Solar Physics at the Kodaikanal Observatory: A Historical Perspective

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1 Background

The Kodaikanal Observatory traces its origins to the East India Company, which started an observatory in Madras "for promoting the knowledge of astronomy, geography, and navigation in India." Observations began in 1787 at the initiative of William Petrie, an officer of the Company, with the use of two 3-in achromatic telescopes, two astronomical clocks with compound pendulums, and a transit instrument. By the early nineteenth century, the Madras Observatory had already established a reputation as a leading astronomical center devoted to work on the fundamental positions of stars, and a principal source of stellar positions for most of the southern hemisphere stars. John Goldingham (1796–1805, 1812–1830), T.G. Taylor (1830–1848), W.S. Jacob (1849–1858), and Norman R. Pogson (1861–1891) were successive Government Astronomers who led the activities in Madras. Scientific highlights of the work included a catalogue of 11,000 southern stars produced by the Madras Observatory in 1844 under Taylor's direction using the new 5-ft transit instrument.

The observatory had recently acquired a transit circle by Troughton and Simms, which was mounted and ready for use in 1862. Norman Pogson, a well known astronomer whose name is associated with the modern definition of the magnitude scale and who had considerable experience with transit instruments in England, put this instrument to good use. With the help of his Indian assistants, Pogson measured accurate positions of about 50,000 stars from 1861 until his death in 1891. During this period, two total eclipses and one annular eclipse of the Sun were visible from India. Pogson led teams to all three of them. The first one of these, a total eclipse on 18 August 1868, created an enormous interest amongst European astronomers and preparations for its observation were made in England and France for many months preceding the event. Teams of professional astronomers from both countries arrived in India and established their camps at Guntoor, on the central line of the eclipse. The Madras Observatory astronomers had their camp at Masulipatam

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and Vunpurthy further east. This eclipse is of great historical significance as it was the first time when spectroscopes were used during an eclipse event. A new line close to the D_2 line of sodium and to the left of it was seen in the spectrum of the chromosphere. Pogson's hand-drawing of the line is shown in Fig. 1.

The discrepancy in the wavelength of this line with the sodium line was confirmed by Norman Lockyer, who could not ascribe it to any known terrestrial element. This observation, in fact, marks the discovery of helium. During the same eclipse, observations of the hydrogen Balmer lines in the spectra of the prominences established their gaseous nature.

Historically, the eclipse of 1868 is an important landmark associated with the birth of solar physics in India. Janssen and Lockyer made effective use of the spectrograph to show that "red prominences could at any time be examined, without waiting for an eclipse at all." During the annular eclipse of 6 June 1872, which was

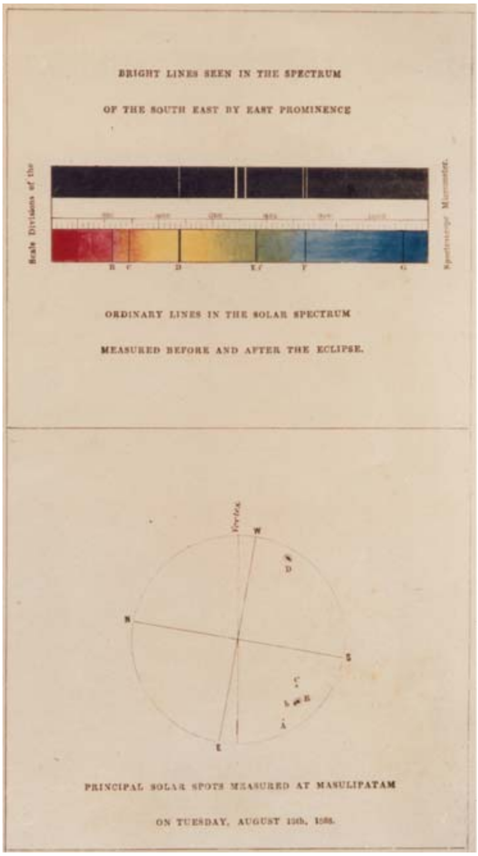

Fig. 1 Hand colored sketch of the solar spectrum recorded during the total solar eclipse at Masulipatam, India, on 18 August 1868 (from IIA archives)

visible from Madras, Pogson found the bright chromospheric spectrum flash out for a short duration on the formation and again at the breaking up of the annulus. This is the first observation on record of viewing the flash spectrum at an annular eclipse.

In May 1882, Pogson proposed a 20-in telescope to augment the needs of his observatory. The proposal had received active support both in India and Britain and the search for a suitable location in the southern highlands of India was authorized. The task was entrusted to Michie Smith, Professor of Physics at the Christian College, Madras, who had arrived in India in 1877. Michie Smith undertook a survey of the Palni and Nilgiri Hills in 1883–1885, his observations covering the twin requirements of transparency and steadiness of image during both day and night. However, there was a delay in the project being cleared by the Astronomer Royal in England as he felt "saddling Pogson with additional work connected with the new large equatorial, when he has accumulated large arrears in observations, would not be desirable".

In 1879, a Committee was appointed by the British Government, consisting of some leading astronomers in the country, to consider and advise on the methods of carrying on observations in solar physics. One of the tasks of the Committee, which came to be known as the Solar Physics Committee (hereafter, SPC), was to reduce the solar photographs taken daily since 1878 in Dehradun with a photoheliograph. The British Government in India had supported the work in the belief that a study of the Sun would help in the prediction of the monsoons, their success and failure, the latter often leading to famines that caused such a havoc. SPC also suggested to the Government of India "that photographs of the Sun should be taken frequently in order that India might assist towards securing a permanent record of the number and magnitude of the sunspots and other changes in the solar surface." At a later date, they added that special spectroscopic observations should also be taken in India in order to collect evidence that will probably throw light on the constitution of the Sun. In 1885, the Royal Society, London, constituted the Indian Observatories Committee comprised of the Astronomer Royal, and a few Fellows of the Royal and Royal Astronomical Societies.

The Committee was entrusted with the task of coordinating the work of Madras and Bombay Observatories and of advising the Secretary of State for India pertaining to the administration of these observatories. The suggestions of SPC regarding regular observations of the Sun and the thinking of the Indian Observatories Committee on the future orientation of activities of the Madras Observatory converged to pave way for the creation of a new observatory in the hills of South India. After the death of Norman Pogson on 23 June 1891, a series of initiatives were taken that eventually led to the establishment of the Solar Physics Observatory in Kodaikanal, a change in the administrative control of the observatories, and the relegation of the Madras Observatory to a secondary status. It took about 9 years to effect this transition.

2 Birth of the Kodaikanal Observatory

In October 1891, John Eliot, the Meteorological Reporter to the Government of India wrote to the Government of Madras about a rethinking of the status of the Madras Observatory by the Secretary of State, Government of India, on the advice of the Astronomer Royal. They felt it was desirable that, in place of the Madras Observatory, a large Astronomical Observatory should be maintained in India, the work at which should, as defined by the Astronomer Royal in a letter dated 14 April 1883, consist of (1) astronomical work proper, including the determination of accurate positions of the Sun, certain fundamental stars, the moon and planets, and (2) astronomical physics, more especially, daily observation of solar prominences and other solar phenomena with the spectroscope, and daily photography of the Sun. Eliot suggested that the work on the Sun, as recommended by the SPC, should get high priority and there was a need to relocate the observatory to a suitable hill-station, where the climate was nicer and more conducive to work. He further suggested that changes and additions of the European staff would be required for the observatory to carry out both solar physics and other astronomical work and changes in the control and inspection of the observatory would be necessary to ensure its working in the way desired by the Secretary of State, Government of India and the Observatories Committee in England.

