VENUS IN INDIA[1]: ♀⊙ THE TRANSIT TALES

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ABSTRACT

This work is about sightings and astronomical observations of transits of Venus across the disk of the Sun 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 some individuals. Of particular interest is the 1761 transit, observed from top of the Governor's house, Fort St George, Madras by the Rev. William Hirst who made a significant observation – of having seen at the moments of ingress a nebulosity about the planet. That in fact is the discovery of atmosphere of Venus, duly recorded in his communication as presented in the *Vol.* 52 of the *Philosophical Transactions* of the Royal Society of London. The discovery of atmosphere of Venus has been attributed to Mikhail Lomonosov alone that he made during the same transit observed from the St. Petersburg Observatory.

Key words: transits of Venus, transit observations from India, discovery of atmosphere around Venus.

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INTRODUCTION

Transits of planets across the disk of the Sun are among the most fascinating phenomena in the Solar System astronomy. As seen from the Earth, transits of only Mercury and Venus are possible. These have held great importance in early telescopic astronomy when the transits enabled astronomers to determine, using triangulation, the solar parallax with an unprecedented accuracy and size up the Solar System.

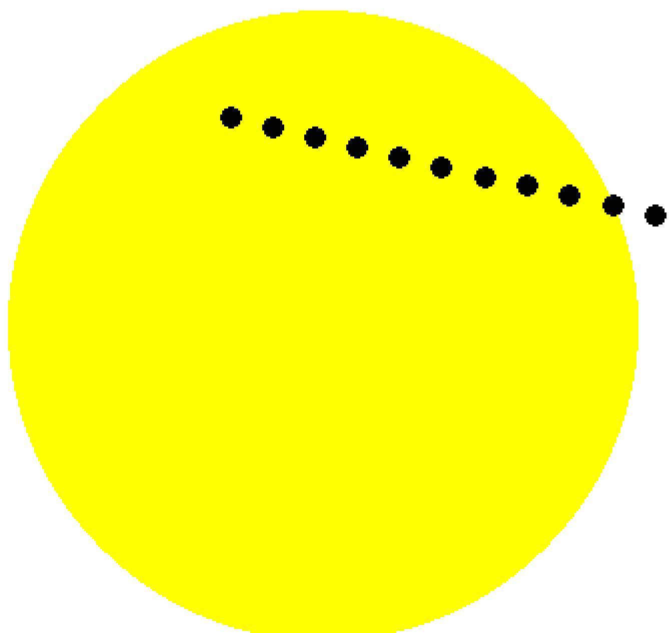
Transit of Venus (oil painting, artist not identified; http://s87767106.onlinehome.us/art/TransitOfVenus.jpg**)**

This is the story of Transits of Venus observed from India.

[1]After the Victorian classic of uninhibited love (Vol. 2) by Captain Charles Devereaux while he set out to free the Afghans from their oppressive warlords.

On the average, there are 13 transits of the planet Mercury in a century. As we look up the transit predictions tables by Fred Espenak (http://eclipse.gsfc.nasa.gov/transit/), all the transits of Mercury over a period of seven centuries between the years 1601 – 2300 CE occur, peculiarly, in the month of May or November. As the orbit of Venus (mean value 0.7233 AU) is much bigger than that of Mercury (0.3871 AU), a transit of Venus is even rarer. The AU, the *Astronomical Unit*, one may note, is one of the most basic units in astronomy. It is used to denote distances, particularly in the Solar System. It is the mean Sun-Earth distance, fixed today from direct ranging measurements and an elaborate planetary ephemeris-fitting, with an accuracy to within a few metres; the value used by the Jet Propulsion Laboratory in the computation of the ephemerides is 1.49597870691 x 10^8 km (JPL Solar System Dynamics: http://ssd.jpl.nasa.gov/). In its course, Venus passes in between the Earth and the Sun and a line-up takes place every 584 days (1.6 years; the time between two successive inferior or superior conjunctions). However, the transit does not always happen since the orbit of Venus is inclined at 3.39 degrees to that of the Earth and each time a line-up takes place, Venus is either above or below the disk of the Sun (the so-called inferior conjunction). In the event the line-up occurs at or very near a place where the orbits cross each other, the transit will happen.

