A

ˁAbbās Wasīm Efendi

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Born **Bursa, (Turkey), 1689**
Died **Istanbul, (Turkey), 1760**

ˁAbbās Wasīm Efendi was a scholar who made many valuable contributions to Ottoman astronomy. These included writing a Turkish commentary on the famous astronomical handbook (*Zīj*) of ► **Ulugh Beg** as well as translating ► **ˁAbd al-ˁAlī al-Bīrjandī**'s work on solar and lunar eclipses into Turkish. In addition to being an astronomer, he was a physician, a calligrapher, and a poet; he was also a member of the Khalwatiyya and Qādiriyya religious orders. Besides knowing Turkish, ˁAbbās Wasīm Efendi knew a number of languages that included Arabic, Persian, Latin, French, and ancient Greek.

ˁAbbās Wasīm Efendi, whose father's name was ˁAbd al-Raḥmān and whose grandfather's name was ˁAbdallāh, was known as Kambur (Humpback) Vesim Efendi and as Dervish ˁAbbās Ṭabīb. He pursued his education with eminent scholars; apparently his teachers appreciated his cleverness, aptitude, and open-minded attitude. His studies and research took him to Damascus, to Egypt, and to Mecca and Medina (where he performed the *ḥajj* or pilgrimage). Upon his return to Istanbul, ˁAbbās Wasīm Efendi opened a pharmacy and a clinic at the Yavuz Selīm Bazaar in the Fatiḥ district of Istanbul, where he treated patients for almost 40 years. He wrote and translated many works on medicine and pharmacology, incorporating the information he obtained through his many contacts with European physicians coming to Istanbul. From these contacts ˁAbbās Wasīm Efendi was able to learn Latin and French, translate Italian medical texts into Turkish, and closely follow advancements in medical science in Europe.

ˁAbbās Wasīm Efendi's main contribution to Ottoman astronomical literature is his translations and commentaries. Without any doubt, his most important work is his Turkish commentary on Ulugh Beg's *Zīj* (astronomical handbook), which was originally written in Persian and was used as the main reference book by the chief astronomers and timekeepers of the Ottoman State for their astrological and astronomical studies. ˁAbbās Wasīm Efendi began working on this book in 1745, at the request of the historian and astronomer Aḥmad Misrī, who convinced him of the importance of a Turkish translation. Upon completion, ˁAbbās Wasīm Effendi presented it to the Ottoman Sultan Maḥmūd I (reigned: 1730–1754). His commentary is written in clear Turkish, in the same style as ► **Mīram Chelebī**'s commentary on the same work. The examples given in the book are all based on ˁAbbās Wasīm Effendi's

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own calculations for the longitude and latitude of Istanbul. He has included findings from ancient Turkish, Hebrew, and Roman Calendars, which were not in the original. He has also explained Ulugh Beg's method for finding the sine of 1°, which was based on the work of ► **Jamshīd al-Kāshī**. One may deduce that ʿAbbās Wasīm Effendi was interested and well informed on astrology since he dedicates a separate and large section of the book to the subject.

A valuable work on solar and lunar eclipses that ʿAbbās Wasīm Efendi also translated into Turkish was Chapter Ten of Bīrjandī's *Ḥāshiyaʿala sharḥ al-Mulakhkhaṣ fī al-hay'a* (which was a supercommentary on ► **Jaghmīnī**'s elementary astronomical textbook). He titled his book *Tarjamat kitāb al-Bīrjandī min al-khusūf wa-'l-kusūf*.

Another astronomical work concerns lunar crescent visibility, which is important for religious observance. ʿAbbās Wasīm Efendi also wrote a work entitled *Risāla al-wafq* dealing with prognostication and astrology.

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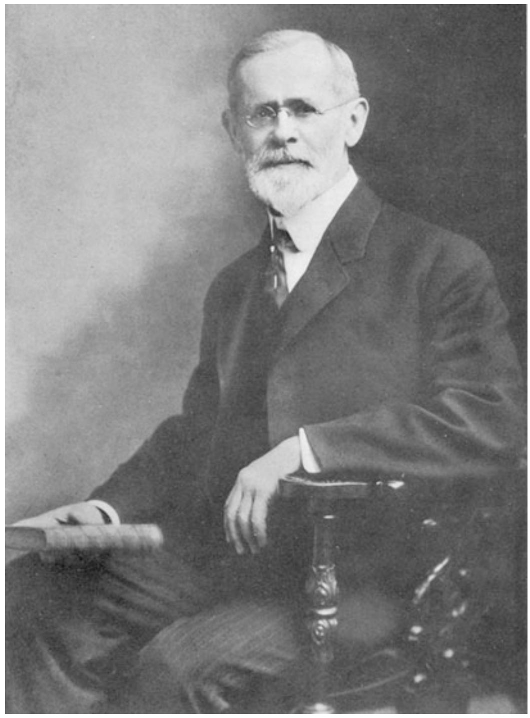
Abbe, Cleveland

Leonard B. Abbey
Atlanta, GA, USA

Born **New York, New York, USA, 3 December 1838**
Died **Chevy Chase, Maryland, USA, 28 October 1916**



Abbe, Cleveland. Reproduced from *Biographical Memoirs, National Academy of Sciences* 8 (1919)

A practical astronomer, mathematician, and meteorologist, Cleveland Abbe is perhaps best noted as the father of weather forecasting in the United States, having produced the first storm forecasts while director of the Cincinnati Observatory. Abbe was the son of George Waldo, a dry-goods merchant and broker, and Charlotte (*née* Colgate) Abbe. The Abbe family emigrated from England in 1635, settling first in Connecticut. The family

Leonard B. Abbey: deceased.

was prominent in the American Revolution and the American Civil War.

Cleveland Abbe's mother presented him with a copy of William Smellie's *Philosophy of Nature* when he was 8 years old. This book awakened in the young boy a lifelong interest in the natural sciences. A-voracious reader for his entire life, Abbe's early education was at a private school in New York City. He entered the New York Free Academy (now the City College of New York) at age 13, receiving his B.A. in 1857, and an M.A. in 1860.

Abbe became seriously interested in astronomy while he was a tutor in engineering at the University of Michigan in 1860. Inspired by ▶ **Franz Brünnow**, director of the Detroit Observatory, Abbe took up the study of astronomy.

However, Abbe's service at the University of Michigan was interrupted when he responded to President Lincoln's first call for volunteers for the American Civil War. Unfortunately, after several weeks in training Abbe was rejected because of his extreme myopia. Instead, Abbe went to Cambridge, Massachusetts, where he assisted ▶ **Benjamin Gould** in the telegraphic longitude work of the United States Coast Survey.

At the end of the war, Gould suggested that Abbe go to Pulkovo Observatory in Russia to study astronomy under ▶ **Otto Wilhelm Struve**. Abbe applied to Struve, who welcomed him with an invitation written in such warm terms that the document became one of Abbe's most treasured possessions. He spent 1865 and 1866 as a supernumerary astronomer (the equivalent of the modern postgraduate fellowship) at Pulkovo, where the Struves treated him as a family member. Abbe seriously considered settling at Pulkovo and marrying Struve's youngest half sister, Ämalie. However, Struve rejected Abbe's petition on the grounds that in the Struve's German culture, Ämalie, the youngest daughter, was expected to remain at home to care for her elderly stepmother. Within a few weeks, Abbe returned to the United States. He regarded his years at Pulkovo as the highlight of his career.

Upon his return to the United States, Abbe filled a short appointment at the United States Naval Observatory before assuming duties as director of the Cincinnati Observatory. During the nineteenth century, astronomical observatories often served as dispensers of more general scientific information to the public. In addition to astronomy, the citizens of Cincinnati wanted authoritative information on meteorology, geology, mathematics, chemistry, and physics. Abbe formulated an ambitious plan to embrace all of these disciplines during his tenure. However, he soon focused his activities on meteorology.

While working for Gould, Abbe saw how the telegraph could be a valuable modern tool in making precision simultaneous scientific observations. With the cooperation of the Cincinnati Chamber of Commerce and the Western Union Telegraph Company, he began to collect simultaneous weather observations from over 100 stations in 1869. Building a database from this information, he was soon able to make weather predictions for the eastern and midwestern United States. Abbe's work constituted the world's first large-scale weather prediction system. The predictions were published daily in hundreds of newspapers. The results of the network were so favorable that within 6 months Western Union took the system over as one of its services. Shortly after that, the United States government assumed control of the operation, assigning it to the United States Army Signal Corps. The service was known as the United States Weather Bureau. Abbe edited weekly and monthly weather reports for the bureau for 45 years, beginning in 1871. The bureau eventually evolved into today's National Oceanic and Atmospheric Administration.

Abbe was a man of great modesty, never touting his achievements. He was always willing to give encouragement and advice to those who worked or corresponded with him. He was particularly talented at mediating between the rigid hierarchy of the military chain of command and the more casual working methods of the scientists. His colleagues noted that he was totally devoid of any hint of envy or jealousy, a rare characteristic for a modern scientist!

Abbe was a skilled mathematician, geodesist, chemist, physicist, and engineer though his primary impact on science was in the field of meteorology. He was active in the field of astronomy for his entire life. Abbe was particularly interested in the effects of the atmosphere on astronomical observations. He was multilingual, and many of his most important contributions were compilations of translated materials on astronomy and meteorology. He was an early advocate of the standard time system, and represented the United States at the International Meridian and Time Standard Congress in Washington in 1884.

Abbe received an honorary Ph.D. from the College of the City of New York in 1891, honorary LL.D.s from the University of Michigan (1889) and the University of Glasgow (1896), and an honorary S.B. from Harvard University (1900). He received many medals, awards, and other honors, including the Franklin Institute's Longstreth Medal of Merit, the United States National Academy of Sciences' Marcellus Hartley Memorial Medal, and the American Philosophical Society's Franklin Medal. He was an *Officier d'Académie* of the French Republic, and a fellow of the Royal Astronomical Society.

Intensely intellectual, Abbe continued to work on his papers and correspondence until the week of his death. He was a prolific writer. There are over 5,500 items in his collected articles, papers, and books, which occupy 15 ft of shelf space in the Library of Congress.

Professor Abbe married Frances Martha Neal of Ohio (1870), and after her death, Margaret Augusta Percival (1909). He had three sons, Cleveland, Jr., Truman, and William. His brother, Richard, was a prominent New York surgeon who pioneered the use of radium and catgut sutures. Abbe was a devout Christian, and attended services of several Protestant denominations at different periods of his life.

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Abbo of Fleury

Thomas Hockey
Department of Earth Science, University of Northern Iowa, Cedar Falls, IA, USA

Alternate Names

► de Fleury, Abbon; ► Fleury, Abbon de

Flourished **France**, ***circa*** **945–1004**

Abbo of Fleury constructed a novel diagram showing planetary positions as a function of time.

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Abbot, Charles Greeley

Thomas R. Williams
Rice University, Houston, TX, USA

Born **Wilton, New Hampshire, USA, 31 May 1872**
Died **Washington, District of Columbia, USA, 17 December 1973**

Charles Abbot refined the value of the solar constant and significantly improved the technology of its measurement, but failed in his long-term effort to correlate small variations in the solar constant with terrestrial weather patterns. Abbot provided critically needed encouragement and financial support from both institutional and private sources to Robert H. Goddard's early research and development of liquid-fueled rocket technology.

The son of Harris and Carol Ann (*née* Greeley) Abbot, Charles studied chemistry and physics at Phillips Andover Academy, Massachusetts, and at the Massachusetts Institute of Technology, receiving an M.S. degree in 1895 for a thesis on osmotic pressure.

Although he knew nothing about astronomy at the time, Abbot was employed following his graduation by ► **Samuel Langley**, director of the Smithsonian Astrophysical Observatory [SAO] and secretary of the Smithsonian Institution. Abbot's work as Langley's aide at the SAO was focused on determination of the solar constant, a measure of the amount of energy received per unit area of the Earth's surface. Langley's preoccupation with this measurement reflected his intent to not only detect variations in that important physical parameter, but also establish correlations between variations in the solar constant and changes in the Earth's weather if possible. Toward that end, Langley had developed the bolometer and other measurement devices and made preliminary measurements of the solar constant, establishing a value of 3 cal cm^{-2} min^{-1}. Abbot replaced Langley as the SAO director upon the latter's death in 1905 and continued his mentor's research programs until his own retirement in 1944. An ingenious experimenter, Abbot developed a series of highly specialized instruments for measuring and characterizing solar energy reaching the Earth, and deployed these instruments at stations located on several continents. His first efforts in the city of Washington concentrated on eliminating sources of error in the measurement of the solar constant through improvements in the measuring device, which ► **Claude Pouillet** had named the pyrheliometer. Measurements with a refined pyrheliometer from Mount Wilson and Mount Whitney, both in California, led Abbot to reduce Langley's value to 2.1 cal cm^{-2} min^{-1} in 1907, with an eventual further reduction to 1.94 cal cm^{-2} min^{-1} after several decades of refined measurements and analysis of the data. Abbot recognized that daily measurements were essential to establish any correlation with weather, and further that measurements had to be made in elevated locations with a maximum of cloudless days and atmospheres clear of any pollution. This led to the establishment and operation of a series of SAO stations on mountains in Chile, Mexico, Algeria, South Africa, and the Sinai Desert as well as in New Mexico and California, USA.

Although Abbot's program of data gathering was endorsed at various times by distinguished scientists, including astronomers ► **George Hale**, ► **William Campbell**, and ► **Walter Adams**, as well as physicists ► **Robert Millikan** and Karl Taylor Compton (1887–1954), and meteorologists C. F. Marvin and H. H. Clayton, there was little agreement that his efforts to correlate small variations in the measured solar constant with weather patterns showed any significant results.

Abbot also developed powerful spectrographs with Langley's bolometers as sensitive radiation detectors. Using these spectrographs, Abbot mapped the solar spectrum in significant detail. On the basis of his results, by 1911 Abbot had concluded, correctly, that the continuous spectrum of the Sun could only be attributed to gas under high pressure, and further that the opacity of that gas would account for the apparent sharp edge of the solar photosphere. Abbot's finding contradicted a previous widely held belief that the photosphere consisted of incandescent solids and liquids.

In his role as home secretary of the United States National Academy of Sciences, Abbot arranged the 1920 William Ellery Hale lectures on the distance scale of the Universe, now known as the Curtis-Shapley debate. Hale was the father of ► **George Hale**, who had suggested the topic to Abbot.

In 1928, Abbot accepted additional administrative responsibility as the secretary of the Smithsonian Institution, which he undertook without yielding his position as director of the SAO.

Abbot's tenure as secretary was dominated by the financial uncertainty endemic in all such institutions during the world economic depression and later during World War II. As a result of both these financial problems and to some extent from Abbot's benign neglect in favor of solar research, development of the Smithsonian Institution was largely stagnant during his service as secretary.

During these years, however, Abbot managed to arrange limited financial support for the rocket research of Robert H. Goddard, who had first contacted the Smithsonian Institution in 1916. Working both with Smithsonian Institution funds and with private support from philanthropist John A. Roebling, Abbot managed to eke out sufficient funds to support Goddard's research until military as well as scientific applications of the liquid-fueled rocket became attractive. Goddard served as a director of Roebling's foundation, The Research Corporation, in New York City from 1928 to 1945.

The practical aspect of Abbot's abilities was revealed in his record of inventions. He patented at least 16 inventions, many of which involved applications of solar energy. Abbot actively promoted the use of solar energy in his popular lectures and popular writing. His commitment to popularizing science was also reflected in the publication of the Smithsonian Scientific Series of popular books on science and technology.

In 1915 Abbot was elected to membership in the National Academy of Sciences, having received the Academy's Draper Medal in 1910. His peers in the American Academy of Arts and Sciences [AAAS] honored him with the Rumford Medal in 1916 and elected him as AAAS fellow in 1921. Abbot was the recipient of honorary doctorates from a number of universities including D.Sc.s from the University of Melbourne (1914), the Case School of Applied Science (1930), and George Washington University (1937), and an L.L.D. from the University of Toronto (1933).

In 1897, Abbot married Lillian E. Moore, who died in 1944. He was survived by his second wife, Virginia A. Johnston, whom he married in 1954.

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Abbott, Francis

Wayne Orchiston
National Astronomical Research Institute of Thailand, Chiang Mai, Thailand

Born **Derby, Derbyshire, England, 12 August 1799**
Died **Hobart, Tasmania, (Australia), 18 February 1883**

Francis Abbott's important contributions to Tasmanian and Australian astronomy and meteorology were overshadowed by his controversial claim to have observed shrinkage of the η Carinae nebula that he believed was evidence of the evolution of a stellar system like our Solar System.

Abbott, the son of John and Elizabeth Abbott, was baptized on 12 August 1799. Trained as a watchmaker in Derby, he established his business there and, in 1825, married Mary Woolley; they had seven children. In 1831 Abbott moved to Manchester where he ran a successful business manufacturing clocks, watches, and astronomical machinery until 1844 when he was found guilty of obtaining two watches under false pretences. Sentenced to penal servitude, he arrived in Hobart, Australia, in June 1845, and after 4 years obtained his ticket-of-leave and set up as a watch- and clockmaker in Hobart. With the passage of time his business expanded to include photography and the supply and repair of optical and other instruments. Despite his less than auspicious arrival in the colony, Abbott and his family (who arrived in 1850) became respected members of Tasmanian society, with three of his sons rising to positions of prominence.

During the 1840s Hobart lacked an astronomical observatory, but it did boast of a geomagnetic and meteorological observatory. While still a convict, Abbott became involved in the Rossbank Observatory's meteorological program. When the observatory closed at the end of 1854, Abbott – by now a free man – immediately established a private observatory at his home in Hobart and continued his meteorological observations. For the next 25 years he authored monthly reports on his thrice-daily readings, and six monographs that documented Hobart's weather from 1841 to 1879 inclusive. These volumes were published, with funding from the government, by the Royal Society of Tasmania (RST). Abbott's private observatory included, apart from its full suite of meteorological instruments, a small transit telescope and an astronomical clock. For nearly 30 years he provided a local time service.

Abbott's observatory was best known for its astronomical output. With the aid of three small refracting telescopes (the largest with an aperture of about 13 cm), he observed a succession of comets and current phenomena including the variable star η Carinae. Abbott published 35 papers in *Monthly Notices of the Royal Astronomical Society*, *Papers and Proceedings of the Royal Society of Tasmania*, and the *Astronomical Register* on the 1861 and 1868 transits of Mercury, the 1874 transit of Venus, sunspots and aurorae, a lunar occultation of Jupiter, meteors, the open cluster κ Crucis, and a number of comets. Apart from providing invaluable data on the Great Comet of 1861 (C/1861 J1), which was discovered by John Tebbutt, Abbott also wrote three papers about the Great Comet of 1865 (C/1865 B1), of which he made an independent discovery – although he is generally not given credit for this.

In contrast to his comet work, it was his observations of η Carinae that brought Abbott international notoriety. He began recording the declining magnitude of this enigmatic variable star in 1856. However, in an 1863 paper in *Monthly Notices*, Abbott postulated that the nebulosity surrounding the star had changed in shape and size since Sir ► **John Herschel** first observed the region in the 1830s. Abbott's claim ran counter to the prevailing wisdom and elicited objections from Herschel and other distinguished Northern Hemisphere astronomers, including Astronomer Royal ► **George Airy**. Abbott continued to press his claim in 13 further papers published until 1871, when the respected astronomer-popularizer, ► **Richard Proctor**, was asked to adjudicate on the matter. Proctor's report was damning:

> Mr. Abbott has supposed the dark spaces (shown in Sir J. Herschel's Monograph) to correspond to the lemniscate, which would unquestionably imply a complete change in the whole aspect of the Nebula. [But] On the scale of Mr. Abbott's drawings, the lemniscate would be about 2/5ths of an inch long; it would, in fact, be a minute and scarcely discernible feature (Richard Proctor).

In spite of Proctor's finding, Abbott published two further papers on the topic before finally bowing to international pressure. Although he did record one of the contact times for the 1874 transit of Venus, the unfortunate η Carinae episode all but terminated Abbott's credibility. After 1873 no further papers by him appeared in European astronomical journals.

Instead, Abbott turned his considerable energy and enthusiasm to the popularization of astronomy. In quick succession he published three short booklets privately to bring recent international developments in astronomy before an Australian audience. Spectroscopy in general and astronomical spectroscopy in particular feature prominently in the first two works, while the third booklet highlights Sir ► **William Herschel**'s important overall contribution to astronomy. In view of the aforementioned η Carinae controversy, it is interesting that this star is scarcely mentioned in any of the booklets. Abbott resisted introducing any semblance of a local flavor into these booklets, not mentioning either his own astronomical endeavors or those of Tebbutt and some of Australia's leading professional astronomers.

Apart from his prominence as a maker of public clocks, from 1855 to 1880, Abbott served as Tasmania's de facto government astronomer and meteorologist. It was only when advancing age made him relinquish this gratuitous role that the RST argued for the urgent need for a colonial observatory. As a result, the government opened the Hobart Observatory in 1882 under the directorship of Captain J. Shortt; its charter included timekeeping, meteorology, and astronomy.

Abbott was an active member and councilor of the Royal Society of Tasmania, and was elected a fellow of both the Royal Astronomical Society and the Royal Meteorological Society.

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Abd al-Wājid: Badr al-Dīn ʿAbd al-Wājid [Wāḥid] ibn Muḥammad ibn Muḥammad al-Ḥanafī

Hüseyin Gazi Topdemir
Philosophy, Ankara University, Ankara, Turkey

Born **Mashhad**, (**Iran**)
Died **Kütahya**, (**Turkey**), **1434**

Abd al-Wājid was a *mudarris* (teacher) who wrote several works on astronomy that indicate that he was greatly influenced by the astronomical educational tradition of the Marāgha circle of scholars (including ► **Ṭūsī** and ► **Shīrāzī**). He traveled to Anatolia from his native region of Khurāsān in Iran, and became a student of Muḥammad ibn Ḥamza al-Fanārī (died: 1431) during the reign of Germiyānoğlu Süleymān Shāh (1368–1387). ʿAbd al-Wājid later settled in Kütahya and taught at the Wājidiyya Madrasa (known as the Demirkapi Madrasa during the Ottoman Period) until his death. The influence of the Marāgha circle had previously been felt in Anatolia because of Shīrāzī, who had also worked at various centers and schools there.

Local traditions indicate that the Wājidiyya Madrasa was a place where astronomical observation and instruction took place, often associated with ʿAbd al-Wājid in the fourteenth century. According to its foundation inscription, this *madrasa* was built in 1308 by Mubāriz al-Dīn ibn Sāwjī. ʿAbd al-Wājid must have been a very prominent professor at this *madrasa* in as much as it seems to have been renamed in his honor; clearly, he was not one of its founding professors. Because ʿAbd al-Wājid had astronomical interests and was the author of several books on astronomy, the local tradition connecting the school with astronomy gains some credibility. This probably consisted of astronomical instruction and some practical applications. It is unlikely, though, that there was a large-scale observatory, such as those at Marāgha and Samarqand, associated with the school.

Among ʿAbd al-Wājid's works on astronomy, *Sharḥal-Mulakhkhaṣ fī al-hay'a* is a commentary on ▶ **Jaghmīnī**'s famous astronomical textbook; ʿAbd al-Wājid dedicated it to Sultan Murād II (1404–1451). *Sharḥ Sī faṣl* is a commentary on Ṭūsī's Persian work on practical astronomy, which consists of 30 chapters. This text was translated into Turkish by Ahmed-i Dāʿī, but it cannot be precisely dated. *Ma ʿ ālim al-awqāt wa-sharḥuhu* is a work about the astrolabe and its uses. It was written in verse and consisted of 552 couplets. It was dedicated to Muḥammad Shāh (died: 1406), the son of ʿAbd al-Wājid's teacher al-Fanārī.

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Abetti, Antonio

Christof A. Plicht
Arbeitsgemeinschaft Hildesheimer
Amateurastronomen, Hildesheim, Germany

Born **Gorizia, (Friuli-Venezia Giulia, Italy), 19 June 1846**
Died **Arcetri near Florence, Italy, 20 February 1928**

Italian astronomer Antonio Abetti revived the Arcetri Observatory south of Florence and made it one of the leading astrophysical institutions in Europe. He was a civil engineer and an architect but turned his interest to astronomy in 1868, almost immediately after he received a degree in mathematics and engineering from the University of Padua. He began his career at the local observatory, then headed by ▶ **Giovanni Santini**, as an assistant until 1893. After an examination Abetti was appointed director of the Arcetri Observatory and professor of astronomy at the University of Florence. In 1921, aged 75, he had to retire from the posts but continued his researches at the observatory.

The main field of Abetti's work was positional astronomy. During the 25 years in Padua he made many observations of small planets, comets, and star occultations, which he published in the *Memoirs and Observations of the Observatory of Arcetri* and in the *Astronomische Nachrichten*. On an expedition led by ▶ **Pietro Tacchini** to Muddapur, Bengal, India, in 1874, he observed the transit of Venus across the Sun's disk through a spectroscope. It was the first time that such an instrument was used for this purpose.

The Arcetri Observatory, founded by ▶ **Giovanni Donati** in 1872, had been partially abandoned after Donati's death. Then one of the first major tasks for Abetti was to erect a telescope that he had built in the workshops at Padua. The objective lens he used was the 28-cm (11 in.)-diameter achromatic doublet with 533 cm focal length constructed by ▶ **Giovanni Amici** in 1839. With this instrument Abetti and others obtained many observations on the positions of minor planets, comets, and stars.

Abetti was a member of the Accademia Nazionale dei Lincei (Rome), associate member of the Royal Astronomical Society (London), and a member of several other Italian academies. In 1879 he had married Giovanna Colbachini, of Padua; they had two sons. The younger son, ▶ **Giorgio Abetti**, shared his father's interest in astronomy and became an astronomer himself, succeeding his father as director of the Arcetri Observatory in 1921.

A lunar crater and minor planet (2646) Abetti are named to honor Antonio Abetti and his younger son.

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Abetti, Giorgio

Margherita Hack
Trieste, Italy

Born **Padua, Italy, 5 October 1882**
Died **Florence, Italy, 24 August 1982**

Giorgio Abetti is most closely associated with detailed measurements and interpretation of the Evershed effect, sometimes called the Evershed-Abetti effect. He also played an important part in the development of astrophysics in Italy in the 1920s and 1930s, when most of the Italian observatories were focused on positional astronomy. Abetti obtained his degree in physics at the University of Padua in 1904, where his primary teacher had been his father, ► **Antonio Abetti**. He spent time at Yerkes, Heidelberg, Mount Wilson (where ► **George Hale** was one of his mentors), and Rome observatories (1910–1919). In 1921, he accepted appointments as professor of astronomy at the University of Florence and director of the nearby Arcetri Observatory, where he remained until his retirement in 1953.

While at Rome, Abetti made use of observations from many locations to show that the true diameter of Neptune is only 2.3″, and the density of the planet therefore is larger than had been supposed up to that time (1912). His primary interest was, however, in solar surface phenomena, and he managed to have built a 24-m-high solar tower at Arcetri in 1924. This was used to obtain spectra of small regions on the solar surface, particularly in and around sunspots. The Doppler shifts of the hydrogen and metallic lines from gas in and around the spots, when observed for spots at different locations on the Sun (so that the Doppler shift provides information about motions both perpendicular and parallel to the solar surface), showed the pattern of gas flows in solar active regions. In particular, Abetti's work revealed that the flow outward in spot areas is extremely variable in both space and time, ranging from almost 0 km s^{-1} to about 6 km s^{-1}, rather than being constant and regular as had previously been supposed. The Doppler shifts caused by these flows are now generally called the Evershed effect, but sometimes the Evershed-Abetti effect. Abetti's solar and other work appeared in more than 250 scientific papers and several books.

Abetti was one of the founders of the International Astronomical Union [IAU] at its first formal meeting in Rome in 1922, participating in several of the commissions devoted to solar studies. He later served as vice president of the IAU. Abetti was elected a corresponding member of the Accademia dei Lincei in 1926 and a national member in 1938 and was a founder (1920) and later president of the Società Astronomica Italiana. He was also active in early work in the attempt to understand solar-terrestrial relations – the relationship between solar activity and the magnetic field, aurorae, weather, and other earthly phenomena. Abetti was the first chair of an IAU committee, organized in 1928, to monitor various solar-activity indicators and to collect and publish the data.

Abetti's influence in Italian astronomy and astrophysics continued through his students and junior colleagues. These (and the observatories they later directed) have included, in chronological order, Attilio Colacevich (Naples),

Margherita Hack: deceased.

Guiglielmo Righini (Arcetri, in succession to Abetti), Giulio Calamai, ▶ Mario Fracastoro (Catania and Pino Torinese), Vinicio Barocas, Maria Ballario, Margherita Hack (Trieste), Giovanni Godoli (Catania), and Mario Rigutti (Catania).

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Abharī: Athīr al-Dīn al-Mufaḍḍal ibn ʿUmar ibn al-Mufaḍḍal al-Samarqandī al-Abharī

Hüseyin Sarioğlu
Istanbul University, Istanbul, Turkey

Born **probably Mosul, (Iraq)**
Died **Shabustar, (Iran), possibly 1265**

Abharī, sometimes referred to as "Athīr al-Dīn al-Munajjim" (the astrologer), was a well-known philosopher who wrote influential texts in logic, mathematics, and astronomy. There has been diverse speculation about where and when Abharī was born, with the predominant opinion being that he was born in Mosul. "Samarqandī" in his name indicates that either he or his ancestors originally stemmed from there, most likely belonging to the Abhar tribe.

Little information is known about Abharī's education. It is thought that he attended primary school in Mosul and later traveled to the scientific and cultural centers in Khurāsān, Baghdad, and Arbil to continue his studies. The biographer Ibn Khallikān reports that Abharī took part in the assemblies of the famous scholar Kamāl al-Dīn ibn Yūnus (died: 1242) and even worked as his assistant at the Badriyya School in Mosul. Other reports claim that Abharī was a student of the renowned theologian Fakhr al-Dīn al-Rāzī (died: 1210), that he taught at the Sharafiyya School in 1248 in Baghdad, that he traveled to Iran from Mosul, that he lived for a time in Sivas in Anatolia, and that he eventually died of paralysis in Azerbaijan.

Abharī was an important figure in Islamic intellectual history not only because of his writings but also because of his teaching and interactions with scholars of the period. Among his students were the famous historian Ibn Khallikān (already mentioned), the philosopher Najm al-Dīn al-Kātibī, and Shams al-Dīn Muḥammad al-Iṣfahānī. He also had fruitful exchanges with the cosmologist ʿImād al-Dīn Zakariyyā ibn Maḥmūd al-Qazwīnī and the famous astronomer and polymath ▶ Naṣīr al-Dīn al-Ṭūsī.

Abharī studied astronomy under Kamāl al-Dīn ibn Yūnus, and his keen interest in the subject, as well as a desire to produce textbooks, led Abharī to deal with astronomy in several of his works. For example, he devoted the second part of the third chapter of his work, *Kashf al-ḥaqā'iq fī taḥrīr al-daqā'iq*, to astronomy. There he accepts the widely held view that the celestial bodies do not undergo the changes found in the sublunar realm, such as division or rejoining, diminution or growth, expansion or contraction, and so forth. He also maintains that stars are alive and have volition, which was the ultimate source of their motion.

Abharī's independent astronomical works include treatises on the astrolabe, commentaries on earlier *zīj*es (astronomical handbooks with tables), and compendia on astronomy. In the latter category, we find a *Risāla fī al-hay'a* (Treatise on astronomy; extant in Istanbul, Süleymaniye, H. Hüsnü MS 1135) and a *Mukhtaṣar fī al-hay'a* (Epitome of astronomy, extant in Istanbul, Süleymaniye, Carullah MS 1499). Both contain standard expositions of the cosmography of the orbs (*aflāk*), spherical astronomy, planetary motion, and the characteristics of the terrestrial climes. This *Mukhtaṣar* includes 22 sections and 119 figures, and is said to be an epitome of astronomical works by ► **Kūshyār ibn Labbān** and ► **Jābir ibn ˁAflaḥ**.

Abharī wrote several mathematical works, including a "Correction" (*Iṣlāḥ*) of Euclid. Among the "corrections" is an attempt to prove the parallels postulate. This was quoted in later works, in particular by ► **Samarqandī**, who was critical of Abharī's proof. In both mathematics and astronomy, Abharī seems to have had a significant influence on science during the Ottoman Period.

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ab Hayck, Tadeá

► Hájek z Hájku, Tadeá

Abī al-Fatḥ al-Ṣufi

► Ibn Abī al-Fatḥ al-Ṣūfī: Shams al-Dīn Abū ˁAbd Allāh Muḥammad ibn Abī al-Fatḥ al-Ṣūfī

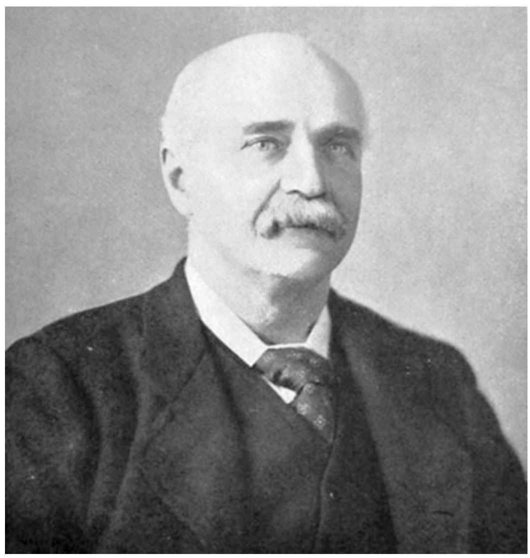
Abī al-Shukr

► Ibn Abī al-Shukr: Muḥyī al-Milla wa-'l-Dīn Yaḥyā AbūˁAbdallāh Ibn Muḥammad ibn Abī al-Shukr al-Maghribī al-Andalusī [al-Qurṭubī]

Abney, William de Wiveleslie

John Hearnshaw
University of Canterbury, Christchurch, New Zealand

Born **Derby, England, 24 July 1843**
Died **Folkestone, Kent, England, 2 December 1920**



Abney, William de Wiveleslie. Reproduced from Proceedings of the Royal Society of London A 99 (1921)

Sir William Abney was a notable pioneer in scientific photography, and his interests included the application of photography to astronomy. He was the son of Canon E. H. Abney, and was educated at the Rossall School. William received military training in the British army at the Royal Military Academy from 1861, entered the Royal Engineers as a lieutenant in 1861, and served briefly in India. After his return, Abney was employed as an instructor at the School of Military Engineering, Chatham, Kent, where he came to be in charge of a photographic and chemical laboratory. Here his pioneering experiments in scientific photography were initiated, and also his deep interest in astronomy was kindled from this time. He became a fellow of the Royal Astronomical Society in 1870, and was promoted to the rank of captain in the Royal Engineers in 1873.

Abney, along with ▶ **Hermann Vogel** and others, pioneered the introduction of dry-gelatin photographic plates in astronomy, and Abney attempted using them for the transit-of-Venus observations of 1874, from Egypt. His most famous scientific work was undoubtedly his development of infrared-sensitive photographic emulsions, produced by mixing gum resins with collodion, for a silver bromide emulsion. This work was undertaken at Chatham from 1875 and allowed Abney to photograph the solar spectrum to 1.2-μm wavelength and catalog lines to beyond 1 μm. The labeling of several strong solar spectral lines, including labeling of the infrared calcium triplet as x_1, x_2, and x_3, are from this work, as is the first use of the term "infrared." The Bakerian Lecture to the Royal Society, London, in 1880 reported on this achievement in solar-spectrum photography.

One further notable astronomical paper of these years concerns Abney's prediction, in 1877, that fast-rotating stars should have broadened nebulous lines, as a result of the opposite signs of the line-of-sight velocities from each limb causing the overall effect of Doppler line broadening. This hypothesis was at first rejected by the distinguished German astronomer Vogel in Potsdam, who believed line broadening was limited to selected lines in stellar spectra and therefore could not be caused by rotation, which would affect all lines. Moreover, Vogel argued that equatorial speeds of over 300 km s^{-1} for some stars seemed implausible. Vogel, however, retracted his hasty objections in 1899, by which time Abney's ideas had become generally accepted.

In 1877 Abney left Chatham for the Royal College of Science, South Kensington, where he served for 26 years. He continued his photographic researches there, and in particular explored the relationship between density and exposure in photographic emulsions, and the phenomenon of reciprocity failure in photographic photometry. He also expanded his researches into color vision, spectrophotometry, and the transmission of sunlight through the Earth's atmosphere.

Abney's hobbies were nature studies in the Swiss Alps, where he took regular summer holidays, and watercolor painting. From his first marriage, to Agnes Matilda Smith in 1864, he had one son and two daughters. After her death in 1888, he married Mary Louisa Meade in 1890, by whom he had another daughter.

Abney served as president of several learned societies, including the Royal Astronomical Society (1893–1895). During the years 1899–1903 he also served as principal assistant secretary to the British Board of Education. He was knighted in 1900.

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Abū al-Ṣalt: Umayya ibn ˁAbd al-ˁAzīz ibn Abī al-Ṣalt al-Dānī al-Andalusī

Mercè Comes
Universidad de Barcelona, Barcelona, Spain

Alternate Name

► Albuzale

Born **Denia (Spain),** ***circa*** **1068**
Died **Bejaïa (Algeria), 23 October 1134**

Abū al-Ṣalt was an accomplished, though not innovative, astronomer whose most important works dealt with instruments. These were read both in the Islamic world and in Europe. He may further be considered a polymath, having also written works in medicine, philosophy, music, history, and literature.

Abū al-Ṣalt's father died while he was still a child. In Denia he studied under al-Waqqashī (1017/8–1095/6), a well-known poet, mathematician, historian, philosopher, grammarian, lexicographer, jurist, and traditionalist, who had emigrated from Toledo. Later, it seems that Abū al-Ṣalt also studied in Seville before leaving al-Andalus for Alexandria and Cairo.

Abū al-Ṣalt arrived in Alexandria, accompanied by his mother, in 1096, during the reign of the Fatimid ruler al-Mustaˁlī ibn al-Mustanṣir, in the epoch of the powerful minister al-Afḍal ibn Amīr al-Juyūsh Shāhanshāh. Al-Afḍal accepted Abū al-Ṣalt in his court immediately because of their common interest in astronomy. Around 1106/1107, Abū al-Ṣalt fell into disgrace and was imprisoned, apparently due to an incident that was recorded by Ibn Abī Uṣaybiˁa. The story goes that a ship with a cargo of copper sank near the port of Alexandria. Abū al-Ṣalt persuaded al-Afḍal that he would be able to refloat the ship; he expended a great deal of effort and money to this objective and the ship was eventually hoisted by using intertwined silk ropes. Unfortunately, however, the ropes broke as soon as the ship started to emerge from the water; the ship sank again and nothing could be done to recover it. Al-Afḍal was furious and sent Abū al-Ṣalt to jail, where he remained for 3 years and 1 month between 1107/1108 and 1111/1112. According to other versions, however, his disgrace was because of the fall of his friend and patron Mukhtār Tāj al-Maˁālī. In any case, during his stay in the jail, Abū al-Ṣalt devoted himself to his writings, and a great deal of his work dates from this time, mainly because he was confined to the building of the library.

On his release, Abū al-Ṣalt left Egypt and, according to some sources, went to Mahdiyya, capital of the Zīrids, on his way back to al-Andalus. He arrived in Mahdiyya in the year 1112/1113 and was welcomed by the educated king Yaḥyā ibn Tamīm al-Ṣanhājī. He settled in Mahdiyya, as a panegyrist and chronicler of the court. He devoted himself to music and pharmacopoeia, and in that city his son ˁAbd al-ˁAzīz was born. During his stay in Tunis, Abū al-Ṣalt traveled to the Sicilian court of Palermo on several occasions, apparently in his role as a physician, under the patronage of the Norman king Roger. He died, probably of dropsy. He was buried in the *Ribāṭ* of Monastir (present-day Tunisia).

Abū al-Ṣalt's works on astronomy, mathematics, music, and optics were quoted by several Hebrew authors such as Samuel of Marseille and Profiat Duran (fifteenth century). Part of his scientific work was translated into Latin and into Hebrew. Thanks to these translations made in the Iberian Peninsula and in southern France he became well known in Europe. Abū al-Ṣalt appears to have composed an encyclopedic work on the scientific disciplines of the quadrivium, to which some of his known treatises on these sciences would have belonged. This work was divided into four sections devoted to geometry, astronomy, arithmetic, and music, following ▶ **Aristotle**'s well-known scheme, which was also used by most medieval Arabic and Hebrew authors. The title of this work, only known in its Hebrew translation, is *Sefer baHaspaqah* (probably *Kitāb al-kāfī fī al-ˁulūm* in Arabic). Several Arabic sources consider him an excellent lute player and credit him with the introduction of Andalusī music to Tunis, which eventually led to the development of the Tunisian *mālūf*. Abū al-Ṣalt was also a well-known poet and a prolific writer on history, medicine, and philosophy.

The king of Mahdiyya was particularly interested in the study of medicinal plants and was keen to discover an elixir able to transmute copper into gold and tin into silver. With this aim in mind, he founded a school of alchemy, where Abū al-Ṣalt taught.

