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NOTES FOR THE OBSERVER

by T. P. Prabhu

Seventy-five years of Nizamiah observatory

The Nizamiah observatory which celebrates its platinum jubilee this year owes its existence to a rich nobleman of Hyderabad, Nawab Zafar Jung, who acquired a 15-inch refractor with a view to setting up an astronomical observatory. On 1901 September 29, Zafar Jung submitted the following petition to Nawab Mir Mahboob Ali Khan Bahadur, the sixth Nizam of Hyderabad state: 'I have obtained a telescope suitable for the purpose of an observatory from England. When this observatory building is constructed it will be one of the greatest observatories in India. If your Highness approves, I will designate it as the Nizamiah or H. H. the Nizam's observatory. My great desire is that after my death the observatory should belong to the government. I shall feel highly honoured, if Your Highness graceously sanctions the proposals.'

The Nizam's reply came the next day: 'Your application is accepted with the greatest pleasure and you are permitted to style the observatory which you want to establish after my name. You can make a gift of it to my government whenever you like.'

Zafar Jung had also acquired besides the 15-inch refractor an 8-inch astrograph and a number of other lenses, clocks and meteorological equipment which had been temporarily set up in his estate at Phisalbanda on the outskirts of Hyderabad. He invited C. Michie Smith, the then director of Kodaikanal & Madras observatories, to examine the two telescopes and suggest improvement in their working. Michie Smith suggested that both telescopes were worth erecting in good domes and at a suitable site.

Following the death of Zafar Jung, the Nizam issued a *firman* on 1907 February 16 for taking over the observatory equipment by the finance department of Hyderabad state. G. C. Walker, the assistant minister of finance, consulted Michie Smith and other astronomers and suggested the appointment of A. B. Chatwood as the director of the Nizamiah observatory. Chatwood was appointed the director on 1970 March 29. Like Michie Smith, he did not consider the site at Phisalbanda suitable for an astronomical observatory. After examining several possible sites, he chose a double-storied bungalow on a high ground near Begumpet station then on the outskirts of Hyderabad, which was taken on rent to be purchased subsequently. The telescopes and the equipment were shifted there by the end of 1908 April.

After holding discussions with Chatwood on 1908 April 7 Walker submitted to the Nizam detailed proposals regarding the financial and staff requirements of the observatory and regarding the nature of work it should undertake. Following the Nizam's approval on July 27, the construction of additional buildings was taken up by the public works department according to Chatwood's design. The construction of the astrograph building was taken up first, followed by workshop building and the transit house. A 75-mm aperture Cooke transit was one of the first instruments to be installed and observations of stars were being made with it by 1913 for determining errors of the observatory clocks which formed part of the original equipment acquired by Zafar Jung.

Work was started on the building for the 15-inch refractor in 1912. The masonary work of the telescope house was completed early in 1914, but did not proceed further because of paucity of funds.

One of the main astronomical activities that the observatory partook on its inception was the 'carte du ciel' or the astrographic catalogue (AC) program. This program was contemplated at an international congress of astronomy held in Paris in 1887 at which the work of photography and measurements of star positions over the entire sky was divided among 18 observatories in both the hemispheres. At the time of establishment of the Nizamiah the work in the section −17° to −23° assigned originally to the Santiago observatory had not proceeded well, and some eminent astronomers such as David Gill (the president of the international congress of astronomy), William Christi (astronomer royal) and H. H. Turner of Oxford university suggested to Chatwood that the new observatory should undertake this work. The international astronomical congress passed a resolution on 1908 April 20, reassigning the work in the −17° to −23° section of the catalogue among the observatories of Santiago, Hyderabad and the university of La Plata. The Nizam approved of his observatory's participation on July 27. Although the building for the 8-inch Cooke astrograph was completed and the telescope installed in it by 1909, the work on the catalogue could not start owing to certain problems with the telescope. In 1913, parts of the astrograph were sent to England for repairs and for mounting of a 10-inch follower telescope in place of its original 4-inch finder.

Chatwood's initial appointment for 3 years was extended by another 3 years and R. J. Pocock succeeded him on 1914 March 28. Pocock vigorously pursued the astrographic catalogue program. The astrograph parts were received back from England on 1914 May 2 and immediately installed. After preliminary tests, the first plate used in the catalogue was taken on 1914 December 9. During the first world war, there was a delay in acquiring photographic plates and several consignments were lost when the ships carrying them were torpedoed and sunk. Some pages of the manuscript of the catalogue sent to printers Messers Neil and Company of Edinburgh were also lost in transit and some were burnt in a serious fire at the printing press. Despite these difficulties, volume 1 of the Hyderabad section containing measurements of −17° zone was published in 1917. In the introduction to that volume the method followed at the Nizamiah for the observation and reduction of plates is described in full detail.

Pocock died on 1918 October 9. At the time of Pocock's death the work on zone −18° had been completed and the work on the −19° and −20° zones was well in progress Photographic work on these zones was completed by 1919 March and at the suggestion of Turner, the Nizam's Government gave permission to extend the catalogue work to −21°, −22° and −23° zones. T. P. Bhaskaran who had been working as assistant since 1912 was made the in-charge director and subsequently appointed director in 1922. Osmania university was established by Nawab Mir Osman Ali Khan Bahadur, the seventh Nizam of the Hyderabad state in 1918. The observatory which had been under the administrative control of the finance department

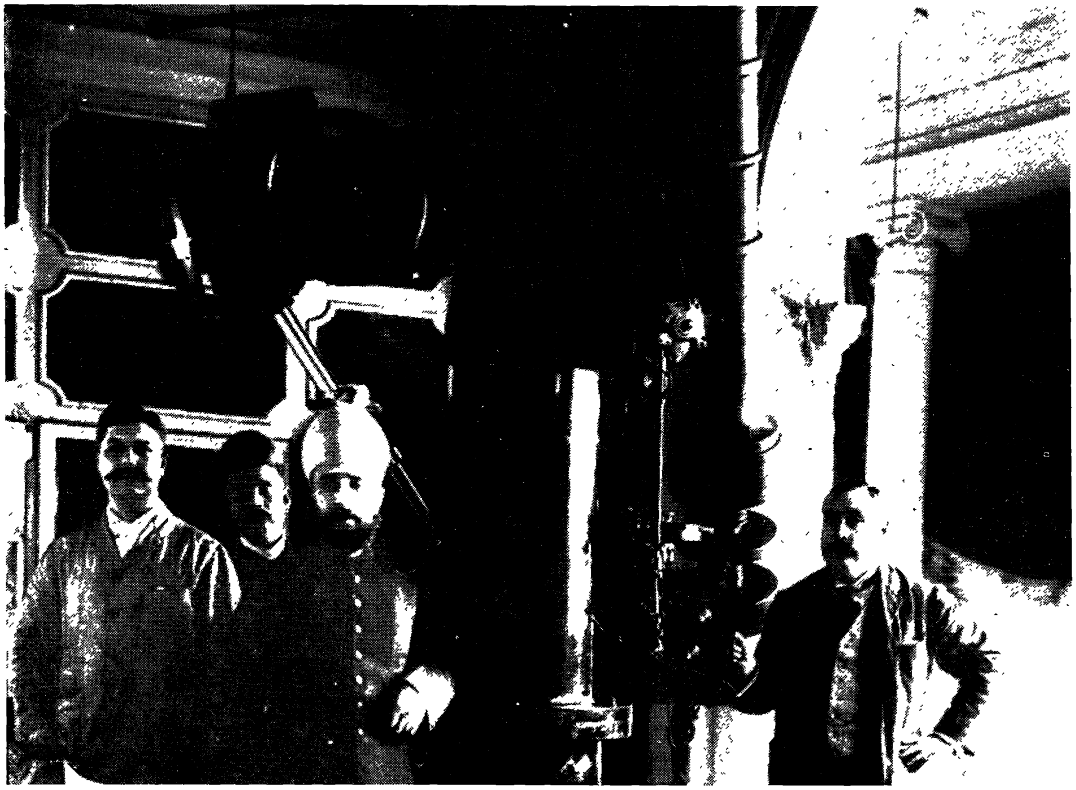

Figure 1. Nawab Zafar Jung (third from left) with his eight-inch astrograph.

since 1908 was transferred at the end of 1919 to the Osmania university under the administrative control of the state education secretariat.