A transit is difficult to notice since the planets are much smaller than the Sun in angular dimensions. Venus (6051.8 km mean radius) is bigger than Mercury (2437.6 km) in physical dimensions and is relatively closer to the Earth at the time of its inferior



Transit of Venus Jun 05-06, 2012; in India, the Sun rises with the transit in progress.
(picture generated from: http://transit.savage-garden.org/en/occultation.html**)**

conjunction. At that time, it has an angular diameter much bigger than that of Mercury. Even then, compared to the 31.5 arc min of the Sun (mean radius 695950 km), it subtends an angle of about 1 arc min only and while in transit, Venus will appear just as a small dot against the bright disk of the Sun. That is also the limit of detection by normal human eyes (20/20 vision). One is aware of claims to seeing sunspots naked eye. Venus in transit can be distinguished from a sunspot only because of its regular shape and the movement across, much faster than the Sun's rotation.

The transits of Venus number about 12 in a millennium. These have interestingly a 243-year repetition, with two transits in December, eight years apart, followed 121.5 years later by two transits in June, eight years apart. There have been seven transits of Venus since the invention of the telescope. There was no transit in the 20th Century after the last transit of Venus that took place a good 130 years ago, on December 06, 1882. In the 21st Century, the first of such lines-up happened on June 8, 2004 followed by the next on June 5– June 6, 2012 and visible over India.

The transit of Venus 1882, painted by Dupain on a dome in the Paris Observatory (1886); Copyright Paris Observatory; adopted from: http://old.transitofvenus.org/misc.htm

We reproduce below a short list of post-telescopic transits (*Transit Predictions by Fred Espenak, NASA/GSFC*):

	Transit Contact Times (UT)									
						Minimum	**Sun**	**Sun**		**Transit**
Date	**I**	**II**	**Greatest**	**III**	**IV**	**Sep.**	**RA**	**Dec**	**GST**	**Series**

	h:m	h:m	h:m	h:m	h:m	"	h	°	h	
1631 Dec 07	03:51	04:59	05:19	05:40	06:47	939.3	16.912	-22.64	5.045	6
1639 Dec 04	14:57	15:15	18:25	21:36	21:54	523.6	16.738	-22.34	4.888	4
1761 Jun 06	02:02	02:20	05:19	08:18	08:37	570.4	4.957	22.69	16.988	3
1769 Jun 03	19:15	19:34	22:25	01:16	01:35	609.3	4.805	22.44	16.842	5
1874 Dec 09	01:49	02:19	04:07	05:56	06:26	829.9	17.056	-22.82	5.182	6
1882 Dec 06	13:57	14:17	17:06	19:55	20:15	637.3	16.881	-22.56	5.025	4
2004 Jun 08	05:13	05:33	08:20	11:07	11:26	626.9	5.121	22.89	17.137	3
2012 Jun 06	22:09	22:27	01:29	04:32	04:49	554.4	4.969	22.68	16.991	5
2117 Dec 11	23:58	00:21	02:48	05:15	05:38	723.6	17.201	-22.97	.320	6
2125 Dec 08	13:15	13:38	16:01	18:24	18:48	736.4	17.026	-22.74	5.163	4

Through the period 5000 BCE to 10000 CE, the Earth is to witness 178 transits of Venus in all. As a mark of recognition of the transit of Venus 1882, in 1886 a dome in the Paris Observatory was painted by Dupain (1847-1933) in a distinct style, as shown here.

PLANETARY TRANSITS IN THE *SIDDHANTA*S ?