Abū al-Ṣalt's most important works on astronomy are: (1) *Risāla fī al-ˁamal bi-'l-asṭurlāb* (On the construction and use of the astrolabe); (2) *Ṣifat ˁamal ṣafīḥa jāmiˁa taqawwama bi-hā jamīˁ al-kawākib al-sabˁa* (Description of the construction and Use of a Single Plate with which the totality of the motions of the seven planets can be calculated); in this work, he describes the last, and least interesting, of the three known Andalusian equatoria, which may have been the link with the eastern Islamic instruments of this kind; however, it does seem that ▶ **Abū Jaˁfar al-Khāzin** had already described an equatorium in tenth-century Khurāsān; (3) *Kitāb al-wajīz fī ˁilm al-hay'a* (Brief treatise on cosmology); (4) a compendium of astronomy that was strongly criticized by Abū ˁAbd Allāh of Aleppo, one of the most important astronomers of the court of al-Afḍal; (5) *Ajwibaˁan masā'il su'ilaˁan-ha fa-ajāba* or *Ajwibaˁan masā'il fī al-kawn wa-'l-ḥabīˁa wa-'l-ḥisāb* (Solution to the questions posed, or answer to questions on cosmology, physics, and arithmetic); and, according to Ibn Khaldūn, an *Iqtiṣār* (Summary) of ▶ **Ptolemy**'s *Almagest*.

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Abū al-ˁUqūl: Abū al-ˁUqūl Muḥammad ibn Aḥmad al-Ṭabarī

David A. King
Johann Wolfgang Goethe-Universität,
Frankfurt am Main, Germany

Flourished **Yemen**, ***circa*** **1300**

Abū al-ˁUqūl was the leading astronomer in Taiz, Yemen, *circa* 1300. His epithet al-Ṭabarī indicates that he or his family came originally from northern Iran. He was a contemporary of the ruler ► **Ashraf** and ► **Muḥammad ibn Abī Bakr al- Fārisī**, the latter also of Iranian stock. No details of Abū al-ʿUqūl's life are known to us beyond the fact that he was the first teacher of astronomy appointed at the Mu'ayyadiyya Madrasa in Taiz by the Sultan al-Mu'ayyad, brother and successor of al-Ashraf.

Abū al-ʿUqūl compiled an astronomical handbook (Arabic: zīj) for the Yemen and was not shy about admitting to having taken most of it from other sources; indeed, he called his work *al-Zīj al-mukhtār min al-azyāj* (The *Zīj* culled from other *Zīj*es). In fact, the work is based heavily on the *Ḥākimī Zīj* of the tenth-century Egyptian scholar ► **Ibn Yūnus**. What is original are the various tables of spherical astronomical functions for latitudes in the Yemen, and it is clear that spherical astronomy was the author's forte.

Abū al-ʿUqūl compiled the largest single medieval corpus of tables for astronomical time-keeping for a specific latitude, with over 100,000 entries. This corpus, entitled *Mir'āt al-zamān* (Mirror of Time), is computed for latitude 13° 37′, an excellent value for Taiz (accurately 13° 35′!) derived by either Abū al-ʿUqūl or al-Fārisī, and obliquity 23° 35′. In addition to tables of the hour angle and the time since sunrise for each degree of solar altitude and solar longitude, such as are found in the Cairo corpus associated with Ibn Yūnus, there are tables displaying the longitude of the ascendant or horoscopus as a function of solar altitude and longitude, and others displaying the altitude of various fixed stars at daybreak as a function of the ascendant. The inspiration for the tables associated with the ascendant seems to come from Iraq or Iran, where such tables are attested, rather than from Egypt. Abū al-ʿUqūl's extensive tables are known from a unique manuscript copied in Mocca on the Red Sea coast of Yemen in 1795. To what extent they were used over the centuries is unclear.

Abū al-ʿUqūl also prepared an almanac in which astronomical phenomena were associated with aspects of agricultural practice.

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Abubacer

► Ibn Ṭufayl: Abū Bakr Muḥammad ibn ʿAbd al-Malik ibn Muḥammad ibn Muḥammad ibn Ṭufayl al-Qaysī

Abū Maʿshar Jaʿfar ibn Muḥammad ibnʿUmar al-Balkhi

Keiji Yamamoto
Kyoto Sangyo University, Kyoto, Kyoto, Japan

Alternate Name

► Albumasar

Born **Balkh, (Afghanistan), possibly 787**
Died **Wāsiṭ, (Iraq), possibly 886**

Abū Maʿshar is best known for his astrological writings; however, he also wrote on other branches of the science of the stars, including astronomical tables. There is some question about his dates of birth and death because the former is based solely on an anonymous horoscope cited in his *Book of the Revolutions of the Years of Nativities*, while the latter comes from Ibn al-Nadīm, the tenth-century bookseller.

But ▶ **Bīrūnī** tells us in his *Chronology of the Ancient Nations* that Abū Maˁshar made an observation in 892, and there is a reference by Abū Maˁshar himself in the *Book of Religions and Dynasties* to stellar positions due to trepidation dated 896/897. Both would have been made when Abū Maˁshar was well over 100 if the birth date is to be believed.

Ibn al-Nadīm reports in his *Fihrist* that Abū Maˁshar was at first a scholar of *ḥadīth* (prophetic traditions), was antagonistic toward the philosophical sciences (i.e., Hellenistic science and philosophy), and sought to stir popular opinion against his contemporary ▶ **Kindī**, one of the champions of these sciences. By means of a ruse, Kindī sought to interest him in arithmetic and geometry. This apparently succeeded in mollifying Abū Maˁshar; though he never became proficient in mathematics, he did become interested later in life (at age 47) in astrology, another of the Hellenistic sciences. This late start, though, did not deter him because he was said to have lived to the ripe old age of 100. Since Abū Maˁshar was considered the greatest astrologer of the ˁAbbāsid court in Baghdad, his works were prominent, and therefore he was occasionally mentioned in tales on astrology. Ibn Ṭāwūs (1193–1266) collected several anecdotes on Abū Maˁshar in his *Faraj al-mahmūm* (Biographies of Astrologers).

All works on astronomy attributed to Abū Maˁshar are lost, and only his astrological works in Arabic are known to us. Much of our knowledge of his contribution to astronomy comes to us either from other sources or by way of information gleaned from his astrological works. Abū Maˁshar's major astrological works that survive in Arabic manuscripts can be classified into three categories, based on the surviving manuscripts.

The first type is works that provide an introduction to astrology. Included in this group is Abū Maˁshar's 106-chapter work, *Kitāb al-mudkhal al-kabīr*, which he wrote "for the establishment of astrology by sufficient arguments and proofs." Not since ▶ **Ptolemy**'s *Tetrabiblos* had philosophical proofs of astrology been argued; Abū Maˁshar's philosophical basis was Aristotelian physics, which he had acquired through Kindī's circle. This work was translated into Latin in 1133 and 1140, and selections from it were translated into Greek *circa* 1000. The Latin translations had a significant influence on western European philosophers, such as ▶ **Albert The Great**. Abū Maˁshar also wrote an abridged version of his introductory work (*Kitāb mukhtaṣar al-mudkhal*), which was translated into Latin by ▶ **Adelard of Bath**.

The second type of work is Abū Maˁshar's historical astrology, which was introduced from the Sasanian tradition by al-Manṣūr, the second caliph of the ˁAbbāsid dynasty. This was part of his political strategy for laying a solid foundation for the newborn dynasty, and indeed it was used most effectively among the early ˁAbbāsids. Abū Maˁshar's monumental book on this subject, the *Kitāb al-milal wa-'l-duwal* (Book on religions and dynasties), is in eight parts in 63 chapters. The work was translated into Latin and read by ▶ **Roger Bacon**, ▶ **Pierre d'Ailly**, and Pico della Mirandola (1463–1494), and discussed in their major works. Other works in this category include *Fī dhikr ma tadullu ˁalayhi al-ashkhāṣ al-ˁulwiyya* (On the indications of the celestial objects [for terrestrial things]), *Kitāb al-dalālātˁ alā al-ittiṣālāt wa-qirānāt al-kawākib* (Book of the indications of the planetary conjunctions...), and the *Kitāb al-ulūf* (Book of thousands), which is no longer extant but is preserved in summaries by ▶ **Sijzī**.

The third and final type is Abū Maˁshar's works on genethlialogy, the science of casting nativities. An example is *Kitāb taḥāwil sinī al-mawālīd* (Book of the revolutions of the years of nativities). The first five parts in 57 chapters (out of nine parts in 96 chapters) were translated into Greek *circa* 1000, and the Greek text was translated into Latin in the thirteenth century. Another work in this genre is *Kitāb mawālīd al-rijāl wa-'l-nisā'* (Book of nativities of men and women). The large number of extant manuscripts suggests its high popularity in the Islamic world.

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a Çamora

► Zamora, Antonio Núñez

Achilles Tatius

Thomas Hockey
Department of Earth Science, University of Northern Iowa, Cedar Falls, IA, USA

Alternate Name

► Statius

Flourished ***circa*** **200**

Achilles Tatius may have been an Alexandrian scholar. His *Isagoge ad Arati Phænomena* (*Introduction to Aratus' Treatise "Phenomena"*) is extant only as a fragment (published in 1567). Achilles's sole surviving intact work (if the author is indeed the same Achilles) is an erotic romance novel.

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Acyuta Piṣāraṭi

Ke Ve Sarma
SSES Research Centre, Chennai, India

Born **Tṛkkaṇṭiyūr, (Kerala, India), 1550**
Died **(Kerala, India), 7 July 1621**

Acyuta Piṣāraṭi was a prominent figure in the annals of the medieval period. He was a versatile scholar and an original thinker who enunciated, for the first time in Indian astronomy, the correction called "reduction to the ecliptic" of the true positions of the planets. Acyuta hailed from Kerala, the narrow strip of land on the west coast of south India, and was part of a long line of astronomers who were related to each other as teacher and disciple or as father and son. Acyuta's teacher was ► **Jyeṣṭhadeva**, author of the *Yuktibhāṣā*, an analytical work on mathematics and astronomy based on the *Tantrasan-graha* of ► **Nīlakaṇṭha Somayāji**.

Among Acyuta's works on astronomy, the *Sphuṭanirṇaya* (*The Accurate Determination of the True Positions of the Planets*) is the most important. Divided into six chapters, the work shows the step-by-step reductions of the positions of the planets from their mean to true places, for an observer stationed on the Earth's surface.

The *Rāśigolasphuṭānīti* is a shorter but highly revealing work in which Acyuta evolves a method for the astronomical procedure known as "reduction to the ecliptic" and sets out its rationale.

The *Karaṇottama* is another important work in which improved methodologies for astronomical computations are displayed, to which Acyuta has added his own commentary.

The *Uparāgakriyākrama* (*Methodology of Computing the Eclipse*) addresses both lunar and solar eclipses, while the *Uparāgaviṃśati* (*Score on Eclipses*) is a more succinct exposition of the same subject.

Another short work is the *Chāyāṣṭaka* (*Octad on the Gnomon's Shadow*) that rationalizes the computation of the Moon's shadow. Still another expositional work of Acyuta is his commentary in Malayalam, the language of Kerala, on an important work called the *Veṇvāroha* by the astronomer Mādhava. Acyuta's commentary enunciates a chart for reading off the position of the Moon every 2 h.

Besides writing works on astronomy and grammar (notably the *Praveśaka*), Acyuta was a master in the field of medicine (*āyurveda*), a fact revealed in an obituary verse composed by one of his pupils, the poet-grammarian Nārāyaṇa Bhaṭṭatiri.

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Ādamī: Abū ʿAlī al-Ḥusayn ibn Muḥammad al-Ādamī

Marvin Bolt[1] and F. Jamil Ragep[2]

[1]Adler Planetarium, Chicago, IL, USA

[2]Institute of Islamic Studies, McGill University, Montreal, QC, Canada

Flourished **Baghdad, (Iraq),** ***circa*** **925**

Ādamī is noted for his work on instruments. Ibn al-Ādamī, presumably his son, wrote an influential astronomical handbook with tables (*zīj*) that was based on Indian sources. The father is mentioned in Ibn al-Nadīm's *Fihrist* (dating from the tenth century), where he is called al-Ādamī. Because of the similarity in names, the two have often been confused in modern sources.

According to the *Fihrist*, Ādamī is the author of a work on sundials, and indeed there is an extant Paris manuscript by him that deals with vertical sundials and contains universal auxiliary tables that are used to simplify calculations. These enabled the drawing of lines for vertical sundials inclined to the local meridian at any desired angle for any latitude. ► **Bīrūnī** tells us in his great work on astrolabes (the *Istīʿāb*) that Ādamī was the first person to construct a "disc of eclipses" for demonstrating solar and lunar eclipses.

The son, ► **Ibn al-Ādamī**, was famous for a *zīj* entitled *Naẓm al-ʿiqd*, which was completed after his death by his student ► **al-Qāsim ibn Muḥammad ibn Hishām al-Madā'inī**, who published it in 949/950. This nonextant work is referred to by several later authors, including ► **Ibn Yūnus** (died: 1009) and ► **Ṣāʿid al-Andalusī**. From the latter we learn that ► **Ibn al-Ādamī's** ***zīj*** was based on the Indian methods contained in the so?called *Sindhind*, a Sanskrit work translated into Arabic by ► **Fazārī**. **Ṣāʿid** also provides crucial evidence that the theory of variable precession (or trepidation) that became known in Europe under the name of ► **Thābit ibn Qurra** may instead have had its source in the *zīj* of ► **Ibn al-Ādamī**, who himself may have gotten the theory from Th?bit's grandson ► **Ibrahīm ibn**

Sinān. Ṣāʿid also informs us that ▶ Ibn al-Ādamī was a source for the story of how Indian astronomy came to Baghdad in the early 770 s by way of an ambassador to the court of ▶ Manṣūr.

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Adams, John Couch

Nicholas Kollerstrom
London, UK

Born **Lidcott near Launceston, Cornwall, England, 5 June 1819**
Died **Cambridge, England, 21 January 1892**

John Adams is best remembered for his calculations concerning the location and discovery of Neptune. Born a farmer's son, Adams showed a precocious mathematical talent and sat for the entrance at Saint John's College, Cambridge, in 1839, winning a sizarship that partially paid his college expenses. He later married Eliza Bruce.

In July 1841, by the end of his first year, Adams began plans to investigate the irregular motions of Uranus to see if they would point to some undiscovered planet. In 1843, he finished as senior wrangler and the first Smith's prizeman, the top mathematician of his year.

By October 1843, Adams had reached a preliminary solution to the Uranus problem. In February 1844, ▶ James Challis, director of the Cambridge Observatory, brought Adams the results of Uranus observations sent from ▶ George Airy, the Astronomer Royal, thereby providing Adams with the best data available. Adams became a close personal friend of Challis.

In September 1845, Challis wrote to Airy that Adams himself hoped to write to Airy concerning the undiscovered planet perturbing Uranus, but Adams did not correspond. Instead, Adams made two unannounced visits to Greenwich, presumably wishing to discuss matters personally with the Astronomer Royal, and left a brief note about his predictions. Airy replied, with a query concerning the impact on Uranus's radius vector, daily values for which had appeared in Airy's *Nautical Almanac* since 1834. Again, Adams did not reply, but following the second letter of Airy, the dated sections of Adams's notebooks show considerable endeavor to compute this parameter, which he finally did on 1 September 1846.

Not until 13 November 1846, 6 weeks after Neptune's discovery, did the public learn of Adams's predictions supposed to have been made in October 1845. At that presentation, both Airy and Challis produced undated scraps of paper with elements of the predicted new planet written out in Adams's hand; both averred they had been given these the previous year. But neither had declared having in their possession these remarkable British predictions upon ▶ Urbain Le Verrier's prediction being published in June, nor upon the new planet being found in September.

The author is a Fellow of the Royal Astronomical Society, M.A. (Cantab) and Ph.D. (London).

Once the new planet was found, Adams utilized the results of Challis's sky search to ascertain Neptune's true distance, eccentricity, and inclination to the ecliptic and published them at once, belying the traditional image of Adams as modest and reluctant over writing letters. He and Challis proposed the name "Oceanus" for the new planet. In recognition for his work on Neptune, the Royal Society awarded him the Copley Medal, its highest prize, in 1848.

In 1851, Adams became president of the Royal Astronomical Society and shortly after began his work on lunar theory. In 1852, he published new and accurate tables of the Moon's parallax, correcting the theory of ▶ **Philippe de Pontécoulant**. The following year saw his memoir on the secular acceleration of the Moon's mean motion, which halved the value in ▶ **Pierre de Laplace**'s incorrect solution.

In 1859, Adams became Lowndean Professor of Astronomy and Geometry at Cambridge University, succeeding George Peacock, and in 1861, director of the Cambridge Observatory, succeeding Challis. Adams demonstrated how the brilliant Leonid meteor shower of 1866 derived from an elliptical orbit being perturbed by the giant planets. He worked on cataloguing ▶ **Isaac Newton**'s unpublished mathematical writings after they were presented to the university in 1872 by Lord Portsmouth.

In 1847, Adams was offered a knighthood, but he refused it. In 1848, Cambridge University founded the Adams Prize in mathematics, physics, and astronomy in recognition of his efforts leading to Neptune's discovery. He received honorary degrees from Oxford University, Cambridge University, and other universities. He served as president of the Royal Astronomical Society from 1851 to 1853 and from 1874 to 1876. In 1866, the Royal Society awarded a Gold Medal to Adams for his lunar theory. In 1895, a portrait of Adams was engraved beside the grave of Newton in Westminster Abbey.

Many of Adams's personal papers are at Saint John's College Archives, Cambridge, and are transcribed in the McAlister collection there. Other papers are in Truro, England. Many of the crucial papers relating to the role of Adams and others about the discovery of Neptune disappeared in the 1960s and were returned to Cambridge University in 1999.

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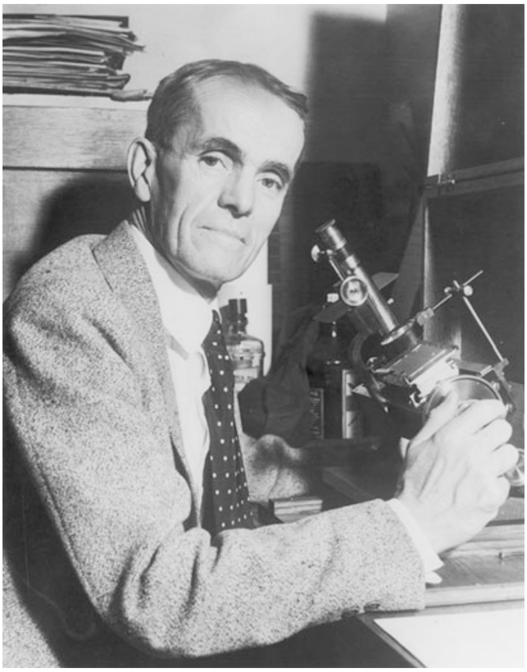
Adams, Walter Sydney

Joseph S. Tenn
Department of Physics & Astronomy, Sonoma State University, Rohnert Park, CA, USA

Born **Kessab, (Syria), 20 December 1876**
Died **Pasadena, California, USA, 11 May 1956**



Adams, Walter Sydney. Reproduced by permission of Yerkes Observatory

Walter Adams directed the greatest observatory on the Earth for a quarter of a century, supervising a staff that included productive astronomers such as ► **Walter Baade**, ► **Harold Babcock**, ► **Edwin Hubble**, ► **Milton Humason**, ► **Alfred Joy**, ► **Paul Merrill**, ► **Rudolph Minkowski**, ► **Seth Nicholson**, ► **Frederick Seares**, and ► **Olin Wilson**, while devoting most of his time to research. He codiscovered the method of determining a star's luminosity from its spectrum and contributed significantly to the design and construction of three successive world's largest telescopes – the 60- and 100-in. at Mount Wilson and the 200-in. Hale telescope on Palomar Mountain, both in California.

Adams was born in the Middle East, where both of his New England-born, college-educated parents, Lucien Harper Adams and Dora Francis Adams, were serving as Congregational missionaries. Home-schooled, Adams was far ahead in Greek and Roman history and theology but rather ignorant of his own country when he first entered an American school at the age of 8. At Dartmouth College he noted that he had a strong preference for exact subjects with definite answers as compared with those involving alternatives and the exercise of considerable judgment.

When he took the astronomy course at Dartmouth, Adams found that his professor, ► **Edwin Frost**, was an admirable teacher who gave the subject a strong appeal both on the mathematical and the physical side. In 1898, when Adams completed his AB, ► **George Hale** hired Frost as one of the first professors of astrophysics at the new University of Chicago. Adams went along as one of Frost's first graduate students. Adams reported that his employment as an astronomer was an interesting illustration of the effect of relatively small events on the course of individual lives in which a very slight change in circumstances might equally well have led him to follow the teaching of Greek as a profession.

After 2 years of studying at Chicago and apprenticing at its Yerkes Observatory, in 1901 Adams went to Munich with the intention of earning a Ph.D. under ► **Hugo von Seeliger** and ► **Karl Schwarzschild**. However, Hale, whom Adams idolized, called him back to Yerkes after a year. Adams remained an associate of Hale for the remainder of the latter's life.

Adams became an expert spectroscopist, and when Hale went to Pasadena in 1904 to establish what would become the Mount Wilson Observatory of the Carnegie Institution of Washington, Adams went along as his right-hand man. Adams served as acting director during Hale's many illnesses and as director from 1923 to 1945.

Adams worked with Frost and others on radial velocities of stars at Yerkes, but in the early years at Mount Wilson he joined Hale in solar investigations. Adams showed that the Sun's equatorial regions rotate in about 25 days, while near the poles the period is almost 34 days. Using large spectrographs with the horizontal Snow telescope and later with the 60-ft. tower telescope that Hale had built, the group obtained high-dispersion spectra of sunspots as well as interspot regions. Adams helped measure some 11,000 spectral lines and showed that the lines enhanced in sunspots were precisely those that were stronger in the cooler parts of a laboratory flame. Some lines in the sunspot spectrum are from neutral atoms, which survive at cooler temperatures, while others in surrounding areas are from ions, which are more abundant at higher temperature. Thus it was shown that sunspots are cooler than their surroundings.

This work led directly to Adams's greatest achievement. Starting in 1914, Adams and a German visitor to Mount Wilson, ▶ **Arnold Kohlschütter**, found that some spectral lines are stronger in luminous stars (giants) while other lines are stronger in stars that are intrinsically dimmer (main sequence stars). Calibrating the measurements with a few stars close enough to have their distances measured directly by trigonometric parallax, Adams and Kohlschütter showed that the ratios of certain spectral lines, especially those from ionized atoms, depended on the luminosities of the stars (via a dependence on the densities of the atmospheric gas, lower in the brighter stars). This allowed stellar distances to be determined with the spectrograph, a procedure now known as spectroscopic parallax. By 1935, when Adams, Joy, Humason, and Ada M. Brayton published their monumental *Spectroscopic Absolute Magnitudes and Distances of 4179 Stars*, the number of stars of known distance was increased 100-fold.

It was Adams who discovered, in 1914, that 40 Eridani B (also designated 2 O Eridani B) and Sirius B were low-luminosity stars of spectral class A. ▶ **Arthur Eddington** pointed out a decade later that these stars, now known as white dwarf stars, must be stars of extraordinary density. In 1925, following Eddington's suggestion that the gravitational redshift predicted by ▶ **Albert Einstein**'s General Theory of Relativity might be observable in these stars, Adams attempted the measurement, finding almost exactly the expected value. After later work showed that the real redshift was even larger (because the star was even more dense than Eddington had supposed), Adams was criticized. However, it became clear still later that he had measured a mix of light from Sirius A and B, so that his measurement was a honest one, but wrong for Sirius B.

Adams collaborated with other Mount Wilson spectroscopists, especially Joy, and he shared data with many others. ▶ **Theodore Dunham Jr.** recalled that they were working on stars one night when Adams suggested that they take a shot at the infrared spectrum of Venus, which was easily observable at the time. Using new infrared-sensitive plates developed at Eastman Kodak, they found some extraordinary band structure. The bands, which had not yet been seen on Earth, turned out to be due to carbon dioxide, as Dunham proved empirically by filling a 70-ft.-long pipe with the gas and obtaining the same spectrum, and for which Arthur Adel soon provided the theoretical basis. It was the first indication that Venus has an enormous amount of carbon dioxide in its atmosphere.

For years Mount Wilson had the world's only Coudé spectrograph, and the staff took full advantage of its high dispersion. Between 1939 and 1941, Adams and Dunham discovered several absorption lines produced in interstellar gas clouds, including some produced by molecules of CN and CH, the first molecules detected in interstellar space. By 1949, Adams had used very high dispersion to show that there are lines produced by several different clouds along the line of sight to some stars.

▶ **Harlow Shapley recalled that**:

> Adams strove to excel in everything he undertook – in endurance at the business end of a telescope, in quality of spectrum plates, in hiking speed up the mountain trail from Sierra Madre, in tennis, golf, billiards, bridge – and he did excel. But I never heard him call attention to his excellence. I remember complimenting him once on his designing the series of powerful and tricky spectrographs that were used in the Mount Wilson stellar and solar work. "It is a very low form of cunning" he replied (Shapley 1956).

Adams was proud to be related to two US presidents, and many of his traits were attributed to his New England heritage. These qualities included his reserve and his legendary frugality. He used 25-W light bulbs in the domes and insisted that observers could take no more than two slices of bread, two eggs, and coffee for the midnight meal. Adams raised salaries only when absolutely necessary, and often returned part of his budget to the Carnegie Institution. When he asked to be allowed to spend a bit to obtain or retain the services of an outstanding astronomer like Baade, he usually offered to find the necessary funds in his own budget.

As director, Adams quietly led by example, preserving the dignity and eminence of the observatory he had inherited from Hale. He hired excellent men, and he helped enormously in the design and construction of Caltech's 200-in. Hale telescope on Palomar Mountain. He spent his retirement years at the Hale Solar Observatory in Pasadena, where he reduced data from previous observations.

Adams married Lillian Wickham in 1910. She died in 1920, and in 1922 he married Adeline L. Miller, with whom he had two sons. Adams was awarded the Gold Medal of the Royal Astronomical Society in 1917, the Henry Draper Medal of the National Academy of Sciences in 1918, the Janssen Prize of the French Astronomical Society in 1926, the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific in 1928, the Janssen Medal of the French Academy of Sciences in 1935, and the Henry Norris Russell Lectureship of the American Astronomical Society in 1947. Although he never completed graduate training, Adams was awarded honorary Ph.D., Sc.D., or LLD degrees by seven universities and colleges.

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Adel, Arthur

Roy H. Garstang
University of Colorado, Boulder, CO, USA

Born **Brooklyn, New York, USA, 22 November 1908**
Died **Flagstaff, Arizona, USA, 13 September 1994**

Arthur Adel was a pioneer in the identification of specific molecules in planetary atmospheres through his studies of planetary infrared spectra, through his fundamental experimental measurements of molecular and gas mixture spectra, and through observational studies of the Earth's atmosphere. He was born to immigrant orthodox Jewish parents, Morris Adel from Russia and Jennie (*née* Schrieber) from Poland. The family relocated to Detroit, Michigan, where Adel received the majority of his precollegiate education while working part-time in a variety of jobs. While in high school, Adel was uncertain of his future career path and took an extended curriculum of practical machine shop and other

Roy H. Garstang died in 2009.

mechanical arts courses in addition to all the science and mathematics courses available. The mechanical skills thus acquired helped him to pay for his college education and later proved of substantial benefit in his experimental scientific work.

After a year of full-time work as a machinist, Adel entered the University of Michigan at Ann Arbor. He graduated with a double undergraduate major in mathematics and physics in 1931. Working with Michigan physicists David M. Dennison, Earnest F. Barker, and Harrison M. Randall, all leading authorities in the rapidly emerging field of infrared spectroscopy, Adel earned his Ph.D. in 1933 with a theoretical dissertation on the infrared spectrum and structure of the carbon dioxide molecule. His work on carbon dioxide proved astronomically timely. Using the energy level diagram he had computed for carbon dioxide, Adel identified the exact vibrational and rotational transitions that were observed experimentally, and in the spectrum of the planet Venus, by ▶ **Walter Adams** and ▶ **Theodore Dunham**, at Mount Wilson Observatory. Thus, Adel was able to confirm their tentative identification of carbon dioxide in the Venusian atmosphere with data in his dissertation.

As a result of an initiative by Lowell Observatory trustee Roger Lowell Putnam, Adel was offered employment at Lowell Observatory after completing his Ph.D. In the previous decades, ▶ **Carl Lampland**, Lowell Observatory, had been working with ▶ **William Coblentz** of the National Bureau of Standards on various spectroscopic projects, but these studies had produced little in the way of published results. Putnam's intent was to reinvigorate astrophysical research at Lowell Observatory, initially using observational work that had been completed but not appropriately interpreted or published by the observatory staff. Adel worked in facilities provided by the University of Michigan under agreement with Lowell Observatory as well as at the Flagstaff, Arizona, observatory. In 1933 and 1934, he analyzed spectra of the major planets (Jupiter, Saturn, Uranus, and Neptune) that had been obtained by observatory director ▶ **Vesto Slipher**. Adel showed that the bands in the spectra of the major planets, which ▶ **Rupert Wildt** had previously attributed to methane and ammonia, were, indeed, harmonics of the fundamental vibrations of methane and ammonia molecules. Adel's proof involved not only the theoretical calculation of all possible harmonics of the fundamental vibrations of these molecules, but also the photography of those spectra. Working at pressures up to 40 atm through 45-m path lengths, Adel photographed the spectra of methane, ammonia, and various mixtures of the two molecules as a function of pressure in the long-path-length tubes to simulate various depths in the planetary atmospheres. Adel's work involved not only the identification of these bands but also the calibration of their strengths as a function of pressure. ▶ **Henry Norris Russell** later commented that Adel's proof was "... as beautiful an application of spectroscopic theory as one could desire to see." During this period of work for the Lowell Observatory, Adel also revised ▶ **Samuel Langley** 's incorrect infrared wavelength scale, and recorded both the prismatic (low-resolution) and the grating (high-resolution) combined spectra of the Sun's and the Earth's atmosphere, known as the solar-telluric spectrum.

After completing 2 years of work on the Lowell Observatory projects, Adel accepted a postdoctoral fellowship at Johns Hopkins University. Before leaving Ann Arbor for Baltimore, Maryland, Adel married Catherine Emilia Backus, who at the time was studying mathematics and French at the University of Michigan. They had no children.

At Johns Hopkins University, Adel was employed by physicist Gerhard Dieke working on the atomic spectrum of hydrogen; he also taught astronomy in an evening class. More importantly, however, Adel also established strong working relationships with Johns Hopkins's distinguished infrared spectroscopists ▶ **Alfred Pfund** and ▶ **Robert Wood**. Adel learned valuable experimental skills from Pfund including the techniques for preparing sintered selenium-on-glass filters that passed infrared radiation but blocked scattered radiation in other wavelengths for improved signal-to-noise ratios.

In 1936, Adel returned to the Lowell Observatory, where the high and dry climate was ideal for his study of water vapor in the Earth's atmosphere. As part of his continued work on the solar-telluric spectrum, he corrected the spectrum of ozone, and discovered the presence of nitrous oxide and deuterium hydroxide in the Earth's atmosphere. At the suggestion of ► **Charles Abbott** of the Smithsonian Institution, and using a potassium bromide prism provided by Abbott, Adel discovered what is now called the 20-μm window in the Earth's atmosphere. This transparent region in which there is no water absorption, from 16 to 24 μm, has since proved vital for astronomical studies in the infrared. Adel's prismatic spectrum of the infrared emissions from the Moon proved for the first time that it radiated as a black body.

Adel's work at Lowell Observatory was interrupted in 1942 by the advent of World War II. After a brief stint in Washington, DC, during which he was involved in degaussing submarines, Adel returned to the University of Michigan, where he taught physics to meteorologists while conducting infrared research. Adel's most important contribution to the war effort was his demonstration that a critical radar system design was flawed. Using exceptionally high resolution, which he achieved with a finely tuned grating spectrometer, Adel showed that the radar frequency chosen coincided nearly exactly with a very narrow band in the infrared spectrum of water, which absorbed and completely masked the radar signal.

In 1946, ► **Gerard Kuiper** offered Adel a position on the staff of the McDonald Observatory. Kuiper's intent was to use the 82-in. telescope and spectrograph to extend spectral studies of the planets. However, living conditions in Fort Davis, Texas, were not attractive, and the Adels returned immediately to Michigan. ► **Robert McMath** offered Adel a position on the staff of the McMath-Hulbert Solar Observatory [MHSO] at Lake Angelus, Michigan. Adel's assignment at MHSO was initially to study solar flares and prominences in hydrogen alpha light, a project which made little use of Adel's real experimental strengths. Soon, however, the observatory received a grant from the United States Air Force to study ozone levels in the Earth's atmosphere. The work was to be carried out at Holloman Air Force Base in New Mexico and was assigned to Adel. At Holloman, Adel designed and supervised the construction of an observatory in a remote part of the base from which atmospheric studies were conducted. He developed a simple method for determining the effective radiation temperature of the ozone layer from ground level. In addition, Adel extended his solar-telluric studies to the near-infrared spectrum using the high-resolution capabilities made possible by the Cashman lead sulfide detector.

In 1948, with the Air Force work completed, the Adels moved back to Flagstaff, where he became a professor of physics at Arizona State College [ASC] (now Northern Arizona University) and spent the remainder of his life. Using the funds provided by the Air Force, Adel built the Atmospheric Research Observatory at Arizona State. The observatory was equipped with the first telescope ever designed specifically for use in the infrared, a 24-in. reflector built by J. W. Fecker Company. Using that telescope and its associated spectrograph, Adel continued to study the vertical atmospheric distribution of ozone. His revised technique, based on both ultraviolet and infrared measurements, not only contributed to improved understanding of the variations in ozone levels, but also identified previously unknown periodic fluctuations in the Earth's upper atmosphere that have since been confirmed using other techniques.

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Adelard of Bath

Charles Burnett
Warburg Institute, University of London, UK

Born **probably Bath, England**, ***circa*** **1080**
Died **circa 1152**

Adelard of Bath, Arabic scholar and humanist, was a pioneer in introducing Arabic science into the Latin curriculum of the liberal arts.

Originally from Bath in the west of England, Adelard went abroad to study – first to France, and then, probably following in the wake of the First Crusade, to the Principality of Antioch, and to Magna Graecia (southern Italy) and Sicily. After 7 years of absence he returned to England, probably spending most of his time in Bath, but during the troubled years of the civil war (1135–1154) he may have joined the household of the Duke of Normandy, since he dedicated his last work, *De opere astrolapsus*, to Henry, the son of the duke, and the future King Henry II. His works were well known both in northern France (e.g., at Mont-St-Michel and Chartres) and in England, where several students and followers of his can be identified.

Adelard regarded “philosophy” (the seven liberal arts that were the backbone of education in the secular arts since late Antiquity) as a whole, whose parts could not be studied without one another. He aimed to show this in an exhortation to the study of philosophy, which he called *De eodem et diverso* (On the same and the different), and we have notes by him on music, and evidence that he wrote a text on rhetoric. Nevertheless, it is to geometry and astronomy that Adelard paid most attention. He made the first complete translation (from Arabic) of Euclid’s *Elements*, and his adaptation of this version for teaching (the so called Adelard II Version) became the standard textbook used for teaching geometry for several generations of students. In astronomy, Adelard translated a set of astronomical tables by ► **al-Khwarizmi**, together with the rules for using them. The starting point of the tables is 1126, and one of the half-dozen extant manuscripts preserves a copy made in the scriptorium of Worcester Cathedral before 1140. They follow the Indian models of computation that had been used by early generations of astronomers of the Abbasid Period in Baghdad, but which had been superseded by Ptolemaic models in the Islamic Orient by Adelard’s time.

Drawing on his translation of the *Elements* and on the *Tables*, as well as on earlier texts on the instrument, Adelard wrote an original work on the astrolabe: *De opere astrolapsus* (1150). Aside from giving instructions on how to use the astrolabe, this work provides an account of Ptolemaic cosmology. Adelard regarded the ultimate aim of astronomy as enabling one “not only to declare the present condition of earthly things, but also their past or future conditions” (*De eodem et diverso*, p. 69), and to further this aim he translated two Arabic texts on astrology: The *Abbreviation of the Introduction to Astrology* of Abu Maʿshar, and the *Hundred Aphorisms* attributed to ► **Ptolemy**, as well as, apparently, comparing the doctrines of Arabic astrology with those of the Latin textbook of Firmicus Maternus. Another application of astronomy was magic, to which Adelard contributed by translating a text on the manufacture of talismans by ► **Thabit ibn Qurra**.

Through his translations of Euclid’s *Elements* and the *Tables* of al-Khwarizmi, Adelard considerably expanded the range of the traditional seven liberal arts. (Both texts were included in the well-known two-volume “Library of the Liberal Arts”-the *Heptateuchon* of Thierry of Chartres of the early 1140s.) However, he also ventured outside this curriculum by introducing (avowedly as a result of his "Arabic studies"-*studia Arabica*) the science of nature, or physics, in the form of a series of questions concerning topics arranged in ascending order, from the seeds within the earth to the highermost heaven (his *Quaestiones naturales*). The physical questions concerning the heavenly bodies include "Why is the Moon deprived of light?," "Why do the planets not move with a constant motion?," "Why do the planets move in the opposite direction from the fixed stars?," "Why do stars appear to fall from the sky?," and "Are the heavenly bodies animate?."

Adelard's influence on the teaching of geometry in Western Europe was much greater than on that of astronomy, since the *Tables* of al-Khwarizmi were soon eclipsed by those of Toledo, and other texts on the astrolabe and astrology issuing especially from Toledo proved more popular than his own. However, the popularity of the *Quaestiones naturales* ensured that his discussions of cosmology were well known, and at least one English scholar, Daniel of Morley (flourished 1175), knew the cosmological section of the *De opere astrolapsus*, which he quotes in his own cosmology, the *Philosophia*.

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Adhémar, Joseph-Alphonse

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Born **Paris, France, February 1797**
Died **Paris, France, 1862**

In 1842, French mathematician Joseph Adhémar proposed that changes in the Earth's orbital elements could affect long-term climate, causing the "ice ages."

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Adrastes of Aphrodisias

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Alternate Name

► Adrastus of Aphrodisias

Flourished **(Turkey), second century**

Theon of Smyrna based his work upon that of peripatetic Adrastes, who speculated on the number of necessary homocentric celestial spheres. Adrastes's own commentary on ▶ **Plato** is lost.

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Adrastus of Aphrodisias

▶ Adrastes of Aphrodisias

Aegidius Colonna [Columna]

▶ Giles of Rome

Aegidius Romanus

▶ Giles of Rome

Aeschylus

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Flourished **late fifth century BCE**

Not to be confused with the Greek dramatist, Aeschylus (with his teacher ▶ **Hippocrates**) concluded that a comet's tail is not part of the cometary body itself; rather it is merely sunlight reflected from atmospheric moisture attracted by the comet.

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Aganice of Thessaly

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Alternate Name

▶ Aglaonike

Flourished **(Thessaly, Greece) – exact dates unknown**

Aganice is cited as the first female astronomer of ancient Greece. She was the daughter of Hegetor, a Thessalian. ▶ Plutarch states that with her knowledge of astronomy and astronomical computation, she was familiar with the periods of the full Moon and could foretell the exact time and place of lunar eclipses. With this knowledge, she would persuade other Thessalian women that she had the ability of drawing the Moon down out of the Heavens (*De defectu oraculorum* 13), hence the Greek proverb, "Yes, as the moon obeys Aglaonike."

Far from praising her skills, however, Plutarch's objective in mentioning Aganice was to make an example out of her by stating that such "witches" intentionally meant to deceive other women without any astronomical training. ▶ **Plato** (*Gorgias* 513), Horace (*Epodes* 5.45), and ▶ **Virgil** (*Eclogues* 8.69) also mention these "Thessalian enchantresses" and their magic powers in making the Moon disappear at will. In Plutarch's "Advice to the Bride and Groom" (*Coniugalia praecepta*, 48), he warns that only by studying philosophy and astronomy can women avoid believing such nonsense and laugh at the ignorance of others who do in fact believe that the Moon could disappear at will. Regardless of the negative opinions of Aganice's contemporaries, we can conclude that she was interested in celestial phenomena and had acquired a fair amount of skill in astronomical observation and computation, a rarity for women in her time.

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Agecio, Tadeá

► Hájek z Hájku, Tadeá

Aglaonike

► Aganice of Thessaly

Aḥmad Mukhtār: Ghāzī Aḥmad Mukhtār Pasha

Salim Aydüz
History of Science Department, Art Faculty, İstanbul Medeniyet University, İstanbul, Turkey

Born **Bursa**, (**Turkey**), **1839**
Died **Istanbul**, (**Turkey**), **21 January 1919**

Aḥmad Mukhtār was a soldier and a statesman (rising to the rank of Turkish general and receiving the title "Ghāzī" or warrior) who also wrote many works in the fields of mathematics and astronomy. He is known especially for his studies on reforming the Islamic calendar as well as the making and use of astronomical instruments.

Aḥmad Mukhtār stemmed from a family prominent in the silk trade; after the death of his father, he was educated in various military schools, and the military became his lifelong career. Aḥmad Mukhtār established close ties with the Ottoman court, which led to his tutoring Prince YūsufʿIzz al-Dīn (1865) and accompanying SultanʿAbd al-ʿAzīz to Europe in 1867. He served the state for 55 years and rose to high rank, becoming president of the Senate in 1911 and Grand Vizier for a brief period in 1912. Aḥmad Mukhtār remained in the Senate until 1918 just before his death. Because of his military success, he was granted numerous titles, including Ghāzī and Pasha.

Aḥmad Mukhtār contributed much to the field of astronomy, especially with regard to reforming the Islamic (*hijra*) calendar. When he was in Egypt between 1882 and 1908 as Ottoman High Commissioner, he wrote his *Iṣlāḥ al-Taqwīm* (written in both Turkish and Arabic) that dealt with the fiscal problems caused by the discrepancies between the *Hijra* and Gregorian calendars. Aḥmad Mukhtār advocated a uniform *Hijra* solar (*Shamsī*) year for all Muslims. In accordance with his new calendar system, the work contains a tabulation of conversions between lunar-*hijra*, Gregorian, and solar-*hijra* New Year's days until 2212. The work was also translated into French. Other works dealing with the calendar include *Taqwīm al-sinīn*, which lists in tabulated form the daily equivalents between the lunar and Gregorian calendars, covering the *hijra* years 1256-1350 (*circa* 1840–1931), and *Taqwīm-i sāl*, which provides general information about the calendar in the Ottoman Empire. He also wrote other works dealing with calendars, some of which are in Arabic.