A serious effort was then made to find a suitable location for an observatory. The regions chosen for further exploration were Kotagiri in the Nilgiris and Kodaikanal in the Palnis. On Pogson's death, The Government of Madras directed Michie Smith to conduct the site survey at Kodaikanal and Kotagiri. In August 1892, Michie Smith submitted to the Government of Madras a detailed report on the relative merits of Kodaikanal, Kotagiri, and Madras as sites for an astronomical observatory. He had based the report on extensive observations of (1) the Sun with respect to faculae, spots, and their spectra, (2) the Venus and Saturn, (3) the star clusters and nebulae, (4) the double stars, and (5) the measurements of apparent magnitudes of stars and (6) the photographs of star trails. The steadiness of the image of the Sun was also studied. On all counts, Kodaikanal appeared to be the best of the three sites. It also had the advantage of altitude, the spot chosen there by Smith was more than a 1,000 ft higher than the highest spot in Kotagiri.

The report was considered by the SPC in July 1892 and by the Indian Observatories Committee under the Chairmanship of Lord Kelvin in October of the same year. SPC suggested that if funds were not available for equipping a complete new observatory with two branches, the furtherance of solar physics in India would be the greater benefit to science. Continuity of the photographic registration of the sunspots in India had to be maintained as it was only with the Indian cooperation the then nearly complete record had been secured. Both the committees endorsed the appointment of Michie Smith on a more permanent basis to superintend the work at the new observatory. It was also said that the magnetic and meteorological observations could continue at Madras, which would become a branch observatory with a superintendent and a small staff. It was asserted that with these changes, the Southern India Astronomical Observatory would become the only Government Astronomical and Solar Physics Observatory in India. It would therefore be a national and not a provincial institution. The committees felt it was essential that the control of the new institution should go to the Imperial Government.

In a gazette notification dated 21 November 1893, it was stated that Kodaikanal afforded the most suitable site for the proposed Solar Physics Observatory. The Meteorological Reporter suggested that the consideration of the question of the permanent site of the Astronomical Observatory be deferred for some 5 years. In 1894, Michie Smith's position as the Government Astronomer became permanent. With the official sanction and notification, actual planning of the observatory started. Michie Smith was allowed additional duty leave to spend time in England from 17 May to 9 October 1895 to enable him to discuss with the astronomers in Europe many issues pertaining to the setting up of the observatory. On 17 July 1895, Michie Smith laid before the Indian Observatories Committee his plans for the proposed Kodaikanal Observatory and the equipment. The Committee strongly recommended acquiring a solar spectroscope. The other major equipment, already collected in Madras from various sources, that had to be shifted to Kodaikanal, consisted of a photoheliograph, a spectrograph, a 6-in Cooke Equatorial, a transit telescope and chronograph, and a 6-in Lerebour and Secretan equatorial. In October 1895, the foundation stone of the new observatory was laid by the Governor of Madras. By the end of 1896, plans and estimates of the new establishment were completed and sanctioned. In July 1897, Michie Smith visited Kodaikanal and laid out a North–South line for the observatory building. The building work was slow to begin with but picked up later. When the large spectrograph – a polar siderostat with an 11-in mirror, a 6-in lens of 40-ft focal length and a concave grating mounted on Rowland's plan – was received in 1897, it had to be temporarily housed in the library building.

On 22 January 1898, there was another total solar eclipse at Sahdol, in the princely state of Rewa. The Secretary of State invited the Astronomer Royal and Sir Norman Lockyer to visit and also report on the various Indian observatories. The Astronomer Royal, W.H.M. Christie, visited Madras early in February (1898) on his way home from his eclipse camp at Sahdol. Christie spent 2 days at the Observatory and carefully went into all questions concerning the equipment and the work that was being carried on. He then visited Kodaikanal and discussed the plans of the new buildings. Various changes which would improve the buildings were suggested and were at once adopted. Sir Norman Lockyer visited Madras but not Kodaikanal and expressed his dissenting views on the planned buildings in Kodaikanal. On his return to England, Lockyer represented to the Secretary of State for India that the buildings were too costly and too permanent, while the structures in his own South Kensington observatory were temporary and cheaper, although his observatory was the most powerful solar observatory in the world. The Secretary of State ordered stoppage of all work at Kodaikanal until the matter was sorted out with the Astronomer Royal. Whether Lockyer's protest was forwarded to the Indian Observatories Committee is not known, but the result was a delay from June to October end, after which the buildings were allowed to go on. Books and instruments were transferred from Madras to Kodaikanal and sent up the ghaut in the dry weather before end of March 1899. About 1,000 coolie loads reached Kodaikanal. No damage was detected. Michie Smith took up residence in Kodaikanal by the end of February 1899, as it was necessary for him to be there to advise the engineer in charge of arrival.

Officially, the observatory started work on 1 April 1899. After the work of construction was largely completed by December 1901, additional measures were taken to protect the Observatory from very strong winds. Progress was made in planting oak and pine trees and laying out grounds, although it was known that many years would elapse before these would take their full effect in modifying the strength of the winds to which the Observatory was exposed. In 1902, a Ca II K spectroheliograph was ordered from Cambridge Scientific Instrument Company. It arrived in Kodaikanal in 1904. The spectroheliograph consisted of a 12-in triple achromatic lens of 20-ft focal length fed by a Foucault siderostat incorporating an 18-in aperture plane silver-on-glass mirror, fitted with differential electric motors for fine adjustments in R.A. and Dec. The design of the instrument was as specified by George Ellery Hale (the discoverer of the spectroheliograph), in which the image of the Sun and the camera remain stationary while the collimating lens, the camera lens, the prisms, and slits are carried on a rigid frame which moves at right angles to the optical axis. This was the instrument that John Evershed put to effective use after his arrival in Kodaikanal in 1907. Evershed joined on 21 January 1907 as Chief Assistant to the Director. Michie Smith went on combined privilege leave and furlough for 9 months from 1 April. Naturally, Evershed took charge of the observatory as soon as he arrived. This was his first professional appointment as an astronomer.

3 John Evershed (1864–1956)

John Evershed was born at Gomshall in Surrey on 26 February 1864. He is a descendant of the ancient family of Evereshavedes in Surrey who can be traced back to before the Norman conquest (1066 A.D.). They were yeoman farmers and Evershed's grandfather was the last of the branch to carry on an unbroken family tradition as yeoman farmers in Surrey for over 600 years. Evershed's mother's side of the family was in Portsmouth where his maternal great grandfather had a shop selling nautical almanacs and charts. He was well known to Lord Nelson.

Evershed's interest in astronomy began rather early. When he was only 11, there was a partial eclipse of the Sun, visible from Surrey, and boy Evershed ran almost all the way from Gomshall to Shere to watch the eclipse using a telescope belonging to a doctor. Even before that when he was six, his imagination was spurred by a picture of German shells falling in the streets of Paris in 1868, during which Janssen, the French astronomer, escaped by balloon from the besieged city to watch the total eclipse of the Sun. It was during this eclipse that Janssen discovered the Hα line in a solar prominence and soon after obtained pictures of the same outside of an eclipse. This was the beginning of the daily spectroscopic observations of prominences without waiting for an eclipse, an activity to which Evershed had a lot to contribute when he grew up.

Evershed was, until his appointment in Kodaikanal, an accomplished amateur astronomer. In the 1890s, when Evershed was already studying solar radiation, he was induced by some great spectroscopists, including Pringsheim and Paschen, to perform experiments on heated gases and study their radiation pattern. As he says "I was able to show that colored vapors of iodine and bromine heated to the temperature of red heat glowed with a continuous spectrum, at the same time giving a discontinuous absorption spectrum by transmitted light.... I was able to show that vaporized sodium could be made to emit its characteristic D radiation by heat alone under conditions where there could be no action other than heat."

