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Historical perspective

India, as can be expected from an ancient culture, has a long astronomical tradition. The oldest astronomical text in India is the *Vedanga Jyotisha* (astronomy as part of the Vedas), one part of which is attributed to Lagadha. It is dated about 1400 BC on the basis of the statement in the book that the winter solstice took place at the star group Shravishtha (Alpha Delphini). A later astronomer of the same school is Garga who is placed at about 450 BC on the basis of his observation that `the sun is found turning [north] without reaching the Shravishthas'. The earliest interest in astronomy was in observing equinoxes and solstices for ritualistic purposes, in making rather inexact luni-solar calendars, and in observing starts (Nakshatras) as a guide to the motion of the moon and the sun.

Siddhantic astronomy

The development of mathematical, or Siddhantic, astronomy came about as a result of interaction with Greece in the Post-Alexandrian period. (Siddhantha literally means the established end). The leading figure in the modernization was Aryabhata I, who was born in AD 476 and completed his influential work, *Aryabhatiya*, in AD 499. The main occupation of Indian astronomers for the next thousand years and more was the calculation of geocentric planetary orbits and developing algorithms for the solution of the mathematical equations that arose in the process. Illustrious names in Indian astronomy following Aryabhata are Latadeva (505) who was Aryabhata's direct pupil; Varahamihira (c.505) a compiler rather than a researcher, and an expert on omens; Bhaskara I (c.574); Aryabhata's bête noire Bharmagupta (b.598) whose works were later translated in Arabic; Lalla (c.638 or c.768); Manjula or Munjala (932); Shripati (1039); and Bhaskara II (b.1114), the last of the celebrated astronomers (Table I).

There was also a host of commentators including such well-known names as Prithudaka (864) in Kannauj, Bhattotpala (966) in Kashmir, and Parameshvara (1380-1460) in Kerala, who were astronomers in their own right. There ware also a number of astronomers whose own work is not extant, but they are cited by others. There is an Indian astronomer Kanaka who is unknown to Indian sources but appears in the Arabic bibliographic tradition as Kanak al-Hindi. He is said to have been a member of the embassy that was sent from Sind to Baghdad to prepare *Zij al-Sindhind* (translation of Brahmagupta's *Brahma-sphuta-siddhanta*). In the absence of any reliable information on him, a large number of legends have grown around him, making him a personification of the transmission of science from India to the Arabs.

In addition to the Siddhantas there are in Sanskrit and allied languages books called Karanas. If Siddhantas are the text books, Karans are the made-easy books (Table 2). They give practical rules for carrying out computations. A noteworthy feature is the Karanas choose a contemporaneous epoch rather than follow the Siddhantas in starting from a Kalpa or a Yuga. As early as about AD 1000, A1 Biruni (973-1048) noted that there were innumerable Karana works. One of the most influential has been Ganesha Daivajna's *Graha-laghava* (1520). Karana activity continued right up to the 19th century, and was even sponsored by the British. There are tertiary texts also associated with Siddhantas and Karanas. They are the Koshtakas or Saranis, which provided ready-made specialist astronomical tables for use by astrologers and almanac makers.

Work on observational aspects has been rather limited. Parameshvara made eclipse observations from 1393 to 1432, and later Achyuta Pisharati (c.1550-1621), also in Kerala, (c.1730-1800) wrote a four-chapter treatise *Uparagakriyakrama* on lunar and solar eclipses. In the 18th century Nandarama Mishra (c.1730-1800) prepared a Karana work, *Grahana-paddhati*, on eclipses.

The Siddhantic school was mildly influenced by the British presence in India. Indian assistants at British Indian observatories tried to update Siddhantic elements. Kero Lakshman Chhatre(1824-84) started his career at Colaba Observatory in 1851, became the professor or mathematics and natural science at Poona College in1865, and was made a Rao Bahadur in 1877 two years before his retirement. In 1860 he brought out in Marathi a handbook *Graha-sadhanachi-koshtake*, based on the 1808 work of R.S. Vince. An assistant at Madras Observatory, Chintamani Ragoonatha Charry (1828-80), completed his Tamil work *Jyotisha-chintamani*, and also on almanac, called *Drig-ganita-panchanga*, based on the Nautical Almanac. Many young men from families with tradition of Sanskrit studies took to modern astronomy. A school teacher Venkatesh Bapuji Ketkar (1854-1930) compiled a modern astronomical almanac *Jyotir-ganita* in Sanskrit, with the year 1875 as the epoch. Ketkar is however better known in India for his published prediction (1911) of the existence of a planet beyond Neptune.

It is a matter of historical curiosity that the last of the classical Siddhantic astronomers

Table 1. Important Siddhantas

Year	Author[1]	Place	Work[2]
b.476	Aryabhata I	Patna	Aryabhata-siddhanta Aryabhatiya (499)
c.505	Latadeva		Redactions of Saura-, Romaka-, Paulisha-siddhantas
c.620-700	Brahmagupta*	Bhillamala, Rajasthan	Brahma-sphuta-siddhanta(628)
fl.629	Bhaskara I	Valabhi, Gujarat	Maha-bhaskariya (629) Laghu-Bhaskaria
8th cent	Lalla	Dasapura, Malwa	Shishya-dhi-vriddhida (748)
c.800	Anon.		Surya-siddhanta
b.880	Vateshvara	Vatangara, N.Gujarat	Vateshvara-siddhanta (904)
c.953	Aryabhata II		Maha-siddhanta
c.1000-1050	Shripati*	Rohinikhand, S. of Ujjain	Siddhanta-shekhara
b.1114	Bhaskara II*	Vijjalavida, Bijapur	Siddhanta-shiromani (1150)
b.1444	Nilakantha Somayaji	Kundapura, Kerala	Tantra-sangraha
c.1475-1525	Jnanaraja	Parthapura, Godavari	Siddhanta-sundra (1503)
c.1550-1621	Achyuta Pisharati*	Kerala	Sphuta-nirnaya-tanta
C.1600-1660	Nityananda	Kurukshetra	Siddhanta-sindhu (1628) Siddhanta-raja (1639)
b.1603	Munishvara	Varanasi	Siddhanta-sarvabhauma (1646)
b.1610	Kamalakara	Varanasi	Siddhanta-tattva-viveka (1658)
1835-1904	Chandrashekhar Simha	Khandapara, Orissa	Siddhanta – darpana (1894)

1. Asterisk denotes appearance in Table 2 also.
2. The number in bracket after the work is the year of its composition or the epoch chosen for computations.

Table 2. Important Karanas

Year	Author[1]	Place	Work[2]
505	Varahamihira	Ujjain	Pancha-siddhanta
c.620-700	Brahmagupta*	Bhillamala, Rajasthan	Khanda-khadyaka (665)
c.650-700	Haridatta	Kerala	Graha-chara-nibandhana (683)
c.650-700	Devacharya	Ketala	Karana-ratna (689)
c.900-950	Manjula (or Munjala)	Prakashpattana	Laghu-manasa (932)
c.1000-1050	Shripati*		Dhi-kotida-karana (1039)
c.1050-1110	Brahmadeva	Mathura	Karana-prakasha (1092)
c.1060-1110	Shantananda	Puri, Orissa	Bhasvati-karana (1099)
b.1114	Bhaskara II*	Vijjalavida, Bijapur	Karana-kutuhala (1183)
c.1280-1350	Chakreshvara Mahadeva	Rasina, Godavari	Mahadevi (1316)
13-14th cent.	Vararuchi	Kerla	Vakya-karana (1282/1306)
1367	Mahadeva	Trymbak, Godavari	Kamadheni-karana
1375	Ishvara		Karana-kantirave
1417	Damodara		Bhata-tulya
c.1450-1510	Keshava	Nandgaon, Maharashtra	Graha-kautuka (1496)
c.1475-1550	Chitrabhanu		Karanamrita (1530)
c.1500-1560	Shankara Variyar	Kerala	Karana-sara
b.1507	Ganesha Daivajna	Nandgaon, Maharashtra	Graha-Laghava (1520)
c.1540-1600	Dinakara		Kheta-siddhi (1578) Chandraki (1578)
c.1550-1621	Achyuta Pisharti*	Kundapura, Kerala	Karanottama (1593)
c.1500-1620	Ramachandra Bhata	Delhi	Rama-vinoda (1590)
c.1550-1620	Vishnu	Golagram, Godavari	Suryapaksha-sharana-karana (1608)
c.1589	Dhundhiraja	Parthapura, Godavari	Graha-mani
c.1590-1650	Nagesha	Gujarat	Graha-prabodha (1619)