Another astronomical work, entitled *Rīyāḍ al-mukhtār mir'āt al-mīqāt wa-'l-adwār*, deals with timekeeping. Written in Istanbul, the work contains information on instruments and their categorization. Other subjects include measurement of time, information about latitude and longitude, and an evaluation of calendars. *Majmūʿ ati'l-*

ashkāl is a supplement at the end of the book containing figures and tables. Aḥmad Mukhtār also wrote a work on the definition and use of an astronomical instrument called *al-Basīṭa*.

Finally, another important work of Mukhtār Pasha should be mentioned here. Entitled *Sarā'ir al-Qur'ān fī taqwīn wa-ifnā' wa-*|*ʕādat al-akwān* and published in Istanbul in 1917, it was written in order to reconcile religious issues with scientific discoveries and discusses how to reconcile Qur'ānic verses with the latest developments in science. This work was one of the first during the modern period to address these issues and was later translated into Arabic from Turkish.

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Ainslie, Maurice Anderson

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Born **Corfe, Somerset, England, 4 October 1869**
Died **Wallisdown, Dorset, England, 19 January 1951**

Maurice Ainslie, an archetypical English amateur astronomer, was particularly involved with telescope design and with observing planets (mainly Jupiter and Saturn). As a contributor to journals and as a radio broadcaster, he was active in promoting astronomy to the general public. A Royal Navy officer by profession, he was a leading member of the British Astronomical Association for many years.

Ainslie was the youngest son of Reverend Alexander Colvin Ainslie and Catherine Susan Sadler. His father was an Archdeacon (senior priest) in the Church of England. He grew up mainly in the rural county of Somerset in the west of England.

From 1884 to 1888 Ainslie attended Marlborough College, a school specializing in the education of sons of clergymen. He became interested in astronomy at Marlborough College, joining the Astronomical Section of the school's Natural History Society. Ainslie gave several talks to the section, covering topics such as the constellations, the planets, and the telescopes (an interest he would hold for the rest of his life). The Astronomical Section enjoyed using a 4-in. Cooke refracting telescope that belonged to the college, and it was with that telescope that he took some photographs of the Moon during the Christmas holidays of 1886.

Ainslie was accepted by Gonville & Caius College in the University of Cambridge. At Cambridge he was able to observe with the 11.5-in. Northumberland Telescope. ► **John Adams**, famous for his prediction of Neptune, was the director of the Cambridge Observatory at that time. Ainslie graduated in 1891 with a BA degree in mathematics and natural sciences.

The next 2 or 3 years must have been a difficult time for Ainslie. He had decided to become a teacher, but it seems that the career did not suit him. He had two short-lived positions as a schoolmaster, first at Derby School and then at Giggleswick, before joining the Instructional Branch of the Royal Navy in 1894.

At that time the Royal Navy was the largest navy in the world. It operated on a worldwide scale and possessed a fine tradition of assisting scientific research and exploration. Furthermore, practical navigation depended very much on astronomical observations and knowledge in that era. Ainslie served with the Royal Navy in the Mediterranean, the Channel, and at various shore establishments including the Royal Naval College at Greenwich.

Shortly after joining the Royal Navy, Ainslie built a telescope for himself. It was a 9-in. reflector set on an altazimuth mount and utilized a mirror he had ground himself. Ainslie retained an interest in all aspects of practical optics for the remainder of his life.

Ainslie was closely involved in the activities of the British Astronomical Association [BAA], which was founded in 1890. He contributed numerous short reports to the *Journal* of the BAA on various topics. Ainslie served as director of the Methods of Observation Section from 1917 to 1932. The Methods of Observation Section would perhaps today be called the "Equipment Section," as it was concerned with the exchange of information on all items of equipment from lenses to mountings. Ainslie also served as director of the Saturn Section for 6 years.

Ainslie was a regular contributor to BAA meetings, offering advice and information from his long experience as an amateur observer. Saturn and Jupiter were the principal objects of Ainslie's observations. He was fortunate to observe a rare event when the ring system of Saturn occulted the star BD +21° 1714 on 9 February 1917. He made a full report of this event in the BAA *Journal*. On the night of 29/30 December 1918 Ainslie was able to observe a complete rotation of Jupiter, making a particular study of the equatorial regions. (On one occasion he related how he observed the Green Flash twice on the same day from the rolling deck of *HMS Roxburgh* in the Bay of Biscay.) Ainslie was elected president of the BAA from 1928 to 1930.

Ainslie had many other scientific interests outside of astronomy. He was an expert in the optics of the microscope and contributed articles on this subject to the *English Mechanic*. He was the president of the Photomicrographic Society in 1920. He also was keenly interested in radio, experimenting with early crystal and valve circuits. Ainslie arranged for experimental Greenwich Mean Time [GMT] time signals to be broadcast from the Eiffel Tower in Paris in 1921. He advocated this as a method of providing amateur astronomers with an accurate time standard. In common with his activity in the BAA, Ainslie was closely involved with the radio amateur fraternity, serving on the council of the Radio Society of Great Britain.

Ainslie retired from naval service in 1922 with the rank of instructor captain. In his active years of retirement Ainslie was involved with the Bournemouth Natural Science Society, a local group dedicated to self-education in the sciences. Despite suffering from arthritis, Ainslie continued to be involved with his many scientific interests. He gave not only gave astronomical lectures but also popular talks on the radio. Poor health forced him to resign as director of the BAA Saturn Section in 1946.

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Airy, George Biddell

Gilbert E. Satterthwaite
Imperial College, London, UK

Born **Alnwick, Northumberland, England, 27 July 1801**
Died **Greenwich, England, 2 January 1892**

Airy, George Biddell. Courtesy of History of Science Collections, University of Oklahoma Libraries

George Airy was the seventh Astronomer Royal; he made major and lasting contributions to many branches of astronomical and physical science and engineering, and his procedures for the mathematical treatment of observations remained the standard for more than a century. His name is associated (Airy diffraction pattern) with the appearance of light that has passed through a small circular aperture.

The son of farmer William Airy and Ann Biddell, Airy was schooled locally at Colchester. At age 12, he asked his uncle, Arthur Biddell, to take him in; his uncle raised him from that point. At school Airy excelled in classics, history, and mathematics. He taught himself a wide range of other subjects, including astronomy, chemistry, and navigation. Airy entered Trinity College, Cambridge, in 1819, and graduated as senior wrangler in 1823. He contributed several papers, mainly on optical subjects, to the Cambridge Philosophical Society. A noteworthy example was "On a peculiar defect in the eye, and a mode of correcting it." Airy was myopic, and wore the usual concave spectacles for this, but his left eye remained almost useless; he discovered by experiment that the eye was seriously astigmatic, and designed a concavo-cylindrical lens to correct it. His solution is routinely prescribed today.

Airy became a fellow of Trinity College in 1824, and Lucasian Professor of Mathematics in 1826. Two years later he was appointed Plumian Professor of Astronomy, which included superintendence of the newly created Cambridge University Observatory. Airy devised a new system for the reduction of the positional observations, and was also responsible for the design and erection of the Northumberland 11¾-in. refractor, in a double-yoke equatorial mounting that he developed from a form previously used only for small instruments. Still in use today, the mounting proved to be extremely successful and was the forerunner of those used for great telescopes at the Mount Wilson Observatory and Palomar Observatory.

Meanwhile, Airy continued his research into the wave theory of light and many other topics. His contributions in such diverse fields as optical diffraction and engineering metrology, for instance, are remembered by the continued use of the terms Airy disk and Airy points. At the second meeting of the British Association for the Advancement of Science in 1832, Airy was invited to present a report on the Progress of Astronomy, which was to prove to be of seminal importance. He arranged for the reduction and publication of ► **Stephen Groombridge**'s *Catalogue of Circumpolar Stars* when Groombridge himself was incapacitated by a stroke, thus salvaging an invaluable reference source. Having directed the Cambridge Observatory so successfully, it was inevitable that Airy should succeed Astronomer Royal ► **John Pond** when the latter retired in 1835.

Airy directed the Royal Observatory for 46 years, and reorganized the establishment so effectively that it continued to be run on the pattern he formulated for more than 120 years. He introduced full reduction and annual publication of all the observations, and also organized the reduction and publication in three massive volumes of all the positional observations of the Sun, the Moon, and the planets that had been made at Greenwich between 1750 and 1830. In addition to maintaining and developing its traditional role in positional astronomy and time determination, Airy introduced regular photography of the

Sun's surface, stellar radial-velocity measurements, and systematic monitoring of the Earth's magnetism. He also designed the great equatorial telescope, a 12¾-in. refractor in a mounting developed from his design for the Northumberland telescope.

Arguably, Airy's greatest achievement at Greenwich was the design of a new suite of instruments to meet the increasing standards of accuracy required for positional astronomy: the altazimuth, the reflex zenith tube, the barrel chronograph, and, most notably, the transit circle. These instruments, introduced between 1847 and 1854, were to prove the best in the world at the time and to have a combined working life of 313 years; they also provided the design basis for major positional instruments for generations to come. Airy retired on 15 August 1881 and moved to a house nearby.

Airy's transit circle – described by ▶ **Simon Newcomb** as "the most serviceable meridian instrument ever constructed" – commenced work in 1851; its last observations were made in 1954, and were reduced using Airy's procedures. At the Washington Conference of 1884, the longitude of the Airy transit circle had been adopted as the prime meridian and the reference for the world's time zones.

Airy undertook many nonastronomical tasks: He served on the Board of Longitude and more than 30 Royal Commissions and government Select Committees, and was the de facto chief scientific advisor to the governments of his day. Airy chaired the committee to restore the national standards of length and weight following their destruction in a fire at the Houses of Parliament, and played a leading role in the introduction of the electric telegraph and the distribution of time signals, the standardization of railway gauges, and the correction of magnetic compass disturbances in iron ships. He also participated in numerous international collaborations, including the Greenwich–Paris and the Pulkovo–Greenwich–Valencia longitude determinations, and organized expeditions to observe several solar eclipses and two transits of Venus. Airy was asked to draw up detailed instructions for the determination of the Canada–United States boundary, and trained the officers concerned for several weeks at Greenwich. He gave similar assistance to the establishment of the Oregon state boundary.

Airy published a dozen books, mainly in the fields of mathematics, optics, and astronomy, and wrote over 500 scientific papers. He also wrote essays on topics ranging from early Hebrew scriptures to Roman military history. One of his most successful books was *Six Lectures on Astronomy* (London, 1849), based on a course of public lectures given on the occasion of the opening of the Ipswich Museum. Twelve further editions of this work, later retitled *Popular Astronomy*, appeared for over 40 years.

Airy served as president of the Royal Society of London during 1871–1873, and was awarded both its Copley Medal and its Royal Medal (twice). He was a member of the Council of the Royal Astronomical Society continuously from 1830 to 1886, during which time he served as the president for four terms. Airy received a knighthood in 1872, and in 1875 became the first scientist to be appointed a freeman of the City of London. He was also honored by several universities and numerous overseas academies.

In character Airy was very industrious and energetic, had total self-confidence, and possessed a strong sense of duty and moral rectitude. He was famously meticulous and carefully preserved all documents and correspondence, even inventing a filing system for the purpose. His sense of order has proved of great benefit to posterity, establishing an archive that is remarkable in its value and completeness. Airy's own high standards led him to expect much of others, but though demanding of his staff he was also very fair. For much of the twentieth century, however, it was fashionable to denigrate him as a tyrannical employer, but these criticisms were greatly exaggerated. They largely arose from the statements of a young assistant, serving under Airy only briefly, who later wrote disparagingly of Airy's style of management in a program that had been completed some three decades before his own birth! Recent research has shown such criticisms to be totally undeserved.

Airy has been unjustly criticized in connection with the prediction and discovery of the planet Neptune, and consequent loss of priority for the young Cambridge student ► **John Adams**. Searching for a hypothetical planet was not within the remit of the Royal Observatory with its extensive programs and limited resources, and Airy quite properly suggested that it could more appropriately be sought with the Northumberland refractor at Cambridge Observatory. If ► **James Challis**, Adams' professor at Cambridge, had not been dilatory Neptune might well have been found there. Archival evidence shows that Airy behaved entirely correctly.

Airy was a devoted family man: In 1830 he married Richarda Smith, eldest daughter of the Chaplain to the Duke of Devonshire. They had nine children; the three eldest all died young. Airy was sparing of his friendship, but remained very close to his lifelong friends, notably Sir ► **John Herschel**.

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Aitken, Robert Grant

Harry G. Lang
National Technical Institute for the Deaf, Rochester Institute of Technology, Rochester, NY, USA

Born **Jackson**, **California**, **USA**, **31 December 1864**
Died **Berkeley**, **California**, **USA**, **29 October 1951**

Harry G. Lang has retired.

Aitken, Robert. Reproduced by permission of the Mary Lea Shane Archives of the Lick Observatory, University of California at Santa Cruz

Binary star astronomer Robert Aitken began to lose his hearing in early childhood. A "Record of Family Traits" filled out for the Eugenics Record Office showed that the cause of his deafness was catarrhal otitis media (middle-ear hearing loss). Despite a progressive type of deafness, he still was able to enjoy music somewhat, with the help of a hearing aid.

Aitken entered Williams College in Massachusetts in 1883, intending to study for the ministry. After graduating in 1887, he married and was hired by Livermore College in California. He moved on to the University of the Pacific in 1891, serving as professor of classics but also teaching some astronomy and supervising the university's modest observatory and 6-in. refractor. Correspondence with ► **Edward Holden**, first director of Lick Observatory, documents Aitken's gradually increasing interest in astronomy, and he was appointed to a 1-year position at Lick in 1895. Curiously, Aitken's successor at the University of the Pacific, ► **Heber Curtis**, also taught classics with mathematics and astronomy initially as sidelines, and also moved on to Lick Observatory. Aitken remained at Mount Hamilton the rest of his career, being promoted from assistant astronomer to astronomer in 1906. He served as associate director from 1923 to 1930 and as the fourth director, succeeding ▶ **William Campbell** in 1930 and retiring in 1935. Aitken had no immediate scientific heirs at Lick Observatory. He had brought in ▶ **Gerard Kuiper**, as a double star observer in 1933, but the next director (▶ **William H. Wright**) preferred to make appointments in observational astrophysics, leaving Kuiper to go on to Harvard.

Communication in the world of pure research was difficult for Aitken because of his deafness. He relied primarily on speech-reading (formerly called lip-reading). One report about an experience at the first Astronomical Union Assembly in Rome in 1922 indicated that Aitken did not respond to a message even when it had been shouted at him. Dr. ▶ **Charles Shane**, in an unpublished autobiography, "Life of Mt. Hamilton, 1914–1920," described Aitken's voice as rather hollow and resonant, a result of a "considerable degree of deafness." At one point in his career, Aitken was nearly killed when he did not hear the approach of an automobile.

During his early years at Lick Observatory, under the direction of ▶ **Edward Barnard**, Aitken worked with the 12-in. refracting telescope, observing comets, asteroids, and other objects. He soon became fascinated with binary stars, and it is as a double-star astronomer that he is best known. His first publication focused on double-star measurements. Its appearance, in an 1895 issue of the *Publications of the Astronomical Society of the Pacific*, led to a comprehensive survey of double stars with ▶ **William Hussey**, making many measurements on 12- and 36-in. telescopes. Hussey left the project in 1905, and Aitkin completed the survey to the 9th magnitude limit of the *Bonner Durchmvisterung*.

Aitken's discovery of over 3,000 double-star systems during this survey was a definitive effort. Great accuracy was required; many of these stars were very close to each other, making the measurements of their orbits tricky. The resulting book, *The Binary Stars*, was published in 1918, with a revised edition in 1935 and a reprinted edition in 1964. In this work, he provided a historical sketch of binary stars, including the discovery of the variability of Algol by another deaf astronomer, ▶ **John Goodricke** in York, England. Aitken also reported on the statistical analyses of the data from his own orbital measurements. He insisted on the necessity for longitudinal studies. Repeated observations were required for accurate orbital determination, including period, eccentricity of orbit, and the orientation of orbit planes relative to our direction of observation. Aitken particularly emphasized the precaution of making measurements only when the observing conditions are good, to avoid misleading results.

The culmination of Aitken's career was in 1920, when he combined the observational data given to him by Eric Doolittle with his own. Aitken updated ▶ **Sherburne Burnham**'s 1906 catalog, and, in 1932, published *A New General Catalogue of Double Stars within 120° of the North Pole*. In preparing this volume, he compared his list of 5,400 double stars with the great *Henry Draper Catalogue*. Aitken's *New General Catalogue* is considered a lasting monument to his work.

Aitken received honorary doctoral degrees from the University of the Pacific (1903), Williams College (1917), University of Arizona (1923), and University of California at Los Angeles (1935). He was awarded the Lalande Gold Medal from the French Academy of Sciences (1906), the Bruce Gold Medal from the Astronomical Society of the Pacific (1926), and the Royal Astronomical Society's Gold Medal (1932). Aitken was elected to the United States National Academy of Sciences in 1918 and held membership and offices in many other professional societies, most notably as president of the Astronomical Society of the Pacific in both 1898 and 1915, the vice president of the American Astronomical Society from 1924 to 1931 (and president from 1937 to 1940), and president of the Pacific Division of the American Association for the Advancement of Science in 1925. He was the first president of the Commission on Double Stars in the International Astronomical Union. As editor of publications for the Astronomical Society of the Pacific for many years, Aitken achieved a level of genuine career satisfaction. Through publication, he had opportunities to converse with the general public by writing about the wonders of the heavens without the stress of the face-to-face communication that had dampened his early efforts.

A minor planet (3070) Aitken and a lunar crater on the Farside are named in his honor.

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al-Bannā’

► Ibn al-Bannā’: Abū al-ʿAbbās Aḥmad Ibn Muḥammad Ibn ʿUthmān al-Azdī al-Marrākushī

Albategnius [Albatenius]

► Battānī: Abū ʿAbd Allāh Muḥammad ibn Jābir ibn Sinān al-Battānī al-Ḥarrānī al-Ṣābi’

Albert, the Great

Stephen Gaukroger
University of Sydney, Darlington, NSW, Australia

Alternate Name

► Albertus Magnus

Born **Lauingen**, (**Bavaria**, **Germany**), ***circa*** **1200**
Died **Cologne**, (**Germany**), **1280**

Albert the Great. Courtesy of History of Science Collections, University of Oklahoma Libraries, Small Portraits Collection

Albertus Magnus is traditionally credited with the introduction of ► **Aristotle**’s philosophy into the Christian West. By doing so, he initiated a period of concern with natural philosophical questions that had been absent from the Neoplatonist thought dominating Christianity up to that time (and which still played a crucial role in Albert’s own thought).

Albertus entered the Dominican order in 1223, studying at Padua, Bologna, and Paris. He taught at the University of Paris from 1245 to 1248, when he moved to Cologne, where he spent the remainder of his life. Albertus probably became familiar with the Aristotelian corpus in the 1240s at the priory of Saint Jacques in Paris. The Arab commentators from whom he learned his Aristotle worked in an environment in which astronomical questions were taken very seriously, and, atypically for his time, Albertus himself pursued such questions.

Albertus developed two notable doctrines. The first was the view that the Milky Way was not a sublunary exhalation (as Aristotle had urged) but rather a configuration of stars.

He was cited by defenders of this view, most notably Gaetano di Thiene, in the fifteenth and sixteenth centuries.

Second, like many medieval and renaissance natural philosophers, Albertus was unhappy about the eccentrics and epicycles of ▶ **Ptolemy**, wondering what physical rationale they could have. Despite the difficulties in reconciling them with the observed motions of celestial bodies, particularly those of the planets, Albertus preferred the homocentric account of celestial motions. The question is complicated, however, by the fact that he distinguished between the mathematical accounts of celestial motion and the natural philosophical (physical) ones. To a large extent, this prevents the two sets of considerations coming into conflict, so that the irreconcilability of the physical arguments, on the one hand, and the mathematical and observational arguments, on the other hand, is not as evident as it became in the sixteenth century. Indeed, in some respects, Albert set in motion a very problematic division of responsibilities with regard to astronomical questions, which fitted in well with the delicate balancing act that the introduction of Aristotelian philosophy required, but which turned out to be quite artificial.

Albert's natural philosophical and astronomical writings are to be found principally in his commentaries on Aristotle.

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Albertus Blar de Brudzewo

▶ Brudzewski, Albertus

Albertus Magnus

▶ Albert, the Great

Albrecht, Sebastian

Rudi Paul Lindner
University of Michigan, Ann Arbor, MI, USA

Born **Milwaukee, Wisconsin, USA, 22 August 1876**
Died **probably Albany, New York, USA, 9 April 1957**

American observational astronomer Sebastian Albrecht was the son of John and Anna Mary Schiessel Albrecht. He married Violet E. Standen in 1910. They had two children. Albrecht was educated at the University of Wisconsin (B.S.: 1900), where he studied under ▶ **George Comstock**, and at Lick Observatory (fellow: 1903–1906) and the University of California, where he received a Ph.D. in 1906 for work on the spectra of variables stars Y Ophiuchi and T Vulpeculae with ▶ **William Campbell**.

From 1900 to 1903 Albrecht taught high-school science in West Bend, Wisconsin. From 1906 to 1910 he was an assistant astronomer at the Lick Observatory, and in 1908 he took part in the Lick Observatory solar-eclipse expedition to Flint Island in the Pacific; in 1909 he was part of a Lick Observatory expedition to observe from the summit of Mount Whitney. From 1910 to 1912 Albrecht joined another former Lick astronomer, ▶ **Charles Perrine**, as astronomer at the Argentine National Observatory at Córdoba. During the year 1912/1913, Albrecht was assistant professor of astronomy at the University of Michigan and took part in recording the spectra of peculiar variable stars and worked on the reduction of his own earlier observations. In 1913 he moved to the Dudley Observatory, where he spent the rest of his career under the auspices of the Carnegie Institution of Washington. Albrecht retired from the Dudley Observatory in 1937. He returned to "active duty" as an instructor in the Navy Program at Rensselaer (1944–1947).

Albrecht was a fellow of the American Association for the Advancement of Science and member of the American Astronomical Society, the

Mexican Astronomical Society, and Sigma Xi. In 1930 he was the secretary of the American Astronomical Society and in 1935 was chair of the committee on standards of wavelength for the American section of the International Astronomical Union.

Albrecht's dissertation was a spectrographic investigation of two variable stars. From this study Albrecht derived his lifelong interest in the precise measurement of wavelengths and the factors that affected their measurement and also changes in wavelength as well. He felt that such studies would affect the accuracy of stellar radial velocity determinations, motions in the line of sight toward or away from the observer, and also studies of the conditions at various levels of stellar atmospheres. The work at Dudley Observatory, however, was centered on the accurate determination of stellar positions and proper motions.

The most important product of Albrecht's work at Dudley was participation in compiling a catalog of positions and brightnesses of 33,342 stars with senior author ► **Benjamin Boss**. Published in 1936–1937, this was one of the first catalogs to tabulate stars with equinox 1,950 coordinates.

There are some records of his later career in the archives of the Dudley Observatory.

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Albumasar

► Abū Maʿshar Jaʿfar ibn Muḥammad ibnʿUmar al-Balkhi

Albuzale

► Abū al-Ṣalt: Umayya ibn ʿAbd al-ʿAzīz ibn Abī al-Ṣalt al-Dānī al-Andalusī

Alcabitius

► Qabīṣī: Abū al-Ṣaqr ʿAbd al-ʿAzīz ibn ʿUthmān ibn ʿAlī al-Qabīṣī

Alchvine

► Alcuin

Alcuin

Paul L. Butzer[1], Kerstin Springsfeld[2] and Walter Oberschelp[3]
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[3]RWTH Aachen, Lehrstuhl Informatik VII, Aachen, Germany

Alternate Names

► Alchvine; ► Ealhwine; ► Flaccus Albinus

Born **near York, England,** ***circa*** **735**
Died **Tours, (Indre-et-Loire), France, 19 May 804**

Alcuin, a universal scholar, educator, and key counselor of Charlemagne, is best known for his astronomical studies and observations, which led to the Carolingian reform of the calendar.

Of noble Anglo-Saxon lineage, Alcuin was educated at York's cathedral school by students of the Venerable ► **Bede**, as well as Colgu from Ireland. He taught at this school from 765 and became its head in 778. While acquiring books on the Continent, he met Charlemagne in Parma in 781. The Frankish king, having heard of Alcuin's learning and teaching abilities, invited him to lead his Palace school at Aachen.

Moving to Francia in 782, Alcuin became the key counselor of Charlemagne for science, education, and church matters. He taught the King, his family, and the Frankish nobles, reforming the Palace school according to the Anglo-Saxon principle of the seven liberal arts. Alcuin instigated the *Admonitio generalis* of 789, now considered instrumental for the Carolingian renewal of education.

Alcuin produced many didactic writings and probably also the oldest collection of mathematical problems in Latin. He is best known for his verses and his large corpus of letters, written mainly after 796, when he became abbot of Saint Martin's in Tours. The correspondence between Alcuin and Charlemagne (54 letters) includes nine letters on astronomy and calendrical reckoning, called "*computus*" (letters 126, 143, 144, 145, 148, 149, 155, 170, and 171 in the *Epistolae*); six such letters are lost.

It was long assumed that Alcuin was the author of four short anonymous writings: *Ratio de luna*, *De bissexto*, *De saltu lunae*, and *Calculatio Albini magistri*, but recent research indicates that only the first (*circa* 798) was certainly his. The *Calculatio* of 776 is based on an Irish text of 675 and provides easy instructions to determine the months and weekdays of the Easter full moon.

Dating the movable feast of Easter (the first Sunday after the first full moon in spring) was the chief computistic problem of the Middle Ages. This was in fact a complex problem related to the 19-year lunar cycle and the 28-year solar cycle comprising a 532-year Easter cycle. The full moon dates fall on the same days of the months after 19 years, the weekdays after four times 7 years, due to the intercalated day.

The most important astronomical-computistic contribution of Alcuin concerned the "moon-leap" or *saltus lunae*. Estimating a lunar month of 29 or 30 days, the 19-year cycle would have 6,726 lunar days, although 19 solar years (of 365 days) would have 6,935 solar days. To reconcile the difference, 7 lunar months of 30 days were intercalated (6,936 lunar days), requiring removal of the supernumerary day at the end of the 19-year cycle.

In his letter 126 (797), Alcuin opted for the *saltus lunae* on 25 November, following Roman tradition. But Charlemagne's new counselors wanted to follow Alexandrian tradition, starting the legal year on 1 September and fixing the *saltus* on 30 July. Alcuin was irritated and in letter 145 (798) called his competitors *aegyptiaci pueri*, "Egyptian Boys," and challenged them with five questions on the calculation of the lunar cycles. Alcuin also promised Charlemagne that he would write up his own treatise on the *saltus lunae*, but it is lost.

In letter 148, Alcuin calculated when the Sun entered each of the 12 signs of the zodiac, to explain why a solar day must be intercalated every 4 years (the *bissextus*). In letter 149, Alcuin reported about the reappearance of Mars, after the Sun had concealed it, on 18 July 798, at the time, he reobserved Sirius. This observation found its way into the Court Annals, which subsequently reported eclipses of the Sun and the Moon, and other notable planetary configurations.

Charlemagne wanted Alcuin to interpret the reappearance of Mars as a good omen for his Saxon campaign, but in letter 155, Alcuin rejected this and gave a different but erroneous explanation, that Mars had stood still for 1 year in the zodiacal sign of Cancer, and was not visible together with Cancer.

Charlemagne had also asked Alcuin to calculate when the Moon entered each of the 12 signs of the zodiac. These calculations are found in *Ratio de luna*, forming an appendix to a later letter by Alcuin. It brings the course of the Moon into mathematical correspondence with that of the Sun, using the formula of "9 lunar hours = 5 solar days."

In letter 170 (799), Charlemagne enquired why the Moon on 18 March did not yet have the appearance of an increasing half-moon in the zodiacal position 7° of Gemini. In letter 171, Alcuin calls Charlemagne's calculations on Moon and *bissextus* a "perfection of my own calculations." But this is not identical to the anonymous *De Bissexto*, which stems from the same author as *De saltu lunae*.

Charlemagne commissioned Alcuin, as the expert on the *computus* (probably in 789), to write a standard work, resulting in his *Libellus annalis*, which is lost except for the dedication verses. But three Carolingian manuals on the *computus* have survived:

1. The short *Annalis libellus* of 793, probably not identical with Alcuin's *Libellus annalis*
2. The first compendium on calendrical reckoning, the seven-book computus written at the Court in 809–812, called *Aachen Encyclopedia*
3. The three-book computus of 818, assembled at Salzburg

The mediocre *Annalis libellus*, containing Alcuin's *Calculatio*, prescribes the Roman *saltus* in November; however, it also refers to Alexandrian tradition. But the "Aachen Encyclopedia," probably edited by Adalhard of Corbie and sponsored by Charlemagne, and including Alcuin's tracts *Calculatio* and *Ratio de luna*, is the most important Carolingian contribution to the *computus*; it does not take sides between Alexandrian and Roman reckoning. The three-book computus, assembled by Arno of Salzburg, encompasses the full Roman tradition propagated by Alcuin in the form of a perpetual lunar cycle calendar.

Alcuin's astronomical observations of the Moon, Sirius, and especially Mars and its "vanishing," initiated systematic astronomical recording at the Frankish Court. His teachings inspired Charlemagne's scholars to make a detailed study of planetary motions in a geocentric system that led to new astronomical diagrams visualizing Plinian planetary theory. A further indirect proof that Alcuin has provided for considerable astronomical know-how at the court even after his death is a letter of Dungal of St. Denis from 811 to Charlemagne. Urged to answer Charles' Question as to why two solar eclipses occurred in 810, Dungal obviously felt obliged to deliver a lengthy and quite instructive essay on astronomy for the Alcuin-educated experts at the court, as a substitute for his own lack of information concerning eclipses. Dungal must have been an insider concerning the scientific situation at the court, despite his geographical and social separation from it. In addition, this letter testifies that the scientists at the court felt able to reconstruct and to predict solar eclipses with the aid of Pliny's Historia Naturalis.

In sum, Alcuin's research and teaching made the Carolingian reform of the calendar possible, so Charlemagne's Aachen had become the European center of computistical and astronomical excellence.

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Born **Chicago, Illinois, USA, 10 January 1890**
Died **Charlottesville, Virginia, USA, 3 February 1964**

Although the Yale University Observatory station in South Africa was the idea of ▶ **Frank Schlesinger**, it was American Harold Alden who took most of the tens of thousands of photographic exposures that led to the determination of hundreds of new stellar parallaxes (1925–1945). Alden was later the director of the Leander McCormick Observatory.

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Aldrich, Loyal Blaine

Teasel Muir-Harmony
Massachusetts Institute of Technology, Cambridge, MA, USA

Born **Milwaukee**, **Wisconsin**, **USA**, **20 November 1884**
Died **Washington**, **District of Columbia**, **USA**, **11 February 1965**

Loyal Blaine Aldrich was the third director of the Smithsonian Astrophysical Observatory [SAO] (1944–1955) and is best known for his contribution to studies of the solar constant. Loyal was the son of Lafayette and Isabella (Hay) Aldrich. He enrolled at the University of Wisconsin, earning his bachelor's degree (1907) and master's degree (1909). Aldrich became a student of Charles Elwood Mendenhall, a professor of physics who had previously been an assistant to ▶ **Charles Abbot**, an astronomer at the SAO since 1895. This connection enabled Aldrich to build a lifetime career at the SAO. In 1919, he married Elizabeth Stanley and the couple had two sons, Stanley and Lafayette. After Elizabeth's death in 1941, Aldrich married Sarah Grace Smith in 1943.

In 1909, Aldrich joined the staff at the Smithsonian Astrophysical Observatory as a "bolometric assistant." The SAO had been founded in 1890 by the Smithsonian Institution Secretary, ▶ **Samuel Langley**, in large part to study the Sun and measure the solar constant or intensity of the Sun's rays outside of the Earth's atmosphere. Abbot became the second director of the Observatory in 1906 and Aldrich started working for Abbot 3 years later. Abbot supported a research program that investigated correlations between variations in the solar constant, weather, and climate change, a relationship that he believed if found would benefit mankind. Aldrich performed some of this research at the Mount Wilson Observatory in California before going to Mount Harqua Hala in the southern Arizona desert in 1920 to help set up an observing station.

The SAO had established a number of field stations around the world to collect solar data using ground-based pyrheliometers (solar heat recorders). Later, Aldrich's son Stanley would become the acting director of the SAO field station in the Chilean Andes, until he returned to the United States in 1957.

Aldrich stayed at the SAO throughout his career, moving from the rank of assistant director (1930–1945) to eventually becoming director when Abbot retired in 1944. He continued to support the solar research program at the SAO, even though he recognized some problems with Abbot's claim that variations in the solar constant influenced the Earth's weather. After becoming director, Aldrich confessed to a colleague that even though he respected Abbot's work, he did not think it was impartial, noting that Abbot would emphasize positive factors while overlooking unfavorable ones.

As director, Aldrich maintained the SAO's field stations and solar constant program because he believed that the observatory played a unique role in solar radiation research. But he was also forward thinking. Aldrich supported scientific rocketry groups, acknowledging that advancements in the precision of the solar constant could only be made from outside of the Earth's atmosphere. Aldrich retired in January 1955; the Observatory moved to the grounds of the Harvard College Observatory in Cambridge, Massachusetts, in July of that same year; and ► **Fred Whipple** became the SAO's new (and fourth) director.

In the early twentieth century, many scientists believed that Abbot's and Aldrich's solar constant research was significant. However, since the 1980s, data collected by satellites have shown very little variability in solar radiation. Scientists have subsequently concluded that the variations in data collected by Aldrich and others were not due to changes of the solar constant but were likely the result of calibration adjustments or variations in atmospheric transmission.

The majority of material available on Aldrich focuses on the history of institutions or the lives of other astronomers, with only limited mention of Aldrich's contributions to astronomy. He appears often in studies that discuss the work of Charles Abbot, in particular.

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Alexander, Arthur Francis O'Donel

Richard Baum
Chester, County Chester, UK

Born **England, 9 November 1896**
Died **Dorchester, England, 29 January 1971**

Arthur F. O'Donel Alexander, an amateur astronomer, applied his outstanding organizational and analytical abilities to the collation of planetary observations. His books on Saturn and Uranus are models of careful historical research and masterly presentation and are still accepted as standard reference works on these two planets. An historian by training, Alexander was an educational administrator by profession. He obtained his B.A. degree in 1918 from University College, Exeter, England, to which he had won an open scholarship in 1915. He was the first student of the college to secure first-class honors in history. Alexander taught for 3 years in the United Kingdom, and then moved to Japan where, until 1924, he instructed science students in English at the Matsuyama National College. On his return to the United Kingdom he took up the posts of secretary for education and executive officer of Londonderry County Borough Authority, Northern Ireland. In 1930, Alexander was appointed assistant director of Education to the Dorset County Council, England, a post he retained until his retirement in 1961. He was awarded a University of London external M.A. degree in 1927 and a doctorate in philosophy, also from the University of London, for a thesis on the early part of the 100 Years War.

Alexander joined the British Astronomical Association [BAA] in 1937, and contributed regularly to the work of its solar, lunar, planetary, comet, and variable star sections. His natural flair for analysis led him to devise new methods of utilizing statistics to study sunspots, the solar cycle, and solar physics generally. He applied statistical techniques to the *Greenwich Photoheliographic Results* to derive valuable results on the areas, distribution, and frequency of sunspots. His analyses were summarized in four papers published in the *Journal of the British Astronomical Association* between 1944 and 1947.

With most regular observers engaged in war service, Alexander organized a team of observers who still had access to their telescopes to cover the Mars opposition of 1941, the most favorable opposition for observers in the United Kingdom since 1926. The effort was a complete success; a full report on the 1941 Mars opposition appeared in 1951. This demonstration of his abilities established his future role in the work of the association.

In 1946 Alexander was appointed director of the Saturn Section and built a large and vigorous team of observers. His 1953 paper "Saturn's Rings – Minor Divisions and Kirkwood's Gaps" is considered an important addition to the literature of the planet. In 1951 he handed over the section to his friend M. B. B. Heath, and took charge of the Jupiter Section, then in shambles. The illness of the elderly ▶ **Bertrand Peek** had forced his resignation in 1949 after many years of outstanding leadership of the Jupiter Section. Unfortunately, Peek's successor, D. W. Millar, also fell ill and provided little guidance to the section for several years. Alexander's personal standing and that of the Jupiter Section were enhanced following the discovery in 1955 of radio emissions from Jupiter, since this led to close collaboration between Alexander and radio astronomers. However, illness obliged Alexander to hand over the section to W. E. Fox in 1957.

After his withdrawal from active sectional leadership, Alexander coupled his historical research skills with his profound knowledge of the planet Saturn to produce a book-length monograph on that planet. The book, subtitled appropriately as "a history of observation, theory and discovery," discusses these three aspects of our knowledge of Saturn from ancient times to the most modern research available in the early 1960s. A similar effort with respect to the planet Uranus was published a few years later, though in that case Alexander's personal involvement in the recent observational history was more limited. Alexander's two monographs, *The Planet Saturn* and *The Planet Uranus*, remained useful resources late in the twentieth century.

Alexander, a talented linguist and very active in astronomical education, had global links with both amateur and professional astronomers. He led a small party of BAA members to the Pic-du-Midi Observatory in 1947, and had honorary membership in the Société Astronomique de France. From 1951 to 1957 he represented the BAA on the British National Committee for Astronomy. Alexander was also a member of the International Astronomical Union Commission 16 (Physical Study of Planets and Satellites), and represented the United Kingdom on the subcommittee set up to revise the nomenclature of Mars. In 1954 he went to Sweden as a member of the joint Royal Astronomical Society/BAA Eclipse Expedition. In addition to contributing monographs on Saturn and Uranus, Alexander contributed important chapters on the planets and minor planets to Dent's *Astronomy for Everyman*.

The BAA honored Alexander in 1962 with its Walter Goodacre Medal and Award.

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Alexander, Stephen

Marc Rothenberg
National Science Foundation, Arlington, VA, USA

Born **Schenectady, New York, USA, 1 September 1806**
Died **Princeton, New Jersey, USA, 25 June 1883**

A frequent observer of solar eclipses, Stephen Alexander also published two major papers that developed out of his interest in ► **Simon de Laplace's** nebular hypothesis: one on the development of nebulae and star clusters and the other on harmonies in the Solar System. His concern for harmonies led him to be called "the American Kepler," and it was evident that the title was not entirely complimentary.

After graduating from Union College in 1824, Alexander taught at Yates Polytechnic, a vocational school in Chittenango, New York. His earliest documented astronomical observations date to 1825. In May 1830 his younger sister Harriet married ► **Joseph Henry**, their first cousin. Thereafter, Alexander's life and career were bound up with those of Henry, who became America's most important scientist. Alexander left Yates within a few months of his sister's wedding to reside with the Henrys in Albany. When Henry accepted a professorship at the College of New Jersey (now Princeton University) in 1832, Alexander followed to attend the Princeton Theological Seminary. A year later he became a tutor at the college. In 1834 Alexander became adjunct professor of mathematics; he also took responsibility for teaching astronomy in 1836. In 1840 he was appointed professor of astronomy, and remained on the faculty at Princeton University until his retirement in 1876.

Alexander was married twice. In 1836 he married Louisa Meads of Albany, with whom he had three daughters. Three years after her death, in 1847 he married Caroline Forman of Princeton. They had two daughters.

Although eclipses were always an interest, Alexander's most important paper on the topic came early in his career. At the 1843 centennial celebration of the American Philosophical Society, an event that attracted the American scientific elite, Alexander presented his "Physical Phenomena Attending Solar Eclipses." Characteristically, he attempted to reduce a wide variety of observations – both his and those he found from an extensive literature search – to a few simple explanations or "laws." He concluded that there was no evidence that any body in the Solar System except the Earth possessed an atmosphere. This paper was later criticized by ► **Charles Young** for its failure to provide "sufficient discrimination between the real and imaginary." All too often Alexander had relied on a single observation by a relatively untrained observer, an acceptable practice among American astronomers in the 1830s, but not so a half century later.

In 1845 Alexander participated in what would be his most important astronomical observations. He and Henry measured the relative temperature of sunspots by placing a thermoelectric device at the focus of the Princeton 3½-in. Fraunhofer refractor, demonstrating conclusively that the sunspots were relatively cooler. They also produced data showing that the solar limb was cooler than the solar center. The only publication that resulted from the observations was a brief description in the *Proceedings of the American Philosophical Society*, and Alexander did not carry on the research after Henry abandoned it.

Despite what a later generation thought of his work, and his thin list of publications, by contemporary standards Alexander was a significant figure in American astronomy. He served on a variety of committees for the American Association for the Advancement of Science, and was president at its 1859 meeting. Alexander was selected as one of the original members of the National Academy of Sciences, established in 1863. In part, his visibility was no doubt due to his family connections. It is also important to take into account Alexander's well-documented reluctance to transform his many oral presentations into publications, which resulted in a higher awareness of his work among contemporaries than among later astronomers. His contemporary reputation also rested on his 1852 publication in the *Astronomical Journal* entitled "On the Origin of the Forms and the Present Condition of Some of the Clusters of Stars and Several of the Nebulae." This eight-part paper argued that some of the stellar clusters and spiral nebulae were disintegrating stars, not stars in the process of formation, as was widely held.