In 1890, Evershed set up a private observatory in Kenley, Surrey, and with the spectroscope, he had designed, and his 3-in telescope, he started a long series of observations of prominences and recorded their distribution in heliographic latitude and their variation with the cycle of sunspots. Between 1890 and 1905, Evershed recorded some 13,458 prominences. In 1890, he became a founder member of the British Astronomical Association and he was the director of the section on solar spectroscopy between 1893 and 1899.

The 1890s were exciting years for solar physics. In the spring of 1891, George Ellery Hale invented the spectroheliograph. Like Evershed, he had set up his own Kenwood Physical Observatory in the backyard of his house in Chicago, where he had a self-made 12-in telescope. Using the spectroheliograph and this telescope, he was soon able to see the reversals in the Ca II H and K lines. Evershed had his own way of photographing prominences in the Hβ line of hydrogen. With this technique of monochromatic photography, he was getting solar images showing the brilliant flocculi around sunspots. When he learnt about Hale's new instrument, he abandoned the idea of working on the hydrogen line and transferred his attention to the Ca II K line.

Evershed got to know Arthur Cowper Ranyard, a barrister by profession with a deep interest in astronomy, who was the editor of Knowledge. Ranyard, who knew Hale personally, introduced him to Evershed when the former visited England in 1894. This was the beginning of a long friendship between the two pioneer solar astronomers of the time, which lasted till Hale's death in 1938. Ranyard died in 1894 and left Evershed with his 18-in reflector and a small spectroheliograph. Evershed found problems with Ranyard's instruments, which produced curved spectral lines and gave distorted images of the Sun. He put the 18-in telescope at Kenley, and designed a spectroheliograph on his own using large direct vision prisms, which gave straight spectral lines and undistorted solar images.

Evershed's immediate superior, in the company he was working, was interested in science and Evershed was granted leave to join solar eclipse expeditions. His first visit to India was in connection with the eclipse of 22 January 1898. He was in the company of W.H.M. Christie, the Astronomer Royal; H.H. Turner, the Savilian Professor of Astronomy at Oxford; Sir Norman Lockyer among others. He obtained excellent flash spectra and caught the emission continuum at the head of the Balmer series extending to the ultraviolet end of the plate. He realized that this was the counterpart of the continuous absorption spectrum seen by William Huggins in stars with strong hydrogen absorption lines. At a later solar eclipse in Algeria in

1900, he repeated the same experiment and again saw the continuum emission. His results definitively proved that the flash spectrum and the Fraunhofer spectrum were of the same origin; the flash spectrum representing the higher and more diffused portion of the gases, which by their absorption gave the Fraunhofer dark line spectrum. At all eclipses, Evershed carried his own home-made instruments – prismatic spectroscopes with a long focal length camera, where only the optical parts were procured from specialized manufacturers. These prismatic spectroscopes consisting of two or more prisms are often referred to as Evershed spectroscopes.

The results of Evershed's eclipse expeditions attracted the attention of the great stellar spectroscopist Sir William Huggins, who was then the President of the Royal Society. Evershed and Huggins had an interesting correspondence in this matter. Later it was Huggins who recommended the appointment of Evershed to the position of the chief assistant to Michie Smith at the Kodaikanal Observatory.

In the original recommendation for setting up an Imperial Astronomical Observatory in the hills of southern India, the Government had indicated that the observatory would be headed by an Astronomer to be appointed by the Indian Observatories Committee in England while the Solar Physics Section would be headed by a Superintendent, either appointed by the Solar Physics Committee and the Observatories Committee, or Michie Smith, the then Government Astronomer, could be appointed to the position. Smith was deemed to have the requisite qualification and experience to run the Solar Observatory, while his suitability to head the Imperial Observatory was somewhat in doubt. It was agreed that the staff of the new observatory should consist of two Europeans and a group of Indian assistants. When the idea of establishing an Imperial Observatory was temporarily abandoned, and it was decided that the Solar Physics Observatory was the one to be immediately established in Kodaikanal, Michie Smith became the natural choice for its directorship. The European assistant to him was not immediately appointed.

The principal thrust of the work at Kodaikanal was to be solar spectroscopy. There were three existing spectroscopes, none of which appeared suitable for obtaining spectra of prominences and sunspots with good efficiency. In 1903, it was decided to build a spectroscope from one of the existing collection (a large six-prism instrument with a collimator and a telescope of 17-in focus), which was dismantled and two lenses from it were mounted with an existing diffraction grating to rig up an instrument that was then used with the 6-in Lerebour and Secretan equatorial to obtain spectra of the solar features. A three-prism Evershed spectroscope was ordered from Hilger Co. during the same year and this went into operation in November 1904. It gave excellent spectra of sunspots and prominences. Also in 1904, the Cambridge spectroheliograph arrived in Kodaikanal. Naturally there was a great need of having a person who would direct the spectroscopic work. Michie Smith visited Hale at Mt. Wilson in early 1904 and discussed in detail the kind of work Kodaikanal should undertake. Hale was also keen on developing an international network on solar research and he was particular that the work with spectroheliographs, at Catania and Yerkes Observatories, his own at Mt. Wilson, yet to be commissioned, and the newly acquired one at Kodaikanal, was done in a coordinated fashion. He was already in correspondence with Evershed and was coaxing him to join this proposed network, as Evershed had his own spectroheliograph and was producing Ca II K spectroheliograms on a regular basis. Hale narrated in detail his conversations with Michie Smith in a letter to Evershed on 2 February 1904. Evershed was quick to respond saying that he felt a cooperation in spectroscopic and spectrographic methods of observation rather than the other older methods of photographic work would indeed be of great help to the community. He called himself "an irresponsible amateur" who was not afraid to be part of any professional network.

3.1 Evershed in Kodaikanal

In 1904, the Government of India sanctioned the appointment of an European Assistant to the Director, Michie Smith. John Evershed was clearly the most eminent choice for the position. According to Evershed, Sir William Huggins greatly influenced the decision of the Government of India in making Evershed the offer, which also had the support of Gilbert Walker, the Director-General of Observatories in India. In a letter to Hale dated 3 December 1904, Evershed said that he had been offered an appointment in Kodaikanal and it would take him 6 months to decide. He was a bit depressed at the prospect of having to close down his private observatory in Kenley. He probably had in mind a personal matter, that of his marriage, before he could definitely take a final decision. He was preparing for the journey to India in 1906. On the advice of Professor Turner of Oxford, he decided to go to India not by the regular route, but by the longer Trans-Atlantic/Trans-Pacific one via America and Japan. Turner gave Evershed introductions to the leading American astronomers of the day: Pickering in Harvard, Frost at Yerkes, and Barnard and Campbell at Lick. Turner also arranged for his visits to Harvard and Princeton, and to these observatories and arranged for the India Office to sanction these visits. Evershed's main aim, of course, was to spend a month with Hale at Mt. Wilson.

At the eclipse expedition of 9 August 1896 in Norway, Evershed had first met Mary Ackworth Orr, a young and sprightly amateur astronomer and a member of the British Astronomical Association. Mary was also interested in Dante Alighieri and was to write a book titled "Dante and the Early Astronomers" in 1914. In 1906 September, John and Mary got married. In a letter to Hale on 28 June 1906, Evershed had told him about his plan to visit America on his way to India. He also wrote that before leaving England he was to be married to Mary A. Orr who would accompany him to America. On 22 September 1906, the Eversheds left England by the Anchor Liner Columbia reaching New York the end of September. The couple traveled to Williams Bay, Wisconsin, where the Yerkes Observatory is situated. Edwin Frost, the Director hosted them for a week. They arrived in Pasadena on 18 October planning to spend several weeks with Hale. However, owing to some mis-communication, Hale was away at the time from Mt. Wilson until the end of November. But the couple had a wonderful and scientifically fruitful time organized by Hale's main solar collaborator Ellerman. Evershed was deeply impressed by the instruments, the method of work, and Hale's organization of the observatory. On 21 January 1907, the Eversheds reached Kodaikanal.