While discussing planetary conjunctions (*yuti*), some *Siddhantic* (astronomical) texts consider occultations (*bheda-yuti*) of planets also. In that event, the particular situation obtains when the longitudinal separation between two planets gets smaller than the sum of their radii with the lower planet covering wholly or partly the orb of the higher planet. The situation is then treated as akin to a solar eclipse and accordingly the computation is made for contact, immersion, emersion and separation. The *bheda-yuti* has been discussed by a few eminent astronomers, e.g., Vatesvara (b. 880 CE, Selin 1997), Bhattotpala (also Utpala; 966 CE) and Bhaskaracharya (Bhaskara II; 1114-1185 CE) (see, e.g., Mukherjee 1985, Ch. 8). Taking the Sun as the object being occulted, and assuming the occulting planet as the Moon, Vatesvara, Bhattotpala and Bhaskaracharya describe an elaborate procedure for the computation that enables one to examine if an eclipse like situation obtains and to determine the time of the apparent conjunction.

The planetary sequence in the *Aryabhatiya* (499 CE) is as follows: Earth - Moon – Mercury – Venus – Sun – Mars – Jupiter – Saturn – Fixed stars. Distinct from a usual *bheda-yuti* what can be only an extreme situation, did the astronomers also look at the more likely situation when the higher planet happened to be the Sun*?* To recall, Venus transited the Sun on Nov 23, 910 CE, beginning in India post-sunset but the event so ended that when the Sun rose at Ujjain, the egress was just getting over. The Indian astronomers knew inclination of the planetary orbits to the ecliptic. They did not factor these in their computations since the magnitudes were small. The only inclination that mattered was that of the Moon in respect of computation of the Lunar and Solar eclipses (see Mukherjee 1985, p. 163). If, in the course of computation and observation, one found that nodes exist and that with respect to the Sun a node is placed in longitude rather critically, a planetary transit situation could in principle be encountered.

In at least two *Siddhanta* texts, we find *planetary transits* considered as such by the respective authors and presented in independent chapters. *Dhruvamanasa,* written in 1056 CE by an astronomer and mathematician Sripati Mishra (1019-66 CE), is a text in

Sanskrit devoted to computation of planetary longitudes and eclipses (J J O'Connor and E F Robertson http://www-history.mcs.st-andrews.ac.uk/Biographies/Sripati.html 28.02.2012). This is the first Indian astronomical work where we find an author considering planetary transits also. Interestingly, Sripati was 13 when Venus transited the Sun in 1032 CE on May 24. The transit was not visible from India. However, the next transit that happened on May 22, 1040 CE was. Sripati's first work *Dhikotidakarana* was on lunar and solar eclipses, written in 1039 CE. So, working on the planetary longitudes and latitudes, it is likely he would stumble upon certain critical situations amounting to transit by a planet. Sripati's time is soon after Al-Beruni's visit to India though he may not have had knowledge of his work. The legendary Al-Beruni (973-1048 CE) of Khwarazm (in Greater Iran, now in Uzbekistan), who came over to India with Sultan Mahmud (971-1030 CE) of Ghazani (a place situated south-west of Kabul) and traveled far and wide between the years 1017-30 CE, was a great Persian scholar with command over astronomy and mathematics and medicine etc. and several languages. He made astronomical observations and determined latitudes and longitudes of many places with accuracy. His encyclopedic work *Ta'riq al Hind* (or *Kitab ul Hind*), now known to us as 'Al Beruni's India' (see tr. in Sachau 2003), bears this out that is a detailed description of the Hindu religion, mythology, customs, philosophy, geography and sciences of India. He discussed at length in his book works of Aryabhatta, Varahamihira and Brahmagupta.