Alexander's most important paper – in his own mind and in the sense that it represented a significant part of his life's work – did not appear until 1875, at the end of his career, but was the product of three decades of thought about the nebular hypothesis in general, and the ratios of planetary distances and those of planetary satellites in particular. "Certain Harmonies of the Solar System," published by Henry's Smithsonian Institution, established "laws" for the distances of the planets from the Sun and the distances of the satellites from the planets and demonstrated that the nebular hypothesis accounted for these laws. By the time Alexander had published, however, the deficiencies in the nebular hypothesis were very evident. It was a paper that appeared too late to add very much to Alexander's reputation.

When Alexander began his eclipse observations in 1825, American astronomy was a minor part of the world community. By his death, the American community was on the edge of becoming a peer of the European communities. He was one of the pioneers, and his education, career, and publication record were typical of the American college professor of his generation.

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Alfarabius

► Fārābī: Abū Naṣr Muḥammad ibn Muḥammad ibn Tarkhān al-Fārābī

Alfonsi, Petrus

Charles Burnett
Warburg Institute, University of London, UK

Flourished **(Spain), 1106–1120**

Petrus Alfonsi is likely to have been instrumental in introducing Arabic astronomy to Christian scholars such as ► **Walcher of Malvern** and

▶ **Adelard of Bath**, and thus played a key role in prompting the wholescale translation of Arabic mathematical and astronomical learning in the twelfth century.

Alfonsi was educated as a Jew in an Arabic milieu in Huesca (Aragon) in the Islamic kingdom of Zaragoza; but, after the Christian conquest of Huesca in 1096, he converted to Christianity, and was baptized on 29 June 1106. Thereafter he traveled in France and England, advertising himself as a "teacher of astronomy," but perhaps returned to Spain (if he can be identified with a "Peter of Toledo") later in his life. Alfonsi was the earliest scholar to bring learned Arabic cosmological and astronomical knowledge to Latin-reading Christians.

Much astronomical and cosmological information is included in his popular *Dialogus contra Iudaeos* (Dialogue against the Jews) in which his old Jewish self, Moses, discusses the relative merits of Judaism and Christianity with his new Christian self, Petrus. In another work, written in the form of a letter addressed to "the Peripatetics of France," he extols the importance of astronomy, and the superiority of Arabic astronomy to that of Latin scholars of his time, and invites students to study the subject with him. The date and place of composition of these two works are unknown.

The two works that Alfonsi devoted specifically to astronomy, however, were both written in the West Midlands of England, and one of them mentions the collaboration of Walcher, prior of the Benedictine abbey of Great Malvern, near Worcester. The first of these is a short text on the movement of the Moon and the cause of eclipses, called in full "The opinion of Petrus, called 'Alfonsus,' concerning the lunar node, which lord Walcher, prior of the church of Malvern, translated into Latin." It mentions the date 1 April 1120 in an example. The second is a version of the astronomical tables of ▶ **Muhammad Ibn Musa al-Khwārizmī**, with a starting point of 1 October 1116, and preceded by a prologue in praise of astronomy that Petrus cites in his letter to the Peripatetics of France. These are the earliest complete astronomical tables known in the Latin Middle Ages. They are not, however, without problems, since, although the starting values (*radices*) of the movements of the Sun, the Moon, and the planets have been calculated from al-Khwarizmi's data quite accurately, the subsequent values have been clumsily and erroneously computed and ineptly adapted to the Latin calendar. Moreover, the canons to the tables in the two extant manuscripts have been combined with chapters from another version of the same astronomical tables of al-Khwarizmi (that by Adelard, which retains the Arabic calendar).

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Alfonso el Sabio

▶ Alfonso X

Alfonso the Learned

▶ Alfonso X

Alfonso the Wise

▶ Alfonso X

Alfonso X

Julio Samsó
University of Barcelona, Barcelona, Spain

Alternate Names

▶ Alfonso el Sabio; ▶ Alfonso the Learned; ▶ Alfonso the Wise

Born **Castile, (Spain), 1221**
Died **Castile, (Spain), 1284**

King Alfonso X reigned from 1252 until 1284. He was a patron of literature and learning and made a great effort to recover Arabic and, very especially, Andalusian astronomical materials by translating them into Spanish, thus becoming a pioneer in the use of the vernacular as a scientific language. Later, probably coinciding with the period (1256–1275) in which he aspired to become the Emperor of Germany, he had some of these works retranslated into Latin. The highest expression of this cultural policy can be found in his *Alfonsine Tables*, in which we find an aspiration to universality very much in keeping with a project of producing a set of "imperial" astronomical tables.

His collaborators were a Muslim convert to Christianity (Bernardo el Arábigo), and eight Christians, of whom four were Spaniards (Fernando de Toledo, Garci Pérez, Guillén Arremón d'Aspa, and Juan d'Aspa), and four Italians (John of Cremona, ▶ **John of Messina**, Petrus de Regio, and Egidius Tebaldi of Parma). The Italian group seems to have been involved mainly with the retranslations into Latin. To these one should add a very important group of five Jews (Yehudah ben Mosheh, ▶ **Isaac ibn Sid** called Rabiçag, Abraham Alfaquín, Samuel ha-Leví, and a certain Mosheh). Two (Yehudah and Rabiçag) take pride of place due to the number and importance of the works they wrote; in particular, they were the authors of the *Alfonsine Tables*. Of these two, only Yehudah was a translator, while Rabiçag wrote original works and built scientific instruments. Alfonso failed in his attempt to persuade a Muslim scientist, Muḥammad al-Riqūṭī, to join his team; they probably met on the king's visit to Murcia in 1271.

Alfonsine translations are based on Arabic works most of which had not been previously translated into Latin. It is conceivable that these sources were found in libraries that came under Christian control as a result of the conquests of Cordova (1236) and Seville (1248) by Alfonso's father king Fernando III. Some of these translations preserve Andalusian astronomical works that would have been lost otherwise; this is the case, for example, of the *Libro de las Cruzes* (Book of crosses), a late Latin astrological handbook based on a versified Arabic version that had been written in the first half of the ninth century and subsequently revised by a certain ʿUbayd Allāh in the eleventh century. Other works that are only known through Alfonso's translations are the *Lapidario* (a book on the magical applications of stones) written by the otherwise unknown author of *Abolays*, the two books on the construction of equatoria written by ▶ **Ibn al-Samḥ** (died: 1035) and ▶ **Zarqālī** (died: 1100), ▶ **ʿAlī ibn Khalaf**'s book on the use of the plate for all latitudes (*Lámina Universal*, Toledo, eleventh century), and Zarqālī's treatise on the construction of the armillary sphere.

King Alfonso seems to have devised a well-structured project for producing two collections of translations and original works. The first collection was devoted to magic and contained the *Picatrix* (only the Latin text is extant), the series of lapidaries, and the *Libro de la mágica de los signos*. The second was an astronomical and astrological collection and in it we find the well-known *Libros del Saber de Astronomía*, ▶ **Ibn al-Haytham**'s *Configuration of the Universe*, ▶ **Battānī**'s Canons (Instructions for the use of his tables), the treatise on the use of the *Cuadrante sennero* (sine quadrant?), the *Alfonsine Tables*, ▶ **Ptolemy**'s *Quadripartitum* with the commentary by ʿAlī ibn Ridwān, the *Libro conplido en los iudizios de las estrellas* (*Kitāb al-Bāriʿ fī aḥkām al-nujūm*) by ʿAlī ibn Abī al-Rijāl, and the anonymous *Libro de las Cruzes*.

The first book of the *Libros del Saber de Astronomía* (*Ochava Espera*) is a treatise on uranography partially based on ▶ **Ṣūfī**. The rest of the collection is composed of treatises on astronomical instruments that are mainly analogical calculators (celestial sphere, spherical and plane astrolabe, saphea, and plate for all latitudes) whose main purpose is to provide graphic solutions for problems of spherical astronomy and astrology that can be applied to the casting of a horoscope. The purpose of the rest of the instruments (quadrant of the type called *vetus*, sundial, clepsydras) is to determine the time, something which is also needed to cast the horoscope. The king wished to have a treatise on the construction and another one on the use of each of these instruments. If an adequate Arabic source was available, Alfonso ordered its translation. Otherwise, an original treatise was written, usually by Rabiçag. For obvious reasons, most of the Alfonsine works that are original are concerned with the construction of instruments, for such texts are more difficult to find than treatises on their use.

We also find in the *Libros* the two treatises on equatoria, instruments whose purpose is to provide approximate calculations of planetary longitudes using Ptolemaic planetary models drawn to scale that allow a graphical solution of a problem that is, again, essential for casting a horoscope. Evidently, Alfonso's tabular works (Zarqālī's *Almanach*, Battānī's *Canons*, and the *Alfonsine Tables*) have exactly the same object.

A last group of Alfonsine works comprises works on judicial astrology (*Quadripartitum*, *Libro de las Cruzes*, *Libro conplido*), which allow the reader to interpret the horoscope and predict the future as well as works on magic whose purpose is to fabricate talismans in propitious astrological conditions in order to modify this same future. When seen from the point of view of a king who was extremely interested in both astrology and magic, his astronomical, astrological, and magical works form an impressive unit that seems to be the result of a well-designed plan. Only two works fall outside this frame; one of them is the aforementioned *Ochava Espera* that contains, apart from a description of the 48 Ptolemaic constellations, enough connections with the lapidaries and other magical texts to consider it as an exception. The second is the translation of Ibn al-Haytham's *Cosmography*, which corresponds to a type of theoretical interest not all that common in the corpus of Alfonso X.

The *Alfonsine Tables* represents Alfonso's most important astronomical work. However, it poses numerous problems, the most obvious of which is the existence of two different versions (one in Spanish, another in Latin). On the one hand, we have the Spanish text of a set of canons without the corresponding collection of numerical tables. These canons have a prologue in which it is said that their authors are Yehudah ben Mosheh and Rabiçag; the text was written between 1263 and 1272; 200 years after the observations of Zarqālī, the king had ordered the construction of the necessary astronomical instruments to make observations in Toledo; and the two astronomers, following the royal orders, made observations of the Sun, planetary conjunctions, and solar and lunar eclipses. Unfortunately, it is difficult to check the veracity of these assertions except for three lunar eclipses (one in 1265 and two in 1266) and one solar (1263) eclipse, on which we have a report transmitted by Isaac Israeli (*circa* 1310). The few numerical parameters mentioned in the canons or in the rest of the Alfonsine works extant in Spanish derive from the *Toledan Tables* or from the work of the Maghribī astronomer ▶ **Ibn Isḥāq** (flourished: *circa* 1193–1222). On the other hand, in the Latin tables one finds new parameters that might be the result of the alleged Alfonsine observations.

In about 1320, a new set of *Alfonsine Tables* appeared containing numerical tables with titles in Latin but without the canons that could be attributed to the Alfonsine circle. Many authors from various parts of Europe (beginning with the Parisian group of ▶ **John of Saxony**, ▶ **John of Murs**, and ▶ **John of Linières**) wrote original canons allowing the use of the numerical tables. The tables were enormously successful and became standard in Late Medieval and

Early Renaissance Europe until 1551, when ► **Erasmus Reinhold** published the *Prutenic Tables*. ► **Nicolaus Copernicus** used parameters derived from the *Alfonsine Tables* in his *Commentariolus*, and the Alfonsine tropical year of 365 days, 5 h, 49 min, and almost 16 s was the mean tropical year used in the *De revolutionibus* and became the basis for the Gregorian reform.

The total lack of information about the tables between *circa* 1272 and *circa* 1320, and their complicated textual history between the fourteenth and sixteenth centuries, when every version or adaptation of this work added new tables to the original corpus, has recently led to a number of different opinions among historians. At least one (Poulle) has denied any relation between the Latin tables and the work of Alfonso X. Others (North, Goldstein, Chabás, Mancha, and Samsó) have discussed this point and argued in favor of the presence of materials in the Latin tables that have a clear relation to others attested in the undisputed Spanish works of Alfonso X. In the opinion of this author, Yehudah ben Mosheh and Rabiçag wrote the Spanish canons under the influence of Zarqālī and the *Toledan Tables*. Later they began a new set of tables following Battānī's tradition. In this second set, the language used was Latin, reflecting the imperial aspirations of King Alfonso. This is not the interpretation adopted by Chabás and Goldstein in a recent book: they believe that the revision was made in Paris, on the basis of the Alfonsine materials mainly represented by the Castilian canons. Whatever the truth, it seems a fact that the *Alfonsine Tables* are the result of the work of the Alfonsine collaborators and that they mark the starting point of an original European astronomy that was still strongly influenced by an Arabic tradition.

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Alfvén, Hannes Olof Gösta

Carl-Gunne Fälthammar
Royal Institute of Technology, Stockholm, Sweden

Born **Norrköping, Sweden, 20 May 1908**
Died **Djursholm, Sweden, 2 April 1995**

Alfvén, Hannes Olof Gösta. Courtesy of Alfven Laboratory, Royal Institute of Technology, Stockholm

Swedish-plasma physicist and astrophysicist Hannes Alfvén is commemorated in Alfvén waves and the Alfvén velocity at which they travel. He shared the 1970 Nobel Prize in Physics for his contributions to plasma physics, especially magnetohydrodynamics, and can be regarded as the founder of the field of cosmic electrodynamics. Hannes Alfvén was the son of Anna-Clara Romanus (a physician) and Johannes Alfvén. He and his wife, Kerstin Erikson (married: 1935), had five children.

Alfvén developed an early interest in astronomy, reading the *Astronomie Populaire* by ► **Camille Flamarion** as a teenager, and in radio communication, building his own receiver.

He was educated in mathematics and physics at the University of Uppsala, receiving a Ph.D. in 1934 for work on ultra-high frequency electromagnetic oscillations. In 1940, Alfvén was appointed professor of electromagnetic theory and electric measurements at the Royal Institute of Technology in Stockholm, where he established a vigorous school of electronics, partly directed toward technical applications. In 1945, he was appointed to a personal chair of electronics, renamed plasma physics in 1963, from which he retired in 1973. From 1967 onward, Alfvén held joint appointments at Stockholm and at the University of California at San Diego as research physicist until 1973, as professor during 1973–1975, and as professor emeritus of electrical engineering and computer science during 1975–1988, when he returned permanently to Sweden.

Alfvén created the research field of cosmical electrodynamics, using his knowledge of experimental and theoretical physics to establish that, in addition to gravity, electromagnetic forces play a significant role in a variety of astrophysical processes. His first contributions were collected in the first edition (1950) of his book *Cosmical Electrodynamics*, with four chapters on general methods followed by three chapters on applications to specific astrophysical problems. A later edition, *Cosmical Electrodynamics – Fundamental Principles* by Alfvén and Fälthammar (1963), has been extensively used in graduate education. Alfvén's cosmogonic work was presented in his 1953 book *Origin of the Solar System*, and greatly extended in the 1976 book *Evolution of the Solar System*, written jointly with the chemist ▶ **Gustaf Arrhenius**.

Alfvén's earliest astrophysical interests were directed toward theory and observations of cosmic rays. In 1933, he published a paper on an electromagnetic origin of cosmic rays, a subject to which he repeatedly returned during the following 25 years. Alfvén (1940) introduced the method of separating the motion of a charged particle in a magnetic field into a fast gyration transverse to the magnetic field and a slower drift of the center of this gyration, which he called the "guiding center." This led to a drastic simplification, which has become a fundamental tool in the entire field of plasma physics, from cosmical plasmas to laboratory plasmas and controlled fusion research. A number of scientists developed the highly sophisticated adiabatic theory of charged particle motion, which is today indispensable in modern plasma physics. The rapid transverse motion gives rise to synchrotron radiation, which was predicted in cosmic contexts by Alfvén and Nicolai Herlofson in 1940 and discovered in the 1940s and 1950s in solar radio emission and optical radiation from supernova remnants.

Alfvén noticed that in our Galaxy, the energy density of cosmic rays is about the same as that of starlight (the Sun excluded). Considering reasonable sources and sinks of these two energies, and the isotropy of cosmic radiation, he predicted in 1937 the existence of a galactic magnetic field due to electric currents carried by the interstellar plasma – a prediction later amply verified by the polarization of starlight scattered by interstellar dust (discovered by ▶ **John Hall** and ▶ **William Hiltner**) and by the synchrotron nature of galactic radio emission.

In addition to his theoretical work, Alfvén, characteristically, conducted careful observations of cosmic rays. Throughout his career, he emphasized the importance of laboratory experiments as a check on theories, including theories of cosmic phenomena, because "the same laws of nature should apply everywhere."

Directing his attention to electromagnetic aspects of solar physics, Alfvén, in 1943, developed a theory of sunspots and the sunspot cycle. In the process of this work, he discovered, in 1942, the existence of a new kind of waves, nowadays known as Alfvén waves. Studying fluids of high electrical conductivity, such as the solar plasma or interstellar plasma, Alfvén showed that a combination of electromagnetic theory and fluid dynamics opened a whole new field of physics: magnetohydrodynamics. Although many decades of new observations have revealed much more complicated magnetic fields in the Sun, and theories of sunspots are accordingly different, Alfvén waves and the Alfvén velocity remain indispensable concepts.

From the existence of solar magnetic fields, Alfvén concluded that beams of charged particles emanating from the Sun during magnetic storms and aurorae must carry magnetic fields. He made this the basis of a new theory of magnetic storms and aurorae (1939). Decades later, this radical and much contested prediction was verified by in situ measurements in space.

A persistent problem in cosmogony has been that the major planets in their orbits carry 98 % of the angular momentum in the Solar System and the massive Sun only 2 %. In 1942, Alfvén showed that a new process of electromagnetic braking during the formation of the planetary system would very efficiently transfer angular momentum from the rotating Sun to the orbits of the nascent outer planets.

To emphasize the significance of electromagnetic forces, Alfvén coined the term Plasma Universe to represent a "new paradigm" in cosmical physics. The astronomical community gradually came, by about 1965, to accept that Alfvén had been essentially right about the importance of magnetic fields in astrophysical contexts. Curiously, he then turned around and advocated large-scale electric fields to account for properties of galaxies and diffuse matter in the Universe. This has not been generally accepted.

In addition to receiving the Nobel Prize, Alfvén received numerous awards, including the Gold Medal of the Royal Astronomical Society, the Lomonosov Medal of the USSR Academy of Sciences, the Gold Medal of the Franklin Institute, the Bowie Gold Medal of the American Geophysical Union, and the Dirac Medal of the Australian Institute of Physics. He was a member of the Royal Swedish Academy of Sciences, the Royal Swedish Academy of Engineering Sciences, the USSR Akademia Nauk, the Royal Society of London, the National Academy of Sciences, Washington, DC, and the American Academy of Arts and Sciences, Boston, as well as of the Yugoslav and Indian academies. He received honorary doctorates from the universities of Newcastle upon Tyne, Oxford, and Stockholm.

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al-Hā'im

► Ibn al-Hā'im: Abū Muḥammad ˁAbd al-Ḥaqq al-Ghāfiqī al-Ishbīlī

al-Haytham

► Ibn al-Haytham: Abū ˁAlī al-Ḥasan Ibn al-Ḥasan

Alhazen

► Ibn al-Haytham: Abū ˁAlī al-Ḥasan Ibn al-Ḥasan

ˁAlī al-Muwaqqit: Muṣliḥ al-Dīn Muṣṭafā ibn ˁAlī al-Qusṭanṭīnī al-Rūmī al-Ḥanafī al-Muwaqqit

İhsan Fazlıoğlu
Istanbul University, Istanbul, Turkey

Born **probably Istanbul, (Turkey)**
Died **Istanbul, (Turkey), 1571**

Muṣṭafā ibn ˁAlī was one of the most important figures of sixteenth century Ottoman astronomy. He was nicknamed *al-muwaqqit* (the timekeeper) because of his theoretical and practical studies of astronomical timekeeping (*ˁ ilm al-mīqāt)* and work on astronomical instruments, and is considered to be the founder of the Ottoman tradition of *ˁ ilm al-mīqāt* and practical astronomy. To a great extent Muṣṭafā ibn ˁAlī continued the movement of the Turcification of Graeco-Hellenic and classical Islamic astronomy literature that was started by ► **Muḥammad al- Qunawī**. He also wrote books in the field of mathematical geography.

Born in Istanbul in the early sixteenth century, Muṣṭafā ibn ˁAlī was educated in the wake of the reigns of Sultan Mehmet the Conqueror and Sultan Bāyazīd II (reigned: 1481–1512), during which time the sciences were nurtured. He took courses from the leading scholars of the time, including ► **Mīram Čelebī** who continued the tradition of astronomy established by his great grandfather ˁ ► **Alī Qūshjī**, his friends, and students. In addition, Muṣṭafā ibn ˁAlī inherited the previous achievements of *ˁ ilm al-mīqāt* (timekeeping) from Muḥammad al-Qunawī, who had relied upon the work of ► **Khalīlī**, and ► **Ibn al-Shāṭir** before him. As the *muwaqqit* (timekeeper) of the Sultan Selīm I Mosque in Istanbul, Muṣṭafā ibn ˁAlī came to be known as the *Koca Saatçi* (grand timekeeper). His precise calculations for determining time were accepted as a primary source not only within the Ottoman State but also, according to Ewliyā čelebi, in Western Europe. After 1560, he was appointed *Müneccimbası* (head astronomer), replacing Yusūf ibn ˁUmar, and thus became well known as "Müneccimbası Muṣṭafā čelebi." Upon his death in 1571, Muṣṭafā ibn ˁAlī was replaced by ► **Taqī al-Dīn**.

It is evident from the prefaces of his books that Muṣṭafā ibn ˁAlī began writing at a rather early age during his tenure as timekeeper of the Yavuz Sultan Selīm Mosque. One of his early works was *I ˁ lām al- ˁ ibād fī a ˁ lām al-bilād* (in Turkish) on mathematical geography. Written in 1525, it was presented to Sultan Süleymān I and included astronomical and geographical information such as the distances to Istanbul (as the crow flies) of 100 major cities stretching from China to Morocco, their longitudes and latitudes, their *qibla*s (directions toward Mecca), and their shortest and longest days. It is clear from the introduction that the author regarded Istanbul as the center of the world, and that he chose cities that were along the lines of the Ottoman army conquest from Istanbul. Given that the book was presented to Sultan Süleymān, it could well be that it was produced for practical needs of the state. There are over 30 copies of the work in the Istanbul manuscript libraries, so it must have been widely read. (Süleymaniye Library, Hacı Mahmud MS 5633 is the author's copy.)

Muṣṭafā ibn ˁAlī's second work on geography, entitled *Tuḥfat al-zamān wa-kharīdat al-awān* (in Turkish), deals with cosmography, astronomy, and geography; a distinguishing feature of the work is its extensive application of mathematics to geography. Also written in 1525, it is clearly meant to complement his *I ˁ lām al- ˁ ibād fī a ˁ lām al-bilād*. The Introduction provides general information about the science of geography and its sources. Chapter One offers detailed information about planetary orbs (*falak* s), planets, and stars; Chapter Two deals with the Earth, seas, islands, rivers, and mountains; Chapter Three takes up the seven climes as well as distances, longitudes, and latitudes of 150 cities within these seven climes; and Chapter Four discusses *zawāl* time. Muṣṭafā ibn ˁAlī relied on earlier Islamic works, namely ► **Jaghmīnī's** *al-Mulakhkhaṣ fīˁ ilm al-hay'a al-basīṭa* (An introduction to astronomy), ► **Qāḍīzāde al-Rūmī's** commentary on Jaghmīnī's work, Damīrī's (died: 1405) para-zoological encyclopedia *Ḥayāt al-ḥayawān*, and Qazwīnī's (died: 1283) cosmological work *ˁ Ajā'ib al-makhlūqāt*.

The fact that Muṣṭafā ibn ˁAlī dedicated most of his important books to Sultan Süleymān and his grand viziers, and that he wrote almost all his works on astronomy and geography in Turkish rather than Arabic, indicate that he took the needs of the Ottoman state bureaucracy and society into account. A vast amount of the Graeco-Hellenic and Islamic astronomical corpus was transferred into Turkish. Indeed, Muṣṭafā ibn ˁAlī made a conscious effort to transform Turkish into a language of science. Out of his 24 astronomical works, 21 are in Turkish and the other three in Arabic. (See *OALT*, Vol. 1, pp. 177–179.) By writing in Turkish he was able to reach a greater audience (*i. e.*, beginning students of astronomy and timekeepers) as indicated by the number of extant manuscripts and late copies. Using Turkish was also an advantage when referring to Ottoman geographical locations, especially in Istanbul, the Balkans, and Anatolia.

Many of Muṣṭafā ibn ˁAlī's books deal with astronomical instruments. His *Faraḥ Fazā*, dedicated to Sultan Süleymān's Grand Vizier Ibrāhīm Pasha, examines the construction and use of the horary quadrant (*al-rub ˁ al-āfāqī*) that he claims as his invention (Veliyüddîn Efendi MS 2282/3). Muṣṭafā ibn ˁAlī's *Kifāyat al-qanū ˁ fī al- ˁ amal bi-'l-rub ˁ al-maqṭū ˁ* (On the quadrant, in Arabic) clarifies and makes accessible the *Iẓhār al-sirr al-mawḍū ˁ* by the famous astronomer-*muwaqqit* ► **Sibṭ al-Maridīnī** (died: 1506) who incorporated the traditions of Khalīlī and Ibn al-Shāṭir.

In 1529, Muṣṭafā ibn ˁAlī wrote *Kifāyat al-waqt li-ma ˁ rifat al-dā'ir wa- faḍlihi wa-'l-samt* (in Turkish). Some 120 copies of the work, also known as *Risāla fī al-muqanṭarāt*, are extant; it deals with various aspects of geometry, trigonometry, and astronomy and also mentions an astronomical instrument called rub ˁ *al-muqanṭarāt* (astrolabic quadrant). Muṣṭafā ibn ˁAlī's *Tas'hīl al-mīqāt*, written in 1529, discusses mathematical and astronomical features of timekeeping and specifically the usage of the astronomical instrument *al-rub ˁal-mujayyab* (sine quadrant). The book has five separate versions indicating that this work was updated. If we consider all five redactions as one work, there are presently about 100 copies that were widely used.

Another work written in 1529 is Muṣṭafā ibn ˁAlī's *Risālah-i jayb-i āfāqī* (in Turkish) in which he mentions the construction, usage, and mathematical properties of an astronomical instrument called *al-mujayyab al-āfāqi*. There are currently 50 known copies. His *Ḥall dā'irat muˁ addil al-nahār* (in Turkish), written in 1531 at the request of Grand Vizier Ayās Pasha, shows how to use this instrument according to the latitude of Istanbul (Nuruosmaniye MS 4891/4, author's copy). The *Risālat al-asṭurlāb al-Selīmī* (in Turkish), his most voluminous work, was written in 1544 and was based on the Zīj (astronomical handbook) of ► **Ulugh Beg**. In it, Muṣṭafā ibn ˁAlī examines the construction, mathematical properties, and usage of the astrolabe. His other works deal with various other instruments and aspects of timekeeping.

In his astronomical corpus, Muṣṭafā ibn ˁAlī al-Muwaqqit utilized a high level of geometry, trigonometry (especially spherical trigonometry), and numerical analysis; however, he writes in a simple language and presents easy and practical solutions. These features were instrumental in his textbooks and handbooks being used over many years in *Muwaqqithânes* (timekeeping institutions attached to mosques) and *madrasas* (schools) throughout a wide geographical area.

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Alighieri, Dante

► Dante Alighieri

ˁAlī ibn ˁĪsā al-Asṭurlābī

Marvin Bolt
Adler Planetarium, Chicago, IL, USA

Flourished **Damascus, (Syria), 832**

ˁAlī ibn ˁĪsā al-Asṭurlābī, author of an early Arabic treatise on the astrolabe and an opponent of astrology, enjoyed renown as an astronomical instrument maker and contributed to observations initiated by the ˁAbbāsid caliph ► **Ma'mūn**. He took part with Khālid ibn ˁAbd al-Malik al-Marwarrūdhī and others in an expedition to the Plain of Sinjār to measure 1° of latitude and, thus, the size of the Earth. ˁAlī ibn ˁĪsā made astronomical observations at Baghdad in 829/830 and at Damascus in 832–833. He divided the mural quadrant used for the Damascus observations to confirm results of the earlier missions.

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King, D. A. (2000). "Too Many Cooks . . . A New Account of the Earliest Geodetic Measurements." *Suhayl* 1: 207–241. (Provides translated texts related to ˁAlī ibn ˁĪsā's involvement with measuring the Earth.)

ˁAlī ibn Khalaf: Abū al-Ḥasan ibn Aḥmar al-Ṣaydalānī

Roser Puig
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Alternate Name

► ˁAlī ibn Khalaf ibn Aḥmar Akhīr [Akhiyar or Akhyar]

Flourished **Toledo (Spain), eleventh century**

ˁAlī ibn Khalaf is known for his work on astronomical instruments. No details of his biography are known. In Arabic sources, he is only mentioned by ► **Ṣāˁ id al-Andalusī** in his *Ṭabaqāt* as an outstanding geometer, who belonged, along with ► **Zarqālī**, to a group of young Toledan scholars interested in philosophy.

There are several variants of his name. A footnote in BūˁAlwān's edition of the *Ṭabaqāt* gives ˁAlī ibn Khalaf ibn Aḥmar Akhīr (Akhiyar or Akhyar) al-Ṣaydalānī, the apothecary. A very similar reading quoted by an anonymous Egyptian fourteenth-century source (preserved in Leiden, Universiteitsbibliotheek, MS 468) is Abū al-ḤasanˁAlī ibn Khalaf ibn Akhir (Akhiyar or Akhyar) bearing the title al-Shajjārī, the botanist. This has led D. A. King to identify him with Abū al-Shajjār, who is mentioned in Zarqālī's treatise on the *ṣafīḥa zarqāliyya* (MS Escorial 962). King also identifies him with ˁAlī al-Shajjār, who appears in a list of astronomers in the zīj of ► **Ibn Isḥāq** (thirteenth century; Hyderabad, Andhra Pradesh, MS 298). According to this source, ˁAlī ibn Khalaf determined a value of 77° 13′ 30″ for the solar apogee, and he made an observation of the obliquity of the ecliptic of 23° 32′ 12″. This observation was made in Toledo in 1084/1085 with the assistance of the well-known physician, pharmacologist, and botanist Ibn Wāfid. Bearing in mind Ibn Wāfid's date of death, generally accepted as 1075, this may not be a completely reliable source.

ˁAlī ibn Khalaf is the author of a treatise on the use of the *lámina universal* or *orizon universal*, which means universal plate, preserved only in a Spanish translation included in the *Libros del Saber de Astronomía* (III, 11–132), compiled by the Spanish King ► **Alfonso X**. To our knowledge, the Arabic original is lost. ˁAlī ibn Khalaf is also credited (in the aforementioned Leiden MS 468) with the construction of a universal instrument called *al-asṭurlāb al-ma'mūnī* in the year 1071, dedicated to al-Ma'mūn, ruler of Toledo.

The universal plate and the *ṣafīḥa* (the plate) of al-Zarqalī are the earliest universal instruments (i.e., serving all terrestrial latitudes) developed in Al-Andalus. They are based on the stereographic meridian projection of the celestial sphere. In fact, it is a dual projection of each celestial hemisphere which superimposes the projection from the vernal point on to the projection from the autumnal point. A further step is needed: to turn one projection over the other in order to have the names of the zodiacal signs along the same diameter. The specific characteristics of both instruments make them, however, quite different.

In ˁAlī ibn Khalaf's universal plate, the markings engraved on the mater – inside a surrounding empty band named *cabeçon* – correspond to longitudes and latitudes of ecliptic coordinates. The horizontal diameter represents the ecliptic, and the names of the zodiacal signs are engraved on the plate. These markings also can be used in a way corresponding to the almucantars and azimuthal circles of horizontal coordinates. The plate is equipped with a rete. One half of it shows a hollowed-out half-set of markings corresponding to the meridians and parallels of declination of equatorial coordinates; the other half shows a selection of star pointers from the Northern Hemisphere and the Southern Hemisphere. The rete is provided with two indexes. It might have included an alidade. Although there is no evidence of examples of that instrument, its influence on the development of subsequent instruments has been suggested by E. Calvo.

In the introduction to his treatise, ˁAlī ibn Khalaf states his intention of writing a theoretical treatise on the several possibilities of projecting the sphere. However, there is no evidence of the existence of such a work.

F. Charette has established that the universal plate was known in the East in the fourteenth century by Najm al-Dīn al-Misrī who describes it as a Byzantine (rûmī) astrolabe in his great account of astronomical instruments.

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ˁAlī ibn Khalaf ibn Aḥmar Akhīr [Akhiyar or Akhyar]

► ˁAlī ibn Khalaf: Abū al-Ḥasan ibn Aḥmar al-Ṣaydalānī

al-Kammād

► Ibn al-Kammād: Abū Jaˁfar Aḥmad Ibn Yūsuf Ibn al-Kammād

al-Khatīb al-Umawī al-Qurṭubī

► Umawī: Abū ˁAlī al-Ḥasan ibn ˁAlī ibn Khalaf al-Umawī

Allen, Clabon Walter

Roy H. Garstang
University of Colorado, Boulder, CO, USA

Born **Perth**, **Western Australia**, **Australia**, **28 December 1904**
Died **Canberra**, **Australia**, **10 December 1987**

Clabon Allen (normally C. W. Allen) is known to every practicing astronomer as the editor of the first three editions of *Allen's Astrophysical Quantities*. Indeed, so closely was his name tied to the concept that the fourth edition, prepared long after his death, is called *Allen's Astrophysical Quantities*, fourth edition, A. N. Cox, editor.

Allen was educated at the University of Western Australia, received a B.Sc. in 1925, and in 1926 was appointed as a Research Fellow at the newly founded Commonwealth Solar Observatory in Canberra (later the Mount Stromlo Observatory). Later, when he was awarded a Hackett Research Studentship for 2 years, the authorities would not grant him a 2-year leave. An act of the Australian Parliament was required to grant him leave, probably the only occasion when an astronomer's career required an act of Parliament to proceed.

Allen spent 1935/1936 in Cambridge University and 1936/1937 at Mount Wilson Observatory. His early work dealt with the spectrum of copper. He showed that some lines in the spectrum were anomalously broad. Their breadths did not depend on pressure; they were due to autoionization. This was the beginning of a lifelong interest in laboratory astrophysics. Allen wrote a thesis on the broadening of spectral lines for his M.Sc. in 1929.

After the solar telescope was completed in 1931, Allen started to work on the solar spectrum, measuring the strengths of a large number of spectral lines and constructing curves of growth. For this work, his university conferred on him the D.Sc. in 1935.

Roy H. Garstang died in 2009.

At Mount Wilson Observatory, Allen worked on the atmospheric oxygen bands and on the central intensities of Fraunhofer lines. He went on five eclipse expeditions, only one of which (observing from South Africa in 1940) was completely successful. Results from that eclipse led him to the correct explanation of the presence of Fraunhofer lines in the coronal spectrum as due to scattering by interplanetary particles. In addition to war-related work at the Mount Wilson Observatory, Allen published important work on the relation between magnetic storms and solar activity.

In 1951, Allen moved to the University of London and became the first holder of the newly endowed Perren Professorship of Astronomy at University College and the director of the University of London Observatory. He reorganized the Astronomy Department in the college.

While in Canberra, Allen had started to collect numerical data from all branches of astronomy. In London, he continued this work, and soon put his compilation into a book, *Astrophysical Quantities*, the first edition appearing in 1955 and the later editions in 1963 and 1973. He also started a program of work on laboratory astrophysics, chiefly the measurement of oscillator strengths. Allen retired in 1972 and returned to Australia.

The best known of Allen's Australian students was Colin S. Gum, who mapped the eponymous Gum Nebula (perhaps a very nearby supernova remnant). Of his London students, best known are infrared astronomer Vincent C. Reddish, (former Astronomer Royal for Scotland), Bruce Woodgate of the National Aeronautics and Space Administration's Goddard Space Flight Center, and solar astronomer Carole Jordan of Oxford University, who was the first woman to be elected president of the Royal Astronomical Society.

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Aller, Lawrence Hugh

Siek Hyung
Bohyunsan Optical Astronomy Observatory, Yeongcheon, Gyeongsangbuk-do, Korea

Born **Tacoma, Washington, USA, 24 September 1913**
Died **Malibu, California, USA, 16 March 2003**

American astronomer Lawrence Aller is known primarily for quantitative analysis of the spectra of stars and nebulae, leading to measurements of their chemical composition. He was among the first to recognize that the stars of ► **Walter Baade's** Population II contain a much smaller share of heavy elements (beyond hydrogen and helium) than does the Sun and that different nova explosions eject different mixes of elements.

As the son of Leslie and Lella Belle (*née* Allen) Aller, Lawrence experienced a troubled childhood. His father moved the family from their hometown to San Francisco, California, where they stayed from 1922 to 1925. After a brief stay in Alaska in 1925, the family returned to Tacoma, where they lived until 1928, moving then to Seattle until 1931. Forced to work with his father and brother to support the family, Aller never graduated from high school. Somehow Aller found access to some Astronomical Society of the Pacific *Leaflets* that captured his imagination. Studying from a copy of the then comparatively new text *Astronomy* by ► **Henry Norris Russell**, ► **Raymond Dugan**, and ► **John Stewart**, Aller gained enough understanding of modern astrophysics to focus his career interests in that field. In a conversation with ► **Donald Menzel**, then at the Lick Observatory, Aller convinced Menzel that he had a thorough enough grounding and ample motivation to pursue astronomy at college level in spite of his lack of a high-school diploma.

After doing well in a few college astronomy course examinations, and with the recommendation of Menzel, Aller entered the University of

California [UC] at Berkeley as a special student in 1932. He became a regular student there in the summer of 1932, and received a B.A. in 1936 with high honors. After completing many graduate courses, some of which provided the essential knowledge for his career (e.g., astrophysics and quantum mechanics), he received his Master's degree in astronomy in 1937, and then went to Harvard University to pursue further graduate studies.

Aller was awarded the M.S. in 1938, and the Ph.D. in 1943, both from Harvard University. His doctoral thesis research, guided largely by Menzel, was based on the spectroscopy of planetary nebulae, using data taken at the Lick Observatory in 1938 and 1939. In 1939, Aller was elected as a Harvard Society Fellow, a position he held for 3 years.

In 1942, Aller became a physics instructor at Harvard University, for a year. He then worked at the UC Berkeley Radiation Laboratory from 1943 to 1945. He was an assistant professor of astronomy at Indiana University from 1945 to 1948. In 1948, Aller went to the University of Michigan as an associate professor of astronomy, and in 1954 he became a professor and stayed there until 1962. He moved to the University of California at Los Angeles [UCLA] in 1962, and was a professor there until his retirement as professor emeritus in 1985.

While in Cambridge, Aller married Rosalind Duncan Hall. The eldest of their three children, Hugh D. Aller, is a radio astronomer with an astronomer wife. The other son is a pathologist, and the daughter a civil engineer.

Aller's astronomical research career spanned over 60 years. During this time, he mentored many generations of students, now scattered around the world; he succeeded in inspiring them and helping them grow into successful astronomers and scientists in their own right.

Aller led a very interesting life, rich with experiences both in and out of the scientific arena. In particular, he recalled two memorable, if somewhat unfortunate, periods of his life. The first was when he was a young boy: He was forced by his father and elder brother to help with grueling, fruitless efforts in their search for gold. The second was the harsh criticism that he had endured while working at the Berkeley Radiation Laboratory. He felt ignored by his superiors there; in such a discouraging environment, it was no surprise that he once remarked: "The greatest threat is not a nuclear attack, but the mere existence of weapons themselves."

Aller's principal contribution to astronomy is in the area of chemical abundance studies of stars and gaseous nebulae. Elemental abundances give us important clues about the nuclear processes occurring at the final stages in the lives of stars like the Sun, the composition of the interstellar medium at the time when the progenitor star was formed, and the condensation of refractory elements onto solid dust grains in space. His efforts were directed mainly toward elemental abundances in the Sun and in gaseous nebulae. In particular, he concentrated on the so-called planetary nebulae; these are the ejecta from dying stars, which result when stellar cores contract to become white dwarfs, and their outer envelopes are blown off into the interstellar medium.

Aller, along with Menzel and ► **James Baker**, was the first to realize the possibility of obtaining nebular chemical compositions. Their pioneering work required the calculation of collision strengths and "A-values." Their work was published in a very long series of classic papers from 1937 to 1945, titled *Physical Processes in Gaseous Nebulae*. With W. Ufford and J. H. Van Vleck, Aller found that the [OII]3729/3726 line ratios in planetary nebulae are governed primarily by the electron density.

While teaching as an assistant professor at Indiana University, around 1946, Aller and David Bohm investigated the problem of the modification of the electron Maxwellian velocity distribution in the nebular plasma, due to the effects of inelastic collisions, recombinations, and bremsstrahlung radiation. They found that the Maxwellian distribution prevails even in the presence of these physical processes. Their new, quantitative analysis of this important astrophysical question yielded a physical solution that would prove essential for all later studies of gaseous nebulae.

Prior to this groundbreaking work, it was widely assumed that stellar spectra, in terms of the elemental abundances in stellar atmospheres, could be interpreted by the simple application of the well-known ▶ **Meghnad Saha** solution first derived in the 1920s. It was also commonly assumed, without any real justification, that chemical abundances in the observed object would be the same as those in the Sun. Aller was one of first pioneers to reject these unfounded assumptions, and in so doing he was the first to discover that there are indeed abundance differences among celestial objects. The currently used abundance determination methods remain essentially unchanged from those first proposed by him.

Aller's other notable works include the study of Wolf-Rayet stars, starting in the 1940s. He secured spectra using the Crossley telescope, and found excitation temperatures and ionic concentrations for both the N (nitrogen) and C (carbon) Wolf-Rayet sequences. He proposed the interpretation that the Wolf-Rayets are the remnants of massive, luminous stars.

During his sojourn in the University of Michigan, Aller undertook a quantitative analysis of high-dispersion spectra of the solar atmosphere. After taking up his UCLA professorship in 1962, he continued to work on problem, i.e., high-dispersion solar spectroscopy and solar abundance determinations, as well as Coude spectroscopy of B and A_p stars. He also obtained planetary nebula spectra with the prime-focus spectrograph and the Lallemand electronic camera on the Lick Observatory 3-m reflector.