Fig. 2 John Evershed working with the spectroheliograph at the Kodaikanal observatory (from IIA archives)

Evershed immediately got involved in solar observations as soon as he arrived in Kodaikanal. The Cambridge spectroheliograph had been put into operation in 1905. The building where it was housed was faulty with a leaky roof and a new one had to be constructed. There was also some problem with the setting of the second slit at the correct wavelength. So, although spectroheliograms were obtained in 1905 and 1906, the instrument did not perform to its full potential. It was left to Evershed to bring the instrument to its fine working order. By then, a new moving roof was in place in the spectroheliograph building with an addition of ruberoid sheets to prevent leaks. A new collimator slit was fitted and Evershed solved the problem with the camera slit, giving it greater stability and incorporating a new device to facilitate the setting of the slit at any desired wavelength. He also started working on an auxiliary spectroheliograph to obtain pictures of the Sun in Hα.

When Comet Daniel showed up in the sky, Evershed used his eclipse prisms (he had brought them with him to India) and made a prismatic camera fitted to the 6-in Cooke equatorial to obtain spectra of the comet. He identified the CN bands in both the nucleus and the tail of the comet. When Halley's Comet appeared in 1910, Kodaikanal geared up to observe the object both photographically and spectroscopically. Between 19 April and 16 May 1910, when the comet was most amenable to observations in the early dawn, Evershed was able to obtain spectra, which showed the CN bands and the C2 Swan bands in the head, while the tail showed bands due to CO. He was ably assisted in the observations by his wife Mary.

3.2 Evershed Effect

However, Evershed's chief work in the initial years in Kodaikanal was on the spectra of sunspots. He used the high dispersion spectrographs at the observatory to systematically study the spectra of spots whenever the weather was favorable. He noted that the sunpsot spectra were constant in character and consisted mainly of intensified Fraunhofer lines. The general absorption was continuous and was similar to the continuous absorption seen in the limb of the Sun. The pressure in the spot regions seemed to be slightly less than in the reversing layer of the photosphere. In 1909, Evershed made another "very powerful spectrograph," one he called spectrograph III. This had a parabolic silver-on-glass mirror, which formed the solar image on the slit plate and he used an excellent 6-in plane grating by Michelson, which the observatory had, as the dispersing element. He employed this instrument to solely concentrate on the spectra of sunspots.

In the early morning of 5 January 1909, on a day when the atmosphere was exceptionally steady and the sky transparency was excellent after some heavy thunderstorm activity, Evershed found two large spots and obtained their spectra. As he says, "the spectra revealed a curious twist in the lines crossing the spots which I at

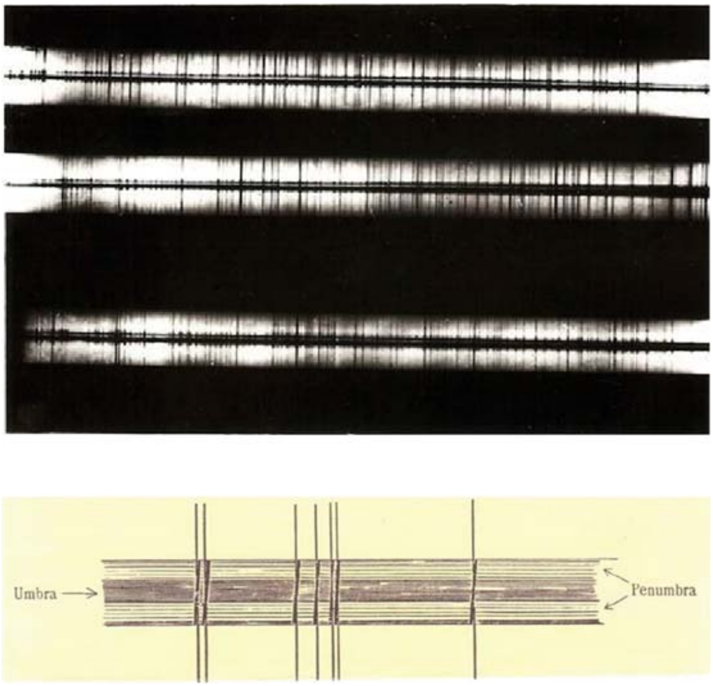

Fig. 3 *Top*: Solar spectra of a sunspot region recorded by Evershed on 5 January 1909 at Kodaikanal. *Bottom*: Line sketch of the spectrum showing the shift of the absorption line penumbra around the sunspot (from IIA archives)

once thought must indicate a rotation of gases, as required by Hale's recent discovery of strong magnetic field in spots, but it soon turned out from spectra taken with the slit placed at different angles across a spot that the displacement of the lines, if attributed to motion, could only be due to a radial accelerating motion outward from the center to the umbra. Later photographs of the Calcium H and K lines and the Hα line revealed a contrary or inward motion at the higher levels represented by these lines." This was the first time line displacements in the penumbral region were seen, indicating an outward radial flow of gases in the spots. None of the previous spectroscopic studies had revealed the dynamics of the flow of gases in the spots. Two days later, Evershed obtained more spectra that confirmed the discovery.

Earlier studies had concentrated on spots near the central meridian of the Sun. Evershed was the first to observe spots at various positions, up to 50°, on either side of the central meridian. He found that the line displacements were more pronounced in the penumbral regions of the spots, which are closer to the limb of the Sun. This established that the flow of the gases was radially outward parallel to the surface of the Sun. In a letter to Hale on 1 February 1909, Evershed described his remarkable discovery and said "I have found that there is a Doppler shift of all the lines in all spot spectra. I made a special study of it having obtained more than one hundred and fifty spectra representing seven northern spots and four southern". The complete results were published in the Kodaikanal Observatory Bulletins of 1909 and the inverse flow seen in the strong lines in a paper in MNRAS in 1910.

Hale responded soon congratulating Evershed for the discovery and stated that because of the pressure of their magnetic field work, they were unable to investigate the dynamics of gases in sunspots.

3.3 Spectral Lines and Diagnostics

The general problem of an unexplained redshift of spectral lines seen at the limb of the Sun with respect to the same lines seen from the centre had occupied the thoughts of all major observers at the time. This was first brought out by Halm at the Cape Observatory in 1907. The Mt. Wilson astronomers, who investigated the phenomenon in great detail, came to the conclusion that the shift was due to the differences in pressure in the two regions – disk centre and the limb. Evershed too was trying to understand the nature and cause of this shift. His observations, however, indicated complexity. His work further showed that the pressure interpretation was incorrect, as some of the lines supposed to be most affected by pressure were actually shifted to the violet. Evershed had developed very accurate methods of measuring extremely small line shifts and much of the spectroscopic work in Kodaikanal was concerned with the measurements of these minute shifts.

It turns out that the astronomers of the time had no idea of the actual value of pressure in the various layers of the solar atmosphere. A commonly accepted notion was that the pressure was several times the Earth's atmospheric pressure. It was also thought for some time that the weak lines formed at lower pressures than did the strong lines. Only after the appearance of Meghnad Saha's work on thermal ionization and its great success in establishing a quantitative effective temperature scale of stars were spectroscopists able to calculate the actual pressure from spectral diagnostics and it turned out that the pressure in the solar atmosphere was only about a tenth of that in the Earth's atmosphere. The solution to the problem of redshifts came from an altogether different quarter. Albert Einstein had calculated the gravitational redshift of spectral lines in his general theory of relativity. As his theory gained credibility, particularly after the solar eclipse expedition by Eddington in 1919 that gave an accurate measure of the bending of a light beam in the gravitational field of the Sun, the effect of gravitational redshift on the spectral lines in the Sun became a major target of study. Towards the end of his stay at Kodaikanal, Evershed made a comparative study of plates taken in 1914, 1921, 1922, and 1923 and found that for the weaker lines, which are supposed to form deep down in the atmosphere, the results of the redshifts were in agreement with Einstein's theory. However, there was an unexplained extra redshift detected in limb spectra whose origin was not known.