The planet Venus transited the Sun next on Nov 23-24, 1153 CE. It is in these times the great Indian mathematician and astronomer Bhaskaracharya (Bhaskara II, 1114-1185 CE) lived too. He authored a number of highly acclaimed texts on mathematics and astronomy, such as *Siddhanta Shiromani* (composed 1150 CE). The event would not be visible from India. However, a people who followed motions of the planets, particularly around the times of heliacal rising and setting, and their conjunctions would know of the forthcoming inferior conjunction of Venus with the Sun (*astamaya* according to *Surya Siddhanta*). They would also learn that the paths critically cross as in the case of a solar eclipse. Even though he gave a procedure for computing *bheda-yuti*, we do not have any commentary specific to an event or situation (not even on the spectacular Halley's Comet that appeared in 1145 CE). Centuries later, in the times of the astronomer and mathematician Kamlakara (b. 1610), there occurred two transits of Venus, on Dec 7, 1631 (visible over India) and Dec 4, 1639. As David Pingree mentions, Chapter 12 in his tract *SiddhantaTatvaViveka* (composed in 1658 on the pattern of the *Surya Siddhanta;* Kamalākara." Complete Dictionary of Scientific Biography. 2008. Encyclopedia.com; accessed 10 Mar. 2012 <http://www.encyclopedia.com>) considers planetary transits. There are thirteen chapters in the tract where topics such as eclipses, mean motions of the planets, planetary diameters and distances and the heliacal rising and setting etc. are dealt with.

The king Vallalasena (Ballal Sena; r. 1158 CE) deserves mention here for his great interest in astronomy. He was a learned man who took observations, determined winter and summer solstices and considered celestial phenomena including comets in his tome *Adbhutasagara* that he began in 1168. He died before he could finish it. The work was completed by his son Lakshmanasena, the great military leader and ruler of Bengal (1122-1205 CE; ascended the throne in 1178; Majumdar et al 1989). *Adbhutasagara* is composed on the lines of *Brhat Samhita* and draws from Garga, Vruddha Garga, Parashara, Varahamihira, Yavaneswara, Brahmagupta and *Surya Siddhanta*, and even from the *Puranas*, the epics *Mahabharata* and *Valmiki Ramayana* etc. (Gorakh Prasad 1956, p. 205). He was aware of Venus-Sun and Mercury-Sun conjunctions, and about the *ayana* (precession) points he says he tested out himself. In the process, whether he encountered the peculiar Venus-Sun inferior conjunction of 1153 CE we do not know.

TRANSITS SEEN NAKED EYE?

In some historical records, instances have been cited suggestive of naked eye witnessing of the transits of Venus, for instance by the 16th century BCE Assyrians and by medieval Arab astronomers in the years 840, 1030, 1068 and 1130 CE, etc. No transit happened in any of the latter years and the sightings could be of sunspots only. The reader may find more on this in Johnson (1882) and in the article by Sten Odenwald (http://sunearthday.nasa.gov/2012/articles/ttt_73.php). Abu Ali Ibn Sina (Avicenna; 980-1037 CE), the renowned Persian natural philosopher, mathematician, physician, poet and prolific author of works ranging from philosophy to sciences and treatises on medical sciences has stated in one of his works to have seen Venus as a spot on the surface of the Sun. There indeed was a transit in the year 1032 CE. In comparison to the other pre-telescopic instances of sighting, we find Ibn Sina's observation to be relatively convincing and amenable to some exploration (Kapoor 2012, work in preparation).

THE TRANSITS OF VENUS IN THE 17th CENTURY

After the telescope, the first of the transits of Venus as predicted by Johannes Kepler (1571-1630 CE) happened on Dec 7, 1631 CE. The French astronomer Pierre Gassendi (1592-1655 CE), who had already watched the transit of Mercury on Nov 7, 1631, tried to observe the transit of Venus the following month from Paris but did not succeed. The accuracy of the prediction in Kepler's *Tabulae Rudolphinae* of 1627 on the one hand, the Contact IV was already over at 06:47 UT before the Sun rose at Paris (sunrise 07:34 UT). Looking through Kepler's tables, the British astronomer Jeremiah Horrocks (1618-41 CE) deduced that there was yet another transit situation, due to fall on Dec 4, 1639 CE. He was able to observe it in Liverpool, as also his friend William Crabtree based in Salford. It was James Gregory in 1663, and later Edmund Halley in 1691, who proposed that one should be able to determine solar trigonometric parallax and deduce an unprecedentedly precise measure of distance to the Sun from the timings of ingress and egress of the transit of an inner planet when observed from different locations on the Earth. Halley died in 1742 CE.