Year	Author[1]	Place	Work[2]
c.1600-1660	Krishna	Konkana	Karana-kaustubha (1653)
c.1650-1720	Jatadhara	Sarhind, Punjab	Phatteshaha-prakasha 1704)
c.1660-1740	Putumana Somayaji	Shivapura, Kerala	Karana-padhati
c.1730-1800	Nandarama Mishra	Kamyaka-vana	Grahana-paddhati (1763)
c.1740-1800	Shankara	Dvarka, Gujarat	Karana-vaishnava (1760)
c.1750-1800	Manirama		Graha-ganita-chintamani (1714)
c.1781	Bhula	Narmada	Brahma-siddhanta-sara
c.1800-1839	Shankara Varma	Katattanadu, Kerala	Sad-ratna-mala (1823)
c.1800-1850	Jyotiraj	Nepal	Jyotiraja-karana (1832)

1. Asterisk denotes appearance in Table 1 also.
2. The number in bracket after the work is the year of its composition or the epoch chosen for computations.

lived right into the present century. Samanta Chandrasekhara Simha (1835-1904) was born in a princely family in the small village of Khandapara in western Orissa. Introduced to the ancient Siddhantic literature in the family library, he soon noticed that the predictions did not match observations. Following instructions in the old texts, he made his own instruments. His main instrument was a tangent-staff, made out of two wooden rods joined together in a shape of a T. 'The shorter rod was notched and pierced with holes at distances equal to the tangents of angles formed at the free extremity of the other rod'. Calling it *Mana-yantra* (measuring instrument) he used it with a precision which was more due to his innate abilities rather than the instrument's. Using Bhaskara II as his role model he then set out in 1894 to write on palm leaf his *Siddhanta-darpana*, consisting of 2284 shlokas of his own composition to which were added another 216 called from old Siddhantas, especially Bhaskara II's *Siddhanta-shiromani* and *Surya-siddhanta*.

Throughout the Siddhantic period instruments and observations played second fiddle to computations. Observational results were not explicitly recorded, the description of astronomical instruments was condensed in a single chapter, *Yantra-adhyaya*. Although Bhaskara II is credited with devising a rather versatile instrument, *Phalaka-yantra*, there is not gainsaying the fact that observational astronomy came to tits own only in the medieval times thanks to India's interaction with central and west Asia.

Zij astronomy

This phase of post-Siddhantic world astronomy may be called Zij astronomy, because the main occupation of its astronomers was the preparation of Zijes that is astronomical tables. Zijes fall into three categories: (i) *Zij-e-Rashadi* (direct tables) based on actual observations; (ii) *Zij-e-Hisabi* (calculated tables) obtained by correcting observational tables for erfrors, precession, etc.; and (iii) *Zij-e-Tas'hil* (simplified tables) which were simplified versions of other tables, for example, for the moon alone. The Zij period began in the 9th Century of Baghdad with the translation of Brahmagupta's Sanskrit works into Arabic, and essentially came to an end in India, with the compilation of *Zij-e-Muhammad Shahi* in 1728 by Raja Jai Singh Sawai. Siddhantic and Zij astronomies flourished simultaneously.

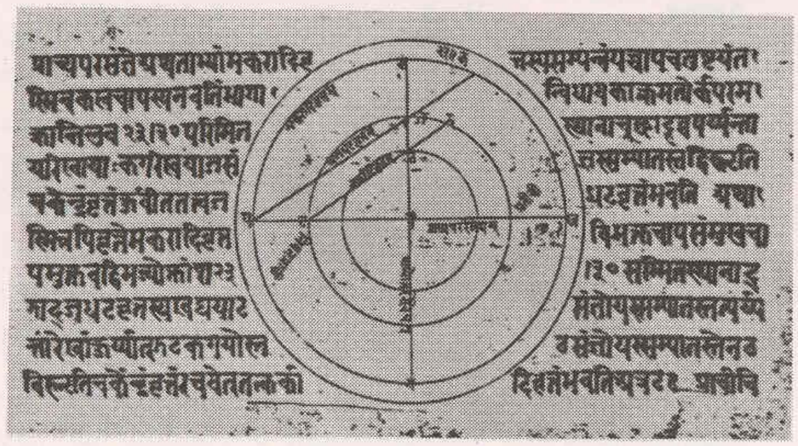
Zij astronomy made its debut in India under the patronage of King Ferozshah Tughlaq who ruled at Delhi from 1351 to 1388. Arabic and Persian Zijes were copied and commented upon. Several books on astronomy were written during his reign, and astrolabes constructed. On this orders, an astrolabe was placed on the highest tower in his capital Ferozabad (in Delhi). In addition, Ferozshah also took steps to Sanskritize instrumentation astronomy. On his orders, Mahendra Suri, head astronomer at the royal court, prepared in 1370 *Yantra-raja* , a monograph on astrolabe. This was the first Sanskrit work exclusively devoted to instrumentation, and was the subject to many later commentaries. Table 3 lists Sanskrit texts exclusively devoted to astronomical instruments.

From 18th century, we have Raja Jai Singh Sawai's treatise on instruments, *Yantra-prakara*, essentially completed before 1`724, with some additions made up to 1729 In 1732, his astronomer Jagannatha translated Nasir al Din al Tusi's (1201-74) Arabic recension of Ptolemy's Almagest into Sanskrit under the title *Samrata-siddhanta*, To it, he added a supplement describing various instruments. Jai Singh went on to establish a number of (pre-telescopic) masonry observatories. The Delhi Observatory set up during 1721-24 was followed by a bigger one at his new capital Jaipur (1728-34). He built smaller ones at Mathura, Ujjain and Varanasi between 1723 and 1734. (All dates are estimates). The Varanasi Observatory was housed in an already existing building; it is probable that Jai Singh renovated an old observatory. Jai Singh's instruments and observations have been extensively dealt with in the literature.

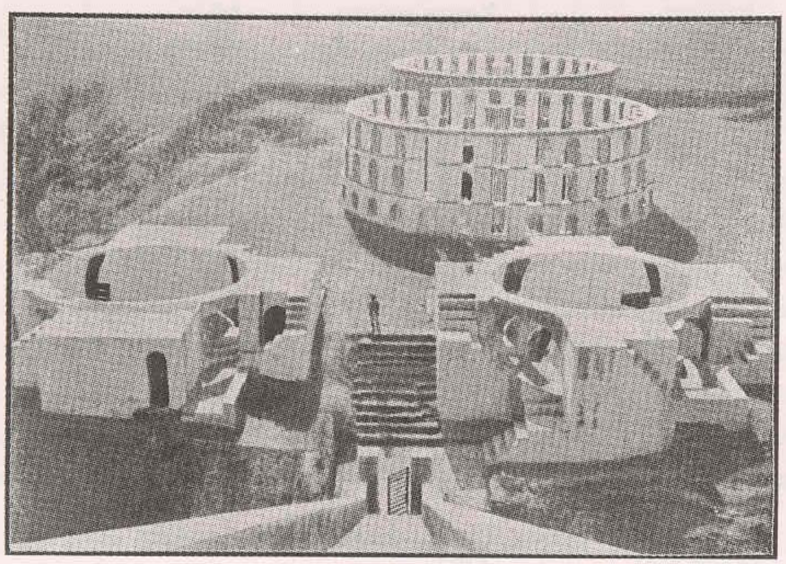
Jai Singh's edifice of science did not survive for long. In 1745, two years after Jai Singh's death, Emperor Muhammad Shah invited Father Andre Strobel to come to Delhi and take charge of the Observatory. He declined. In 1764 the Observatory was severally vandalized, when Javahar Singh, son of Suraj Mal, the Jat Raja of Bharatpur, Plundered Delhi. More than 150 years later,

Table 3

Year	Author[1] (Place)	Work	Instrument
1370	Mahendra Suri (Delhi)	Yantraraja	Astrolabe
c.1400	Padmanabha	Yantra-Kiranavali	Astrolabe Dhruva-bhramana-yantra
1428	Ramchandra (Sitapur, U.P.)	Yantra-prakasha	Misc.
15th cent.	Hema (Gujarat)	Kasha-yantra	Cylindrical sundial
b.1507	Ganesha Daivajna	Pratoda-yantra	Cylindrical sundial
		Sudhiranjana-yantra	Graduated strip
c.1550-1650	Chakradhara (Godavari)	Yantra-chintamani	Quadrant
1572	Bhudhara (Kampilya)	Turiya-yantra-prakasha	Quadrant
c.1580-1640	Jambusara Vishrama (Gujarat)	Yantra-shiromani (1615)	Misc.
Fl.1720	Dadabhai Bhatta	Turiya-yantropatti	Based on Chakradhara's work
1688-1743	Jai Singh Sawai (Jaipur)	Yantra-prakara Yantra-rajarachana	Misc. Astrolabe
c.1690-1750	Jagannatha (Jaipur)	Samrata-siddhanta (1732)	Tr. Of Almagest with suppl. on instruments
c.1700-1760	Lakshmipati	Dhruva-bhramana-yantra Samrata-yantra	
c.1700-	Nayansukha Upadhyaya	Yantra-raja-risala-bhisa-baba or Yantra-raja-vichara-vimshadhyay	Astrolabe (Tr. Of MS by Nasir at Din al Tusi, 13th cent., Iran)
c.1750-1810	Nandarama Mishra (Kamyakavana, Rajasthan)	Yantra-sara (1772)	Misc.
c.1750-1810	Mathuranatha Shukla (Varanasi)	Yantra-raja-ghatana (1782)	Astrolabe
c.1736-1811	Chintamani dikshit	Golananda (1800)	Misc.



