Journal of Astronomical History and Heritage, 17(1), 113-135 (2014).

INDIAN ASTRONOMY AND THE TRANSITS OF VENUS.
2: THE 1874 EVENT

R.C. Kapoor
Indian Institute of Astrophysics
Koramangala, Bangalore – 560034, India.
Emails: rck@iiap.res.in; rckapoor@outlook.com

Abstract: This paper is about sightings and astronomical observations of the 1874 transit of Venus made from the Indian region. The sources of the information presented here range from some classic texts and historiographies, publications and records of institutions, and chronicles, to accounts by individuals. Of particular interest is the fact that the transits of 1761 and of 1874 both provided independent evidence of an atmosphere around Venus in observations made from India, and the transit of 1874 led to spectroscopic confirmation of the presence of this atmosphere.

Keywords: 1874 transit of Venus, India, A.C. Bigg-Wither, S. Chandra Sekhar, C. Ragoonatha Charry, J.B.N. Hennessey, Rev. H.D. James, N. Pogson, E.W. Pringle, G. Strahan, P. Tacchini, J.F. Tennant.

1 INTRODUCTION

The present work, the second part of the account of transits of Venus relating to those observed from India, is specifically about the transit of Venus of 1874, and is an extension of an earlier work (Kapoor, 2012). Part 1 dealt with transit observations up to and including the transit of 1769 (Kapoor, 2013a).

2 THE 1874 TRANSIT OF VENUS

Interestingly, in 1672 astronomers had attempted to measure parallaxes from observations of Mars made simultaneously from different locations. However, the results ranged from 20″ to 9.5″, and were not accurate, and even were questionable (see Dick et al., 1998). The 1761 transit produced a solar parallax that had much less uncertainty, but it did not cheer up the astronomers. Meanwhile, the 1769 transit provided an improved value for the solar parallax, but a divergence of results remained that implied a not so exact value for the distance to the Sun. A detailed discussion is given in Dick et al. (1998) and in Orchiston (2005).

The astronomers hoped that the next transit pair, falling in 1874 and 1882, would reduce the scatter. After all, a century had passed, the techniques for angular measurements and geopositions and instrumentation had improved greatly, and more observatories had been built. On the other hand, the Solar System itself had grown larger with the discovery by Sir William Herschel (1738–1822) of Uranus on 13 March 1781 and of Neptune by Johann Gottfried Galle (1812–1910) and Heinrich Louis d'Arrest (1822–1875) on 23 September 1846. The science of astrophysics came into being in the nineteenth century with the introduction of spectroscopy and photography to astronomy. In India, it was pursued in due course. In this regard, the most notable development was the first use of a spectroscope during the total solar eclipse of 18 August 1868, and the identification at that time of a new line in the solar spectrum by Norman Pogson (1829–1891), who carried out his observations from Masulipatam.[1]

The forthcoming transits of Venus gave rise to widespread excitement, and scientific activity of even greater magnitude. Observatories braced themselves for the observations, whereas a number of expeditions to far-off lands also were planned. The transit of Venus was going to be observed for the first time using photography and spectroscopy. Observations by British observers gave parallax values ranging from 8.75″ to 8.88″. Simon Newcomb (1835–1909) then worked on the results derived from the 1761, 1769, 1874 and 1882 transits and came up with a value of 8.794″ for the solar parallax, which is remarkably close to the modern value of 8.794148″ that was adopted by the IAU in 1976 (see Dick et al., 1998).

In India, the plan was to observe the 9 December 1874 transit of Venus from several different places. The most prominent among these, the Madras Observatory, was suitably equipped for the occasion. In comparison, the Colaba Observatory in Bombay was not as well equipped as it had fewer instruments. Observations were planned also at the headquarters of the Great Trigonometrical Survey in Dehra Dun. The interest and the preparatory activity can be gauged also from the references to the forthcoming transits of Venus in the meetings of the Asiatic Society of Bengal during 1873 and 1874. In its meeting of February 1873, T. Oldham, Esq., LL.D. (1816–1878), in his Presidential Address, impressed upon the members as to how significant the observations of the rare transit events would be, which were planned to be carried out from regular and makeshift observatories at various places the world over, and that

> … the Government of India have, on representations made to them of the value of a series of observations especially photographic in the clearer atmosphere of some high elevation in North India, at once sanctioned the necessary

expenditure for instruments, and have telegraphed for their immediate preparation.

In connection with this, the General Committee of the British Association at their meeting in 1872, August last, requested the Council to take such steps as seemed desirable to urge the Indian Government to prepare these instruments, with the view of assisting in the Transit of Venus in 1874. (*Proceedings of the Asiatic Society of Bengal*: 58-62 (1873)).

Table 1: Details of the 1874 and 1882 Transits of Venus.

	Transit Contact Times (UT)					Minimum	Sun	Sun	Transit	
Date	1	2	Greatest	3	4	Sep.	RA	Dec	GST	Series
	h:m	h:m	h:m	h:m	h:m	"	h	°	h	
1874 December 09	01:49	02:19	04:07	05:56	06:26	829.9	17.056	–22.82	5.182	6
1882 December 06	13:57	14:17	17:06	19:55	20:15	637.3	16.881	–22.56	5.025	4

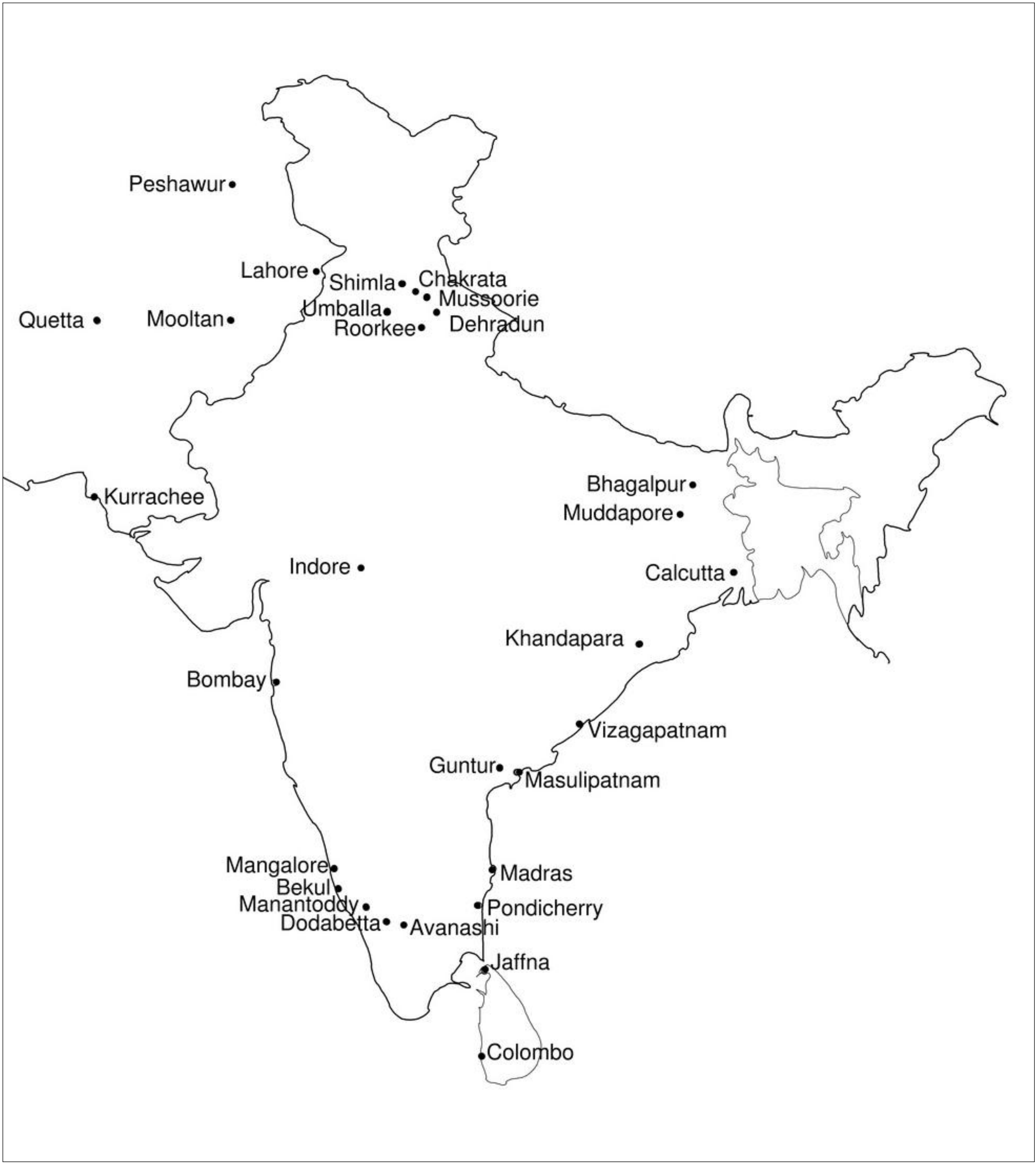


Figure 1: Outline map of the Indian Subcontinent showing localities mentioned in the text. Note that Kurrachee, Lahore, Mooltan, Peshawur and Quetta are now in Pakistan, and Colombo and Jaffna are in Sri Lanka.

The British Association had urged the Government of India to establish a solar observatory, and suitable locations for it existed in the mountain ranges (*Proceedings of the Asiatic Society of Bengal*, 1873; 1875). Colonel H. Hyde (Royal Engineers) succeeded Dr Oldham as the President of the Society, and in his address at the February 1874 meeting he stated that

> In India, however, Spectroscopic observation is making some progress in the Department of the Great Trigonometrical Survey and the atmospheric lines of the Solar Spectrum are being observed.
>
> Mr. J.B.N. Hennessey has continued observing and mapping the atmospheric lines of the Solar Spectrum, employing in super-session of the instrument formerly used, an excellent three-prism (compound) spectroscope with automatical adjustment belonging to the Royal Society of London. This instrument is placed at a height of about 6,500 feet above sea level, on a projecting spur of the Himalayan range on which the Sanitarium of Mussoorie is located, so that a clear view is obtained of the Sun down to the very horizon … (*Proceedings of the Asiatic Society of Bengal*: 46-48 (1875)).

As a ready reference, the circumstances of the 1874 and 1882 transits are listed in Table 1 (after Espenak, 2012),[2] and localities in the Indian region mentioned in the text are shown in Figure 1.[3] Note that the transit of 6 December 1882 would not be visible from India. For example, first contact was at 19:27 hrs (UT+5:30) whereas the Sun, and Venus, had set at Madras by 17:40 hrs.

3 THE MADRAS OBSERVATORY AND THE 1874 TRANSIT

The Madras Observatory staff made elaborate arrangements to observe the transit. However, for most of the event clouds frustrated these preparations. The Observatory has no publiccation about the observations except for a brief account that forms part of the Administration Report of the Madras Observatory for the year 1874, and Norman Pogson's letter to *The Astronomical Register* (1876b) where he reports on the failure, but also lays emphasis on determination of the solar parallax from observations of Mars when it is at opposition. But let us first have a glimpse at some history.

The earliest scientific astronomical observatory in India was established in 1786. This was a private facility erected at Egmore in Madras (now Chennai) by William Petrie (1747–1816), an officer with the East India Company. The first observation on record, on page 164 in the MS Observations in the Indian Institute of Astrophysics Archives, dates to 5 December 1786 and pertains to the determination of the coordinates of the Masulipatam Fort flagstaff. In 1789 the East India Company took over Petrie's observatory, and in 1792 it was shifted to new premises at Nungambakkam, designed by the Company's new Astronomer and Marine Surveyor Michael Topping (1747–1796), and renamed Madras Observatory (see Figure 2).

In *A Memoir on The Indian Surveys*, the noted British geographer Sir Clements Markham (1830–1916) has this to say:

> The Madras Observatory is now the sole permanent point for astronomical work in India, and the only successor of the famous establishments founded by Jai Sing. It has been presided over by a succession of six able and accomplished astronomers, it has produced results which entitle it to take rank with the observatories of Europe, and its present Director is engaged in the prosecution of labours which are of great importance to astronomical science. (Markham, 1878: 323-341).