The next transits of Venus were to happen in 1761 and 1769. As the time drew near, the forthcoming transits evoked great scientific interest in Europe to observe these from different parts of the globe. The transits were observed from many observatories in Europe. In addition, many expeditions were mounted to diverse places with a view to gain long baselines. What then followed is history, and well documented, vide Kurtz (2004) and http://www.transitofvenus.nl/history.html.

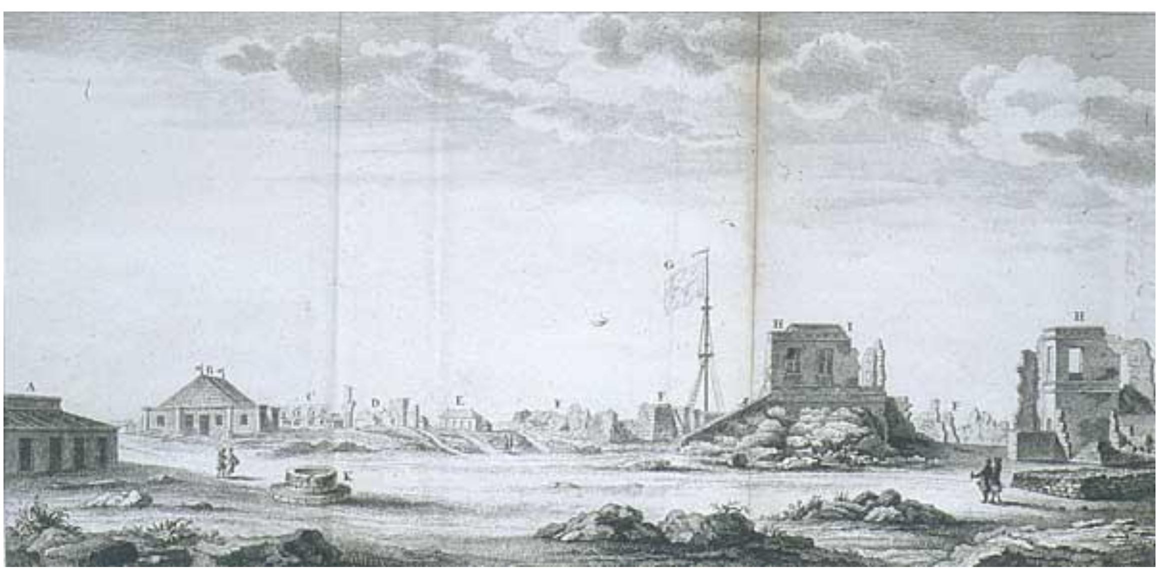
THE TRANSITS OF VENUS IN THE 18th CENTURY

The transit of Venus 1761

In London, the Royal Society made plans to observe the transit of 1761. One of its expeditions with Nevil Maskelyne (1732-1811) who later rose to become the Astronomer Royal went over to the island of St Helena. The other expedition with Charles Mason and Jeremiah Dixon mounted to go over to Sumatra observed it from the Cape of Good Hope. The French had prepared for four expeditions, namely, to Siberia, Vienna and to the southern locations. Astronomer Alexandre Gui Pingrè (1711-96) went over to the island of Rodriguez in the Indian Ocean, about 1300 km east of Madagascar while Guillaume Le Gentil (1725-1792) proceeded to India.