The observatory also furnished the times of sunrise and sunset to the cantonment engineer at the twin city of Secunderabad for the preparation of street-lighting time-table. From 1919 onward the observatory was given the responsibility of the preparation of both English and Urdu versions of the official almanac for use of the various departments of the Nizam's government. The observatory also continued to maintain correct time which was intimated to the residency and offices of the Nizam's government. For a number of years, time from the observatory mean time clock was provided for firing the hourly gun signals in Hyderabad city. From 1933 onwards, correct time was intimated to the Hyderabad state electricity department for issuing time signal at 9 P.M.

The work of installation of the 15-inch refractor was resumed in 1921. The 15-inch lens along with 3 other lenses of 12-inch, 7-inch and 4-inch aperture had been sent on loan to the Kodaikanal observatory in 1915 January for its Kashmir site-survey expedition. It was received back in 1922 September when the mounting was ready for installation. The 15-inch telescope, the telescope house and the dome are described by Bhaskaran (1923 : *Popular Astr.* **31**, 497). From 1924 onwards this telescope was used regularly for visual brightness estimates of variables stars—particularly long-period variables with faint minima and irregular and semiregular variables. Between 1000 to 1500 visual estimates of brightness were made each year, many of them by M. K. Bappu, whose son M. K. Vainu Bappu was to have a glorious career in astronomy. From 1924 onwards the 15-inch refractor was also used for the timing observations of lunar occultations.

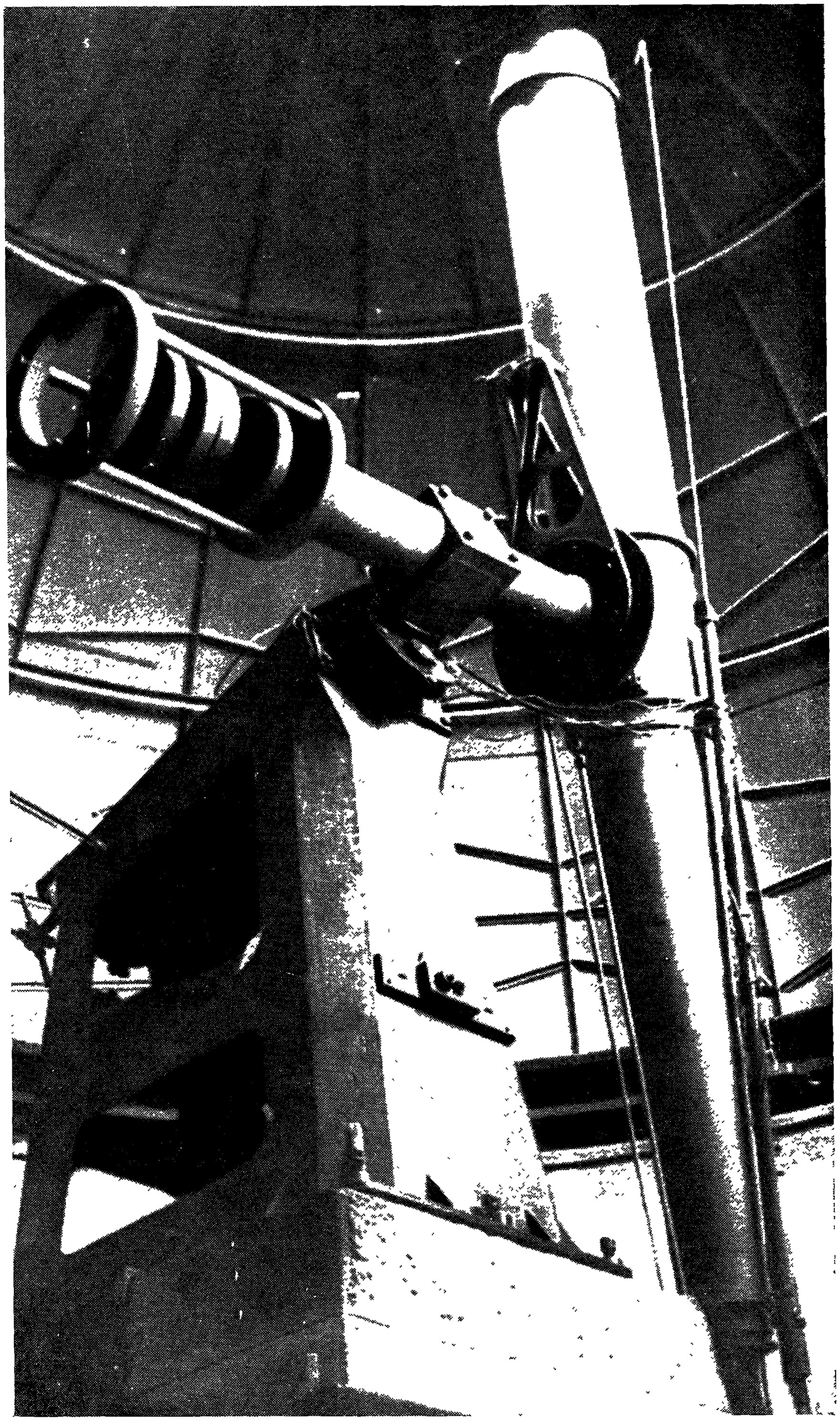

Figure 2. The 15-inch refractor of the Nizamiah observatory.

In 1923 September, the observatory acquired a horizontal pendulum-type Milne Shaw seismograph which was set up to measure the east-west component of the seismic vibrations. Another instrument of the same type was added in 1929 February to record the horizontal component in the north-south direction. These instruments have maintained an uninterrupted seismographic record.

A number of meteorological instruments were part of the equipment bequeathed by Zafar Jung. Additional meteorological instruments were acquired in subsequent years to equip the observatory towards routine observations of temperature, humidity, wind velocity, rainfall, *etc*. In 1929 the Hyderabad government sanctioned setting up of a pilot balloon station at the observatory in collaboration with the India meteorological department to study the air currents in the upper atmosphere. The first pilot balloon was released on 1929 September 15. The surface meteorological observatory maintained by the public works department in Hyderabad was also placed under the control of the Nizamiah in 1932. The observatory was the controlling office of the dominion rainfall organization, receiving from stations in the various parts of Hyderabad state information on the amount of rainfall recorded by them. The rainfall statistics compiled from these reports was supplied to the revenue department and to the meteorological department.

After the completion of the work on −17° to −23° section of astrographic catalogue in 1928, it was decided, following the suggestion of Turner, to re-observe the Potsdam zones +36° to +39° so that the results from the two observatories located at different geographical latitudes could be compared. The eleven volumes of the Hyderabad section of the catalogue published between 1917 and 1946 contain measurements of x- and y-positions and image diameters of 763,542 stars.

In addition, the astrograph was used to obtain 22 plates of Eros at the time of its close approach in 1930–31. In 1932, the observatory acquired a blink comparator made at the Yale observatory workshop according to the design of Schlesinger. A program of taking repeat plates of the Hyderabad zones which had been photographed at the Nizamiah some 20 years earlier was started and this led to the discovery of a large number of stars having proper motions larger than 0.15 arcsec.

A course of lectures on elementary astrophysics for the B.A. students of the Osmania university was started in 1935 by the observatory. The following year the course was also offered to the B.Sc. students. From 1939 onwards, another course on practical astronomy was given by the director to the students preparing for the M.A. degree.

In 1939 a Hale spectrohelioscope supplied by Messrs Howell & Sherburne, Pasadena was acquired, and set up in a specially constructed hut.

The title of Rao Sahib was conferred on Bhaskaran by the Viceroy of India in 1940 in recognition of his public services. Bhaskaran retired in 1944 July and was succeeded by Akbar Ali. Bhaskaran was, however, reappointed for two years as a research professor of astronomy at the university. Akbar Ali continued as director until his death in 1960. During this period, the astrograph could not be put to much use because of the difficulties in importing photographic plates. Therefore, computational work was taken up by making use of the published AC data to search for stars with large proper motions, common proper motion pairs and double stars. The variable star observations with the 15-inch refractor were stopped but the program of observation of occultations continued. The work on routine weather observations was continued until 1951 April when it was taken over by the meteorological department. But the observatory continued to compile rainfall statistics of Hyderabad state until the reorganization of states in 1956. The seismological observations were continued till 1970, when the seismographs were handed over to the National Geophysical Research Institute, Hyderabad.

The spectrohelioscopic observations were seriously taken up in 1945. The observatory participated in the solar and seismological observation programs during the international geophysical year (1957–58) and the observation of the sun during the international quiet sun year (1964–65).

Plans to modernize the observatory were taken up with the financial assistance provided by the University Grants Commission (New Delhi). A 48-inch telescope was ordered in 1957 December. A number of other measuring instruments and machinery were also acquired. In 1959, a separate teaching department of astronomy was started in the university.

