse of 1898, January 22*. London: Hazell, Watson and Viney.

Meadows, A.J. (1970). *Early Solar Physics*. Oxford: Oxford University Press.

Menzel, D.H. (1949). *Our Sun*. London: Churchill.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Windaow on the Universe*. Cham: Springer.

Nath, B.B. (2013). *The Story of Helium and the Birth of Astrophysics*. New York: Springer.

Obituary. *The Observatory, 38,* 190 (1915a).

Obituary. Lieut.-General James Francis Tennant. *Journal of the British Astronomical Association, 25,* 240 (1915b).

Orchiston, W., & Pearson, J. (2017). American observations of the 22 January 1898 total solar eclipse from Jeur, India. In T. Nakamura, & W. Orchiston.

Orchiston, W., Chen, K.-Y., Lee, E.-H., & Ahn, Y.S. (2006). British observations of the 1868 total solar eclipse from Guntooor, India. In K.-Y. Chen, W. Orchiston, B. Soonthornthum, & R. Strom (Eds.), *Proceedings of the Fifth International Conference on Oriental Astronomy* (pp. 23–34). Chiang Mai: Chiang Mai University.

Popular Astronomy (1913).

Ranyard, A.C. (1879). Observations made during total solar eclipses. *Memoirs of the Royal Astronomical Society, 41,* 1–792 (plus plates).

Tennant, J.F. (1867a). On the solar eclipse of 1868, August 17. *Monthly Notices of the Royal Astronomical Society, 27,* 79–80.

Tennant, J.F. (1867b). On the eclipse of August 1868. *Monthly Notices of the Royal Astronomical Society, 27,* 173–178.

Tennant, J.F. (1867c). Memorandum on preparations for observing the total eclipse of the Sun on August 18, 1868. *Monthly Notices of the Royal Astronomical Society, 27,* 323–325.

Tennant, J.F. (1869). Report on the total eclipse of the Sun, August 17–18, 1868 … *Memoirs of the Royal Astronomical Society, 37,* 1–55.

Tennant, J.F. (1875). Report of observations of the total eclipse of the Sun on December 11–12, 1871, made by order of the Government of India, at Dodabetta, near Ootacamund. *Memoirs of the Royal Astronomical Society, 42,* 1–33.

Tupman, G.L. (1878). On the mean solar parallax as derived from the observations of the transit of Venus, 1874. *Monthly Notices of the Royal Astronomical Society, 38,* 429–457.

Weiss, E. (1867). Remarks on the total solar eclipse of August 17th, 1868. *Monthly Notices of the Royal Astronomical Society, 27,* 305–311.

Young, C.A. (1902). *The Sun*. New York: Appleton.

Chapter 26

American Observations of the 22 January 1898 Total Solar Eclipse from Jeur, India

Wayne Orchiston and John Pearson

26.1 Introduction

At the time Lick Observatory's great 36-in. (91.4-cm) refractor saw first light in 1888, the facility became a research department of the University of California, USA. The solar eclipse expeditions were an integral part of the Observatory's research strategy from early 1889 until 1932. This forced the Observatory's management to solicit funding, employ staff, and allocate valuable resources to the eclipse program. The solar eclipse expeditions themselves were financed almost entirely by philanthropy (see Pearson and Orchiston 2008).

Altogether, 15 Lick Observatory solar eclipse expeditions were sent around the globe, and Fig. 26.1 shows the locations of the various eclipse stations and the approximate paths of totality. The red circle indicates the station in India for the 1898 eclipse (Pearson and Orchiston 2008).

26.2 Coronal Science Pre-1898

From ancient to modern times, mankind has been awed, terrorized, and has paid religious homage to the apparition of a total eclipse of the Sun. The white apparition surrounding the Sun only seen during a total eclipse, known as the solar corona, gave the appearance of large wings and mystic forms. Lick expeditions focused on the investigation of the corona.

Initially, knowledge of the solar corona developed at a very slow rate due to the rarity of solar eclipses. The frequency of solar eclipses was approximately one every 18

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Historical & Cultural Astronomy, DOI 10.1007/978-3-319-62082-4_26

Fig. 26.1 The paths of totality, dates and locations of the various Lick Observatory solar eclipse expedition stations. The Indian station, near Jeur, is indicated by the large red circle (*Map* John Pearson)

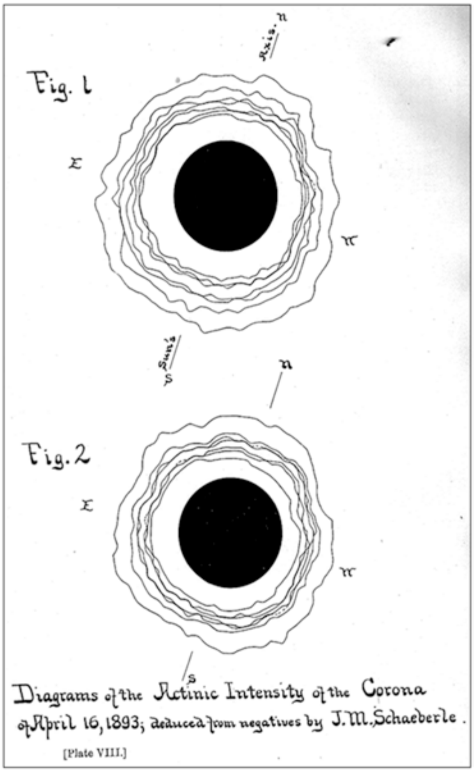
months. Widely scattered about the planet, sometimes inaccessible due to location, and with no guarantee of clear skies, an individual astronomer might accumulate less than 75 min of useful observing time in the course of an entire lifetime (Campbell 1907: 1). Astronomers needed to generate permanent records in a very short time so that they could carry out a later analysis. The development of photography enabled them to do just that and in a more accurate way, than drawing allowed. Up to the end of the nineteenth century, drawing and photography coexisted together, with photography finally replacing drawing by the start of the twentieth century (Campbell 1907: 1).

It was not until the period of the Lick Observatory eclipse expeditions that a very detailed examination of the solar corona by photography became the norm (see Pearson et al. 2011). A good portion of these detailed studies were made possible by the use of the Schaeberle Camera (Pearson and Orchiston 2008) and the advancement of photographic techniques developed at the Observatory by E.E. Barnard, S.W. Burnham, and J.M. Schaeberle (Pearson 2009).

Prior to 1898, the emphasis of coronal studies was on:

1. Schaeberle's Mechanical Theory of the Corona (Schaeberle 1890a, 1890b, 1890c, 1891a, 1891b).
2. Coronal form/structure.
3. Coronal composition.
4. Coronal brightness (see Fig. 26.2).
5. Coronal motion.
6. The 'flash spectrum'.
7. The identity and precise location of the green coronal line.

Fig. 26.2 C.D. Perrine's 1000-point contour mapping of coronal brightness from the 1893 coronal photometry (after Schaeberle 1895)



Coronal studies of form and structural detail were made of the inner and outer corona. Some of these coronal forms took on the appearance of streamers, rifts, cusps, winged appendages, curves and other interesting shapes classified as 'disturbances'. Some coronal features were found in the vicinity of solar surface disturbances such as sunspots, flares and faculae. Coronal features were found to vary considerably in appearance according to their proximity to the solar equator and polar regions.

Coronal motion studies were made in order to explain the differences of coronal form. Other relationships were found to exist between the coronal streams of ejected matter and the rotation of the Sun. Measurements of the velocity of ejected matter from the photosphere and chromosphere were applied to the study of coronal form.

Coronal constitution studies were concerned with the particle-gas content and distribution within the inner and outer corona. Researchers made polarization studies of the corona in order to determine particle density and distribution by measuring reflected sunlight from particle content within the corona. Photometric studies of the corona were also carried out in a bid to measure the variability of brightness within the inner and outer corona.

26.3 The 1898 Lick Expedition to Jeur, India

26.3.1 Expedition Planning

Of the numerous United States Government, State and private observatories, Lick Observatory under the directorship of Edward S. Holden (1846–1914; Osterbrock 1984), located in the state of California, was one of only two stations to mount an expedition to India. The second party, the small-scale Chabot University Observatory under Professor Charles Burckhalter (1849–1923), came from Oakland in the near proximity of Lick Observatory (Burckhalter 1898: 4). The Lick and Chabot staff had a very close working relationship, with Chabot often loaning their instruments to Lick's expeditions in time of need (Holden 1897a).

By 21 June 1897, Lick's William Wallace Campbell (1862–1938; Wright 1949) still did not have a field expedition approved (Holden 1897b). Four days later the expedition was approved by the University of California Board of Regents. Holden asked Robert Ball (1840–1913; Marché 2014a), President of the Royal Astronomical Society, to help obtain the necessary permissions and site arrangements in India (Holden 1897c). The English Government in India sent detailed meteorological reports. Banker magnate Charles F. Crocker (1854–1897), as for previously expeditions, funded the expedition at a cost of $1250.00 (Schaeberle 1897). This would be the first eclipse expedition on which Mrs. Campbell would accompany her husband, and she maintained a lengthy diary of the trip, *In the Shadow of the Moon*, which remains unpublished (see Campbell n.d.).

26.3.2 The Trip to India

On 21 October 1897 the expedition departed San Francisco onboard the steamer *China* for the trans-Pacific segment of the voyage to Hong Kong. After stopping in Honolulu, Hawaii, they arrived in Hong Kong after 28 days at sea. *En route*, the Campbells spent many hours in their stateroom seasick, with their luggage sliding back and forth across the floor. In Honolulu the ship picked up 300 scantily-dressed Chinese passengers who gambled incessantly. The ship left in a festive mood for Yokohama, Japan, with seasickness returning for the duration of the voyage. After a train trip to Tokyo, Osaka and Mogi, the Campbells departed for Kobe, with Mt. Fuji as a scenic back drop. Next they visited Nagasaki, Shanghai and finally Hong Kong. They then boarded the P & O ship *Ancona* for the 17-day trip to Bombay, India, stopping *en route* in Singapore and Colombo (Ceylon) before finally reaching Bombay, in India, on 10 December. By this time W.W. Campbell was feeling very ill from the 'rotten chow' (Campbell 1898a: 131–132; Campbell n.d., 1898: 1–64).

Fig. 26.3 Local inhabitants in Jeur meet the Lick Observatory expedition party (*Courtesy* Mary Lea Shane Archives)

26.3.3 Establishing the Eclipse Station

In Bombay Campbell rounded up a small army of military and scientific volunteers, and soon became mired in logistical red tape. They learned that their intended destination of Karad, was closed due to the bubonic plague. Other parties sent by the British and Japanese were faced with the same issues as the Lick party (Maunder 1899). Campbell picked another site 4 miles from the railroad station at Jeur, where they were greeted by the local natives (Fig. 26.3).

Campbell had a very difficult time rounding up more volunteer workers as the non-commissioned officers could not eat or sleep with the commissioned officers. The promised time signals for the establishment of the exact positional coordinates of the site did not materialize. When Campbell asked the station official for an accurate time reading to 1 s, the operator replied: “Why should he be so impatient over one second? There are plenty of seconds.” (Campbell 1898a).

Days were hot, typically in the mid-90s, with the nights in the low to mid-40s, giving a diurnal range of around 50 °F.

26.3.4 The Eclipse Instruments

Campbell roped off an area for the instruments (Fig. 26.4) and set to work erecting the impressive-looking 40-ft. Schaeberle Camera. Originating from the Lick Observatory’s 1893 eclipse expedition, this camera had produced exquisite

Fig. 26.4 A scene showing the Lick Observatory party ready for the eclipse. All of the instruments are in place and the volunteers are at their practice stations. The 40-ft. Schaeberle Camera with its twin wooden towers dominates the scene (*Courtesy* Mary Lea Shane Archives)

large-scale images on 18-in. × 20-in. glass plates of the eclipsed Sun, and its ability to reveal the complex form of the coronal matter was fundamental to the solar researcher's early understanding of the physics of the corona.

Campbell had selected the original eclipse station site using contour maps to locate a suitable hill for the camera, but the terrain was flat at the new site so Campbell (1898a: 133) came up with the original idea of supporting the Camera's primary lens and tube cover with two isolated wooden towers.

The local natives were amazed at Campbell's ability to work hard. Mrs. Campbell noted in her diary: "He is working from before dawn till after the sun has left the sky. Stones that four men cannot move, he lifts with ease. And he is never tired!" On flat ground, Campbell set forth to build the two towers needed to raise the objective lens and tube of the Camera to an altitude of nearly 51°. He initially lacked materials and skilled labor to construct them and figured that he would have to do everything himself that needed accuracy. Teak lumber and nails, for the towers, were obtained from the Indian city of Poona which was 100 miles away. Campbell (1898a: 134–135) did the work himself, erecting the towers after he fired the local lead worker. The diagonal-braced wood tower frame measured 12-ft. square at the bottom and tapered to 14-in. square and inclined at the top. The tube end was held in place by iron pins driven into the ground. The tube was further anchored with a system of duplicate wire cables. A 9-ft. rock wall surrounded and anchored the bottom of the tower. The 5-in. (12.7-cm) Clark primary lens was fastened to a plank at the top of its separate wooden tower. The south, north and east faces of the outer tower were completely covered by a large canvas sheet from above the lens to the bottom of the rock wall. Despite strong winds the optical system remained vibration free. The day before the eclipse, Campbell discovered that an animal had bumped into or someone had tampered with the plate guiding tracks and clock mechanism, so he had to spend valuable rehearsal time re-adjusting the affected parts. To prevent any further disruption, that night the eclipse camp was placed under guard (Campbell 1898a: 136–137).

Other cameras represented a range of focal-lengths, and provided very wide to moderately long field of views. There were two notable cameras among the array of instruments used:

1. The 5-in. (12.7-cm) aperture, 33-in. (83.8-cm) focal length Pierson Dallmeyer Camera, which was basically a high quality portrait lens camera; and
2. The Floyd photographic telescope of 6-in. (15-cm) aperture and 67-in. (1.7-m) focal length (Schaeberle 1893).

The first camera provided plates from which sky brightness measurements could be made, while the plates from the Floyd camera were ideal for the study of overall coronal form.

In addition to the photographic program, the 1898 eclipse was also to be the subject of spectroscopic analysis. Altogether there were four spectrographs, and Campbell designed three of them, which for the first time used moving plate-holders (see Fig. 26.5). Three spectrographs were for recording the spectrum of the solar

Fig. 26.5 Campbell's moving plate spectrographs as they appeared in 1905, showing one of the gas-driven pistons that moved the plate-holder in order to obtain a continuous recording of the coronal spectrum throughout totality (*Courtesy* Mary Lea Shane Archives)

limb continuously. One of the spectrographs featured a Rowland grating. Professor Charles A. Young (1834–1908; Frost 1913) of Princeton University loaned a train of four compound prisms for the spectrographs which were used to assemble a one prism spectrograph and a six prism spectrograph. The six-prism spectrograph would record the bright coronal green line at 1474 K in an attempt to measure the displacement of the bright line due to motion in the line of sight, and to determine the rate of rotation of the corona for the first time. The Bruce spectrograph from the Observatory's Crossley Telescope rounded out the spectrographic array. A clock driven equatorial mounting made of shipping crates that rotated on steel pivots carried five of the instruments (Campbell 1898a: 127–131). Driving clocks for the instruments were loaned by W.J. Hussey (1862–1926; Lindner 2014) and L.C. Masten (Campbell 1898b).

26.3.5 The Scientific Staff and Volunteers

As with previous Lick Observatory eclipse expeditions, the successful observation of the Indian eclipse depended to a large extent on the input of volunteers. W.W. Campbell led the expedition with Mrs. Campbell and Miss R. Beans as official American volunteers, but between 17 and 21 January highly-qualified locally-sourced volunteers arrived at the eclipse station and began practising their assigned duties. The list of personnel included: Captain H.L. Fleet, R.N. who was in charge of Her Majesty's marine forces in Bombay Harbor; Royal Navy Lieutenants Kinehan, Mansergh and Corbett; Major Boileau and Mr. Garwood from the Royal Engineers; the Reverend Dr. J.E. Abbott, who was one of Professor Young's former Dartmouth College students; Major S. Comfort, the U.S. Consul at Bombay, and Mrs. Comfort (see Fig. 26.6).

26.3.6 The Schedule of Solar Observations

The expedition focused on obtaining spectrograms of the chromosphere, reversing layer and corona. Campbell (1897) wanted to test whether H, K or hydrogen lines were truly coronal, or whether they diffused from the chromosphere and prominences. He also wanted to find if the lines were due to diffusion, as this would apply to Deslandre's theory on the rotation of the corona. This was an important development as the Observatory had not attempted eclipse spectroscopy since the January 1889 eclipse.

In contrast, the direct coronal photographic program would continue as at previous eclipses. Brightness studies of the corona would be conducted with photometry of selected standardized plates.

Fig. 26.6 The Campbells and the volunteer instrument operators (*Courtesy* Mary Lea Shane Archives)

26.3.7 Eclipse Day

Eclipse day arrived with perfectly calm and clear weather conditions. All natives and non-participants were kept away from the stations by the Government of India (Campbell 1898a: 137–140). The eclipse had began at sunrise in central Africa with the path heading northeast across India to end at sunset in Mongolia. The eclipsed Sun at an altitude of 51° saw 2nd contact at 00 h 59 min 14.8 s and 3rd contact at 01 h 01 min 15.0 s, Local Mean Time. 1st and 4th contacts were not recorded (Campbell 1900a). Totality lasted for a rather short 01 min 59.5 s.

Captain Fleet at the Schaeberle Camera called out the traditional 'Go' signal at 2nd contact. Volunteers, Captain Fleet and Engineer Garwood, operated the camera having practiced the plate loading, timing of the plate exposures, and plate removal many times. Captain Fleet began the 1st exposure at exactly the moment of 2nd contact. There was a small area arranged for the two operators to escape and view the eclipse directly during the longer exposure, but they did not leave their stations at the plate holder. The rest of the eclipse party carried out their observations in a

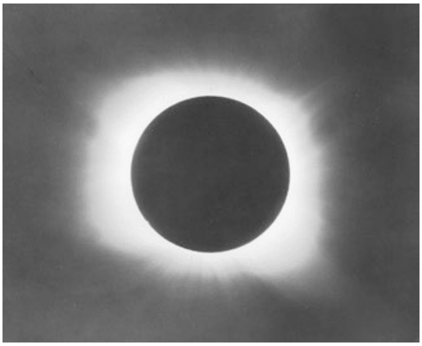


Fig. 26.7 A coronal image made with the 40-ft. Camera (8-s exposure) in 1898 (*Courtesy* Mary Lea Shane Archives)

calm professional manner. According to Campbell (1898a: 139), "It is plain that no astronomer was ever more ably assisted by volunteer observers."