1. A page from the Sanskrit manuscript *Yantra-raja-kalpa* (1782) by Mathuranatha, describing the construction of an astrolabe. The manuscript, copied in 1820, is at Sampurnanand Sanskrit University, Varanasi (S.R.Sarma).



2. Raja Jai Singh Sawai's Observatory, Jantar Mantar, Delhi, photographed in 1911 a year after its renovation (Journal of Astronomical Society of India, Calcutta, vol.2, 1912).

the then Maharaja of Jaipur perfunctorily renovated the Observatory to give it a presentable look at the time of 1911 Delhi darbar of King George V. (The Delhi and Jaipur Observatories are now in a rather dilapidated state and no more than popular tourist spots.

Perhaps the most telling commentary on Jai Singh's dedicated but largely irrelevant scientific enterprise comes from the rather disconcerting fact that his grandson converted Jaipur Observatory into a gun factory and used his ancestral 400kg astrolable for target practice.

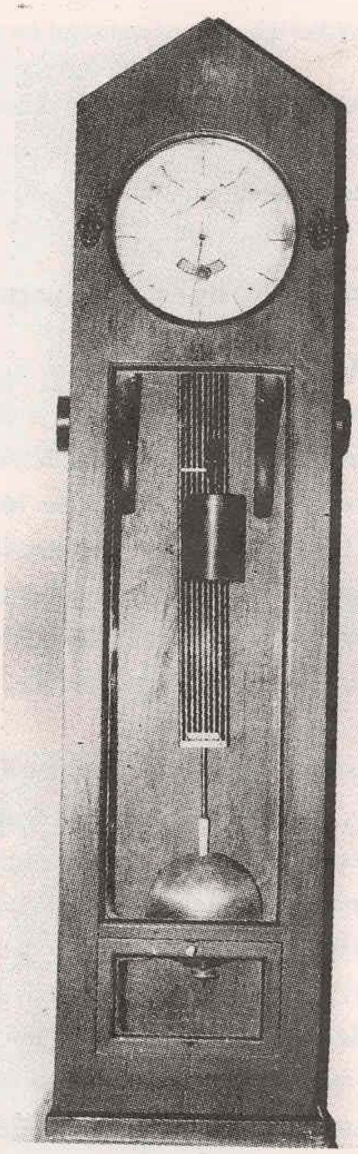
Advent of modern astronomy

Modern astronomy came to India in tow with the Europeans. The earliest recorded used the telescope in India was rather a typical; it was in the field of pure astronomy rather than applied. The observer was an Englishman, Jeremiah Shakerley (1626-c.1655). He was one of the earliest followers of Kepler and viewed the 1651 transit of Mercury from Surat in west India. He could however time neither the ingress nor the egress. His observation therefore was of no scientific use and remains a curiosity. More representative of the things to come was the work of the Jesuit priest Father Jean Richaud (1633-93) who in 1689 discovered from Pondicherry that the bright star Alpha Centauri is in fact double.

Early use of telescopic astronomy by the Europeans as a geographical aid in India was desultory, sporadic and often motivated by personal curiosity. The 1761 and 1769 transits of Venus were perceived as a continuation of the ongoing rivalry between Finance and England, and brought many instruments and a general awareness of astronomy of colonial India. What however led to the institutionalization of modern astronomy in India was not the love of stars, but rather the fear of the Coromandel coast. Rocky and full of shoals, and devastated by two monsoons a year, India's east coast became the graveyard of many a sailing ship. It survey literally became a matter of life and death for the British. Accordingly, a well-equipped, trained surveyor – astronomer Michael Topping (1747-96) was brought to Madras in 1785.

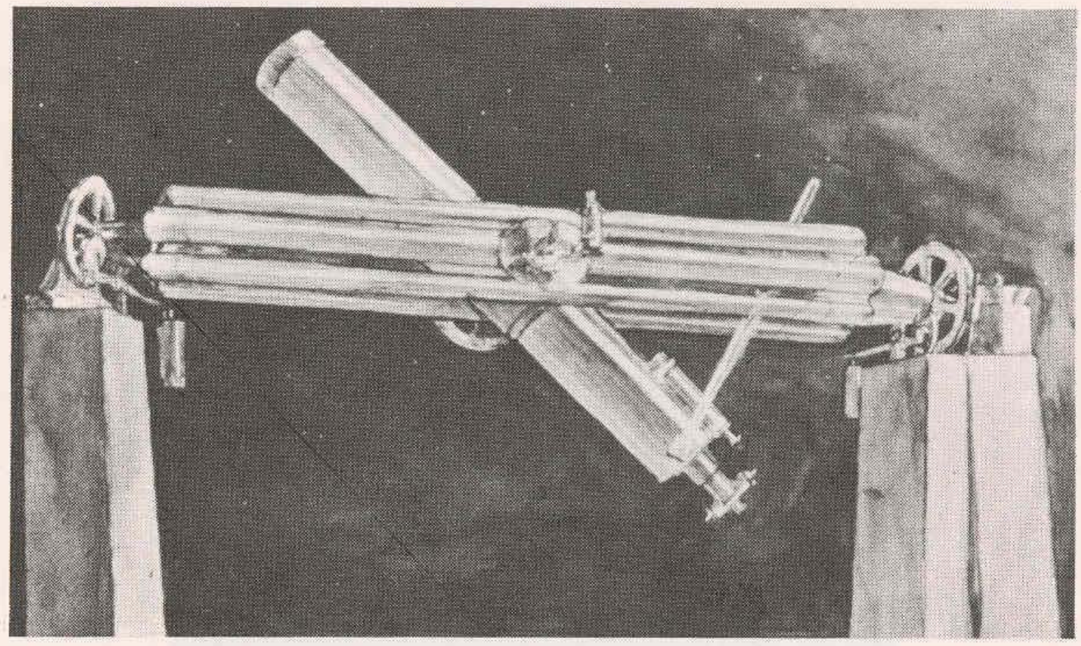
Madras Observatory (1786)

Next year, perhaps more by design than chance, there came up at Egmore in Madras a small private observatory. Its founder was William Petrie (d.1816), an enlightened and influential company officer, who later officiated as the governor of Madras for a few months. It was used by Topping as a reference meridian and on Petrie's persuasion was taken over by the company in 1790. Two years later the Observatory moved to its own campus at Nungambakkam in Madras, where some of its old remnants can still be seen. A hundred years later, in 1899, astronomical activity was shifted to Kodaikanal, and the Madras Observatory became a purely meteorological observatory. One of the instruments that Petrie bequeathed to the Observatory was a pendulum clock by John Shelton. Believed to be made for the 1769 transit of Venus and identical to the one used by Captain James Cook in his voyages, it is still ticking at Kodaikanal, a witness to the advent and growth of modern astronomy in India.