After the demise of Akbar Ali on 1960 February 7, A. K. Das served as the director for a short period from 1960 April 12 until his death on 1961 February 18. R. V. Karandikar was appointed the next director but joined only in 1963 June. In the interim period, K. D. Abhyankar served as the in-charge director. The selection of a site for the 48-inch telescope near Japal and Rangapur villages about 55 km south-east of Hyderabad, acquisition of land, provision of road, electricity and water for the field station now known as Japal-Rangapur Observatory was completed during this period. Building activity at the new observatory was started after Karandikar took over. In 1964, UGC recognized the astronomy department and the observatory facilities at the Nizamiah and Japal-Rangapur as a centre of advanced study in astronomy and provided special financial assistance. The 48-inch telescope was commissioned in 1968 December. The telescope and its auxilliary equipment have been described by Sanwal (1974 : *Bull. Astr. Soc. India* **2**, 7). Photoelectric and spectroscopic observations of variable stars—primarily the eclipsing and spectroscopic binaries—were taken up with the 48-inch telescope.

A photoelectric photometer was built in the observatory workshop and has been used with the 15-inch refractor for photoelectric observations of β Canis Majoris and δ scuti type variables and a number of eclipsing binaries. Theoretical research was also started in the fields of dynamics of galaxies and radiative transfer.

As Japal-Rangapur fell in the path of totality of total solar eclipse of 1980 February 16, the astrograph was shifted there for an observation of the gravitational deflection of light. A 10-feet radio telescope operating at 10 GHz was also installed for the measurement of variations in the brightness of the sun at the time of the solar eclipse. Besides these, several other experiments were conducted. The observatory was also host to a large number of Indian and foreign scientists who did experiments at the time of total solar eclipse.

The advance study centre has so far awarded M.Sc., M.Phil. and Ph.D. degrees to 57, 11 and 13 students respectively. The centre has also organized a number of seminars, symposia and schools—including an IAU school for young astronomers. Besides the monumental astrographic catalogue work and the proceedings of the seminars, the centre has published over 200 research papers. It was decided in 1979 to shift the Nizamiah observatory to the Osmania campus. The new building is now complete and the observatory is being shifted from Begumpet. The UGC has now plans to develop this observatory as a major astronomical centreto serve scientists from all over the country in their training and research work.

(*N. B. Sanwal*)

John Evershed and the Evershed effect

1984 January 7 marks the seventy-fifth anniversary of the discovery of the Evershed effect. On this day 75 years ago, John Evershed—then the chief assistant at Kodaikanal observatory—obtained the spectra of sunspots which showed the outward motion of matter from the centre of the spot to the penumbra (J. Evershed 1909 : *Kodaikanal Obs. Bull.* **2**, 63; *M.N.R.A.S.* **69**, 454; *Mem. Kodaikanal Obs.* **1**, part I; 1910 : *M.N.R.A.S.* **70**, 217). The discovery appeared puzzling since the magnetic fields of sunspots and the vortex structure of filaments in the neighbourhood of the spots—both having been detected by George Ellery Hale the previous year—suggested the gas motion in the sunspots to be circular. Evershed was certainly ahead of his times, and it is only in the recent decades that the effect has drawn considerable attention. The full impact of the discovery was felt only when it became possible to achieve very high spatial resolution using vacuum solar telescope at sites with a high degree of atmospheric serenity, in addition to the observations with the stratospheric balloons. The next 'major advances in our empirical knowledge of the dynamical phenomena in the visible layers of sunspots will probably have to await observations from space, such as expected from the 125-cm Solar Optical Telescope to be flown on the NASA shuttle/spacelab in the late 1980's' (R. L. Moore 1981 : *Sp. Sci. Rev.* **28**, 387).

The discovery of the Evershed effect not only examplifies the scientific intuition of Evershed, but also his skill in instrumentation which enabled him to measure such minute shifts. Indeed, the spectrograph on which the spectra were recorded, and the measuring engine on which the shifts of wavelengths measured, were designed and fabricated by Evershed himself. Furthermore, Evershed also devised a photographic 'positive-on-negative' method to determine the relative shifts between different spectra.

John Evershed began his astronomical career in 1890—at a young age of 27—as an amateur solar spectroscopist at Kenley in England. He was at the heels of Hale in inventing the spectroheliograph. Evershed in Britain, and Deslandres in France, working independently, lost the race to Hale who built the first spectroheliograph in 1891. Evershed built one a little later, and also several other instruments for his private observatory. He also travelled to Norway (1896), India (1898), Algeria (1900) and Spain (1905) to observe solar eclipses. While he was clouded out in Norway and Spain, he obtained very good records of the flash spectrum and the spectrum of the corona during the other two eclipses. 'In eclipse observation Mr Evershed has shown extraordinary resource in so arranging his apparatus that he could himself control a considerable number of operations' (P. A. MacMahon 1981; *M.N.R.A.S.* **78**, 326).

In 1906, Evershed was appointed the chief assistant at Kodaikanal observatory. The observatory was ambitiously planned by its founder director C. Michie Smith, but it was due to Evershed's skill in instrumentation that it emerged as one of the three leading solar observatories in the world. Its only rival was probably the Mt Wilson solar observatory where Charles St John (1913 : *Ap. J.* **37**, 322) was able to verify the Evershed effect and discover its dependence on the strength of the line—and hence on the height in the atmosphere. Though Evershed (1916 : *Kodaikanal Obs. Bull.* **3**, 378) himself continued his observations, it was nearly two decades later that such observations were repeated by George Abetti (1932 : *Publ. R. Osserv. Arcetri* **50,** 47) and another two decades passed before T. D. Kinman (1952 : *M.N.R.A.S.* **112**, 425) could undertake a detailed analysis of the velocity field of a sunspot.

The interest in Evershed effect was revived during the early 1960s because of two major advancements. First, Martin Schwartzschild initiated in 1957, a program for obtaining high-resolution photographs of the sun from the undisturbed stratospheric layers (80,000 ft altitude) by means of unmanned balloon flights (Stratoscope I). The 12-inch solar telescope which was flown several times gave a wealth of information on the fine structure of solar surface. E. H. Schröter (1962 : *Z. Ap.* **56,** 183) used some of the photographs obtained in 1959 to investigate the structure, evolution and especially the 'proper motion' of the granulation (mean size of ~ 1 arcsec) in the vicinity of sunspots. These observations confirmed the Evershed effect for the first time in the integrated light, and showed directly the transverse motion that was inferred by Evershed using ingeneous indirect means of comparing the radial velocities as a function of distance from the centre of the solar disc.

The second important advancement which took place about the same time as Schröter's work was J. M. Beckers' (1962 : *Aust. J. Phys.* **15**, 327) revival of the study of inverse Evershed effect in the chromosphere. While Evershed had already pointed out in 1909 and St John confirmed that the central absorptions of calcium H and K as well Hα—which are formed in the chromosphere—show a movement of matter from the outer regions towards the centre of the sunspots, Beckers made more accurate measurements using tunable-filter photographs – a technique that would find more widespread use. While the earlier investigators had concentrated mainly on photospheric Evershed effect, beginning with Beckers' work the chromospheric Evershed flow with a much larger magnitude has received greater attention (see *e.g.* P. Maltby 1975 : *Solar Phys.* **43,** 91). The technique of filtergrams and the ability to achieve better angular resolution by controlling the turbulence in and around the telescope has now resulted in a spurt of information on the 'dynamical phenomena in the visible layers of sunspots' (R. L. Moore 1981 : reference quoted above). John Evershed was awarded the gold medal of Royal Astronomical Society in 1918 'for his investigations of Radial Motion in Sunspots and other contributions to Astrophysics'. His contributions to astrophysics were certainly not restricted to solar spectroscopy during and outside eclipses, but covered a wider range. During his stay at Kodaikanal, and particularly during his directorship of the observatory (1911–1922), Evershed not only built improved instruments and surveyed sites for a future observatory, but also obtained important observations on comets (Daniel 1907 and Halley 1910), planet Venus, nova Aquilae 1918 and Sirius. His stay at Kodaikanal ended on a sad note. His eclipse expedition to Australia in 1922, where he planned to measure the Einstein deflection of starlight in sun's gravitational field, was a total failure in spite of a perfect sky. This was 'a result of dependence on equipment of bad workmanship taken on loan that even Evershed's wizardry could not rectify' (M. K. V. Bappu, *Astronomy in India during the period 1787-1947*, unpublished). Yet, this failure—and even the retirement from the government service—was only a passing phase in Evershed's astronomical career. While presenting the gold medal of the R. A. S., its president, Major P. A. MacMahon had exclaimed that Evershed's attitude towards life followed the dictum 'work as if each day was the last, and also as if life were everlasting'—quotation attributed to M. Loewy of the observatory of Paris. And just so, Evershed returned to his private observatory after retirement, and continued to study solar spectra. Undaunted by his failure in 1922 to measure the gravitational deflection of starlight, he began to study the gravitational redshift in the lines of solar spectrum. Continuing his invaluable contributions to instrumentation, he invented a liquid prism to reduce the effects of absorption that made the conventional prism spectrographs too slow. John Evershed's six decades of astronomical research were nearly equally distributed about his date of retirement. This remarkable man died in 1956 at a ripe old age of 93.