In the spring of 1996, Aller had a paralyzing stroke, and had to be confined to a wheelchair. With what little remaining use he could make of his left hand, he was barely able to type. However, despite his handicap, he never stopped pursuing his research, and continued to investigate planetary nebulae with the help of his several coworkers. The honors he received included the 1992 Russell Lectureship of the American Astronomical Society.

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al-Majdī

▶ Ibn al-Majdī: Shihāb al-Dīn Abū al-ʿAbbās Aḥmad Ibn Rajab Ibn Ṭaybughā al-Majdī al-Shāfiʿī

Alpetragius

▶ Biṭrūjī: Nūr al-Dīn Abū Isḥāq [Abū Jaʿfar] Ibrāhīm ibn Yūsuf al-Biṭrūjī

al-Raqqām

▶ Ibn al-Raqqām: Abū ʿAbd Allāh Muḥammad ibn Ibrāhīm ibn ʿAlī ibn Aḥmad ibn Yūsuf al-Mursī al-Andalusī al-Tūnisī al-Awsī ibn al-Raqqām

al-Ṣaffār

► Ibn al-Ṣaffār: Abū al-Qāsim Aḥmad ibn ˁAbd Allāh ibn ˁUmar al-Ghāfiqī ibn al-Ṣaffār al-Andalusī

al-Samḥ

► Ibn al-Samḥ: Abū al-Qāsim Aṣbagh Ibn Muḥammad Ibn al-Samḥ al-Gharnāṭī

al-Shāṭir

► Ibn al-Shāṭir: ˁAlā' al-Dīn ˁAlī ibn Ibrāhīm

Althans, Karl Ludwig

Thomas Hockey
Department of Earth Science, University of Northern Iowa, Cedar Falls, IA, USA

Born **Bückeburg, (Niedersachsen, Germany), 5 December 1788**
Died **Bettendorf, (Rheinland-Pfalz, Germany), 10 October 1864**

Privy Counselor Karl Althans made his mark as a mining expert and engineer, eventually heading one of the most famous foundries in Germany. Althans noticed that the lunar craters much resembled the scars left in armor plating when struck by a bullet.

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Alvarez, Luis Walter

Fathi Habashi
Department of Mining, Metallurgical, and Materials Engineering, Laval University, QC, Canada

Born **San Francisco, California, USA, 13 June 1911**
Died **Berkeley, California, USA, 1 September 1988**

American particle experimentalist Luis Alvarez is best known in the field of astronomy for work with his son, geophysicist Walter Alvarez that led to the idea that the wave of extinctions at the end of the Cretaceous Period, including the demise of the dinosaurs, was the result of an asteroid or comet impact. This was signified by an iridium-rich layer found at the Cretaceous-Tertiary boundary in a well-known deposit sequence at Gubbio, Italy.

Luis Alvarez was the son of physician Walter Alvarez, who continued to write down-to-earth columns of medical advice for the *Los Angeles Times* well into his 1990s. The name had come directly from Spain a generation earlier.

Luis received his B.S. (1932) and Ph.D. (1936) from the University of Chicago, the latter for work in optics, and retained a lifelong research interest in ophthalmic optics. However, he simultaneously pursued, under the guidance of ► **Arthur Compton**, a project in which he adapted a Geiger counter for the study of secondary particles produced in the Earth's upper atmosphere by galactic cosmic ray impacts. He used the device to demonstrate, from a mountain top in Mexico, that the initial incoming particles must be primarily protons.

Alvarez joined the Radiation Laboratory of the University of California, Berkeley, as a research fellow in 1936, but was on leave at the Radiation Laboratory of the Massachusetts Institute of Technology [MIT] from 1940 to 1943, at the Metallurgical Laboratory of the University of Chicago in 1943/1944, and at the

Los Alamos Laboratory of the Manhattan Project from 1944 to 1945. In 1937 Alvarez gave the first experimental demonstration of the existence of the phenomenon of *K*-electron capture by nuclei and a method for producing beams of very slow neutrons. This method subsequently led to a fundamental investigation of neutron scattering in *ortho*- and *para*-hydrogen (with Kenneth Pitzer) and to the first measurement of the magnetic moment of the neutron (with Felix Bloch). Along with Jake Wiens, Alvarez was responsible for the production of the first ^{198}Hg lamp; this device was developed by the United States National Bureau of Standards into its present form as the universal standard of length. Just before World War II, Alvarez and Robert Cornog discovered the radioactivity of ^{3}H (tritium) and showed that ^{3}He was a stable constituent of ordinary helium. Tritium is best known as a source of thermonuclear energy, and ^{3}He has become important in low-temperature research.

Alvarez also maintained a lifelong research interest in air navigation and was a skilled amateur pilot who could sometimes be persuaded to give a lecture at an out-of-the-way place if he had never flown into its airport before. He received the Collier Trophy (the US government's highest aviation award) for his contributions to radar and navigation.

During the war, while at MIT, Alvarez was responsible for developing important radar systems: the microwave early warning system, the Eagle high-altitude bombing system, and a blind landing system of civilian as well as military value. While at Los Alamos he developed the detonators for setting off the plutonium bomb. He also was responsible for the design and construction of the Berkeley 40-ft. proton linear accelerator, which was completed in 1947. In 1951 Alvarez published the first suggestion for charge exchange acceleration that quickly led to the development of the "Tandem Van de Graaf accelerator."

From that time on, Alvarez was engaged in high-energy physics, using the 6-billion electron volt Bevatron at the University of California Radiation Laboratory. His main efforts there were concentrated on the development and use of large liquid hydrogen bubble chambers, and on the development of high-speed devices to measure and analyze the millions of photographs produced each year by the bubble-chamber complex. The result of this work has been the discovery of a large number of previously unknown fundamental particle resonances by Alvarez' research group. It was for the bubble-chamber improvements and discovery of many resonances (which, in turn, led theorists to a coherent picture of proton and neutron structure that fit into the scheme of particles in general) that he received the 1968 Nobel Prize in Physics.

In 1955, Alvarez organized an expedition to use cosmic ray secondaries (muons) to look for previously unknown chambers in the pyramid of Khufu (Cheops). The point is that the muons reach the ground with enough energy to penetrate a fair amount of rock. Therefore, they put detectors in the known chambers and recorded the rate of muon arrival as a function of direction, looking for angles where more muons might get through than expected, implying additional chambers in the pyramid. None were found.

Alvarez shared his last major scientific achievement with his son Walter, who was then a professor of geology at Berkeley. They accidentally discovered a band of sedimentary rock in Italy that contained an unusually high level of the rare metal iridium. Dating techniques set the age of the layer at about 65 million years. The two hypothesized that the iridium came from an asteroid that struck the Earth, thereby sending huge volumes of smoke and dust (including the iridium) into the Earth's atmosphere. They suggested that the cloud covered the planet for an extended period of time, blocked out sunlight, and caused the widespread death of plant life on Earth's surface. The loss of plant life brought about the extinction of dinosaurs that fed on the plants. An impact origin for the major extinction episode at the end of the Cretaceous is generally accepted, though its interaction with other mechanisms remains under debate, as does the implication for possible similar effects ("nuclear winter") of extended nuclear warfare.

Alvarez served on the President's Science Advisory Committee (1971/1972) and as the president of the American Physical Society (1969). He received the National Medal of Science, the Einstein Medal, and about half a dozen honorary D.Scs.

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Amājūr Family

İhsan Fazlıoğlu
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Flourished **late 9th/early 10th century**

The Amājūr Family includes Abū al-Qāsim ʿAbd Allāh ibn Amājūr al-Turkī al-Harawī, his son Abū al-Ḥasan ʿAlī, a certain ʿAlī ʿAbd Allāh ibn Amājūr, and Abū al- Ḥasan's freed slave Mufliḥ ibn Yūsuf. They are known for their extensive observational astronomical work, and for compiling the results of these observations into several *zīj*es (astronomical handbooks). It is said that they were assisted in their observations by a large group of people.

There is little information about the Amājūr Family's lives in either historical or modern sources. There is also some ambiguity about their names and identities. ► **Ibn Yūnus** refers to the father as al-Turkī and mentions another person as having assisted him in doing the astronomical observations along with his son and his slave. Ibn al-Qifṭī, though, refers to Abū al-Qāsim as al-Ḥarawī from the city of Herat; he informs us that the son Abū al-Ḥasan ʿAlī was raised by his father, who had educated him in the sciences. Ibn al-Qifṭī considers ʿAlī ibn Amājūr as a separate person, and not necessarily related to Abū al-Qāsim. Both Ibn al-Nadīm and Ibn al-Qifṭī believe that the family hailed from Farghāna.

The Amājūr Family carried out their astronomical observations between 885 and 933; most of their work took place in Baghdad and, to a lesser extent, in Shīrāz. Their long-term astronomical observations, which lasted 30–50 years, involved work on the fixed stars, the Sun, the Moon, and the planets. There has been speculation that there was an observatory of some sort in connection with the Amājūr Family based on their needs for precise observations and for recording their results. There is also a report that a large group aided the Amājūr Family with their observations. Ibn Yūnus, who records observations of solar and lunar eclipses and planetary positions by the Amājūr Family, indicates that they carried out their observations at a raised, flat place with a view, called a "ṭārum" or "ṭāruma." On the basis of his research, Caussin concludes that there was an observatory.

There is little information regarding the instruments that were used by the Amājūr Family. However, ʿAbd Allāh ibn Amājūr mentions one he used to observe a solar eclipse on 18 August 928 with Abū al-Ḥasan and Mufliḥ. From the information provided on this observation, Caussin determined that the instrument had to be quite large given the preciseness of the measurements.

ʿAbd Allāh ibn Amājūr was apparently well known in his time, and he wrote a number of books, most of them *zīj*es. According to D. King, ʿAlī ibn Amājūr worked on improving ► **Khwārizmī**'s (ninth century) prayer tables, providing the approximate times for different latitudes. ʿAlī ibn Amājūr also prepared a prayer table for Baghdad, based upon precise trigonometrical calculations.

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Ambartsumian, Victor Amazaspovitch

Adriaan Blaauw
Groningen, The Netherlands

Born **Tbilisi, (Georgia), 18 September 1908**
Died **Byurakan, Armenia, 12 August 1996**

Victor Ambartsumian formulated ideas pertinent to the structure and evolution of stars, of galaxies – especially active ones – and of the entire Universe. Some of these ideas, for instance, the unboundedness of many star clusters and the need for star formation to be an ongoing process, have stood the test of time. Others have not.

Victor was the son of Amazasp Asaturovich Ambartsumian, a historian (and, later in life, professor at Yerevan University), and Ripsame Ambartsumian. He married Vera, the adopted daughter of ▶ **Grigory Shain**, the then director of the Crimean Observatory. Victor and Vera had two daughters and two sons.

Ambartsumian's elementary and secondary schooling took place in Tbilisi, Georgia. He graduated from the University of Leningrad, Russia, in 1928. Ambartsumian was a staff member of the Pulkovo Observatory (near Leningrad, now Saint Petersburg, Russia) from 1928 to 1931. In 1931, he became a lecturer, and, in 1934, a professor, at the Leningrad University. In 1943, Ambartsumian founded, and, from 1944 to1988, was director of the Byurakan Observatory, Armenia. In 1947, he was appointed professor of astrophysics at the University of Yerevan, Armenia.

Ambartsumian was the president of the Armenian Academy of Sciences from 1947 to 1993. In 1953, he became a member, and, in 1961, a member of the presidium, of the Academy of Sciences of the Soviet Union. Ambartsumian held numerous foreign memberships of academies, among which were the Royal Society, the United States National Academy of Sciences, the Indian Academy of Sciences, and the Royal Netherlands Academy of Sciences. He was a recipient of the Gold Medal of the Royal Astronomical Society in 1960 and the Bruce Medal of the Astronomical Society of the Pacific, also in 1960. In 1971, Ambartsumian received the Helmholtz Medal of the East German Academy of Sciences.

In 1965, Ambartsumian founded the journal *Astrofizika*, in Russian, with its English translation *Astrophysics*.

In a 1929 paper, Ambartsumian studied the problem: To what degree do the eigenfunctions of an ordinary differential operator determine the functions and parameters entering into that operator? Fifteen years later (1944), this paper attracted the attention of mathematicians in the context of the theory of inverse problems.

Ambartsumian's earliest astrophysical work was in solar physics, in collaboration with ▶ **Nikolai Kozyrev**, and in the physics of emission nebulae and radiation transfer, starting from ▶ **Herman Zanstra**'s papers in this field. Ambartsumian applied this work to the planetary

Adriaan Blaauw: deceased.

nebulae and to the so-called Wolf-Rayet stars, both being cases of interaction between a star and its gaseous envelope. This effort led to Ambartsumian's prediction of the existence of a forbidden He line in the spectra of Wolf-Rayet stars, which later was identified. In 1939, he published a comprehensive book on astrophysics, a more extended version of which was published in 1952 in collaboration with E. R. Mustel, A. B. L. Severny, and V. V. Sobolev under the title *Theoretical Astrophysics*.

Studies of the brightness distribution of the Milky Way, in particular the correlation of the brightness in two different directions, led Ambartsumian to estimates of the properties of interstellar clouds. Although it is obvious both from photographs of emission nebulae and dark clouds and from radio-astronomical surveys that description of the structure of the interstellar medium [ISM] in terms of discrete clouds is an oversimplification, this concept has proven to be very helpful in describing the ISM. Ambartsumian's estimates of the dimensions and optical depth of these clouds, and his studies of the relation between the clouds and the exciting, luminous stars, belong to the early pioneering steps in this domain.

By the end of the 1930s, Ambartsumian's interest shifted to problems of stellar evolution and to the still more fundamental question of the formation process of the stars. Early work on stellar dynamics had convinced him that wide double stars, contrary to the prevailing view, could not have existed over a timescale (the "long" timescale proposed by ► **James Jeans**) very much longer than 10 billion years. He now concentrated on the birth and evolution of small, compact clusters (and the rate of evaporation of their member stars) and of the much larger, very loose groups of stars for which he introduced the term "stellar associations." Although the existence of the latter had been long known, Ambartsumian stressed the fact that, due to the gravitational field of the Galaxy, these associations would disperse relatively rapidly among the general galactic stellar population and, hence, could not have existed over a time-span comparable to the age of the Galaxy (in fact, not even longer than tens to hundreds of millions of years). The inference was that the stellar associations must have been born very recently on the galactic timescale and star formation must still be an ongoing process in the Galaxy. This unorthodox view found support from various sides, including studies of the source of stellar (nuclear) energy and the study of the relative motions of the stars in the associations. To a considerable extent, he and his staff devoted the facilities of Byurakan Observatory to research on stellar associations and extragalactic systems.

With regard to the origin of the associations, Ambartsumian also took an unorthodox view. He postulated that stars were formed from superdense bodies, a hitherto unknown state of matter, which was contrary to the general belief that star formation was preceded by gradual contraction in an interstellar gas cloud. He identified the very young, compact groups, for which he introduced the name trapezium systems (in analogy with the well-known compact cluster in Orion), with the earliest emergence from this primordial matter. This view, however, has not found general acceptance; subsequent developments fully confirm the classic view that star formation follows contraction in the interstellar medium. Ambartsumian also postulated an origin from this superdense matter in the case of stellar systems as a whole, referring to the violent processes observed in the central regions of certain galaxies. Here, too, his concept has not found confirmation. However, the extensive surveys of quasars and active galaxies carried out at Byurakan Observatory by his associates, in the context of Ambartsumian's ideas (in particular by ► **Beniamin Markarian**), have contributed greatly to our knowledge of extragalactic systems.

Ambartsumian played a prominent role in the international relations of Soviet science, in particular in the domain of astronomy. When, shortly after the termination of World War II, the International Astronomical Union [IAU] resumed its activities at the Zürich (Switzerland) General Assembly in 1948, Ambartsumian became one of the vice presidents (for the years 1948–1955) of the newly elected Executive Committee. During the years 1961–1964, he was its president. From 1968 to 1972, he was the president of the International Council of Scientific Unions [ICSU].

In 1940, Ambartsumian became a member of the Communist Party of the Soviet Union and, in 1950, Deputy to the Supreme Soviet on behalf of the Republic of Armenia. He received many awards of the Soviet Union, including the Hammer and Sickle Gold Medal, five orders of Lenin, and the Stalin Prize. He was twice Hero of Soviet Labor. He was awarded the medal of a National Hero of Armenia. As is evident from these honors, his political views harmonized to a considerable degree with those of Soviet rulers. Involvement, early in his career, of Ambartsumian and some young collaborators in a conflict with the director of Pulkovo Observatory, ► **Boris Gerasimovich** (which coincided with the years of Stalin's purges), led to their alienation from the observatory and to the imprisonment of Gerasimovich, who was executed in 1937, along with several other members of the Pulkova staff. During Ambartsumian's vice presidency of the IAU, his political position and his diplomacy were severely tried. At the invitation of the Soviet Academy of Sciences – an invitation extended by Ambartsumian himself – the 1951 General Assembly of the IAU was to be held in Leningrad, an invitation prompted by the inauguration of the rebuilt Pulkovo Observatory (which had been destroyed in the siege of Leningrad). However, half a year before the assembly, the IAU Executive Committee felt obliged to cancel the assembly in view of rapidly increasing international tensions, the "Cold War." This decision caused deep disappointment and incomprehension among the astronomical community of the Soviet Union and its political allies, so much that even their withdrawal from the IAU was feared. Only in 1958 did the IAU meet in the Soviet Union, in Moscow. During these years, Ambartsumian, although violently opposing the IAU's policy, remained loyal to the Executive Committee's majority decisions for the sake of safeguarding international collaboration, an attitude that contributed to his election as President of the IAU in 1961.

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Ames, Adelaide

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Born **Rock Island**, **Illinois**, **USA**, **3 June 1900**
Died **Squam Lake**, **New Hampshire**, **USA**, **26 June 1932**

Adelaide Ames is best known for her work on galaxies with Harlow Shapley, which resulted in the Shapley-Ames catalogue of galaxies, published in 1932.

Ames was born in Rock Island, Illinois, on 3 June 1900, the daughter of Colonel Thales Lucius Ames of the United States Army and Margaretta Natline Kelton. She attended Vassar College, graduating in 1922, and earned an M.A. from Radcliffe College in 1924. She had thought of a career in journalism, but Shapley hired her in 1923 as a research assistant at the Harvard College Observatory. They worked together on photometry of the brighter galaxies. In 1931 she published a catalogue of some 2,800 galaxies in Coma Berenices and Virgo. She collaborated with Shapley on *A Survey of the External Galaxies Brighter than the Thirteenth Magnitude*, published in 1932, incorporating all known galaxies down to magnitude 13.2. This catalogue included positions, dimensions, and classifications of 1,246 galaxies over the entire sky. The Shapley-Ames catalogue was a standard reference until it was revised and expanded in 1981 by A.R. Sandage and G.A. Tammann.

Ames was a member of the American Astronomical Society and attended the International Astronomical Union meeting in Leiden in 1928.

Her promising career in astronomy was cut short on 26 June 1932, when she was drowned in a canoeing accident on Squam Lake, New Hampshire. Her body was not recovered for ten days. She is buried at Arlington National Cemetery.

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Amici, Giovanni Battista

Mariafortuna Pietroluongo
Università di Molise, Campobasso, Italy

Born **Modena, (Italy), 25 March 1786**
Died **Florence, Italy, 10 April 1863**

Giovanni Amici was an expert in optics as well as a very talented maker and user of lenses, objectives, prisms, and optical instruments.

After obtaining a degree in engineering, Amici became professor (from 1815) at Modena University. Here he began his studies in astronomy, making observations of the Sun, comets, Jupiter, and Saturn. In 1831 the Grand Duke of Tuscany, Leopoldo II, appointed him as director of Florence's observatory.

Amici's prism is quoted in every book on optics, and ► **Giovan Donati** was able to discover ► **Joseph von Fraunhofer**'s lines in stellar spectra by using a spectroscope suggested by Amici. Amici was also a great botanist.

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ˁĀmilī: Bahā’ al-Dīn Muḥammad ibn Ḥusayn al-ˁĀmilī

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Born **Baˁlabakk near Jabal al-ˁĀmilī, (Lebanon), 18 February 1547**
Died **Isfahan, Iran, 1 September 1621**

Bahā’ al-Dīn Muḥammad ibn Ḥusayn al-ˁĀmilī, better known in Iran as Shaykh-i Bahā’ī, was probably the last scholar in the chain of universal and encyclopedic scholars that Islamic civilization was still producing as late as the sixteenth century. A major figure in the cultural revival of Safavid Iran, he wrote numerous works on astronomy, mathematics, and religious sciences and was one of the very few in the Islamic world to have propounded the possibility of the Earth's movement prior to the spread of Copernican discoveries in astronomy.

Bahā’ī's family came from the village of Jubaˁ near the coastal town of Sidon in southern Lebanon, in the vicinity of Jabal ˁāmil, whence his name. He was still a young boy when his whole family, as part of a wave of Shīˁa scholars, migrated to Iran to escape the persecutions of the Shiite Muslims by the Ottomans.

Bahā’ī's father, a prominent scholar with an impressive reputation, was well received in the court of the Safavid monarch Shah Ṭahmāsb, assuming the office of chief jurisconsult in the Safavid administration. Bahā’ī's father takes the credit for Bahā’ī's early education, by virtue of which he mastered the religious sciences. He further studied logic, philosophy, mathematics, and astronomy under the most prominent scholars of the day, excelling in these sciences as well.

Bahā’ī soon rose to prominence in the Safavid court and was appointed to the office of chief jurisconsult in the court of Shāh ˁAbbās the Great. Nevertheless, court engagements and public duties never seem to have deterred him from his scholarly activities, both as a teacher and as a writer. He trained many students, some of whom became the most prominent scholars of the period.

Bahā’ī may be counted among the most prolific writers of Islamic civilization, having written more than 100 treatises and books. His works cover a wide range of subjects, from religious sciences to mathematics, astronomy, and the occult sciences. In addition to these, he wrote a literary-religio-scientific anthology known as *Kashkūl*, which, apart from its literary and scientific merits, is of utmost importance in understanding the man and his thoughts. Bahā’ī's *Khulāṣat al-ḥisāb* (Essentials of arithmetic), was to become the most popular textbook throughout the Islamic lands from Egypt to India until the nineteenth century. This book was translated into German by G. H. F. Nesselmann and published in Berlin as early as 1843; a French translation appeared in 1854.

Our sources do not provide a definitive list of Bahā’ī's astronomical works. However, he seems to have written as many as 17 tracts and books on astronomy and related subjects, including a number of glosses and commentaries on the works of past masters. He also wrote *Risālah dar ḥall-i ishkāl-i ˁuṭārid wa qamar* (Treatise on the problems of the Moon and Mercury), in an attempt to find solutions to the inconsistencies of the Ptolemaic system within the context of Islamic astronomy. In his summary of theoretical astronomy entitled *Tashrīḥ al-aflāk* (Anatomy of the celestial spheres), he upholds the view of the positional rotation of the Earth, arguing that no sufficient proof has been offered so far to the contrary. In expressing this view, Bahā’ī stands out as one of the very few Muslim scholars to have advocated the feasibility of the Earth's rotation as early as the sixteenth century, this independent of Western influences.

Since no serious study of Bahā’ī's scientific works (especially those related to astronomical fields) has been made so far, one cannot make a critical assessment of his achievements and contributions in this area. Yet his works clearly demonstrate the fact that he was a scholar with a critical and disciplined mind. Furthermore, Bahā’ī's works demonstrate the clarity and discipline of a mathematician's mind that is able to present scientific issues in a simple and easy-to-understand manner.

A number of architectural and engineering works have been attributed to Bahā'ī as well, though none can be substantiated by the sources. He is credited with the distribution of the waters of the Zayandeh-Rud River through a complex network of irrigation canals, based on a distribution map known as Bahā'ī's scroll. Furthermore, according to a popular legend he engineered a heating system for a public bath in Isfahan that drew all the energy needed for heating the water and the bath itself from a single candle!

In addition to his many-faceted scientific capabilities, Bahā'ī was a gifted poet and has bequeathed some very fine pieces of poetry, mostly with mystical themes, which are still cherished by the public. Some of Bahā'ī's works, particularly the *Kashkūl*, demonstrate very strong mystical tendencies of the author. He spent part of his life traveling in Ottoman territories, which brought him into close contact with prominent scholars of his time in Aleppo, Damascus, Jerusalem, Cairo, and elsewhere. Brief reports of some of these meetings and exchanges have been recorded in his *Kashūkl*.

Bahā'ī was also famed for his works of charity, which had turned his home into a shelter and refuge for orphans, widows, and the needy. Bahā'ī has remained a very popular figure in public memory, and many anecdotes about him have passed from generation to generation, some even attributing miraculous acts to him. Bahā'ī died in Isfahan and his body was carried to Mashhad (in northeast Iran) to be laid to rest in the shrine of Shiʿism's eighth *īmām*, ʿAlī ibn Mūsā.

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Ammonius

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Born **probably Alexandria, (Egypt), *circa* 440**
Died **Alexandria, (Egypt), *circa* 521**

Neoplatonist Ammonius was the son of Hermeias (the scholarch of the Alexandrian school) and Aidesia (admired for her prudence and piety, "the most beautiful woman in Alexandria," and a close relative of Surianus, scholarch of the Athenian Academy from 431 to 437). His younger and less studious brother ► **Heliodorus** was also a philosopher, while his paternal uncle Gregorius was an astronomer.

Ammonius was born under the learned emperor and legal codifier Theodosius II, and was an adolescent when Rome fell to the Vandal army. He studied philosophy at the academy in Athens for many years from about 460 under ► **Proclus** of Lydia (scholarch there from 437 to 485), among whose students Ammonius is said to have excelled in mathematics and astronomy. He then succeeded his father as scholarch in Alexandria in 485, a post he held, through a time of religious strife and political regionalism, until his death.

Ammonius's students include many productive philosophers: Asklepius of Tralles, Damaskius, Gesius, ► **Olympiodorus**, ► **Ioannes Philoponus**, ► **Simplicius**, Theodotus, and Bishop Zacharias of Mytilene. His own publications appeared between 485 and 510, though much of what Philoponus published thereafter contains Ammonian material. (His name refers to the god and oracle Ammôn at Siwa in the Egyptian desert; the native form is "Amun," the chief god of Thebes and of Egypt generally.)

Ammonius wrote Neoplatonic philosophy; in his era this meant primarily commentaries on ► **Plato** and ► **Aristotle**, which had the goal of demonstrating the essential unity and harmony of their thought. (Ammonius also wrote on grammar, rhetoric, mathematics, and astronomy.) Most of his work is lost or survives only in extracts.

Among Ammonius's known astronomical contributions is his denial of determinism (i.e., astrology). He argued that gods know all of time, but that such knowledge does not constrain future events: they have knowledge of future contingents, but not as future (an idea derived from Iamblichus' suggestion that the divine knowledge is definite but is about indefinites). Ammonius is attested to have made observations (with his brother and his uncle) of planetary occultations or near conjunctions, as well as of the longitude of Arcturus (with Simplicius), the latter to check ► **Ptolemy**'s value of the precession of the equinoxes (which Ammonius erroneously confirmed). On this basis, he conjectured (or caused Simplicius to conjecture) that outside the geocentric sphere of the fixed stars, there was a further starless sphere, the eternal "prime mover" of the *kosmos*. Finally, and coupled therewith, Ammonius argued on teleological grounds for the eternity of the *kosmos* (as had Aristotle), and interpreted Plato's *Timaeus* as teaching an eternal *kosmos* (a doctrine contradicting the dominant theology of the Christians, despite his attested accommodation with Archbishop Athanasius). Recently, Ammonius's work on the use of the astrolabe has been rediscovered and published (though no English translation exists).

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Ananias of Sirak

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Born **Anania, (Armenia),** ***circa*** **595–600**

Alternate Name

▶ Shivakatsi, Anania

Ananias prepared the perpetual calendar for the Armenian church. He taught the advanced idea that the Moon is not a mirror reflecting the Earth: Its surface markings are real and due to an uneven surface.

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Anaxagoras of Clazomenae

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Born **(Greece), 500 BCE**
Died **(Greece), 428 BCE**

The dates for Greek cosmologist Anaxagoras' birth and death come from Diogenes Laertius, a Greek biographer of the third century, famous for his 10-volume *Lives of Eminent Philosophers*. Anaxagoras was "said to have been 20 years old at the time of Xerxes' crossing (the Persian king led an army into Greece in 480 BCE) and to have lived to 72." Diogenes also cited Apollodorus, an Alexandrian chronographer of the second century who wrote in his *Chronicles* that Anaxagoras "was born in the 17th Olympiad and died in the first year of the 88th." (The first year of the first Olympiad was 776 BCE; each Olympiad lasted 4 years).

A major problem for ancient philosophers was how to explain change – how there could be coming-to-be and passing away. Philosophers argued for varying numbers and types of elements that, combining in different proportions, accounted for all known substances. For ▶ **Thales**, water was the basic matter or principal of things; for ▶ **Anaximenes**, it was air; for ▶ **Heraclitus**, fire; for ▶ **Xenophanes**, everything was composed of water and earth; and for ▶ **Empedocles**, there were four primary elements: earth, water, air, and fire. Anaxagoras seems to have argued that no natural substance was more elemental than any other, that every kind of natural substance existed together in the primordial mixture when everything was together, and that every type of natural substance now existed in every object. His speculations were preserved by the commentator ▶ **Simplicius**, writing in Athens in the sixth century: "All things were together, infinite in respect of both number and smallness . . . all things are in the whole . . . nothing comes into being nor perishes, but is rather compounded or dissolved from things that are." Early Greek philosophers instituted the practice of rational criticism and debate by tackling the same problems, investigating the same natural phenomena, and confronting their opponents' theories. But unlike modern scientific research, their speculations were largely devoid of experimental confirmation.

Anaxagoras is sometimes cited as an early victim of the conflict between science and religion. His new theory of universal order collided with popular faith – the belief that gods ruled the celestial phenomena – and he was expelled from Athens. The indictment against him, however, included the accusation of corresponding with agents of Persia, and impiety might have been an incidental charge. The conflict between science and religion, though accurately characterizing later ages, is not necessarily applicable to the ancient world.

Historians of astronomy also have tended to make their subject a chronology of accumulating

Norriss S. Hetherington: deceased.

positive achievement, emphasizing ancient speculations and observations later validated as scientific by modern standards. The correct explanation of eclipses is often credited to Anaxagoras. The source for the attribution is Hippolytus, a theologian in Rome in the third century, who attempted to refute Christian heresies by showing them to be revivals of pagan philosophy. Seemingly, Anaxagoras believed that "the Sun, the Moon, and all the stars are red-hot stones which the rotation of the aether carries round with it," yet "the Moon has not any light of its own but derives it from the Sun . . . . Eclipses of the Moon are due to its being screened by the Earth, or, sometimes, by the bodies beneath the Moon; those of the Sun to screening by the Moon when it is new."

According to Diogenes Laertius, Anaxagoras predicted the fall of a meteorite: "They say that he foretold the fall of the stone at Aegospotami, saying that it would fall from the Sun." Perhaps this large meteorite, which fell in 467 BCE, led to his belief that the Sun, the Moon, and the stars were red-hot stones.

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Anaximander of Miletus

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Born **Miletus (near Söke, Turkey),**
circa **611 BCE**

Anaximander of Miletus is generally regarded as the second philosopher in the western philosophical tradition after ▶ **Thales**. He was the son of Praxiades. Miletus was a commercial city on the coast of Ionia (part of present-day Turkey).

Details of Anaximander's life are lacking, though it seems certain that he was the first to write a treatise on nature. Only a single fragment of this work remains, in which he announced that the "boundless" or "indefinite" is the first principle or primal "stuff" from which all things originate. Still, his theories are widely attested in the doxography, allowing a general picture of his cosmology.

Departing from the Homeric view that the Earth was a flat plate or disk, Anaximander characterized it as a drum-shaped cylinder suspended in midair. This placement strongly suggested that the heavenly bodies passed through the sky and then under the Earth to reappear again the next day, thereby superseding earlier cosmological tendencies that limited the movement of heavenly bodies only to the sky above. On one surface of the drum was the inhabited world. On the other was another world, though there is some question about whether Anaximander thought it was inhabited as well.

The diameter of the Earth was three times its height. Circling the Earth were rings of fire encased in mist, with apertures through which the fire would shine, thereby explaining the heavenly bodies. The ring of the Sun was 27 times the diameter of the Earth, and that of the Moon was 18. There was a separate ring for each of the stars and planets, inclined at various angles, each located closer to the Earth than the Moon, unlike the views of later Greek cosmologists. Because of a lacuna in the ancient sources, we do not know the precise size of these rings, though Anaximander's mathematical method would seem to suggest that they were nine times the diameter of the Earth. Anaximander accounted for eclipses and the phases of the Moon by hypothesizing that the apertures in the pertinent rings would expand and contract.

According to ancient tradition, Anaximander introduced the gnomon, or sundial, into Greece, and used it to mark the hours and seasons, along with the solstices and equinoxes. Consequently, he is generally credited with discovering the obliquity of the zodiac, most likely accounting for its north/south wobble by an appeal to wind. Anaximander is also reputed to have been the first to draw a map of the inhabited world. Most surprising, perhaps, in Anaximander's cosmology, is the view that there are innumerable worlds or other *kosmoi*, though scholars disagree on whether the theory held that these worlds coexisted in space or whether they existed only in temporal succession.

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Anaximenes of Miletus

James Dye
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Born **Miletus (near Söke, Turkey),** ***circa*** **586 BCE**
Died **Miletus (near Söke, Turkey),** ***circa*** **526 BCE**

Anaximenes was a fellow citizen, friend, and student of ► **Anaximander**, and much of his thought is a revision of Anaximander's. Some aspects of his physical theory, notably his use of empirical models and his attempt to identify a cause of elemental change, constitute scientific advances, but his astronomical views are less original and more traditional than those of his predecessor.

Nothing is known of the details of Anaximenes' life. Even the dates given above are highly conjectural. They derive from Apollodorus, who liked to correlate historical figures' flourishing, invariably at the age of 40, with some notable historical event. In Anaximenes' case, the event was Cyrus' victory over Croesus in 546 BCE.

Anaximander had hypothesized that the infinite space beyond the visible cosmos is filled with undifferentiated, indeterminate stuff (*apeiron*), from which the determinate kinds of matter we perceive are spun off. Anaximenes, seeing no need to postulate an imperceptible form of matter, proposed instead that air is infinite. Although this idea probably arose from the fact that atmospheric air has no readily discernible boundaries, Anaximenes extended the sense of air's infinity. Those parts of space occupied by fire, liquids, or solids are really filled with air, these being air of nonstandard density. Fire is rarefied air; "wind, then cloud, . . . water, then earth, then stones" are progressively denser forms of air. This theory of rarefaction and condensation is the first recorded attempt to explain material differences by a single mechanism. Air is not an inert material but is "divine" or "a god" – an active agency holding the Universe together analogously to the way souls, conceived following the ancient notion of the "breath of life," unify living organisms.

Anaximenes modified Anaximander's astronomical views to fit his physics. Anaximander supposed the Earth to be a columnar body maintaining its central location in the cosmos because it is at the center of mass and so has no tendency to move in any direction, whereas Anaximenes postulated a thinner, table-shaped Earth, supported pneumatically. The air beneath the Earth supports it because of Earth's flat shape. Aristotle thought his point was that the Earth functioned as a lid and commented that size, rather than shape, should have been the relevant condition, since air can only support objects, of whatever shape, which do not permit the air to leak past them. However, if the air is infinite it could not be contained as ▶ Aristotle presumed; so, perhaps Anaximenes' idea was that Earth's flatness enables it to float on the air or even that infinite free fall would be indistinguishable from rest.

For reasons unknown, Anaximenes took Earth to be an early condensate from air, and visible celestial objects to be end products of sublimation or evaporation from the Earth. He believed the incandescent objects consisted of fire, but he also posited invisible earthy companions orbiting along with them. Some have supposed these to be part of a theory of eclipses, but more likely their purpose was to explain meteorites.

The Sun rides on the atmosphere because it is "flat, like a leaf" (Aetius II, 22, 1). Aetius reports that some say the stars too are leaf-like, but in the same passage he writes that Anaximenes said they were like nails embedded in a transparent shell. Some scholars harmonize these conflicting claims by suggesting that Anaximenes may have been the first to distinguish between planets and fixed stars, the former floating "leaf-like" and the latter being stuck in a crystalline, or membrane-like, dome.

For Anaximenes, the sky really was a dome, not a sphere; celestial bodies do not pass under the Earth but revolve around it, as a felt cap might be turned on one's head. The diurnal setting of astronomical objects is not explained by their rotating through antipodean positions, but by a shallower rotation that carries them further from us until they eventually disappear behind more elevated parts of the Earth to the north. Perhaps he had heard of northern lands where the summer Sun did not set. Presumably, annual declinational changes would have been explained as rhythmically alternating northerly and southerly tilting of the celestial "cap."

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Andalò di Negro of Genoa

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Died **1342**

Andalò di Negro wrote on the distances and magnitudes of the planets.

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Anderson, Carl David

Helge Kragh
Aarhus University, Aarhus, Denmark

Born **New York, New York, USA, 3 September 1905**
Died **San Marino, California, USA, 11 January 1991**

American cosmic-ray physicist Carl Anderson is best known for the discovery of the positron (a particle with the same mass as the electron but positively charged) for which he shared the 1936 Nobel Prize in Physics, with ▶ **Viktor Hess**, who was recognized for the discovery of cosmic rays.

Anderson was the child of Swedish immigrants Carl David Anderson and Emma Adolfina Ajaxon. He married Lorraine Bergman in 1946, and they had two children. Anderson spent his entire professional career at the California Institute of Technology, receiving a B.S. (1927) and a Ph.D. in physics (1930), the latter for work with ▶ **Robert Millikan** on particle detectors. He was appointed a research fellow for the period 1930–1933, becoming assistant professor of physics in 1933, then associate professor, and being promoted to full professor in 1939, only after he had won the Nobel Prize. Anderson's work during World War II was under the auspices of the National Defense Research Council and the Office of Scientific Research and Development (1941–1945). He chaired the division of physics, mathematics, and astronomy at Caltech from 1962 to 1970, and received honorary degrees from Colgate University, Gustavus Adolphus University, and Temple University, and other major awards from the Franklin Institute and the American Society of Swedish Engineers.

Anderson described his own research interests as X-rays, gamma rays, radioactivity, and cosmic rays, but is best known for the last of these, beginning with the study of cosmic-ray secondary particles using cloud-chamber photographs obtained from balloons. In 1933 he concluded that positively charged particles, which he had originally identified as protons, must have the mass of an electron. The new particle, which Anderson called a positron, was soon confirmed by other physicists and identified with the antielectron predicted by Paul Dirac in 1931. In 1937 Anderson, together with Seth Neddermeyer, studied highly penetrating particles in the cosmic radiation and suggested the existence of yet another elementary particle, the mesotron or meson, now called the muon or μ meson. This new particle was initially mistaken for the carrier of the nuclear force, which was later also found in cosmic-ray showers and has about the same mass (called the pion or π meson), but otherwise very different properties. Instead, the muon proved to be the very first member of two whole new families of particles (including multiple kinds of quarks, neutrinos, and other leptons), just as the positron proved to be the first antimatter particle recognized by physicists. Anderson thus, in effect, enormously expanded the repertoire of fundamental particles to be found in the Universe.

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Anderson, John August

Klaus Hentschel
University of Stuttgart, Stuttgart, Germany

Born **Rollag, Minnesota, USA, 7 August 1876**
Died **Altadena, California, USA, 2 December 1959**

American spectroscopist John Anderson made important contributions to astronomy by ruling excellent gratings for spectrographs, developing techniques to study gases at stellar temperatures, and supervising the production and testing of optical components for the 200-in. telescope on Palomar Mountain. Anderson was the son of Norwegian immigrants and was educated at Concordia College, the State Normal School in Moorhead, Minnesota, and Valparaiso College, Indiana (B.S.: 1900), interrupted by periods working in a hardware store and at a lumberyard. He taught physics and other subjects in Clay County, Minnesota, before beginning graduate studies at Johns Hopkins University, where he received his Ph.D. in 1907 with a thesis on the absorption and emission spectra of compounds of neodymium and erbium. In 1908, Anderson worked on absorption spectra of solutions with Harry C. Jones (physical chemistry) at John Hopkins University, participated in a United States Naval Observatory eclipse expedition to Spain, and spent the summer at the University of Virginia, attempting to measure the interaction of plane-polarized light with tourmaline crystals (which are birefringent).

Anderson returned to Johns Hopkins University as an instructor (1908/1909), then served as a research associate (1909–1911), and an associate professor (1911–1915), working on the improvement of reflection gratings for spectrographs, for which ▶ **Henry Rowland** had made the department famous. Anderson developed methods for making grating replicas and studied the effect of groove form on the distribution of light in various orders of diffracted light – thus preparing the way for the ruling of blazed gratings. He also oversaw the design and construction of a new ruling engine for gratings as large as 18 × 24 in. But the technical problems posed by the longer master screw and the heavier grating carriage turned out to be insurmountable, and smaller ruling engines proved better at making high-quality gratings.