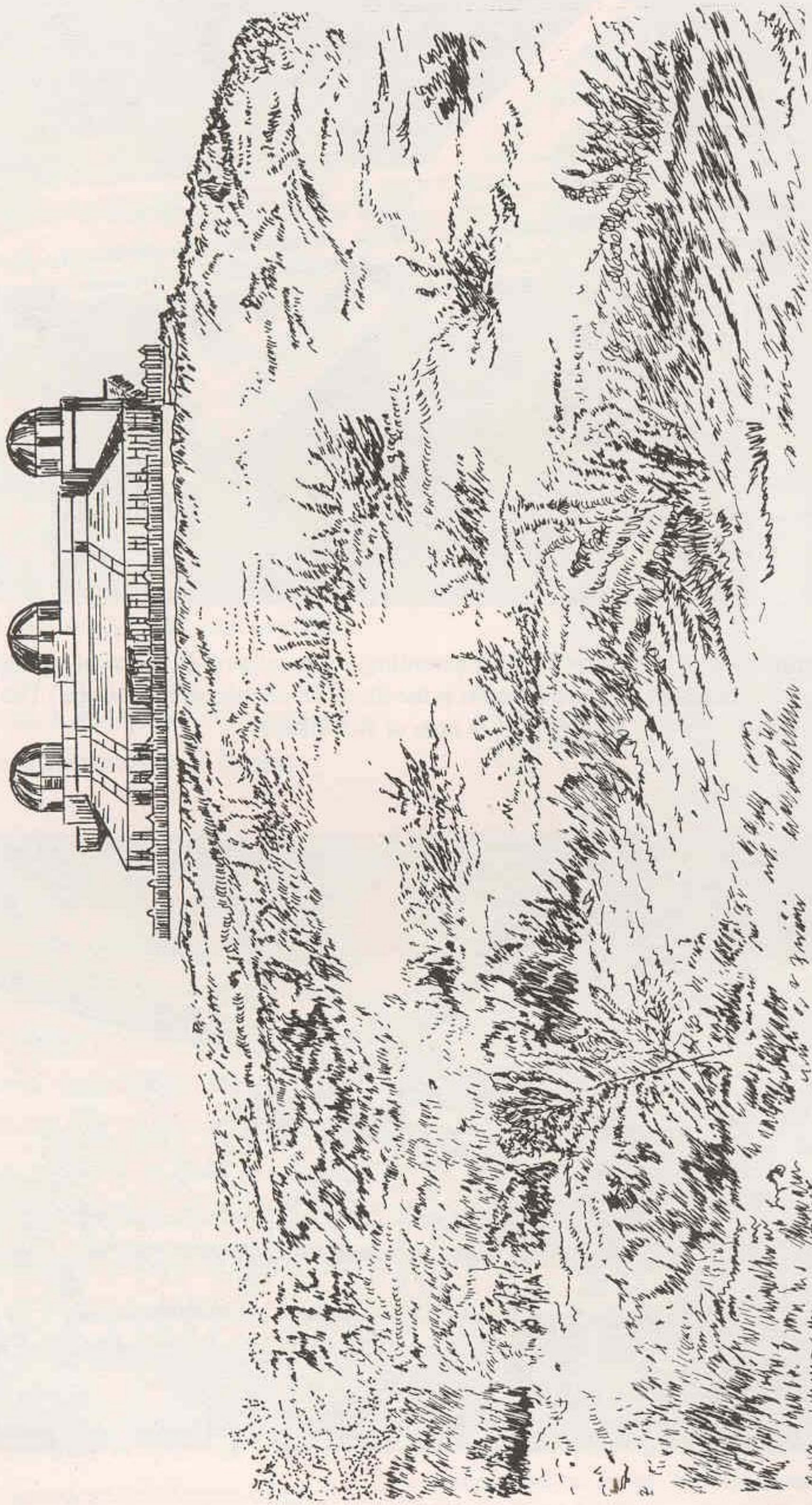
3. Gridiron pendulum clock by John Shelton. Identical to the one used by Captain Cook in his famous voyages, and to the one used by Charles Mason and Jeremiah Dixon in N. America to determine the Mason-Dixon Line, this Shelton was a part of the original equipment of the Observatory set up by William Petrie at Madras in 1786. The clock has been at Kodaikanal since 1899, and is still ticking.

In the early years Madras Observatory not only provided the reference meridian for the work of the Great Trigonometrical Survey of India (GTS) but also manpower and instruments. Increasing overseas involvement of Britain required familiarity with the southern skies. Accordingly, in 1843, after 13 years of painstaking work with the newly acquired transit instrument and mural quadrant (both by Dollond and with 4 inch aperture telescopes), Thomas Glanville Taylor (1804-48), former assistant at Greenwich, produced the celebrated Madras Catalogue of about 11000 southern stars. It was hailed by the Astronomer Royal Sir, George Biddell Airy as the greatest catalogue of modern times. (It was revised in 1901.)

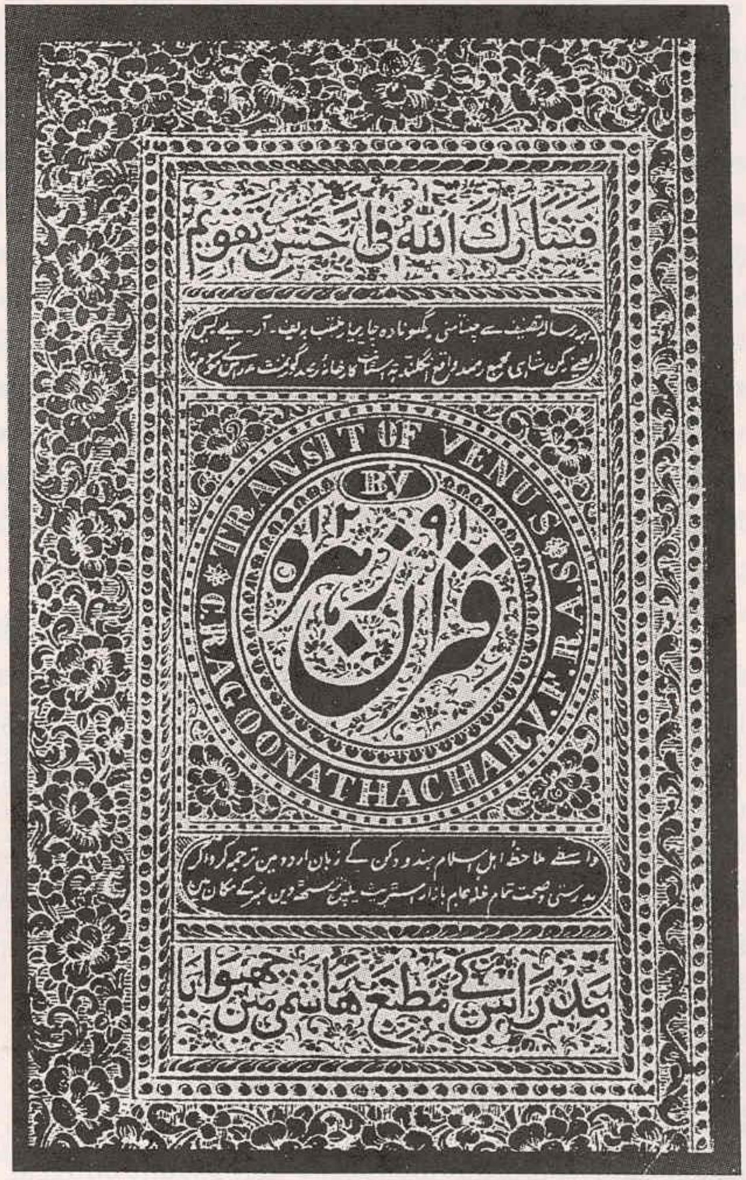


4. Six inch aperture lens telescope on English mounting, by Lerebours & Secretan of Paris. Sketched in colour by Charles Piazzi Smyth in 1851. (The original is at the Royal Observatory, Edinburgh.) The telescope was ordered for Madras Observatory. Since modified, it is now at Kodaikanal.

5. Five inch aperture, 7 foot focus, lens telescope on English mounting by Dollond, it was acquired by Trivandrum Observatory in 1842.



6. A (retouched) sketch of Trivandrum Observatory (Madras Journal of Literature & Science, vol. 6, 1837).



7. The title page of a booklet in Urdu brought out by Chintamani Ragoonathachary on the occasion of the 1874 transit of Venus. (His names is spelt variously). He was an assistant at Madras Observatory, and is the discoverer of a variable star R Reticuli.

In 1850, the Observatory acquired its first fixed extra-meridional instrument, a 6 inch aperture lens telescope by Lerebours & Secretan of Paris. It was used by Captain William Stephan Jacob (1813-62) to show that the recently discovered crepe ring of Saturn was in fact translucent. (The same discovery was independently made a little later by William Lassel at Malta using a 20 inch reflector). The only other telescope at Madras, an inch lens equatorial by Troughton & Simms, was ordered in 1861. (Both these telescopes are now at Kodaikanal.)

The Madras Observatory had already become redundant as far as utilitarian astronomy was concerned. And when observatories came up in South Africa and Australia, even the British astronomers lost interest. Norman Robert Pogson's (1829-91) 30years uninterrupted stint from 1861 till his death is a traffic testimony to the wasted opportunities at Madras. H was the first astronomer at Madras who did not have any surveying connection. His own neurosis was matched by the Astronomer Royal's imperiousness. Left to himself Pogson would have liked to extent Argelander's survey to the southern skies and work on his variable star atlas. Instead, he was forced to carry on routine, drab, irrelevant observations of transits year after year, which he most obstinately refused to reduce and publish. No new instruments were ordered during Pogson's long tenure. What kept the Observatory in working order was the help given by the workshops established by the governments public works department for its own use.

Watching the GTS and the Madras Observatory at work, two native rulers came forward to extend patronage to modern astronomy. It is not that they strove to update the elements of traditional astronomy in the light of new developments in the west or wanted their subjects to learn new astronomy. Instead, they simply funded British efforts. When the Nawab of Oudh (correctly Avadh, eastern Uttar Pradesh) decided in 1831 to set up an observatory he asked the governor general to send one of his GTS officers (Major James Dowling Herbert 1791-1833) as the director. As befit a Nawab's whim, Lucknow Observatory was equipped with the best instruments money could buy, but closed down as soon as the novelty and the instruments were off. The Observatory, reduced as well as unreduced, were eaten by ants. Thus ended a first class, though unproductive, observatory which need not have been set up in the first place. Circumstances attending the Trivandrum Observatory were slightly different. Here the initiative came from the British men of science, whom the King gladly obliged. The Observatory was established in 1837 with John Caldecott (1813-47) as the astronomer. Astronomy met the same fate as a t Lucknow. But thanks to Trivandrum's proximity to the magnetic equator and to Madras presidency, the Observatory could do sustained work in the fields of magnetism and meteorology under John Allan Broun (1817-79), on the lines suggested by the British Association for the Advancement of Science.