In January 1911, Michie Smith retired and Evershed became the Director of the Kodaikanal Observatory. T. Royds joined as the new Assistant Director. In the same year, Evershed put into operation a second spectroheliograph as an auxiliary to the Cambridge instrument utilizing its perfect movement and using a grating and special arrangements for getting photographs of the solar disk in Hα. As red-sensitive plates became available, he started obtaining daily spectroheliograms in Hα along with the same in the Ca II K line. Several spectacular eruptions were recorded, in some of which the speed of recession of the flying fragments was measured.

3.4 Prominences

The study of prominences had continued uninterrupted into the Kodaikanal days. Mary Evershed too developed an interest in the prominences after moving to Kodaikanal. In 1913, she published a paper in which she analyzed observations of prominences associated with sunspots made between 1908 and 1910. The number of prominences recorded at Kodaikanal during the years 1904–1914 numbered nearly 60,000 and these, supplemented by the earlier Evershed collection at Kenley, formed the subject of an exhaustive study and was jointly published by Mary and John Evershed as a Memoir of the Kodaikanal Observatory in 1917.

In 1913, the Eversheds visited Kashmir on 3 months leave and found the observing conditions in the Kashmir valley excellent for solar work. As Evershed wrote later, "The valley of Kashmir is a level plain containing a river and much wet cultivation of rice. It is 5,000 ft above sea level and is completely surrounded by high mountains. Under these conditions, the solar definition is extremely good at all times of the day, and unlike most high level stations, it is best near noon and in hot summer weather." He established a temporary observatory near Srinagar in 1915–1916 obtaining very high-quality photographs of prominences and sunspots. This experience of Evershed was later extended to various localities including one on an ocean liner in tropical waters. The view that the best solar definition is found in low level plains near the sea or on small islands surrounded by extensive sheets of water grew out of these experiences.

In 1915, Evershed was elected a Fellow of the Royal Society and he was awarded the Gold Medal of the Royal Astronomical Society in 1918. At the award ceremony, the President of the RAS, Major P.A. MacMahon, gave a full account of Evershed's work up to that time giving maximum prominence to the discovery of the radial motion in sunspots. The other contributions that he highlighted were (1) prominence observations, (2) spectra of sunspots in general, (3) investigations into the reversing layer, (4) the minute displacements of lines at all parts of the solar disk, (5) eclipse and cometary observations, and (6) the invention and perfection of instruments of observation and measurement. Major MacMahon compared Evershed with Sir William Huggins saying "There is much in our medallist's career which is a reminder of the scientific life of William Huggins. They come from the same English neighborhood, and began as amateurs of the best kind. They both possess the same kind of scientific aptitude."

John Evershed retired in 1923 and left Kodaikanal for England. As the Eversheds went down the ghaut road, a tiger darted across their path, the only time in 16 years in India that they saw a tiger! They returned to Surrey, where Evershed established his own observatory in Ewhurst near Guildford and continued with his solar observations for well over another 30 years. He made liquid-filled prisms, which revealed great possibilities for high dispersion work. He obtained Zeeman spectra of sunspots using these prisms as dispersers. He and Mary continued to take part in solar eclipse expeditions and also attended meetings of the IAU every 3 years. Mary died in 1949 at the age of 83 and John Evershed in 1956 at the age of 92.

4 Scientific Impact of the Evershed Effect

As we look back at the spectroscopic detection, through Doppler shifts, of gas motions in the penumbral photospheric layers of sunspots in 1909 by Evershed at the Kodaikanal Solar Observatory, this discovery clearly stands out as the earliest successful observation of velocity fields due to a complex magnetohydrodynamic phenomenon in action in an astrophysical setting. The most remarkable aspect of Evershed's work was his ingenuity, given the limited resources and sensitivity of the instruments that he used, in providing accurate interpretations of his observations that the gas motions in sunspot penumbrae were indeed radial outflows parallel to the solar surface. This dominant dynamical phenomenon discovered by Evershed can be clearly detected using modern observations with vastly improved spectral and spatial resolution, though additional components involving vertical and wave motions are also seen in the spectra. Yet, a century later, we still do not have a clear physical understanding of this phenomenon.

The immediate scientific impact of Evershed's discovery pertained to another momentous event in astrophysics, viz. the detection of magnetic field in sunspots

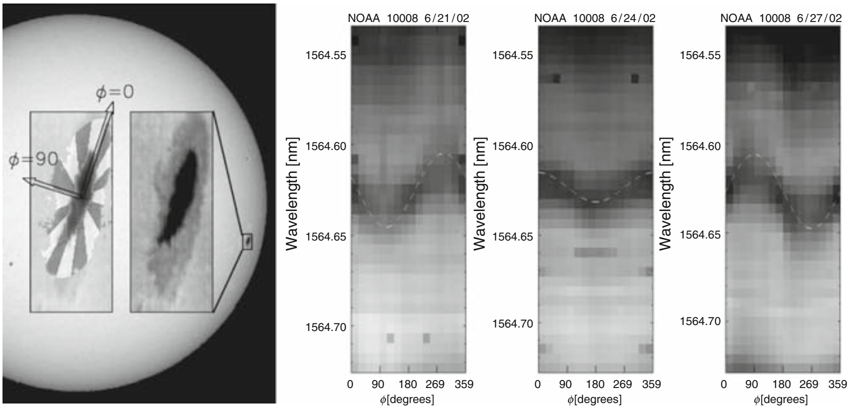

Fig. 4 A modern observation in the CN absorption line at 1546.6 nm of the Evershed effect depicting the radial outflow of material in a sunspot penumbra (observed by Penn et al. 2003)

by George Ellery Hale a year earlier in 1908 at the Mt. Wilson Observatory. This was the first ever discovery of a magnetic field outside the terrestrial environment, and was motivated by the prevailing speculations at that time that sunspots were giant vortices and that all rotating heavenly bodies harbored magnetic fields. Hale considered his detection of magnetic fields in sunspots, in turn, as an indication of swirling flow of ionized gas, which could have generated the magnetic field locally. However, as Evershed pointed out in his discovery paper of 1909, his observations of radial outflow of gas made the circular flow hypothesis untenable. It was not until the early 1930s that the local generation of magnetic field due to axisymmetric motions was shown to be impossible by Cowling through theoretical calculations, and in particular, he suggested sunspots to be composed of tubes of magnetic flux breaking through the surface.

The two momentous discoveries by Hale and Evershed occurred in an exciting era during the early twentieth century when spectroscopic techniques had begun to be used to study the Sun. An immediate follow-up of research on the Evershed effect was through intense observational investigations, particularly at the Mt. Wilson Observatory. More observational programmes followed gradually world-wide, and in general, observational studies continued over the last century. However, theoretical attempts to explain the physical causes and to understand the origin of this effect have gone through several inert periods. We are currently in a period of revived attention largely fueled by our increased numerical computational capabilities to simulate MHD processes.

Evershed's initial estimates of flow speeds were around 2 km s^{-1}, and he found increasing speed with distance from the spot center, and no tangential components for flow velocity. His later results, using chromospheric lines, indicated a radial inflow of gas at these heights, and he measured small tangential components in photospheric velocity, but considered them unreliable because they were irregular.