Guillaume Le Gentil a French astronomer originally set sail in 1760 to come over to India to follow the transit of Venus of Jun 6, 1761 from Pondicherry then in French possession. Le Gentil who had been inducted into astronomy by Jacques Cassini at the Paris Observatory at a young age and grew to be a dedicated astronomer was in the French expedition that was part of an international collaboration for the purpose. Caught in the Seven Years' War between two European superpowers the French and the British, he could not make it for on May 24, 1761, when they were off the Malabar coast, he came to know that the British had taken Mahe and Pondicherry (Proctor 1882, p. 55). He had to return to the Isle de France (now Mauritius). It was on his way, between Point de Galle that he touched on May 30 and the Isle de France where he arrived on June 23 that he observed the transit from a moving ship, with an objective of fifteen feet focus, and timed the contacts, and a total duration of 8h27m56 1/2s (*The New York Times*, 1874).

Disheartened but not giving up having ventured so far from France, Le Gentil knew that the next transit was due on Jun 4, 1769 and so determined to stay around and observe it.



The ruins of Pondicherry in 1769 seen from the north. Le Gentil set up his observatory in the ruins of the former Governor's palace, in the structure to the right of the flag pole (picture from www.transitofvenus.nl/history**)**

The intervening period spent in Isle de France, drifting and sails was sufficiently trying but he eventually returned to Pondicherry on Mach 27, 1768, well in time to be able to observe the transit that to his misfortune was clouded out.

Hogg (1951) in her four-part-essay presents us a wonderful peep into the life and travails of Le Gentil from his memoirs in French. He published in 1782 a detailed account of his expeditions in two volumes, namely, '*Voyages dans les mers de l'Inde fait par ordre du roi, à l'occasion du passage de Vénus sur le disque du soleil le 6 juin 1761, & le 3 du même mois 1769*'. She calls his eleven-year voyage to the Indian Ocean to observe the transits of Venus of 1761 and 1769 as the longest lasting astronomical expeditions in history. Pondicherry in the mean time had its own tryst with the French and the British. When he landed, it was under French occupation. M Law, the Governor General for the King of all the French establishments in India, accommodated him well and asked him to go around next day, find a suitable site and build an observatory. Hogg (1951) reproduces the original drawing of Le Gentil's observatory that was got ready by June 11 and equipped. She also mentions that it was the British of Madras who provided Le Gentil with an excellent telescope, an achromatic three feet long to observe the transit. Here he began with determining precisely the latitude and longitude of Pondicherry and in the course of his work had an exposure to Indian astronomy. He marveled at the fine art of eclipse calculations by the locals and even tried to learn it. A local Tamil Brahmin computed for him in three quarters of an hour's time using shells, and tables from his memory, the circumstances of a lunar eclipse of Aug 30, 1765 that Le Gentil had

Le Gentil (1725-92);
(http://avelinom.files.wordpress.com/2011/01/le-gentil1.jpg)

observed from elsewhere. Upon cross checking with the tables of Tobias Mayer then considered the most accurate, he was astonished to find the Tamil giving the eclipse duration short by only 41 sec, in contrast to Mayer's tables that gave a duration longer by 68 sec. Le Gentil found computation of solar eclipses much more difficult to comprehend and master. As we get it from Banerjee (1920, p. 157), it was Tamil Brahmins of Trivalore (near Tanjore) from whom he learnt the art and 'they communicated to him their tables and rules which were published by Le Gentil as the "Tables of Trivalore", in the memoirs of the Academy in 1772'. One wonders what the Tamil astronomers had to comment on the planetary transits Le Gentil was virtually laying down his life for.