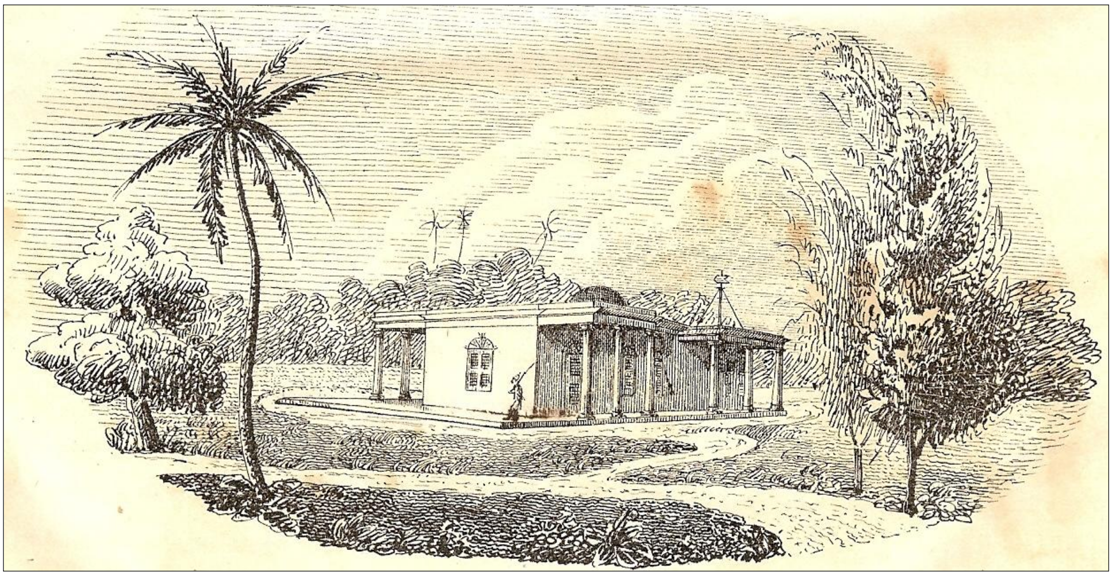


Figure 2: The Madras Observatory at Numgambakkam (after Taylor, 1838: front cover; courtesy: Indian Institute of Astrophysics Archives).

Figure 3: Norman Pogson, 1829–1891 (courtesy: Indian Institute of Astrophysics Archives).

The Director referred to in the above quotation is Norman Robert Pogson (Figure 3), who occupied the post from 1861 until his death on 23 June 1891. Pogson started his career as an astronomer at George Bishop's South Villa Observatory in London where he trained under John Russell Hind (1823–1895). Then followed fruitful days at the Radcliffe Observatory in Oxford from the close of the year of 1851, and at the Hartwell Observatory, beginning 1 January 1859. Although his name is well known as the 'founder' of the modern logarithmic magnitude scale (see Pogson 1856; cf. Reddy et al., 2007), while at the Madras Observatory, he also used the new 8-inch Cooke equatorial to discover five asteroids and seven variable stars. At Madras, he also rediscovered the lost asteroid *Freia* (D[reyer], 1892). In addition, his assistant, C. Ragoonatha Charry (1828–1880),[4] made a notable astronomical discovery in January 1867: that R Reticuli was a variable star (Markham, 1878: 333-334; see, also, Kameswara Rao et al., 2009). Pogson was awarded the Lalande Medal by the French Academy of Sciences for his discovery in 1856 of asteroid *Isis* (42) (named after his daughter), and later was honoured when a lunar crater and asteroid (1830) Pogson were named after him. In 1860 he was elected a Fellow of the Royal Astronomical Society and on 1 January 1878 he became a Companion of the Indian Empire. One can find more about Pogson in the obituary which was published in *Monthly Notices of the Royal Astronomical Society* (see D[reyer], 1892).

The Madras Observatory (Figure 4) continued to evolve during and following Pogson's Directorship, eventually becoming the Indian Institute of Astrophysics (IIA). Now there is nothing but a conspicuous monument in Nungambakkam to mark the original buildings (Figure 5). For further details of the Observatory's history see Kochhar 1985a and 1985b.

Figure 4: The Madras Observatory at Numgambakkam during the period 1860-1890 (courtesy: Indian Institute of Astrophysics Archives).

4 THE TRANSIT OBSERVATIONS

4.1 Norman Pogson's Report on the Transit

Well before the transit of Venus was to take place, Pogson was concerned that it be observed from various stations in India. The following is from the 'Notes' in *Nature* (Notes, 1873):

> We learn from the Times of India that Mr. Pogson, the Government Astronomer of Madras, has written a long letter to the local Government, suggesting that some special arrangements should be made for observations of the Transit of Venus in December 1874, in Northern India, independently of the Madras Observatory. The letter has been forwarded to the Government of India for consideration.

Post-transit, Pogson's account of the transit and comments form part of the "Administration Report of the Madras Observatory for the year 1874" (Indian Institute of Astrophysics Archives). First he says:

> The two equatoreals, by Messrs. Troughton and Simms and by Messrs. Lerebours and Secretan; the silver glass reflector by Browning, and seven smaller telescopes, four of which are provided with portable equatoreal stands, were all in good order and ready for the long-expected Transit of Venus on December 9th, which, however, was not observable at Madras owing to cloudy weather …

Furthermore:

> *Transit of Venus* – As at almost every other observatory in the world at which the important event was visible, very complete and careful preparations were made in anticipation of the Madras Observatory contributing its share to the general results. The valuable aid and experience of Colonel A. Ritherdon, Mr. G.K. Winter, and Mr. F. Doderet, all so signally successful on the occasion of the last total eclipse of the sun at Avenashy in 1871, were enlisted, but in vain. Venus was briefly seen once or twice during the transit, but only through thick clouds which rendered photographs or measurement of any kind impossible. The second internal contact, noted by Miss E. Isis Pogson and C. Ragoonatha Chary, was the only record obtainable after all the trouble incurred; but had the undertaking been crowned with success and the Transit photographed and observed throughout in an unclouded sky, the geographical position of Madras, or indeed any part of India, would have rendered such results only of very secondary importance compared with those secured by astronomers at the southern island stations of Kerguelen and elsewhere; which, combined with other equally valuable observations at the northern stations of Russia and China, would have amply sufficed to determine the solar parallax without the interference of any mid-way observers at all, so far as the method is capable of yielding the solution of this great problem. For two centuries past the Transits of Venus have been popularly regarded as the only means available for settling the precise value of the solar parallax, and thereby the earth's mean distance from the sun; but this delusive prejudice is now breaking down, and certain insurmountable drawbacks in the favorite method will probably lead to a more just recognition of the superior advantages offered by other means, of more frequent recurrence, and which involve no costly expeditions to remote parts of the earth. The oppositions of Mars, already observed here on five unfavorable occasions, but which in 1877 and 1879 will be especially favorable, will probably yield as good a determination, when discussed, as all the late Transit observations put together; though after all it is very questionable whether any direct method of observation will ever achieve more than a mere verification of the latest value of the parallax deduced by the triumphant theoretical researches of M. Le Verrier of Paris.

Figure 5: The Madras Observatory monument photographed by the author in July 2011.

The excitement of this rare event notwithstanding, Pogson was clear that the precision achievable by its observations was limited and that the method for determining the mean Earth-Sun distance from oppositions of Mars was better, more convenient and more accurate. His reference to Kerguelen is in respect of the Royal Observatory's expedition to Kerguelen Island in the southern Indian Ocean that was led by the Reverend Stephen Perry (1833–1889). Despite the failure of the observations due to bad weather, Pogson provided valuable help to observers stationed elsewhere through telegraphic determination of their respective longitudes, and in his words, "… one of the most important and yet the most difficult of all the requisite data for rendering their observations available for the determination of the solar parallax." Telegraph lines from London to India had been laid and connected only recently, in January 1870, first to Calcutta and then to Bombay and Madras (see Karbelashvili, 1991). Pogson's longitude work subsequently was published in 1884.

Of the two observers that Pogson mentions, Elizabeth Isis Pogson was his daughter, who

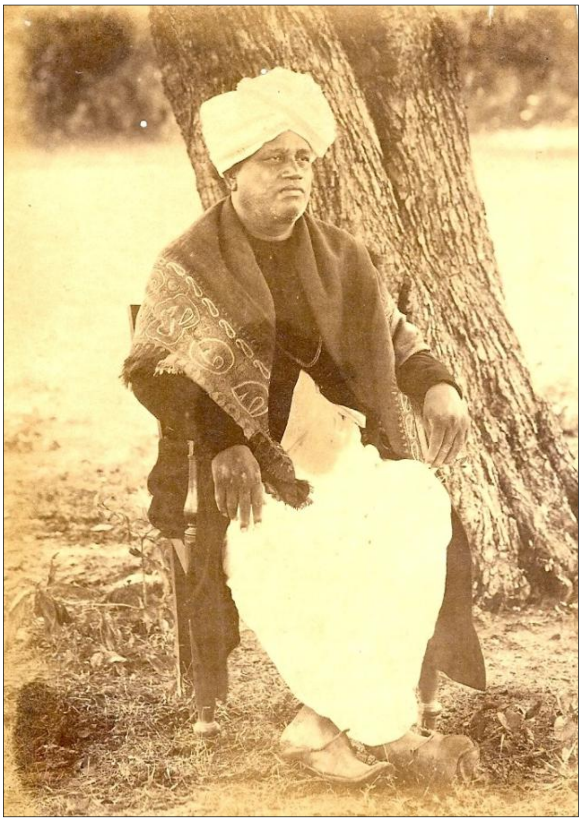
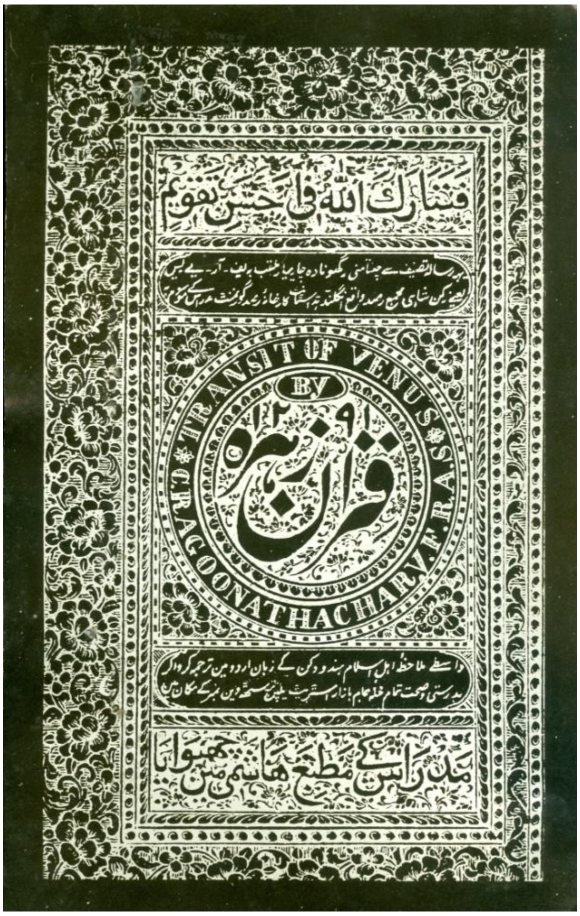


Figure 6: C. Ragoonatha Charry (courtesy: Indian Institute of Astrophysics Archives).



فتبارك الله فى حسن تقويم

TRANSIT OF VENUS

BY

C. RAGOONATHACHARYA. F.R.A.S.

قران زہرہ

۱۲۹۱

مدراس کے مطبع ہاشمی مین چھپوایا

Figure 7: The cover page of the Urdu version of Ragoonatha Charry's pamphlet on the 'Transit of Venus' (courtesy: Indian Institute of Astrophysics Archives).

worked at the Observatory as an Assistant Astronomer (*Nature*, 1873: 513) whereas Ragoonatha Charry (Figure 6) was the First Assistant to the Astronomer. Charry came from a family of almanac-makers and when about eighteen years of age, in 1847, he had joined the Observatory (during T.G. Taylor's time as Director). Pogson (1861) spoke highly of Charry. In 1874, as the transit date drew near, Charry prepared a 38-page pamphlet titled *Transit of Venus* which was written in English, Kannada, Urdu and other languages (e.g. see Figure 7). As he states in the preface to the English edition:

> Having been accustomed for many years to discuss astronomical facts and methods verbally with Hindu professors of the art, my present sketch has naturally, as it were, taken the form of a dialogue; but in the Sanscrit, Canavese, Malayalum, and Maharathi versions I have found it convenient to vary the arrangement. The sketch was first drafted in Tamil, and then translated into English and the other languages.