Detailed observational programmes started in Mt. Wilson (St. John 1913) and across several countries in Europe, most notably at Arcetri in Italy (G. Abetti 1929), at Oxford using the Oxford Solar Telescope (Kinman 1952), in France and in the Soviet Union in the early 1960s, and at Oslo during the mid 1960s. All these observational studies essentially confirmed the results of Evershed, added more details on the spatial variation of flow over the penumbra, established the filamentary structure of the flow, and tentatively identified the magnetic and flow field associations. Considerable improvements in spatial and spectral resolutions emerged in the late sixties, and with that came the identification that the Evershed flow is concentrated into dark penumbral filaments where the magnetic field is more horizontal.

Starting from the 1990s, high resolution observations, from various groups all over the world, have served to spatially resolve the flow and magnetic structures, which have the following dominant properties: the flow occurs mainly in the dark penumbral filaments where the field is more nearly horizontal than the average, the inner penumbral heads of horizontal flow structures have concentrated but bright upflows, which feed the horizontal flows.

Even though a dominant role for the magnetic field in the thermal and dynamical structures of a sunspot was envisaged early on by Biermann and Cowling, it was the work Alfvén, largely responsible for the development of the new field of magnetohydrodynamics, that provided the conceptual framework for analyzing this phenomenon. Theoretical interpretations of the Evershed flow started relatively late in 1955 when Sweet found an origin in convectively driven motions. Since then, various magneto-convective processes have been proposed – they form a large body of research on sunspot related problems.

There have been several different theories based on magneto-convective mechanisms to explain the Evershed flow, most notable ones being (1) a linear theory of convective rolls in horizontal magnetic field proposed by Danielson and its nonlinear modification by Galloway to drive a radial outflow, (2) Busse's theory of three dimensional convection in an inclined magnetic field, where Reynolds stresses drive an Evershed flow, and (3) interchange convection where a dynamical evolution of thin flux tube produces the Evershed flow. Currently, a new magnetoconvective picture of Evershed flows has emerged based on 2D and 3D MHD simulations (discussed in greater detail in this monograph), where the convective interactions between an upward hot plume and magnetic field produce the necessary ingredients to drive a horizontal Evershed flow as observed. A complete and fully consistent picture of Evershed flows with ability to match all the observed features is yet to be realized, even 100 years after its discovery. It is likely that a more comprehensive picture of the Evershed flow would emerge from the high spatial and spectral resolution spectropolarimetric observations planned in the near future. It is equally probable that the fast developing computational resources and algorithms could get complex enough to accurately reproduce the observations.

5 Kodaikanal Observatory: 1923–1960

Following John Evershed's retirement in 1923, activity in solar physics continued unabated at Kodaikanal and work progressed along the lines of the early years. The successive directors at the Observatory were T. Royds (1923–1937), A.L. Narayan (1937–1946), and A.K. Das (1946–1960). The scientific highlights of this era were (1) discovery of oxygen lines in emission in the chromosphere without the aid of an eclipse, (2) center-to-limb variations of hydrogen lines and their use to study the solar atmosphere, and (3) detailed study of the properties of the filaments, seen in Hα. Significant progress was made on the instrumentation front during this period; the new ionospheric and geomagnetic laboratory was set up in the mid-fifties and a major solar facility the solar tunnel telescope was commissioned in 1960.

5.1 Eclipse Expeditions

Eclipse studies constituted an important activity of the Observatory. Royds led expeditions to the eclipses in 1929 to Siam, and in 1936 to Japan. While the totality at Siam was lost to clouds in Japan, Royds used one of the largest ever spectrographs to record the spectra and he was the only observer to get any results. Royds carried out measurement of lines at the extreme limb of the Sun. The 1952, totality in Iraq and the 1955 one in Sri Lanka were again lost to cloudy skies.

5.2 The Saha Committee

A committee appointed by the Government of India, with Meghnad Saha as the chairman, examined in 1945 a plan for the post-war development of astronomical research and teaching at the existing observatories and the universities in the country. One of the main recommendations of this committee was aimed at improving the facilities for solar observations, especially during the first 5 year plan. A solar tower telescope, a coronagraph, and a laboratory for solar terrestrial studies in Kodaikanal were proposed. Most of these were implemented by 1960.

5.3 Ionospheric and Geomagnetic Laboratory

Another post-independence development carried out at Kodaikanal was the setting up of a magnetic and ionospheric laboratory in order to study the response of the earth's ionosphere and magnetic field to transient solar events. Two aspects of Kodaikanal greatly stimulated much of the research carried out subsequently in this area. The first one was the ready and immediate availability of information on solar phenomena observed optically with the Kodaikanal telescopes or by radio techniques. Few places in the world had readily available an ionospheric laboratory and a solar station in close proximity. The advantages in quick experimentation and inference were substantial. The second feature is Kodaikanal's location very close to the geomagnetic equator; hence several aspects of the ionosphere so vital in radio communication could be studied at Kodaikanal with much advantage.

The laboratory went into operation around 1955, just before the International Geophysical Year. There have been numerous studies of the properties of the ionosphere over low equatorial latitudes, which have improved our understanding of the phenomena governing radio propagation and its dependence on the solar radiation characteristics. Interestingly, the laboratory once recorded the geomagnetic effects of a stellar X-ray source.

5.4 Solar Instrumentation

A Hale spectrohelioscope for visual observations of the Sun was received as a gift from the Mt. Wilson Observatory during 1933–1934 for participation in an international programme for systematic monitoring of the Sun. The Hα line in the first order of the grating was used for visual observations of prominences, dark markings, and solar flare patrol. A line shift device was soon added for visual estimation of the Doppler shifts. This instrument was in regular use for the next 60 years. Transient activity first noticed with this instrument was followed up with fast sequences using the main spectroheliographs and also to alert the ionospheric and geomagnetic laboratory on campus.

A tunnel telescope by Grubb Parsons, purchased in 1958, was commissioned in 1960. It consists of a 60-cm diameter two-mirror coelostat, mounted on a 11-m high tower, that directs light via a flat mirror to a 38-cm aperture, f/90 achromat, which forms a 34-cm diameter solar image at the focal plane. A Littrow-type spectrograph with an inverse dispersion of $9\,\mathrm{mm}\,\text{Å}^{-1}$ in the fifth order of its grating and a spectroheliograph capable of giving pictures in a chosen line became available for use. These continued to be, for nearly half a century, the country's main facility for high spectral resolution observations of the Sun.

The Kodaikanal Observatory continued its programmes of cooperation with the Greenwich, Cambridge, Meudon, and the Mt. Wilson observatories, especially with regard to exchange of observations for missing days. The Observatory was responsible for communicating to the IAU material for publication of Hα flocculi and dark markings, for most part of the above period. The spectrohelioscope observations were sent regularly as inputs to the quarterly bulletins of the IAU on solar activity. Beginning 1949 May, the Observatory started sending regular messages on solar activity for the benefit of the meteorological department, geophysicists, and radio specialists in the country and abroad. The Observatory continued to publish regularly the Kodaikanal Observatory Bulletins and also the half-yearly bulletins of solar statistics.