Advent of physical astronomy

While positional astronomy was slugging it out at Madras, there was taking shape in Europe the new science of physical astronomy of astrophysics. Spectroscopic and photographic techniques were used in the Indian observations of the solar eclipses of 1868, 1871and 1872, which attracted observers from Europe also. The French astrophysicist Pierre Jules Cesar Janssen (1824-1907) observing the total solar eclipse of 1868 from Guntur (now in Andhra Pradesh) detected a spectral line due to a new element, aptly names helium by the independent co-discoverer Joseph Norman Lockyer (1836-1920). During his post-eclipse stay at Simla, Janssen created the first spectroheliosocope, which facilitated daily examination of the sun. It was the transit of Venus of 9 December 1874 that led to institutionalization of astrophysics in India. This time the state had no major stake in the new astronomy. The initiative and the pressure came from the European solar physicists who wanted the benefit of India's sunny days for their research. The government was interested in the work as it was told that a study of the sun would help predict the failure of monsoons, then as now India's life-line.

Dehra Dun Observatory (1878-1925)

When India-based Col. James Francis Tennant (later Lieut.- Gen. and President of the Royal Astronomical Society) requested the government for setting up a solar physics observatory with the instruments already in India for the 1874 transit, he was turned down. The government was however more responsive when Lockyer used his equation with Lord Salisbury, the secretary of state for India. Salisbury wrote to the viceroy on 28 September 1877: 'Having considered the suggestions made by Mr. Lockyer, and viewing that a study of the conditions of the sun's disc in relation to terrestrial phenomenon has become an important part of physical investigation, I have thought it desirable to assent to the employment for a limited period of a person qualified to obtain photographs of the sun's disc by the aid of the instrument now in India for transit of Venus observation. Accordingly, starting from early 1878 solar photographs were regularly taken at Dehra Dun under the auspices of Survey of India, and sent to England every week. Dehra Dun continued solar photography till 1925,but more out of a sense of duty than enthusiasm. The larger of the two photoheliographs fell into disuse, and in 1898 Lockyer was stung by on the spot discovery that the dome has been taken possession of by bees.

St Xavier's College Observatory, Calcutta (1879)

Sunny India caught the attention of astronomers in the continent also. The Italian transit-of-Venus team led by Professor P. Tacchini of Palermo Observatory stationed itself in Bengal, its Chief instrument being the spectroscope, `an instrument not recognized in the equipment of any of the English parties'. A co-opted member of the Italian team was the Belgian Jesuit Father Eugene Lafont (1837-1908) professor of science at St. Xavier's College, who though no researcher himself was an inspiring educator and science communicator. The College provided education to sons of Europeans, Anglo-Indians, rajas, zamindars, and Indian men of note. Lafont therefore `secured great influence among these classes' which he put to good use in the service of science. Tacchini suggested to Lafont 'the advisability of erecting a Solar Observatory in Calcutta, in order to supplement the Observations made in Europe, by filling up the gaps caused in the series of solar records by bad weather'. Lafont soon collected a sum of Rs. 21000 through donations, including Rs 7000 from the Lieut.-Governor or Bengal, ` and in a couple of years the present spacious dome was constructed and fitted with a splendid 9" Refractor by Steinhill of Munich to which was adapted a large striking work, thanks to the customary thoroughness and dedication of the Jesuit men of science. At about the same time there came up at Poona a research observatory for entirely different reasons.

Takhtasingji Observatory, Poona (1888-1912)

This was the most personalized of all observatories. In spite of its name, it was owned by the Bombay government and was set up for one man, Kavasji Dadabhai Naegamvala (1857-1938). Naegamvala was a brilliant student. In January 1878, he passed his M.A. examination in physics and chemistry in first class from Elphinstone College, Bombay, and was awarded the chancellor's gold medal, the highest honour of the Bombay University. He returned to the college in 1882 to fill the newly created post of lecturer in experimental physics at a salary of Rs. 250 p.m. When the Maharaja of Bhavnagar visited Elphinstone College in October 1882, Naegamvala represented to him for a donation so that a spectroscopic laboratory could be started at the college.

8. The government matched the royal gift of Rs. 5000 with an equivalent grant and sent Naegamvala to England to finalize the equipment `in consultation with the Committee on Solar Physics and best makers of spectroscopic apparatus'. While in England Naegamvala boldly jettisoned laboratory spectroscopy in favour of the celestial. `By advice of the Astronomer Royal, he allotted the bulk of the funds at his disposal to the purchase of a Reflector Telescope which would be the largest in India'. (This 20 inch Grubb telescope remained the largest in India for eight decades, even if half its time was spent in the boxes). In view of the better credentials of Poona as an astronomical site, the Observatory and Naegamvala were transferred in 1888 to

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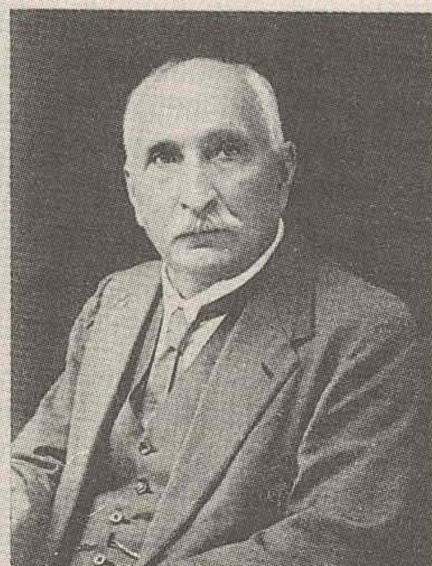
હિંદી-ગ્રાફીક



THE LATE PROFESSOR KAWASJI DADABHOY NAEGAMWALLA,
M.A., F.R.A.S., etc.

A renowned and foremost Parsee Astro-Physicist, Scientist and Educationist that the community has produced. He was a well-known research scholar in solar spectroscopic work and an author in original scientific research work which has found high recognition in India, England and America.

આદેશ પારસી વિજ્ઞાનશાસ્ત્રી મરહુમ પ્રો૦ કાવસજી દાદાભાઈ નાયગામવાલા,
એમ. એ., એફ. આર. એ. એસ.

વિજ્ઞાન-વિદ્યા સંબંધી શોધખોળ કરનારા એક કાબેલ સ્કોલર તરીકે પ્રો૦ નાયગામવાલા હિંદુસ્તાન ઉપરાંત ઇગ્લાંડ અને અમેરીકામાં જાણીતા હતા. છેલ્લાં ૩૦ વર્ષોથી મુંબઈ યુનીવર્સીટીમાં સાયન્સના પરિક્ષક નિમાતા હતા અને સીન્ડીક અને ફેલો હતા.

8. Cover page of the April 1939 issue of the Gujarati-English magazine *Hindi Graphic* (Bombay) paying tribute to K.D.Naegamvala: 'A renowned and foremost Parsee Astro-Physicist,Scientist and Educationist that the community has produced'.

The College of Science (now College of Engineering) there. Naegamvala was a member of the British scientific team that went to Norway in 1896 to observe the total solar eclipse. For the 1898 eclipse that was visible from India, Naegamvala was given a sum of Rs 5000 by the government to match an equivalent sum raised through donations, ranging from Rs 100 to Rs. 500. (Jamsetji Nusserwanji Tata contributed Rs 250.) The eclipse brought Sir Norman Lockyer and the Astronomer Royal, Sir W.H.M.Christie, to India who were asked by the Government of India to report on the observatories here.

The best thing that could have happened to Naegamvala was his discovery by Lockyer. Lockyer in his report paid glowing tributes to Naegamvala `who, so far as I know, is the only person in India practically familiar with solar physic work'. On Lockyer's recommendation, Naegamvala was relieved of teaching duties and appointed full-time director of the Observatory. He was asked to send data regularly to Lockyer. If Lockyer had had his way, he would have appointed Naegamvala as the director of the proposed Solar Physics Observatory at Kodaikanal in place of the Madras Astronomer Charles Michie Smith about whose capabilities Lockyer had a very low opinion. Naegamvala did not go to Kodaikanal, but in 1912 all his equipment was sent there, when the Poona Observatory was closed down on his retirement.

Kodaikanal Observatory (1899)

Although the question of upgrading the astronomical facilities at Madras had been brought up off and on in the British quarters, it was only after the death of Pogson in 1891 that the matter was taken up in earnest. It was finally decided in 1893 to establish a solar physics observatory at Kodaikanal in the Palani hills of south India with Michie Smith as the director. All astronomical activity was shifted from Madras to Kodaikanal, and the new observatory was transferred from Madras government to the charge of the imperial government's India Meteorological Department.