Through several figures, the pamphlet beautifully explains the transit to the lay public. The English version is presented as dialogue but the style differs when he presents the versions in the local languages. The 'pamphlet', as he called it, was printed but was not published as such. It includes Charry's passionate address at the Pacheappa's Hall, Madras, on 13 April 1874 (one day after the Tamil New Year) to a large gathering of 'Native Gentlemen'. Here, he urges them to support a modern *Siddhānta* that he wished to bring out; the establishment of an observatory for which he offers a few crucial instruments of his own; and the formation of a society along the lines of the Royal Astronomical Society. A favourable review of the pamphlet appeared in *The Astronomical Register* (see Ragoonatha Charry, 1875).[5]

4.2 Observations by J.B.N. Hennessey and the Reverend H.D. James

A brief account of the observations of the transit from various other stations in India also is given in Markham (1878: 339-340). He writes that from Mussoorie (Masauri) in the Shivalik Hills, 6,765 ft above mean sea, the transit was observed by J.B.N. Hennessey (1829–1910; Figure 8) from The Great Trigonometrical Survey of India. Hennessey

> …. was appointed to the Indian Trigonometrical Survey in 1844, and in the times of the Mutiny was under arms and on a harassing duty for five months protecting a large number of ladies and children. In 1863, when on leave in England, he entered Jesus College, Cambridge and worked under Profs. Adams, Challis, and Walton to improve his mathematical and astronomical knowledge … (H[ollis], 1910).

At Dodabetta in the Nilgiri Hills, Hennessey and Captain James Waterhouse (1842–1922) had photographed the solar corona during the 1871 eclipse, under the superintendence of Colonel James Tennant. Solar physics was then in its infancy. At the compound of the Survey of India's Geodetic Branch Office in Dehra Dun the Hennessey Observatory still exists (Figure 9). This originally was established in 1884 to carry out photoheliography and take 30-cm images of the Sun. Nowadays, all the instruments are gone, but the dome remains, and it and the building require conservation.

Hennessey's main objective was to observe the transit of Venus from a high altitude, hence his decision to locate his observing station near Mussoorie. He used an 'equatoreal' telescope from the Royal Society given him by Captain John Herschel, R.E. (1837–1921), an alt-azimuth telescope, a mountain barometer and a thermometer. In the course of his professional duties, he was already in the Shivalik Hills at a location some 22 km from Mussoorie. He chose an observing site, then determined its altitude, latitude and longitude, and carried out observations to rate his chronometers. Mary Villa at Mussoorie, where he placed the equatorial, was appropriately named 'Venus Station'. Its coordinates, namely, 30º 27′ 36″.3 N, 78º 3′ 3″.2 E, and a height of 6,765 feet above sea-level, place the station south of the Municipal Garden, the erstwhile Company Bagh. Hennessey set up the equatorial in an observatory tent with a removable canvas top. By trial and error, he chose an eye-piece, one of 125 power, just suitable to view the ingress (when the Sun's altitude would increase from 2º 24′ to 7º 29′) as well as the egress (with the Sun at ~26º). He had two flat glasses to give a neutral and bluish field for ingress, and changing one of these with a deep red glass for egress (Hennessey, 1874). At the crucial moments of the transit, W.H. Cole

Figure 8: John Babonau Nickterlein Hennessey, F.R.S. (after Phillimore, 1945-1968: V, Plate 23).

Figure 9: The Hennessey Observatory, Survey of India, Geodetic Research Branch, Dehra Dun (photograph: R.C. Kapoor, February 2013).

did the seconds count, audible for obvious reasons, and

> Baboo Cally Mohan Ghose took up a position by my side, pencil in hand, noting down such remarks as the phenomena, viewed through the equatorial, elicited from me. (Hennessey, 1873-1874: 318).

Hennessey had determined zenith-distances of the 'clock stars' α Tauri (east) and α Aquilae (west).

Hennessey enjoyed fine weather for his observations. He knew what was in the offing to the minutest detail and rehearsed his observations. As the moments of the transit drew near and Venus closed in, he noticed the beginning only after the planet had made a 'dent' on the Sun's disc. At 8½ minutes before the second contact he saw a thin luminous ring around the planet, but not the black-drop effect, despite the advantage of a high altitude (Hennessey, 1874-1875; for a comparison of their observations, see Tennant; 1877: 41). For about half an hour, he watched the planet and then he substituted a spectroscope for the eyepiece. Its slit placed across the centre of the planet gave a black band all through the length of a bright solar spectrum. However, when the slit was placed tangential to the disc, Hennessey got a faint glimmer, "… slightly brighter than the solar spectrum over which it appeared …", and the lines identical to those seen in the solar spectrum.

Table 2: Hennessey's contact times.

Contact	h	m	s
Ist internal	14	17	09.0
2nd internal	18	05	32.6
2nd external	18	32	49.6

Reducing his local mean time to Greenwich Mean Time, Hennessey (1874-1875: 381) gives the contact timings listed above in Table 2.

The black-drop however was noticed clearly by Colonel James Thomas Walker (1826–1896), who, 16 km south of Hennessey, made his observations from 'Dehra Doon', in the foothills at 2,200 feet. At that time, Walker was Superintendent of the Trigonometrical Survey of India, but he rose to become the Surveyor General from 1878 until 1884.

The Reverend H.D. James observed the transit from Chakrata, a place in the Shivaliks at an elevation of 7,300 feet (30º 43′ N, 77º 54′ E) with a telescope of his own—made by Smith and Beck—with a 3.5-inch object-glass and a focal length of 4 feet. For timing, he used a pocket-watch that he says gained a minute in 12 hours. Chakrata lies 80 km by road west of Mussoorie. It was a cantonment of the British Indian Army, founded in 1866 by Colonel Hume and occupied in 1869. In the course of his observations, the Reverend was ably attended by his son, Henry. About the Reverend James, Hennessey (1874-1875: 381) says: "His station is distinctly visible from Mussoorie on a clear day." Hennessey cites from his correspondence with the Reverend James what the latter observed:

> When she (i.e. Venus) was about halfway on (at ingress) the sun we both noticed a fringe of white light illuminating that rim of the planet which was yet on the dark sky. When she went off we noticed the same fringe of light, but for a much shorter time, and when only about one eighth of her had passed the sun's disk. (Hennessey, 1874-1875: 382).

In his note to the Reverend James, Hennessey (ibid.) says: "I had seen a ring of light, but no "pear-drop" or other ligament, at internal contacts." The Reverend James subsequently wrote him (see Hennessey, 1874-1875: 382-383):

> When about half her orb had entered (alluding to ingress) my attention was attracted to the other half yet on the dark sky: to me it was dark; hence I infer that ray field was not so light as it ought to have been. Its outline, up to this time quite invisible to me, became now illumined with a fringe of white light. I then also noticed a much fainter, thinner, edging of light on the outline of the limb on the sun's disk, which soon ceased to be visible. The fringe external was rather less in width than 1/64 of the planet's diameter. The light somewhat resembled that which we see so plainly in India lighting up the dark side of the moon three or four days old; but it was brighter, not diffusive as that is, its inner edge being clearly marked. It remained visible as long as there was any appreciable portion of the planet beyond the sun's circumference.
>
> As the time for the internal contact approached, that half of the planet which was still entering appeared to lose its semicircular shape and to become oval. I compared it to the thinner half of an egg; but, since, I have examined several eggs, and find that my comparison would represent a distortion greater than I had intended. Just before the contact ceased, the end of the oval seemed as it were adhering to the sun's edge, and could not get free, rendering it difficult to decide when the contact ceased. Another impediment in the way of accurate timing was, that the outline of Venus looked woolly and wave-like, from a very annoying tremor in the air. Hence the notes we entered were, 'Internal contact ceased 7^h 41^m 20^s, quite clear 7^h 42^m.' As to the ligament which seemed to knit the two edges together, I am disposed to attribute it solely to the billowy motion of the planet's outline; for it had a hairy appearance, and sunlight could be seen through it.

Hennessey (1879) later supplemented his analysis of the observations.

4.3 Transit Observations by Colonel J.F. Tennant and Captain G. Strahan

On 21 March 1872, the Astronomer Royal, Sir George Airy (1801–1892), urged J.F. Tennant to arrange observations of the forthcoming 1874 transit of Venus from India, and especially to make use of photography. Consequently Tennant prepared to observe the transit from two stations: at Roorkee, where he would be based, and at Lahore, where he would send Captain George Strahan from the Royal Engineers.

Born in Calcutta, James Francis Tennant (1829–1915; Figure 10) joined the Bengal Engineers in 1849 as a Second Lieutenant, and was then attached to the Great Trigonometrical Survey of India (H[ollis], 1915). Tennant briefly directed Madras Observatory from 13 October 1859 until October 1860, when Norman Pogson was appointed Astronomer (subsequently becoming Director in February 1861). Tennant observed Donati's Comet (C/1858 L1) between 5 and 12 October 1858 from Mussoorie (30º 17′ 19″ N and 5^{h} 12^{m} 17.7^{s} E), and Halley's Comet (1P/Halley) on 16 May 1910 from "… somewhere in the Himalayas …" (Tennant, 1910: 297), at an altitude of 7,500 feet. Most likely, this observation was made from Lal Tibba, Mussoorie. In 1890 and 1891, Tennant was the President of the Royal Astronomical Society.

For the attention of the scientific world, Lieutenant Colonel Alexander Strange, F.R.S. (1818–1876) presented in *Nature* a detailed account of preparations and instruments being employed by Colonel Tennant at the Roorkee station (Strange, 1874). It was dated November 1874 but only appeared in print after the transit was over. Strange was Inspector of Scientific Instruments to the Government of India and he had superintended the manufacture of some of the instruments. He mentions also Peshawur (Peshawar, now in Pakistan) and Bombay as other transit stations, and more than one station in the southern part of the peninsula of India under the care of Mr Pogson, that are to be provided with sufficient equipments. Ragoonatha Charry (1874: 17) also mentions that

> The most important spot in India has been shown to be Peshawur, and accordingly both this station and Roorkee will be occupied by Colonel Tennant, F.R.S., assisted by officers of Trigonometrical Survey of India.

The city of Peshawar adjoins the eastern end of the Khyber Pass, the historical trade route that connects Pakistan and Afghanistan. Peshawur, however, does not figure in Tennant's (1877: 2) accounts, for, he says that

> When it was determined that I should be employed to superintend the observations, my first care was to select positions for the observing stations. The Punjab is often cloudy in December, and thus it was desirable not to go too far west.

At Roorkee, Tennant had Captain William M. Campbell, Royal Engineers of the Great Trigonometrical Survey, Captain James Waterhouse, Royal Engineers, Sergeant J. Harrold, Royal Engineers, Lance-Corporal George and Private Fox as part of the team. Tennant set up a solar observatory by installing the photoheliograph; an equatorially-mounted 6-inch Cooke refractor with a double image micrometer, sheltered in a circular building with a revolving roof; an altazimuth-mounted refractor; and a portable transit instrument and chronograph. The values adopted by him for the latitude and longitude of the transit pillar, 29º 51′ 33.81″ N and 5^{h} 11^{m} 31.09^{s} E, were determined with reference to the longitude of Madras. The spot where Tennant's observatory was sited is a few hundred metres north of where the present-day Dehra Dun-Saharanpur Road crosses the Right Bank Canal Road, and between the former and the Upper Ganga Canal, as we make it out from *Google Maps*. This is consistent with a sketch of part of Roorkee showing the location of the observatory, as given by Tennant (1877). Among the transit party, the tasks were divided as follows:

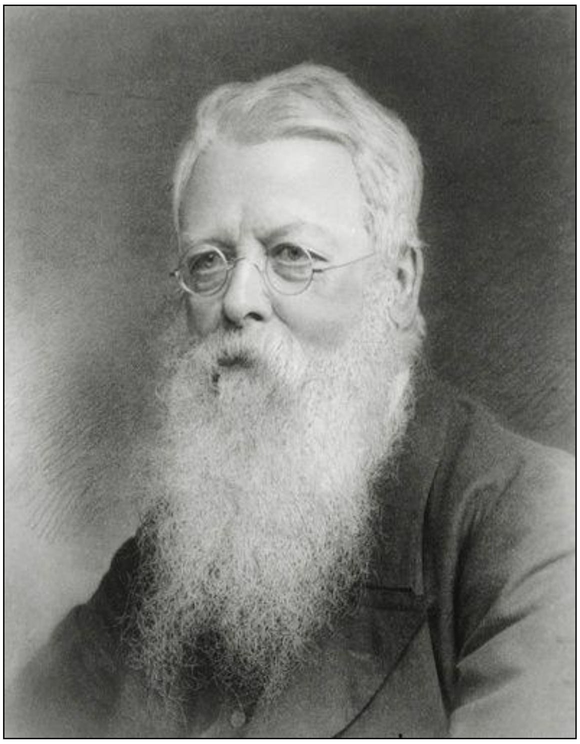


Figure 10: J.F. Tennant (courtesy: Indian Institute of Astrophysics Archives).