Post eclipse, the plates were processed. The chemical plate developer formula had to be altered to accommodate the extreme range of temperatures from 93 °F in the daytime to a cold 42 °F at night and to allow for the humid climate (Campbell 1898a: 139). The plates were processed at night in moments of cool weather, and Campbell (1898a: 139) judged all of the negatives to be successful for their intended area of study. A print of one of the exposed plates is reproduced here in Fig. 26.7.

26.3.8 The Observations and Scientific Results

Campbell (1898a: 139) described totality: "… it is impossible to describe the beauty of the Sun's surroundings. The corona was exquisite more beautiful by far than anything else we saw in a journey around the world." (cf. Fig. 26.7).

From selected plates, he found a unique feature of streamers beautifully displayed with streamer hoods enclosing the prominences. There are no published reports that coronal structure analysis was conducted, even though a full range of cameras was employed, and Campbell judged the expedition a success (see Schaeberle 1898). Addressing the issue of coronal motion, Campbell (1898c) found:

> All the evidence given by the prominences leads to the conclusion that ... instead of rising from the sun's surface in irregular masses ... every prominence and protuberance visible during this eclipse was made of individual streams of matter apparently moving in elliptical orbits with the prominence at one of their foci.

In the spectrographic report there is mention of enclosed 'hoods' around the principal prominences. A strange series of 5303 λ line masses existed and were uniformly distributed in the equatorial region on either side of the Sun, but the 40-foot Camera plates did not reveal a correlation between these masses and prominences or curved streamers. Campbell wondered (1900b: 229–232) what forces might be at work and brought to the table the idea that radiant pressure may have been present.

Campbell's measurement of the wavelength of the coronal green line agreed closely with the value published by Norman Lockyer (Campbell 1899), but the spectrographic plates failed to provide him with information about the rotation of the solar corona (Campbell 1899).

After the eclipse, the expedition members packed up all of their equipment and the collection of plates. The plates were then sent home via Hong Kong on the stream ship *Socotra*, while the Campbells separated from the rest of the eclipse party and before setting off on a world tour visited Delhi, Agra and the Himalayas. They then stopped off at the observatories in Cairo, Rome, Florence, Milan, Nice, Paris, Greenwich, Tulse Hill, Kensington, Cambridge, Oxford and Williams Bay before finally returning to Lick Observatory (Campbell 1899).

26.4 Discussion

While scientific astronomy has a long history in India (see Kochhar 1991; Kochhar and Narlikar 1994; Kochhar and Orchiston 2017), solar astronomy was a phenomenon of the second half of the nineteenth century, when total solar eclipses in 1868, 1871 and 1898 attracted the attention of overseas and Indian-based astronomers. All three eclipses occurred at a time when the introduction of the spectroscope led to important advances in coronal science (Meadows 1970), and India would play a pivotal role in these developments.

The 1868 eclipse has a special place in astronomical history, as explained by Agnes Clerke (1893: 209; our italics):

> In the year 1868 *the history of eclipse spectroscopy virtually began* … On the 18th of August 1868, the Indian and Malayan peninsulas were traversed by a lunar shadow producing total obscuration during five minutes and thirty-eight seconds. Two English and two French expeditions were dispatched to the distant regions favoured by an event so propitious to the advance of knowledge, chiefly to obtain the verdict of the prism as to the composition of prominences.

As described in the previous chapter of this book (Orchiston et al. 2017), one of the British expeditions to India was mounted by the Royal Astronomical Society and led by Major J.F. Tennant (1869). They were based at Guntoor (see Fig. 26.8 for Indian localities mentioned in the text) and successfully carried out photographic, polarisation and spectroscopic observations. The second British expedition to India, based at Jamkandi, was led by Lieutenant John Herschel from the Indian Trigonometrical Survey. They used equipment supplied by the Royal Society and also succeeded in observing the eclipse (see Herschel 1869). There was also a local professional observing party which successfully observed the eclipse. This was led by Madras Observatory Director, Norman Pogson, and was based at Masulipatam, on the east coast, near Guntoor (Ranyard 1879). The sole French eclipse expedition to India was led by the celebrated Jules Janssen (Launay 2008), and also was based at Guntoor, less than a kilometre to the west of Tennant's compound. Janssen (1869) and his team also succeeded in observing the eclipse.

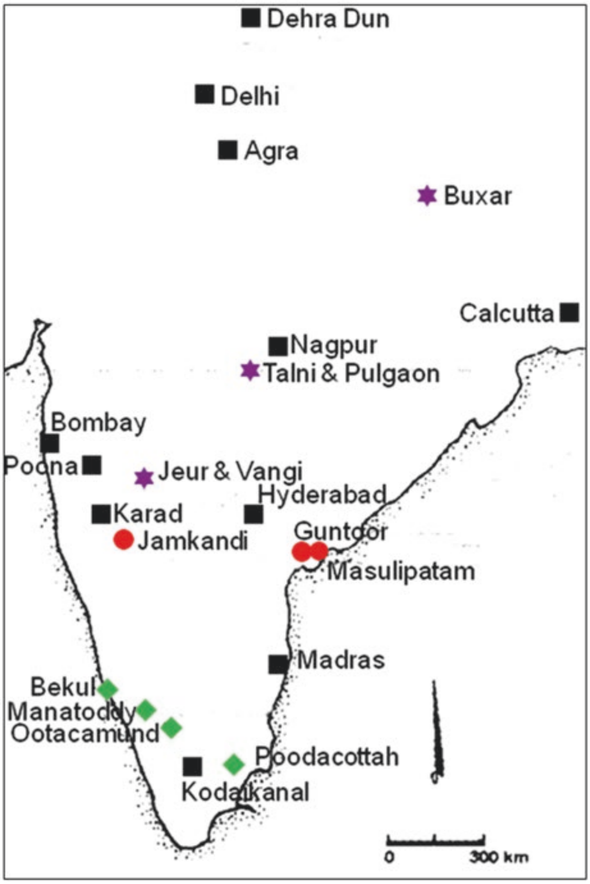


Fig. 26.8 Map of India showing localities mentioned in the text. Eclipse key: *red dots* = 1868 eclipse; *green diamonds* = 1871 eclipse; *purple stars* = 1898 eclipse (*Map* Wayne Orchiston)

During the 1868 eclipse, apart from an obvious corona (see Fig. 25.10), a remarkable feature of the eclipsed Sun was the ‘Great Horn’, a massive prominence that extended ~142,000 km beyond the solar limb (see Fig. 26.9). Collectively, the Indian observations of this eclipse confirmed the solar nature of the corona and showed that it shone by reflected sunlight. They also established the gaseous composition of the prominences and revealed emission lines associated with hydrogen, magnesium and helium (although this last-mentioned identification only came later).

Having another total solar eclipse that was also visible from India so soon after the success of the 1868 event meant that overseas expeditions again flocked to India in 1871. With the aid of British Government funding, Lockyer (1874) led a team of nine astronomers, who carried out successful observations from Bekul, Poodocottah and Manatoddy in India and two sites on the neighbouring island of

Fig. 26.9 A drawing of the 'Great Horn' (after Tennant 1869)

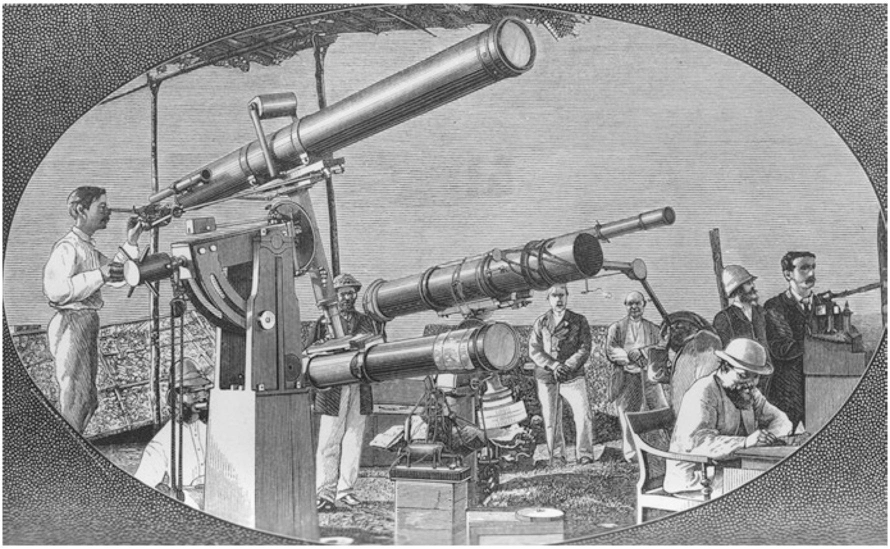


Fig. 26.10 Some of the instruments at Bekul ready for the 1871 eclipse (after Lockyer 1874: f343)

Ceylon (now Sri Lanka). This ambitious expedition (e.g. see Fig. 26.10) attracted general attention back in England, where it featured in the pages of *The Illustrated London News* (see The eclipse expedition … 1872). The well-known Italian astronomer, Lorenzo Respighi (1824–1889) was also based at Poodocottah (Janssen 1873). As might be anticipated, this eclipse also attracted Herschel and Tennant (1875), who joined forces and carried out successful observations from Dodabetta Peak near Ootacamund (see Fig. 26.8). Nor could the Madras Observatory miss this fine opportunity, and it mounted a successful eclipse expedition, using an observing

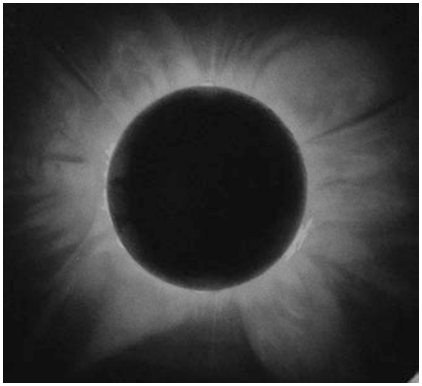


Fig. 26.11 A combination of images of the 1871 eclipse obtained by Tennant and Davis, showing fine coronal detail (after Ranyard 1879: plates)

site at Avenashi, which was also near Ootacamund. Meanwhile, Jules Janssen (1873; cf. Launay 1997) also returned to India, and recorded the eclipse from the village of Sholur in the Nilgiri Hills near Ootacamund (Mahias 2010).

Results from all of these Indian observations of the 12 December 1871 total solar eclipse consolidated those obtained in 1868, although one new area of special interest was the investigation of the coronal green line at 1471 K, which C.A. Young had discovered during the 7 August 1869 eclipse and assigned to 'coronium' (Maunder 1899). The 1871 total solar eclipse (see Fig. 26.11) therefore built on India's reputation as a place that could contribute in a meaningful way to solar science.

The 1898 solar eclipse offered India one final nineteenth-century opportunity to build on the legacy established in 1868 and 1871 and contribute to the rapidly-accumulating international knowledge of the solar corona. Apart from Lick Observatory's venture, various overseas expeditions headed for India. The British Astronomical Association (BAA) mounted an ambitious expedition, using two observing sites, and in a copiously-illustrated 184-page book, Edward Maunder (1899) provides a detailed account of this venture by some of Britain's leading amateur astronomers (e.g. see Figs. 26.12 and 26.13). One of the BAA camps was at Talni (see Fig. 26.8) where Maunder (1851–1928; Baum 2014) and John Evershed (1864–1956; Stratton 1957) carried out spectroscopic observations (Maunder 1899: 4–28), while the other was at Buxar (Fig. 26.8) where successful photographic observations were made (Maunder 1899: 31–46).

Just 9.5 km from Talni, at the site of Pulgaon, the British Government party led by E.H. Grove-Hills (1864–1922) and H.F. Newall (1857–1944; Hearnshaw 2014) carried out successful spectroscopic observations (Grove-Hills and Newall 1898), while the Astronomer Royal of Scotland, Dr. Ralph Copeland (1837–1905; Marché 2014b), made his observations from the site of Ghoghlee, 16 km north-west of Nagpur (Copeland 1898).

At Jeur three other parties were sited near to the Lick Observatory eclipse camp. Immediately adjacent to the Lick astronomers was a group from the College of Science in Poona (Fig. 26.14) under Professor K.D. Naegamvala (1902), and just

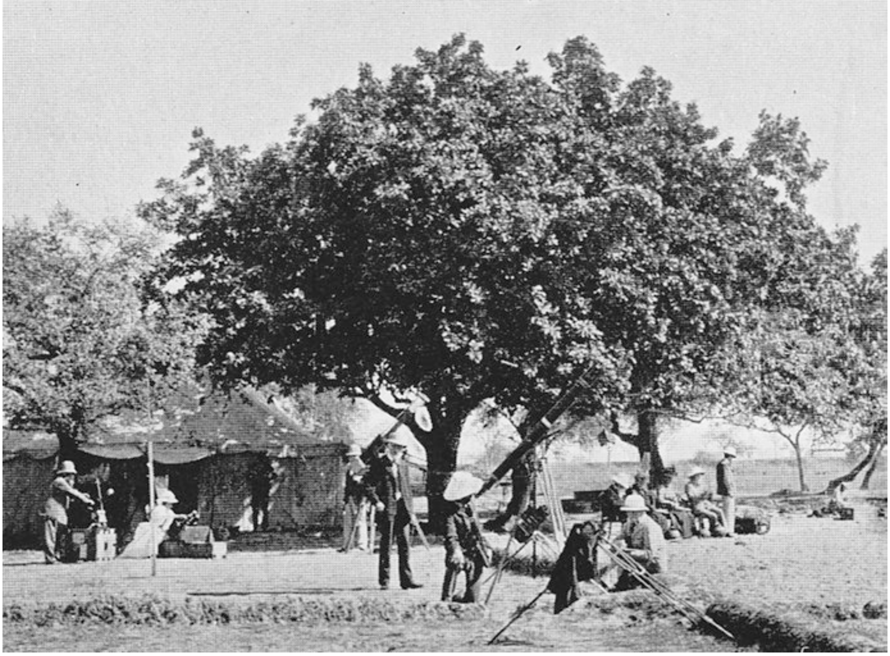


Fig. 26.12 Part of the BAA eclipse camp at Buxar with various instruments being readied for the 1898 eclipse (after Maunder 1899: 42)

Fig. 26.13 The BAA eclipse camp at Talni in 1898 (after Maunder 1899: 15)

90 m from them was the Japanese team from Tokyo University led by Professor Hisashi Terao (1855–1923; Terao and Hiryama 1910; see Figs. 2.8 and 2.9 in this *Asian Astrophysics* book). A little further away, adjacent to the village of Vangi, was a U.S. party from Chabot Observatory led by Professor Burckhalter (1898).

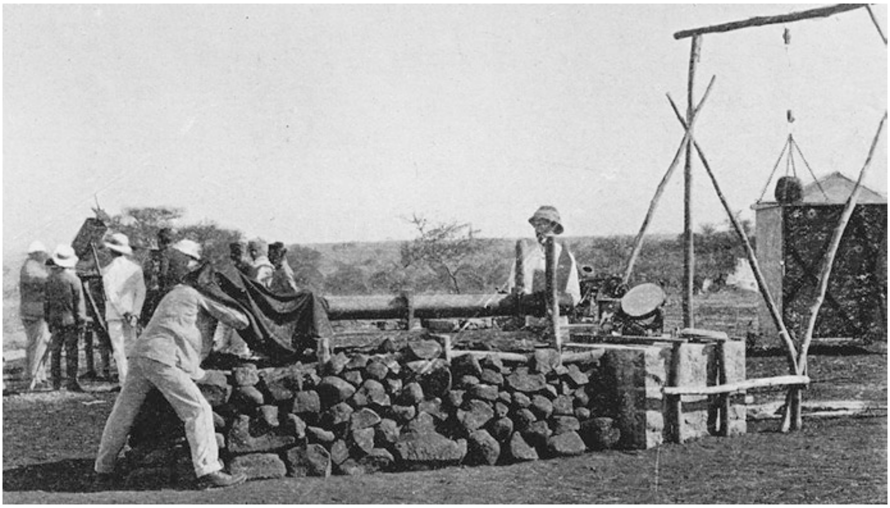


Fig. 26.14 Professor Naegamvala's horizontal photographic telescope at Jeur in 1898 (after Maunder 1899: 81)

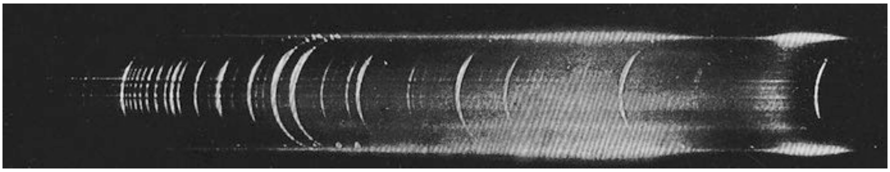


Fig. 26.15 Example of one of the photographs of the flash spectrum obtained by BAA observers in 1898 (after Maunder 1899: 73)

All carried out successful observations, and one of the notable successes during this eclipse was the photographs taken of the flash spectrum (e.g. see Fig. 26.15). Although this unusual spectrum was first observed during the 22 December 1870 eclipse by Professor Young, the first successful attempt to photograph it only occurred in 1896 (Maunder 1898), and the images of it obtained during the 1898 Indian eclipse marked a major advance.

26.5 Concluding Remarks

When combined with the excellent daytime seeing condition that typified parts of the Indian Subcontinent, the cumulative effect of the 1868 and 1871 solar eclipse expeditions on Indian astronomy was profound, and led to the establishment (with aid

Fig. 26.16 The original building at Kodaikanal Observatory (https://en.wikipedia.org)

from the Solar Physics Committee in England) of a solar observatory at Dehra Dun, in northern India, in 1878 (Kochhar 1991). It was hoped that regular solar photography would aid our understanding of the Sun and its role in the monsoonal weather patterns, which was vital for the survival of rural and urban communities in India. Solar photography continued at Dehra Dun until 1925 (Kochhar 2002).

However the foundations of a more permanent solar facility rested on the initiative of those at Madras Observatory, and

> At the Indian Observatories Committee meeting of July 20, 1893 with Lord Kelvin in the Chair, the decision was taken to establish a Solar Physics Observatory at Kodaikanal with Michie Smith as Superintendent … The observatory was to be under the control of the Government of India … (Bappu 2000: 105).

This was the genesis of Kodaikanal Observatory (Fig. 26.16), which formally came into existence on 1 April 1899 and since 1901 has continued to make a valuable and ongoing contribution to solar physics (see Bappu 2000; Kochhar 2002). Kodaikanal Solar Observatory is now owned and operated by the Indian Institute of Astrophysics.

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References

Bappu, M.K.V. (2000). The Kodaikanal Observatory – a historical account. *Journal of Astrophysics and Astronomy, 21,* 103–106.

Baum, R. (2014). Maunder, Edward Waler. In Hockey, pp. 1420–1421.

Burckhalter, C. (1898). A general account of the Chabot Observatory-Pierson eclipse expedition to India. *Publications of the Astronomical Society of the Pacific, 10,* 203–212.

Campbell, E.B., (n.d.). *In the Shadow of the Moon: India, January 22, 1898.* SA. 1898 Eclipse file, 1–200 (undated diary).