Discovery af galaxies

Whereas Copernicus displaced the human abode from the centre of the universe to a mediocre planet circling the sun, another blow to the anthropocentric views came with the discovery of galaxies. Though the idea of 'island universe' was advocated by many an astronomer—and philosopher—during the last century, hard observational evidence was hard to come. The final understanding of the structure of our Galaxy, the denigration of the sun to a mediocre star closer to the edge of the Galaxy than to its centre, and the realization that the Galaxy itself is a mediocre system among billions of other galaxies in the universe are the achievements of the present century. Unlike the Copernican case, the discovery of galaxies was the result of efforts by several individuals—prominent among them, Harlow Shapley and Edwin Hubble. The discovery itself was stretched over the first three decades of the twentieth century. R. Berendzen, R. Hart & D. Seeley (1976) describe the excitement of these years in a great detail in their book *Man Discovers the Galaxies* (Science History Publ., New York).

A debate on the 'scale of the universe' was held by the American Association for Advancement of Science on 1920 April 26, when the humankind was on the threshold of new understanding on the nature of galaxies. During this debate that has gone into the annals of astronomy as the 'Great Debate', Harlow Shapley proposed that the Galaxy is about 100 kpc in diameter with the sun displaced 20 kpc from its centre (the modern value is smaller, ~10 kpc). Heber D. Curtis, on the other hand, argued that the so-called spiral nebulae are stellar systems like our own. Human frailties, and the dim light of the dawn of the new era, made the two facts appear conflicting. Shapley, with his fresh doctorate under the high priest of American astronomy—Henry Norris Russell—and an ambition for the directorship of Harvard observatory, emerged victorious. But soon, Edwin Hubble was to resolve the controversy using the then largest, 100-inch, telescope at Mt Wilson observatory. The human aspects of the Great Debate are investigated by M. A. Hoskin (1976: *J. History Astr.* 7, 169). *The Expanding Universe* (R. W. Smith 1982, Cambridge Univ. Press), based on a thesis under Hoskin's supervision, gives a highly informative account of the controversy and its subsequent resolution.

The understanding of the nature of galaxies was an outcome of the introduction of the new detector—the photographic emulsion—in astronomical observations. In comparison with the human eye, the photographic emulsion is not only superior in detecting the faint signals from distant astronomical objects, but as an information storage device also adds objectivity and precision to astronomical measurements. Thus an explosive increase resulted in precision information on all kinds of objects in the sky, leading inevitably to a comprehension of the cosmic distance scale.

The first attempt to measure the distances to stars was made by Galileo Galilei in the beginning of the 17th century. Galileo attempted to measure the angular diameter of Vega by determining the distance at which a silk thread would exactly occult it. He could then compare this angular size with that of the sun to determine how far the star is. Galileo was not aware of the smearing effect of the earth's atmosphere, and hence measured only the size of the 'seeking disc' of ~ 5 arcsec. Yet, his attempt gave us the first indication of the enormity of the universe. Later Newton was to compare the brightness of a star with that of the sun and get an estimate close to the modern values (R. Hanbury Brown 1974 : *The Intensity Interferometer*, Taylor and Francis, pp. 1–2). As the technique of astrometry was developed during the last century, the direct measurement of distances by triangulation (trigonometric parallax) became possible for the nearest stars. But the distance scale on the galactic and extragalactic dimensions needed a longer yardstick which was provided by the stellar clocks only in the beginning of this century. These clocks are the pulsating variables of RR Lyrae, δ Cephei and W Virginis types.

The pulsating variables are stellar analogues of a simple pendulum. In fact, one can generalise from the period of an oscillating pendulum $p \propto \sqrt{l/g}$ to the period of a pulsating variable $p \propto \sqrt{R^3/M}$ using $g = GM/R^2$ and replacing l by r the stellar radius. A pendulum serves as a clock since we can alter its length and obtain the desired period. On the other hand, a stellar clock can only be observed from a distance, and its period determined. The knowledge of its period of pulsation helps us measure the physical parameters of the star—its absolute luminosity in particular. A comparison with the apparent luminosity as observed from earth, with due correction for absorption by intervening matter, allows us to evaluate its distance using the inverse-square fall-off of light intensity with distance.

The pulsating variables of RR Lyrae type were generally known as 'cluster variables' since they are found often in globular clusters. Solon Bailey of Harvard discovered that these variables had a restricted range of absolute brightness of 0.5 ± 0.5 mag. Shapley (1914–1919) immediately realized their importance as distance indicators and proceeded to estimate the distances to several globular clusters. He went a step further to determine the diameters and total luminosities of the clusters themselves which helped him to estimate the distances to the clusters that were too far to detect the variables in them. With the absolute positions known for 93 globular clusters, it was obvious that they were distributed spherically symmetrically about a point 20 kpc away from the centre of the sun in the direction of the great star clouds of Sagittarius. The galactic centre was thus discovered.

About the same time, Henrietta Leavitt, also of Harvard, studied the δ Cephei type variables in the large Magellanic Cloud, and discovered that their periods were linearly related to their luminosities—the brighter a Cepheid, the larger is its pulsation period. Thus Cepheids by their higher intrinsic luminosities formed a new distance indicator that was useful even at larger distances. Yet it took Hubble the 100-inch Mount Wilson telescope to resolve the Cepheids in a few nearby galaxies in the 1920s and thus to resolve the problem of island universes. The immensity of the universe was thus realized. The distances were further doubled in 1954 when Baade discovered that the Cepheids resolved by Hubble belonged to population II like the W Virginis type stars in our Galaxy, and unlike the classical Cepheids seen in the Magellanic clouds and the population I objects in our Galaxy.

As in every other example of cosmic distance scale, the further steps of the ladder were soon built over the Cepheids. The novae, supernovae and the brightest resolved stars served as secondary distance indicators to farther galaxies. Several other indicators were added to these later to fathom the universe out to hundreds of megaparsecs.

Befor Hubble succeeded in determining the distances to galaxies, several attempts were made to measure their rotation. The spirals, in particular, appeared like a vortex in rotating gas. It was believed by many that we witness here the formation of a star and its planetary system from a rotating solar nebula. If so, its period of rotation should be measurable. While at Mt. Wilson, Adrian van Maanen undertook to measure the rotation from the proper motions of individual knots in the nebulae, Parcival Lowell asked V. M. Slipher to measure the rotation velocities spectroscopically. Van Maanen measured some rotations that later turned out to be spurious, attributable to the difficulties of measuring the centres of diffuse H II regions. Slipher, using the 24-inch refractor of the Lowell observatory could measure spectroscopically the Doppler shifts due to line-of-sight velocities of the galaxies, as well as the rotation of the inner regions. These absolute rotation speeds, coupled with the angular speeds derived by van Maanen could yield the distances to the galaxies directly just as in the cluster parallax method. Even with the small erroneous value obtained by van Maanen at the limit of detectability, it should have been obvious that the spiral nebulae do not belong to our Galaxy. One can certainly draw a comparison here with Galileo's determination of the distance to Vega While Galileo underestimated the distance by a factor of 10^4, van Maanen's underestimate would have been only a factor of 10^2.

On the other hand, Slipher's measures of the line-of-sight velocities led to a greater revelation. Of course, the magnitudes of these velocities were so large that—if they belonged to the Galaxy—the gravitation of the Galaxy could not have stopped them from escaping away. Furthermore it was startling that nearly all of them were receding away from us. When Hubble plotted Slipher's rotation velocities of about two scores of galaxies against his own distance estimates, he found that the universe is expanding linearly. Though such a relation had been suggested by Knut Lundmark a few years earlier, only Hubble's accurate distances could dispel doubts in 1929. This expansion could be explained by the world models based on Einstein's general theory of relativity. Much efforts are going on even now towards improving the estimate of Hubble constant—the rate of expansion of the universe. The current best estimate stands between 50 and 100 km s^{-1} Mpc^{-1}, much smaller than Hubble's early estimate of 500 km s^{-1} Mpc^{-1}. That is to say, we now realize that the universe is 5–10 time larger than what Hubble thought.