Time Determination:	Colonel Tennant
The Equatorial Telescope:	ditto.
The Alt-azimuth Telescope:	Captain Campbell
The Photoheliograph:	Captain Waterhouse

The team was later joined by Captain William James Heaviside, Royal Engineers, who also brought along the Royal Society's Slater Telescope. He was assigned responsibility for the chronograph: winding up the used record strips and their replacements when due. Besides, he was to observe the egress with the Slater Telescope. Regarding direct viewing, Tennant (1877: 44) held that

> ... where the spectroscope is not used, external contacts should be observed with a pale dark glass, so as to facilitate the seeing of Venus outside the Sun's limb, but that a smoke-colored glass (brown yellow) as deep in tint as is convenient should be used for internal contact to diminish, as far as may be, the irradiation and the haze round the planet.

Just when the transit began, with the Sun low, Tennant noticed the planet only four or five seconds after the first contact. However, he could observe the ingress in progress, and also the third and fourth contacts at egress. Tennant (1875a: 209) initiated micrometer measures of the cusps, obtaining sixteen measures of the chord joining the cusps at ingress, and also at egress. At the first internal contact, no black-drop or distortion was seen, that he had expected, and it was the same at egress. He even sent a telegram to Captain Strahan about this.

Table 3: Some values derived from the Indian observations of the transit made under Tennant's direction (after Tennant 1877: 44).

Observer	Venus' radius	Parallax
Tennant	30.87″	8.160″
Hennessey	31.18″	8.342″
Strahan	31.70″	8.260″

Tennant also measured the diameter of the planet, first horizontally so that it was free of refraction and atmospheric boiling, and later also in declination and in right ascension. The right ascension value exceeded slightly the one obtained in declination when corrected for refraction. He found a mean value of 63.948″ ± 0.0603″, for Venus as a sphere (Tennant, 1875b). Captain Waterhouse, assisted by 'Serjeant Harold', took 109 photographs while the transit was in progress and at the time of egress. Meanwhile, Captain Campbell observed the transit with the great theodolite.

Captain Strahan set up equipment in Lahore in the compound of a house occupied by Dr Calthrop that was known as Mr Elphinstone's house, the property of the Maharaja of Kashmir. Tennant deduced his position as 31° 23' 23.5″ N, 74° 19' 27.2″ E = 4h 57m 17.81s E. Strahan had a 6-inch Simms refractor and two solar and sidereal chronometers. Ingress was not visible here, but with favourable weather Strahan made his observations as the transit progressed. He, too, did not see the black drop effect at egress as such, but noticed the planet's atmosphere; to quote from his report and the notes presented in Tennant (1877: 36-38):

> As the planet moved towards the Sun's limb, she appeared to push away his edge before her, the cause of which became evident in a few seconds; the planet's edge was, in fact, encircled by a ring of light nearly as bright as the Sun, which prevented any contact, properly so called, from taking place at all … The part of the planet outside the Sun was palpably darker than the sky; dense black background being purplish. Its shape in no way distorted, magnified or diminished … It is difficult to account for the position of the strongest part of the ring of light being unsymmetrically situated with regard to the line joining the apparent centres of the Sun and Venus; but this is established beyond all doubt —indeed, the most unpractised eye must have noted the circumstance. It will be observed that the brightest part of it is almost exactly on the preceding portion of the disc reckoning along the line of the planet's motion; but whether this is a mere coincidence or a significant fact, is not readily apparent. The ring was visible up to the time of external contact, which enables one to make a rough estimate of the refractive power of the planet's atmosphere; inasmuch as the minimum (?) duration of a solar ray reaching the observer's eye after refraction when Venus is at exterior contact must evidently be the apparent diameter of Venus as seen from the Earth + the apparent diameter as seen from the Sun. This deviation, in the present case, amounts to about 1′ 27″.

Tennant provided a detailed account of the observations of the transit that were made under his charge, and he duly presented results in an 1877 report, together with a plan of the observatory that he had set up. The transit date printed in the report is 8 December 1874, which is according to the day that it commenced (Tennant 1877; see also Tennant 1875a and 1875b).

In the report, he used Hennessey's observations as well, and he deduced a few results for the three observing sites. The crucial ones are listed in Table 3. Based on these, he assigned a mean value of 8.260″ for π. It is of interest to note that this figure is not grossly dissimilar to the best figure for the solar parallax available at that time, Encke's 1824 value of 8.5776″, which was derived from observations of the 1761 and 1769 transits (see Dick et al., 1998: 223).

After the transit expedition, Tennant proposed the establishment of a solar observatory at Shimla, for spectroscopy and photography and observations of Jupiter's satellites, but his proposal was not accepted. However, arrangements were made to take daily photographs of the Sun with the Dallmeyer photoheliograph, under Colonel Walker's superintendence, and this is how the Dehra Dun Observatory came into existence.

4.4 Captain A.C. Bigg-Wither's Observations

Captain A.C. Bigg-Wither (1844–1913) was an engineer with the Indus Valley Railway, and he observed the transit of Venus on 9 December 1874 from his observatory at Mooltan in the Punjab (30º 11′ 5″ N, 4^h 45^m 59.5^s E; Multan—the current spelling—is now in Pakistan) where many gathered to watch the event. Bigg-Wither was a keen astronomer since his younger days, and he maintained a personal observatory for 45 years where he would carry out many different types of observations with his 5-inch telescope and a transit circle, so much so that

> At Quetta and Mooltan, his observatory was the scientific centre of the Civil and Military stations. After a long day in the Public Works Department he would be invariably found in the midst of calculations or working with his instruments till the night was far advanced. (*Monthly Notices of the Royal Astronomical Society*, 1914: 270).

Some details about him are provided by Gosnell (2012).

On the crucial day, Bigg-Wither observed the transit with a 4-inch equatorially-mounted Cooke refractor of 5 feet focal length using powers from 55× to 300× and a solar diagonal eyepiece, while the Sun rose with half of the planet's orb already on the disk of the Sun (Bigg-Wither 1883). He had fine weather, but even at the time of second contact the Sun and Venus were still very close to the horizon. Yet he was able to observe the black-drop effect, and he timed the second contact at 12^h 17^m 8^s Mooltan Sidereal Time, just when he saw the 7″ wide black band break.

As the transit progressed, he watched carefully to see if he could detect any trace of light on the disk of the planet. Only at its edge did he notice that "… the Sun's light appeared as if it were slightly encroaching …" (Bigg-Wither, 1883: 97). Over the disk of the Sun he also looked around the planet, though in vain, for any spot caused by a possible satellite.

At egress, he was surprised to notice no traces of the black drop effect. However, just as the planet reached the limb of the Sun,

> … she appeared to push before her a ring of light concentric with her disk; this was first noticed at about 16h 3m Mooltan Sidereal Time, when otherwise from her position Apparent Contact would have taken place; this ring soon appeared thicker in the middle, in fact taking the shape of a crescent, the inner edge of which was evidently the same as that of the planet's disk ... The appearance at this time, when the crescent was at its best, was very beautiful; the planet seemed to start out stereoscopically, with a kind of glow on its disk shaded like the light on a globe, so that I could see it was a sphere between the Earth and the Sun, an effect that no effort of the imagination could produce during the Transit … When the western part of the crescent vanished, as stated above, it appeared to leave exactly half, the thin end joining on to the Sun as before, and the other end corresponding to what was the middle. This appearance lasted some time; at 16^h 18^m the planet was about bisected by the Sun's limb, and the half crescent therefore covered about one-fourth of the planet's circumference. (Bigg-Wither, 1883: 98-99).

Bigg-Wither wondered how this crescent formed; it was not there at the ingress. Nor had he noticed this at the time of egress when he observed the transit of Mercury on 5 November 1868 with the same telescope, and while in England.

During the 1874 transit of Venus, the last external contact (contact 4) happened at 16^h 30^m 1^s, which Bigg-Wither says actually differed quite substantially from the calculated time.

4.5 Observations from Bushire, Calcutta and Kurrachee

We have little information on observations made at some of the other stations. According to Proctor (1882: 218),

> The whole transit was also observed by amateur astronomers at Kurrachee, Indore, and Calcutta, a fact rather showing what ought to have been done by official astronomers in England to strengthen the north Indian position, than (in all probability) adding much to the value of northern Halleyan operations.

Unfortunately we cannot identify these amateur astronomers, and we have no details of their observations.

David Gill also mentions observations of the transit made from Kurrachee (Karachi, now in Pakistan), Calcutta and also Bushire. These places are listed, together with Roorkee and Maddapore, in a table by Gill (1878: xxx-xxxii) showing stations where observations of the transit were carried out more or less successfully. He comments that the stations marked in his table with an asterisk had at least some persons present with previous training and good instruments. Of the stations mentioned above, Bushire and Calcutta are not so marked, and Gill raises the question as to whether the observations made without these conditions should be relied on. Bushire (Bushehr), we may recall, is situated on the Persian coast and was then a British India Political Residency in the Gulf. The *Astronomical Register* (Notes …, 1875) carried the latest information received by the Astronomer Royal, Sir George Airy through

Reuter's brief telegrams that he presented before the Royal Astronomical Society in its meeting on 11 December 1874. The telegram from Bushire merely said "The transit was beautifully observed …", and Airy lamented that the telegram

> … does not say by whom, and that is a misfortune attending most of Reuter's telegrams; though we shall hear more about them in time, no doubt. 'The interval from the commencement to the end of the apparent contact, 4h.37m.32s.; the interval between two internal contacts, 3h.42m.56s.'. And then comes the remark, which is worth notice, 'No black drop appeared'. (ibid.).

Airy then read out the content of a telegram from Calcutta that said the observations were excellent: mean time of the ingress centre: 7.56 a.m.; middle, 10.5 a.m.; egress centre, 12.13 p.m. The observer is unknown. While Madras reported a near wash-out due to clouds, Reuter's agency learnt from Kurrachee that the first contact happened before sunrise, at $6^h\ 10^m\ 26^s$. Airy commented that in such a case the observer, unable to observe it, would have taken the published time only and therefore one may pass over his other times. Lieutenant Stiff mentioned that the observer at Kurrachee was General Addison who used an equatorially-mounted Cooke refractor. Stiff said there might be some inaccuracy in the telegram itself as to the timing. Apparently, Stiff was referring to General Thomas Addison who had set up his own small observatory. According to Pogson (1884: 47),

Figure 11: Father Eugene Lafont (courtesy: en.wikipedia org).

> The telegraphic determination of the difference of longitude between Madras Observatory and Karachi was of two-fold importance and interest, from its being one of the Indian stations at which observations of the Transit of Venus, on 1874 December 8th, were arranged to be made; and still more as a means of comparison between Madras and Greenwich, in conjunction with the similar operations by Drs. Becker and Fritsch, members of the German Transit of Venus Expedition to Ispahan … His observatory was connected by triangulation with that of the Great Trigonometrical Survey, on Bath Island, and the latter was found to be 0.60 second further West of Madras … It is surprising, that with only three clock stars at Karachi such accuracy should have been attained.

The *Proceedings* of the Asiatic Society of Bengal for December 1874 carried a note from Captain Campbell detailing the equipment and the transit observations proposed to be made at Roorkee by J.F. Tennant et al. (Asiatic Society of Bengal, 1875: 241-44). Campbell's communication is followed by the Society's *Note*, as follows:

> The Transit of Venus having taken place since the above was written it may be interesting to state before going to press that the Transit was successfully observed in India, by Col. Tennant's party at Roorkee where 107 six-inch photographs and 6 Janssen plates were taken, with favourable weather; at Lahore by Captain G. Strahan R.E.; at Masúri by Mr. J. B.N. Hennessey, who obtained some interesting results with the spectroscope; at the Surveyor General's Office, Calcutta, where 39 photographs and several eye observations were made; at Muddapur by a party of Italian astronomers under the direction of Sig. Tacchini, the distinguished spectroscopist, and at Kurrachee by General Addision. At Madras the weather proved unfavourable.
>
> Tidings of the observations have also been received from the parties scattered in various parts of the world, mostly satisfactory.