On the other side, the British too had prepared for and had observed the two transits from various locations in India. The 1761 transit was observed from top of the Governor's house, Fort St George, Madras by an astronomer the Rev. William Hirst (Hirst 1761-1762) with a

'reflecter 2 feet long, made by Mr. Adams, of Fleetftreet, London, and lately fent, as a prefent, by the Eaft India company, to the Nabob Mahommed Allah Cawn, of whom the Governor Pigot was fo kind to borrow it, on this occafion. The governor himself, and, alfo Mr Call, a very ingenious gentleman, affifted in the obfervation; the former with a 4 feet reflecter, of Mr Dolond's new conftruction, the latter with a 2 feet reflecter, formerly belonging to Dr. Mead'.

The time of beginning as calculated by the Jesuits for *Pondichery* was 6h 57m. The London calculations reduced to the meridian of the Fort St. George (taken as 13º 8' N and 3' 4" east of Pondichery) gave 7h 26m 35s apparent time. The timings they noted are 7h 31 10 and 7h 47m 35s (ingress) and 1h 39m 38s and 1h 55m 44s (egress) apparent time. As 'William Hirft' wrote his communication to 'the Right Honourable, the Earl of Macclesfield, Prefident of the Royal Society, Dated Fort St. George, 1ft July, 1761', he made a significant observation – of having seen at the moments of ingress a nebulosity about the planet. The relevant part in the communication (Hirst 1761-1762) reads thus –

'The morning proved favourable to the utmoft of their wishes, which the more increafed their impatience. At length, as Mr Hirft was ftedfaftly looking at the under limb of the Sun, towards the fouth, where he expected the planet would enter, he plainly perceived a kind of penumbra, or dufky fhade, on which he cried out 'tis a-coming, and begged Mr. Call to take notice of it. Two or three feconds after this, namely, at 7^{h} 31' 10" apparent time, happened the firft exterior contact of Venus with the Sun, which all the three obfervers pronounced the fame inftant, as with one voice. Mr. Hirft is apprehenfive, that to be able to difcern an atmofphere about a planet at fo great a diftance as Venus, may be regarded as chimerical; yet affirms that fuch nebulosity was feen by them, without prefuming to affign the caufe. They loft fight of this phenomenon as the planet entered the difk, nor could Mr. Hirft perceive it after the egrefs.'

That in fact is the discovery of atmosphere of Venus, and independently so. The discovery of atmosphere of Venus has been attributed to Mikhail Lomonosov alone that he made during the same transit observed from the St. Petersburg Observatory (see Mikhail Marov's paper in Kurtz 2004 for details on Lomonosov's observations). The assertion by the Rev. Hirst on this aspect has remained neglected. In the glare of the Sun, the approaching planet can not be seen but it is possible to see its atmosphere that begins to be back-illuminated by the Sun between the Contact I and Contact II. That apart, William Hirst also mentions seeing at the time of ingress the planet assuming shape of a bergamot pear, with the preceding limb of the disc very well defined what is known as the black-drop effect. He tried to rectify a possible defect by checking the focus of his instrument several times but was convinced as the same effect was seen at the time of egress also. It should be borne into mind that to exactly time the Contacts I - IV is very difficult, for both objective and subjective reasons. That is because of the optical effects, namely, atmospheric seeing and instrumental diffraction, vide Proctor (1882, p. 224), and the solar limb darkening, see Duval et al (2005), distorting the silhouette of the planet's disk - the black drop effect, that may seem to last from seconds to a minute (Maor 2000, p. 95). One can find a brief biography of the Rev. William Hirst at http://en.wikisource.org/wiki/Hirst,_William_(DNB00).

From Calcutta, the 1761 transit was observed by Mr William Magee. He noted that the total ingress began at 8 20 58 hours and the egress began at 2 11 34 hours post meridian. As Proctor (1882) notes,

'At Madras, Mr. Hirst, and at Calcutta, Mr. Magee (whom M. Dubois converts into Magec) observed the duration of transit, obtaining respectively the periods 5 h. 51 m. 43 s., and 5 h.50m. 36 s., values which differ much more from each other than parallax will account for'.