To start the Observatory, Greenwich sent (on permanent loan) a photoheliograph, one of the five identical ones made by John Henry Dallmeyer for the 1874 transit-of-Venus expeditions. The 6 inch refracting telescope by Lerebours and Secretan of the 1850 vintage was remodeled and installed for daily photography of the sun. (This must be one of the oldest telescopes still in scientific use.) The arrival of John Evershed in 1907 (as assistant director to begin with) heralded the Observatory's golden age. Choosing to come to India, no doubt to work in solitary splendour, Evershed made Kodaikanal into a world-class, state-of-the art observatory. He put the newly acquired spectroheliograph into working order, made a prismatic camera using the prisms he had brought with him, and assembled a number of spectrographs. In 1911 he finally constructed an auxiliary spectroheliograph and bolted it to the existing instrument so that now the sun could be photographed not only in the light of calcium K spectral line but also in hydrogen alpha. In 1909, Evershed made the important discovery of radial flow of gases in sunspots (the Evershed effect). After Evershed's retirement in 1923, the Observatory slowly fell behind times, and became routine-work oriented. It assiduously took solar pictures every day (weather permitting) and exchanged them with other observatories the world over, building in the process an enviable collection of solar pictures that now spans eight complete solar cycles.

Nizamiah Observatory (1901)

The positional astronomy slot that fell vacant in 1899 with the winding up of the Madras Observatory was filled by the Nizamiah (Nizam's) Observatory at Hyderabad. Its founder was a rich England-educated nobleman, Nawab Zafar Jung. The Nawab purchased a small telescope and set up an Observatory at his estate at Phisalbanda in Hyderabad. Very far-sightedly, in 1901, he took the Nizam's permission to name the Observatory the Nizamiah and made sure that it would be taken over by the government on his own death. He subsequently acquired a 15 inch aperture Grubb refractor...Curiously, he also obtained an 8 inch aperture astronomical camera, or astrograph, which later became the Observatory's chief instrument. Zafar Jung died in 1907 and as planned his Observatory was taken over by the government. Thus ironically the formal establishment of the Observatory had to await the founder's death.

The next year the Observatory was formally inducted into an ambitious, on-going, international programme, called Carte-du-Ciel, or astrographic chart and catalogue. The aim of this programme was to photographically map the whole sky by assigning various celestial zones to 18 different observatories around the world. The Nizamiah was asked to take over from Santiago Observatory in Chile, which had defaulted on the (17º to 23º S) zone assigned to it. Finally the Observatory also ended up doing the Potsdam zone 36º to 39º N. In the meantime (March 1908) Arthur Brunel Chatwood, B.Sc., had been brought from England as the director on a monthly salary of Rs 1000 (about 1200 a year). Chatwood's tenure was far from a success. He did not go beyond the installation of the astrograph at the new site of Begumpet, and quit in 1914, unlamented.

Astrographic work could be taken up in earnest only in 1914 with the arrival of Robert John Pocock (1889-1918). Pocock was the protégé of the influential Oxford professor Herbert Hall Turner (1861-1930) and came direct from Oxford', armed with a special grant. The first usable plate was taken on 9 December 1914, and the first volume of results published in 1917. When the work finally ended in 1946, a total of 7,63,542 stars had been observed, and 12 volumes published. These data were in turn used by the Observatory astronomers to extract information on proper motion of stars and on double stars.

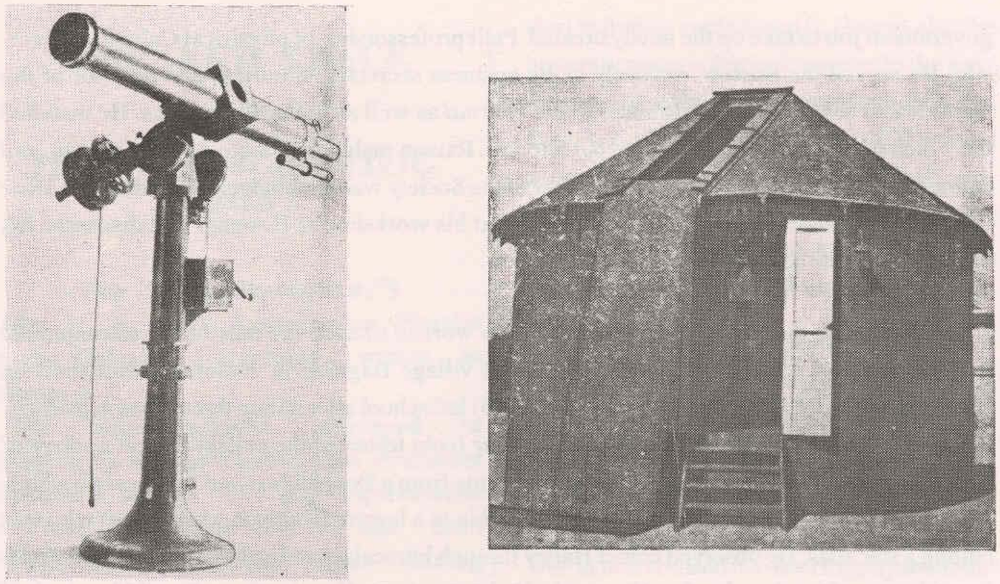

9. The 8 inch Cooke astrograph of the Nizamiah Observatory, used in the Carte-du-Ciel programme 1914-46.

Pocock was the last European director of the Observatory. On his untimely death in 1918 he was succeeded by his erstwhile assistant [Rao Sahib] Theralandoor Panchapagesha Bhaskaran (1889-1950), who however had to wait for four years before getting the formal appointment. Bhaskaran was a foundation fellow of the Indian National Science Academy (INSA) established in 1935 under the name National Institute of Science of India (The name was changed in 1970.) In the Academy records his name appears as T.P. Bhaskara Shastri.

Apart from the astrographic work, Nizamiah had other smaller irons in the fire. The 15 inch Grubb refractor was at long last install in 1922 and used for visual observations of variable stars as well as of lunar occultations sun also received some attention, thanks to a Hale spectrohelioscope acquired in 1939. Observatory also did some community service. It kept standard time and prepared government calendars in Urdu and English.

Indian response

Just as the British needed (modern) science in India, they needed Indians also. Accordingly, the `natives' were introduced to English education. As the scientific content to administration increased, the natives graduated from being clerks and writers to become doctors and engineers, and finally scientists. In January 1876, Dr Mahendra Lal Sircar collaboration with Fr. Lafont, generated support among Indians as well as in government for setting up at Calcutta the rather oddly named Indian Association for the Cultivation of Science (IACS). It was the scientific wing of the Indian Association, which was a political organization.



10. Seven inch aperture lens telescope by Merz-Browning at the Indian Association for the Cultivation of Science, Calcutta. It was extensively used by C. V. Raman. The Observatory building is to the right (Report of IACS FOR 1913)

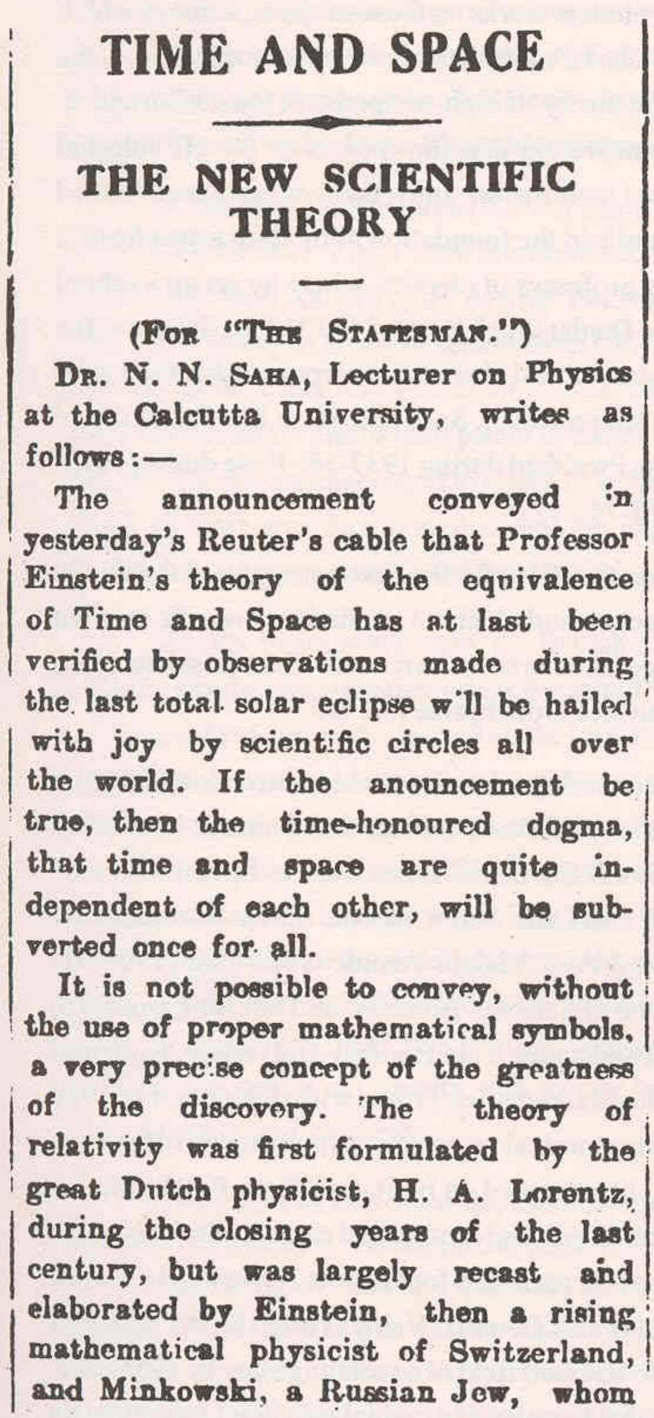
of educated Indians and a precursor of the Indian National Congress. Its aim was to enable the 'Natives of India to cultivate Science in all its departments with a view to its advancement by original research'. A rich benefactor (Kumar Kanti Chandra Singh Bahadur) presented IACS with a valuable 7 inch aperture Merz-Browning equatorial telescope in 1880. It however had to wait for more than 30 years to find a user. Observational astronomy simply failed to take off under Indian auspices.