The Calcutta observations mentioned above by Airy (The transit of Venus, 1875) may not be the same ones as in the *Note* in the *Proceedings of the Asiatic Society of Bengal*.

4.6 Father Lafont's Observations

Founded in 1860, St Xavier's College in Calcutta made a seminal contribution to the promotion of science and technical education. The Belgian Father Eugene Lafont (1837–1908; Figure 11) of the Society of Jesus began working in 1875 to establish the first spectro-telescopic observatory at St Xavier's College, having joined the staff in 1865 when he came there to teach. In 1867 he established a meteorological observatory and participated in the expedition organized by the Italian astronomer, Pietro Tacchini (1838–1905; Figure 12), to observe the transit of Venus on 9 December 1874 from Muddapore (Madhupur) in Bihar. In the process Father Lafont discovered the presence of water vapour in the atmosphere of Venus (Biswas, 1994).

Tacchini had persuaded Father Lafont to establish an astronomical observatory at the College and in 1877 he installed an equatorially-mounted 23-cm Steinheil refractor and an 18-cm Merz equipped with a Browning spectroscope, and a coelostat, etc., in a 22-ft diameter rotating dome erected on a terrace at the school (Udias, 2003).

In November 1874 Father Lafont was joined at St Xavier's College by a mathematician and astronomer, Father Alphonse de Penaranda. Until his death in 1896 Father Alphonse participated in the astronomical observations made by Father Lafont. These included: the solar eclipse of 17 May 1882 (magnitude 0.48 at mid-eclipse at 08:45 UT in Calcutta); the Mars-Saturn conjunction of 20 September 1889; the 17 June 1890 annular solar eclipse observed from Bhagalpur (magnitude 0.973, annularity 3^{m} 27.9^{s}, post-meridian; values from *Eclipse Predictions by Fred Espenak, NASA's GSFC*); the 10 May 1891 transit of Mercury; and the occultation of Jupiter by a Full Moon on 6 October 1892.

Biswas (1994) details Father Lafont's scientific work at St Xavier's College, and his contribution with Dr Mahendralal Sircar (1833–1904) in founding the Indian Association for the Cultivation of Science in 1876.

Of the transit of Venus expedition to Muddapore, Father Lafont wrote:

> After all the careful preliminary arrangements, we were all anxiously awaiting the rising of the sun; anxiously, for though the weather had been excellent almost every day since the arrival of Professor Tacchini, the clouds two or three days before had caused the astronomers great fear and anxiety. From 4 O'clock all were up, gazing at the sky, and the sight was not quite reassuring, light but numerous clouds overspread the horizon, and assumed rosy tinges as the sun began to rise. Nothing daunted however the four observers, who each with his chronometers in hand, entered their respective observatories to prepare for work. (Biswas, 2003: 97).

Pietro Tacchini was the Director of the Palermo Astronomical Observatory. Pigatto and Zanini (2001) have described in detail Tachini's expedition to India. On the basis of the maps provided in the 1874 edition of Richard Proctor's book on the transit of Venus and input from the Italian Consul in Calcutta, he decided to observe the transit from Bengal. Muddapore (24º 17′ 0″.96 ± 0″.34 N and 5^{h} 46^{m} 20.570^{s} E), the place they chose for their observations, is 300 km north-west of Calcutta. The high costs involved in mounting an international transit of Venus expedition prevented them from having a second station for the purpose of determining the solar parallax, and so they settled on making spectroscopic observations in order to obtain exact contact timings. Tacchini was accompanied by Alessandro Dorna (1825–1886; Figure 13) from the Observatory of Torino, Antonio Abetti (1846–1928; Figure 14) and Antonio Cagneto from Padova and Carlo Morso from Palermo. Italy's leading expert on astronomical spectroscopy, Angelo Secchi (1818–1878), could not come because of health issues. Tacchini's team had four instruments that required revolving observatories.

Figure 12: Pietro Tacchini (after Macpherson, 1905: facing page 77).

Figure 13: Alessandro Dorna (courtesy: www.torinoscienza.it/accademia/personaggi/alessandro_dorna_20107.html).

Tacchini had an equatorially-mounted refractor furnished with a spectroscope, as also did Professor Abetti. Father Lafont and Professor Dorna also had equatorially-mounted refractors, but they would use these visually to record the contact timings with the aid of rated chronometers. Despite frustration caused by clouds, Lafont and Dorna were able to time both pairs of ingress and egress contacts. Near the start of the transit, the clouds dispersed and allowed the observers to attend to their assigned tasks. Tacchini diligently observed and found evidence of water vapour in the Venusian atmosphere, an observation that was corroborated by Abetti. These observations from India provided the first *spectroscopic* confirmation of the existence of an atmosphere around Venus.

The idea was to detect the presence of the planet over the red chromospheric emission by keeping the slit of the spectroscope tangential to the solar limb just as the former entered and exited the slit, and time it. Tacchini commented that "… before the second contact, Venus was visible over the chromosphere …" (see Pigatto and Zanini, 2001: 49). Father Lafont (Biswas, 2003) further says

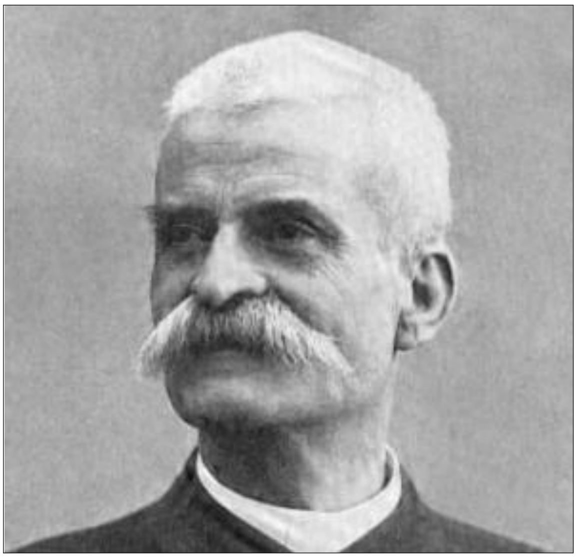


Figure 14: Antonio Abetti (courtesy: en.wikipedia.org).

> I may mention, before concluding, that Prof. Dorna observed the black dross both at ingress and egress, whereas not a trace of it was seen with the instrument I used, a German telescope by Starke, 52 lines aperture, and 6 feet focal distance. According to my results, the whole transit lasted 4 hours, 41 minutes, 1.5 seconds.

Tacchini and Abetti missed out on timing contacts 1 and 2 due to clouds, but what is remarkable is that between the five observers, spectroscopic contacts 3 and 4 occurred earlier than the telescopic ones. Tacchini concluded that when viewed through the spectroscope the Sun's diameter was smaller than seen visually in the telescope, a discrepancy that previously had been observed. In the following days, they measured the solar diameter visually and spectroscopically. The latter always turned out to be smaller, by an amount between 2.82″ and 4″ (Pigatto and Zenini 2001). Since the chromosphere lies above the photosphere, these observations are hard to reconcile with our current knowledge of solar physics.[6]

4.7 Transit Observations by Dr Mahendralal Sircar

Biswas (2003) mentions that Dr Mahendralal Sircar (Figure 15) also carried out telescopic observations of the transit. These may have been from Calcutta. At the insistence of Father Lafont, on 7 March 1874 Sircar acquired a telescope from a Dr J.N. McNamara. There is no information on the manufacturer or aperture of this instrument, which we can presume was a small refractor, except that it had an alt-azimuth mounting and five eyepieces: it was "… without equatorial … [and with] five powers …" (Biswas, 2000: 19). Apparently, Sircar would often observe planets with this telescope. Diary entries for the year 1882 also describe observations of a comet—which is not identified—but judging from the entries dating between 23 September and 9 October (see Biswas, 2000: 87) it must have been the Great Comet of 1882 (C/1882 R1) that even was visible during the day for part of this interval.

Observations of the transit of Venus listed in Sircar's diary (Biswas, 2000: 39), indicate that the total duration of the event was $4^h\ 37^m\ 30^s$, which is 3.5 minutes shorter than the duration reported by Father Lafont (see Table 1 in Pigatto and Zenini, 2001). Sircar's contact timings also differ from the corresponding ones of Father Lafont by between 7 and 10 minutes. Could Sircar have been so far off the mark? Maybe not. Tacchini's team did not use sophisticated equipment to time the transit, and they and Sircar may not have synchronized their chonometers. It is as well to remember that these observations date before British India adopted two time zones, with Calcutta using the 90º E meridian and Bombay the 75º E meridian. This scheme was only introduced in 1884, with Calcutta time set at GMT + $5^h\ 30^m\ 21^s$ and Bombay Time at GMT + $4^h\ 51^m$.

So what time system(s) did our transit of Venus observers use so that they could eventually match their observations? We cannot be certain, but we are inclined to believe that the various contact times recorded in Sircar's diary and reproduced here in Figure 16 are in local mean time. Notably, Sircar's times are consistently ahead of the Muddapore contact times (which were in Muddapore Local Mean Time).

The illustration which follows may therefore help. Calcutta local mean time (Greenwich Mean Time + λ/15º) is about $5^h\ 53^m$ ahead of GMT, so sunrise on 9 December 1874 was at 06:30 local mean time. If we factor in the longitudinal difference between Muddapore and Calcutta (~7 minutes), a more consistent set of contact times emerges, with the disparity in the respective contact times between Sircar and Father Lafont shrinking to within 3 minutes. In fact, the discrepancy decreases with each contact. The upcoming transit was a subject of great local interest (e.g. see Asiatic Society, 1873, 1875), and interactions with Father Lafont would have apprised Sircar of what to expect, and how to make meaningful observations and time the various transit contacts. We can only imagine that he viewed the transit through his telescope using a dark, coloured or smoked glass as a filter, or some sort of optical modification (e.g. a Herschel Wedge), or eyepiece projection, although Sircar does not specifically mention any of these. For one with a medical background who regretted that his telescope could not resolve Saturn's rings (Biswas, 2000: 27), we may judge that his account of the transit was a fair observation.

Interestingly, Father Lafont's own contact times also are consistently ahead of the predicted times by a similar magnitude, when we compare them with Espenak's (2012). Precision in computation of the circumstances apart, the fact is that to time exactly contacts 1 and 4 visually is very difficult, for both objective and subjective reasons. That is, because of the optical effects, namely atmospheric seeing and instrumental diffraction (e.g. see Proctor, 1882: 224); solar limb darkening (see Duval et al., 2005); and distortion of the silhouette of the planet's disk—the notorious 'black drop effect', these may seem to last from seconds to a minute (Maor, 2000: 95).

4.8 Nursing Row's Observations

As one keen to pursue astronomy with modern equipment, G. Venkata Jugga Row (1817–1856), an affluent *zemindar* (landlord), was a pioneer whose personal interest saw the erection of a private observatory in the backyard of his residence in Daba Gardens at Vizagapatnam in 1840 (see Figure 17) that continued to function under his descendants until the late nineteenth century. He acquired a Troughton transit circle and a chronometer, and the optics for a refracting telescope of 4.8 inches aperture and 5 feet 8 inches focal length telescope. Here, he carried out astronomical and meteorological observations, and he also determined the latitude and longitude of Vizagapatnam. On a nearby hill known as the Dolphin's Nose he installed a flagstaff to provide time signals for the public. Each day at 9 a.m. the flag was lowered, setting time for all who lived too far away to hear the report of the time-gun fired from the fort.