While the half century after Hubble has seen tremendous strides in our understanding of the structure, content, evolution and formation of galaxies and of the universe in general, the recent revolution in detector technology has made the strides even more rapid. We now appear to be on the verge of resolving several unsolved problems of the physics of galaxies and the universe.

Extragalactic supernovae

On 1885 August 31, E. Hartwig of Dorpat observatory discovered a new star near the centre of Andromeda nebula. Hartwig immediately publicised it, believing that he had witnessed the birth of a star in the centre of the nebula in accordance with the Laplace theory of the formation of solar system. There were many who believed that the 'spiral nebulae' were examples of such solar systems in the making. However, the brightness of this star began to decline every night until it disappeared altogether in a period of six months.

Hartwig's star, later termed S Andromedae, is the first confirmed extragalactic supernova. During the days when the existence of external galaxies was not known, S Andromedae was believed to be similar to the galactic novae. Its light curve was remarkably well-observed, thanks particularly to several amateur astronomers. Actually, the star was discovered independently by several amateurs much before Hartwig, the earliest discovery being on August 19 by Isaac Ward. Furthermore, Silcock was certain that it was not visible the previous night. There was a continuous record of observations through its rise to a maximum of $\sim$ 7 mag on August 31–September 1 to several months thereafter, aided by professional observers during the decline of its light.

The next extragalactic supernova was Z Centauri in NGC 5253 discovered by M. Wolf in 1895 which did not receive as much attention since it was discovered when rapidly fading in brightness. Several supernovae were discovered during the first two decades of this century, particularly by Curtis, Ritchey and Pease who had begun to photograph the spiral nebulae. The year 1917 particularly saw a large number of supernovae (5 in all). Heber Curtis, borrowing an idea due to the physicist F. W. Very, compared the brightness of these 'novae in spiral nebulae' with the galactic novae to deduce the distances to the spirals (H. D. Curtis 1917: *P. A. S. P.* **29**, 180). Harlow Shapley also made a similar attempt independently (H. Shapley 1917: *P. A. S. P.* **29**, 213). While both Curtis and Shapley believed that the novae furnished the strongest evidence that the spiral nebulae are external galaxies, Shapley changed his views later, due to his strong faith in van Maanen's measurement of rotation of nebulae. On the other hand, he thought that the novae in spirals may actually be intrinsically fainter than the galactic novae; they certainly needed to be if spirals were within the galactic system. It is ironical that what later turned out was just the opposite.

It is not unlikely that—if not impressed by van Maanen's results—Shapley would have been the one to discover the differences in the magnitudes of outbursts of novae and supernovae. One of the first few examples of the extragalactic counterparts of normal galactic novae was discovered by Shapley himself. It was in 1917 that Shapley discovered a 17.5 mag nova in the Andromeda nebula while two others of similar brightness were discovered the same month by Ritchey on old (1909) plates of the nebula. Sixteen more were discovered by the year 1920, the year of the Great Debate on the existence of island universes. More than 100 normal novae of magnitude $\sim$17 were discovered in the Andromeda nebula before Walter Baade & Fritz Zwicky (1934: *Proc. Nat. Acad. Sci.* **20**, 254) advocated that there exists a class of 'super-nova' to which S Andromedae, Z Centauri and the galactic novae of Tycho (1952) and Kepler (1604) belong.

Fritz Zwicky, a physicist at California Institute of Technology, had an extremely broadminded approach to scientific research. His 'morphological method' of using 'directed intuition' to unravel Nature's mysteries consisted of fitting in every aspect of knowledge into a harmonious whole. He envisioned—far ahead of his times—the existence of matter in a continuum of degree of compactness from the tenuous intergalactic matter to the most compact objects from which even light cannot escape (blackholes). The compact neutron stars were thus predicted to be between the white dwarfs that were already known, and the matter in the highest degree of compactness. Baade & Zwicky argued that the supernova events take place as the core of a star implodes to form a neutron star and the energy thus released would expell the envelope explosively. Characteristic of Zwicky's 'many-sided' approach, the theory predicted several things simultaneously—the existence of supernovae, neutron stars, and high-energy cosmic rays of extragalactic origin formed during such an event. Zwicky even put forward a supernova theory of runaway stars.

The theory came under severe criticism since many leading scientists—Arthur Eddington prominent among them—firmly believed that the white dwarfs marked the end products of stars of every initial mass. One may recall Eddington's criticism of the Chandrasekhar limit not very much later (1935). The neutron stars had to await for over three decades for their final discovery in the form of pulsars.

While Zwicky's unlimited faith in his scientific method was generally ridiculed, it only served to increase his contempt for professional astronomers who 'simply did not know enough physics to apply its fundamental principles to their science' [F. Zwicky 1974 : *Supernovae and Supernova Ramnants* (ed. : C. B. Cosmovici) D. Reidel, p. 1]. His morphological approach insisted on having as complete record as possible of all kinds of objects and events in the universe. Regarding the scientists in general, Zwicky felt that 'Once a man is in a rut he seems to have the urge to dig ever deeper. And what often is most unfortunate, he does not take the excavated debris with him... but throws it over the edge, thus covering up the unexplored territory and making it impossible for him to see outside his rut. The mud which he is throwing may even hit his neighbours in the eyes, intentionally or unintentionally, and make it difficult for them to see anything at all. (F. Zwicky 1957 : *Morphological Astronomy*, Springer-Verlag, p. 6).

Zwicky estimated that about one supernova would explode in a millenium in every galaxy—a highly conservative estimate from the present day standards. He reasoned that if he monitors a thousand galaxies, he would discover one every year. One can imagine his excitement if one compares this figure with a total of a dozen supernovae discovered in the previous half a century. Thus Zwicky found himself buying a Wollensack 3¼-inch lens camera and starting to photograph the Virgo cluster of galaxies.

It is amusing to see how, in spite of meticulous planning, Zwicky could not escape Murphy's law during those few years of struggle againt the laughing-crowd of astronomers. The Virgo cluster chose to remain silent, though a few chance discoveries of supernovae were made here earlier and many more were made later. Undaunted, Zwicky persuaded Hale to build an 18-inch Schmidt 'on the pretext that it was needed as a scout instrument for the 200-inch telescope' which was in Hale's plans. This Schmidt telescope was ready within a year, and Zwicky put it in operation in 1936 September, surveying a much larger area of the sky than the mere Virgo cluster. He found his first supernova in 1937 March (in NGC 4157), the second in August (IC 4182) and the third in September (NGC 1003) of the same year. Several others joined Zwicky in the project—the Palomar supernova search—and the average rate of discovery reached four supernovae per year. Hale gave a priority on the 100-inch telescope to the spectroscopy of supernovae, and Zwicky, aided by Baade and Minkowsky in recording the spectra, arrived at the taxonomy of supernova (spectral) types.

Following his 'many-sided' approach, Zwicky used the 18-inch Schmidt to discover many dwarf galaxies and clusters of galaxies. The success of the Schmidt telescope induced Hale to build a bigger (48-inch) one, which was put in operation in 1949. This telescope was, however used exclusively for the National Geographic Society—Palomar observatory sky survey till 1958, after which it became available for supernova search, among other projects.

It is surprising why supernovae could not be discovered with the 48-inch Schmidt while the sky survey was in progress. Probably it was partly because scanning the large-size plates under a blink microscope was too time-consuming and the comparison plates of the same region of the sky taken with the same telescope were not immediately available. It also appears that the sky survey plates were not immediately available to Zwicky and others who were interested in scanning them for supernovae. Over 50 supernovae were later discovered on these plates after a closer examination of individual objects; it was then too late to monitor these supernovae or to obtain their spectroscopic types. The 18-inch Schmidt used smaller-size films, which could be superposed over comparison films and scanned quickly under small-power binoculars. The most effective way to undertake supernova search now appears to b5 of using a small telescope and simple instruments—at the cost of missing fainter supernovae in distant galaxies. On the other hand, a larger telescope needs to be backed by more elaborate scanning instruments to speed up discovery.