Campbell, W.W. (1897). Unpublished document, dated 25 March. SA, microfilm, v59, 249-250.

Campbell, W.W. (1898a). A general account of the Lick Observatory-Crocker Eclipse Expedition to India. *Publications of the Astronomical Society of the Pacific, 10,* 127–140.

Campbell, W.W. (1898b). Memo to Burckhalter, dated 17 May. SA, Campbell Letter File.

Campbell, W.W. (1898c). Letter to Hale, dated 19 April 19. SA, Microfilm v60, 381.

Campbell, W.W. (1899). The wave-length of the green coronal line, and other data resulting from an attempt to determine the law of rotation of the solar corona. *Astrophysical Journal, 10,* 186–192.

Campbell, W.W. (1900a). Observations of the second and third contacts at the solar eclipse of 1898 January 22, in India. *Astronomical Journal, 20,* 144–145.

Campbell, W.W. (1900b). Some spectrographic results obtained at the Indian eclipse by the Lick Observatory-Crocker Expedition. *Astrophysical Journal, 11,* 226–233.

Campbell, W.W. (1907). The Lick Observatory Expedition of 1905. *Chronicle* IX: 1, University of California at Berkeley, University Press, June.

Clerke, A.M. (1893). *A Popular History of Astronomy during the Nineteenth Century*. London: Adam & Charles Black.

Copeland, R. (1898). Total solar eclipse of January 22 1898. Report on observations made at Ghoglee, Central Province. *Proceedings of the Royal Society, 64,* 21–26.

Frost, E.B. (1913). Biographical memoir of Charles Augustus Young. *Biographical Memoirs, National Academy of Sciences, 7,* 89–114.

Grove-Hills, E.H., & Newall, H.F. (1898). Total solar eclipse of 1898 January 22. Preliminary report on the observations made at Pulgaon, India. *Proceedings of the Royal Society, 64,* 43–61.

Hearnshaw, J. (2014). Newall, Hugh Frank. In Hockey, pp. 1561–1563.

Herschel, J. (1869). Account of the solar eclipse of 1868, as seen at Jamkandi, in the Bombay Presidency. *Proceedings of the Royal Society, 17,* 104–120.

Hockey, T. (Ed.) (2014). *Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Holden, E.S. (1897a). Letter to C. Burckhalter at the Chabot Observatory, dated 25 August. SA, v59, 480-481.

Holden, E.S. (1897b). Letter to Maunder, dated 21 June. SA, microfilm v58, 466.

Holden, E.S. (1897c). Letter to R.S. Ball, President of the Royal Astronomical Society, dated 24 June. SA, microfilm v58, 485.

Janssen, J. (1869). Observations spectrale prises pendant l'éclipse du 18 Août 1868, et méthode d'observation des protubérances en dehors des éclipses. *Comptes Rendus de l'Académie des Sciences, 68,* 367–376 (in French).

Janssen, J. (1873). Rapport relatif à l'observation de l'éclipse du 12 décembre 1871, addressé par M.J. Janssen au Ministre de l'Instruction Publique. *Journal Officiel de la République Française*, Jan. 16: 312–313; Jan 19: 392–394; Jan. 20: 408–409 (in French).

Kochhar, R.H. (1991). The growth of modern astronomy in India 1651–1960. *Vistas in Astronomy, 34,* 69–105.

Kochhar, R. (2002). Madras and Kodaikanal Observatories: a brief history. *Resonance*, August, 18–28.

Kochhar, R., & Narlikar, J. (1994). *Astronomy in India, A Perspective*. New Delhi: Indian National Science Academy.

Kochhar, R., & Orchiston, W. (2017). The development of modern astronomy and emergence of astrophysics in India. In T. Nakamura & W. Orchiston.

Launay, F. (1997). Autour de l'éclipse de soleil en Indie le 12 décembre 1871. Le voyage du couple Janssen aux Neelgherries. *L'Astronomie, 111,* 111–115 (in French).

Launay, F. (2008). *Un Globe-trotter de la Physique Céleste, L'Astronome Jules Janssen*. Paris, Vuibert and L'Observatoire de Paris (in French).

Lindner, R.P. (2014). Hussey, William Joseph. In Hockey, pp. 1032–1033.

Lockyer, N. (1874). *Contributions to Solar Physics*. London: Macmillan.

Mahias, M.-C. (2010). The black Sun of the Nilgiris: astronomy, photography and physical anthropology in South India. *Visual Anthropology, 13,* 129–148.

Marché, J.D. II (2014a). Ball, Robert Stawell. In Hockey, pp. 151–152.

Marché, J.D. II (2014b). Copeland, Ralph. In Hockey, pp. 460–461.

Maunder, E.W. (1898). The spectroscope in eclipse work. *Observatory*, 21, 308–312.

Maunder, E.W. (ed.) (1899). *The Indian Eclipse 1898. Report of the Expeditions Organized by the British Astronomical Association to Observe the Total Solar Eclipse of 1898, January 22*. London: Hazell, Watson and Viney.

Meadows, A.J. (1970). *Early Solar Physics*. Oxford: Oxford University Press.

Naegamvala, K.D. (1902). *Report on the Total Solar Eclipse of January 21–22, 1898, as Observed at Jeur in Western India*. Bombay: Government Printer.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Orchiston, W., Lee, E.-H., & Ahn, Y.-S. (2017). British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In T. Nakamura, & W. Orchiston.

Orchiston, W. & Pearson, J. (2011). The Lick Observatory solar eclipse expedition to Jeur (India) in 1898. In T. Nakamura, W. Orchiston, M. Sôma, & R. Strom (Eds.), *Mapping the Oriental Sky. Proceedings of the Seventh International Conference on Oriental Astronomy* (pp. 197–206). Tokyo: National Astronomical Observatory of Japan.

Osterbrock, D.E. (1984). The rise and fall of Edwin S. Holden. *Journal for the History of Astronomy, 15,* 81–127, 151–176.

Pearson, J.C. (2009). *The Role of the 40 Foot Schaeberle Camera in the Lick Observatory Investigations of the Solar Corona*. Unpublished Ph.D. thesis, James Cook University, Townsville, Australia.

Pearson, J.C., & Orchiston, W. (2008). The 40-foot solar eclipse camera of the Lick Observatory. *Journal of Astronomical History and Heritage, 11,* 25–37.

Pearson, J.C., Orchiston, W., & Malville, J.McK. (2011). Some highlights of the Lick Observatory's solar eclipse expeditions. In Orchiston, W., Nakamura, T., & Strom, R. (eds.). *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the 6th International Conference on Oriental Astronomy* (pp. 243–337). New York: Springer.

Ranyard, A.C. (1879). Observations made during total solar eclipses. *Memoirs of the Royal Astronomical Society, 41,* 1–792 (plus plates).

Schaeberle, J.M. (1890a). A mechanical theory of the solar corona. *Publications of the Astronomical Society of the Pacific, 2,* 68–70.

Schaeberle, J.M. (1890b). The solar corona. *Publications of the Astronomical Society of the Pacific, 2,* 260.

Schaeberle, J.M. (1890c). A mechanical theory of the solar corona. *Monthly Notices of the Royal Astronomical Society, 50,* 373.

Schaeberle, J.M. (1891a). Some physical phenomena involved in the mechanical theory of the corona. *Publications of the Astronomical Society of the Pacific, 3,* 71–73.

Schaeberle, J.M. (1891b). A mechanical theory of the solar corona by J.M. Schaeberle. *Contributions of the Lick Observatory, 2*. 47–103.

Schaeberle, J.M. (1893). The Dallmeyer lens of the eclipse expedition. *Publications of the Astronomical Society of the Pacific, 5,* 230.

Schaeberle, J.M. (1895). *Report of the Total Eclipse of the Sun, observed at Mina Bronces, Chile, on April 16, 1893*. Contributions from the Lick Observatory No.4. Regents of the University of California, State Printing. 1895.

Schaeberle, J.M. (1897). Letter to Campbell, dated 15 October. SA, Campbell letter file 292-298.

Schaeberle, J.M. (1898). Solar eclipse expedition of the Lick Observatory. *Astronomical Journal, 18,* 152.

Stratton, F.J.M. (1957). John Evershed. *Biographical Memoirs of Fellows of the Royal Society, 3,* 41–51.

Tennant, J.F. (1869). Report on the total eclipse of the Sun, August 17–18, 1868 … *Memoirs of the Royal Astronomical Society, 37,* 1–55.

Tennant, J.F. (1875). Report of observations of the total eclipse of the Sun on December 11–12, 1871, made by order of the Government of India, at Dodabetta, near Ootacamund. *Memoirs of the Royal Astronomical Society, 42,* 1–33.

Terao, H., & Hirayama, S. (1910). Report on the Total Solar Eclipse of the Sun observed at Jeur, in Western India on January 22, 1898. *Annales de l'Observatoire Astronomique de Tokyo, III*(1).

The eclipse expedition in India. *The Illustrated London News*, 10 January 1872.

Wright, W.H. (1949). William Wallace Campbell. *Biographical Memoirs, National Academy of Sciences, 25,* 35–74.

Chapter 27
The Early Development of Indian Radio Astronomy: A Personal Perspective

Govind Swarup

27.1 Introduction

There are many instances in the field of astronomy where initial pioneering work at field stations has led to the development of major instruments for the investigation of the mysteries of the Universe. Although Karl Jansky serendipitously discovered radio emission from our Galaxy in 1931 while working at the Bell Labs in USA, active research in the field of radio astronomy only started after 1945, following developments in electronics and radar engineering during WWII (see Sullivan 1984, 2009). The discoveries made between 1945 and 1955 at Sydney, Cambridge, Harvard, Jodrell Bank and Leiden laid a firm foundation for the new field of radio astronomy. In this chapter, I describe my initiation into the field of radio astronomy in Australia during 1953–1955 (see Swarup 2006); my contributions during 1956–1963 in the USA; early attempts by Sir K.S. Krishnan to form a radio astronomy group at the National Physical Laboratory in New Delhi (for Indian localities mentioned in the text see Fig. 27.1); and the subsequent development of radio astronomy at the Tata Institute of Fundamental Research (TIFR) in Mumbai, as a result of initial support given by Dr. Homi J. Bhabha (who was one of the main architects of the growth of modern science in India). For further details, also see Swarup (1997, 2014).

Radio astronomical research is also being carried out at other institutions in India, mainly at the Raman Research Institute (Bangalore), the Indian Institute of Astrophysics (Bangalore) and the Physical Research Institute (Ahmedabad). The facilities developed by these institutes are described on their websites. There has been a close collaboration between the TIFR and the Raman Research Institute, where Professor V. Radhakrishnan (1929–2011) established a radio astronomy group in 1971, after spending nearly 20 years abroad (mostly at Caltech in the

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Historical & Cultural Astronomy, DOI 10.1007/978-3-319-62082-4_27

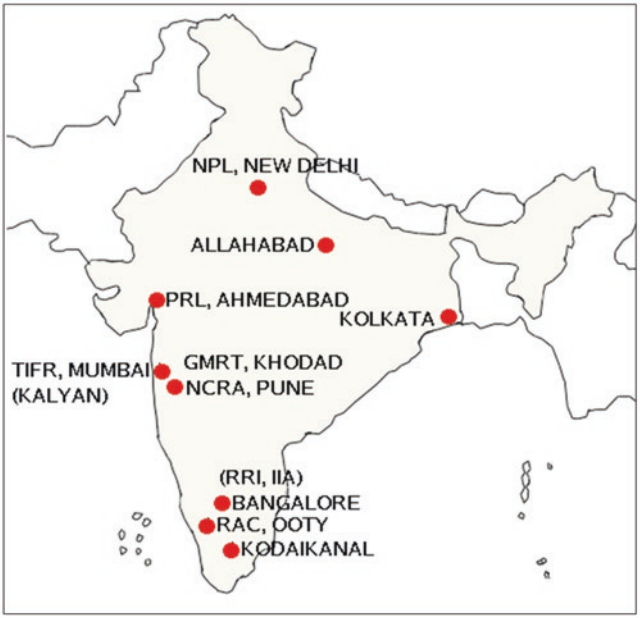

Fig. 27.1 Indian localities mentioned in the text (*Map* Govind Swarup)

USA, and at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia).

27.2 The Initial Years

After obtaining an M.Sc. degree in Physics from Allahabad University (India) in 1950, I joined the National Physical Laboratory (NPL) of the Council of Scientific and Industrial Research (CSIR) in New Delhi, and worked in the field of paramagnetic resonance under the guidance of K.S. Krishnan (1898–1961; Fig. 27.2), who was the Director of the Laboratory. During 1946–1947 he had taught me Electricity and Magnetism in the first year of the B.Sc. degree at Allahabad University before moving to the NPL. Krishnan was the co-discoverer of the Raman Effect which won C.V. Raman (1888–1970) the Noble Prize in Physics. Later Krishnan shifted his research interests to the field of magnetism, and he asked me to develop equipment that could be used to investigate the phenomena of electronic para-magnetic resonance at a wavelength of 3 cm. Over the next 18 months, I was able to set up equipment by cannibalizing surplus radar sets procured by the NPL, and by studying parts of the remarkable set of 28 volumes of the Radiation Laboratory Series that described almost all the radar techniques that were developed during WWII.

In August 1952 Krishnan attended the General Assembly of the International Radio Scientific Union (URSI) in Sydney (Robinson 2002) and he was struck by the dramatic and remarkable discoveries being made in the field of radio astronomy by

Fig. 27.2 Dr. K.S. Krishnan, Director of the National Physical Laboratory, New Delhi (*Courtesy* National Physical Laboratory)

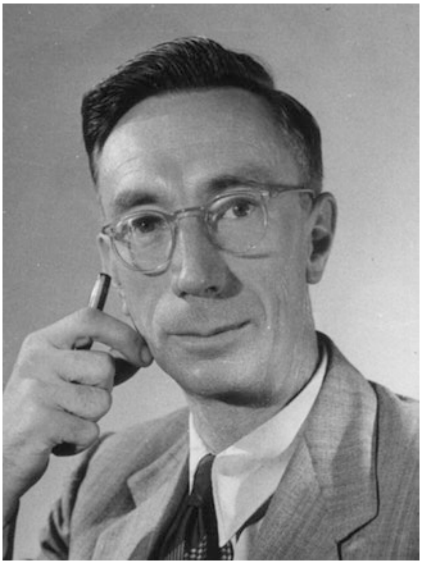

Fig. 27.3 Dr. J.L. Pawsey, leader of the radio astronomy group within the CSIRO's Division of Radiophysics in Sydney (*Courtesy* CSIRO RAIA: 7454-2)

staff from the CSIRO's Division of Radiophysics (RP). Under the inspired leadership of Joseph Lade (Joe) Pawsey (1908–1962; Fig. 27.3; Lovell 1964), several ingenious radio telescopes had been developed by the Australian scientists to investigate radio emission from the Sun and distant cosmic sources in our Galaxy (see Davies 2005; Orchiston and Slee 2017; Sullivan 2009, 2017).

On his return to India, Krishnan described these developments in a colloquium at the NPL, and these caught my imagination. I then visited the NPL library, where I studied some of the 30 papers that had been published by the RP scientists in the *Australian Journal of Scientific Research* and in *Nature* describing these discoveries.

I was told that these were almost half of the papers on radio astronomy that had been published worldwide up to that time. I, too, was fascinated by this new field. Krishnan was also interested in initiating radio astronomical research at the NPL, and he put my name forward for a 2 year Fellowship under the Colombo Plan to work at RP in Sydney.

27.3 My Introduction to Radio Astronomy, and the Grating Interferometers at Potts Hill

The Colombo Plan application was successful, and in March 1953 R. Parthasarathy from the Kodaikanal Observatory (in South India) and I joined RP to work under Pawsey's guidance (Fig. 27.4).

Australian-born Joseph Lade Pawsey was a scientific leader *par excellence*. In 1931 he obtained a Cambridge Ph.D. under J.A. Ratcliffe (1902–1987) in the field of ionospheric research, and then spent several years working on antennas and

Fig. 27.4 Govind Swarup (*left*) and R. Parthasarathy (*right*) at Potts Hill field station in 1954. At this time, searches were being made for 21 cm hydrogen emission in the Milky Way with this 16 × 18 ft ex-radar antenna (after *Illustrated Weekly Times of India* 1954)

transmission lines in the television industry in UK before returning to Australia and joining the newly formed Division of Radiophysics, which was involved in radar research. In October 1945, as the War ended, he initiated a study of the Sun using a radar installation in suburban Sydney (Orchiston et al. 2006). This produced immediate results which led to further successful studies, and the small RP radio astronomy group never looked back! In a pioneering paper published in *Nature* in 1946, Pawsey announced that radio emission from the Sun arises from a hot corona at a temperature of 10^6 K. Soon, several different research groups were formed at RP (Orchiston and Slee 2017; Sullivan 2009), and under Pawsey's guidance they conducted detailed investigations of radio emission from the Sun, our Galaxy and distant extragalactic radio sources, with new discoveries being made every few months!

After finding that my interest was more in experimental rather than theoretical work,[1] Pawsey suggested that I work for 3 months each in the groups led by W.N. Christiansen, J.P. Wild, B.Y. Mills and J.G. Bolton. Each of these scientists (see Fig. 27.5) had made important discoveries, and they were already acknowledged world leaders in their respective fields. I was to report back to Pawsey every 2 weeks. Stefan F. (Steve) Smerd (1916–1978; Wild 1980), a very pleasant man but a tough task master, was asked to coordinate my activities and to provide me with guidance on the rapidly growing literature in radio astronomy. For his part, Parthasarathy was

Fig. 27.5 Some of the distinguished radio astronomers who attended the 1952 URSI Congress in Sydney. Chris Christiansen, Paul Wild and Bernie Mills (in the *dark* suit) are first, third and fifth from the left respectively, and Steve Smerd is in the front row immediate to the right of Mills. John Bolton is the man on the extreme right of the group photograph (*Courtesy* CSIRO RAIA: 2842-43)

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[1] Pawsey remarked that I was unlike most Indians, who preferred theoretical work.

to develop a 10.7 cm solar radio telescope, as this was needed by the Kodaikanal Observatory (which had a long history of solar observations at optical wavelengths—see Kochhar and Orchiston (2017)—and now wanted to expand into radio astronomy). Then, after the first year, Parthasarathy and I would select a joint project. What a great opportunity for initiation into the new field of radio astronomy!