Appearance of comet Halley in 1910 activated astronomy buffs at Calcutta, who set up an Astronomical Society of India. There were 192 original members including not only men of science but also informed laypersons and Christian missionaries. In addition, there were some rich Indian patrons. The first President was Bengal's accountant general Herbert Gerald Tomkins (1869-1934), who remained the Society's driving force during its decade-long existence. It is not clear whether the Society was formally wound up or simply became defunct. The last available issue of the Society's Journal is dated June 1920. (The name of the Society was reused 53 years later while setting up a new Society at Hyderabad in 1973).

An active member f the Society was Chandrasekhar Venkata Raman (1888-1970), the young deputy accountant general and part-time researcher at IACS who quit his lucrative government job to take up the newly created Palit professorship of physics at Calcutta University. He served the Society variously as its business secretary, librarian, and director of the variable star section, and contributed to the Journal as well s to the discussions. He installed the 7 inch telescope of the IACS and put it to use. Raman maintained a life-long interest in, and enthusiasm for, astronomy. Another member of the Society was a subjudge, Nagendra Nath Dhar (1857-1929), who made optics for telescopes at his workshop at Hooghly and discussed his techniques at the Society meetings.

The most dedicated observer of the time worked outside the pale of the astronomical society. Born in a zamindar family at a small village Bagchar in Jessore district (now in Bangladesh) Radha Gobinda Chandra (1878-1975) left school after failing three times in matriculation examination and took up a job as a *poddar* (coin tester) at the collectorate at a salary of Rs.15 monthly. His introduction to astronomy came from a Bengali text and practical acquaintance with the sky from his scientific apprenticeship to a lawyer (Kalinath Mukherjee) who was editing a star atlas. He observed comet Halley through binoculars and in 1912 purchased a 3 inch lens telescope from London for 13 pounds. He became a regular observer of variable stars and a member of the American Association of Variable Star Observers (AAVSO), which in 1926 gave him a 6 inch aperture telescope, originally belonging to AAVSO's patron and friend' Charles W.Elmer. Chandra certainly made good use of it, communicating a total of 37215 trained-eye observations up to 1954, when he finally retired from observing. The value of his prodigious work lies in the fact that he worked at a longitude far from that of most observers, greatly improving the temporal completeness of the observational records for the stars he observed'. Chandra was asked to pass on the AAVSO telescope to Manali Kallat Vainu Bappu (1927-82) then at Naini Tal. The Elmer-Chandra telescope, one of the very few American telescopes in British India (if not the only one), is now at Kavalur.

A rather atypical scientific enterprise in the 19th century British India was a private astronomical and meteorological observatory at Daba Gardens. Vizagapatnam (Vishakhapatnam, now Andhra Pradesh). It was established in 1841 at his residence by a rich zamindar Gode Venkata Juggarow (1819-56), who had earlier gone to Madras to take tuition from the astronomer Thomas Glanville Taylor. On Juggarow's death the zamindari and the Observatory passed on to his son-in-law Ankitam Venkata Nursing Row (1827-92) who resigned his job as a deputy collector with the east India company to look after his wife's estate. He furnished the Observatory (in 1874) with a 6 inch Cooke equatorial, a transit circle, and a sidereal clock. He communicated his observations of solar eclipses, transits of Venus and Mercury, and comets to British astronomers and the Royal Astronomical Society. He obtained equipment for celestial photography but



TIME AND SPACE

THE NEW SCIENTIFIC THEORY

(For "The Statesman.")

Dr. N. N. Saha, Lecturer on Physics at the Calcutta University, writes as follows:—

The announcement conveyed in yesterday's Reuter's cable that Professor Einstein's theory of the equivalence of Time and Space has at last been verified by observations made during the last total solar eclipse will be hailed with joy by scientific circles all over the world. If the anouncement be true, then the time-honoured dogma, that time and space are quite independent of each other, will be subverted once for all.

It is not possible to convey, without the use of proper mathematical symbols, a very precise concept of the greatness of the discovery. The theory of relativity was first formulated by the great Dutch physicist, H. A. Lorentz, during the closing years of the last century, but was largely recast and elaborated by Einstein, then a rising mathematical physicist of Switzerland, and Minkowski, a Russian Jew, whom

11. A clipping from The *Statesman*, Calcutta, 13 November 1919, showing Meghnad Saha's report on experimental verification of Einstein's theory of general relativity. Note that Saha's first initial is misprinted.

Died before he could install it. He was also the honorary meteorological reporter to the government of India for Vizagapatam. His son Raja A.V. Jugga Rao Bahadur (d.1921) served as the Vice-President of Astronomical Society of India for a year 1911-12. the Observatory seems to have closed down afterwards. (The side is now occupied by Dolphin hotel).

In passing, we may notice a small telescope with an unusual history. In 1938, the infamous Adolf Hitler presented a 5 inch aperture Zeiss telescope to the Rana of Nepal. In 1961, his son, the new Rana, passed on the telescope to the Everest hero Tenzing Norgay, who in turn donated it to the Himalayan Mountaineering Institute, Darjeeling, which he headed.

Although the Indian response to observational astronomy was rather lackluster, it was pathbreaking in the field of theoretical astrophysics. While the well-placed Calcuttan astronomy enthusiasts were forming their Society, unknown to them a bright lad in the backwaters of east Bengal was making his acquaintance with astronomy. Meghnad Saha (1893-1955) wrote an essay on comet Halley in Bengali for the Dacca College magazine. As lecturers in physics in the Calcutta University Saha and Satyendranath Bose (1894-1974) brought out in 1920 an English translation of Einstein's papers on relativity. Reviewing it, the science magazine Nature wrote on 26 August 1922: Provided it is studied with care, the translation will nevertheless be of service to those who are unfamiliar with German, and wish to grapple with the pioneer works on these subjects, some of which are rather inaccessible'. 'Stimulated' by Agnes Clarke's popular books on astrophysics, Saha published in 1920 his epoch-making work on the theory of high-temperature ionization and its application to stellar atmospheres. Saha's demonstration that the spectra of far-off celestial objects can be simply understood in terms of laws of nature as we know them on earth transformed the whole universe into a terrestrial laboratory and laid the foundation of modern astrophysics. In 1923, Saha moved to Allahabad University as professor of physics where he set up a school of astrophysics, training outstanding students like Daulat Singh Kothari (1906-93). Saha was the first one to point out (in 1937) the need to make astronomical observations from outside the earth's atmosphere. He returned to Calcutta in 1938 as Palit professor. Saha and Bose, like Raman, were the foundation fellows of INSA. Saha became its President during 1937-38, Bose during 1949-50, whereas Kothari held the post during 1973-74.

At Madras, Subrahmanyan Chandrasekhar (b. 1910) for the first time applied the theory of special relativity to the problems of stellar structure and obtained preliminary results on what after his rigorous work at University of Cambridge came to be known as the Chandrasekhar mass limit. Chandrasekhar belated by received the physics Nobel prize in 1983.