Since 1959, several observatories joined the cooperative program of supernova search initiated by Zwicky. The 48-inch Palomar Schmidt had started in 1958 a limited search of 38 fields containing nearby groups and clusters of galaxies. Three dark nights were allocated each month for the programme which continued till 1976. The Asiago observatory joined the search in 1959 with its 16-inch Schmidt telescope. Occasionally, a larger 27-inch Schmidt was also used. While 36 fields were maintained under strict control, a maximum of 74 fields were surveyed. The average interval between two consecutive exposures of the same region was 14 days. As soon as a supernova was discovered, it was monitored photometrically and spectroscopically with the larger Schmidt, or the 122-cm reflector. The Zimmerwald observatory of Bern university, Switzerland, also joined the program, with a 16-inch Schmidt. A few dozen supernovae have been discovered with this telescope, despite the poor weather conditions at this site, with an average of 35 nights spent on the search every year. The Konkoly observatory in Hungary joined in 1963. Spending a similar number of nights, it has contributed over one supernova per year. Others who have contributed occasionally include the Correlitos observatory, New Mexico, where the images of a few galaxies are examined on a television screen, and the screen is photographed whenever a supernova is discovered. Amateurs with better-than-average telescopes have also joined the race, notably R. Evans of Australia who has discovered SN 1981A (N1531), SN 1981D (N 1316), SN 1983N (N 5236) and SN 1983U (N 1448). He also discovered SN 1983 G (N 4753) independently of Okazaki of Tokyo astronomical observatory who is the first discoverer of this supernova.

The number of supernovae recorded since 1885 are shown as a histogram in figure 3. The supernovae discovered on old plates after their inspection several months to several years later are shown unshaded. It becomes evident that prior to Zwicky's search with the 18-inch Schmidt, the rate of discovery was very low; a large fraction of the ones that occurred prior to 1937 have been discovered on old plates. Zwicky's initial survey, seen as an isolated peak between 1937 and 1941, was discontinued during the second world war. The 'old plates' peak between 1950 and 1956 is due to a large number of supernovae recorded on the Palomar sky survey plates but identified much later. The modern period in supernova search begins in 1959 with the international cooperation in supernova search initiated by Zwicky. There was a slack season during 1976–79 beginning with the withdrawal of the 48-inch Schmidt and slowing down of other participants in the cooperation. The subsequent restoration of the discovery rate is largely due to the Cerro el Roble search initiated by J. Maza of the University of Chile, while a significant fraction is contributed by the Sternberg Astronomical Institute in Crimea.

An ambitious program of quick scanning of bright galaxies by an automated telescope and data acquision system was launched nearly a decade ago by S. Colgate of Socorro. This project has not met with success yet, because of the hardware and software complications involved.

It is evident from figure 3 that the efforts in supernova search have not been sustained at a steady level. The supernova surveys are far from complete and any statistics based on these fragmentary data require heavy correction for incompleteness. Several problems related to the supernova phenomenon would find more definite answers if some observatories come forward to keep at least the brighter galaxies under a strict observational watch, and obtain the follow-up photometric and spectroscopic observations as soon as a supernova is discovered.

Occultations

Planetary occultations

It appears that Saturn has faint rings in the outer magnetosphere. The ion-density measurements by Voyagers 1 and 2, and by Pioneer 11 all show dips at distances

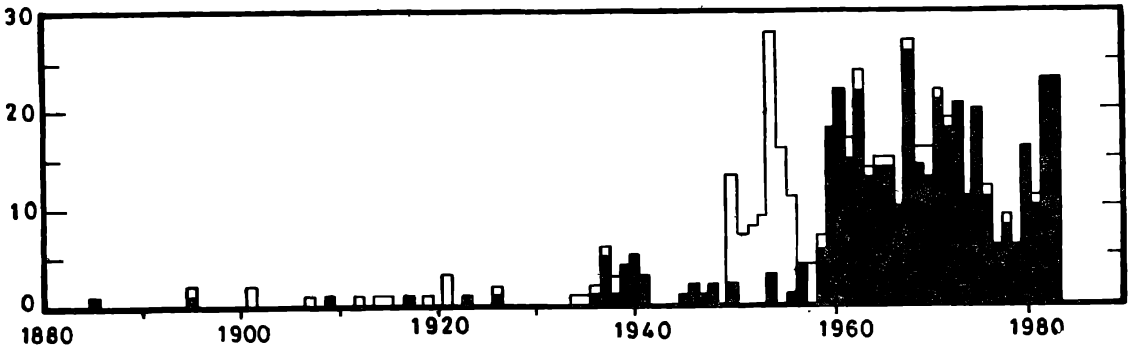

Figure 3. Histogram of supernovae recorded during different years since S Andromedae 1885 in M31. The shaded area represents the supernovae recorded on the photographic plates exposed during the corresponding year, but identified on these plates much later. The largest fraction of these (1950–56) were recorded on the NGS-POSS plates. The figure is based on the master list of supernovae kindly supplied by C. Kowal & W. L. W. Sargent.

corresponding to 14 and 19 radii from Saturn. The neutral material in these regions that probably causes this decrease in number density of ions may be detected by occultation techniques. D. J. Mink (1983 : *Astr. J.* **88**, 559) has tabulated predictions of occultations of stars by possible rings up to 19 Saturn radii, visible from various places on earth. Table 1 lists details of such events visible from Asia between 1984 March and May. Mink indicates that pre-Saturn and post-Saturn events can be more than 24 hours apart, and because it can take more than three hours for a star to pass through the region of interest even on one side of the planet, cooperative observations by geographically diverse observers are needed to define the extent and structure of any possible rings.

The occultation of Uranus on 1984 June 18 (A. R. Klemola, D. J. Mink & J. L. Elliot 1981 : *Astr. J.* **86**, 138) can be best observed in the near-infrared. The expected drop in light is only 4% at 8600Å, and lower at shorter wavelengths. The visual brightness of the star is fainter than 12 mag and hence at least a medium-size telescope is necessary. The duration given in table 1 is that for the body of the planet only. As the sky-plane velocity is rather large, a time resolution of at least 0.25 s is necessary to bring out the fine structure of the Uranian rings.

The occultation of the 11.7-mag asteroid Hygiea on 1984 March 26 is of great interest (G. E. Taylor 1981 : *Astr. J.* **86**, 903). Simple timing observations of the disappearance and subsequent reappearance of this 8.9 mag star will directly yield the size of the minor planet. Accurate time base in terms of either UT or IST and accurate knowledge of the observer's geographical co-ordinates are needed. The timing observations may be made visually using a stop-watch, or from the photoelectric observations. If observations are made by a large number of observers at various locations in India, one will have enough number of chords to yield precise information on the shape of the asteroid. One example of such detailed observations is that of the occultation of AG + 0° 1022 by Juno on 1979 December 11. Thirty-eight observers at 15 different sites observed this occultation to derive the elliptical shape of Juno with a semimajor axis of 145.2 ± 0.8 km and semiminor axis of 122.8 ± 1.9 km (R. L. Millis *et al.* 1981 : *Astr. J.* **86**, 306). Unfortunately the occultation of Hygiea occurs just before dawn. Thus, while a six-inch telescope would normally suffice in observing such an event, an eight-inch or larger one may be needed to record it against the brightened sky.

Lunar occultations

Table 2 lists the lunar occultations of bright stars ($\leqslant$ 7.5 mag) predicted for Kavalur. Some additional information on a few stars appears in table 3.

(*R. Vasundhara*)

Table 1. Predictions of planetary occultations

Date 1984		UT h	m	Planet or Asteroid	Star (SAO)	Mag	Sp T.	α (1950) h	m	s	δ °	′	″	Notes
March	24	18	41	Saturn	158913	8.8	A5	14	53	55.3	−13	56	11.5	14 Saturn radii; Immersion
	25	21	36	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	14 Saturn radii; Emersion
	26	23	17	Hygiea	163443	8.9	G0	20	16	25.0	−19	43	52.1	Max. duration 15s; drop in light 2.2 mag.
May	12	20	44	Saturn	158763	9.0	F2	14	41	03.3	−12	54	34.5	19 Saturn radii; Immersion
	13	15	06	,,	,,	,,	,,	,,	,,			,,		,, Emersion
June	18	19	34	Uranus	—	∼12	—	16	35	10.2	−21	58	42.2	Max. duration 35 min for planet body occultation