For the first 3 months (see Swarup 2008) I assisted Wilbur Norman (Chris) Christiansen (1913–2007; Frater and Goss 2011; Wendt et al. 2011a) and J.A. (Joe) Warburton (1923–2005; Joseph Aubrey Warburton 2005) to make a two dimensional map of the quiet Sun at a wavelength of 21 cm, using strip scans obtained with the E-W and a N-S grating interferometers at the Potts Hill field station (see Wendt et al. 2008, 2011b)—which are shown in Figs. 27.6 and 27.7). I first Fourier transformed each scan manually using an electrical calculator, plotted the outputs on large graph paper along respective angles of the scans, scanned the resulting 2-dimensional Fourier-transformed map at various angles and again reversed the process thereby obtaining a map of the quiet Sun at 21 cm. The final result, after Christiansen and Warburton (1955), is shown in Fig. 27.8. I highlight this work here in some detail because a decade later that painstaking experience gave me an idea of a simpler scheme to make maps from one-dimensional scans without taking Fourier transforms. The new concept was described by me to Ronald N Bracewell in late 1962, just before I returned to India from Stanford. In this method, a 2-dimensional map can be readily obtained by multiplying amplitudes of each of

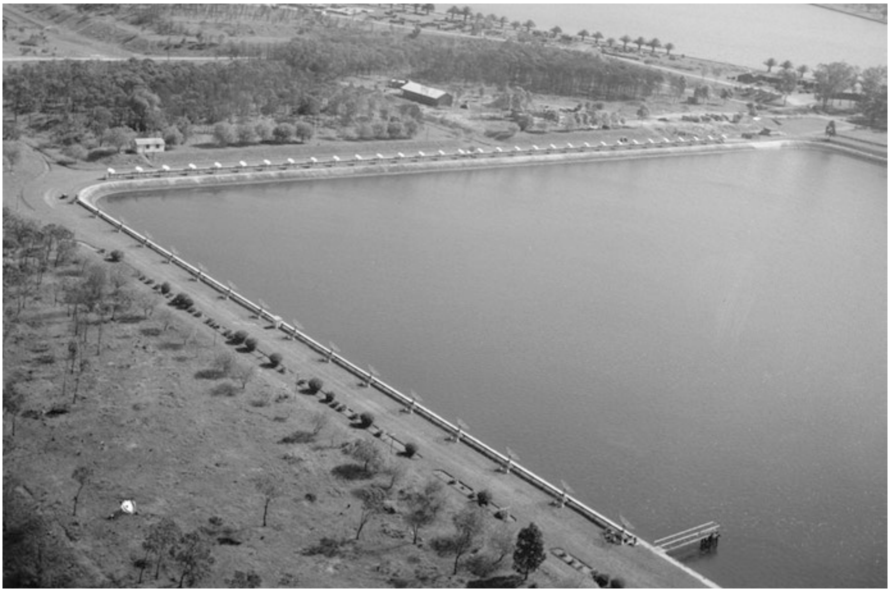

Fig. 27.6 A view looking south-west across the two Potts Hill water reservoirs in 1953, showing Christiansen's solar grating arrays along the banks of the eastern reservoir. The E–W array consisted of 32 elements and the nearer N–S array just 16 elements (*Courtesy* CSIRO RAIA: 3475-1)

Fig. 27.7 A view looking east along the E–W grating array (*Courtesy* CSIRO RAIA B2638-2)

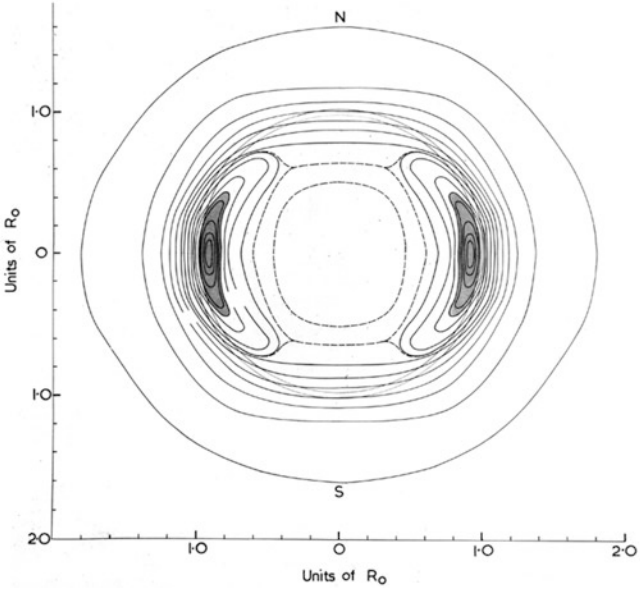

Fig. 27.8 Isophote map of the quiet Sun at 21 cm, showing equatorial limb-brightening (*Courtesy* CSIRO RAIA: B3400-3)

the one-dimensional strip scans by appropriate weights and then plotting the resulting modified scans along corresponding scan-angles, in order to obtain a 2-dimensional map (Bracewell and Riddle 1967). This technique is widely used today in X-ray imaging and has revolutionized medical tomography.

During the next 3 months, under the guidance of J. Paul Wild (1923–2008; Frater and Ekers 2012; Stewart et al. 2011b), J.A. (Jim) Roberts and I developed a 45 MHz receiver that was then used at the Dapto field station to determine the velocity of ionospheric turbulence (see Stewart et al. 2011a). After this, I spent 3 months developing a phase-shifter for the prototype Mills Cross antenna that Bernard Yarnton (Bernie) Mills (1920–2011; Frater et al. 2013) and Alec Little (1925–1985) were building at Potts Hill field station (see Mills and Little 1953), and for the final 3 months of the first year I worked in the Dover Heights group led by John G. Bolton (1922–1993; Robertson 2015), and made a highly stable D.C. power supply.

In 1954, Christiansen went to work at Meudon Observatory in France for a year. After discussions with Pawsey, Parthasarathy and I decided to convert the Potts Hill E-W grating array (Fig. 27.7) from 21 to 60 cm (500 MHz), in order to investigate whether the quiet Sun exhibited limb brightening at that frequency. This was predicted by Smerd (1950), but was in conflict with measurements made at Cambridge by Stanier (1950). Our results (Swarup and Parthasarathy 1955, 1958) agreed with Smerd's prediction. For us, this was a great experience: building dipoles, a transmission line network and a receiver system; making the observations; and finally, carrying out data reductions—not to mention saving my dear friend Parthasarathy from drowning in the Potts Hill reservoir! At the time he was using a bucket to draw some water from the Reservoir so that we could make a cup of tea and wash our faces (after a day of hard work), and he accidentally fell into the water.

Upon his return from France in early 1955, Christiansen decided to build a new cross-type antenna array at RP's Fleurs field station near Sydney. Known as the 'Chris Cross', this consisted of two orthogonal grating interferometers, which were used to make daily solar maps at 21 cm (see Orchiston 2004; Orchiston and Mathewson 2009). As a result, all 32 of the 6-ft diameter dishes making up the E-W grating array at Potts Hill, along with associated equipment, became surplus to requirements and were to be scrapped. Pawsey liked to visit all the RP field stations unannounced to see what his staff were doing (Sullivan 2017), and during one of his surprise visits to Potts Hill I asked whether these dishes could be gifted to India. He readily agreed to this suggestion, as did E.G. (Taffy) Bowen (1911–1991), Chief of the Division of Radiophysics.[2] On 23 January 1955, I wrote to K.S. Krishnan about the possibility of transferring the 32 dishes from Sydney to the NPL in New Delhi (Swarup 1955). I proposed simultaneous dual frequency observations with a 2100-ft long grating interferometer using the 32 dishes at 60 cm and 1.8 m. On 22 February Krishnan (1955) replied: "I agree with you that we should be able to do some radio

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[2] Dr. Bowen had played an important role in the development of radar in the UK and the USA during the War years. After joining RP, rain-making and upper atmospheric physics became his personal fields of research, but throughout his directorship he continued to provide vital support for the growth of radio astronomy within the Division. His principal legacy must surely be the 64-m Parkes Radio Telescope (see Robertson 1992).

astronomy work even with the meager resources available." Pawsey obtained approval from the CSIRO authorities for the donation of the dishes to India under the Colombo Plan scheme, but with the proviso that India must bear the cost of their transportations (which amounted to about 700 Australian Pounds, as I recall).

27.4 Radio Astronomy at the National Physical Laboratory

Upon my return to New Delhi in August 1956, Krishnan gave approval to start a radio astronomy program at the NPL. I then began building a sensitive receiver system for operation at 500 MHz. However, Krishnan could not get approval from the CSIR authorities in New Delhi for transfer of the dishes from Sydney. Instead, the CSIR had suggested that the Australian authorities should bear the cost of transportation, considering the shortage of foreign exchange in India at the time, but this request was turned down. As there seemed to be no early resolution to the tangle, later in 1956 I decided to go to the USA for a year or two. Meanwhile, Parthasarathy had also joined the NPL in 1956, and he went on to build a 10.7 cm receiver, but left the NPL in the following year and joined C.G. Little's group in Alaska. T. Krishnan (b. 1933) also joined the NPL in 1956, after completing the physics tripos at Cambridge and spending a year working with Martin Ryle. In late 1958 he joined RP to work with Pawsey and Christiansen (Fig. 27.9). Dr. M.R. Kundu (1930–2010) joined the NPL in 1958 after completing his Ph.D. in solar radio astronomy in

Fig. 7.9 W.N. Christiansen (*left*) and T Krishnan (*right*) at Fleurs field station in front of one of the Chris Cross antennas (Krishnan collection)

France (see Orchiston et al. 2009), but also went to the USA soon afterwards. M.N. Joshi (1933–1988) and N.V.G. Sarma (1932–2008) joined the NPL soon after finishing their M. Sc. degrees in India in 1956, and they built a 500 MHz receiver for the proposed grating array. Later, Joshi went to France for a Ph.D. degree, which he obtained in 1962. For his part, Sarma spent 2 years at Leiden Observatory, where he built radio astronomy receivers. Both he and Joshi subsequently returned to India and joined the NPL. In the meantime, CSIRO eventually paid for the transport of the 32 Potts Hill dishes to New Delhi. Thus, it may be said that the NPL acted as a foster mother for the subsequent development of radio astronomy in India by the above persons, who were trained across the world.[3]

27.5 Indian Radio Astronomers in the USA in the Early Years

I joined the Fort Davis Radio Astronomy Station of the Harvard Observatory in August 1956. This Texas field station (Thompson 2010) was set up by Dr. Alan Maxwell (b. 1926), a New Zealander with a Ph.D. from Manchester, in order to record the dynamic spectra of solar radio bursts over the frequency range 100–600 MHz using a swept-frequency receiver connected to a 28-ft dish (Fig. 27.10). In December 1956 I discovered the Type U burst while Maxwell was on a holiday in New Zealand (Maxwell and Swarup 1958). In early 1957, I decided to work for a Ph.D. degree in the USA and received favourable responses from Harvard, Caltech and Stanford, all of which were already active in radio astronomy (e.g. see Bracewell 2005; Cohen 1994; Kellermann et al. 2005). Pawsey (1957) wrote:

> Stanford is famous for radio engineering, Caltech for its physics and, of course, its astronomy research, and Harvard for its training in astronomy … If you are returning to India, I should recommend to you to place great emphasis in electronics. It is a key to open many doors.

I decided to join Stanford University, and in September 1957 began Ph.D. research under the guidance of Australian-born Ronald N. Bracewell (1921–2007; Thompson and Frater 2010), who was in the process of building a cross-antenna interferometer (Fig. 27.11; Bracewell 2005) that would be used to generate daily solar maps at 9.2 cm (Bracewell and Swarup 1961). Fig. 27.12, which was taken in about 1960, shows the two of us examining solar records obtained with the interferometer. On 1 January 1961, soon after obtaining my Ph.D. degree, I joined the University as an Assistant Professor.

After graduating from the Indian Institute of Science in Bangalore in 1950, T.K. Menon (Fig. 27.13) went to Harvard University in 1952, where he completed M.S. and Ph.D. degrees. He was on the faculty of the Astronomy Department from 1956 to 1958, before joining the (U.S.) National Radio Astronomy Observatory in

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[3] In recent years, tens of radio astronomers and engineers have migrated from India to observatories around the world, thus proving that the Earth is round!

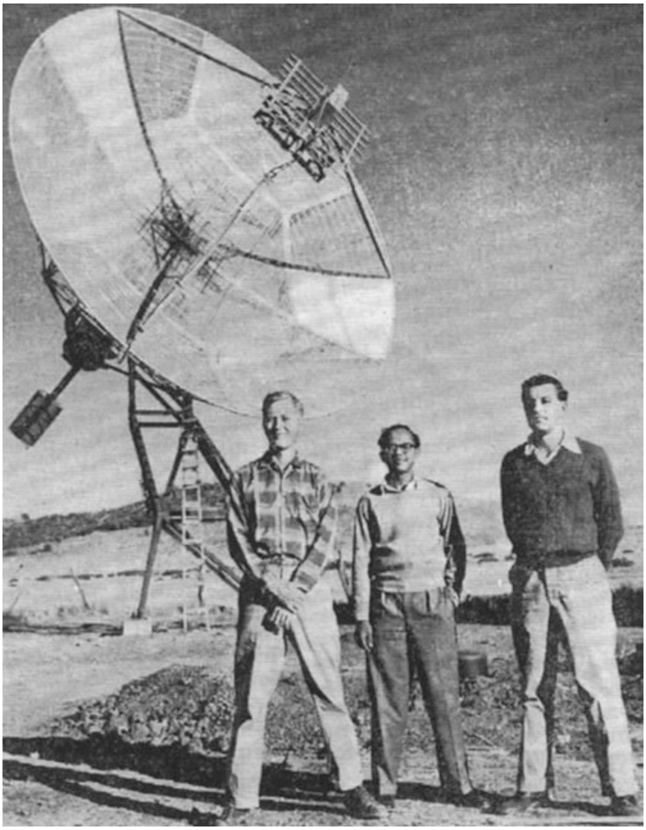

Fig. 27.10 Alan Maxwell, Govind Swarup and Sam Goldstein (*left* to *right*) posing in front of the 28-ft dish at Harvard Observatory's Fort Davis field station in Texas (Swarup Collection)

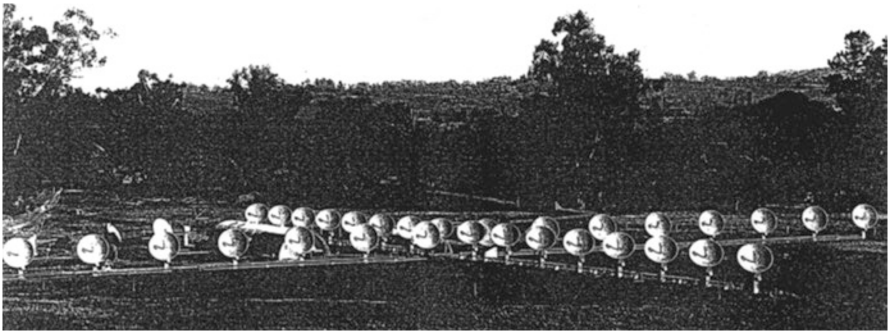

Fig. 27.11 The completed Stanford 9.2 cm cross-antenna interferometer (after Bracewell 2005: 75)

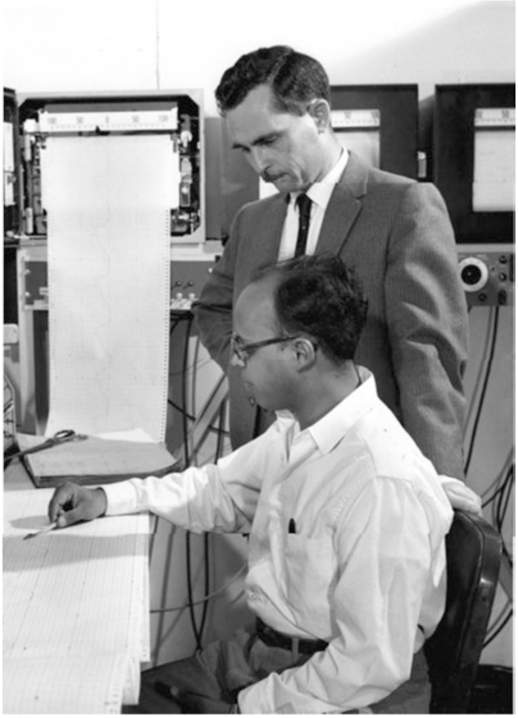

Fig. 27.12 Ron Bracewell and Govind Swarup examining solar records (*Courtesy* Stanford University News Service)

Fig. 27.13 T.K. Menon (*left*) and M.R. Kundu (*right*) at the Berkeley IAU General Assembly in 1961 (Menon Collection)

1959 as one of the senior scientists. He went on to make pioneering contributions to the studies of HII regions and HI clouds in our Galaxy.

In 1958, M.R. Kundu (Fig. 27.13) joined the radio astronomy group led by Fred Haddock at the University of Michigan, and he soon became an internationally recognized leader in the field of solar radio astronomy.

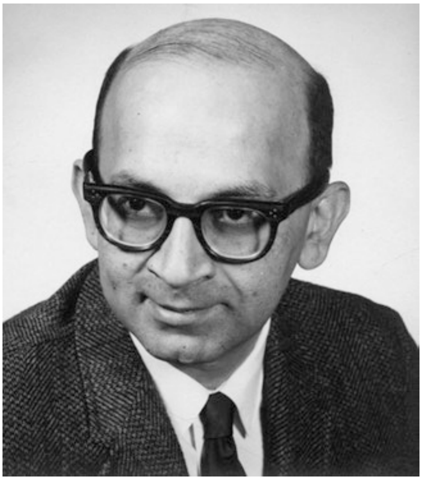

Fig. 27.14 T Krishnan in India in 1970 (Krishnan Collection)

During meetings of the American Astronomical Society and of the URSI chapter in the USA, on several occasions the three of us working in USA discussed the possibility of returning to India and forming a major radio astronomy group. In 1960 and 1961, I also corresponded with Christiansen, Frank J. Kerr (1918–2000) and Pawsey in this regard. They recommended to us T. Krishnan (Fig. 27.14), who was then at the University of Sydney. Then on 22 September 1960, Christiansen (1960) wrote "… you two and Menon and Kundu should get together for a united attack on the monolith of Indian bureaucracy….", and on 26 October Pawsey (1960) wrote: "But keep off the fashionable ideas. Be original."

In August 1961, Krishnan, Kundu, Menon and I met at Berkeley during the General Assembly of the International Astronomical Union (Fig. 27.13), and we discussed our interest in returning to India to form a radio astronomy group. We wrote a detailed proposal indicating our initial plans to start solar radio astronomical observations using the 32 dishes already donated to the NPL (which had still not been used), and thereafter to set up

> … a very high resolution radio telescope of a novel design would be the next step in our programme … certain types of radio telescopes would be cheaper to build in India due to lower labour cost … such as a Mills Cross operating at low frequencies … (Menon et al. 1961).

In September 1961, the proposal was sent to five major scientific organizations and agencies in India, indicating our desire and willingness to return to India and form a radio astronomy group and also to attract others in due course.