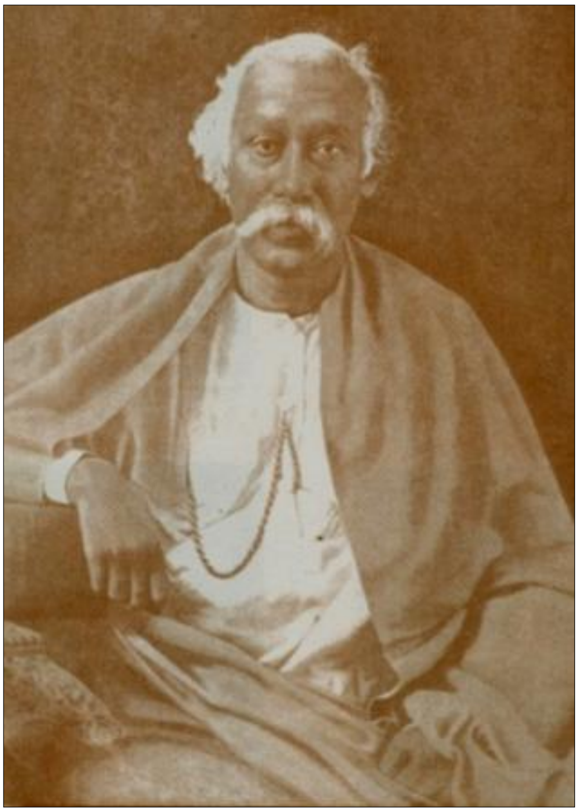
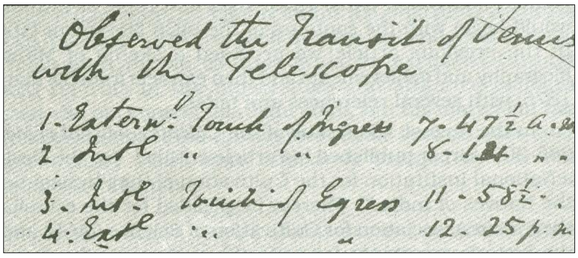


Figure 15: Dr Mahendralal Sircar (after Biswas, 2000: Plate 1).

Jugga Row had assisted Thomas Glanville Taylor (1804–1848), the Director of the Madras Observatory, in observing Halley's Comet (1P/1835) in 1835, and he independently published a paper in the *Madras Journal of Literature and Science* in 1836 where he determined the mass of Jupiter to be 302 times that of the Earth, using the motion of the Jovian satellites and Kepler's laws of planetary motion (Kameswara Rao et al., 2011). This figure is close to the modern value of 317.83 times the mass of the Earth (Allen, 1976: 140).

Subsequently, A.V. Narsinga Rao (1827–1892, Figure 18), who is better known by his Anglicized name of 'Nursing Row', inherited the observatory from his father-in-law, Jugga Row. Nursing Row then carried out astronomical and meteorological observations, and he maintained



Observed the Transit of Venus
with the Telescope
1. Extern: Touch of Ingress 7.47½ a.m
2 Intl " " 8.1[illegible] "
3. Intl Touching Egress 11.58½ "
4: Extl " " 12.25 p.m

Figure 16: Excerpt from Dr Sircar's diary (after Biswas, 2000: 39).

Figure 17: The private observatory that G. Venkata Jugga Row erected at Daba Gardens in Visakhapatnam. However, this photograph was taken in 1874 by which time the observatory was owned by Nursing Row, and it shows European and Indian observers of the transit of Venus (adapted from Rao et al., 2011: 1575).

a local time service. To observe the solar eclipse of 18 August 1868, he assembled the 4.8-in telescope whose optics the observatory already had. He then published his observations, at the same time establishing contact with the Astronomer Royal of Scotland, Charles Piazzi Smyth (1819–1900) and one of England's foremost authorities on astronomical spectroscopy, William (later Sir William) Huggins (1824–1910). When the Government discontinued firing the time-gun at the Dolphin's Nose in 1871 Nursing Row came forward and maintained it at his own expense.

Figure 18: A.V. Nursing Row (courtesy: http://www.avncollege.ac.in/).

After erecting the 4.8-in telescope Nursing Row observed the 5 November 1868 transit of Mercury and published a report in *Monthly Notices of the Royal Astronomical Society* (Nursing Row, 1869). His subsequent papers in this journal speak of a keen interest in and knowledge of astronomy. He also observed the solar eclipses of 12 December 1871, 6 June 1872 and 17 May 1882; transits of Mercury on 8 November 1881 and 10 May 1891. He also carried out some astrophotography with the telescope.

By the time he observed the 9 December 1874 transit of Venus Nursing Row had replaced the original telescope in the dome room with a 6-inch, clock driven, equatorially-mounted Cooke refractor of 7½ feet focal length. Clouds allowed him to observe only the last thirty minutes of the transit, but including both egress contacts (Nursing Row, 1875: 318). He noted that

> After the second external contact, when the limb of the Sun had resumed its natural appearance of an arc, a slight indentation was directly formed in the Sun's limb. This indentation was not so dense as that caused by the planet, but more or less tending to an ash colour, and was apparently greater in arc than the previous one.

Nursing Row recorded the contact times shown here in Table 4. He surmised that the indentation was perhaps caused by the atmosphere of the planet.

In 1871, Nursing Row was elected a Fellow of the Royal Astronomical Society and the following year of the Royal Geographical Society. Today the Dolphin Hotel, which was established in 1980, stands on the site of the observatory.

4.9 E.W. Pringle's Observations

As the transit of Venus drew near, the journal *Nature* commenced a regular coverage of the preparations being made to observe it, then after the transit the journal reported in successive issues on successful observations made at various places throughout the world, and also referred readers to accounts that appeared in *The Times* newspaper.

One of the communications *Nature* received about the transit was from Manantoddy (Mananthavady) in India. The observations in question were carried out by E.W. Pringle (The transit of Venus, 1875), who employed a small Cooke refracting telescope of 24 inches focal length and a 53× eyepiece. Pringle's account does not mention contact timings or the geographical coordinates of his site, merely stating that he was located nine miles from Manantoddy on top of an 800-feet high hill and an elevation of 3,600 feet above mean sea level. In van Roode's (2011) maps, the site is tentatively pinpointed, but with the rider that Pringle's description of his location is vague. This location is in the Wayanad mountain ranges, in Kerala, about 40 km from Mangalore.

Pringle was an engineer with the Madras Public Works Department. We note that previously he had participated in the expedition to Bekul (Baikul) in South Canara that Britain's solar physics pioneer Norman (later Sir Norman) Lockyer (1836–1920) organized to observe the total solar eclipse of 12 December 1871 (Maclear, 1872). The *Illustrated London News* (see Loney, 2013) carried pictures of the expedition taken by Mr McC. Webster, the Collector of South Canara, that were featured also in the 1 February 1872 issue of *Nature* (see The eclipse observations …, 1872). These showed the fort where Lockyer and Captain J.P. Maclear had installed their instruments, with the men all at their posts and ready. Also seen therein are Mr Henry Davis and Dr Thomas Thompson, a botanist carrying out photographic and polariscopic observations. What is interesting to note is

> … the 9¼ reflector constructed by Mr. Browning, with a mounting by Cooke, and the double refractor, consisting of two telescopes of six inches aperture, mounted on one of the universal stands prepared for the Transit of Venus observations in 1874, and lent by the Astronomer Royal." (The eclipse observations …, 1872: 268).

Pringle timed the transit with the aid of an ordinary watch. There is a brief account of his observations in his letter from Manantoddy, dated 13 December 1874, to *Nature* and published in the 14 January issue (The transit of Venus, 1875). It says that Pringle was expecting equipment from England but this did not arrive in time so he had to make do with the little 24-inch long refractor. The morning of 9 December was clear and weather perfect. Pringle missed the first ingress contact, but he continued watching the ingress for the second contact. Then, when half the disc had moved onto the Sun he saw the whole disc become visible where the portion exterior to the Sun's limb showed up rimmed by a "… fine silvery ring like a minute corona." The observation also was verified by Pringle's brother, and they saw the same thing happen at egress. Regarding the black drop effect, Pringle (The transit of Venus, 1875: 214-215) reports:

> As first internal contact approached I looked carefully for the 'black drop', but, to my astonishment, the horns of the sun grew nearer and nearer, and at last seemed to fade into the last portion of the before-mentioned silvery ring, without my seeing the smallest vestige of the far-famed 'drop', or any apparent elongation of the limb of the planet. Had it existed to the extent of one hundredth of the diameter of Venus, I am confident I should have seen it ...

Table 4: Nursing Row's egress contact times.

Contact	h	m	s
2^{nd} internal	16	47	15.4
2^{nd} external	17	15	27.2
Disappearance of the slight indentation	17	15	54.0

He also mentions an attempt to detect absorption bands from the atmosphere of Venus during the transit, but had to give up for want of sufficient power and "… the difficulty of keeping the slit of the stellar spectroscope fixed, on the planet, with altazimuth motion." (The transit of Venus, 1875: 215).

In its 17 December 1874 issue, where reports from diverse groups appeared, *Nature* (1874: 121-123) transcribed a telegram giving an account of Janssen's transit observations. The transcription read "Nagasaki, Dec. 9: Transit observed and contacts obtained. Fine telescopic images. No ligament. Venus seen over sun's corona …" Pringle's (1875) subsequent letter to the Editor of *Nature* brings out his grasp of the phenomena observed during the course of the transit, where (referring to *Nature*, 1875: 122), he contests Janssen's observation that "Venus was seen over the sun's corona before contact …", first asking, "… which contact, external or internal, is unfortunately not mentioned." He says that the idea of a rim of light around the disc of Venus being due to the solar corona has not found favour with others. To explain his point, Pringle (1875) presents a diagram showing Venus at first internal contact, as also at half immersion. He says that he did not see the retreating edge of Venus after the last external contact. In fact, referring to his diagram, he says he noticed a brighter spot on the lower limb of the planet at about half immersion that could have been due to the atmosphere of Venus being freer of cloud and thus refracted more light.

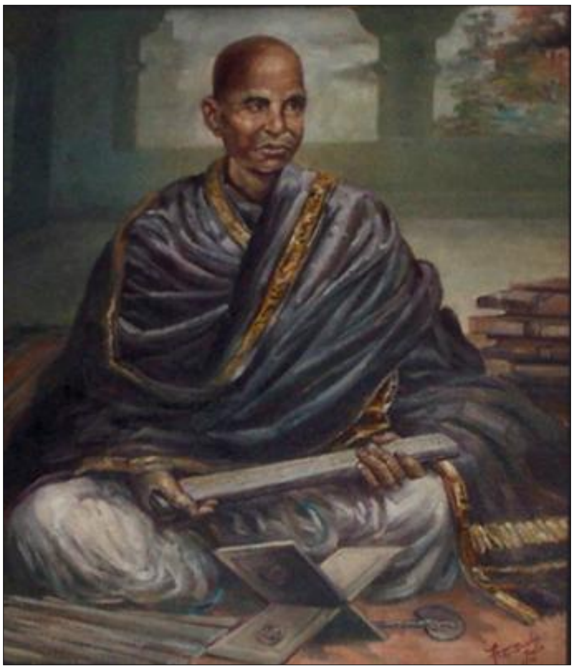


Figure 19: Samanta Chandra Sekhar Simha (http://www.iopb.res.in/~duryo/Samanta_Chandrasekhar/tn/Picture_1236.jpg.html).

4.10 Some Other Observations

Apart from Pringle's observations, *Nature* (The transit of Venus, 1875) mentions observations of the transit from some other places in the region. One of these was by George Wall from Colombo. A botanist and astronomer, George Wall (1820–1894) was a person of eminence in Ceylon (now Sri Lanka). As per the report, the observations recorded turned out to be similar to what Chappe d'Auteroche had made during the 1769 transit. Reporting on Wall's observations, the *Ceylon Times* (1875) remarked that "… it is clear that science will lose much from an incomplete discussion of all the observations made in 1761 and 1769."

The 'Notes …' (1875: 202) in the *Monthly Notices of the Royal Astronomical Society* about the 1874 transit of Venus cite places around the globe from which the Astronomer Royal received information that naked eye or photographic observations of the different phases of the transit were recorded. Places in India that he cited were: Indore, Calcutta, Kurrachee, Maddapore, Mooltan, Mussoorie, Roorkee and Umballa. Of these, we have not been able to obtain any information about the observations made at Indore and Umballa (Ambala).