A brief visit to Mount Wilson Observatory led to a permanent appointment there in 1916, from which Anderson officially retired in 1943, but he continued his involvement with instrumentation for the 200-in. telescope until its completion in 1948. Anderson participated in the effort by ▶ **Albert Michelson** to measure angular diameters of stars by interferometric methods and applied interferometry to determine the separation of close visual binary pairs. He made major contributions to the research of ▶ **Arthur King** and ▶ **Harold Babcock**, who were measuring the Zeeman and Stark effects on spectra of elements important in stellar atmospheres. During World War I, Anderson worked on micrometers and sonic submarine detection devices for the navy. Beginning in 1919, Anderson began experimenting with exploding wires in order to generate emission spectra of atoms and ions at temperatures up to 20,000 K, much higher than the 3,000 K possible in King's electric furnaces. The high temperatures lasted only a microsecond or less, and Anderson developed, with student ▶ **Sinclair Smith**, rotating mirror cameras with which the temporal changes in the spectra could be followed. He also developed a vacuum spectrograph for work at ultraviolet wavelengths.

Planning for the 200-in. telescope began with a grant of $6 million from the International Education Board (which ▶ **George Hale** had persuaded John D. Rockefeller to establish). Anderson was appointed Executive Officer, responsible for the optical components. He received a Gold Medal from the Franklin Institute in 1924 and was elected to the National Academy of Sciences in 1928 for his contributions to laboratory and astronomical optics.

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Anderson, Thomas David

Thomas R. Williams
Rice University, Houston, TX, USA

Born **Edinburgh**, **Scotland**, **6 February 1853**
Died **Edrom**, (**Borders**), **Scotland**, **31 March 1932**

Although he had been trained for the ministry (M.A. University of Edinburgh), Thomas Anderson's accidental discovery of Nova

Aurigae at fifth magnitude on 1 February 1892 (several months past its maximum brightness when it had not been observed by any other astronomer) prompted Anderson to devote the remainder of his life to the study of the night sky with the intention of discovering other new stars. Armed with only a modest telescope and the *Bonner Durchmusterung* [BD], but possessing unsurpassed diligence, Anderson is credited with the discovery of 50 variable stars, but he discovered only one additional nova (Nova Persei, 1901). In the process, Anderson had updated his copy of the BD to include at least 70,000 additional stars that were fainter than the atlas's limiting magnitude. In recognition of his achievement, Anderson was the recipient of the Gunning Prize of the Royal Society of Edinburgh, the Gold Medal of the Société Astronomique de France, and the Jackson-Gwilt Medal of the Royal Astronomical Society. Anderson also received an honorary D.Sc. from the University of Edinburgh. Surprisingly, no obituary was ever published.

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Anderson, Wilhelm Robert Karl

Piret Kuusk
Institute of Physics, University of Tartu, Estonia

Born **Minsk (Belarus), 28 October 1880**
Died **Meseritz (Miedzyrzecz, Poland), 26 March 1940**

Wilhelm Anderson was a Baltic–German–Estonian astronomer working as *Privatdozent* at the University of Tartu, Estonia, whose calculations anticipated the existence of a maximum mass for white dwarfs, now known as the Chandrasekhar limit.

Wilhelm Anderson was born in Minsk where his father, Nikolai Anderson (6 October 1845, Viru-Jaagupi, Estonia, to 22 March 1905, Narva-Jõesuu, Estonia), was a high school teacher. His mother was Adele Anderson, born Vogt. In 1894, Nikolai Anderson was elected as professor of the University of Kazan, Russia, in Finno-Ugric languages, and the family moved there. Wilhelm graduated from the III Gymnasium of Kazan and then studied mathematics, physics, and astronomy at the University of Kazan from 1902 to 1909. He graduated with a second-grade diploma and from 1910 to 1918 worked in Samara, Russia, teaching mathematics, physics, and cosmography in different gymnasiums. From 1918 to 1920, he was a teacher at the technical high school in Minsk. After World War I in 1920, the family moved to Tartu, Estonia. Here Wilhelm Anderson obtained the Master of Astronomy degree from the University of Tartu with the thesis *Über die Existenzmöglichkeit von kosmischen Staube in der Sonnenkorona* (About the possibility of the existence of cosmic dust in the Sun's corona, 1923) and *doctor philosophiae naturalis* (DSc) degree with the thesis *Die physikalische Natur der Sonnenkorona* (The physical nature of the Sun's corona, 1927). In 1936, he presented a habilitation thesis in astrophysics, *Existiert eine obere Grenze für die Dichte der Materie und Energie* (Is there an upper bound for the density of matter and energy?) and was employed as *Privatdozent* in the faculty of Mathematics and Sciences of the University of Tartu. In 1936–1937, he gave lecture courses on the commendatory subjects about the interior of stars and degenerate matter and questions of equilibrium for the Sun's chromosphere, for two-to-four students. In 1938, his health was deteriorating and his lectures cancelled. In October 1939, Anderson, together with other Baltic Germans, left Estonia for Germany. Because of his poor health, he did not long survive the difficulties of the resettlement.

Wilhelm Anderson remained a bachelor and lived in Tartu together with the family of his younger brother Walter Anderson (10 October 1885, Minsk, Belarus, to 23 August 1962, Kiel, Germany) who was an internationally known folklorist specializing in fairy tales and national songs. He was the full professor for Estonian and comparative folklore at the University of Tartu from 1920 to 1939, professor at the University of Königsberg from 1940 to 1945, and at the University of Kiel from 1945 to 1953. Their youngest brother, Oskar Johann Viktor Anderson (2 August 1887, Minsk, Belarus, to 12 February 1960, Munich, Germany), was educated in mathematics and economics and worked as the professor of statistics in several universities in Russia, Ukraine, Hungary, Bulgaria, and Germany.

Anderson's earlier work concerned the physics of the Sun's corona. He was well informed about the works of others, e.g., Svante Arrhenius, ► **Hans Ludendorff**, and ► **Jan Woltjer**. Anderson proposed that the Sun's corona consists of electron gas and demonstrated with detailed calculations that the other theories had larger problems to explain the observations. The main problem of his own hypothesis was the repulsive force between electrons, but he assumed that for unknown reasons this force does not act in the corona.

From 1929, Anderson began investigations into the physics of extremely dense white dwarf stars. Using quantum mechanical Fermi-Dirac statistics, ► **Ralph Fowler** had derived the relation between the pressure and the density of a degenerate electron gas in 1926. In 1929, Edmund Stoner tried to find a possible upper bound for the density of white dwarfs consisting of a degenerate electron gas and basically came to the same equation. Anderson noticed that in the derivation of this equation, it was assumed that the pressure is small and the speed of electrons is nonrelativistic. He took into account relativistic effects and obtained an improved relation between the pressure and the density, now known as the Stoner–Anderson state equation. In 1939, ► **Subramanyan Chandrasekhar** acknowledged that Anderson was the first to hint at the importance of relativistic effects in astrophysics.

At the same time Anderson, inspired by the work of Stoner, tried to find an upper bound for the density of white dwarf stars. Stoner searched for it by looking at the equilibrium conditions between kinetic energy of the degenerate electron gas and the gravitational potential energy of the star using his nonrelativistic equation of state. He found that in equilibrium the density of the star composed of a degenerate electron gas has to be proportional to the square of its total mass. Anderson took into account relativistic effects and obtained a rather complicated equation. He calculated numerically the values of the total mass of the star as a function of its density. His relations contained a consequence that even for an infinitely large density the star's mass is finite. So the next step could have been the determination of the maximum possible equilibrium mass, but Anderson did not calculate this limiting value. Instead, he brought forth arguments to prove that, for high densities, his equation did not hold, anyway.

In 1937, Anderson published a paper in *Publications of Tartu Observatory* on an elementary derivation of an expanding cosmology without using ► **Albert Einstein**'s general relativity. In fact, he obtained the Einstein-de Sitter Universe analogously to the derivation that ► **Edward Milne** has presented in 1934. Anderson was not aware of Milne's paper, but soon Milne sent him a copy, and Anderson discussed it thoroughly in his next paper in the same year 1937.

Anderson's articles were published, in German and English, in such high-level scientific journals as *Astronomische Nachrichten*, *Zeitschrift für Physik*, *Annalen der Physik*, and *Philosophical Magazine*. But they attracted little attention. Perhaps the reason was Anderson's way of presentation, which was somewhat obscure and often without necessary structure. He was mathematically minded and liked to calculate, not only with formulas but also with numbers – his papers contain many numerical tables. In any case, his results were not favored by physicists and astronomers of his time.

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Andoyer, Marie-Henri

Jérôme Lamy
Observatoire de Paris, Paris, France

Born **Paris, France, 1 October 1862**
Died **Paris, France, 12 June 1929**

Henri Andoyer contributed to three principal areas of scientific research: (1) observational and practical astronomy, (2) mathematical astronomy and celestial mechanics, and (3) textbooks and historical accounts. Andoyer's father was bureau chief at the Banque de France. The young Andoyer completed his secondary studies at the Lycée d'Harcourt. Later, he was admitted to the École Normale Supérieure and graduated at the top of his class in 1884, with a degree in mathematical sciences. That year, ▶ **Benjamin Baillaud**, director of the Toulouse Observatory, hired Andoyer as *astronome adjoint* and *chargé de conférences* at the Faculté des sciences at Toulouse.

Andoyer completed graduate coursework at the University of Paris and was awarded a doctorate in mathematical sciences in 1886. His dissertation (published the following year) was entitled, *Contribution à la théorie des orbites intermédiares* (Contribution to the theory of intermediate orbits). In 1887, he was named *aide-astronome* and *maître de conférences* at Toulouse. Two years later, Andoyer married Mademoiselle Périssé, from whom he had three children, two sons and one daughter. One of his sons was killed during World War I.

In 1892, Andoyer accepted the post of *maître de conférences* in celestial mechanics at the Faculté des sciences in Paris. Soon, he was named assistant professor, and in 1903, professor of astronomy. Upon the death of ▶ **Jules Poincaré** in 1912, Andoyer occupied the chair of general astronomy and celestial mechanics. Until 1905, he remained a member of the examination committee for mathematical sciences.

While at Toulouse Observatory, Andoyer was given charge of the new service of the *Carte du Ciel* in 1889. There, he became a pioneering figure in that vast international scientific enterprise. Before his departure for Paris, he devoted a large part of his time to the organization of celestial photography. Concurrently, Andoyer made observations of the satellites of Jupiter, meridian observations of the Moon, and observed minor planets, comets, and double stars. After the discovery of minor planet (246) Asporina in 1885, he calculated the orbital elements and projected an ephemeris for its opposition of 1885 and that of 1886.

Andoyer's studies in celestial mechanics were first carried out along the lines of ▶ **Hugo Gyldén**. One of the important classes of phenomena that Andoyer examined was that of near-commensurabilities or resonances. He studied the orbits of minor planets in which the mean motion was sensibly double that of Jupiter, *e.g.*, asteroid (108) Hecuba. Andoyer's work contributed to further explanation and acceptance of the gravitational explanation offered for the Kirkwood gaps in the asteroid belt, first enunciated by American astronomer ▶ **Daniel Kirkwood**. It was to this discipline that Andoyer was particularly devoted, as evidenced by his numerous memoirs on the subject. He proposed general methods of integration for solving problems in celestial mechanics and therefore extended the theorems of ▶ **Siméon Poisson**, relative to the invariability of the semimajor axes of planetary orbits.

Andoyer's most important research concerned the theory of the Moon's orbit. He determined the intermediate orbit of the Moon and, more specifically, the secular inequalities of the movements of its nodes and perigee. His comparison of various theories of the Moon allowed him to uncover differences between the results of ▶ **Charles Delaunay** and those of ▶ **Philippe le Doulcet de Pontécoulant**. Reporting the errors incumbent on the former, he concluded that "all the complementary terms calculated by Delauney beyond the seventh order are inexact; on the other hand, the earlier terms of the orders below the eighth, are in general exact." Andoyer examined the *n*-body problem, wherein he expanded upon the results of ▶ **Joseph Lagrange** concerning the equilibrium solutions for three bodies.

Andoyer's fundamental works are represented in the two-volume outline he prepared for his *Cours d'Astronomie de la Faculté des Sciences*: *I – Theoretical Astronomy* (1906), and *II – Stellar Astronomy* (1909), along with his two-part *Cours de Mécanique céleste* (1923 and 1926). Andoyer produced several textbooks on mathematical analysis and a three-volume work on trigonometric tables. He also published a scientific biography of ▶ **Pierre de Laplace**.

A member of the Paris Académie des sciences in 1919, Andoyer was also made in 1909, president of the Commission of Ephemerides of the Permanent International Council for the execution of the photographic *Carte du Ciel*. A member of the Bureau des longitudes in 1910, he was appointed editor (1911) of the *Connaissance des Temps*, the French nautical almanac. Andoyer was named an *Officier de la Légion d'honneur*.

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André, M. Charles

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Department of Earth Science, University of Northern Iowa, Cedar Falls, IA, USA

Born **Chauny, Aisne, France, 7 March 1842**
Died **Saint-Genis-Laval, Rhône, France, 6 June 1912**

▶ **Charles Wolf** brought Charles André to the Paris Observatory, but André soon left to direct the Observatoire de Lyon. André investigated why the minor planet (433) Eros varies in brightness (rotation). He was also a veteran of the 1874 transit of Venus expeditions.

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Angelus

▶ Engel, Johannes

Ångström, Anders Jonas

Sven Widmalm
Department of History of Science and Ideas, Uppsala University, Uppsala, Sweden

Born **Hässjö, Sweden, 13 August 1814**
Died **Uppsala, Sweden, 21 June 1874**

Anders Ångström was an astronomical observer, physicist, and a pioneer in spectroscopy. His father Johan was a clergyman in the Lutheran church of Sweden. Ångström and his two brothers, Johan and Carl, all received higher education. Carl became a professor of mining technology; Johan became a physician and well-known botanist. Ångström studied at Uppsala University, and in 1839, he became a *docent* in physics there. As the professor in physics was a fairly young man, and as there were no other academic positions in physics other than the professorship, Ångström switched to astronomy, where there was a position as astronomical observer at the university.

During the 1840s and 1850s, Ångström worked as astronomical observer and acting professor of both astronomy and physics at Uppsala University. He did research in various fields during these years, for example, in geomagnetism and the heat conduction of metals.

By the time he was appointed as a regular professor of physics, in 1858, Ångström had already published one of his two most famous contributions to the new scientific field of spectroscopy. The paper *Optical Researches* was published in Swedish in 1853 and in English and German 2 years later. In it, Ångström has presented, in an unsystematic fashion, a number of experimental results concerning the absorption of light from electrical sparks in gases. He also made theoretical interpretations indicating, among other things, that gases absorb light of the same wavelengths that they emit when heated, and suggesting, somewhat obliquely, that the Fraunhofer lines could be explained in this way.

During the priority disputes that followed ► **Gustav Kirchhoff**'s publication of the law of absorption and the explanation of the Fraunhofer lines around 1860, Ångström and his collaborator at Uppsala University, Robert Thalén, vigorously defended the Swede's priority. Their claims were to some extent recognized also in Britain when the Royal Society elected Ångström as a foreign member in 1870 and awarded him the Rumford Medal 2 years later. These honors were also given in recognition of Ångström's other important spectroscopic work, an atlas of the solar spectrum published in 1868. Much of the painstaking work that went into the atlas of the Fraunhofer lines (identified by wavelengths, which led to the designation *Ångström* being used for the unit of length 10^{-10} m) had been carried out by Thalén, though Ångström appeared as sole author of the work. During the 1860s and 1870s, Ångström and Thalén carried out a great number of spectroscopic measurements, not only on the Fraunhofer lines but also on the wavelengths of emission spectra of many substances.

During these decades and into the early 1880s, Ångström and Thalén dominated European spectroscopy. A measure of their influence is the publication of lists of spectroscopic data for the elements carried out by the British Association for the Advancement of Science [BAAS] in the mid-1880s. Of 67 elements, measurements by Ångström and Thalén (mostly by the latter) were given for 60; no other spectroscopist came close to that figure. Ångström's atlas was used as a standard reference by the BAAS, though it was soon to be superseded by the photographic atlas of ► **Henry Rowland**.

Ångström became a member of the Royal Swedish Academy of Sciences in 1850, of the Prussian Academy of Sciences in 1867, of the Royal Society in 1870, and of the French Academy of Sciences in 1873. He was elected a member of several other Swedish and foreign scientific societies as well.

In 1845, Ångström married Augusta Bedoire, and they had four children, two of whom survived to adulthood. Their son Knut became a professor of physics at Uppsala University, succeeding his father's successor Robert Thalén in 1896. Their daughter Anna married Carl Gustaf Lundquist, a student of her father, who in 1875 succeeded Thalén as professor of theoretical physics. There were additional family ties between the Ångströms and other scientific families at Uppsala. Hence, Anders Ångström was a founder not only of the science of spectroscopy but also of a scientific dynasty.

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Anthelme, Voituret

Kunitomi Sakurai
Kanagawa University, Yokohama, Japan

Born **probably France, 1618**
Died **probably France, 1683**

Voituret Anthelme was a French astronomer specializing in comets. Although he was a monk in a Catholic monastery, he spent much of his time studying stellar motions and searching for comets. Anthelme discovered several comets and investigated the cause of the brightness change of the variable star Mira. Using his own observations of comet C/1680 V1, he published *Explication de la comète* in 1681. Anthelme's idea on cometary orbits was that one of the foci of an orbit is located far away from the Earth, so that their orbital eccentricity is extremely large. He argued that comets are made of transparent materials, contrary to the vortex hypothesis proposed by ► **René Descartes**.

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Antoniadi, Eugène Michael

William Sheehan
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Born **Istanbul, (Turkey), 1 March 1870**
Died **Paris, France, 10 February 1944**

Eugène Antoniadi was one of the leading visual observers of the planets in the late nineteenth and early twentieth centuries. Born of Greek parents, Antoniadi became interested in astronomy during his boyhood. His talent for beautiful draftsmanship became evident at an early age; it appears he received at least some formal training in architecture. When he was only 17, Antoniadi began making drawings of sunspots and the planets with a 3-in. refractor at Constantinople and on the island of Prinkipio in the Sea of Marmara. He began submitting his work to the Société Astronomique de France, which had been founded in 1887 by ► **Camille Flammarion**. At this time, conditions in the Ottoman Empire were worsening under Sultan Abdülhamid II – the Red Sultan – and Antoniadi was eager to escape his disordered homeland. He accepted an invitation to become assistant observer at Flammarion's private observatory, located at his chateau at Juvisy-sur-Orge, between Paris and Fontainebleau.

Antoniadi began work under Flammarion whom he addressed as "my dear Master" in 1893. Although working at the observatory, Antoniadi lived in Paris. He frequently contributed articles to both Flammarion's journal *L'Astronomie* and the *Journal of the British Astronomical Association*. Antoniadi already was equally fluent in English and French, though he had little appreciation for American English; he once commented, "Reading the *New York Herald* after Gibbon gives me nausea. The Americans are seriously damaging the language."

In 1896 Antoniadi succeeded Bernard E. Cammell as director of the British Astronomical Association Mars Section, and remained in this position for more than 20 years. Eventually, his relationship with his "dear Master" became more and more strained. In part it seems Antoniadi resented Flammarion's tendency to appropriate credit for his own work. (His contract called on him to keep a notebook for Flammarion, and four volumes of his splendid drawings are still preserved at Juvisy). Then too, Antoniadi's own desire to achieve more independence may have played a role in this estrangement. In particular, Antoniadi was having private doubts about the reality of the so called canals of Mars, regular linear markings with which he had covered his earlier maps with Flammarion's blessing. Antoniadi's health was beginning to suffer, and in 1902 he resigned his position at Juvisy, and briefly pondered a move to England.

However, at about this same time Antoniadi acquired financial security – through marriage to Katherine Sevastapulo, whose parents were also Greek and seem to have been very well off – and he did not take a salaried position again for the rest of his life. He and Katherine moved to rue Jouffroy, located in a tony district of Paris, and for a number of years the pursuit of architectural matters seems to have overtaken his interest in astronomy. He obtained permission from the Red Sultan himself to draw and photograph the interior of Saint Sophia in Constantinople. This effort led to the publication, in 1907, of a three-volume work (in Greek) on the architectural masterpiece.

Antoniadi's return to astronomy came with the favorable opposition of Mars in 1909. In August, he recorded dust clouds on the planet from rue Jouffroy, using an 8½-in. reflector. He described Mars as covered with a "pale lemony haze." Soon afterward, Antoniadi received an invitation from ► **Henri Deslandres**, director of the Meudon Observatory, to observe the planet with the Grand Lunette, the 33-in. (83-cm) Henry Brothers refractor, and – as Richard McKim has noted – "his drawings of the 1909 apparition were unsurpassed both artistically and areographically." It is clear that his drawings, which can now be compared with charged-couple-device images of the planet, were remarkably accurate in their depiction of the main features of the Martian surface. With the great telescope, Antoniadi saw Mars "more detailed than ever;" the planet's appearance resembled that of the Earth as he had seen it in 1900 from a balloon at a height of 12,000 ft. He figured "a vast and incredible amount of detail," and presented a devastating assault on the reality of the canal network. The latter, he was convinced, was an illusion presented in small apertures or under indifferent conditions of "seeing." He announced this privately in correspondence to the leading canal advocate of the day, ► **Percival Lowell**, and published his observations and conclusions in a series of interim reports in 1909 and 1910 and in a memoir on the opposition that appeared in 1916.

His work during the 1909 opposition established Antoniadi as the leading authority on Mars – a position that he consolidated in his work at later oppositions (except during the war years) – and by publication of his great book *La Planète Mars* (1930). He was also a prolific observer of other planets, notably Mercury, the subject of a careful study with the Meudon refractor between 1924 and 1929. Though the work was carried out with great care, it is obvious that Antoniadi was unconsciously influenced by the earlier study by the Italian astronomer ► **Giovanni Schiaparelli**. He reached the same erroneous conclusions about the planet's rotation (which he regarded as synchronous with the period of revolution, 88 days) and the presence of frequent and obscuring dust clouds. His book on Mercury, published in 1934, is a record of mirages.

Antoniadi regarded himself as a "volunteer observer" at Meudon. He possessed a "naturally curt manner," and preferred to work in isolation, though he maintained an extensive correspondence with astronomers overseas. He was a perfectionist, a man of high standards; he rarely found others who could live up to those he imposed on himself. He was known – but just – by some of the leading planetary observers of the next generation, for example Henri Camichel who met him, but never assumed the role of a mentor to them.

The frequency of Antoniadi's observational work with the great refractor declined during the 1930s. He still railed against the Martian canalists, and devoted much time to investigating the astronomical ideas of the ancient Egyptians, about which he published a book the same year his memoir on Mercury appeared. On the other hand, he had no use for modern ideas of astrophysics or relativity.

With the occupation of Paris on 14 June 1940, Antoniadi's overseas contacts were cut off, and soon afterward he gave up his work at Meudon. The bitter war years undoubtedly depressed him; during these dark years his health began to fail as well. Sometime before he died – 6 months before the liberation of Paris – he destroyed all his unpublished records.

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Apian, Peter

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Apian, Peter. Courtesy of History of Science Collections, University of Oklahoma Libraries, Small Portraits Collection

Alternate Name

► Petrus Apianus

Born **Leisnig, (Sachsen, Germany),** ***circa*** **1501**
Died **Ingolstadt, (Bavaria, Germany), 1552**

Very little is known about uranographer Peter Apian's early life. Some confusion exists among the family records. The earliest unequivocal reference to his career is among the matriculation records of the University of Leipzig in 1516. It was at Leipzig that he Latinized his family surname from Bienewitz to Apianus (from the Latin word for "bee"), before subsequently moving to the University of Vienna. At Vienna, Apian studied with Georg Tannstetter, a renowned teacher of astronomy and former personal physician to Emperor Maximilian I, and he also brought out his earliest known publication, a map of the world that was printed in 1520.

► **Edmund Halley**'s prediction that the comet he observed in 1682 would return again 76 years later is credited as the earliest recognition of cometary periodic orbits. A prior appearance of comet 1P/Halley in 1531, however, was also responsible for prompting a less well-remembered discovery concerning the nature of comets. In the earlier instance, Apian observed this comet over many nights and noted for the first time that regardless of its position, a comet's tail always points away from the direction of the Sun. He described his observations in a printed astrological prognostication for the year 1532, in which he also included a woodcut illustration showing the comet's motion relative to the Sun. Observations of three more comets in later years allowed Apian to confirm this discovery, although like virtually all of his contemporaries, he continued to believe that comets were a product of the Earth's upper atmosphere rather than independent celestial bodies.

Apian's 1520 world map was a forerunner to a long succession of publications that he produced throughout his life for both scholarly and general audiences. Most of these works appeared either from his brother's printshop in Landshut or from his own printshop in Ingolstadt, where he was appointed a professor of mathematics at the university in 1527 and subsequently taught for nearly 25 years. As a cartographer, Apian published further maps of the world and different European regions, as well as maps of the celestial constellations, and he wrote an introductory text on geography that became immensely popular. The latter work, simply entitled the *Cosmographicus Liber* (Cosmographical book), went through dozens of printed editions in Latin, Dutch, French, and Spanish, especially in a form that was edited by the Dutch mathematician ► **Gemma Frisius**, and remained a staple textbook across Europe until the end of the sixteenth century.

Apian produced other well-illustrated books in both Latin and German describing measurement techniques for a wide range of mathematical instruments, and he also wrote an instructional manual on commercial arithmetic. In addition, a 500-page volume reproducing ancient Roman inscriptions from across Europe, which he edited along with his fellow Ingolstadt professor Bartholomew Amantius, gives ample evidence of both the breadth of Apian's scholarly interests and the advanced technical capabilities of his printshop.

In the realm of astronomy, Apian wrote books on several instruments of his own design that could be used for timekeeping or for making celestial observations, and he published new editions of ► **John of Holywood**'s *Sphere*, ► **Georg Peurbach**'s *New Planetary Theories*, and ► **Jabir ibn Aflah**'s *Nine Books on Astronomy*. Like his astronomical colleagues at many other universities, Apian issued regular calendars and short astrological forecasts such as the ones that included his observations on comets.

Apian's most famous publication, however, was the *Astronomicum Caesareum* (Imperial astronomy), brought out in 1540 and dedicated to Emperor Charles V and his brother Ferdinand. A spectacular achievement of Renaissance printing, this volume allowed its user to reproduce the motions of all the heavenly bodies through combinations of elaborately decorated rotating paper disks up to six layers deep and arranged on nonconcentric axes. For this work, Apian was rewarded by the emperor with 3,000 gold coins and elevated to membership among the hereditary nobility, as well as bestowed other honors and privileges. After his death, his son Philipp, one of 14 children with his wife Katharina Mosner, succeeded to Peter's mathematical chair at the University of Ingolstadt.

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Apian, Philipp

Jürgen Hamel
Universität Landau, Landau in der Pfalz, Rheinland-Pfalz, Germany

Born **Ingolstadt** (**Bavaria**, **Germany**), **14 September 1531**
Died **Tübingen** (**Baden-Württemberg**, **Germany**), **12 November 1589**

Philipp Apian received his early education from his father, the astronomer Peter Apian. He made rapid progress and took a particular interest in mathematics. He spent just a short time at the University of Ingolstadt and in 1547 went to live with his uncle Georg, the municipal official responsible for weights and measures. In 1549, Philipp Apian moved to Strassburg, where he entered into contact with Johann Sturm, then moved on to Paris and, in 1552, returned to Ingolstadt, shortly before the death of his father.

As a 20-year-old, Philipp Apian was appointed professor of Mathematics as his father's successor, only about 2 months after the latter's death. Apian devoted himself to the teaching profession with a great deal of energy and great success. It was said of him that he was a highly gifted teacher and attracted a great number of students.

In addition, in 1554 Apian started to study medicine, which in his time had many links to astronomy and astrology. In doing so, we may suspect that he had the rather broader motive of changing from being a poorly paid professor in the arts faculty to the better remuneration of a professor of medicine, law, or theology or combining both posts. Apian's attempt at this, however, was interrupted, because in the same year he was given the task of surveying the Duchy of Bavaria.

Apian carried out the field work for the survey over 6–7 years alongside his academic duties, which, given the difficulties of travel at that time, represented an extraordinary amount of effort and physical strain. The "Bairische Landtaflen" map appeared in 1566 and had 33 plates. Each map is accompanied by a list of cities, market towns, monasteries, castles, manor houses, mountains, and rivers. The maps themselves have a scale of miles and, in some cases, an additional decorative panel with plant and animal ornamentation, together with representations of coats of arms. There were many editions of these maps. Apian had already published a general map of Bavaria in 1561.

In 1568, during the course of the Counter-Reformation and as a result of a papal bull, all professors in Bavaria were obliged to take an oath to abide by the resolutions taken by the Council of Trent. Apian refused to make the required declaration of faith and, as a result, was stripped of his professorship and expelled from the state. His search for a new home was successful. In October 1569, Apian was appointed professor of Geometry and Astronomy at the Württemberg State University in Tübingen. After 14 years of a further successful academic career, the same fate befell Apian in Protestant Tübingen as previously in Catholic Ingolstadt. Apian refused to make a declaration of the oath of concordance and was dismissed from the University at the age of 52. Apian did not try to begin again, but retired into private life.

Alongside his own work, Philipp Apian took on his father's unfinished work and, in 1586, published this as "De utilitate trientis." It was a 120° circular sector, designed to be an instrument for astronomical observation and calculation. As late as 1687, this device, known as a "Triens," was constructed at the Nürnberg Observatory from Apian's description for use as an observational instrument.

Phillip Apian was one of the first scholars to recognize that comets were objects belonging to the planetary sphere and, as such, were not within the Earth's atmosphere, and he published a paper on this in 1572. He wrote a statement on the calendar reform of 1582 for the Elector of Saxony, which, as a Protestant, he rejected.

Acknowledgments Translated by Storm Dunlop.

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Apollonius of Myndos

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Born **Myndos (Gümüşlük, Turkey), 140 ± 10 BCE**
Died **90 ± 10 BCE**

Apollonius was the earliest known astronomer to argue that comets were orbiting bodies like the planets (within a geocentric framework). His place of origin is known, but his dates are an estimate, and nothing certain is known of his life.

Apollonius is mentioned by only one extant author, Seneca, in his *Natural Questions*. In addition to Apollonius's place of origin, Seneca records that Apollonius studied with the "Chaldeans," i.e., Babylonian astrologers. Those two facts suggest that Apollonius came after ▶ **Hipparchus**, consistent with his claim that a comet is a "proper star, just like the sun or moon" (i.e., as exemplary bodies whose motions were believed to be well-understood due to Hipparchus).

If, as some scholars have suggested, Seneca is relying on ▶ **Poseidonius** for his account, then Apollonius precedes Poseidonius. That order is very likely in any case, since Poseidonius's theory of comets held that they were heliocentric, which itself was very likely based on the extant but anonymous theory from *circa* 90 BCE that Venus and Mercury orbit the Sun, which in turn (along with the Moon and the three then-known superior planets) orbit the Earth. Since the heliocentric theory of comets would explain the orientation of their tails, which the theory of Apollonius did not address, it seems likely that Apollonius preceded Poseidonius.

Apollonius's place of origin hints at two further possibilities. Myndos was a small coastal city (modern Gümüşlük: 37°02′ N, 27°14′ E) with strong walls and a good harbor, plus a moderately glorious history; Livy indicates that from 197 BCE, and in his own time, Myndos was a free city, striking its own coins, and allied with Rome. The only other scientist recorded from ancient Myndos comes from the same period of her history: Alexander, who wrote on geography and biology. The context of a prosperous mercantile free city, even a small one, seems to have promoted science.

Furthermore, although he is not cited by name, the next citation of Apollonius's theory that comets are periodic is found in the Talmud, recording that, in about 95, the learned rabbi ▶ **Joshua ben Hananiah** said that "a certain star rises once in 70 years and leads the sailors astray." Jewish communities existed in the region already in the second century BCE, including at Myndos itself (as well as at Halikarnassos and Knidos), as recorded in an open letter of *circa* 140 BCE (preserved in *I Maccabees*). Although most Greek names used by Jews were non-theophoric, such as Aristobulus, ▶ **Dositheus**, Eupolemus, Iason, or Philon, the name "Apollonius" is attested by Josephus for a Jewish envoy of King Hyrcanus I, *circa* 120 BCE.

Seneca states that Apollonius wrote a work explaining comets as long-period planets of elongated shape and on noncircular orbits, only visible when their orbit brings them close to the Earth. Apollonius's theory (essentially correct) was an application of the recently successful solar and lunar epicyclic theory of Hipparchus – he evidently suggested that comets had extremely large epicycles. Apollonius's theory (but not Apollonius's name) was cited as late as the fifth century by some authors who collected opinions about comets, although by *circa* 200, the consensus had mostly reverted to ▶ **Aristotle**'s theory that comets were atmospheric phenomena.

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Apollonius of Perga

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Flourished **Alexandria**, **(Egypt)**, ***circa* 247–205 BCE**

Apollonius laid two foundations, one in astronomy and the other in mathematics.

Ancient sources have Apollonius flourishing in the reign of Ptolemy Euergetes (Ptolemy III: 247–222 BCE) and Ptolemy Philopator (Ptolemy IV: 222–205 BCE). He was born in Perga (near the southern coast of what is now Turkey), and moved to Alexandria, where he spent his working life. The move to Alexandria may have been spurred by Euergetes’ naval forces conquering the coastal regions all the way to the Hellespont early in his reign, which made Alexandria the capital of the entire eastern Greek world.

In astronomy, ► **Ptolemy** used Apollonius as his authority on epicycles and eccentrics to account for the apparent motions of the planets. The propositions cited by Ptolemy as proven by Apollonius show mathematically at what points the planet appears stationary, switching from apparent forward to apparent retrograde, and vice versa.

In mathematics, Apollonius’s Conics gives us the concept and nomenclature for ellipse, parabola, and hyperbola. These curves originate with the mental exercise of pushing a plane through a cone and contemplating the shape of the intersection. Apollonius found a new generalized way to describe the properties of all three conic sections, and went on to discuss a number of problems connected with them. The *Conics* were originally in eight books; books I–IV survive in the original Greek, and books V–VII survive in Arabic. They were studied by Arab astronomers and by ► **Johannes Kepler**, ► **René Descartes**, ► **Edmund Halley**, and ► **Isaac Newton**.

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Appleton, Edward Victor

Peter S. Excell
University of Bradford, Bradford, UK

Born **Bradford**, **England**, **6 September 1892**
Died **Edinburgh**, **Scotland**, **21 April 1965**

British radio engineer and space physicist Edward Appleton received the 1947 Nobel Prize in Physics for his discovery of the layer in the Earth’s ionosphere that reflects short wavelength radio. He was the eldest of three children of warehouseman and church-organist Peter Appleton and his wife Mary; he married Jessie

Longson in 1916 (and had two daughters) and, after her death, Helen Lennie in 1965. Appleton developed an interest in physics at the Hanson School in Bradford, and went to Cambridge University to read natural sciences at Saint Johns College in 1911, receiving a first-class degree in 1914. His studies included geology and mineralogy, especially the optical properties of crystals, as well as physics. After graduation, Appleton became the first research student of William Bragg, intending to work on X-ray crystallography. Both, however, volunteered for service at the outbreak of World War I.

Appleton was assigned to the Royal Engineers, being employed primarily as an instructor with a signals unit, but also investigating the possibility of eavesdropping on radio communications – his first exposure to radio technology, of whose importance he was quickly persuaded. He returned to Cambridge and began work as a research (graduate) student with J. J. Thomson, receiving in due course an M.Sc. (1919) and a D.Sc. (1921), both external degrees from the University of London for work on radio wave generation, propagation, and detection.

In 1924, Appleton was appointed to the Wheatstone professorship of physics at King's College, London, taking with him a new student, Miles A. F. Barnett. The probability of a radio-reflecting layer somewhere in the Earth's atmosphere was already clear from the experiments of Guillermo Marconi (transmission of radio waves across the Atlantic in 1901) and theoretical considerations by Arthur E. Kennelly and Oliver Heaviside (hence the Kennelly-Heaviside layer). But Appleton and Barnett devised a method to trace out the location and properties of the layer, thereby definitely establishing its existence. They persuaded the British Broadcasting Company [BBC] to sweep the frequency of its transmitter at Bournemouth back and forth while they sat at Oxford measuring the intensity of the received signal. The two cities are about 75 miles (120 km) apart, the perfect distance for what Appleton and Barnett were trying to do, which was to see the interference between radio signals that traveled along the ground and those that had been bounced off the reflecting, partly ionized layer. Wavelengths of a meter or two were nicely reflected at about 100 km, and the height varied between day and night and with the seasons, showing that radiation from the Sun was responsible for what radar pioneer Robert Watson-Watt later named as the ionosphere.

In practice, the first discovery (now called the E layer), and the one higher in the atmosphere at 200–300 km (which reflected shorter wavelengths and is now called the F layer), was generally called the Appleton layers. A lower-lying D layer at about 70 km is closely associated with the name of ► **Sydney Chapman**. Very similar investigations were also under way by 1924 in the United States, with ► **Edward Hulburt** and E. Hoyt Taylor working at the Naval Research Laboratory, and Gregory Breit and Merle Tuve at the Carnegie Institution. Nevertheless, Appleton was considered to have got the answer first, and most clearly, and received the Nobel Prize (as well as many other honors) for it. He took up a professorship at Cambridge University in 1938, but less than 3 years later (as war returned), he was asked to take over the secretaryship of the Department of Scientific and Industrial Research [DSIR].

Appleton headed DSIR until after the end of World War II and provided leadership to the national efforts in ionospheric research (for communications and intelligence purposes) as well as radar and atomic weapons. Toward the end of the war, he foresaw a need for ongoing, peacetime, government-sponsored research and played a leading role in the establishment of the Harwell Research Laboratory near Oxford. Another laboratory there, also engaged in a variety of kinds of physics and related research (much of it with defense implications), is now called the Rutherford-Appleton laboratory.

One of the key junior wartime workers in radar was ► **Bernard Lovell**, who after 1945 developed plans for a major research effort in radio astronomy at Jodrell Bank (near the University of Manchester). Appleton helped to ensure that government funding supported this program.

From 1934 to 1952, Appleton was president of URSI (the French acronym of the International Union of Radio Science) and lent his prestige to its activities, including the sharing out of available radio frequencies among defense, civilian communication, and astronomical research. He also started a research journal, which, under the title of *Journal of Atmospheric and Solar-Terrestrial Physics*, remains important in the field he helped to found. Appleton accepted the post of vice chancellor and principal of the University of Edinburgh in 1949. He maintained a section for ionospheric research there, but was himself increasingly involved in administration and plans for substantial expansion of the university. Although somewhat beyond standard retirement age, Appleton still held the post at the time of his death.

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Aquinas, Thomas

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Born **Rossasecca, (Lazio, Italy),** ***circa*** **1223**
Died **Fossanova, (Lazio, Italy), 5–7 March 1274**

Thomas Aquinas' importance to the history of astronomy lies in his reconciliation of Aristotelian cosmology and twelfth-century astrology with Christian theology.

Saint Thomas Aquinas was the foremost Catholic theologian of the medieval world. Born into an aristocratic south Italian family, he became a Dominican Friar at the age of 16. In 1245, he arrived in Paris, where he became a student of ▶ **Albert the Great**, the most prominent exponent of Aristotelian philosophy. Aquinas took his bachelor's degree in 1248, returning to Paris in 1253 to prepare for his master's degree, which he received in 1257. He was sent to Italy to teach in various Dominican houses in 1259, returned to Paris in 1269, and was sent to Naples in 1272 to set up a Dominican school. His reputation in the modern world was affirmed in 1879 when Pope Leo XIII named him "the chief and master among all the scholastic doctors" in his encyclical *Aeterni patris*.

▶ **Aristotle**'s work had become familiar to Western scholars in the twelfth century partly through original translations, notably the *Meteorologica* (translated by Henry Aristippus between 1150 and 1160) and partly through the work of Arabic scholars such as Avicenna (▶ **Ibn Sina**) and Averroes (▶ **Ibn Rushd**). The overall effect of this material was quite revolutionary. It introduced into Catholic learning the work of a philosopher who had accepted ▶ **Plato**'s doctrine of a single God, and hence whose work seemed compatible with Christianity, but argued for the eternity of the Universe, thus denying both the reality of the Genesis creation myth and the possibility of the Last Judgment and inauguration of the Kingdom of God. The introduction of Aristotelian material was accompanied by the translation of major astrological texts, particularly Claudius ▶ **Ptolemy**'s *Tetrabiblos* (1138), the pseudo-Ptolemaic *Centiloquium* (1136), and the *Maius Introductorium* (1140), the major introduction to astrology composed by the Persian astrologer Abu Ma'shar. Combined with Aristotle's statement that "the celestial element, . . . [the] source of all motion, must be regarded as first cause" (*Meteorologica* I.ii), such work established astrology as a central feature of Western science and an integral part of medieval astronomy. If, for example, an understanding of the wider celestial environment was essential to the analysis of events on Earth, then astronomy now possessed directly practical applications in the treatment of disease, the prophecy of peace and war, the prediction of individual fortunes, and the selection of auspicious moments to inaugurate important enterprises.

The extent of Aquinas' writing is immense, and his highest achievement was the *Summa Theologica*, a complete systematization of Christian theology. His writings on the stars are contained in the *Summa contra Gentiles*, a textbook for missionaries, which summarizes the arguments to be put in response to various non scriptural claims. All thirteenth-century Catholic theologians were obliged to take a position *vis-à-vis* Aristotelian teaching, its implications for astronomy, and the safe philosophical ground it provided for astrology. Many were hostile. Aquinas, following Albertus Magnus' example, was openly sympathetic to both Aristotle and the associated astrological texts, and his contribution to the history of astronomy lies in the third way he established between astral determinism and the requirement, central to Christianity, that the individual must be able to make a free choice between good and evil and thus achieve salvation. Saint ► **Augustine**'s solution, which was still prevalent in the thirteenth century, was that the stars had no influence at all and that all power lay with God. Aquinas' alternative solution, set out in *Summa contra Gentiles* (Chaps. 83–88), allowed the stars, as secondary causes in an Aristotelian sense, to rule the physical world, while retaining the Augustinian doctrine that the human will, and hence the chance of salvation, was responsible to God alone. Thus, any form of astrology that dealt with the consequences of natural disorder or physical passion was permissible. Medical astrology was acceptable, as was the prediction of war and peace. The election of auspicious astronomical moments to inaugurate new enterprises was deemed unacceptable because it impinged on God's providential right to dictate the outcome of events, as was the use of interrogations, the casting of horoscopes to answer precise questions about the future. Genetheliacal astrology, which dealt with individual lives, was acceptable in as much as it dealt with physical existence, but not if it denied moral choice.