Copies of our proposal were also sent to five distinguished astronomers, Bart Bok (1906–1983), Jean-François Denisse (1915–2014), Jan Oort (1900–1992), Joe Pawsey and Harlow Shapley (1885–1972), and they were asked to send their confidential assessments to the authorities in India. Copies of the letters of recommendation from Bok, Oort and Pawsey to Bhabha are available in the TIFR archives. Bok's (1961) recommendation was very generous:

Fig. 27.15 Dr. Homi Bhabha (1911–1966), founding Director of the Tata Institute of Fundamental Research, Mumbai (*Courtesy* TIFR Archives)

> … it seems to me that their offer to return to India as a group is a unique one, and that should by all means be accepted and acted upon promptly. An offer like the present one comes only rarely in the history of a nation, which scientifically, is obviously coming of age.

We got replies from all the concerned authorities from India, but the most encouraging and highly supportive was from the great visionary scientist and a dynamic organizer, Dr. Homi J. Bhabha (Fig. 27.15), Director of the Tata Institute of Fundamental Research (TIFR) in Mumbai. He sent a cable to all four of us on 20 January 1962: "We have decided to form a radio astronomy group stop letter follows with offer … " (Bhabha 1962a). He wrote to me on 3 April 1962: "If your group fulfills the expectations we have of it, this could lead to some very much bigger equipment and work in radio astronomy in India than we can foresee at present." (Bhabha 1962b). The above-mentioned correspondence and several other related letters from the period 1955–1963 in my files have been scanned, and are now available at the NCRA Library in Pune.

27.6 Radio Astronomy at the TIFR: Beginning with the Kalyan Radio Telescope

I resigned from Stanford, and returned to India on 31 March 1963. On a request made by Homi Bhabha to the NPL and CSIR authorities, the 32 Potts Hill dishes were transferred to the TIFR by the middle of 1963. In the meantime, I developed a design involving 20-ft dishes to complement the 32 smaller dishes for operation at a longer wavelength.

Soon after, in June 1963, I came across a paper by Cyril Hazard (b. 1928) in a recent issue of *Nature* describing observations of a lunar occultation of the radio source 3C273 made with the 64-m Parkes Radio Telescope (Hazard 1963), as well as a companion paper by Maarten Schmidt (b. 1929), concluding that the enigmatic spectrum of the blue stellar object identified with 3C273—which had been a great puzzle for several years—was easily explained for an object with a redshift of 0.17 (Schmidt 1963). This marked the discovery of quasars (see Hazard et al. 2015; Kellermann 2014), and has revolutionized our understanding of the Universe. While reading the two papers, a thought flashed through my mind: that the lunar occultation method could provide accurate positions and angular size measurements of a large number of radio sources, much weaker than those in the 3C catalogue, and thus distinguish between competing cosmological models. At that time there was a raging controversy between the Steady State and Big Bang cosmologies. A quick calculation showed that in order to obtain occultation observations of a sizable sample of distant weak radio sources, say ~200 per year, one would need a telescope with a collecting area of more than four times that of the 64-m Parkes or the 76-m Jodrell Bank Radio Telescopes, which was not practical to build, even in advanced countries. It occurred to me that the solution would be to construct a large cylindrical radio telescope on a suitably inclined hill in southern India so as to make its axis parallel to the Earth's axis, and thus taking advantage of India's close proximity to the Equator. I discussed this idea with Professor M.G.K. Menon (1928–2016), Dean of the Physics Faculty, who responded enthusiastically. In August 1963 I had a long discussion with Bhabha, who grilled me for over 2 h. I asked him whether I should write a detailed Project Document and he replied:

> Young man, do not waste your time writing a project report; your main problem would be to collect a team; when you have managed that, you can submit a project report and proceed with its design and construction.

In August 1963, V.K. Kapahi (1944–1999) and J.D. Isloor, fresh graduates from the Atomic Energy Establishment Training School (AEET) and two scientific assistants, joined the young radio astronomy group of the TIFR. R.P. Sinha, who was also from the AEET, joined in August 1964. As a first step, a grating type of radio interferometer was set up at Kalyan near Bombay to observe the Sun at 610 MHz (Fig. 27.16). The array consisted of 32 ex-Potts Hill parabolas; 24 of them were placed along a 630-m east-west baseline and the remaining eight along a 256-m north-south baseline. As we used a simple and novel transmission line system to connect the antennas, we were able to complete the Kalyan Radio Telescope by April 1965 (Swarup et al. 1966). This radio telescope was used to investigate properties of the quiet and active radio Sun at 610 MHz during 1965–1968. It was found that the Sun showed considerable limb brightening, and that the solar corona had a temperature ~ 10^6 K.

N.V.G Sarma and M.N. Joshi resigned from the NPL and joined the TIFR in 1964. D.S. Bagri, with a fresh M.Tech degree, joined the group in August 1964.

Fig. 27.16 A view of the east-west grating array consisting of twenty-four 6-ft diameter dishes built at Kalyan, near Mumbai, in 1965 (*Courtesy* TIFR Archives)

Mukul Kundu returned from USA in early 1965 and contributed a great deal to the growth of the group during its critical formative years. Later, in 1968, he returned to the USA and joined the University of Maryland.

27.7 The Ooty Radio Telescope

In early 1965, after an extensive search Sinha and I located a suitable hill at Ooty for the proposed equatorial radio telescope. This site is situated in the picturesque Nilgiri Hills in southern India, at an altitude of about 2100 m. In late 1965, Bhabha approved the setting up of the Ooty Radio Telescope at that site, as part of an Inter-University Centre (IUC). After corresponding with Jawahar Lal Nehru (1889–1964), India's Prime Minister, funding designed to give a boost to science education in India was obtained by Bhabha. A 600-acre plot of land was earmarked by the Tamil Nadu State Government for the IUC (Bhabha 1966). Soon after, in January 1966, Bhabha met a tragic end in a plane crash in The Alps at a relatively young age of 55 years, and the IUC did not materialize. However, the radio astronomy group continued to receive support from the TIFR, due to the close interest and guidance of Professor Menon, an eminent cosmic-ray physicist who succeeded Bhabha as Director of the TIFR.

Fig. 27.17 The Ooty Radio Telescope, consisting of the 530-m long and 30-m wide cylindrical parabolic antenna placed along a north-south sloping hillside at an angle of 11.35° so that its axis of rotation was parallel to that of the Earth (*Courtesy* TIFR Archives)

The Ooty Radio Telescope (ORT) was completed in December 1969, and it is still in operation. It consists of a 530-m long and 30-m wide parabolic cylindrical antenna (Figs. 27.17 and 27.18), located along a north-south hill with a slope equal to the latitude of the station (+11.35°). It is, therefore, possible to track celestial radio sources continuously every day for up to 9.5 h by a simple mechanical rotation of the telescope along its long axis. Along its 500-m long focal length is placed a phased array consisting of 1024 dipoles operating in the RF band of 322–328.6 MHz, an internationally protected band for radio astronomical observations. The structural and mechanical design was done by M/s Tata Ebasco, later named as Tata Consulting Engineers (TCE).

The ORT was completed at the end of 1969, and the first occultation observations were made on 18 February 1970 (see Swarup et al. 1971). By early 1971 the radio astronomy group consisted of 16 research workers: S. Ananthakrishnan, D.S. Bagri, V. Balasubramanian, Gopal Krishna, J.D. Isloor, M.N. Joshi, V.K. Kapahi, S. Krishna Mohan, V.K Kulkarni, D.K. Mohanty, T.K. Menon, A. Pramesh Rao, N.V.G. Sarma, C.R. Subrahmanyan, T. Velusamy and myself. Dr. V.R. Venugopal joined in 1971. In addition, the group included several engineers and technical staff members. S.V. Damle, who had built the novel trombone-type phase shifters for ORT in collaboration with Kapahi, shifted to the microwave group at the TIFR. S.M. Bhandari from the Physical Research Laboratory also worked at Ooty for a Ph.D. degree. The design and construction of the ORT was a great challenge to the above team, as the development of technology in India was still in its infancy in

Fig. 27.18 Another view of the Ooty Radio Telescope; reflections of sunlight by 1100 stainless steel wires are seen on the *right* (*Courtesy* TIFR Archives)

those years, and foreign exchange for importing components was very limited (particularly after the India-China conflict in 1962, and later during the war between India and Pakistan).

We were fortunate to receive a grant of US$70,000 from the National Science Foundation of the USA, which was used mainly to import a Varian Computer and test equipment. For the required electronic components, we ended up arranging for coaxial cables, type N and UHF connectors, and many other critical components to be developed by various firms for the first time in India. It must be noted that our success was solely due to a close teamwork of all the staff, whose median age in 1971 was about 27 years. The above scientists made many pioneering contributions and gained world-wide recognition for themselves and for Indian radio astronomy, thus paving the way for the future growth of radio astronomy in India.

T.K. Menon joined the TIFR in 1970 and guided several of the young research workers in the radio astronomy group. He returned to USA in 1974.

During the 1970s, lunar occultation observations of more than 1000 radio sources were made at a frequency of 327 MHz using the ORT. The median flux density of these sources is about 0.6 Jy at 327 MHz, being about ten times lower than that of the 3C catalogue. The occultation survey was able to provide accurate positions of the source, and to reveal their angular structure with arc-second resolution. The data provided independent support for the Big Bang model

(Kapahi 1975; Swarup 1975). Detailed physical properties of many galactic and extragalactic sources also were derived. In addition, interplanetary scintillation (IPS) observations of selected samples of radio galaxies and quasars provided information on their compact structure with a resolution of 0.05–0.5 arc-second at 327 MHz. Valuable contributions were also made in the new field of pulsar astronomy (Swarup 1986). By 1984, the Ooty Synthesis Radio Telescope (OSRT) of 4-km extent was set up. It consisted of seven small parabolic cylindrical antennas measuring 23 m × 7.5 m and the large ORT itself, all combined with rather cumbersome radio links. The OSRT provided a resolution of ~45 × 50 arc second at 327 MHz. Scientific contributions made by the above group during the first 25 years are described elsewhere (Swarup et al. 1991b).

27.8 The Giant Equatorial Radio Telescope (GERT)

Following the success of the equatorially mounted ORT, a proposal was mooted, first in 1976 and later more formally in 1978, to construct a Giant Equatorial Radio Telescope (GERT) consisting of a 2-km long and 50-m wide cylindrical radio telescope. This would be placed at a suitable site at the Earth's Equator in either Kenya or Indonesia. It was envisaged as the focal point of an associated International Centre for Space Sciences and Electronics (INISSE), a collaborative effort between several developing countries (Swarup et al. 1979). There was much talk at that time by world leaders stressing the need for South-South cooperation and India was very supportive of this concept. UNESCO provided a grant of US$14,000 for a feasibility study of the GERT and also arranged visits by Professor A.R. Hewish (b. 1924), Nobel Laureate, and myself to Kenya, Nigeria and Senegal, and later by an Indian team to Indonesia. The TIFR provided funds for the design and cost estimates of the proposed telescope, and also of a proposed 10-km synthesis radio telescope consisting of ten 100-m × 50-m parabolic cylinders in conjunction with the 2-km × 50-m main telescope. India indicated support for half of the all-up cost of the project, which was estimated as US$20 million.

With the help of the local authorities, a suitable site was located close to the Equator in Kenya. However, Kenyan scientists were not able to follow up on the project after the demise of President Kenyatta. Later, two suitable sites were identified in West Sumatra (Indonesia) very close to the Equator, but progress was slow because of a lack of astronomical interest in most of the developing countries. In 1983 President Suharto of Indonesia pledged support for half the cost of the GERT. However, concerns were expressed about the high levels of seismic activity in West Sumatra, even though our engineers indicated that a suitable antenna could be built there without much cost penalty. Meanwhile, other major developments were taking place in international radio astronomy instrumentation and image processing techniques, as summarized below.

27.9 The Giant Metrewave Radio Telescope

By early 1982, revolutionary methods of phase and amplitude closures and self-calibration allowed radio astronomers to obtain radio maps of celestial sources of high quality even in the presence of phase and amplitude variations caused by electronics, the ionosphere or the atmosphere. It also seemed feasible to connect the antennas of a radio interferometer of a relatively large separation by using lasers and optical fibres. Further, after Ravi Subrahmanyan joined our radio astronomy group in 1983, we started calculating whether the ORT or the Very large Array (VLA) in the USA or the GERT would be suitable for studies of proto-clusters, the postulated condensates of neutral hydrogen existing at very high redshifts prior to the formation of galaxies in the Universe. To pursue this interesting problem, which is still a major challenge for radio astronomy, it became clear to us that a major new instrument was needed in order to fill the existing gap in radio astronomical facilities at metre wavelengths. This goal, experience gained in designing and building the ORT, and the dynamism of the younger members of our group propelled me to propose the Giant Metre-wave Radio Telescope on 1 January 1984.

Initially, in a flash, I divided the 2-km long and 50-m wide GERT into 34 smaller parabolic cylindrical antennas, joined by optical fibres, to form a synthesis radio telescope of about 25-km in extent. Since the operation over a wide frequency range seemed problematic using parabolic cylinders, we finally invented the concept of SMART (Stretched Mesh Attached to Rope Trusses) in order to build parabolic dishes of 45-m diameter economically and affordably: in this case necessity was the mother of invention![4] The GMRT project was approved by the Government of India in March 1987.

The GMRT consists of 30 parabolic dishes of 45-m diameter each, located across a region of about 25 km (Fig. 27.19). Fourteen antennas are placed somewhat randomly in a central array of about 1 km × 1 km in extent, while the other 16 dishes are situated along three 14 km long arms, making a Y-shaped array (Swarup et al. 1991a). The GMRT operates at five radio frequency bands between ~110 and 1430 MHz. Because of recent developments in electronics, it seems feasible to be able to operate the GMRT in any band free of radio frequency interference between ~40 MHz to 1700 MHz. The GMRT became fully operational in 2000. Since January 2001 Indian and international astronomers have been invited to apply for observing time, which is subsequently assigned to those who submit the best proposals. The GMRT has become the world's largest radio telescope operating in the above frequency range, and it complements existing large telescopes elsewhere. During the last 17 years, it has been used by more than 500 astronomers from over 32 countries, and many interesting results have been obtained.[5]

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[4] We understand that Chinese radio astronomers adopted some aspects of the above concept when designing their 500-m diameter antennas for the SKA, and that they constructed a 30-m diameter prototype antenna.

[5] For examples of some of the research results see the web site: www.ncra.tifr.res.in

Fig. 27.19 A close-up view of one of the thirty 45-m diameter fully steerable parabolic dishes of the Giant Metre Wavelength Telescope located at Khodad, near Pune, in western India. A few dishes of the central array of the GMRT are also visible in this photograph (*Courtesy* Prem Kumar, NCRA-TIFR Archives)

I may note here that the untimely demise of M.N. Joshi (1988) and of V.K. Kapahi (1999), who were amongst the main architects of the group, was a great loss to the India and the international radio astronomical community. Likewise, Mukul Kundu's unexpected death in 2010 was a great shock to all of us.

27.10 The Square Kilometre Array Project (SKA): A Look at the Future

In 1960 Jan Oort highlighted the importance of building a radio telescope with a collecting area of about one million square metres in order to investigate the distribution of neutral hydrogen gas and its evolution in our Galaxy and across the Universe. As a result, Belgian and Dutch astronomers proposed a large Cross-type antenna with an area of ~1 million square metres, which they called the Benelux Cross, but this did not materialize. After noting the success of the one mile telescope in the UK and developments in interferometry in Australia and elsewhere, the Dutch astronomers decided to build the Earth's Synthetic Radio Telescope at Westerbork, consisting of 12 dishes each 25-m in diameter (two more were added later).

Oort's vision of a radio telescope with a large collecting area also led to a proposal for an array of 'Venetian blind' type configuration with a large number of parabolic cylindrical antennas (see Bracewell et al. 1962). In 1980, Barney Oliver proposed construction of 1000 microwave antennas each of 100-m diameter in order to search for evidence of extra-terrestrial intelligence (SETI). In 1988, a proposal was put forward by Swarup at the International Astronautical Congress at Bangalore, for the construction of 1000 dishes of 45-m diameter (similar to the GMRT antennas) for SETI, as well as for radio astronomical studies. In a symposium held at Socorro on the occasion of tenth anniversary of the operation of the VLA, Peter Wilkinson (1981) proposed construction of 100 antennas of 100-m diameter, called 'The Hydrogen Array'. Swarup (1991) examined the cost of a large number of 45-m dishes for such a telescope, and called it the International Telescope for Radio Astronomy (ITRA). Earlier, Jan Nordaam in Netherlands had informally discussed a large telescope with similar objectives, called the SKAI. All of these ideas led to the setting up of a 'Large Telescope Working Group' at the Kyoto URSI meeting in 1993, and the IAU endorsed this group in 1994.

These historical developments paved the way for a more definite proposal for the Square Kilometre Array (SKA), which is currently being built in southern Africa and Australia-New Zealand. This is mankind's most ambitious step in the exploration of the Universe through the radio window of the electromagnetic spectrum.

27.11 Epilogue

Ever since its independence, India has made steady progress in scientific endeavours, thanks largely to the substantial support of the great visionary Prime Minister, Jawahar Lal Nehru, who viewed the newly established scientific laboratories as the temples of modern India. Although pioneering work in inter-national radio astronomy started at metre wavelengths, the emphasis in advanced countries soon shifted to much shorter wavelengths, in order to obtain high angular resolution (even though it required more expensive equipment). However, there are many exciting and challenging astrophysical problems that can be studied better, or exclusively, at metre wavelengths. At such long wavelengths the required tolerances of antennas are much lower, and wire mesh suffices as the reflecting surface of parabolic antennas, and minimizes the wind loading. Further, such antennas are labour-intensive, and because of low labour costs they can be built economically in India. The above factors have contributed to the success of radio astronomy endeavours in India.

Currently, several countries are building order-of-magnitude larger facilities at decimeter and metre wavelengths, such as LOFAR in Netherlands, the Murchison Widefield Array in Australia (a joint venture of US and Australian scientists), and the seeding of the very ambitious SKA project. India can make substantial contributions to these efforts by using expertise developed in the field of radio astronomy and its proven expertise in the area of computer software development.

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Our success with the Ooty Radio Telescope and the GMRT has been due to the close teamwork of the NCRA staff, and I am grateful to all of them.

References

Bhabha, H.J. (1962a). Western Union telegram to T. Krishnan, M.R. Kundu, T.K. Menon and G. Swarup, dated 20 January. Original in the NCRA Library, Pune.

Bhabha, H.J. (1962b). Letter to G. Swarup, dated 3 April. Original in the NCRA Library, Pune.

Bok, B. (1961). Letter to Dr Homi J. Bhabha, dated 5 October. Copies in the TIFR Archives, Mumbai, and the NCRA Library, Pune.

Bracewell, R. (2005). Radio astronomy at Stanford. *Journal of Astronomical History and Heritage, 8,* 75–86.

Bracewell, R.N., & Riddle, A.C. (1967). Inversion of fan-beam scans in radio astronomy. *Astrophysical Journal, 150,* 427–434.