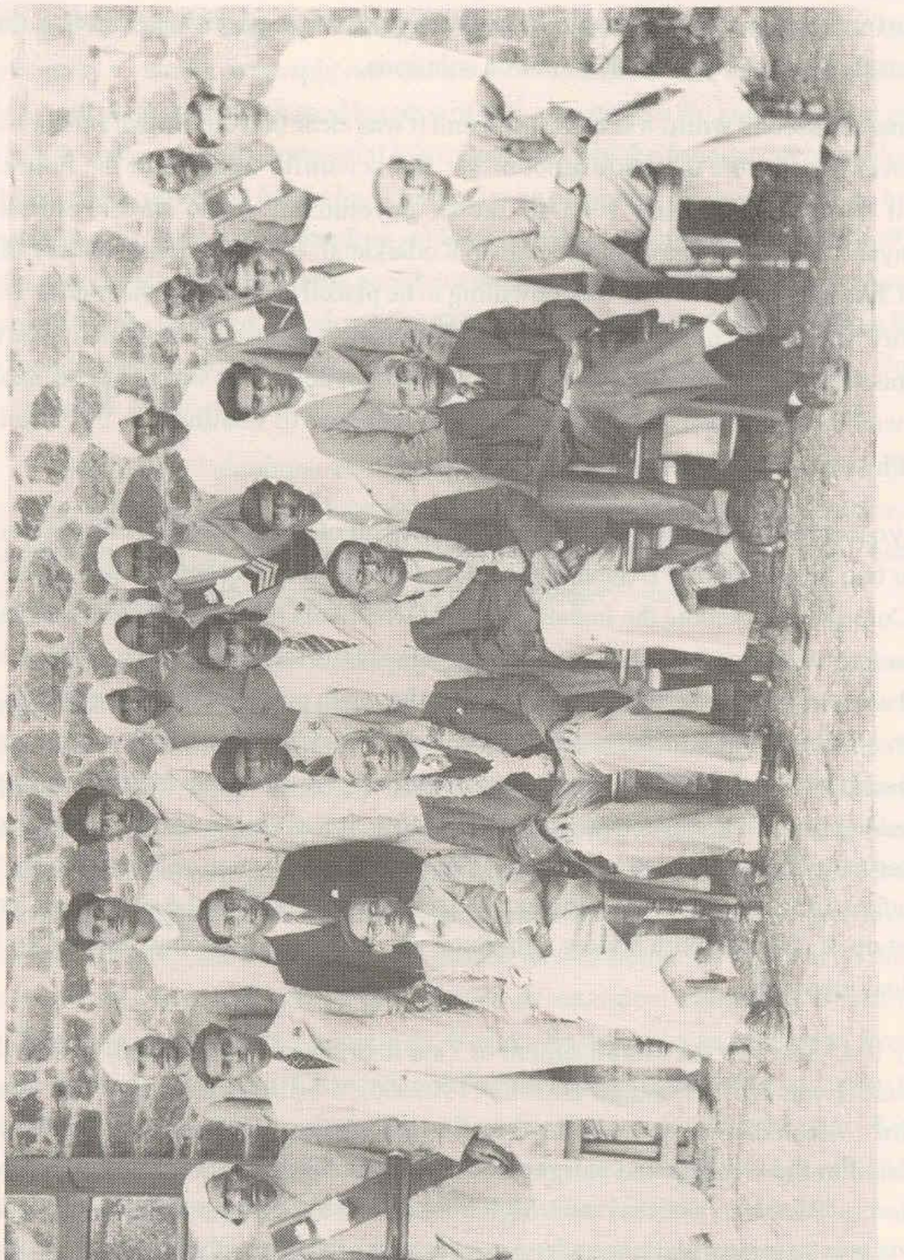
Curiously, unlike the Indian physicists, pioneering relativists were trained abroad. Nikhil Ranjan Sen (1894-1963), a class fellow of Saha and Bose, joined as a lecturer in applied mathematics at Calcutta in 1917. He obtained his D.Sc. in 1921, but went to Berlin where he obtained his Ph.D. under the supervision of Prof. Von Laue. Sen's was the first Indian doctorate in relativity and he joined INSA as a foundation fellow. Vishnu Vasudeva Narlikar (1908-91) obtained his B.Sc. in 1928 from the Royal Institute of Science, Bombay, and left for Cambridge University for higher studies, thanks to financial assistance from Bombay University, Kolhapur state, and the J.N. Tata endowment. He passed the Mathematics Tripos with distinction in 1930 and went on to win the Rayleigh prize for his astronomical researches. Spurning an offer to go to California Institute of Technology, U.S.A., he accepted an invitation from Pandit Madan Mohan Malaviya, the Vice-Chancellor of Banaras Hindu University, and came to Banaras as the head of the mathematics department in 1932, where he remained for the next 28 years. He trained and guided a large number of students including Prahlad Chunilal Vaidya (b.1918), the author of the well-known Vaidya metric (1943) for the gravitational field of a radiating star. In 1955 came Amal Kumar Raychaudhuri's (b.1923) equation that has played a crucial role in investigation of singularity in relativistic cosmology.

In 1938, B. Datt from Sen's group gave the solution for a gravitationally collapsing spherical ball of dust. This solution was published in 1938 in *Zeitschrift fuer Physik*, volume 108, page 314. It precedes the more commonly known solution of Oppenheimer and Snyder. In 1947, S.Datta Majumdar (University of Calcutta) published a class of exact solutions of Einstein's equations for the case of an electrostatic field with or without spherical symmetry; these are now known as the Datta Majumdar-Papapetrou solutions.

By the time the second world war came to an end it was clear that the British rule in India would soon be over. Plans were therefore afoot to set the scientific agenda for the future. It is not very well known that during 1943-45 Indian government made sincere efforts to bring Subramanyan Chandrasekhar from Chicago to Kodaikanal. He was offered a salary three times the usual. Chandrasekhar however was unwilling to be placed in charge of the routine work of any observatory and 'would prefer to have a job in University'. Although Meghnad Saha felt that 'Dr. Chandrasekhar ought to return to India to train our own boys', this was not to be. Daulat Singh Kothari was then sounded, but he 'expressed preference to continue as the Head of Department of Physics in Delhi University'.

Twenty years previously, the British Director General of Observatories had offered to Saha the number two position under Evershed at Kodaikanal. Now, in December 1945, Saha led a five-member Committee including the Indian Director-General of Observatories to Kodaikanal to prepare a plan for 'Astronomical and astrophysical observatories in India'. The Saha Committee proposed updating of astronomical facilities including, as a part of a long-range plan, 'the establishment in Northern India of an astronomical observatory provided with a large sized telescope for special stellar work'. The Saha report came in handy 20 years later when Bappu successfully pleaded for a stellar spectroscopic observatory at Kavalur in Jawadi Hills, Tamil Nadu. (the Observatory has since been named after Bappu.) As a follow-up of Saha's report, and on his own initiative, in 1955 a National Almanac Unit (renamed Positional Astronomy Centre in 1979) was set up at Calcutta with a view to helping the traditional almanac makers update their astronomical elements.

The year 1945 also saw the establishment of Tata Institute of Fundamental Research at Bombay. Its founder was Homi Jahangir Bhabha (1909-66), a brilliant physicist who shared Jawaharlal Nehru's vision of a scientific India as well as his aristocratic background. Additionally, he was related to the wealthy and enlightened industrial family of the Tatas. (Sir Dorab Tata was married to Bhabha's paternal aunt Meharbai in 1898). An important item on Tata Institute's agenda was experimental research on cosmic rays', in which Bhabha was personally interested. The scientific ballooning in course of time led to the advent of space astronomies in India. It was also with Bhabha's support that radio astronomy was successfully introduced in the 1960s by Govind Swarup (b.1929).



12. Government of India's Committee for the planning of the post-war development of Astronomy and Astrophysics in India, at Kodaikanal with the Observatory staff during 21-23 December 1945. Seated from left to right are Prof. D.S. Kothari, Delhi University; Dr. S.K. Banerji, Director General of Observatories; Prof. M.N. Saha (chairman); Dr. A.L. Narayan, Director Kodaikanal Observatory; and Prof. M. Ishaque, Aligarh Muslim University, Absentee members were Prof. K.S. Krishnan, Rao Sahib T.P. Bhaskara Shastri, Prof. S. Bhagvantam, and Prof. A.C. Banerji. The Committee invited and received views from C.V. Raman and others.

Critique

We can single out three cosmic events from the past two centuries and use them as benchmarks in discussing the advent and growth of modern astronomy in India. The 1769 transit of Venus took place at a time when England and France were engaged in bitter rivalry over India. This brought positional astronomy to India as a navigational and geographical aid. The 1874 transit of Venus saw India firmly in the British grip. The new science of physical astronomy was taking shape, and the British scientific activity was commensurate with its economic and political status. Solar physics came to India because the British astronomers wanted data from sunny India, and because the government was given to understand that a study of the sun would help predict the failure of monsoons. Interestingly, the work plan prepared by the Royal Society for Kodaikanal Observatory in 1901 makes no mention of the solar-terrestrial connection. By the time comet Halley appeared in 1910, India's new middles class had become politically assertive and scientifically ambitious. While the Indians on their own remained mere dabblers in observational astronomy, they made original contribution in the fields of theoretical astrophysics and relativity, in which they no doubt felt more at home.

At the time of independence in 1947, India could boast of only two, rather outdated, observatories: central government's Solar Physics Observatory at Kodaikanal which stood where Evershed had brought it in 1911, and Osmania University's non-teaching Nizamiah Observatory with equipment of still earlier vintage. Saha Committee's rather pious recommendation for upgradation of the astronomical facilities was on record, but there was nobody at hand to drive home the advantage. Bhabha's nascent Institute was still housed in his aunt's mansion, but was poised for take off in a big way. And finally there were a number of universities which would multiply but fail to keep the early promise.