Aquinas' work was condemned at Paris in 1277, but in 1278, the Dominican General Chapter officially imposed his teachings upon the order. His moral cosmology remained an influential component within Catholic thinking on astronomy until the seventeenth century and provided a rationale for astrology that was unavailable within more conservative wings of the Church, which remained loyal to Augustine.

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Arago, Dominique-François-Jean

Antonio E. Ten
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Born **Estagel**, (**Pyrénées-Orientales**), **France**, **26 February 1786**
Died **Paris**, **France**, **2 October 1853**

Arago, Dominique-François-Jean. Courtesy of History of Science Collections, University of Oklahoma Libraries, Large Portraits Collection

François Arago directed the Paris Observatory, was a patron of ► **Urbain Le Verrier**, and made significant contributions to the physics of light and electromagnetism. Arago was the fifth son in a family of 11 children raised by François Bonaventure Arago and Marie Roig. Born in the small town of Estagel in Roussillon close to the Spanish border, he was part of a middle-class family of farm origins. His father, who, in 1774, passed his school-leaving examination with the right to enter the University of Perpignan, became mayor of Estagel in 1789 and led a lively public career until his death in 1815.

It was a mark of his growth as a youth that, in 1795, François Arago moved with his family to Perpignan to commence his secondary studies, which he abandoned in 1800 to prepare himself for entrance into the prestigious École Polytechnique de Paris.

In Toulouse, in 1803, he passed the entrance examination for the École Polytechnique and moved to Paris to take up his studies. Two years later, his friend ► **Denis Poisson**, with the aid of the all-powerful ► **Pierre de Laplace**, proposed him officially for the post of secretary of the Paris Observatory, a position that had been left vacant by the negligent Augustin Méchain, son of the astronomer of the same name, and that Arago filled temporarily from the end of 1804. On 22 February 1805, he was effectively named to a post at the Bureau of Longitudes, on which the observatory depended.

The young Arago's astronomical career began at the Paris Observatory. After meeting with ► **Jean Biot**, an already recognized scientist, they worked out a plan to complete the geodesic operations that ► **Pierre Méchain** had left uncompleted in Spain. With the support of Laplace, Biot and Arago were designated to complete the work of extending the meridian of Paris as far as the Balearic Islands in the Mediterranean Sea, a task they performed between 1806 and 1808.

On his return to Paris in July 1809, after many vicissitudes, Arago took possession of the post of *astronome adjoint* at the Bureau of Longitudes, a position to which he had been appointed, *in absentia*, in 1807. Two months later, on 11 September, again with the support of Biot and Laplace, he was elected as an astronomer to the Paris Academy of Sciences, in his 23rd year, with 47 of the 52 votes cast. With the confirmation of this appointment by Emperor Napoléon on 23 October 1809, Arago became a public figure. Also in 1809, he succeeded Gaspard Monge in the chair of analytic geometry at the École Polytechnique.

From his post in the academy and as a member of the Bureau of Longitudes, Arago assumed the effective control of the Paris Observatory. Formal control of the observatory fell to the bureau in a collegial way, although always one of its members took responsibility for the establishment. From 1809, this happy responsibility fell upon Arago, who then moved into a building of the observatory in 1811, after his wedding. On 9 April 1834, in recognition of the actual situation, Arago was named "director of observations," a post he would hold on until his death. He had two sons, Emmanuel and Alfred, from his marriage.

At the Paris Observatory, Arago began to consolidate his scientific career, which primarily developed between 1809 and 1830. A physicist more than a positional astronomer, Arago mainly occupied himself with the subject of light, its properties, and the instruments for its study. His first discoveries came in 1811 in the area of polarization of light, just before the discoveries of Etienne Malus. In this year, he invented an instrument that measured the angle of polarization, and with polarized light, he carried out various experiments that convinced him of the superiority of the wave theory over the corpuscular theory of light.

As a member of Parisian cultivated society at the beginning of the century, Arago forged good friendships with important people. Having close relations with J. -L. Gay-Lussac and ► **Alexander von Humboldt**, he was occasionally invited to the Société d'Arcueil, private meetings encouraged by Claude Berthollet and Laplace, and began surrounding himself with other promising young men. Among his closest friends at the time were Malus (died: 1812), Claude Mathieu, Augustin Fresnel, and André-Marie Ampère, but he was estranged from his first friend, Biot.

In the middle of political changes in post-Napoleonic France, and from his post at the observatory, Arago specialized in the study of light and the phenomena of electromagnetism. He discovered chromatic and circular polarization of light and investigated refraction in solids and liquids. Defender of the wave theory in opposition to Laplace and Biot, but supported by Fresnel, he was little by little able to overcome the resistance to the theory within the academy. With his support, Joseph Fourier was elected perpetual secretary, and Arago succeeded him in June 1830.

In fact, after the fall of Charles X, in July 1830, Arago was elected a deputy. From the Chamber of Deputies and the Academy of Sciences, he promoted important initiatives in science policy and education, while at the observatory, he encouraged research plans. Le Verrier, for example, owed to him the suggestion to carry out investigations that led to the discovery of Neptune.

From his high posts, Arago looked out for the careers of the young physicists and astronomers around him. In addition to the polarization of light, he studied the velocity of light, terrestrial and celestial bodies, the phenomena of refraction, and the recently invented photography. Arago was now at the beginning of a stage in his career as a successful science popularizer and more and more turned his attention to political life.

In spite of his much lesser discoveries in fields as far from astronomy as geodesy, optics, electromagnetism, or meteorology, Arago's primary activity was as a cheerleader for science rather than as a pure scientist. A convinced and outspoken republican, he promoted the abolition of slavery in French territories and, after the Revolution of 1848, was named minister of marine and war, a post he held for 4 months. Arago was skillful at emphasizing new ideas, important among them being the discoveries in optics, astronomy, and technology. Almost blind during his last years and more preoccupied with politics than with pure science, he died, still in his position of director, to which the rival of his last years, Le Verrier, would succeed.

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Aratus

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Born **Soli** (**near Mersin**, **Turkey**), **late fourth century BCE**
Died **Pella**, (**Macedonia**, **Greece**), **before 240 BCE**

Aratus is the author of the *Phaenomena*, a description in poetry of the constellations and the apparent motions of the sky, which was widely read throughout Antiquity and the Middle Ages.

After studying with Stoic (and Peripatetic?) philosophers in Athens, Aratus was invited, in 276 BCE, to the court of Antigonus Gonatas in Pella, where he seems to have spent most of his active career as a scholar and poet. Ancient sources, besides offering many less trustworthy biographical details, ascribe to Aratus occasional poetry (e.g., celebrating Antigonus' marriage), a collection of "light verse" (*Kata lepton*), epigrams, hymns, epistolary character sketches, and an edition of ▶ **Homer**.

But Aratus was best known for his didactic poems on anatomical, pharmacological, and especially astronomical subjects. The *Kanôn* (measuring rod) probably held a mathematical description of the planetary orbits. The first part of the *Phaenomena*, Aratus' only surviving major work, contains a catalog of the makeup and relative position of the constellations and is laced with stories about their mythological origin. The description passes from the poles and the northern constellations to the southern constellations, the principal circles of the celestial sphere, the risings and settings of the 12 signs, and finishes with the movements of the Moon and the Sun (lunar month and seasons) and their influence on human affairs. The second part of the poem, which bears the separate title *Diosemeiai* ("Weather signs"), contains practical advice on forecasting the weather by observing the skies and other natural phenomena.

The poem generally emulates the *Works and Days* of ▶ **Hesiod**, and supplements that work by providing the description of the constellations that Hesiod presupposes, and by offering instructions to seafarers (i.e., traders) rather than farmers. This is one of many indications that, just as *Works and Days* is representative of the society of archaic Greece, Aratus wanted his poem to reflect the new, cosmopolitan worldview propagated at the Hellenistic courts. The Stoic Zeus whom Aratus invokes in his introduction stands for the "first cause" guaranteeing cosmic order, which on the human level is represented by the ruler. Aratus' work is, therefore, just like that of Hesiod, concerned with the principle of *dikê* (good order).

The *Phaenomena*, already regarded as Aratus' masterpiece by contemporaries, remained widely read throughout Antiquity. It evoked many commentaries (e.g., by ▶ **Hipparchus** and ▶ **Theon of Alexandria**), translations, and reworkings (e.g., by Varro Atacinus, ▶ **Cicero**, ▶ **Virgil**, Germanicus, ▶ **Manilius**, and Avienus). Although this popularity was mostly driven by admiration for Aratus' successful transformation of "dry" scientific material into elegant, sophisticated verse, it also had an impact on the history of astronomy by divulging (and, finally, preserving) the ideas of Eudoxus (Aratus' main source for the section on the constellations) and peripatetic meteorological doctrine (taken from a work by ▶ **Aristotle** or ▶ **Theophrastus**). Aratus' sources were not widely read outside "professional" circles, the general educated public took its astronomical and meteorological instruction largely from the *Phaenomena* and commentaries on it. In the Middle Ages, the work continued to circulate in Greek (as part of the Byzantine school curriculum), Latin (the socalled *Aratus Latinus*), and Arabic, but it gradually lost ground to ▶ **Ptolemy**'s *Almagest*.

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Archelaus of Athens

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Flourished (**Greece**), **5th century BCE**

A disciple of ▶ **Anaxagoras**, Archelaus held a cosmological view similar to that of his mentor. However, Archelaus saw no need for a creative force (*nous*).

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Leibniz-Sozietät der Wissenschaften zu Berlin (Leibniz Society of Sciences), Berlin, Federal Republic of Germany, Germany

Born **Lichtenau**, (**Hessen**, **Germany**), **2 October 1861**
Died **Berlin**, **Germany**, **14 October 1939**

Astronomy popularizer Friedrich Archenhold completed his secondary education at the Realgymnasium in Lippstadt. In 1882, he began to study the natural sciences at the Friedrich Wilhelm University (now Humboldt University) in Berlin. There, Archenhold came under the influence of Wilhelm Förster, director of the Berlin University Observatory, who was committed to diffusing scientific knowledge among the public. In 1888, Förster cofounded the Urania Society as an outreach function of Science.

From 1890 to 1895, Archenhold served as astronomer and manager of the Grunewald Observatory, a small station located outside the city of Berlin. In 1893, he began a campaign to construct a large telescope in Germany. Three years later, this was accomplished with construction of the longest refracting telescope in the world, a 26.8-in. (68-cm) objective with a focal length of 69 ft. (21 m), financed by private donations. The new Treptow Observatory had an original, timber-supported framework (as demonstrated at the Treptow Industrial Exhibition of 1896). That wooden structure was replaced, however, when the present main building was constructed in 1908–1909. Archenhold served as director of the Treptow Observatory from 1896 to 1931.

Archenhold developed an active program of events and publications, while the observatory itself was supported by a voluntary organization. In 1900, he founded the popular astronomical magazine *Das Weltall* (The Universe), which was published until 1944. He also traveled widely to places such as Sweden, Great Britain, Spain, and the United States. In 1907, Archenhold was awarded an honorary doctorate by the Western University of Pennsylvania. Always interested in the educational potential of new media, he established a "cinematographic study society" to aid the production of scientific films (1913). Archenhold was also a leading member of the Panterra Organization that promoted international research projects of a peaceful nature. He subscribed to the Jewish faith.

Archenhold resigned his post in 1931 at the age of 70. After the Nazis came to power, his family members were gradually expelled from the observatory. His sons Horst and Günter (who also became an astronomer) immigrated to England, but Archenhold's wife Alice and daughter Hilde lost their lives in the Theresienstadt concentration camp.

Archenhold was an original and, on occasion, a somewhat outlandish personality and the subject of countless anecdotes. From his broad outlook, he successfully advocated the placement of large astronomical telescopes on mountaintops, the construction of a projection planetarium in Berlin, and the production of inexpensive telescopes for school districts. In 1946, the Treptow Observatory was renamed the Archenhold Observatory after its founder.

Acknowledgments Translated by Peter Nockolds.

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Archimedes

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Born **Syracuse**, (**Sicily**, **Italy**), **287 BCE**
Died **Syracuse**, (**Sicily**, **Italy**), **212 BCE**

Archimedes. Courtesy of History of Science Collections, University of Oklahoma Libraries

Archimedes is widely regarded as the greatest mathematician of Antiquity and one of the greatest mathematicians of all time. He lived in Syracuse on the island of Sicily, and was a *protégé* of its kings Hieron and Gelon. Archimedes was killed by a soldier during the Second Punic War between Rome and Carthage. Episodes in the life of Archimedes have become legendary, the information coming in large part from ▶ **Plutarch's** account in his description of the conquest of Syracuse by Rome in his *Life of Marcellus*.

The contributions of Archimedes to astronomy are less well known. There was a lost work on optics, *On Catoptrica*, some of which is transmitted in a commentary by ▶ **Theon of Alexandria** on ▶ **Ptolemy's** *Almagest*. ▶ **Cicero**, who was treasurer of Sicily in 75 BCE, wrote that spheres built by Archimedes were brought to Rome by Marcellus and that one of these was a planetarium, a mechanical model showing the motions of the Sun, the Moon, and the planets. It is believed that Archimedes wrote a paper on the construction of his planetarium, *On Sphere Making*, as is mentioned by ▶ **Pappus**. Since lost works of Archimedes were rediscovered as late as 1900, it is not inconceivable that these works may eventually be found.

The surviving astronomical work of Archimedes is contained in his *The Sand Reckoner*, and the rest of this article is concerned with this work. Apart from its inherent contributions, *The Sand Reckoner* might be the best introduction to classical science.

Archimedes set for himself not just the task of calculating a number greater than the number of grains of sand not just on a beach, or on all of the surface of the Earth, or even the Earth filled with sand, but the task of calculating a number that would be greater than the number of sand grains that could fill up the whole Universe. To do this, he required, among other things, the circumference of the Earth in stades, and the distance between the center of the Earth and the center of the Sun in Earth radii. He saw the Universe as a sphere with the Earth at its center; the Sun revolved around the Earth in a circle. The ratio of the diameter of the Universe to the diameter of the Sun's orbit around the Earth is less than the ratio of the diameter of the Sun's orbit around the Earth to the diameter of the Earth.

Archimedes used known estimates on the circumference of the Earth. By this time, ► **Eratosthenes** had given his celebrated estimate of the Earth's circumference, coming up with a value very close to the correct 40,000 km. Archimedes' upper bound of 3 million stades is therefore consistent with his strategy of giving an estimate at least 10 times larger than the currently accepted figure.

Archimedes' estimate of the distance between the Earth and the Sun is more interesting; this appears to be one of the earliest attempts to determine this distance. His method was to use contemporary estimates for the size of the Moon relative to the Earth (relatively easy) and the size of the Sun relative to the Moon (very difficult). Since the Sun and Moon have the same angular diameter for a terrestrial observer, as seen during solar eclipses, it follows that the distances of the Sun and Moon from the Earth are proportional to their size. The distance to the Sun is then computed once the angular size of the Sun, as seen on the Earth, has been estimated, a measurement which Archimedes himself carried out experimentally.

The measurement was done by observing the Sun at sunrise, using a horizontal ruler on a vertical stand, and a cylinder placed on the ruler. The ruler is directed toward the Sun, and the eye is placed at the end of the ruler opposite the Sun. The cylinder blocks the Sun from the eye, and is moved away from the eye until a small piece of the Sun can be seen. The resulting angle between the sides of the cylinder and the eye, imagined to be a point at the end of the ruler, is a lower bound on the angular size of the Sun. The cylinder placed where it just blocks out the Sun will produce an angle that provides an upper bound on the angular size of the Sun.

Archimedes used the simplest estimate on the size of the Moon, namely that it is smaller than the Earth. This is obvious from observation of lunar eclipses. Archimedes then used the estimate of ► **Aristarchus** that the Sun is between 18 and 20 times the size of the Moon. Since Archimedes only required a safe upper bound, he overestimated this to 30 Moon diameters. Archimedes' final assumption was that the Sun's diameter was no larger than 30 Earth diameters.

Archimedes also took into account solar parallax, in other words, the fact that his estimate of the distance to the Sun was taken from a measurement on the surface of the Earth, while the actual distance that he was interested in is from the center of the Earth. Apparently, this is the first known example of solar parallax being taken into account.

Archimedes then concluded that the estimate of 0.36° would be a safe underestimate for the angular size of the Sun. Given the previous assumption that the diameter of the Sun is no larger than 30 times the diameter of the Earth, this meant that the orbit of the Sun was less than 30,000 Earth diameters. This led to the final estimate that the distance from the center of the Earth to the center of the Sun was less than 10,000 times the radius of the Earth.

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Archytas of Tarentum

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Flourished **(Italy)**, **fourth century BCE**

Archytas is called the last of the Pythagoreans. He was a student of ► **Philolaus**, friend of ► **Plato**, and, according to some sources, teacher of ► **Eudoxus**. Archytas argued that things cannot exist independently of place. Consequently, if one travels to the supposed “edge” of the Universe, and there stretches out both arms, only one arm would continue to exist. As this seemed absurd, Archytas concluded that the premise is false and that the Universe must be unbounded. A crater on the Moon is named for Archytas.

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Argelander, Friedrich Wilhelm August

Tapio Markkanen
University of Helsinki, Espoo, Finland

Born **Memel, Prussia (Klaipeda, Lithuania), 23 March 1799**
Died **Bonn, Germany, 17 February 1875**

Argelander, Friedrich Wilhelm August. Reproduced by permission of Helsinki University Museum (A photograph of the portrait by Carl Peter Mazer in 1837)

Friedrich Argelander was an observatory director who confirmed solar motion from stellar proper motions; he later produced the *Bonner Durchmusterung*. Argelander was the son of merchant and shipowner Johann Gottfried Argelander (whose father was Finnish) and Wilhelmina Dorotea Grünhagen. In 1823, Argelander married Maria Sophia Charlotte Courtan, and they had one daughter: Maria Wilhelmina Amalia.

Argelander studied astronomy in the University of Königsberg under ► **Friedrich Bessel**, completing his dissertation in 1822. Next year, he was appointed as observator (associate professor) in Finland, at the University of Turku (Åbo in Swedish). The observatory in Turku had been founded in 1819, but its first observator, Henrik Johan Walbeck, died unexpectedly. During his time at Turku, Argelander observed positions of stars and comets, lunar occultations, and also aurorae borealis. He published five volumes of his observations and drafted a star catalog, especially from his 1827–1831 observations, known as the Turku catalog (*Catalogus Aboensis*). It was published in Helsinki in 1835. The *Catalogus*

Aboensis contains over 10,000 precise observations of 560 stars whose positions in the sky change at least one fifth of a second of arc per year. By comparing the positions Argelander measured with the positions of these stars measured in the beginning of the eighteenth century, he could determine their proper motions very precisely. His research was the most extensive and precise account of proper motions of stars by that time.

On the basis of his data, Argelander could determine if the Sun moves in relation to the surrounding stars. ► **William Herschel** had found the motion of the Sun based on a few stars, but Bessel, using much broader and more precise data, had come to a negative conclusion. Argelander showed that the Sun does move, and the motion is directed toward an apex in the constellation of Hercules. Argelander published his study in the series of the Academy of Science of Saint Petersburg in 1837 and was awarded the great Demidov Prize of the academy for it. The work consolidated his position as one of the leading astronomers of his time.

The town of Turku was badly burned in 1827, and the university was transferred to Helsinki. In 1828, a chair of astronomy was created at the University of Helsinki, and Argelander was the first to be appointed. In cooperation with architect Carl Ludwig Engel, Argelander designed a new observatory in Helsinki. It was completed in 1834. The Observatory of Helsinki was built according to the newest demands of astronomy, and it became a model for many observatories, above all the Central Observatory of Russia in Pulkovo near Saint Petersburg, completed in 1839.

In 1836, a professorship in astronomy opened in the University of Bonn, and Argelander moved there in 1837. As there was no observatory in Bonn, he had one built. Before the completion of the new observatory in 1845, Argelander used small portable instruments for his observations. At that time, he created the first viable method to measure the variations of stellar magnitudes and thus funded the research on variable stars.

In 1852, Argelander started a decade-long work that since its completion has been known as the *Bonner Durchmusterung* (Bonn survey). It consists of an extensive star catalog and map, and contains all stars of the Northern Hemisphere brighter than the 10th magnitude. There are altogether 324,198 stars in the survey. The catalog and map have been used for over a century. The *Bonner Durchmusterung* was published in 1863.

The previous year, Argelander's student and assistant of many years in Bonn, ► **Karl Krüger**, was appointed professor of astronomy at the University of Helsinki. Before leaving Bonn, Krüger married Argelander's daughter who had been born in Helsinki.

In 1863, because of Argelander's influence, the German astronomical society *Astronomische Gesellschaft* was founded. It soon became one of the most important organizations in the field. On Argelander's initiative, the society launched in 1869 a cataloging project to observe as precisely as possible the positions of all the stars of the *Bonner Durchmusterung* brighter than the ninth magnitude. The work was divided among 13 observatories. Helsinki participated in the project under Krüger's lead. The 15-volume star catalog, known as *Katalog der Astronomischen Gesellschaft* (*AGK*), was completed in 1910.

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Argoli, Andrea

Giancarlo Truffa
Milan, Italy

Born **Tagliacozzo**, (**Abruzzo**, **Italy**), **1570**
Died **Padua**, (**Italy**), **27 September 1657**

Argoli, Andrea. Courtesy of History of Science Collections, University of Oklahoma Libraries

Andrea Argoli produced ephemerides and general works on astronomy. Argoli's father, Ottavio, was a lawyer. Argoli's son, Giovanni, would also become a lawyer and a precocious poet. Argoli studied in Naples but (he stated) without the help of a teacher. He also claimed to have studied privately in Padua with ► **Giovanni Magini**, teacher of mathematics and astronomy at the University of Bologna. Between 1622 and 1627, Argoli taught mathematics at the University La Sapienza in Rome. After ► **Benedetto Castelli** replaced him at the University La Sapienza, Argoli received support from Cardinal Biscia for 5 years. In 1632, Argoli was called to teach mathematics in Padua, where he taught until his death.

Argoli dedicated his ephemerides, published in 1623, to the Abbot of the Congregation of the Camaldolesi of Santa Mariå, another ephemerides, published in 1629, to Prince Filippo Colonnå, and two of his later works, *De diebus critici* and *Ptolomaeus parvus*, to Queen Christina of Sweden.

He had a good reputation as compiler of ephemerides based first on the Prutenic Tables and later on Tychonic observations.

Argoli was frequently cited in the correspondence between ► **Galileo Galilei** and Fulgenzio Micanzio, a Venetian friar friend of Galileo, as someone who had converted to the new astronomical theories, but no trace of his Copernicanism and his appreciation of Galilei can be found in Argoli's works.

In the *Astronomicorum libri tres* first published in 1629, Argoli presented his own system of the world. It was a geocentric system with the orbits of Mercury and Venus centered on the Sun; the Moon, Sun, Mars, Jupiter, and Saturn centered on the Earth like the scheme of ► **Martianus Capella**, but with the addition of the rotation of the Earth on its own axis. He also believed in the fluidity of the heavens and rejected the notion of solid spheres. Argoli's contention that the Earth rotates was supported by his belief in the world's spherical structure. Yet, despite this argument, he allowed for the stars to be spread out. He saw no necessary limit to the extension of the stellar region, though he remarked that those stars that we see must be at a finite distance. Argoli also claimed that the stars' unequal distance is directly perceptible. He penned several works on astrology, such as *De diebus criticis* and *Pandosion sphaericum*.

Argoli was a member of the Accademia Patavina dei Ricovrati (now Accademia Galileiana) in Padua and of the Accademia degli Incogniti in Venice. In 1638, the Venetian Republic gave him the title of Knight of Saint Mark, presented him with a gold chain, and raised his salary; by 1651, his salary was 1,100 florins.

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Aristarchus of Samos

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Born **Samos**, **(Greece)**, ***circa* 310 BCE**
Died ***circa* 230 BCE**

Aristarchus as astronomer and mathematician has not always been given the credit he deserves by historians of science, even though he made two remarkable contributions to astronomy: a heliocentric solar system and estimates of the relative sizes and distances of the Sun and the Moon.

Aristarchus was a native of the island of Samos, and a contemporary of Euclid and ▶ **Archimedes**. Not very much is known of his early life or his work except for comments by later writers or his contemporaries. Only one of his works is extant, *Aristarchus on the Sizes and Distances of the Sun and Moon*, which is the oldest surviving mathematical work on determining the sizes of the Sun and the Moon in terms of the dimensions of the Earth and the relative distance to the Sun in terms of the distance to the Moon. He reportedly also wrote on vision, light, and colors. Aëtius tells us that Aristarchus was a pupil of Strato of Lampsacus, either in Athens or in Alexandria. A comment by ▶ **Ptolemy** in *Almagest III* that Aristarchus observed the solstice of 281/280 BCE (the only date for Aristarchus we know for sure) and Archimedes' comments in the *Sand Reckoner* concerning Aristarchus' heliocentric theory of the motion of the Earth help to place his floruit. ▶ **Vitruvius** in his *De architectura* tells us that Aristarchus invented the "hemisphaerium" or "scaphe," a sundial with a hemispherical surface, and he is also identified as having invented the "discus in planitia," a dial with a horizontal shadow-receiving surface.

Among the ancient astronomers, ▶ **Philolaus** and Aristarchus stand alone in believing that the Earth moved in an orbit. Aristarchus proposed that it rotated about its axis and revolved around the Sun. Our most secure evidence for attributing the heliocentric hypothesis to Aristarchus comes from Archimedes' *Sand Reckoner*, where he explains to Gelon, son of Hieron II, King of Syracuse, how one might express very large numbers, and mentions Aristarchus: "Aristarchus of Samos . . . supposes that the fixed stars and the sun do not move, but that the earth revolves in the circumference of a circle about the sun, which lies in the middle of the orbit, and that the sphere of the fixed stars, situated about the same center as the sun, is so great that the circle in which the earth is supposed to revolve has the same ratio to the distance of the fixed stars as the centre of a sphere to its surface."

In *Aristarchus on the Sizes and Distances of the Sun and Moon*, Aristarchus applied geometry to the problem of determining the distances to the Sun and the Moon and their sizes relative to that of the Earth. Aristarchus made the following hypotheses (Heath 1913):

1. The Moon receives its light from the Sun.
2. The Earth is like a point and is center to the sphere in which the Moon moves.
3. When the Moon appears to us halved, the great circle that divides the dark and the bright portions of the Moon is in the direction of our eye.
4. When the Moon appears to us halved, its distance from the Sun is less than a quadrant by one-thirtieth of a quadrant.
5. The breadth of the (Earth's) shadow is (that) of two moons.
6. The Moon subtends one-fifteenth part of a sign of the zodiac.

Hypotheses (1) and (2) are straightforward in their meaning. The implication of hypothesis (3) is that the angle formed at the Moon between the Earth and the Sun is a right angle when the Moon's terminator appears to be a straight line to an observer on the Earth, and of hypothesis (4) that the angle between the Moon and the Sun viewed from the Earth is 87°. Hypothesis 4, of course, requires an extremely difficult measurement, the actual value being about 89° 51′. As ► Otto Neugebauer and others point out, it is extremely difficult to determine the exact time of a straight terminator to within a day or two, which makes this approach observationally improbable. Hypothesis (5) claims the diameter of the Earth's shadow at the orbit of the Moon is 2 diameters of the Moon; the actual value is closer to Ptolemy's estimate of 2 and 3/5ths diameters of the Moon. Finally, hypothesis (6) claims that the angular diameter of the Moon is 2°, a value four times too big. From the first three hypotheses, Aristarchus determined that the distance of the Sun from the Earth is greater than 18 times, but less than 20 times, the distance of the Moon from the Earth. During a total solar eclipse, it is observed that the Moon just covers the Sun; with this fact and the preceding conclusion, simple geometry gives the relative diameter of the Sun to be between 18 and 20 times the diameter of the Moon. Finally, from the hypothesis about the size of the Earth's shadow at the orbit of the Moon compared with the size of the Moon, he obtained that the Sun is between 19/3 and 43/6 (between 6.3 and 7.2) times the diameter of the Earth.

How do these numbers compare with current calculations? The actual distance to the Sun in terms of the distance to the Moon is 389, compared with the 18–20 times determined by Aristarchus. The actual size of the Sun compared to that of the Moon is 400, compared to 18–20 times the diameter of the Moon for Aristarchus. Both calculations are in error by roughly a factor of about 20. His determination of the size of the Sun ranges between 6.33 and 7.2 times the diameter of the Earth, with the actual value about 109 times. Using Aristarchus's numbers, the size of the Moon is between 0.389 and 0.317 Earth diameters, with the actual value being 0.272, a value that is surprisingly comparable.

Although the values determined for the sizes and distances do not compare well with modern determinations, the methods set forth by Aristarchus were employed and modified by succeeding generations of astronomers, and marked a move to sophisticated methods of mathematical astronomy. Although he is credited with numerous other contributions, his hypotheses concerning the motion of the Earth and his theoretical approach to mathematical astronomy are truly remarkable.

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Aristotle

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Born **Macedonia, (Greece), 384 BCE**
Died **322 BCE**

The ancient Greek worldview featured a central Earth surrounded by rotating spheres carrying the planets and stars; it persisted for some two millennia, from ancient Greece through medieval Islam to Renaissance Europe, and was largely the creation of the Greek philosopher Aristotle.

Aristotle's father was the personal physician of Amyntas II of Macedon, a poor land of unruly people at the northern edge of the Greek peninsula. At age 17, in 367 BCE, Aristotle left

Norriss S. Hetherington: deceased.

Macedon for Athens. There he entered ► **Plato**'s Academy, and stayed there for 20 years.

Philip II claimed the crown of Macedon in 359 BCE, gradually consolidated his control, and emerged as Athens' main opponent. Plato's death in 347 BCE, combined with an anti-Macedonian mood in Athens, saw Aristotle set sail across the Aegean Sea to Asia Minor. There, he founded a new academy under the patronage of a local ruler, whose 18-year-old niece and adopted daughter Aristotle married. From his later description of the ideal age for marrying as 37 years for the man and 18 for the woman, it may be inferred that Aristotle's voluntary exile was not an unhappy one.

Aristotle returned to Macedon in 342 BCE to tutor the young Prince Alexander. Philip II completed his conquest of Greece in 338 BCE. In 336 BCE, following the assassination of his father, Alexander took the throne and Aristotle returned to Athens comfortably on the side of the victors. After Alexander's death, in 323 BCE, Aristotle again went into voluntary exile. He died a year later.

The standard interpretation of Aristotle's thought is that he began close to Plato's intellectual position and gradually departed from it. An alternative interpretation has Aristotle fundamentally a biologist interested in classification, and employing teleological and animistic, rather than mechanical, explanations. Also, and perhaps inevitably in pretelescopic times, Aristotle's astronomy was not one of meticulous observation followed by induction of theories, but rather the incisive and compelling deduction typical of geometry. A major strength of Aristotle's worldview lay in its completeness; every part followed logically from the other parts. From basic concepts in Aristotle's *Physica* (Physics) follow ideas developed in *De caelo* (On the heavens).

To have knowledge of something, or to have grasped the "why" of it, was, for Aristotle, to know the cause of the phenomenon. Aristotle classified causes into categories: the material cause, of what the object is made; the formal cause, the shape of the object; the efficient cause, who made it; and the final or purposeful cause, the object's use or purpose.

Aristotle's emphasis on the final cause, or purpose, underlies his otherwise confusing definition of motion. It was not solely change of position, called locomotion, but more broadly the fulfillment of potentiality. This sense of motion leads to a particular understanding of place, encompassing both motion and potential. Each of the four elements – earth, water, air, and fire – has its natural place. Moved from its natural place, each element has a natural tendency to return to its natural place.

This concept of place is not compatible with the existence of a void, because in a void, there is no place. Thus, the laws of natural motion cannot work in a void. To argue in this fashion, *reductio ad absurdum*, is to start with a seemingly plausible statement – the existence of a void – and then to deduce such absurd consequences from it that one is forced to conclude that the original statement cannot be true.

Also, projectile motion is not explicable in a void, because movement supportly requires constant contact between the moved object and the mover. The case of a thrown object raised a problem that would puzzle and plague generations of philosophers and scientists after Aristotle. Eventually, attempts to explain projectile motion would lead to the concepts of impetus and momentum and on to the concepts of inertia and a body remaining in motion until some force acted to stop it.

Another problem with motion in a void was why would motion ever cease, if there were nothing to stop it? Modern physics contemplates a body remaining at rest or in motion until acted upon by another force. For Aristotle, however, perpetual motion seemed absurd.

In the last book of *Physics*, Aristotle discussed the one form of locomotion that could be continuous. Locomotion was either rotatory or rectilinear or a combination of the two; only rotatory motion could be continuous. Furthermore, rotation was the primary locomotion because it was more simple and complete than rectilinear motion.

Aristotle's views on the organization and structure of the Universe are found in *De caelo*. All locomotion is straight, circular, or a combination of the two, and all bodies either are simple – composed of a single element, such as fire or earth – or are compounds. The element fire and bodies composed of it have a natural movement upward; bodies composed of earth have a natural movement downward (actually, toward the center of the Universe, and the Earth is thus at the center). Circular movement is natural to some substance other than the four elements. Aristotle infers that there is something beyond the region of the Earth, composed of a different material, of a superior glory to our region of the Earth, and also unalterable. This substance is more divine than the four elements, since circular motion comes before straight movement.

In Aristotle's two-sphere Universe, there is a region of change with the Earth in the center, surrounded by water, with air and fire above. This region extends up to the sphere of the Moon. Beyond are the heavenly bodies in circular motion, in a realm without change. There is a separate set of physical laws for each of the two regions, since they are composed of different types of matter.

Aristotle's Universe is not infinite, he argued, because the Universe moves in a circle (as we can see with our eyes if we watch the stars). If the Universe were infinite, then it would be moving through an infinite distance in a finite time, which is impossible.

In another argument involving motion, Aristotle stated that bodies fall with speeds proportional to their weights. The statement is incorrect; bodies of different weights fall with the same speed. As a weak point in Aristotle's science, his comments on the speeds of falling bodies furnished an opening to critics, and the problem of falling motion became important in the development of the modern laws of mechanics.

The world was finite, and there was only one world. Were there more than one world – each world with a center as the natural place for earthy material to move to and a circumference for fire to move to – then the Earth could move toward any of the centers and fire toward any of the circumferences, and chaos would ensue.

Aristotle also argued that the heavens are unalterable. Not until the late sixteenth and early seventeenth centuries would observations of comets moving through the heavens and observations of novae (stars that flare up in brightness) reveal changes occurring in Aristotle's purportedly unalterable heavens.

Aristotle next showed that the heavens rotate and the Earth is stationary in the center. The shape of the heavens is spherical, the shape best suited to its nature, and the motion of the heavens is regular.

The composition of the stars was susceptible neither to observational nor to experimental inquiry until the middle of the nineteenth century, after the development of the science of spectroscopy. Aristotle, nonetheless, argued that the stars are composed of the same element as the heavens and are fixed to circles that carry them around. They do not move of their own effort.

Finally in his inquiry, Aristotle came to the Earth. At the center of the Universe, it is at rest. Its shape must be spherical, the shape it would take as its particles pack into the center. Also, the evidence of the senses indicates that the Earth is spherical: Eclipses of the Moon reveal that the Earth casts a circular shadow. The fact that different stars are seen from different parts of the Earth further demonstrates the spherical shape of the Earth.

Such observations were used more to persuade readers of the truth of the conclusions than as an aid in arriving at conclusions. Also Aristotle did not devise critical experiments with which to test his conclusions.

Whatever the shortcomings of Aristotle's worldview, for nearly two millennia, it dominated much of the intellectual world. It was the astronomy of ► **Geoffrey Chaucer** and ► **Dante Alighieri**, and of the Catholic Church. Aristotle's astronomy remains an integral and important part of our intellectual heritage – of our literature, our art, our philosophy, and our very language and way of thinking.

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Aristyllus

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Flourished **third century BCE**

Aristyllus was an early astronomer in the school of Alexandria. Little is known about him. He made astronomical observations during the first half of the third century BCE, and was probably a pupil of ▶ **Timocharis**.

Aristyllus and Timocharis are usually considered to have compiled the first true catalog of the fixed stars, in which stars are identified by numerical measurements of their positions. (In earlier lists, stars had been identified by descriptions of their locations, typically with respect to other stars and constellations.) The catalog is not extant. Indeed, while Aristyllus and Timocharis certainly amassed a set of numerical observations of star positions, it is not, strictly speaking, known whether these observations were assembled into a catalog or table. Probably fewer than 100 stars were observed, and the positions were reputedly of low accuracy. Observations by Aristyllus or Timocharis survive in ▶ **Ptolemy**'s *Almagest* for some 18 stars. The observations of Timocharis and Aristyllus were practically the only historical measurements of the positions of the fixed stars available to ▶ **Hipparchus**, who used them in combination with his own observations to discover the precession of the equinoxes.

Aristyllus is included in two lists of authors who wrote commentaries on the astronomical poem the *Phaenomena* by ▶ **Aratus**. (This poem enjoyed widespread popularity in Antiquity.) However Aristyllus' commentary is not extant. He is also included in a list of astronomers who wrote about "the pole," that is (in modern terms) stars close to the pole. In this context it might be noteworthy that three of the observations attributed to Aristyllus in the *Almagest* are of stars in the tail of Ursa Major. In *De Pythiae oraculis* (402 F) Plutarch includes Aristyllus in a list of astronomers who wrote in prose. However, most of the information about him comes from Ptolemy's *Almagest*, particularly the discussion of precession and its discovery by Hipparchus.

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Arrhenius, Svante August

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Born **Vik (or Wijk), Sweden, 19 February 1859**
Died **Stockholm, Sweden, 2 October 1927**

Chemist Svante Arrhenius was considered a child prodigy who reputedly taught himself how to read at the age of three. His father, Svante Gustaf Arrhenius, was a surveyor and estate manager for the University of Uppsala; his mother was Carolina Thunberg.

Arrhenius began his university education studying physics at the University of Uppsala. He felt that he was not receiving the best education, so he went to Stockholm to study under Professor Erik Edlund and to work on his doctorate. Arrhenius' dissertation, entitled

Recherches sur la conductibilité galvanique des é lectrolytes (Investigations on the galvanic conductivity of electrolytes), was presented in 1884, but mainly because his professors did not fully understand his work, the thesis and its defense received a low grade. In this treatise, Arrhenius began to develop his theory on the dissociation of ions in water, which led to his receiving the Nobel Prize for Chemistry in 1903. The mathematical formula for determining the effect of temperature on the reaction (velocity) rates of dissociated ions is now known as the Arrhenius equation.

In 1900, Arrhenius published his work *Lärobok I teoretisk elektrokemi* (Textbook of Theoretical Electrochemistry). In addition to his interest in chemistry, Arrhenius also studied physics and in 1903, he published his work on the physics of the northern lights in *Lehrbuch der kosmischen Physik* (Textbook of Cosmic Physics).

Arrhenius was offered a chair in the chemistry department at the University of Berlin in 1905, but, citing patriotic reasons, he declined the offer, desiring to stay in Sweden. The position of director of the Nobel Institute for Physical Chemistry in Stockholm was soon created for Arrhenius.

In addition to chemistry, Arrhenius contributed to physics, immunology, geology, cosmology, and climatology. In his 1906 book, entitled *Världarnas utveckling* (Worlds in the making), Arrhenius theorized that cool stars can collide and form nebulae from which new stars and planets are born and that life was spread via living spores scattered throughout the Universe carried by light pressure (panspermia). His *Stjärnornas öden* (Destiny of the stars) appeared in 1915. The latter two books went through several editions and translations into many languages.

Arrhenius has recently come into renewed prominence for a late nineteenth century calculation, the first, of the increase in the temperature of the Earth to be expected if the carbon dioxide content of the atmosphere increases. His estimate – a few degrees for a doubling of CO_2 as it then stood – is within the range of most modern calculations.

Arrhenius received several prestigious scientific honors and awards in addition to the Nobel Prize. In 1911, he was elected a fellow of the Royal Society and received its Davy Medal. He was awarded honorary degrees from Birmingham, Oxford, Cambridge, Greifswald, Groningen, Heidelberg, Leipzig, and Edinburgh universities.

Arrhenius was twice married and had two sons and two daughters. He is buried at Uppsala. A nearside lunar crater at latitude 55°.6 S, longitude 91°.3 W was named in 1970 by the International Astronomical Union to honor Arrhenius.

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Āryabhaṭa I

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Alternate Name

► Āryabhaṭa the Elder

Born (**India**), **476**

Āryabhaṭa I is the foremost astronomer of the classical age of India. He was born in Aśmaka, but later lived in Kusumapura, identified as the modern city of Patna. Nothing much is known about his personal life, except that he was a great and revered teacher. He is referred to as Kulapa (or Kulapati, vice chancellor), quite possibly of the Nalanda School. His work *Āryabhaṭīya* is the earliest preserved astronomical text of the scientific period of ancient Indian astronomy that bears the name of an individual.

Āryabhaṭa wrote at least two works on astronomy: (1) *Āryabhaṭīya*, a very well known work and (2) *Āryabhaṭa-siddhānta*, a work known only through references to it in later works. *Āryabhaṭīya* deals with both mathematics and astronomy and is noted for its brevity and conciseness of composition. It contains 121 stanzas in all and is divided into four chapters, each called a pāda. There exist a number of commentaries written in Sanskrit and other regional languages of India, and there also exist a large number of independent astronomical works based on it. Several English translations of *Āryabhaṭīya* have been published, including a critical edition of the text in Sanskrit accompanied by an English translation. Several critically edited commentaries on *Āryabhaṭīya* by earlier Indian astronomers, together with English translations, have also been published. *Āryabhaṭīya* was translated into Arabic around 800 as the *Zīj al-Arjabhar*.