Bracewell, R.N., & Swarup, G. (1961). The Stanford microwave spectroheliograph antenna, a microsteradian pencil beam interferometer. *IRE Transactions on Antennas and Propagation, 9,* 22–30.

Bracewell, R.N., Swarup, G., & Seeger, C.L. (1962). Future large telescopes. *Nature, 193,* 412–416.

Christiansen, W.N. (1960). Letter to G. Swarup, dated 22 September. Original in the NCRA Library, Pune.

Christiansen, W.N., & Warburton, J.A. (1955). The distribution of radio brightness over the solar disk at a wave-length of 21 cm. Part II. The quiet Sun, two-dimensional observations. *Australian Journal of Physics, 8,* 474–486.

Cohen, M. (1994). The Owens Valley Radio Observatory: early years. *Engineering and Science, 57*(3), 9–23.

Davies, R.D. (2005). A history of the Potts Hill radio astronomy field station. *Journal of Astronomical History and Heritage, 8,* 87–97.

Frater, R.H., & Ekers, R.D. (2012). John Paul Wild 1923–2008. *Historical Record of Australian Science*, *23*, 212–227.

Frater, R.H., & Goss, W.M. (2011). Wilbur Norman Christiansen 1913–2007. *Historical Record of Australian Science*, *22*, 215–228.

Frater, R.H., Goss, W.M., & Wendt, H.W. (2013). Bernard Yarnton Mills 1920–2011. *Historical Records of Australian Science*, *24*, 294–315.

Hazard, C. (1963). Investigation of the radio source 3C273 by the method of lunar occultation. *Nature, 197,* 1037.

Hazard, C., Jauncey, D., Goss, W.M., & Herald, D. (2015). The sequence of events that led to the 1963 publications in *Nature* of 3C273, the first quasar and the first extragalactic radio jet. In F. Massaro, C.C. Cheung, E. Lopez, & A. Siemiginowska (Eds.), *Extragalactic Jets from Every Angle* (pp. 183–189). Cambridge, Cambridge University Press.

Illustrated Weekly Times of India, 14 September 1954.

Joseph Aubrey Warburton. *Reno Gazette-Journal*, 3 May 2005.

Kapahi, V.K. (1975). Cosmology from angular size counts of extragalactic radio sources. *Monthly Notices of Royal Astronomical Society, 172,* 513–533.

Kellermann, K.I. (2014). The discovery of quasars and its aftermath. *Journal of Astronomical History and Heritage, 17,* 267–282.

Kellermann, K.I., Orchiston, W., & Slee, B. (2005). Gordon James Stanley and the early development of radio astronomy in Australia and the United States. *Publication of the Astronomical Society of Australia, 22,* 12–23.

Kochhar, R.K., & Orchiston, W. (2017). The development of astronomy and emergence of astrophysics in India. In T. Nakamura, & W. Orchiston.

Krishnan, K.S. (1955). Letter to G. Swarup, dated 22 February. Original in the NCRA Library, Pune.

Lovell, A.C.B. (1964). Joseph Lade Pawsey 1908–1962. *Biographical Memoirs of Fellows of the Royal Society, 10,* 229–243.

Maxwell, A., & Swarup, G. (1958). A new spectral characteristic in solar radio emission. *Nature, 181,* 36–38.

Menon, T.K., Krishnan, K., Kundu, M.R., & Swarup, G. (1961). Proposal for the Formation of a Radio Astronomy Group in India. Dated 23 September. Copies were sent to H.J. Bhabha (Director, TIFR), D.S. Kothari (Chairman, University Grants Commission), M.S. Thacker (Director General of CSIR) and Vikram Sarabhai (Director, PRL and Director General of Observatories). Copy in the NCRA Library, Pune.

Mills, B.Y., & Little, A.G. (1953). A high-resolution aerial system of a new type. *Australian Journal of Physics*, *6*, 272–278.

Nakamura, T., & Orchiston, W. (Eds.), (2017). *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe*. Cham: Springer.

Orchiston, W. (2004). The rise and fall of the Chris Cross: a pioneering Australian radio telescope. In W. Orchiston, R. Stephenson, S. Débarbat, & I.-S. Nha (Eds.), *Astronomical Instruments and Archives from the Asia-Pacific Region* (pp. 157–162). Seoul: IAU Commission 41.

Orchiston, W., & Mathewson, D. (2009). Chris Christiansen and the Chris Cross. *Journal of Astronomical History and Heritage, 12,* 11–32.

Orchiston, W., & Slee, B. (2017). The early development of Australian radio astronomy: the role of the CSIRO Division of Radiophysics field stations. In T. Nakamura, & W. Orchiston.

Orchiston, W., Nakamura, T., & Strom, R. (Eds.), (2011). *Highlighting the History of Astronomy in the Asia-Pacific Region. Proceedings of the ICOA-6 Conference*. New York: Springer.

Orchiston, W., Slee, B., & Burman, R. (2006). The genesis of solar radio astronomy in Australia. *Journal of Astronomical History and History*, *9*, 35–56.

Orchiston, W., Steinberg, J.-L., Kundu, M., Arsac, J., Blum, É.-J., & Boischot, A. (2009). Highlighting the history of French radio astronomy. 4: Early solar research at the École Normale Supérieure, Marcoussis and Nançay. *Journal of Astronomical History and Heritage, 12,* 175–188.

Pawsey, J.L. (1946). Observation of million degree thermal radiation from the Sun at a wavelength of 1.5 metres. *Nature, 158,* 633–634.

Pawsey, J.L. (1957). Letter to G. Swarup, dated 8 February. Original in the NCRA Library, Pune.

Pawsey, J.L. (1960). Letter to G. Swarup, dated 26 October. Original in the NCRA Library, Pune.

Robertson, P. (1992). *Beyond Southern Skies: Radio Astronomy and the Parkes Radio Telescope*. Cambridge: Cambridge University Press.

Robertson, P. (2015). *John Bolton and the Nature of Discrete Radio Sources*. Ph.D. Thesis, University of Southern Queensland, Toowoomba, Australia.

Robinson, B. (2002). Recollections of the URSI Tenth General Assembly, Sydney, Australia, 1952. *Radio Science Bulletin, 300*, 22–30.

Schmidt, M. (1963). A star-like object with large red-shift. *Nature, 197,* 1040.

Smerd, S.F. (1950). Radio-frequency radiation from the quiet Sun. *Australian Journal of Scientific Research, A3,* 34–59.

Stanier, H.M. (1950). Distribution of radiation from the undisturbed Sun at a wavelength of 60 cm. *Nature, 165,* 354–355.

Stewart, R., Orchiston, W., & Slee, B. (2011a). The contribution of the Division of Radiophysics Dapto field station to solar radio astronomy, 1952–1964. In W. Orchiston et al., pp. 481–526.

Stewart, R., Orchiston, W., & Slee, B. (2011b). The Sun has set on a brilliant mind: Paul Wild (1923–2008). In W. Orchiston et al., pp. 527–542.

Sullivan, W.T. III (1984). *The Early Years of Radio Astronomy: Reflections Fifty Years after Jansky*. Cambridge, Cambridge University Press.

Sullivan, W.T. III (2009). *Cosmic Noise. A History of Early Radio Astronomy*. Cambridge: Cambridge University Press.

Sullivan, W.T. III (2017). The beginning of Australian radio astronomy. In T. Nakamura, & W. Orchiston.

Swarup, G. (1955). Proposed Investigation: Study of Solar Radiation Using a 2100 ft. long 32-element Interferometer to Operate Simultaneously at 60 cm and 1.8 m Wavelengths. Dated 23 January. Submitted to K.S. Krishnan, Copy in the NCRA Library, Pune.

Swarup, G. (1975). Angular size flux density relation for extragalactic radio sources. *Monthly Notices of Royal Astronomical Society, 172,* 501–512.

Swarup, G. (1986). The story of Ooty Radio telescope. In R. Cowsik (Ed.). *Cosmic Pathways* (pp. 349–360). New Delhi: Tata McGraw Hill.

Swarup, G. (1991). An international telescope for radio astronomy. *Current Science, 60,* 106–108.

Swarup, G. (1997). Experimental astronomy in India. In T. Padmanabhan (Ed.), *New Challenges in Astrophysics* (pp. 3, 165–173). New Delhi: New Age International Publisher.

Swarup, G. (2006). From Potts Hill (Australia) to Pune (India): the journey of a radio astronomer. *Journal of Astronomical History and Heritage, 9,* 21–33.

Swarup, G. (2008). Reminiscences regarding Professor R.N. Christiansen. *Journal of Astronomical History and Heritage, 11,* 194–202.

Swarup, G. (2014). Growth and development of radio astronomy in India. In T. Padmanabhan (Ed.), *Astronomy in India: A Historical Perspective* (pp. 73–110). New Delhi: Springer.

Swarup, G., & Parthasarathy, R. (1955). Solar brightness distribution at a wavelength of 60 centimetres. I: the quiet Sun. *Australian Journal of Physics, 8,* 487–497.

Swarup, G., & Parthasarathy, R. (1958). Solar brightness distribution at a wavelength of 60 centimetres. II: localized radio bright regions. *Australian Journal of Physics, 11,* 338–349.

Swarup, G., Odhiambo, T.R., & Okoye, S.E. (1979). Report of a UNESCO Workshop on Proposals for an International Institute of Space Sciences and Electronics and Giant Equatorial Radio Telescope. Ootacamund, UNESCO. Pp. 103. Copy in the NCRA Library, Pune.

Swarup, G, Kapahi, V.K., Isloor, J.D., & Sinha, R.P. (1966). Radio observations of the quiet Sun at 49 cm. *Nature, 212,* 910–911.

Swarup, G., Ananthkrishnan, S., Kapahi, V.K., Rao, A.P., Subrahmanyan, C.R., & Kulkarni, V.K. (1991a). Current science. The Giant Metrewave Radio Telescope. *Current Science, 60,* 95–105.

Swarup, G., Kapahi, V.K., Velusamy, T., Ananthkrishnan, S., Balasubramanian, V., and 4 coauthors (1991b). Twenty-five years of radio astronomy at TIFR. *Current Science, 60,* 79–94.

Swarup, G., Sarma, N.V.G., Joshi, M.N., Kapahi, V.K., Bagri, D.S., and 5 coauthors (1971). Large steerable radio telescope at Ootacamund, India. *Nature, 230,* 185–188.

Thompson, A.R. (2010). The Harvard radio astronomy station at Fort Davis, Texas. *Journal of Astronomical History and Heritage, 13,* 17–27.

Thompson, A.R., & Frater, R.H. (2010). Ronald N. Bracewell: an appreciation. *Journal of Astronomical History and Heritage, 13,* 172–178.

Wendt, H., Orchiston, W., & Slee, B. (2008). W.N. Christiansen and the development of the solar grating array. *Journal of Astronomical History and Heritage*, *11*, 173–184.

Wendt, H., Orchiston, W., & Slee, B. (2011a). An overview of W.N. Christiansen's contribution to Australian radio astronomy, 1948–1960. In W. Orchiston et al., pp. 547–587.

Wendt, H., Orchiston, W., & Slee, B. (2011b). The contribution of the Division of Radiophysics Potts Hill field station to international radio astronomy. In W. Orchiston et al., pp. 379–431.

Wild J.P. (1980). The Sun of Stefan Smerd. In M.R. Kundu, & T.E. Gergely (Eds.), *Radio Physics of the Sun* (pp. 5–21). Dordrecht: Reidel.

Wilkinson, P.N. (1981). The hydrogen array. In T.J. Cornwell, & R.A. Perley (Eds.), *Radio Interferometry, Theory, Techniques and Applications* (pp. 428–432). San Francisco: Astronomical Society of the Pacific.

Part X
Uzbekistan

Chapter 28
The Development of Astronomy and Emergence Astrophysics in Uzbekistan

Shuhrat Ehgamberdiev

28.1 Introduction

The Ulugh Beg Astronomical Institute (UBAI) of the Uzbek Academy of Sciences (Tashkent Astronomical Observatory from 1873 to 1966) is the oldest scientific institution not only in Uzbekistan, but in the whole of Central Asia. During its 140-year history, UBAI staff worked on different problems of astronomy, geodesy, meteorology, seismology, gravimetry, etc. Many of these problems, such as the determination of geographical coordinates of Central Asian localities, time service, solar monitoring, satellite ranging have been of great practical importance. In the present paper we review the main astronomical branches on which UBAI has worked. Before opening Mt. Maidanak, the UBAI was mostly known as an astrometric institution. Today the institute still continues some 'classical' duties, such as global geodynamics and plate tectonics (the UBAI hosts two ground-based beacons of the GPS system located in Tashkent and Kitab as well as the French DORIS system beacon). But the main fields of research are now being conducted in the field of astrophysics. These are: non-stationary stars, extragalactic astronomy, helio- and asteroseismology, physics of the solar corona, open clusters, asteroids, ground-based follow-up support for space observations etc.

Besides observational studies UBAI at present carries out theoretical investigations concentrating on non-stationary models of galaxy formation, relativistic astrophysics of magnetized compact objects (neutron stars, black holes, etc.), the search for exact solutions of Einstein's equations and field equations in the background gravitational field (Abdujabbarov and Ahmedov 2010). Recently, the results of investigations on space-time structure, obtained by Turakulov (2010) have been presented in his monograph *Space, Time and Motion*. These results include a functional space of general-relativistic

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models of a rotating material disk with its field and a complete theory of gravi-magnetic charge. This approximation makes it possible to solve all stationary axially-symmetric problems analytically the same way as is done in Newtonian theory.

28.2 Tashkent Astronomical Observatory

Tashkent Astronomical Observatory (TAO) was founded in 1873 (Fig. 28.1). The primary aim of the Observatory was the determination of the geographical coordinates of Central Asian cities. For this purpose it was equipped with portable instruments such as Repsold's large vertical circle, Wagener and Pistor's mirror circle, and a transit instrument (Shcheglov 1974). It is important to note that D.D. Gedeonov (1854–1908), the Director of the TAO from 1890 to 1900, suggested that Repsold make a vertical circle providing the same accuracy, but half the size, which was important for a portable instrument. The first such instrument made by Repsold according to Gedeonov's specifications was sent to Tashkent in 1892, and is now exhibited at the museum of the UBAI (see Fig. 28.2). The accuracy of determination of latitude with that instrument using one pair of stars (16 settings) was about ±0.64″, whereas clock corrections using one pair of stars (Zinger method) was ±0.059″. These instruments were known for their very high accuracy and were referred to as Repsold's 'small vertical circles'. They are described by Repsold (1914), but unfortunately he does not mention Gedeonov's role. Nevertheless, this was a notable contribution by Tashkent astronomers to the development of geodetic instrumentation.

In May 1893 Tashkent Astronomical Observatory received the Visual Zenith Telescope (VZT) made by Wanschaff in Berlin. This provided an opportunity to

Fig. 28.1 The original Tashkent Astronomical Observatory building in 1885 (*Courtesy* UBAI)

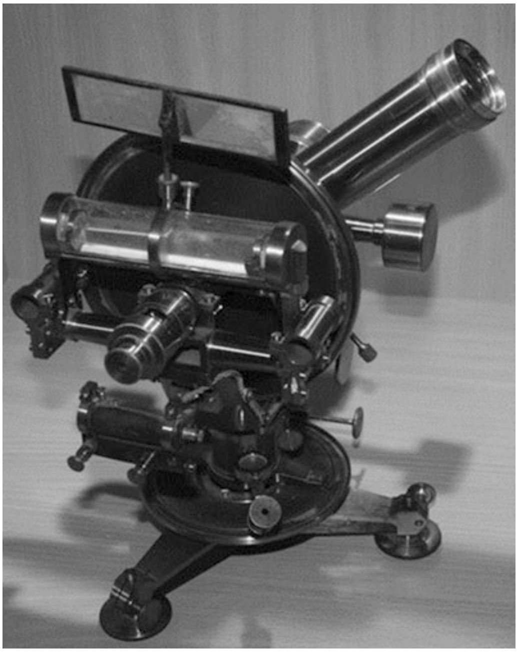

Fig. 28.2 Repsold's small vertical circle of the TAO (*Courtesy* UBAI)

carry out precise measurements of the latitude variation in Tashkent. However, Gedeonov was employed by the Russian military-topographical department, and his main duties of did not allow him to carry out this latitude work before the summer of 1895. Measurements of the latitude of Tashkent were made from 1 July 1895 to 1 September 1896 (Gedeonov 1899), and the mean latitude (φ) was found to be

$$\varphi = 41^{\circ}\,19^{\prime}\,38.29^{\prime\prime} \tag{28.1}$$

Later, Kaganovski (1972) carried out measurements of the latitude of Tashkent in 1969–1970 using the same method as Gedeonov. However, the VZT which Gedeonov had used was no longer available and so Kaganovski used a transit instrument instead. Figure 28.3 shows the variation of Tashkent's latitude determined both by Gedeonov and 75 years later by Kaganovski. The mean latitude determined by Kaganovski in 1970 was:

$$\varphi = 41^{\circ}\,19^{\prime}\,37.986 \pm 0.018^{\prime\prime} \tag{28.2}$$

The difference,

$$\Delta\varphi\left(1970-1896\right) = -0.309 \pm 0.021^{\prime\prime} \tag{28.3}$$

was in good agreement with the value $\Delta\varphi = -0.252''$ obtained for secular motion in Tashkent from ILS data.

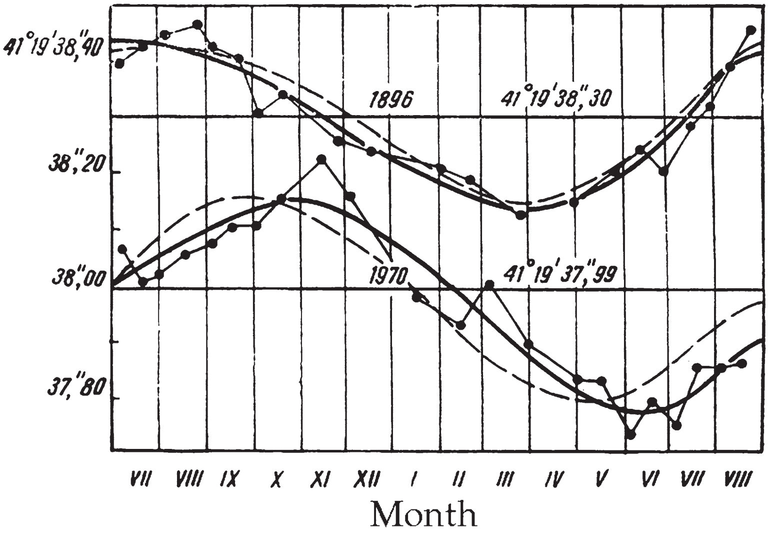

Fig. 28.3 Latitude variations observed at Tashkent from July 1895 to September 1896 (*top*) with the VZT by Gedeonov (1899) and 75 years later (*bottom*) by Kaganovski using a transit instrument (after Kaganovski 1972)

28.3 Participation of TAO in the International Latitude Service

During the 12th General Conference of the 'International Erdmessung' held in Stuttgart in 1898, it was decided to start a new series of latitude measurements within the framework of the International Latitude Service. Four stations (Mizusawa, Carloforte, Gaithersburg and Ukiah) were supported by the 'International Erdmessung' and equipped with visual zenith telescopes (VZT) made by Wanschaff. The aperture of the objectives of these VZTs was 10.8 cm and the focal length was 130 cm. The Italian astronomer, Giovanni Schiaparelli (1835–1910; Beech 2014), and Pulkovo astronomers were particularly interested in getting measurements taken in Tashkent, which was far from European observatories. The TAO then was assigned the responsibility for organizing permanent observations in the Central Asian area, so it equipped the Tschardjui station (Fig. 28.4) with the Wanschaff VZT that had been used earlier by Gedeonov at the TAO (Ehgamberdiev et al. 2000a, b). This had an aperture of 68 mm and a focal length of 87 cm. Construction of the Tschardjui station began in July 1898 and the first observations were carried in September of that same year. This station operated until 1919, and during this 20-year it provided the ILS with >35,000 instantaneous latitudes.