5 SAMANTA CHANDRA SEKHAR AND THE 1874 TRANSIT OF VENUS

Samanta Chandra Sekhar Simha (1835–1904; Figure 19) from Odisha, popularly called Pathani Samanta, was a traditional *Siddhāntic* (theoretical) astronomer in a relatively modern age. He devised a number of instruments to carry out naked eye astronomical observations and gathered together his knowledge and experience in an invaluable tract, *Siddhānta Darpana*, which was written in Sanskrit. This work was published in 1899 by the Indian Depository in Calcutta (Naik and Satpathy, 1998). Chandra Sekhar's results compare well with the true positions and movements of the celestial objects, including their conjunctions etc., even though he had no exposure to modern scientific works or instruments (see for detail, Satpathy, 2003).

In the *Siddhānta Darpana* (XI, 110), Chandra Sekhar describes, in the stanza reproduced below in Figure 20, *Shukra* seen eclipsing the Sun in the Kali year 4975. Naik and Satpathy (1998) state that Chandra Sekhar predicted the eclipse from his computations and observed it with the naked eye. The observation may have been made from Khandapara in the Nayagarh district, where he was born. A translation of the stanza, by Upadhyaya (2012), follows:

> Solar eclipse due to *Sukra* (Venus) – To find the eclipse of the Sun due to *Sukra*, their *bimba* (angular diameter) and size of other *tara graha* (stars and planets nearby) is stated. In the Kali year 4975 (AD 1874) there was a Solar Eclipse due to *Sukra* (Venus) in *Vrischika Rasi* (Scorpio). Then *Sukra bimba* (Venus' shadow) was seen as 1/32 of the solar *bimba* (Solar shadow) which is equal to 650 *yojana* (a scale of several miles). Thus it is well proved that *bimba* of *Sukra* and planets are much smaller than the Sun.

To express numbers, Chandra Sekhar uses symbolical words, the traditional wont of Sanskrit scholars. The numbers for years and the size are

दृष्टं शुक्रस्य गाढास्तमचसमचजं मण्डलं चण्डभानौ कीटांशे पञ्चबिंशे गत बर्तिं कलितोहर्थाहद्रिगोहब्ध्यब्दबृन्दे ।
भास्वद् बिष्कम्भदन्तां शमितमित इदं खार्थषट् योजनं स्यात् । इत्यन्यजज्ञेयमस्मांत्तनब इन – तंनोस्तारका ः कोर्ग्रहा ः स्युः ।

Figure 20: Chandra Sekhar's description of *Shukra* seen eclipsing the Sun in the Kali year 4975.

given in reverse. To date the event, the conventional *Saka* year, or *Kalidina* (the number of days elapsed since a particular zero day—counted in Hindu astronomy from 17/18 February 3102 BCE when the astronomical *Kali* era commenced; see Somayaji 2000: 162) is not used. A description of this event which was unusual on all counts, and the timings of immersion (*sparsha*: touch) and separation (*moksha*) —which he would have deduced from computations, and possibly measured from observations —are not given.

Using *Solar System Live* (Walker, 2013), we get for Khandapara (20.26º N, 85.17º E) the Sun's altitude as 12.8º on 9 December 1874 when the transit commenced. By mid-transit (04:07 UT) it had reached 37.3º, and it was at 46.8º when the transit ended. From the Horizons System (Jet Propulsion Laboratory, 2012), we get the respective angular diameters of Venus and the Sun as 63.1″ and 1949.2″ at mid-transit, giving a ratio of 1/30.9. The word *danta* (dent) in Chandra Sekhar's stanza implies one of the 32 dents, and comes close enough when translated to mean 1/32 of the solar *bimba*. That is accuracy down to 1′, and is a remarkable result. Just how it is arrived at is not clear. If he had timed the events, say the ingress/egress, he had to know also the phenomenology beforehand. If it was from measurements with home-made instruments (Naik and Satpathy, 1998), we have no idea of their precision.

The *Sūrya Siddhānta* (ca. 400 CE - 12th Century; Burgess, 1860, VII: 13-14) defines the planetary diameter at the Moon's mean distance, where the brighter the object the greater the diameter. The unit used is *yojana*, a measure of distance. Its value is not standardised and different authors give different values in the classical Indian texts. Generally, it is taken to be equivalent to about 5 miles. Here, 15 *yojanas* make an arc minute and Venus is 4′, equivalent to 60 *yojanas*; Mars is similarly attributed 30 *yojanas*, etc. (see Burgess, 1860: 170). In the present observation, the planet, termed *bimba* in the translation, appeared as a black extended disc (on the *bimba* of the Sun) rather than a luminous disc. Chandra Sekhar assigns it a size again, also in *yojana*, and that must be the physical size. Chandra Sekhar could not have arrived at it without finding out the coveted distance. In the *Siddhāntas*, it is customary to express the circumference of a planetary orbit also in *yojana*. A distance to the Sun can then be deduced, where, ironically, one has to start from a certain value assigned to its orbital circumference, and the result turns out to be far less than the actual value (see Burgess, 1860: 126-127). One should refer to Naik and Satpathy (1998: 41) for the different values adopted in the various *siddhāntas*, including the *Siddhānta Darpana*.

At mid-transit, the modern computed true position of the Sun was λ = 257.0º (Horizons System). In the word *Keetāmsha* in the first line of the above-mentioned stanza, *Keet* stands for Scorpio, implying that the conjunction took place in Scorpio; *amsha* means part, but also 'degree'. The word *panchabinshe*, that appears next, means *25 of/in*. Taken as a phrase, *25 of/in Scorpio* implies that Chandra Sekhar probably meant the solar longitude to be 235º. That would be in the sidereal system, measured from a fixed Initial Point of the zodiac. From Chatterjee and Chakravarty (2000: 320-324), we learn of the attempts in the past by Indian classical astronomers to fix the position of the Vernal Equinox. These appear to have been made on three different occasions, circa 300 CE, 500 CE and 570 CE. It is not clear which one of the reference points Chandra Sekhar used. If it was the point 180º opposite the star *Chitrā* (Spica; epoch 1874.94 λ, β: 202.8º, –2.05º) which was fixed ca. 300 CE, we come very close to the computed tropical value of the longitude (the discrepancy is only ~0º.07) when we factor in the precession differential of Spica with respect to the position of the Vernal Equinox in 300 CE. Incidentally, this point was adopted in Varāhamihira's *Sūrya Siddhānta*, and possibly the founder astronomers of the *Sūrya Siddhānta* also used the same point (see Chatterjee and Chakravarty, 2000: 321). However, using ζ Piscium (epoch 1874.94 λ, β: 18.8º, –0.2º) as the Initial Point of the zodiac, fixed in ca. 570 CE, the corresponding position differs from the modern computed value for the longitude by 3.8º. We can imagine a consistency in Chandra Sekhar's computations, where the true position of Venus would match the true position of the Sun on the day so well that a transit would result. However, the longitude discrepancy translates into 4 days, a grave error that a *Siddhāntic* astronomer could not have committed. Chandra Sekhar's day of the event is, by implication, synchronized with the Gregorian date. Therefore, ζ Piscium as the reference is unlikely. We have also considered if by *'25'* he meant the *ayanamsha* (in degrees), the precession correction accumulated over a certain period since an initial epoch, that the Hindu astronomers needed to fix longitudes.[7] It may not be so; then the question is: why bring in an *ayanamsha* of 25º if one has merely to place the Sun in Scorpio?

With the Sun intense and high in the sky, how was the observation conducted? One may also like to question the precision of the instruments and their calibration where no standards were yet within sight, leading to astronomy of precision. As for timing the event, one can only wish that more than just the Kali year was given. These questions notwithstanding, what is commendable here is that Chandra Sekhar was able to recognize an unusual positioning of the planet —the *gāḍhāstamaya* (transit)—computed solely using the Hindu astronomical system, and then observe it. In a naked eye observation, it was rather unprecedented for a classical Hindu astronomer to witness a planet passing in front of the Sun, appreciate that it is an extended body and then express their relative sizes quantitatively. All this deserved more commentary from him. As an astronomer, Chandra Sekhar would know of the *Venus Pentacle*, but whether he realized the next such conjunction due eight years later in December 1882, and then worked out the circumstances, is not known. In the entire episode, we do find a keenness to confirm computations from observations that reminds us of Ibn Sīnā's observation of the transit of Venus in 1032 CE. We have worked out the phenomenology of the 1032 CE transit elsewhere (see Kapoor, 2013b) and parallels can be drawn.

6 CONCLUDING REMARKS: THE TRANSITS OF VENUS IN THE TWENTY-FIRST CENTURY

About the next pair of transits of Venus, Richard Proctor (1882: 231-32) concluded his book on a touching note:

> We cannot doubt that when the transits of 2004 and 2012 are approaching, astronomers will look back with interest on the operations conducted during the present 'transit-season;' and although in those times in all probability the determination of the sun's distance by other methods - by studying the moon's motions, by measuring the flight of light, by estimating the planets' weight from their mutual perturbations, and so on, will far surpass in accuracy those now obtained by such methods, yet we may reasonably believe that great weight will even then be attached to the determinations obtained during the transits of the present century. The astronomers of the first years of the twenty-first century, looking back over the long transitless period which will then have passed, will understand the anxiety of astronomers in our own time to utilise to the full whatever opportunities the coming transits may afford; and I venture to hope that should there then be found, among old volumes on their book-stalls, the essays and charts by which I have endeavoured to aid in securing that end (perhaps even this little book in which I record the history of the matter), they will not be disposed to judge overharshly what some in our own day may have regarded as an excess of zeal.

We are among the fortunate ones to have lived and experienced the transits of Venus in 2004 and 2012. Venus will next have a date with the Sun in 2117 on 11 December, and again in 2125, on 8 December.

7 NOTES

1. Some time after this eclipse the French physicist Jules Janssen (who had observed the event from Guntur) realized that the line was not associated with sodium, as he originally supposed, or with any known element. Lockyer then named it 'helium', after the source. It was only years later that the new element was isolated in the laboratory (see Nath, 2013).
2. As per international convention, in this paper contacts 1 and 2 refer to the first and second ingress contacts, and contacts 3 and 4 to the first and second egress contacts, respectively.
3. In most instances, the original spellings rather than the modern spellings are used here.
4. Various spellings of Ragoonatha Charry's name have appeared in print over the years. In this paper I have adopted the spelling of his name that Ragoonatha Charry used for his signature.
5. Near the time of the 2012 Transit of Venus the Indian Institute of Astrophysics brought out a reprint of the English edition of this pamphlet (see Ragoonatha Charry, 1874).
6. Professor Jagdev Singh from the Indian Institute of Astrophysics says (pers. comm., 2014):

   > … it is difficult to give a definite reason for this … result, [and] it might be a combination of the factors: (1) scattered light of the solar disc by the Earth's atmosphere dominating at the edge of the photosphere as compared to the chromospheric radiation that decreases exponentially with the distance from the edge of Sun; (2) the finite width of the slit; (3) the methodology of observations in defining the contact during the spectroscopic observations; and (4) scattered light in the instrument might affect the edge of Venus differently in the two cases.

   It is noteworthy that Tacchini's observations were never confirmed during any of the later transits, in 1882, 2004 or 2012.
7. The value for the precession rate Chandra Sekhar deduced was 57″.6/yr. Naik and Satpathy (1998: 42) mention that the year he used was sidereal, and correcting for the extra motion of the Sun over the tropical year, the rate came out as 49″.3/yr, which is much closer to the modern value of 50″.3/yr. To reach an *ayanamsha* of 25º, 1830 years should have elapsed since the reference epoch. In the context of classical Indian astronomy, the year 44 CE as the reference epoch does not quite fit. Also, it could not be the *Saka* era that is reckoned from the reign of the Kushana King Kanishka (r. 78-102 CE), i.e., 15 March 78 CE. The era came to

be used by Indian astronomers for astronomical calculations since the time of Varāhamihira and perhaps earlier (Saha, 1955: 255).

8 ACKNOWLEDGEMENTS

I am grateful to Dr Baba Varghese for his help with Figure 1 and to Professor Jagdev Singh, Indian Institute of Astrophysics (IIA), for discussions. I thank the Director of the IIA for permission to use material in the IIA Archives. I am grateful to Drs Christina Birdie and A. Vagiswari and the IIA Library for help in accessing various references. Discussions and email exchanges with Dr S. Balachandra Rao and Dr B.S. Shylaja were helpful. My sincere thanks are due to the Survey of India, Geodetic Research Branch, Dehra Dun, for permission to photograph the Hennessey Observatory and consult reference material there. I also wish to thank Professor Wayne Orchiston for useful comments that led to an improved manuscript. I am thankful to the Sanskrit scholar Brahmananda Vidalia for discussions about the Sanskrit stanza by Samanta Chandra Sekhar. I gratefully acknowledge having used the *Transit Predictions by Fred Espenak, NASA/GSFC.* Star positions were computed for different epochs from Chandra X-ray Center's *Coordinate Conversion and Precession Tool* (http://asc.harvard.edu/toolkit/precess.jsp). Certain references and pictures included in this paper have been gratefully adopted from websites, which are appropriately credited.