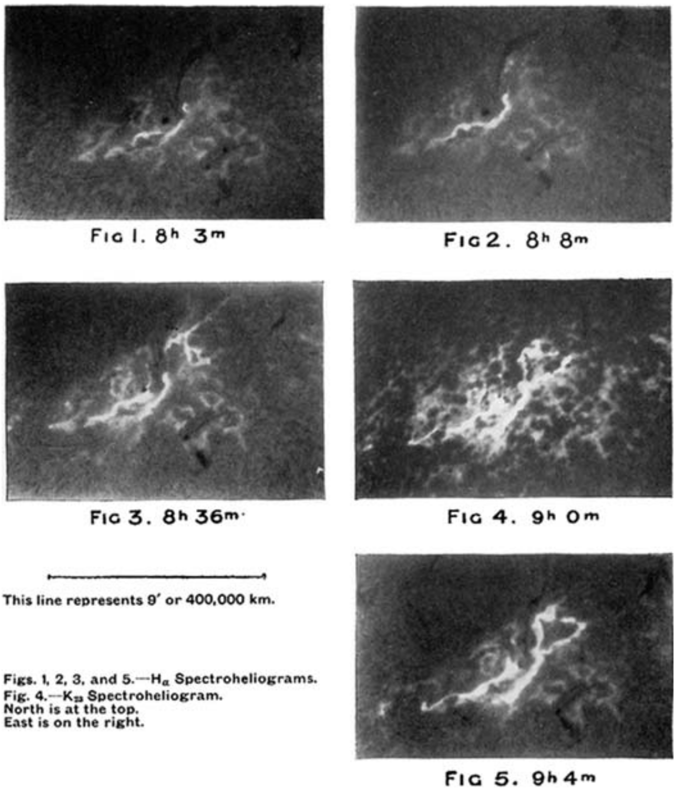

Fig. 5 Royd's flare of 22 February 1926, covering two large sunspot groups, is one of the largest ever recorded at Kodaikanal (from IIA archives)

5.5 Scientific Highlights

Royds carried out laboratory studies of spectra with a view to investigating the cause of observed displacements of solar lines with reference to lines in the spectra of terrestrial sources. Royds and Narayan later observed the centre-to-limb variations of several strong solar lines. Royds succeeded in photographing, outside an eclipse, the infrared triplet of oxygen lines at 7,771, 7,774, and 7,775 Å as emission lines in the chromosphere. These lines are normally observed as absorption lines in the Fraunhofer spectrum.

Rao and his team observed Hα, Hβ, D, and several other lines near simultaneously during the maximum phase of a solar flare. They argued that the observed line broadenings were mostly due to the Doppler effect and were not assignable either to the Zeeman effect or to the Stark effect. Narayan and co-workers studied several atoms, ions, and molecules in the laboratory and looked for their signatures in the solar spectrum. They established the presence of P_2 and studied CN spectral lines on the Sun.

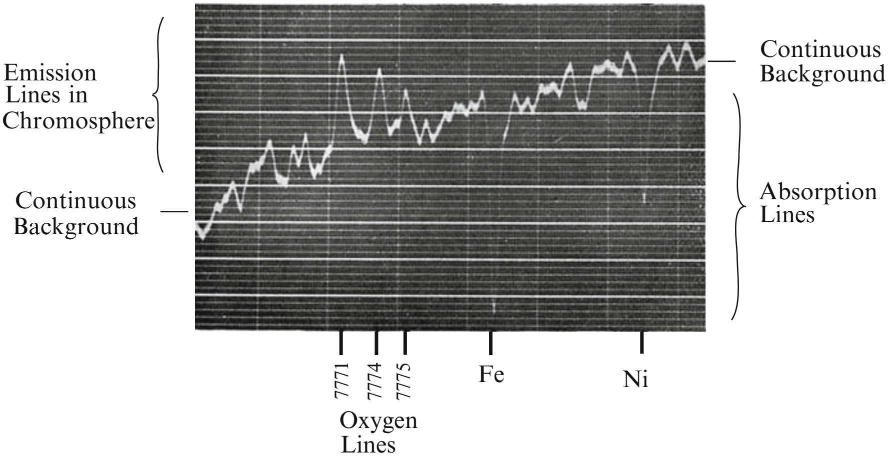

Fig. 6 Microphotometer scan of the spectrum obtained in oxygen emission lines in the chromosphere without the aid of an eclipse. Royds used a straight slit tangential to the Sun's limb to record the triplet (from IIA archives)

Das and Ramanathan observed the distribution of radiation flux across sunspots in the continuum and narrow band windows of the Ca II H and K lines. They demonstrated that certain sunspots show the presence of bright rings and that they are especially more intense in the wavelength of K_2. Statistical studies of solar features, such as sunspots, prominences, and filaments and their periodicities, longitudinal and latitudinal distributions, migration patterns, changes in orientations, and rates of occurrences were carried out.

Flare patrol and follow up observations were carried out routinely at the Observatory. All efforts were made to not miss particularly strong events. In 1926, Royds obtained extensive spectroheliogram coverage of an exceptionally strong and widespread flare (which was known for long at Kodaikanal as Royds' flare). The observations were later used for various studies. In 1949, Das and Raja Rao observed a 3+ flare followed by a great magnetic storm starting 40 h later but lasting over 2 days. Peculiarities of the storm were studied in detail.

In 1953, Das and Sethumadhavan recorded observations of an apparently quiescent prominence, not visibly associated with any sunspot, grow into a dramatic eruptive event. Spectra of the dramatic event were recorded and the associated radio noise bursts were also observed.

6 Solar Physics Research at Kodaikanal from 1960 Onwards

M.K. Vainu Bappu arrived in Kodaikanal Observatory in 1960, and by the end of 1962, he put into operation the newly installed solar instruments, especially the

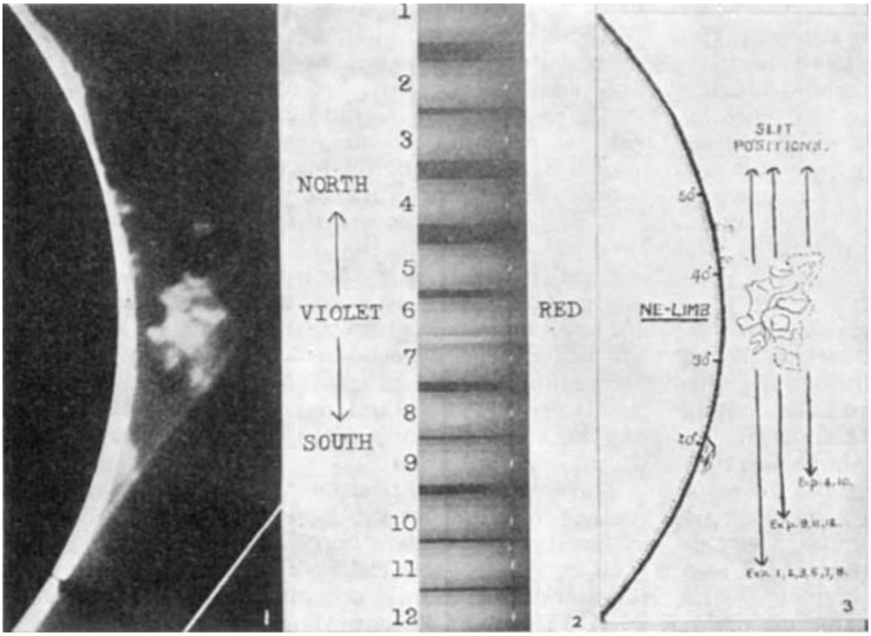

Fig. 7 An apparently quiet prominence suddenly grew to twice its height and erupted. Doppler shifts were measured from the Hα. Associated radio noise bursts were also studied (from IIA archives)

solar tunnel telescope. While solar observations continued with these facilities, new horizons were opening up in the area of night time astronomy.

Renewed vigor and productivity characterized solar research in Kodaikanal under the leadership of Bappu. The solar tower telescope was in regular operation in 1962, and by 1965 it had a spectrograph and a Babcock-type magnetograph. There were three spectroheliographs housed in the building adjacent to the solar tower. The photoheliograph of 20-cm diameter was also in operation.