The TAO later was responsible for establishing a new ILS station in Uzbekistan. The site chosen was near the city of Kitab, and the Kitab station inherited the Wanschaff VZT and the Strasser-Rohde pendulum clock from the Tschardjui station, but it also was equipped with an Askania-Werke VZT (D = 11.0 cm, F = 129.0 cm). Since its foundation in 1930 the Kitab Station has continued obser-

Fig. 28.4 A map of Uzbekistan showing the capital, Tashkent, Kitab Latitude Station (*diamond*), Maydanak Observatory (*star*), educational observatories (*circle*), and the site of the former Tschardjui latitude station (*square*, in Turkmenistan) (*Map* Shuhrat Ehgamberdiev)

vations over the whole period of the ILS, and has provided the international data bank with >110,000 instantaneous latitudes.

28.4 Time Service

The determination of geographical coordinates requires the precise measurement of time. This is why time measurements were carried out at the TAO from the very outset. One of the first duties of the Observatory was to regularly check the chronometers, and to transfer time by telegraph for the determination of longitudes. For these purposes the TAO was equipped with two Hohwū clocks: No. 36 was adjusted for sidereal time and No. 21 for mean solar time and for the determination of clock corrections with the Herbst transit instrument as well as the Repsold meridian circle. In 1881 the TAO was connected with the city telegraph station for the transmission of time.

In 1926 the then Director of the TAO, Mikhail F. Subbotin (1893–1966), initiated the establishment of a time service equipped with contemporary instruments (Postoev 1931). His initiative was supported by the Government and by 1930 the TAO was provided with the following instruments: Askania-Werke (Bamberg) transit instrument (Germany), the first-class Riefler No. 515 clock (Germany) and a ‘free pendulum’ Shortt clock purchased from the Synchronom Co. Ltd. (England). Very substantial improvement in the quality of those clocks came from the construction of a 12-m deep subterranean clock-room which kept the annual variation in external air temperature as small as 0.4 °C (Postoev 1933).

For time transmission, Leroy (France) ‘pendulettes’ were employed. Signals from TAO became receivable in Europe and the Observatory collaborated with the Bureau International de l’Heure (BIH). According to the *Bulletin Horaire* for 1933, the yearly absolute deviation of TAO results from the derived values of 15 stations of the BIH was 0.014 s, with an average error of 0.007 s, which consequently placed TAO at the fifth and third place among 15 stations. As a very impressive example of TAO's time service quality, we can say that the longitude difference between Paris and Tashkent was measured with an average accuracy of ±0.0009 s (Postoev 1935).

At the beginning of WWII, when astronomical observatories in the European part of the former Soviet Union were destroyed or evacuated, the TAO alone provided the whole country and army with precise time during a period of 4 months. Such a situation was repeated in 1944, when those stations were once again evacuated.

28.5 Solar Observations

Solar observations started at the TAO in 1884 with the help of a Merz 6-in. (15.2-cm) refractor. The 15-cm diameter solar image was projected onto a screen and the positions of sunspots as well as their shapes were penciled in. Observational data were sent to Zurich (Slonim 1974).

In 1932 the Soviet Solar watch was organized with headquarters at the Pulkovo Observatory. At the beginning it consisted of only three stations, Pulkovo and Kharkov Observatories and the TAO. Since that time, solar observations have been carried out in a regular way. In the autumn of 1932 the TAO was equipped with a Zeiss solar spectroscope provided by Pulkovo. Since then, regular Hα observations of prominences have been carried out. The spectroscope was attached to the Merz refractor and provided with a micrometer which allowed the heights of prominences to be measured. These visual observations continued until 1952. Prior to 1932, solar observations were carried out, but not so regularly.

Since 1936 the TAO also has taken part in the International Flare Patrol, organized through George Ellery E. Hale's initiative. Visual observations were carried out with the Zeiss spectroscope and since 1957 with a Hale-type spectrohelioscope. In 1958 a new chromospheric telescope with an Hα-filter (a birefringent filter with a pass-band of 0.5 Å) was installed, which allowed the making of a cinematographic survey of the chromosphere and flares. A Maksutov-type photoheliograph with a meniscus tele-objective, which operated in a Cassegrain format (aperture 10 cm, equivalent focal length 825.2 cm) allowed full-disk white light images of the Sun to be received.

The next important step in the development of observational facilities at the TAO (since 1966 renamed as the Astronomical Institute of the Uzbek Academy of Sciences) was the installation in 1967 of a horizontal solar telescope, AZU-5. The diameters of the coelostat, main and secondary mirrors of this telescope were 44.0 mcm. The image of the Sun at the Newtonian focus is 16.0 cm, and at the Cassegrain focus it is 60.0 cm. The AZU-5 was equipped with a spectrograph with a grating, which allowed operation in the second order with a dispersion of about 1 Å/mm (Shcheglov and Slonim 1970).

Using observational data that—in the main—have been collected over many years, UBAI astronomers have carried out research on: features of the 11-year solar

Fig. 28.5 The TON telescope for local helioseismology (*left*), and the astrograph observatory (*right*) that was installed at the TAO campus in 1895 (*Courtesy* UBAI)

cycle, properties of solar flares, and the structure and evolution of active regions (Shcheglov and Slonim 1970, Slonim 1974). Sattarov (2003) also used the AZU-5 for high-resolution observation of photospheric structures in white-light, and he succeeded in recording images with a spatial resolution as high as 0.5 arcsec.

A new era in solar research at the TAO started in 1987 when a spectrophotometer of the helioseismological IRIS (International Research on the Interior of the Sun) project—with headquarters at the University of Nice in France—was installed on Kumbel mountain, 75 km north-east of Tashkent (Ehgamberdiev and Fossat 1991). With six identical instruments installed around the Earth, the IRIS project aims to obtain an uninterrupted time series of global oscillations of the Sun as a star for as long as possible. The Kumbel station of the IRIS network to be one of the best, and has provided the IRIS data bank with ~40% of its observational data (see Ehgamberdiev et al. 2014).

Along with other members of the IRIS project, Uzbek astronomers have contributed to obtaining important scientific results. These include measurements of the p-mode amplitude modulation rate (related to the excitation and damping of the oscillations); the determination of the solar atmospheric acoustic cutoff frequency; and studies of the acoustic flux propagating upwards to the chromosphere, which could explain the temperature rise in this upper part of the solar atmosphere (Serebryanskiy et al. 2001). However, the most important result obtained with the IRIS network is the measurement of the solar core rotation rate up to 0.2 solar radii. On the basis of analyses of about 10,000 h of nearly continuous time series of solar global oscillations, it was shown that the solar core is rotating as fast as the envelope. This experimental result was in contradiction with the previously-existing opinion that the core rotated at least ten times faster than the envelope (Ehgamberdiev 1996).

In the summer of 1996, the UBAI became involved in the Taiwan Oscillation Network (TON) project, designed to measure high-order solar oscillations observed in the Ca K-line intensity for helioseismology studies of the solar interior (Chou et al.

1995). One of the TON telescopes was installed in Tashkent (Fig. 28.5). The TON data can provide information about modes up to $l = 1000$. With this wide range of orders, the TON data can be used to study the local properties of the Sun in the subsurface layers. In particular, the data taken with the TON instrument in Tashkent were used to construct three-dimensional intensity and phase maps of the solar interior (Kholikov et al. 2004; Ladenkov et al. 2002). The most interesting result received with the TON network is the first experimental measurement of sunspot depth. On the basis of the originally-developed method of acoustic tomography, it was shown that sunspots can penetrate as deep as 5% of the solar radius (Chang et al. 1997).

Today, together with traditional TAO solar investigations, new fields of research, such as X-ray bright point sources (Ehgamberdiev 1983; Sattarov et al. 2005) and earthshine monitoring for the study of global warming mechanisms (Chou et al. 2010) are being carried out.

28.6 Maidanak Observatory

When the TAO was organized in 1873 it was located outside the city. One century later it was inside a large city with a population exceeding one million, and with a significant level of light pollution and industrial contamination. By the early 1960s, the TAO decided to organize a site-testing campaign for the selection of a suitable site for the future observatory of the TAO. As result of a decade-long site assessment, Mt. Maidanak was selected (Shevchenko 1973). This is located ~500 km south-east of Tashkent (Fig. 28.4), and lies on spurs of the Pamir and Alai mountain system at an altitude of 2600 m above sea level.

At the end of the 1960s Shevchenko and co-workers began site testing at Mt. Maidanak (Shevchenko 1973), and the first stage of astro-climate studies at this site continued up to the beginning of the 1990s. This provided detailed meteorological information, such as the amount of clear time, temperature variations, wind speed, humidity and their seasonal distribution, sky background, as well as comprehensive optical and aerophysical studies (Gur'yanov et al. 1992). Estimations of a basic parameter of the atmosphere for an astronomical site, namely seeing, have been repeatedly conducted at Mt. Maidanak by several groups of researchers using different methods and instruments (Shcheglov and Gur'yanov 1991).

However, for many modern observational programs it was necessary to establish whether atmospheric conditions at Mt. Maidanak match the requirements for modern high-resolution astronomical observations. The statistical analysis of seeing measurements carried out at Mt. Maidanak with the ESO DIMM (accepted by now as a standard instrument for such studies) during the period from August 1996 to July 1999 (Ehgamberdiev et al. 2000a, b) showed that atmospheric conditions at Mt. Maidanak (median value of seeing is 0.69 arcsec) are comparable with the seeing conditions at the ESO observatories of La Silla and Paranal in Chile and at Roque de los Muchachos Observatory (ORM) at La Palma (see Fig. 28.6). The next step was to measure other atmospheric parameters relevant to adaptive optics and

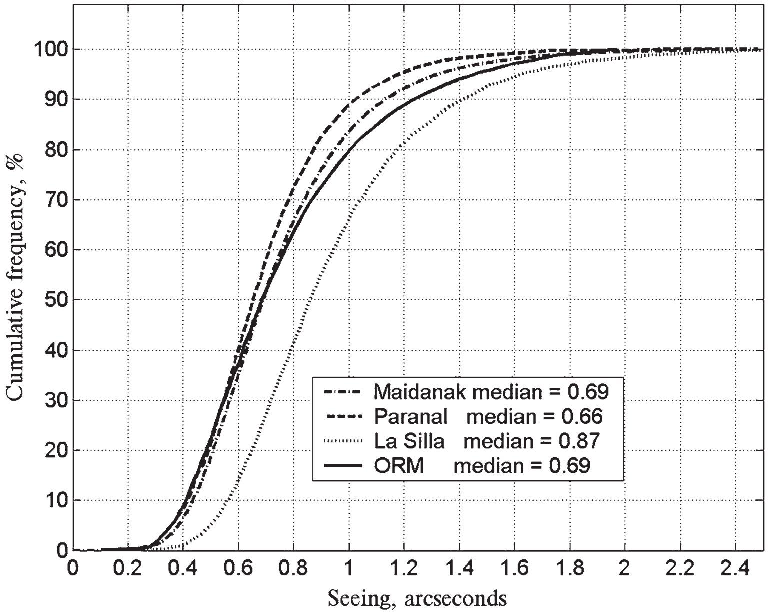

Fig. 28.6 Statistical distribution of the seeing at Maidanak (1996–1999) compared with ESO observatories at La Silla and Paranal and Roque de los Muchachos Observatory at La Palma (after Ehgamberdiev et al. 2000a, b)

interferometry, such as the wavefront outer scale, the isoplanatic angle, high altitude wind, etc. In July 1998, during a site-testing campaign, all these parameters were measured with the Generalized Seeing Monitor (GSM) developed at the University of Nice. Comparison of these parameters with the results of measurements carried out at other sites confirmed the high quality conditions at the Maidanak Observatory site (Ehgamberdiev et al. 2000a, b).

28.7 Variable Star Studies

The study of variable stars at Tashkent began at the end of the nineteenth century. Owing to insistent initiatives of the famous Russian astronomers Fyodor Bredihin (1831–1904; Balashov 2014) and Aristarkh Belopolsky (1854–1934; Bogdan 2014)[1] in 1893 the TAO was provided with an astrograph. This was one of the 16 standardized instruments made for the international 'Carte du Ciel' program, and therefore comprised a telescope ($D = 25.0$ cm) for visual observations and guiding

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[1] Belopolsky independently discovered the changing wavelength of light emitted by a moving object, which is why the Russian literature sometimes refers to this as the 'Belopolsky-Doppler effect'.

attached to the astrograph ($D = 33.0$ mm, $F = 343.6$ cm). The optics of the astrograph were made by the French Henry Brothers, and the mounting was by the German firm Repsold. Vsevolod V. Stratonov (1869–1938), who was assigned the position of astrophysicist, arrived in Tashkent from Pulkovo in 1895, and started photographic observations. His first photographic plates captured the planetary nebula in Lyra and a few variable stars.

At the same time, Stratonov (1904) started visual observations of β Lyr, δ Cep, η Aql and 13 other bright variable stars. He made these observations with amazing accuracy ($0^{m}.085$). In the publications of the TAO we can also see the names of B.V. Kukarkin (1909–1977), N.F. Florya (1912–1941), V.P. Tsesevich, academicians E.R. Mustel' (1911–1988; Trimble 2014) and V.G. Fesenkov (1889–1972; Gurshtein 2014), who are considered to be the founders of the study of variable stars. It is worth mentioning that between 1932 and 1935 Kukarkin and Florya published about 60 papers devoted to the observation of different types of variable stars (Florya 1935). They discovered secular variations in the periodicity of Cepheids, and this work initiated the organization of a Cepheid monitoring program.

In the 1930s the TAO participated in observations of RR Lyrae-type stars. Most of the 18,269 observations of these objects were made at the TAO. Between 1935 and 1960 variable stars were studied using photography with wide-field cameras. However, this method was limited to stars down to 11.5 magnitude, which prevented further progress in this field. In 1963 Shevchenko (1974) invented an infrared camera using an infrared-optical converter. With this camera he discovered the infrared excess of stars in Orion and other T-associations.

Further progress in the study of variable stars was closely connected with the Maidanak Observatory. In the early 1970s Zeiss-600 and 48-cm AZT-14 telescopes were installed there. The observing program was aimed at obtaining long-term (over several years) sets of UBVR observations of about ten non-stationary pre-main sequence stars located in star-forming regions such as Herbig Ae/Be (HAEBE) stars, T Tauri stars (TTS) and FUors. In the 1980s the number of objects was considerably expanded (to >200). As result of two decades of intensive observations more than 80,000 UBVR-observations of HAEBEs, 'classical' TTS, 'weak' TTS and FUors have been collected (Herbst and Shevchenko 1999). Besides this main program, a considerable amount of observational data on spotted close binary systems (RS CVn binaries) was collected, as well as spotted main-sequence stars (BY Draconis and FK Comae variables), 'black hole' candidates, etc. (Grankin et al. 2007).

28.8 Extragalactic Astronomy

Systematic and active searches in the field of extragalactic astronomy at the UBAI have been conducting in the following three main directions:

1. Observations of Active Galaxy Nuclei (QSOs, BLazars and Seyfert galaxies);
2. Observations of Gravitationally Lensed Systems (macrolensing); and
3. Monitoring of optical afterglows from Gamma-Ray Bursts (optical transients).

Observations of QSOs have been carried out since 1996 in cooperation with the University of Pittsburgh (Pittsburgh, USA) as a long-term multicolour monitoring of brightness variations for more than 200 quasars. A general sample was constructed to.

1. provide equal distribution of all the three known physical types of QSOs (radio-loud, radio-quiet and quasars with broad absorption lines); and
2. to divide all program quasars into two main sub-samples: moderate z ($1 < z < 3.5$) and low-z ($1 > z$) QSOs.

The main task of the project is the monitoring of QSO brightness variations and the determination of the so-called characteristic time-scales of the variations. The statistical comparison of derived characteristic time-scales for both sub-samples should satisfy the $1/(z + 1)$ proportionality, if our knowledge of the Universe is correct. In other words, the observed characteristic time-scales for the moderate-z sample will be statistically $(z + 1)$ times longer than the same times for the low-z sample. Obviously, it will take no less than 10–15 years of systematic photometric data-gathering for all program QSOs to provide statistically-reliable results (Chatterjee et al. 2009).

BLazar searches involve about 30 well-known and physically active BLazars. They have been observed in two main modes:

1. uninterrupted optical monitoring to detect and study optical flares in Blazars; and
2. ground-based follow-up observations to support space missions. The most active BLazars have been monitored at the Maidanak Observatory (Villata et al. 2009) over the period 2000–2007, when the Observatory was a member of the international cooperation 'Whole Earth Blazar Telescope' (WEBT).

The Gravitationally Lensed Systems (GLS) project deals with systematic investigations of about 20 objects. The main goal of the project is a direct measurement of the Hubble parameter using the time delay effect in GLS which is determined using long-term and high-accuracy photometric monitoring of such systems. Good and stable image quality and high angular resolution are believed to be mandatory requirements to provide successful implementation of such a project. Both of them are perfectly provided at Maidanak (Figs. 28.7 and 28.8), which allows us to undertake original GLS investigations at the Observatory and to participate successfully in international campaigns on cooperative GLS observations. For example, participation of the UBAI in the international COSMOGRAIL project (Cosmological Monitoring of Gravitational Lenses, a project which includes astronomers from Switzerland, Belgium and Uzbekistan) concluded with a derivation of the Hubble parameter with a higher accuracy than ever before of 3.8% for the lens SDSS J1650 + 4251 (Vuissoz et al. 2007).

Investigations of the optical transients of Gamma-Ray Bursts at Maidanak have been carried out since April 2003, when the 'first light' of the well-known GRB030329 was obtained. Currently the most important results obtained are

1. two- and three-colour observations taken of some afterglows; and
2. an independent detection of a 'dithering' phase in a late part of the GRB030329 optical light curve (Pandey et al. 2009).