9 REFERENCES

Allen, C.W., 1976. *Astrophysical Quantities*. London, Athlone Press.

Bigg-Wither, A.C., 1883. Observations of the transit of Venus, 1874, December 8-9, as observed at Mooltan, Punjab, India. *Memoirs of the Royal Astronomical Society,* 47, 97-99.

Biswas, A.K., 1994. Reverend Father Eugene Lafont and the scientific activity of St. Xavier's College*. Indian Journal of History of Science*, 29, 77-88.

Biswas, A.K., 2000. *Gleanings of the Past and the Science Movement: in the Diaries of Drs Mahendralal and Amritlal Sircar*. Calcutta, The Asiatic Society.

Biswas, A.K. (ed.), 2003. *Collected Works of Mahendralal Sircar, Eugene Lafont and the Science Movement (1860-1910).* Kolkata, The Asiatic Society.

Burgess, E., 1860. *Surya-Siddhanta* (English translation). New Haven, The American Oriental Society (http://www.wilbourhall.org/).

Chatterjee, S.K., and Chakravarty, A.K., 2000. Indian calendar from Post-Vedic Period to AD 1900. In Sen and Shukla, 276-336.

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

D[reyer], J.L.E., 1892. Obituary: Norman R. Pogson. *Monthly Notices of the Royal Astronomical Society*, 52, 235-238.

Duval, M., Gendron, A., St. Onge, G., and Guignier, G., 2005. The Black-Drop Effect during the Transit of Venus on June 8, 2004. *Journal of the Royal Astronomical Society of Canada*, 99, 170-176.

Espenak, F., 2012. *Six Millennium Catalog of Venus Transits: 2000 BCE to 4000 CE.* NASA Web Site. (http://eclipse.gsfc.nasa.gov/transit/catalog/VenusCatalog.html).

Gill, D., 1878. Introduction. In Gill, Mrs. *Six Months in Ascension – An Unscientific Account of a Scientific Expedition*. London, John Murray (see: http://www.bweaver.nom.sh/gill/gill_intro.html).

Gosnell, C, 2012. The Bigg-Wither Family. http://ocotilloroad.com/geneal/bigg-wither1.html

Hennessey, J.B.N., 1873-1874. Particulars of the transit of Venus across the Sun, December 9, 1874, observed at Mary Villa, Mussoorie on the Himalaya Mountains ... In *General Report of the Operations of the Great Trigonometrical Survey of India, 1873-74.* Dehra Dun, Survey of India. Pp. 318-323,

Hennessey, J.B.N., 1874-1875. Some particulars of the transit of Venus across the Sun, December 9, 1874, observed on the Himalaya Mountains Mussoorie, at Mary Villa. Note II, with Appendix. *Proceedings of the Royal Society of London*, 23, 379-384 (Internet Archives: https://archive.org).

Hennessey, J.B.N., 1879. Further particulars of the transit of Venus across the Sun, December 9, 1874; observed on the Himalaya Mountains, Mussoorie, at Mary-Villa Station, Lat. 30° 28' N., Long. 78° 3' E., height above sea 6,765 feet, with the Royal Society's 5-inch Equatoreal. Note III. *Proceedings of the Royal Society of London*, 29, 297-302 (Internet Archives: https://archive.org).

H[ollis], H.P., 1910. J.B.N. Hennessey. *The Observatory*, 33, 315-316.

H[ollis], H.R., 1915. Lieutenant-General James Francis Tennant. *Monthly Notices of the Royal Astronomical Society*, 76, 272-276.

Jet Propulsion Laboratory, 2012. Horizons ephemeris system. JPL Solar System Dynamics. (http://ssd.jpl.nasa.gov/).

Kameswara Rao, N., Vagiswari, A., Thakur, Priya, and Birdie, C., 2009. C. Ragoonatha Charry and variable star astronomy. *Journal of Astronomical History and Heritage*, 12, 201-210.

Kameswara Rao, N., Vagiswari, A., and Birdie, C., 2011. Early pioneers of telescopic astronomy in India: J.V. Jugga Rao and his observatory. *Current Science*, 100, 1575-1581.

Kapoor, R.C., 2012. Venus in India: the Transit Tales. Indian Institute of Astrophysics website: www.iiap.res.in (http://prints.iiap.res.in/handle/2248/5757).

Kapoor, R.C., 2013a. Indian astronomy and the transits of Venus. 1: The early observations. *Journal of Astronomical History and Heritage*, 16, 269-286.

Kapoor, R.C., 2013b. Did Ibn Sīnā observe the transit of Venus 1032 AD? *Indian Journal of History of Science*, 48, 405-445.

Karbelashvili, A., 1991. Europe-India telegraph bridge via the Caucasus, *Indian Journal of History of Science*, 26, 277-281

Kochhar, R.K., 1985a. Madras Observatory: The beginning. *Bulletin of the Astronomical Society of India*, 13, 162-168.

Kochhar, R.K., 1985b. Madras Observatory – buildings and instruments*. Bulletin of the Astronomical Society of India*, 13, 287-302.

Loney, W., 2013. William Loney RN - Documents, The Illustrated London News, 10 January 1872, The eclipse expedition in India, http://www.pdavis.nl/Eclipse.htm accessed 09.04.2013.

Maclear, J.P., 1872. Captain Maclear's observations. *Nature*, 5, 219-221.

Macpherson, H., 1905. *Astronomers of Today and Their Work*. London, Gall and Inglis.

Maor, E., 2000. *June 8, 2004 Venus in Transit*. Princeton, Princeton University Press.

Markham, C.R., 1878. *The Indian Surveys. Second Edition*. London, W.H. Allen & Co. (Internet Archives: https://archive.org).

Monthly Notices of the Royal Astronomical Society, 74, 269-271 (1914).

Naik, P.C., and Satpathy, L., 1998. Samanta Chandra Sekhar: The great naked eye astronomer. *Bulletin of the Astronomical Society of India*, 26, 33-49.

Nath, B.B., 2013. *The Story of Helium and the Birth of Astrophysics*. New York, Springer.

Nature, 11, 121-123 (17 December 1874).

Notes. *Nature*, 7, 369-371 (13 March 1873) (http://digital.library.wisc.edu/1711.dl/HistSciTech.Nature18750114).

Notes on some points connected with the progress of astronomy during the past year. *Monthly Notices of the Royal Astronomical Society*, 35, 201-218 (1875).

Nursing Row, A.V., 1869. On the transit of Mercury over the Sun's disk on 5th Nov. 1868, as seen at Vizagapatam. *Monthly Notices of the Royal Astronomical Society*, 29, 278.

Nursing Row, A.V., 1875. Observation of the transit of Venus at Vizagapatam. *Monthly Notices of the Royal Astronomical Society*, 35, 317-318.

Orchiston, W., 2005. James Cook's 1769 transit of Venus expedition to Tahiti. In Kurtz, D.W. (ed.). *Transits of Venus: New Views of the Solar System and Galaxy.* Cambridge, Cambridge University Press. Pp. 52-66.

Pigatto, L., and Zanini, V., 2001. Spectroscopic observations of the 1874 transit of Venus: the Italian party at Muddapur, eastern India. *Journal of Astronomical History and Heritage*, 4, 43-58.

Phillimore, R.H., 1945-1968. *Historical Records of the Survey of India Eighteenth Century*. *Five Volumes*. Dehra Dun, The Surveyor General of India.

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

Pogson, N.R., 1861. *Proceedings of Madras Government Public Department*. Madras, Madras Government.

Pogson, N.R., 1884. *Telegraphic Determinations of Difference of the Longitude between Karachi, Avanashi, Roorkee, Pondicherry, Colombo, Jaffna, Muddapur and Singapore, and the Government Observatory, Madras*. Madras, Lawrence Asylum Press (Internet Archives: https://archive.org).

Pringle, E.W., 1875. The transit of Venus. *Nature*, 11, 306.

Proceedings Asiatic Society of Bengal January to December 1873. Calcutta, Baptist Mission Press (1873). (Internet Archives: www.archives.org).

Proceedings Asiatic Society of Bengal January to December 1874, Calcutta, Baptist Mission Press (1875). (Internet Archives: https://archive.org).

Proctor, R.A., 1882. *Transits of Venus*. London, Longmans, Green, and Co. (Internet Archives: https://archive.org).

Ragoonatha Charry, C., 1874. *Transit of Venus*. Reprinted 2012, Indian Institute of Astrophysics Archives, Bangalore.

Ragoonatha Charry, C., 1875. Reviews: *The Transit of Venus*. A discourse by C. Ragoonatha Chary, F.R.A.S., First Assistant Madras Observatory, Madras. *Astronomical Register,* 12, 69-71.

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

Royal Astronomical Society: Second Meeting after the Long Vacation, December 11th, 1874. *The Astronomical Register*, 13, 1-15 (1875).

Roode, S. van, 2011. Transits of Venus: 1639-2012. Map Display, www.transitofvenus.nl

Saha, M.N., 1955. *Report of the Calendar Reform Committee*. New Delhi, Government of India, Council of Scientific and Industrial Research.

Satpathy, L. (ed.), 2003. *Ancient Indian Astronomy and contributions of Samanta Chandra Sekhar*. New Delhi, Narosa Publishing House.

Sen, S.N., and Shukla, K.S. (eds.), 2000. *History of Astronomy in India. Second Revised Edition*. New Delhi, Indian National Science Academy.

Somayaji, A., 2000. The Yuga System and the computations of mean and true planetary longitudes. In Sen and Shukla, 162-207.

Strange, A., 1874. Transit of Venus. Colonel Tennant's Station at Roorkee, India. *Nature*, 11, December 17, 130-132.

Taylor, T.G., 1838. *Results of Astronomical Observations Made at The Honourable The East India Company's Observatory at Madras by T G Taylor*, *Volume IV. For the Years 1836 and 1837*. Madras, Madras Observatory.

Tennant, J.F., 1875a. Letter dated Roorkee, December 11, 1874. *Monthly Notices of the Royal Astronomical Society*, 35, 209-210.

Tennant, J.F., 1875b. On the dimensions of Venus as determined during the recent transit. *Monthly Notices of the Royal Astronomical Society*, 35, 345-347.

Tennant, J.F., 1877. *Report on the Preparations for, and Observations of the Transit of Venus, as seen at Roorkee and Lahore, on December 8, 1874*. Calcutta, Office of the Superintendent of Government Printing.

Tennant, J.F., 1882. An examination of the Roorkee observations of the transit of Venus, 1874, December 8. *Monthly Notices of the Royal Astronomical Society*, 42, 352-355 (Internet Archives: https://archive. org).

Tennant, J.F., 1910. Halley's Comet. *The Observatory*, 33, 297.

The eclipse observations at Bekul. *Nature*, 5, February 1, 265-268 (1872).

The transit of Venus. *Nature*, 11, 214-215 (1875) (http://digital.library.wisc.edu/1711.dl/HistSciTech.Nature18750114).

Transit of Venus. *The Astronomical Register*, 12, 116 (1875).

Udias, A., 2003. *Searching the Heavens and the Earth: The History of Jesuit Observatories*. Dordrecht, Kluwer.

Upadhyaya, A.K., 2012. Cited in *Nayagarh District,* *Eminent personalities* (http://nayagarh.nic.in/sonofsoil/ eminent person.html).

Walker, J., 2013. Solar System Live (http://www.fourmilab.ch/cgi-bin/Solar).

Dr Ramesh Kapoor began his career in 1971 at the Uttar Pradesh State Observatory (now the Aryabhatta Research Institute of Observational Sciences, ARIES) at Naini Tal in observational astronomy. From 1974 until 2010 he was with the Indian Institute of Astrophysics (IIA) in Bangalore where he worked on various topics in relativistic astrophysics. He also participated as an observer and organizer in a few IIA solar eclipse expeditions. His current interest is in the historical side of the lesser-known comet sightings and observations made from the Indian region. He is active in popularizing astronomy, and has also published on Indian systems of medicine.