6.1 Velocity Fields in the Solar Atmosphere

Bhatnagar undertook a detailed study of the Evershed effect based on observations in Zeeman insensitive lines of Ni I and Fe I. He measured sizeable tangential velocities in the sunspot penumbrae, with a maximum value of about 0.6 km s^{-1}, and studied in detail the line asymmetries, which were first observed by Evershed in 1916. Bhatnagar also performed correlative studies of continuum brightness and equivalent widths and found that darker regions of the penumbra show larger equivalent widths while an opposite correlation was found for the brighter regions. This was one of the earliest identification of flow and brightness associations that have now been well studied by high spectral and spatial resolution observations. Studies on solar 5-min oscillations were undertaken by Sivaraman during 1966–1972, culminating in a Ph.D. thesis. A comprehensive study of various properties of the solar velocity and intensity oscillations was done, and though it fell short of bringing out the resolved $k - \omega$ diagnostic diagram and thus the resonant-cavity nature of solar interior for acoustic waves, this work was among the early observational studies of solar oscillations. Temperature and velocity fields in the temperature-minimum region and the low chromosphere were studied using photoelectrically determined profiles of molecular lines of CN and C2 by Nirupama Subrahmanyam in 1965. Studies of solar rotation, by means of sunspot observations and estimation of their anchor depth in the convection zone, have formed a major research activity in more recent years and have been carried out by Sivaraman, Gupta, and Howard. The white light images recorded at Kodaikanal, from early 1900s, have been used in a number of studies, including solar surface and internal rotation, evolution of large scale bipolar regions, solar diameter, solar activity cycle dependent zonal velocity bands, optical flares, correlations between rotation of bipolar sunspots and flares.

6.2 Magnetic Fields

Regular observations of strong magnetic fields in sunspots began in 1963. Measurements were made by means of the compound quarter-wave-plate technique and using the 6,303 Å line, with a major objective of evaluating the spatial distribution of longitudinal magnetic field. A longitudinal magnetograph of the Babcock type was designed and brought into use by J.C. Bhattacharyya in 1965. It operated at a chopping frequency of 50 Hz and was in use for the study of weak longitudinal magnetic fields on the solar surface. Weak field in the polar regions and elsewhere were also studied by Bhattacharyya.

6.3 Chromospheric Features and Dynamics

Exhaustive studies of Ca II K line spectra were carried out during 1969–1976 by Bappu and Sivaraman. The analyses and results included role of the Ca II K line as a reliable diagnostic of chromospheric activity, the solar cycle variation of Ca II K line emission profiles of integrated sunlight, association between photospheric magnetic structures and Ca II K structures and their use in inferring the morphological evolution of photospheric structures, and the implications of the above for other stars. Variation of the luminosity of the Sun as a star in the Ca II K line was studied by Sivaraman, Singh, Bagare, and Gupta in the mid-eighties. During this same period, Singh and co-workers carried out a detailed study of active region contributions to Ca II K luminosity variations over a solar cycle. Intensity fluctuations in the Hα line due to chromospheric mottling were studied by Bappu in 1964. Singh and Bappu studied the supergranular network size and its variation with solar cycle. Bappu also carried out detailed observations of prominences and calcium flocculus in the early sixties. Sivaraman and Makarov observed filament migrations, and poleward migration of magnetic structures, meridional motions, and polarity reversals at the poles.

6.4 Coronal Studies

Bappu, Bhattacharyya, and Sivaraman observed the Hα and Ca II K lines during the solar eclipse of 1970. Important coronal studies, most notably on coronal wave dynamics, were carried out over several eclipse expeditions starting from 1983 to date. The recent eclipse expeditions have achieved high spatial resolution narrow band photometry of coronal structures to investigate the nature of waves in the corona. Studies of intensity oscillation in the coronal green line and red emission line have also been carried out.

6.5 Solar Terrestrial Studies

Several studies relating to the ionosphere over Kodaikanal and the electrojet have been carried out in the early sixties. Notable among them are the variation over a solar cycle of ion densities at different levels of the equatorial ionosphere, and the spatial, seasonal, and solar cycle variations in the lunar semi-diurnal oscillations in the ionospheric F-region. An analysis of magnetic crochets associated with relativistic flares was done in 1964 and the amplitude characteristics of geomagnetic sudden commencements with energetic proton events were studied.

6.6 Current Observational Facilities and Programmes

Ca II K, Hα images, and spectroheliograms continue to be obtained at Kodaikanal for studies of the chromospheric network, solar cycle variations of the background flux in the K line, and synoptic observations of solar activity. Digitization of Kodaikanal data is one major new project: a new digitizer using a sophisticated CCD camera with a uniform light source has been fabricated to digitize solar images with high spatial resolution (1 arcsec) and with high photometric accuracy.

A new indigenously designed and built spectropolarimeter has been installed and is in use at Kodaikanal for the study of active regions on the Sun. A new system to obtain K-line images of the Sun using a K-line filter has also been installed. These K-filtergrams are recorded on a 1K × 1K CCD. The system has been operational since 1996–1997.

Other research areas of study include the following:

- Oscillation in the chromospheric network
- Solar cycle variations and synoptic observations of solar activity
- Dynamics of the solar corona and coronal holes
- Sunspots and local helioseismology
- Solar interior
- Coronal mass ejections

7 Future Programmes

7.1 National Large Solar Telescope

The National Large Solar Telescope (NLST) will be a state-of-the-art 2 m class telescope for carrying out high-resolution studies of the solar atmosphere. Sites in the Himalayan region at altitudes greater than 4,000 m that have extremely low water vapor content and are unaffected by monsoons are under evaluation. This project is led by the Indian Institute of Astrophysics and has national and international partners. Its geographical location will fill the longitudinal gap between Japan and Europe and is expected to be the largest solar telescope with an aperture larger than 1.5 m till the 4 m class Advanced Technology Solar Telescope (ATST) and the European Solar Telescope (EST) come into operation.

NLST is an on-axis alt-azimuth Gregorian multi-purpose open telescope with the provision of carrying out night time stellar observations using a spectrograph at the Nasmyth focus. The telescope utilizes an innovative design with low number of reflections to achieve a high throughput and low polarization. High order adaptive optics is integrated into the design that works with a modest Fried's parameter of 7 cm to give diffraction limited performance. The telescope will be equipped with a suite of post-focus instruments, including a high-resolution spectrograph and a polarimeter. A small (20 cm) auxiliary telescope will provide full disk images.

The detailed concept design of the telescope is presently being finalized. First light is expected in 2013.

7.2 Space Coronagraph

A visible emission line coronagraph that uses an innovative design to simultaneously obtain images of the solar corona in the Fe XIV green emission line at 530.3 nm and the Fe X red line at 637.4 nm is under development. The mission is capable of taking images in the visible wavelength range covering the coronal region between 1.05 and 3 solar radii with a frequency of 4 Hz using an efficient detector. High cadence observations in the inner corona are important to understand the rapidly varying dynamics of the corona as well as to study the origin and acceleration of CMEs. There are currently no such payloads planned for the near future.

This 20 cm space coronagraph, which will be executed under the leadership of the Indian Institute of Astrophysics, is planned for launch in 2012. It will obtain simultaneous images of the solar corona in the green and red emission lines simultaneously with a field of view between 1.05 and 1.60 solar radii to (1) study the dynamics of coronal structures; (2) map the linear polarization of the inner corona; and (3) monitor the development of CME's in the inner corona by taking coronal images with high cadence up to 3 solar radii.

The large telemetry capability of the dedicated mission will permit a monitoring of CMEs for about 18 h a day. This project with several national partners has been accepted in principle by the Indian Space Research Organization.

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