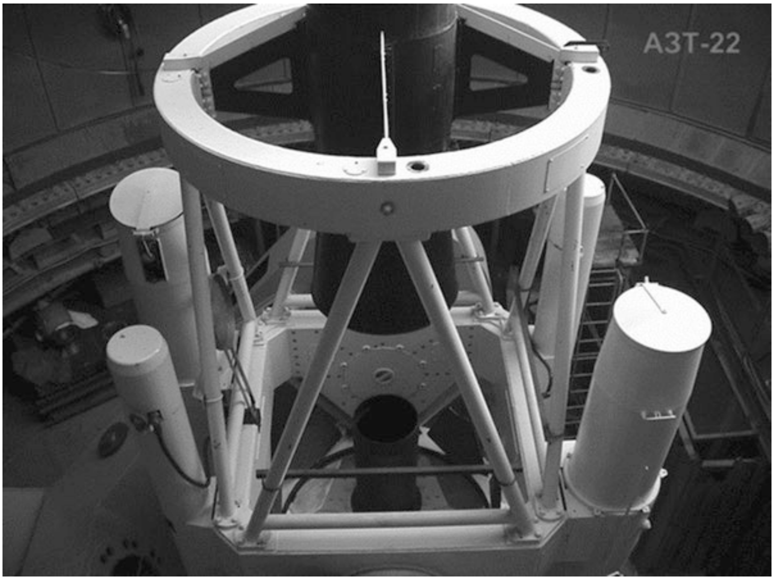
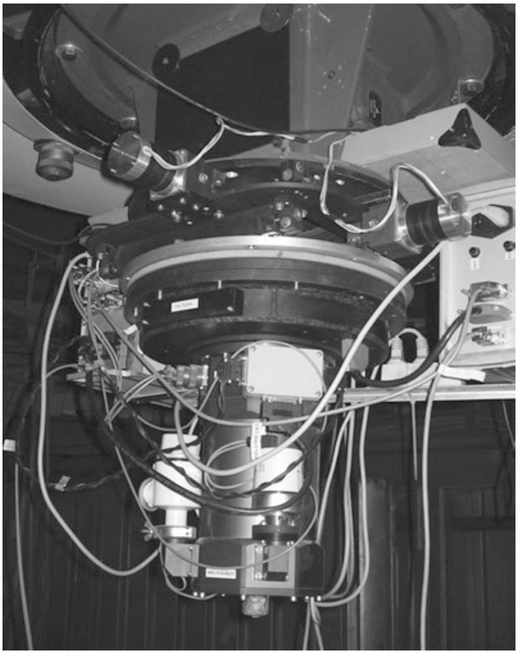


Fig. 28.7 The main telescope at the Maydanak Observatory is the 1.5-m AZT-22 reflector, which is the largest operational telescope in Central Asia (*Photograph* Shuhrat Ehgamberdiev?)

Fig. 28.8 The AZT-22 telescope is equipped with a 4 k × 4 k CCD camera (*Photograph* Shuhrat Ehgamberdiev?)



28.9 Teaching of Astronomy in Uzbekistan's Universities

Uzbekistan takes a leading position in teaching astronomy in the whole Central Asia area. Today in the Uzbekistan National University as well as in Samarkand and Karshi Universities about 300 students are taught ‘Astronomy’ as a specialization. In Nizami Pedagogical and Namangan Universities, as well as in five pedagogical institutes, about 2000 students are being taught the ‘Teachers of Physics and Astronomy’ specialization. However, until recently, neither universities nor pedagogical institutes had their own educational observatories. Professors and students had to be content with small-aperture telescopes.

In 2005 the Astronomical Institute decided to build a network of educational observatories (see Fig. 28.4) to provide easy access for students to telescopes on an annual basis. For this purpose, the use of small telescopes with apertures between 30 and 50 cm, which are not used by UBAI staff for scientific purposes, was planned (Ehgamberdiev 2003).

The first observatory to be erected was at the Samarkand State University. It was equipped with a 48-cm Grubb Parsons telescope that had ‘first light’ on 29 March 2006—the day when a partial solar eclipse occurred. Since then, students of Samarkand University and two nearby pedagogical institutes have had an opportunity to observe night sky objects during their summer practical courses. Beside this, undergraduates and Ph.D. students participate in regular observations of δ Scuti stars (e.g., see Fig. 28.9) and BLazars at that telescope.

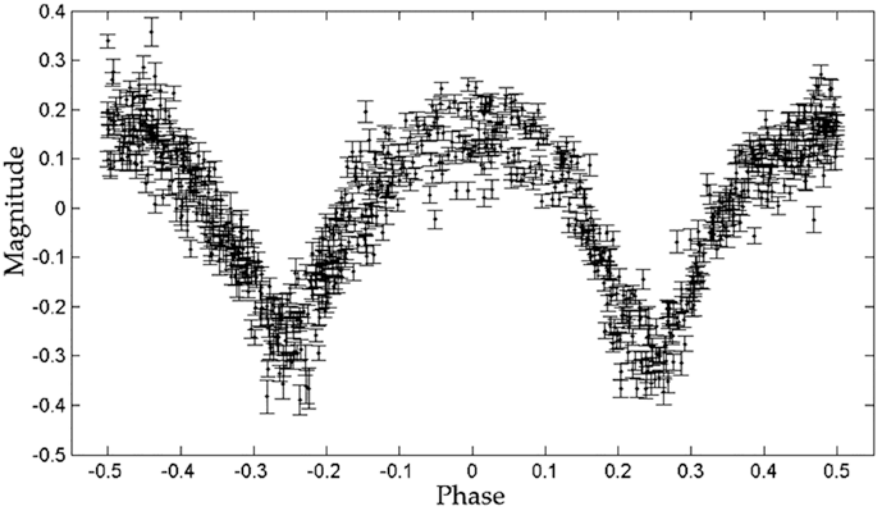


Fig. 28.9 The light curve of GSC 02007–00761 derived from observations made at Samarkand University. This was previously thought to be a δ Scuti star, but analysis of the light curve showed that it is in fact a close binary system (after Ehgamberdiev 2011)

The second telescope in the educational network, with an aperture of 30 cm, was installed in 2008 at the University of Andijan, located in the Ferghana Valley. Now students of the nearby University of Namangan and the Kokand Pedagogical Institute have an opportunity to observe night sky objects all year round.

The third 48-cm AZT-14 telescope of the astronomical educational network was installed in 2011 at the National University of Uzbekistan in the city of Parkent, 45 km north-east of Tashkent. The forth telescope was installed in 2012 at the Nizami State Pedagogical University of Tashkent and the last telescopes in the network were installed in 2014 in observatories at Karshi State University and Nukus Pedagogical Institute (see Fig. 28.4).

28.10 The Future of Astronomy in Uzbekistan

The future of astronomy in Uzbekistan is closely related to the development of international cooperation with advanced world astronomical centres. A basis for such cooperation is the fact that the Maidanak Observatory of the UBAI is located at one of the best astronomical sites in the world. Moreover, it is located at mid distance between the main astronomical facilities of the world in the Canary and Hawaiian Islands. This makes Maidanak a very important site for observational programs requiring continuous monitoring of astronomical objects.

Another important circumstance which makes Maidanak favourable for international cooperation is the availability of a satellite internet through the SkyEdgeIP station, which is based on a VSAT-type system. This was far from being an obvious perspective for Maidanak just a few years ago. Today we already have two automated telescopes at Maidanak which can be operated remotely.

The UBAI has established long-term cooperation with the National Astronomical Observatory of Japan. The scientific aim of this cooperation is joint observations and studies of Solar System small bodies. However, from an organizational point of view, it is a much broader cooperation on further development of infrastructure of Maidanak Observatory. Maidanak users' meetings have been regularly held since 2009 to help coordinate observational programs as well as promote collective efforts on improvements to the infrastructure of the observatory.

The UBAI also has a very successful cooperation with the Astronomical Consortium of Korean universities. This is a broad cooperation which is aimed at the study of various types of Galactic and extragalactic objects: open clusters, supernova remnants, quasars, optical afterglows of γ-ray bursts, and ground-based follow-up support for space observations. The Consortium has provided Maidanak Observatory with a large-format SI 600 Series 4096 × 4096 CCD camera—the most advanced CCD among FSU observatories.

28.11 Concluding Remarks

In 2008 Professor John Hearnshaw from the Department of Physics and Astronomy of the University of Canterbury (New Zealand) visited Uzbekistan as Chairperson of the Program Group for the World-wide Development of Astronomy of IAU Commission 46. In his report to the IAU General Secretary he wrote:

> Apparently the world is now becoming aware that Maidanak is one of the best astronomical sites in the northern hemisphere, and possibly the best. The future looks quite bright, because international collaboration with Uzbek astronomers will lead to improved infrastructure, telescopes and instruments on Mt Maidanak.
>
> A survey of research papers in ADS with at least one Uzbek author and published in the 15 years 1991–2005 since Independence, showed that there were 142 papers published in this time which is unusually high for a developing country.
>
> The facts that Uzbekistan employs a substantial number of professional astronomers (probably about 50 if one includes those in the universities), that it has one of the best climates in the world for observational astronomy, and that it has a very rich heritage in astronomical history, all make a compelling case for eventual IAU membership.
>
> With this level of activity, one can confidently state that of all the non-IAU member countries, the level of astronomical activity in Uzbekistan from the existing infrastructure and facilities is greater than in any other. In fact, there is more astronomical education and research in Uzbekistan than in many IAU national members. Uzbekistan has one of the world's best sites for observational astronomy, and the IAU should encourage the development of the Maidanak site for optical and infrared astronomy by promoting astronomical collaborations with developed countries.

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References

Abdujabbarov, A.A., & Ahmedov, B.J. (2010). Test particle motion around a black hole in a braneworld. *Physical Review D,* 81(4), id. 044022.

Balashov, Y. (2014). Bredikhin, Fyodor Aleksandrovich. In T. Hockey et al., p. 306.

Beech, M. (2014). Schiaparelli, Giovanni Virginio. In T. Hockey et al., pp. 1934–1936.

Bogdan, T.J. (2014). Belopolsky, Aristarkh Apollonovich. In T. Hockey et al., pp. 193–194.

Chatterjee, R., Marscher, A.P., Jorstad, S.G., Olmstead, A.R., McHardy, I.M., and 31 coauthors (2009). Disk-jet connection in the radio galaxy 3C 120. *Astrophysical Journal,* 704, 1689–1703.

Chang, H.-K., Chou, D.-Y., Labonte, B., & TON Team (1997). Ambient acoustic imaging in helioseismology. *Nature,* 389, 825–827.

Chou, D.-Y., Sun, M.-T., Fernandez, J. F., Wang, L.-H., Jimenez, A., Serebryanskiy, A., & Ehgamberdiev, Sh. (2010). Taiwan Automated Telescope Network. *Advances in Astronomy,* 4–8.

Chou, D-Y., Sun, M.-T., Huang, T.-Y., Lai, S.-P., Chi, P.-J., and 16 coauthors (1995). Taiwan Oscillation Network. *Solar Physics,* 160, 237–243.

Ehgamberdiev, Sh. (1983). The placement of X-ray bright points relative to the chromospheric network. *Soviet Astronomy Letters,* 9, 385–389.

Ehgamberdiev, Sh. (1996). The IRIS network for whole disc helioseismology: recent results. Proceedings of the 7th Asian Pacific Regional meeting of the IAU. *Journal of the Korean Astronomical Society,* 29, *Supplement,* 287–290.

Ehgamberdiev, Sh. (2003). Astronomical Education in Uzbekistan. Paper presented at the IAU General Assembly, Sydney, Australia.

Ehgamberdiev, Sh. (2011). Emergence of modern astronomy and astrophysics in Uzbekistan. In T. Nakamura, W. Orchiston, M. Sôma, & R. Strom (Eds.), *Mapping the Oriental Sky. Proceedings of the Seventh International Conference on Oriental Astronomy,* pp. 187–196. Tokyo: National Astronomical Observatory of Japan.

Ehgamberdiev, Sh., Bayjumanov, A., Ilyasov, S., Sarazin, M., Tokovinin, A., & Ziad, A. (2000a). The astroclimate of the Maidanak Observatory in Uzbekistan. *Astronomy and Astrophysics, Supplement Series, 145,* 293–304.

Ehgamberdiev, Sh., & Fossat E. (Eds.), (1991). Proceedings of the 2nd IRIS Workshop. Tashkent, Sept. 3–9, 1989. *Solar Physics,* 133, 69–80.

Ehgamberdiev, Sh., Eshonkulov, S., & Litvinenko, E. (2000b). Kitab as one of the five stations of the ILS: history and present. In S. Dick, D. McCarthy, & B. Luzum (Eds.), *Polar Motion: Historical and Scientific Problems,* pp. 163–167. San Francisco: Astronomical Society of the Pacific.

Ehgamberdiev, Sh., Fossat E., & Serebryanskiy, A.V. (2014). Twenty-five years of helioseismology research in Uzbekistan. *Journal of Astronomical History and Heritage,* 17*,* 45–64.

Florya, N.F. (1935). Photometry and variable star study at TAO. *Proceedings of Tashkent Astronomical Observatory,* 5, 59–78 (in Russian).

Gedeonov, D.D. (1899). Les variations de la latitude à Tachkent 1895–1896. *Astronomische Nachrichten,* 148*,* 173–174. (in French).

Grankin, K.N., Melnikov, S. Yu., Bouvier, J., Herbst, W., & Shevchenko, V.S. (2007). Results of the ROTOR-program. The long-term photometric variability of classical T Tauri stars. *Astronomy and Astrophysics,* 461, 183–195.

Gurshtein, A. (2014). Fesenkov, Vasilii Grigorevich. In T. Hockey et al., pp. 716–717.

Gur'yanov, A.E., Kallistratova, M.A., Kutyrev, A.S., Petenko, I.V., Shcheglov, P.V., & Tokovinin, A.A. (1992). The contribution of the lower atmospheric layers to the seeing at some mountain observatories. *Astronomy and Astrophysics,* 262, 373–381.

Herbst, W., & Shevchenko, V. (1999). A photometric catalogue of Herbig AE/BE stars and discussion of the nature and cause of the variations of UX Orionis stars. *Astronomical Journal,* 118, 1043–1060.

Hockey, T. et al. (Eds.), (2014*). Biographical Encyclopedia of Astronomers. 2nd Edition*. New York: Springer.

Kaganovski, G.M. (1972). Variation of the latitude of Tashkent due to the Earth's polar motion. *Transactions of the Uzbek Academy of Sciences,* 7, 5–8. (in Russian).

Kholikov, Sh.S., Burtseva, O.S., Serebryanskiy, A.V., & Ehgamberdiev, Sh.A. (2004). On the variations in the parameters of high-degree acoustic modes with solar cycle. *Astronomy Letters,* 30*,* 577–581.

Ladenkov, O.V., Hill, F., Egamberdiev, Sh.A., & Chou, D.-Y. (2002). Acoustic power mapping for active regions from MDI, HLH, and TON data. *Astronomy Letters,* 28, 411–418.

Pandey, S.B., Castro-Tirado, A.J., Jelinek, M., Kamble, A.P, Gorosabel, J., and 22 coauthors (2009). Multi-wavelength observations of the GRB 080319B afterglow and the modeling constraints. *Astronomy and Astrophysics,* 504, 45–48.

Postoev, A.I. (1931). Time service of TAO. *Publications of the Tashkent Astronomical Observatory,* IV, 3–13 (in Russian).

Postoev, A.I. (1933). The new subterranean clock room of the TAO. *Publications of the Tashkent Astronomical Observatory,* IV*,* 50–52 (in Russian).

Postoev, A.I. (1935). Time service of TAO. *Publications of the Tashkent Astronomical Observatory,* V, 35–41 (in Russian).

Repsold, J.A. (1914). *Zür Geschichte der astronomischen Messwerkzeuge von 1880 bis um 1900*. Leipzig: Zweiter Band.

Sattarov, I. (2003). Fine structure of sunspots from the groundbased small telescope. In A.A. Pevtsov, & H. Uitenbroek (Eds.), *Current Theoretical Models and Future High Resolution Solar Observations: Preparing for ATST,* pp. 307–314. San Francisco: Astronomical Society of the Pacific.

Sattarov, I., Pevtsov, A.A., Karachik, N.V., & Sattarova, B.I. (2005). Large-scale structures in distribution of coronal bright points. In K. Sankarasubramanian, M. Penn, & A. Pevtsov (Eds.), *Large-scale Structures and their Role in Solar Activity,* pp. 363–367. San Francisco: Astronomical Society of the Pacific.

Serebryanskiy, A., Ehgamberdiev, Sh., Kholikov, S., Fossat, E., Gelly, B., and 6 coauthors (2001). An estimation of global solar p-mode frequencies from IRIS network data: 1989–1996. *New Astronomy*, 6, 189–195.

Shcheglov, V.P. (1974). A short history of the Tashkent Astronomical Observatory – Astronomical Institute of the Uzbek Academy of Sciences. In *100th Anniversary of the Astronomical Institute of the Uzbek Academy of Sciences,* pp. 6–22. Tashkent: Fan (in Russian).

Shcheglov, P.V., & Gur'yanov, A.E. (1991). The atmospheric quality of astronomical seeing at several points in the USSR. *Soviet Astronomical Journal,* 68, 632–638.

Shcheglov, V., & Slonim Yu. (1970). Solar physics at Tashkent Astronomical Observatory, *Solar Physics,* 11, 157–160.

Shevchenko, V.S. (1973). The results of astroclimate studies at Mt. Maidanak. *Soviet Astronomical Journal,* 50, 632–644.

Shevchenko, V.S. (1974). Non stationary stars. In *100th Anniversary of the Astronomical Institute of the Uzbek Academy of Sciences,* pp. 113–121. Tashkent: Fan (in Russian).

Slonim, Yu.M. (1974). Solar investigations. In *100th Anniversary of the Astronomical Institute of the Uzbek Academy of Sciences,* pp. 88–112. Tashkent: Fan (in Russian).

Stratonov, V.V. (1904). Amas stellaire de l'equ Sobieski. *Publication de l'Observatoire de Tashkent,* 5, 1–124 (in French).

Trimble, V. (2014). Mustel', Éval'd Rudol'fovich. In T. Hockey et al., pp. 1543–1544.

Turakulov, Z. (2010). *Space, Time and Motion. Real Space-Time and its Models*. Saarbrucken: Lambert Academic Publishing.

Villata, M., Raiteri, C.M., Larionov, V.M., Nikolashvili, M.G., Aller, M.F., and 51 coauthors (2009). The correlated optical and radio variability of BL Lacertae. WEBT data analysis 1994–2005. *Astronomy and Astrophysics,* 501, 455–459.

Vuissoz, C., Courbin, F., Sluse, D., Meylan, G., Ibrahimov, M., and 6 coauthors (2007). COSMOGRAIL: the COSmological MOnitoring of GRAvItational Lenses. V. The time delay in SDSS J1650+4251. *Astronomy and Astrophysics,* 464, 845–849.

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