Table 2 Lunar occultations predicted for Kavalur between 1984 January–June

Date 1984		Time (UT)				Object	Mag.	Sp T	α (1984) h	m	s	δ °	′	″	Altitude deg	Percentage illumination
January	6	13	24	56	R	κ Capricorni	4.8	G5	21	41	44.0	−18	56	36	23	10^+
	8	12	53	45	R	HR 8836	6.4	K5	23	13	48.7	−10	46	45	51	24^+
	13	20	12	33	D	52 Geminorum	7.3	A0	3	13	14.4	+15	31	53	7	73^+
	15	13	57	52	D	BD + 22° 0776	7.4	K0	4	55	09.0	22	33	10	59	89^+
		20	08	52	D	BD + 22° 0818	6.7	B5	5	04	39.9	23	02	26	33	90^+
	16	13	52	22	D	BD + 24° 1039	7.4	B8	5	56	38.3	24	36	45	44	95^+
	17	14	02	30	D	BD + 25° 1542	6.9	A2	7	1	8.8	25	26	59	33	99^+
		14	00	33	D	BD + 25° 1545	7.2	A3	7	1	22.0	25	23	20	32	99^+
		21	10	7	D	BD + 25° 1618	6.0	K0	7	13	43.9	24	54	51	46	99^+
	19	22	17	18	R	BD + 20° 2318	6.7	G5	9	23	51.9	19	51	22	60	97^-
	20	15	31	20	R	BD + 16° 2098	7.3	K0	10	13	40.2	16	13	03	11	93^-
	22	17	54	59	D	BD + 04° 2583	6.8	A0	12	10	51.0	4	8	40	17	76^-
		18	01	25	R										18	76^-
	24	20	54	57	R	BD − 7° 3748	6.7	K0	13	59	13.2	−8	05	02	33	53^-
	25	21	14	58	R	BD − 12° 4152	7.4	F0	14	51	18.8	−13	26	22	24	42^-
		23	24	30	D	Saturn	.5		14	55	29.3	−14	16	14	50	41^-
	26	00	39	58	R	Saturn	.5		14	55	29.9	−14	16	16	61	41^-
	29	23	22	21	R	CD − 25° 13170	6.2	B2	18	28	20.7	−25	16	07	4	8^-
February	3	13	13	54	D	BD − 16° 6057	7.1	K0	22	16	33.4	−16	03	48	10	2^+
	5	14	26	06	D	HR 9014	6.3	K2	23	47	41.6	− 6	28	21	15	11^+
	11	12	28	37	D	HR 1403	5.7	A5	4	27	03.4	+21	35	08	69	64^+

(*Continued*)

Table 2. *(Continued)*

Date 1984		Time (UT)				Object	Mag	Sp T	α (1984) h	α m	α s	δ °	δ ′	δ ″	Altitude deg	Percentage illumination
February	12	17	10	48	D	BD + 24° 0854	6.9	B8	5	32	31.9	24	37	10	55	76^+
		17	52	32	D	BD + 24° 0868	7.4	K0	5	34	04.9	24	16	54	46	76^+
		20	16	13	D	BD + 24° 0909	7.0	F2	5	38	52.8	24	13	05	14	77^+
		20	29	29	D	BD + 24° 0913	7.1	K0	5	39	19.5	24	31	51	11	77^+
	13	20	58	47	D	ε Geminorum	3.2	G5	6	42	57.4	25	08	55	18	86^+
		21	54	15	R										6	86^+
	14	19	18	19	D	κ Geminorum	3.7	G5	7	43	29.7	24	26	16	53	92^+
		20	02	46	R										44	92^+
		21	24	10	D	BD + 24° 1777	7.1	F5	7	48	21.9	24	31	48	26	93^+
		21	55	37	D	BD + 24° 1785	7.0	F0	7	49	42.8	24	12	09	19	93^+
	15	23	33	31	D	BD + 21° 1952	7.5	G5	8	58	01.6	21	13	44	11	98^+
	16	14	32	26	D	BD + 19° 2254	6.9	K0	9	44	59.6	18	45	26	29	100^+
	17	20	47	06	R	BD + 13° 2322	7.5	K0	10	53	27.8	12	27	19	76	99^-
	18	16	50	05	R	BD + 07° 2480	7.1	M0	11	45	17.6	7	15	43	34	95^-
	19	00	04	13	R	BD + 06° 2529	7.5	K0	11	55	59.7	5	25	58	41	94^-
	21	23	43	48	R	BD − 12° 4104	7.4	G0	14	37	14.9	−12	50	33	64	68^-
	22	22	06	31	R	BD − 16° 4093	7.2	F0P	15	28	39.9	−17	23	13	48	58^-
	24	22	02	08	R	CD − 23° 13297	6.7	G5	17	17	07.5	−24	03	25	24	37^-
	25	23	59	19	D	CD − 25° 12995	6.4	K0	18	17	41.1	−25	36	45	35	27^-
March	6	14	58	25	D	BD + 06° 0275	7.3	K0	01	47	48.7	7	36	10	10	13^+
	9	17	55	20	D	53 Tauri	5.4	B8	4	18	28.6	21	06	17	4	39^+
	12	14	17	25	D	BD + 25° 1594	7.0	G0	7	08	36.7	25	45	25	76	70^+
		16	42	11	D	BD + 25° 1609	6.9	A0	7	11	50.6	25	46	39	57	70^+
	14	13	09	54	D	BD + 21° 1991	6.1	A0	9	12	43.4	21	20	59	42	88^+
		20	00	22	D	BD + 20° 2318	6.7	G5	9	23	52.2	19	51	23	41	90^+
	15	13	44	25	D	BD + 16° 2098	7.3	K0	10	13	40.8	16	13	03	37	95^+
		18	17	59	D	BD + 16° 2116	7.4	G5	10	21	53.4	15	25	30	79	96^+
	16	19	00	45	D	BD + 09° 2482	6.7	A2	11	21	01.5	9	15	17	81	99^+
		21	33	49	D	BD + 09° 2494	6.8	K0	11	25	29.3	8	44	46	45	99^+
	17	15	15	26	R	BD + 04° 2583	6.8	A0	12	10	52.0	4	08	35	31	100^-
	18	19	13	02	R	BD − 02° 3651	7.5	K2	13	12	32.5	− 3	24	43	68	97^-
	19	16	58	12	R	BD − 08° 3689	6.5	A0	14	03	31.3	− 9	10	59	27	92^-
		20	15	39	R	96 Virginis	6.5	G5	14	08	10.0	−10	15	40	64	91^-
	20	22	05	30	R	γ Librae	5.3	K0	15	05	44.4	−16	11	49	61	83^-
	21	17	11	32	R	47 Librae	5.9	B5	15	54	05.1	−19	20	16	3	76^-
		23	58	39	D	ω² Scorpii	4.6	G0	16	06	28.2	−20	49	39	53	74^-
	22	19	36	48	R	24 Ophiuchi	5.6	A0	16	55	50.1	−23	07	36	21	65^-
	24	22	32	23	D	σ Sagittarii	2.1	B3	18	54	15.9	−26	19	06	32	44^-
		23	45	24	R										44	44^-
	28	00	15	46	D	37 Capricorni	5.8	F5	21	33	56.1	−20	09	29	27	17^-