The notable features of Āryabhaṭa's contributions are his acceptance of the possibility of the Earth's rotation, a set of excellent planetary parameters that may be based on his own observations, and a theory of epicycles. It may be noted that his theory of epicycles differs from that of ► **Ptolemy**. Ptolemy's epicycles remain the same in size from place to place whereas Āryabhaṭa's epicycles vary in size from place to place. Āryabhaṭa's contributions in mathematics include an alphabetical system of numerical notation, and giving the approximate value of Pi (π) as 3.1416. He also provided a table of sine differences, and formulae for sines of angles greater than 90°. He gave solutions to some indeterminate equations.

The other work, *Āryabhaṭa-siddhānta*, is known only through the references to it by other astronomers such as ► **Varāhamihira** and ► **Brahmagupta**. The astronomical methods and parameters in *Āryabhaṭa-siddhānta* differed somewhat from those in the *Āryabhaṭīya*, notably the reckoning of the day from midnight to midnight. Unfortunately, after Brahmagupta wrote the *Khaṇḍakhādyaka* based on the *Āryabhaṭa-siddhānta*, the original work was lost. Brahmagupta was a severe critic of Āryabhaṭa.

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Āryabhaṭa II

A. Vagiṣwari
Indian Institute of Astrophysics, Bengaluru, India

Alternate Name

► Āryabhaṭa the Younger

Flourished (**India**), ***circa* 950–1100**

Āryabhaṭa II, the Hindu astronomer, is best known for his work entitled *Mahāsiddhānta* or *Āryasiddhānta*. It has been established indirectly that he lived and worked around the tenth century. In order not to confuse him with the well-known astronomer Āryabhaṭa, who lived in the fifth century, he is known as Āryabhaṭa II or the Younger.

The *Mahāsiddhānta* or *Āryasiddhānta* is an astronomical compendium based on the orthodox tradition of *Smṛti*s (passages from Vedic literature). The treatise written in Sanskrit consists of 18 chapters and 625 *śloka*s (verses). The first 12 chapters deal with mathematical astronomy. Detailed derivations are presented on topics such as the mean and true longitudes of the planets, eclipses of the Sun and the Moon, the projections of eclipses, the lunar crescent, and the heliacal rising and settings of planets, including some calculations on conjunctions of planets as well as planets with stars. The remaining six chapters of the *Mahāsiddhānta* form a separate section called the *Golādhyāya* (On the sphere) where topics on geometry, geography, and algebra are discussed with reference to celestial astronomy. In Chapter 17, for example, shortcuts are provided for determining the mean longitudes of the planets. In Chapter 18, under the section called *Kuṭṭakādhyāya*, Āryabhaṭa II discusses the topic of the solution of indeterminate equations of the first degree. He improves upon earlier methods and suggests a shorter procedure. In his work, Āryabhaṭa II also touches upon several arithmetical operations such as the four fundamental operations, operations with zero, extraction of square and cube roots, the rule of three, and fractions. To represent numbers, he adopts the famous *kaṭapayādi* system of letter numerals. This practice does not conform to the method followed by some of his predecessors, who used the well-known *bhūta saṃkhyā* system of word numerals. The text does not say anything about the year and place of Āryabhaṭa II's birth, nor does it give any other personal information. In recent years several scholars have tried to establish an approximate period in which he lived based on the cross-references to his work made by other contemporary and younger scholars. D. Pingee believed that Āryabhaṭa II's treatise was written between 950 and 1100, and G. R. Kaye concludes that he lived before ► **Bīrūnī** (973-*circa* 1050). However, B. Datta disagrees with the date given by Kaye and argues that Āryabhaṭa II must have lived much later. Many recent articles on this subject state that his main work was written in 950. ► **Brahmagupta** (born: 598) leveled several criticisms on Āryabhaṭa I but not on Āryabhaṭa II. S. Dikshita has therefore put forward the argument that places Āryabhaṭa II later than Brahmagupta. Another important point noted is that Āryabhaṭa II tried to remove some discrepancies involving the criticism of Brahmagupta on Āryabhaṭa I. Thus Dikshita assigns him a date around śātavāhana śaka 875, which corresponds to 953. This corroborates the opinions of other historians as well.

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Āryabhaṭa the Elder

► Āryabhaṭa I

Āryabhaṭa the Younger

► Āryabhaṭa II

Asada, Goryu

Steven L. Renshaw
Kanda University of International Studies,
Chiba, Japan

Alternate Name

► Yasuaki

Born **Kitsuki**, (**Oita Prefecture**), **Japan**, **1734**
Died **Osaka**, **Japan**, **1799**

Goryu Asada played an important role in reforming the Japanese calendar and in inspiring Japanese astronomers to move from traditional Chinese to contemporary Western instrumentation and techniques. He was the fourth son of Keisai Ayabe, who was a Confucian scholar and physician in the *Kitsuki* domain. At birth, Goryu was given the name Yasuaki. He educated himself in astronomy and medicine and took over his father's practice in 1767 as official physician appointed to the *daimyo*, though Yasuaki's passion was studying astronomy and calendar making. In 1772, when the *daimyo* refused to release him from duties so that he could pursue his astronomical interests, Yasuaki left illegally from his domain. He fled to Osaka, where he changed his name to Goryu Asada and took up the study of astronomy and calendar science with a passion, while practicing medicine to make ends meet.

Asada gained a high reputation for his brilliance in calendar studies, including the development of his own calendar system. Much of his work was based on scientific ideas that were slowly and secretively creeping into the closed Japan of the Edo era (1603–1867). Many young and talented scholars who would later exert influence, such as ► **Yoshitoki Takahashi**, Shigetomi Hazama, and Tachu Nishimura, became Asada's pupils in what was called the *Senjikan* academy. In 1795, he was invited by the shogunate to join a project to reform the *Horyaku Reki* calendar, but he declined because of ill health. Instead, he recommended his best pupils, Takahashi and Hazama; both ended up going to Edo in Asada's place. Although Takahashi was the main representative, it was the combined effort of the Asada school that led to the *Kansei* calendar reform of 1798. This was the first calendar reform in Japan that was based on Western concepts of celestial movement. Because of poor health and perhaps overdrinking, Asada died the following year.

Asada made several observational "firsts," being the first Japanese astronomer to measure the Sun's rotation by observing sunspots. However, it is his steadfast use of both rational and empirical methods, and the inspiration he gave his students within that methodological framework, that gives lasting significance to his work. Asada stood in the middle of a time when trends were changing in Japan, trends that would culminate in major reforms of the nineteenth century. Dismayed with crude observational methods and outdated celestial models, members of the Asada school were encouraged to develop accurate observational techniques as well as creative mathematical modeling. Often, this work stood in direct opposition to what had become the rigid bureaucratic structure of the Tsuchimikado family in Kyoto that contained titular professionals.

Asada's school actively encouraged learning Western models and modes of astronomical observation, replacing traditional Chinese instruments with modern equipment and leading to more observational precision and accuracy. While not fully understanding all the written material obtained or translated from Western sources, Asada inspired his students to conduct systematic observations in order to empirically test models used in calendar reckoning.

The lack of historical background in the development of Japanese science and the associated political and social upheaval in the West were each a curse and a blessing. On the one hand, they were a handicap to acquiring full understanding of all theoretical concepts being developed. On the other hand, they allowed a certain intellectual freedom from debates regarding human positioning within the cosmos that characterized so much thinking in Europe. As a result, Asada and his students often developed unique if not wholly original solutions to calendrical problems.

Asada is sometimes seen as making the only original achievement in the history of astronomy in Japan, discovery of the so-called *Sho-Cho* (*Hsiao-Ch'ang*) law. This law dealt with variability in the length of the tropical year, of obvious concern in the development of an accurate calendar. (Earlier Chinese calendar scholars in both the Sung and the Yuan dynasties had discussed variation in the tropical year.) Asada sought to reconcile observed data obtained from Western sources with available historical sources and his own observations. Although not as elegant as ► **Pierre de Laplace**'s work based on perturbation theory, and perhaps somewhat simplified in its algebraic formulation, its "goodness of fit" to observed data at the time is quite remarkable.

Acknowledgments Assistance in Japanese translation by Saori Ihara.

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Ascham, Anthony

Thomas Hockey
Department of Earth Science, University of Northern Iowa, Cedar Falls, IA, USA

Alternate Name

► Askham, Anthony

Flourished **England, sixteenth century**

Englishman Anthony Ascham's *A Lytel Treatyse of Astronomy* (1552) is one of the earliest astronomy books written in English. A chronological list appears in the selected reference below.

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Johnson, Francis R. (1968). *Astronomical Thought in Renaissance England*. New York: Octagon Books.

Ashbrook, Joseph

Leif J. Robinson
Sky & Telescope, Cambridge, MA, USA

Born **Philadelphia, Pennsylvania, USA, 4 April 1918**
Died **Weston, Massachusetts, USA, 4 August 1980**

As a member of the *Sky & Telescope* staff from 1953 until his death, and its editor from 1964, Joseph Ashbrook augmented the high editorial and scientific standards established by its founders, ► Charles Federer and his wife Helen Federer. Ashbrook joined *Sky & Telescope* after receiving a Ph.D. from Harvard University in 1947 and teaching at Yale University (1946–1950) and Harvard University (1950–1953). His academic teaching career was compromised by a speech impediment, but as an editor, he taught by example through his dedication to clear and accurate writing.

Ashbrook's longest-lasting scientific contribution was the determination of the rotation period of Mars, which was incorporated in the *American Ephemeris and Nautical Almanac* from 1960 to 1983. He is also remembered for his discovery, in 1948, of periodic comet 47P/Ashbrook-Jackson. Ashbrook loved to compute things, almost obsessively. As a result, during his tenure, *Sky & Telescope* was awash with reductions of reader observations of lunar eclipses, transits of Mercury, young Moons, eclipsing stars, and other phenomena. Ashbrook had a lifelong interest in variable stars, and his knowledge of them was encyclopedic. The same was true of lunar and planetary astronomy, which throughout most of his career was a backwater for professionals. All these interests allied him closely with the amateur community. Ashbrook clearly helped usher in the modern era of professional-amateur collaboration.

Leif J. Robinson: deceased.

Yet it was as a purveyor of astronomical curiosities and arcana that Ashbrook is most remembered. His bimonthly feature "Astronomical Scrapbook" was a staple in *Sky & Telescope* from 1954 to 1980; most of his columns were collected in a book. Ashbrook brought a rare perspective to astronomical history since he was as familiar with German and French literature as he was with English literature. He read everything and remembered it; his home was lined with books.

Ashbrook was a member of the American Astronomical Society and the International Astronomical Union. A minor planet, (2157) Ashbrook, and a crater near the Moon's south pole were named in his honor. As Clark Chapman stated in his remembrance of the second editor of *Sky & Telescope*: "Astronomy has lost a fine man, a rigorous scientist, a gifted educator, and a skilled craftsman in the increasingly important field of scientific communication."

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Ashe, Edward David

Richard A. Jarrell
York University, Toronto, ON, Canada

Born **Bath, England, circa 1813**
Died **Sherbrooke, Quebec, Canada, 30 March 1895**

Ashe was the first professional astronomer employed by the Canadian government, an early practitioner of determining longitude by telegraph, and a pioneer in solar photography.

Ashe joined the Royal Navy in March 1830. With evident mathematical and scientific abilities, he studied gunnery at Portsmouth and, having passed his examinations in 1836, was posted to several ships serving in the Mediterranean and the Pacific until 1849 when an accident removed him from active duty. He received a commission of Lieutenant in 1842.

The government of the Province of Canada proposed building a small observatory in the Citadel in Quebec City to provide accurate time to the port. Ashe was proposed by the Royal Navy to direct the observatory; he arrived in 1850 having obtained instruments from the Royal Greenwich Observatory. Machinery for a time ball was soon in place, along with a small telescope for transit observations. After a request from the Geological Survey of Canada, Ashe broke his routine during the winter of 1856–1857 by determining the longitudes of a number of Canadian towns. This was accomplished with a portable transit and telegraphic connection to the Quebec Observatory. Given the imprecision of Quebec's longitude, Ashe exchanged signals with ▶ **William Bond** at Harvard College Observatory, as the longitude of Cambridge, Massachusetts, had been measured relative to Greenwich by the exchange of chronometers.

Ashe joined the American eclipse expedition to Cape Chidley, Labrador, in July 1860. This experience persuaded him to obtain a larger telescope for solar observations. In the early 1860s, he observed sunspots visually with his smaller telescope and followed keenly the work of ▶ **Richard Carrington** and ▶ **Warren de la Rue**. Ashe's theory of sunspot formation through the infall of meteor-like bodies, published in the *Monthly Notices* in 1865, was dismissed by de la Rue. After 5 years of lobbying, funds were provided for an 8-in. equatorial refractor by ▶ **Alvan Clark**. In addition to the refractor, he obtained a Voigtländer camera, but having no one to tutor him in astronomical photography, he corresponded with ▶ **Hermann Vogel**, editor of the *Photographische Mittheilungen*.

With a total eclipse due in August 1869 in the American Midwest, Ashe organized a small "Canadian Eclipse Expedition." The Clark refractor and camera were shipped to Jefferson City, Iowa, where he was able to obtain four good plates. His observations and interpretations of prominences were dismissed out of hand by de la Rue at the Astronomical Society, of which Ashe was a fellow, although other astronomers, such as Lord Lindsay, found his work valuable.

During the 1870s Ashe undertook further longitude determinations for the Quebec Crown Lands Department. Solar observations with the Clark telescope appear to have ceased in 1873. He joined with other Canadian observers in preparing for the transit of Venus in 1882 and retired the following year; a son, William Austin Ashe, eventually succeeded him as director. Ashe was promoted to Commander in 1865.

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Ashraf: al-Malik al-Ashraf (Mumahhid al-Dīn) ʿUmar ibn Yūsuf ibn ʿUmar ibn ʿAlī ibn Rasūl

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Abteilung Islamwissenschaft, Rheinische Friedrich-Wilhelms Univeristät Bonn, Bonn, Germany

Born ***circa*** **1242**
Died **(Yemen), 22 November 1296**

al-Ashraf ʿUmar, the third of the Rasulid sultans in Yemen, was a prolific scholar who wrote a number of works with astronomical content. The date of al-Ashraf ʿUmar's birth is uncertain, and only a few details of his life are recorded. In 1266–1267, al-Ashraf ʿUmar commanded a military mission for his father, al-Muẓaffar

Yūsuf, to the northern town of Ḥajja. Later, he became governor of al-Mahjam along Wādī Surdud in the coastal region of Yemen. In 1295, his father appointed him coregent. Four months later al-Ashraf ʿUmar succeeded him on the throne. In the same year the sultan visited al-Dumluwa and later the coastal town of Zabīd. He reigned in Yemen for about 2 years until his death in 1296. al-Ashraf ʿUmar was buried in the Ashrafiyya school he had founded in Taʿizz. He left behind six sons and two daughters, both married to sons of al-Ashraf ʿUmar's brother, al-Muʾayyad Dāwūd, who succeeded him on the throne.

In contrast to his father's reign, which was long and prosperous, al-Ashraf ʿUmar's own reign was short-lived and without major historical significance. His minor importance for the political history of his realm is counterbalanced by his considerable contribution to science.

al-Ashraf ʿUmar wrote some 13 treatises on a variety of scientific fields including medicine, genealogy, agriculture, veterinary medicine, astronomy, and astrology. He made several astronomical instruments, among which were astrolabes. For the sake of brevity, this article will mention only his extant contributions to astronomy and astrology.

The Metropolitan Museum of Art in New York possesses an Islamic astrolabe that is signed by ʿUmar b. Yūsuf b. ʿUmar b. ʿAlī b. Rasūl al-Muẓaffarī, i.e., al-Ashraf ʿUmar, dated 1291. The instrument measures 15.5 cm in diameter. It is competently made without being particularly sophisticated, but some unusual features make it unique: among others, the rete presents a scale for the lunar mansions; and the astrological information on the back is given by using planetary symbols probably adopted by Muslims from Greek sources. The plates are engraved for latitudes in Yemen and Hejaz and were constructed using the tables presented in al-Ashraf ʿUmar's instrument book, not by using geometrical construction.

al-Ashraf ʿUmar's instrument book, entitled *Muʿīn* (or *Minhaj*) *al-ṭullāb fī al- ʿamal bi-'l-asṭurlāb*, is preserved in two manuscripts in Cairo and Tehran. The sultan mentions there the extensive treatise on spherical astronomy and astronomical instruments written by ▶ **al-Marrākushī**. al-Ashraf ʿUmar's treatise contains an explanatory text on the construction of an astrolabe, diagrams of its different parts, and tables for the construction of, for example, the altitude circles and the azimuth circles for specific latitudes in Yemen and Hejaz and tables of the shadow lengths and the altitude of the Sun at the beginning of the afternoon prayer. The two star catalogues use the degree of the ecliptic with which the star culminates and the radius of the day circle of the star and not, as more usual, the ecliptic or equatorial coordinates.

The star pointers on the rete of al-Ashraf ʿUmar's astrolabe do not correspond with the star positions mentioned in his treatise. Nevertheless, the connection between instrument and text is definite. In particular, the back of the astrolabe made by al-Ashraf ʿUmar and the illustration of the back of an astrolabe in his treatise are virtually identical. It is indeed rare that we find references in the medieval literature to specific instruments that have survived to this day.

In his instrument book, al-Ashraf ʿUmar deals not only with the astrolabe but also with horizontal sundials, the water clock, and the magnetic compass. At the end, there are notes by two of al-Ashraf ʿUmar's teachers. The section on the sundial contains tables of coordinates for marking the seasonal hours on the shadow traces of the zodiacal signs computed for latitudes in Yemen and Hejaz, using 23° 30′ for the obliquity of the ecliptic. These tables are of the same kind as those of ▶ **Ḥabash** and ▶ **al-Marrākushī**, who use 23° 51′ and 23° 35′, respectively. The section on the magnetic compass describes the construction and use of a floating compass.

al-Ashraf ʿUmar explains the making of the compass bowl, with the rim and the scales engraved there, and the preparation of the magnetic needle, which is inserted crosswise in a stalk. He continues with the determination of the meridian under bad weather conditions, using the magnetic compass, and the use of this information to find the *qibla*, the sacred direction of Islam to Mecca, which one should know to fulfill several Islamic religious obligations such as the five daily prayers. This is the first time the magnetic compass is mentioned in a medieval astronomical treatise and also the first time that it is used as a *qibla*-indicator.

The notes by two of his teachers inform us that they have inspected four or six astrolabes, made by al-Ashraf ʿUmar himself that are most accurate and skillful. They testify to his excellence in the construction of astrolabes and give him permission to make whatever he likes in the way of astrolabes. Additionally, they mention two water clocks made by al-Ashraf ʿUmar. Therefore, it is probable that the sultan also made other instruments, such as the sundials described in his instrument book.

al-Ashraf ʿUmar's third contribution to the science of the stars is his extensive *Kitāb al-Tabṣira fī ʿilm al-nujūm*, preserved in Oxford. It contains 50 chapters on astrology, astronomy, and related subjects. In essence, it represents an introduction to medieval astronomy and astrology that includes basic zodiacal and planetary astrology as well as a range of information on timekeeping systems. The subjects covered include the zodiac, the course of the Sun, the course of the Moon, planets, fixed stars, eclipses, astrolabes, lunar mansions, calendar systems, determination of the *qibla*, weather, medicinal regimes for each season, the agricultural calendar, and systems of numbers. Most of the chapters deal with astrology, but there are also lengthy chapters on timekeeping including tables displaying the solar altitude and longitude of the horoscope as functions of the solar longitude for each seasonal hour of the day. Another table gives the geographical coordinates of different localities. The *Tabṣira* draws on a wide variety of earlier texts and authors; among others, Dorotheus, ► **Kūshyār ibn Labbān** and ► **al-Fārisī** are mentioned.

In Chap. 32, al-Ashraf ʿUmar documented the seasonal reckoning of changes in nature and human activities. This almanac is the earliest known treatise of this kind written in prose about Yemen and was compiled probably in about 1271. It is arranged in tabular form. Each page contains daily data for half of the solar Christian month (beginning in October) and informs on the entry of the Sun in each sign, the hours of daylight and darkness, and the shadow lengths for the beginning of the midday and afternoon prayers (for the beginning and midpoint of each month). It also includes days elapsed since *nawrūz*, the Persian New Year. Another Yemeni source at about the same time, ► **al-Fārisī**'s folk-astronomical treatise *Tuḥfat al-rāghib wa-turfat al-ṭālib fī taysīr al-nayyirayn wa-ḥarakāt al-kawākib*, makes use of this navigational calendar of the seafarers in the Indian Ocean, too. For the *anwāʾ* (certain stars used for weather prognostication) al-Ashraf ʿUmar relied upon Ibn Qutayba. The information in the almanac derives both from the general almanac tradition and from knowledge of local practices and folklore.

al-Ashraf ʿUmar was not a great genius but a teachable pupil and a versatile scholar. His astronomical treatises bear a great deal of information about earlier texts. The uniqueness of his astronomical work is due in part to the vicissitudes of history. al-Ashraf ʿUmar's oeuvre, for the first time, documents in tabular form the yearly astronomical and agricultural events in medieval Yemen. It is al-Ashraf ʿUmar's description of the magnetic compass that, for the first time, proves that the magnetic compass was used as a *qibla*-indicator, though the author makes no claim to have invented the device. And it is a real windfall that one of the sultan's astrolabes and his treatise on the construction of the astrolabe are preserved.

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Askham, Anthony

▶ Ascham, Anthony

Asten, Friedrich Emil, von

▶ von Asten, Friedrich Emil

Aston, Francis William

Scott W. Teare
New Mexico Tech, Socorro, NM, USA

Born **Birmingham**, **England**, **1 September 1877**
Died **Cambridge**, **England**, **20 November 1945**

English physicist William Aston is best known for the invention of the mass spectrograph to measure accurate masses of the atoms of individual isotopes of many elements. He is known within astronomy particularly for the demonstration that one helium atom is about 0.1 % less massive than four hydrogen atoms, thus making clear the potential of hydrogen fusion as a stellar energy source.

Aston was rare among scientists in that he chose to work both inside and outside academic circles, and through this choice he achieved great success. He began his early education at Harborne Vicarage School and Malvern College, and then entered Mason College, Birmingham, as a student of physics and chemistry in 1894. During his time at Mason College, Aston had the opportunity to study with the eminent physicist ▶ **John Poynting** and other notable scientists of the day.

In an interesting career choice, Aston took a position in the laboratory of a brewery, which excited his interest in the techniques and tools of evacuating pressure vessels. He took this position in spite of his having the early career success of publishing the results of his studies of the optical properties of organic acids. (This work was sponsored by the Forster Scholarship he received in 1898.) His interest in vacuum science led to Aston receiving a scholarship to the University of Birmingham in 1903, and he returned to academic life to study the properties of discharge tubes.

His work at the University of Birmingham brought Aston to the attention of Sir J. J. Thomson (1856–1940). It resulted in an offer to work as Thompson's assistant at the prestigious Cavendish Laboratory in Cambridge. At the laboratory, Aston worked on studies of positive rays, i.e., accelerated atoms or molecules carrying positive charge, and searched for evidence that there was more that one isotope of neon.

With the exception of the period of World War I, Aston remained at Cambridge for the remainder of his career. During the war, he supported the effort by working on enhancing airplane fabrics and coatings with the Royal Aircraft Establishment in Farnborough. At the end of the war he returned to the Cavendish Laboratory and restarted his work on the separation of the isotopes of neon.

Aston's study of neon isotopes led directly to his development of the mass spectrograph, which could determine the mass of an isotope to better than one part in thousand. Using his invention, Aston discovered that the masses of other isotopes could be expressed as multiples of the mass of oxygen, which became known as the "Whole Number Rule." He eventually discovered 212 isotopes (more than two-thirds of the stable ones now known).

Aston received numerous awards for his work including honorary doctorates and several academic medals. Among his more prestigious awards were the fellowship of the Royal Society and the Nobel Prize in Chemistry (1922); he accepted the latter with the lecture entitled "Mass Spectra and Isotopes." Aston's Nobel citation recognizes his invention of the mass spectrograph and the discovery of the "whole number rule."

Aston wrote several books, and his work on the mass spectrometer was published in the most prestigious journals of the day. In addition to being a gifted academician, Aston was a musician and a sportsman. He played several instruments and enjoyed a number of diverse sporting activities.

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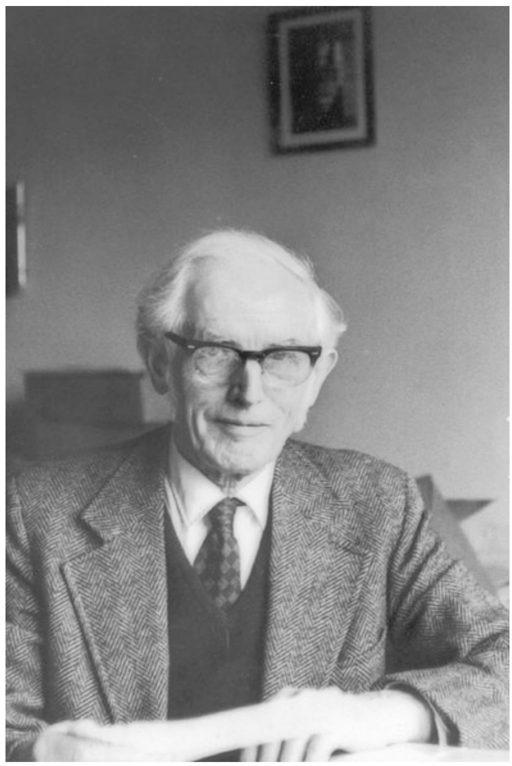
Atkinson, Robert d'Escourt

Matthew Stanley
Iowa State University, Ames, IA, USA

Born **near Rhayader**, **(Powyss) Wales**, **11 April 1898**
Died **Bloomington**, **Indiana**, **USA**, **28 October 1982**



Atkinson, Robert d'Escourt. Reproduced by permission of Indiana University Department of Astronomy and Indiana University Archives

Robert Atkinson is best known for his contributions to stellar energy theory.

Atkinson's childhood education was at Manchester Grammar School. Attending on an

Open Scholarship, he graduated from Hertford College, Oxford, in 1922 with a first-class degree in physics. Under the supervision of ► **Adolph Lindemann** he worked as a demonstrator and researcher at the Clarendon Laboratory for 4 years. In 1926 Atkinson received a Rockefeller Traveling Fellowship, which he used to study in Göttingen with James Franck. He attained his D. Phil. in 1928 in physics with minors in mathematics and astronomy. After teaching briefly at the Technische Hochschule in Berlin, he took a professorship of physics at Rutgers University in New Jersey, USA, in 1929. Atkinson remained at Rutgers University for 8 years, once turning down a job offer from Princeton University. In 1937, he accepted the post of chief assistant at the Royal Observatory, Greenwich, England, and for a time he worked at Aberdeen Proving Ground in Maryland, USA under ► **Edwin Hubble** – one of several times he was sent abroad during World War II. In 1964, Atkinson retired from Greenwich and took a professorship at Indiana University. He became emeritus in 1979, and died in Bloomington in 1982.

Atkinson was named fellow of the Royal Astronomical Society [RAS] in 1937, and served as secretary from 1940 to 1941. He was a founding member of the Institute (later Royal Institute) of Navigation, becoming a fellow in 1953. He served as president of the British Astronomical Association in 1960–1961 and 1961–1962. Atkinson received the Eddington Medal at the RAS in 1960 for his work on fusion in stars. He was awarded a Royal Commission Award to Inventors in 1948. In 1977, the International Astronomical Union named a minor planet (1827) Atkinson in his honor.

In the late 1920s, Atkinson worked with ► **Fritz Houtermans** on the application of ► **George Gamow**'s barrier penetration theory to stellar interiors. Their work showed that Gamow's theory allowed for nuclear synthesis of the elements as a source of stellar energy, a possibility suggested earlier by ► **Arthur Eddington** and others, but never put on a firm physical basis. They calculated reaction rates for proton capture by light nuclei, and showed that heavier elements could be created by a sequence of two-body interactions. This dismantled the widely held objection that transmutation in stellar interiors would require a spectacularly improbable simultaneous meeting of four or more particles, and eventually helped pave the way for the acceptance of fusion as the energy source for stars. The process they described was a series of cyclic nuclear reactions that used heavier elements as catalysts: once there were sufficient amounts of certain heavy elements, helium production could be a regenerative process. The fundamentals of their theory were strikingly similar to the cycles described by ► **Hans Bethe** and ► **Carl von Weizsäcker** in the late 1930s.

Atkinson and Houtermans published their work in 1929 in the *Zeitschrift für Physik*, but it received little attention since their calculations rested on the still dubious assumption that the majority of matter in stars was hydrogen. In 1931 and 1936, after a high hydrogen content came to be better accepted, Atkinson recast and extended their work in papers titled "Atomic Synthesis and Stellar Energy" in the *Astrophysical Journal*. Here he showed the steep dependence of reaction rates on temperature, which was consistent with Eddington's theory of a small range of stellar core temperatures in the main sequence and inconsistent with ► **Edward Milne**'s proposal of a constant energy generation rate throughout a star. Atkinson argued that his work suggested that the brightest stars would have a short lifetime (roughly 10^8 years for a B star), and used this to support the "short" timescale universe, in contradiction to the "long" timescale of 10^{11-12} years espoused by ► **James Jeans**. Finally, Atkinson contended that the cosmic abundances of the elements could be accounted for largely by the processes in stellar interiors, and that white dwarf stars did not need any nuclear source of energy to maintain their luminosity.

Atkinson's move to Greenwich in 1937 largely halted his work on stellar physics. He later said he regretted taking the chief assistant position. The observatory was "a little like a factory" and provided little opportunity to pursue his scientific interests that were not directly related to pragmatic astronomical matters. The war in Europe provided him with plenty of work, however, and he found himself degaussing ships and calculating ballistics until 1943. He then worked on photometry with Hubble until 1946, when he was sent to Europe to find out what the observatories there needed to recover from the war. (His fluency in German was invaluable.)

After the war Atkinson's astronomical work focused on instrumentation and positional astronomy. He designed a major improvement on the transit circle, and developed a theory of, and measurement techniques for, the problem of telescope tube flexure. He brought attention to systematic errors from the 1930/1931 Eros Campaign caused by tube flexure in the Greenwich Astrographic, which led to a revision of the value for the solar parallax. Atkinson also invented novel techniques for filming solar eclipses, and persuaded the International Astronomical Union to redefine the instantaneous pole of celestial coordinates to remove its dependence on the rotation axis of the Earth. His final years at the Royal Observatory were spent overseeing the institution's move to Herstmonceux Castle in Surrey.

After retiring as chief assistant, Atkinson returned to stellar physics and began work on general relativity. He taught courses at Bloomington on relativity, binary stars, and positional astronomy. While there, he designed a unique "standard time" sundial that remains a landmark on campus. His personal research was investigating general relativity in the framework of Euclidean geometry.

Atkinson's papers are at Indiana University, Bloomington, in excellent condition, and well organized. The finder's guide is online and includes a list of most of his published papers. The American Institute of Physics has an extensive oral history interview with Atkinson recorded in 1977. They also hold correspondence between him and figures such as ▶ **Arthur Eddington** and ▶ **Henry Norris Russell**.

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Augustine of Hippo

Nicholas Campion
University of Wales, Trinity Saint David, Ceredigion, GB

Alternate Name

▶ Aurelianus Augustinus

Born **Tagasta (Souk-Ahras, Algeria), 354**
Died **Hippo (near Annaba, Algeria), 430**

The son of a pagan father and Catholic mother, Saint Augustine had a good classical education though, perhaps unique among classical philosophers, he failed to learn Greek, which he disliked intensely, to any more than a rudimentary level. At the age of 19 he joined the Manicheans, a Christian church that had adopted the Persian cosmology in which the structure and history of the Universe was based on the perpetual struggle between light (good) and darkness (evil). To the Manicheans, Christ was the representative of light. During this period Augustine achieved recognition for his philosophical work and was appointed professor of rhetoric at Milan. At the age of 28, he converted to Catholicism and at the same time began reading ▶ **Plato** and the Neoplatonic philosophers, Plotinus and Porphyry. Although he personally challenged such elements of Neoplatonic cosmology as the divinity of the stars, the stamp of Augustine's authority established a favorable attitude to Platonic cosmology within medieval Christian culture. He was baptized in 387, and in 391 he was ordained a priest in Hippo, near Carthage in what is now Tunisia. Augustine was appointed bishop of Hippo in 395 and spent the rest of his life there.

In his two great works, *Confessions*, composed around 397, and *City of God*, written in 410, Augustine established himself as the foremost theologian of the Catholic church. His argument that the newly christianized Roman state was the representative of the Kingdom of God on Earth gave the church a firmly conservative identity as the ally, rather than opponent, of the political order. This convenient relationship was to be the basis of church-state relations through to the early modern period.

Augustine's contribution to the history of astronomy is based on his definitive denunciation of astrology, the result of which was to both confirm the separation of astrology from astronomy for many Christians and provide a rationale for Christian opposition to astrology to the present day. Augustine had studied astrology during his time as a Manichean and found he had no theological objection to it, because astrologers neither offered sacrifices nor prayed to spirits for assistance in their divination. However, his conversion to Catholicism resulted in a substantial change of heart. He now regarded God as the only supreme power in the Universe, possessing direct and immediate authority over the entire natural world. He tackled astrology in two levels: First, Augustine argued that it was incompatible with Christianity, and second, he pointed out illogicalities in its reasoning.

In the *Confessions* Augustine claimed that to argue that God's authority could be exercised via the stars caused theological offense, for it both limited God's power to intervene directly in human affairs and implicated Him in the stars' less worthy decisions. It also absolved human beings from responsibility for their own actions and, ironically, pushed that guilt onto God who, according to Augustine's version of astrological logic, would have instructed the stars to cause men to sin in the first place. To pursue this argument to its logical conclusion, God was the cause of sin. He widened his attack in the *City of God*, dealing at length with the issue of twins and the question of how two babies born at the same time could have different lives. Augustine also tackled the problem of the apparent contradiction between the astrally determined fate inherent in an astrology of individual births on the one hand and the assumption of free will inherent in the astrological election of auspicious moments to begin new enterprises on the other. He questioned whether astrology applied to worms or trees and challenged the belief that the rise of the Roman Empire had been astrologically determined rather than the result of God's favor. Augustine also dealt with the claim that astronomical alignments functioned as signs rather than causes, pointing out that even astrologers who argue that the stars signify events nevertheless talk as if they cause them and hence are still impinging on territory rightly reserved for God. In Book VII he went on to ridicule the flawed logic behind stellar divinities, although in Book V he had also sought allies among the pagans, appealing to them on the grounds that, if astrologers ascribed power over human affairs to the stars, they were challenging the authority of pagan deities as well as the Christian God.

Even though Augustine regarded the reasoning behind astrology as profoundly flawed, he had no doubt that it worked, although he changed his mind on how. In the *Confessions* he argued that it appeared to work because of chance. Thus an astrological forecast appeared to be right in the same way as a volume of poetry might fall open at a page meaningful at that moment. In the *City of God*, Augustine took a firmer line, claiming that evil spirits fed correct predictions to astrologers.

Augustine's attack on astrology should be seen as an attempt to despiritualize the Universe at the same time as he constructed a new moral cosmology, saving religious authority for God alone. His criticism of secular, liberal education and advocacy of Scripture as the ultimate source of truth also left little room for classical astronomy, leaving the Genesis creation story as the basis of Catholic cosmology. Although he singled out **Thales**' prediction of the eclipse of 585 BCE for praise, his philosophy is clearly dominated by a combination of Scripture and Neoplatonism, which between them taught that all truth is based on faith and abstract reason rather than evidence or observation. While Augustine's separation of astrology from astronomy was therefore of great significance, the effect of his teaching was to retard the development of astronomy in the Christian world until the seventeenth century.

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Aurelianus Augustinus

► Augustine of Hippo

Autolycus

Ian T. Durham
Saint Anselm College, Manchester, NH, USA

Born **Pitane** (**Candarli**, **Turkey**), ***circa*** **360 BCE**
Died ***circa*** **290 BCE**

Two of Autolycus's three books have come down to us and are considered the oldest original treatises on mathematics that have survived (in translation) in their entirety.

Little is known about the life of Autolycus, and even the dates associated with him are not clear. It is generally believed that he was older than Euclid, and it is known that he taught the philosopher Arcesilaus, founder of the Middle Academy. Autolycus was a contemporary of ► **Aristotle** and is generally considered to have been primarily an astronomer. The only known specific piece of information on his life comes to us from Diogenes Laertius, who reports that Autolycus was accompanied by Arcesilaus on a trip to Sardis.

The two of Autolycus' treatises on astronomy that have survived are *De orto* (On risings and settings) and *De sphaera mota* (On the moving sphere). They survived in large part due to their inclusion in *Little Astronomy*, which was an early compilation similar to ► **Ptolemy**'s later *Great Collection* or *Almagest*. *De sphaera mota* deals generally with great circles, including meridian circles and latitudinal parallels. It also deals with visible and invisible areas produced by a light source shining on a rotating sphere. In this book Autolycus used the same form of writing as Euclid, including propositions and proofs.

De orto is largely a book on observational astronomy. Autolycus is known to have relied heavily on ► **Eudoxus** for his astronomical ideas and was a supporter of Eudoxus' theory of homocentric spheres (a series of embedded spheres that held the stars and planets, and that all rotated on an axis parallel to the Earth's). Autolycus attempted (unsuccessfully) to explain the variability in brightness of Venus and Mars within the context of this theory and also attempted to rectify the theory with the concept of eclipses, again with no real success. It is interesting to note that there is no evidence that Autolycus, despite his work with spheres, had any knowledge of spherical trigonometry. However, his propositions indicate that there should have been some knowledge of that type at the time. Many scholars conjecture that there must have been a contemporary standard textbook on the subject that has been lost to history. Some suggest, simply through the process of elimination, that the author of this unknown textbook was Eudoxus, but not a shred of proof exists to support that claim.

A crater on the Moon is named for Autolycus.

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Auwers, Arthur Julius Georg Friedrich von

► von Auwers, Arthur Julius Georg Friedrich

Auzout, Adrien

Robert A. Garfinkle
Union City, CA, USA

Born **Rouen**, **France**, **28 January 1622**
Died **Rome**, (**Italy**), **23 May 1691**

Adrien Auzout is known primarily for his work in astronomy, mathematics, and physics, with his main contribution to astronomy being his efforts in the development of the filar micrometer and telescopic sights. Auzout's father was a local government official in the court of Rouen and possibly also the Viscount of Rouen. There appears to be no record of Adrien's schooling, but it was not unusual for the son of an aristocrat to have received his education by private tutors. The evidence is not clear whether he was a Catholic or not. His first notable scientific work came in 1647, when he created a vacuum inside another vacuum in order to prove that the pressing weight of a column of air causes the mercury in a barometer to rise.

In a letter in 1665, Auzout wrote that he believed the heliocentric universe hypothesis of ► **Nicolaus Copernicus** was not absurd nor a false philosophy and that those ideas were not in conflict with Biblical teachings. He felt the Bible was not designed to teach people about the sciences, in particular physics and astronomy.

In the same year Auzout was instrumental in convincing King Louis XIV to create an observatory in Paris and to establish a French scientific society consisting of professional scientists. The following year, Auzout became one of the founding members of the Académie des sciences when it received its official government sanction and was a founding member of the Royal Observatory. On 22 March 1667, the site for the Paris Observatory was purchased, and construction of the observatory was soon under way. Auzout was also involved in the negotiations to bring Italian astronomer ► **Giovanni Cassini** to Paris in 1668.

The first telescope micrometer, used for measuring the angular distance between two celestial objects, was developed in the late 1630s by English astronomer ► **William Gascoigne**. Gascoigne used threads from a spider web for the instrument's crosshairs. (He also invented the knife-edge micrometer.) In 1666, Auzout, unaware of Gascoigne's work, developed a filar micrometer with the assistance of the astronomer ► **Jean Picard**. The device employed a stationary and a movable wire used for making measurements through a telescope. Auzout refined and improved his micrometers between 1666 and 1671. In his first micrometer, he moved the wire by hand and later used a threaded screw for more accurate movement of the wire. In 1667, Auzout developed the idea of placing the cross wires at different planes so that the line of sight between them could be assured by the observer. His invention was used for both astronomical measurements and land surveying. In the 1700s, filar micrometers were used for the first time for determining the exact position of lunar features.

A dispute over a flawed translation of the works of ► **Vitruvius** by the physician and architect Claude Perrault - another founding member of the Académie des sciences - appears to be the primary reason for Auzout's resignation from the Académie in 1668. Shortly after this dispute erupted, Auzout left to live in Rome.

A lunar nearside crater at latitude 10°. 3 N, longitude 64°. 1 E, was named for Auzout by the International Astronomical Union in 1961.

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Avempace

► Ibn Bājja: Abū Bakr Muḥammad ibn Yaḥyā ibn al-Ṣā'igh al-Tujībī al-Andalusī al-Saraqusṭī

Averroes

► Ibn Rushd: Abū al-Walīd Muḥammad Ibn Aḥmad Ibn Muḥammad Ibn Rushd al-Ḥafīd

Avicenna

► Ibn Sīnā: Abū ʿAlī al-Ḥusayn ibn ʿAbdallāh ibn Sīnā

Azarquiel

► Zarqālī: Abū Isḥāq Ibrāhīm ibn Yaḥyā al-Naqqāsh al-Tujībī al-Zarqālī