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April	4	12	59	05	R	BD + 15° 0430	6.6	K0	3	3	45.7	15	47	37	31	8^+
	5	15	12	24	D	BD + 19° 0643	6.8	G5	4	00	09.7	20	09	18	13	15^+
	6	14	29	50	D	BD + 23° 0757	6.6	K0	4	52	35.0	23	17	26	34	23^+
		15	40	57	R										18	23^+
	8	14	51	36	D	BD + 25° 1460	6.9	F8	6	50	00.8	25	46	55	53	43^+
		15	32	27	D	BD + 25° 1469	6.6	A2	6	50	58.6	25	41	03	45	44^+
		15	50	55	D	BD + 25° 1479	7.5	F0	6	51	54.7	25	47	09	41	44^+
	9	19	46	52	D	BD + 24° 1826	7.5	K0	8	00	33.0	23	57	31	2	56^+
	10	17	09	49	D	BD + 22° 2029	7.0	G5	8	56	10.2	21	55	23	50	67^+
	12	17	11	32	D	BD + 13° 2322	7.5	K0	10	53	27.9	12	27	21	76	86^+
		20	35	59	D	BD + 12° 2284	6.4	F5	10	58	51.9	11	47	27	27	87^+
	13	13	54	17	D	BD + 07° 2480	7.1	M0	11	45	17.9	7	15	42	43	93^+
	16	22	24	31	R	BD − 13° 3944	7.2	K5	14	39	40.6	−13	58	51	42	98^-
	17	23	31	17	R	41 Librae	5.5	G5	15	38	00.2	−19	15	07	37	94^-
	21	23	28	22	R	CD − 25° 14115	7.4	K0	19	30	18.1	−25	46	18	50	60^-
	24	21	36	00	R	BD − 18° 6056	6.4	G5	22	01	18.6	−17	58	54	11	32^-
	25	22	27	29	R	τ^2 Aquarii	4.2	K5	22	48	44.0	−13	40	42	14	23^-
	26	23	41	55	R	BD − 09° 6220	7.3	F5	23	35	09.8	− 8	51	21	23	16^-
May	12	14	03	59	D	BD − 02° 3651	7.5	K2	13	12	32.8	− 3	24	43	49	91^+
	13	15	50	30	D	96 Virginis	6.5	G5	14	08	10.6	−10	15	42	57	97^+
	14	17	19	10	D	γ Librae	5.3	K0	15	05	45.3	−16	11	52	58	100^+
		17	55	20	D	BD − 15° 4028	6.6	40	15	05	56.8	−16	25	32	60	100^+
	16	19	15	21	R	CD − 24° 13050	7.3	K2	17	02	33.1	−24	13	14	51	97^-
		19	49	26	R	CD − 24° 13070	7.4	K0	17	03	30.7	−24	13	12	53	97^-
	17	19	12	40	R	CD − 26° 12724	7.5	A0	18	02	25.4	−26	19	16	43	92^-
		23	28	33	R	CD − 26° 12862	7.5	G0	18	08	16.8	−26	07	08	39	91^-
	24	21	00	06	R	30 Piscium	4.7	M3	00	01	08.1	−06	06	11	5	30^-
June	3	13	22	18	D	BD + 24° 1903	7.0	G5	08	18	11.6	24	13	37	44	17^+
		14	05	07	D	λ Cancri	5.9	A0	08	19	34.6	24	04	30	35	17^+
		14	41	59	R										26	17^+
	4	16	44	00	D	BD + 20° 2318	6.7	G5	09	23	51.2	19	51	28	12	27^+
	5	17	12	35	D	BD + 16° 2116	7.4	G5	10	21	52.6	15	25	35	17	38^+
	7	13	28	06	D	BD + 05° 2580	7.5	MA	12	03	30.4	05	01	13	82	60^+
	8	19	34	03	D	BD − 02° 3621	7.5	F0	13	03	4.5	−03	08	02	15	73^+
	10	20	36	47	D	BD − 14° 4045	7.4	F5	14	50	11.9	−14	57	51	20	91^+
	15	16	11	21	R	CD − 25° 14115	7.4	K0	19	30	19.8	−25	46	15	15	95^-
	16	17	09	54	R	CD − 24° 16056	6.9	G0	20	27	34.2	−24	12	55	16	90^-
	16	17	20	16	R	CD − 24° 16058	6.9	K0	20	27	49.1	−24	02	09	19	89^-
	17	19	16	48	R	33 Capricorni	5.5	K0	21	23	16.8	−20	55	09	33	82^-
		20	51	04	R	BD − 21° 6016	7.3	K0	21	25	29.1	−21	04	02	49	82^-
	21	23	14	09	R	BD − 02° 0069	6.8	A0	00	30	52.0	−01	52	50	57	45^-
	22	23	48	06	D	89 Piscium	5.3	A2	01	16	58.5	+ 3	31	53	57	35^-
	25	22	08	36	R	BD + 17° 0575	6.4	K0	03	33	13.1	17	46	53	6	11^-

Table 3. Additional information on bright stars being occulted by moon

HR	Other name	Companion			Notes
		Δm	Separation arcsec		
8288	43 κ Capricorni				
8836		4.5	3.5	AB	CPM
2725	52 Geminorum	6.3	23.9		Optical D
6929	V 4031 Sagittarii				Shell Star
1403		.8	0.01		OD. Third Component (10.5 mag)at 161 arcsec
2473	ε Geminorum	6.0	110.3		O Diameter 0.0018, 0.0056 arcsec He 10830 em., abs. comp. 9.22 mag
2985	77 κ Geminorum	5.8	7.1		
1339	53 Tauri				Mn star; SB 4.452064 d shortest for Mn stars unresolved by speckle interferometry
5915	47 Librae	2.0	0.7		Var. ?
5997	10 ω^2 Scorpii				Var. Amp. 0.02 (*b-y*)
6291	24 Ophiuchi	.3	1.0		
7121	34 σ Sagittarii	7.4	309.0		Lyman α, β em.; interferometry indicates multiplicity
8679	71 τ^2 Aquarii	4.5	132.5		
9089	30 Piscium				UV Fe II em.

*CPM = Common proper motion; D = double; O = occultation; em. = emission; abs. = absorption; Var. = variable.

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On the absorption of He I 10830 Å line by spicules

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Abstract. The possible applications of the time-dependent measurements of the equivalent width of the He I 10830 Å line for a better understanding of the growth of spicules and the evolution of coronal holes and x-ray bright points on the sun are discussed.

Key words: sun-spicules—He I 10830 Å

A significant fraction of the solar chromosphere is in the form of spicules. Spicules, when seen on the limb, resemble jets of cold dense gas shooting out with velocities ~20 km s^{-1} and penetrating into the lower corona. Several models exist (Beckers 1972) but it is only recently that time-dependent models have been considered (Hasan & Venkatakrishnan 1981; Suematsu *et al.* 1982). A better understanding of the processes leading to the formation of spicules can be obtained if these could be observed on the disc. The earlier investigations in this direction have concentrated on the Hα line. However, this line has several drawbacks related to the fact that it is formed over a wide range of densities and can either be emitted or absorbed along the line of sight. Thus the identification of the disc counterparts of spicules has remained a major problem to this day (Beckers 1981, personal communication).

The use of UV lines of highly ionized elements for such identifications is not satisfactory since most of the spicule is in the form of cool (6000 K) dense gas. This is probably the reason for the failure to detect the effects of spicules in EUV emission lines using skylab data by Vernazza *et al.* (1975). It is interesting to note in this connection that De Jaeger, Namba & Neven (1966) have identified the He-mottles with spicules.

Observations in He I 10830 Å by Giovanelli & Hall (1977) with a resolution of 2 arcsec indicate that the assumption of a uniform chromosphere is incompatible with the data. These highly resolved observations have revealed that the line-depth over supergranular cell centres (~0.021) is smaller than over the network boundary (~ 0.075). By assuming a triangular profile for the 10830.3 Å line with a width of 2 Å at the continuum, one can crudely estimate the equivalent width to be 21 mÅ at the centre and 75 mÅ at the boundary. If one further assumes that network centre is completely devoid of spicules and the boundary is filled with them, then the widths of 21 mÅ and 75 mÅ could be attributed separately to "inter-spicule" and "spicular" material.

However, spicules are not long-lived structures as is well seen from the limb observations (Kulidzhanishvili & Nikolsky 1978). Typically they begin as bright points in Hα and then quickly (~ 30 s) extend to their maximum height (~ 10,000 km) which they maintain for ~5 min before fading away. One would, therefore, expect the spicule to be projected over a given area on the disc only for a finite time. During such time as when the spicule exists, the absorption by the denser matter would produce an equivalent width of 75 mÅ which would drop to 21 mÅ when the spicule disappears (either by falling back or by expanding into a rarer state). With sufficient temporal (~ 1 min) and spatial resolution (~ 2 arcsec), but with only moderate spectral resolution (~ 200 mÅ), it would be possible to detect these changes in the equivalent width. The frequency of the occurrence of spicules as well as their distribution on the disc could then be studied, and used as input data for developing stochastic models for the appearance of spicules in the light integrated over the visible hemisphere of the sun. Such models in turn would be extremely useful for the detection of similar phenomena in stellar chromospheres.

A similar monitoring of the absorption of 10830 Å line on a longer time-scale (~ hours) over the boundaries of the evolving coronal holes on the sun could indicate the time-scale for change in intensity of the coronal soft x-radiation. The x-ray observations of Solodyne, Krieger & Nolte (1977) have given only an upper limit for this time-scale. If the formation of a coronal hole occurs due to a transient readjustment of the coronal magnetic field geometry, then the associated changes in density could be equally rapid (Hasan & Venkatakrishnan 1982). Thus the 10830 Å absorption measurements could give a valuable insight into the mechanism of the formation of coronal holes. The evolution of smaller structures like x-ray bright points could likewise be observed in He I 10830 Å. In this case, however, the absorption would be due to atoms excited by coronal radiation as well as by collisions in the regions heated by thermal conduction along the legs of the x-ray emitting flux-tube.

In conclusion, we have pointed out that measurements of the absorption of the He I 10830 Å line with sufficient spatial and temporal resolution could give useful information on the growth and decay of spicules as well as on the evolution of coronal inhomogenieties like the coronal holes and x-ray bright points.

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