From the Court of Directors of the East India Company, William Magee's contribution was communicated to the Royal Society by Charles Morton, M.D., F.R.S. which appeared in the Vol **52** (1762, p. 582-583) of the *Philosophical Transactions* (published in 1763). He had noted the timings with a 'ftop-watch of Mr. Elicott's, having no pendulum-clock or time-piece'. For several days, the weather had been cloudy that disallowed determination of errors of the watch. On the day of observation, he compared its reading with 'a meridian line in the town-hall', and did so on the 7th, 8th and 9th June as well while the Sun was on the meridian.

The transit of Venus 1769

For the next transit that happened on Jun 4, 1769, observations were planned to be carried out from places far apart and astronomers traveled long distances. In 1768, the Royal Society petitioned King George III to organize scientific expeditions to observe the forthcoming transit of Venus. Thus, the most famous expedition was undertaken to Tahiti by James Cook (1728-1779) who was specially promoted to the position of *Liutenant* and given command of the HM Bark Endeavour, with Charles Green as the official astronomer and Joseph Banks the other astronomer on board (see James Cook - Papers, 1768-1773, State Library, New South Wales, http://acms.sl.nsw.gov.au/item/itemDetailPaged.aspx?itemID=440400). Expeditions were also sent to Ireland, Cornwall, Norway and Hudson's Bay.

In India, the transit was observed from Dinapoor (25º 27' N) by Capt Luis Degloss, Captain of Engineers (Degloss 1770), and from 'Phesabad, lat. 25º 30' north' by Capt Alexander Rose of the 52d Regiment (Rose 1770). Capt Degloss had made his observations with three Quadrants and a reflecting telescope. At sunrise it was cloudy but at 5h 20m 32s, 'the Sun disengaged from the clouds when Venus appeared on the ☉'s disk'; he timed the beginning of the egress at 7 5 22 hrs, end of the egress 7 23 36 hrs.

With a telescope and a stop-watch, Capt Rose observed the transit when it was in an advanced stage. He saw the egress and measured at the moment of egress, the timings of the first (at 6 52 25 hrs) and the last contacts (7 10 47 hrs) (the Contacts III and IV respectively), their interval being 18 min 22 sec.

Le Gentil writing in his memoirs on the sky conditions states also about a Mr Call who was stationed at Madras to observe the transit (Hogg 1951):

'There was the same thing at Madras, where Mr Call, chief engineer of that place, had been commissioned by N. Maskelyne to make the observations…..The observers were sleeping tranquilly when they were awakened by a most abundant rain and by a gusty wind, which carried off the tent and upset a part of their instruments….. This whirlwind was felt along the coast of Coromandel for more than thirty leagues advancing along the land of the peninsula'.

Recall that Mr (John) Call had assisted the Rev. William Hirst during the earlier transit observed from the Fort St George, Madras. Back home, the Reverend himself observed the 1769 transit from Greenwich. His communication (Hirst 1769) on the transit observations makes for an interesting reading where he re-affirms his impressions about the existence of an atmosphere around Venus even though this time over he says he could not take notice of it:

'….when I took the obfervation of the tranfit of Venus at Madras, in the year 1761, I faw *a kind of penumbra or dufky fhade, which preceded the firft external contact two or three feconds of time, and was fo remarkable, that I was thereby affured the contact was approaching, which happened accordingly….*I may venture to fay, that my obfervation of the tranfit of the prefent year feems to corroborate my affertion, in the account of the tranfis obferved in India, in 1761'.

In the same communication, William Hirst (1769) also reproduces an extract of his original letter from India to Lord Macclesfield that was not published then and was about his looking for a satellite of Venus during the transit of 1761. Before the transit, he came across in the *Philosophical Transactions* an observation of a stellar object observed by a Mr Short near Venus giving rise to speculation that the planet had a satellite. As the Rev. Hirst writes,

"…A corroborating circumftance was added, viz, M. Caffini, in his *Elements d'Aftronomie*, mentions a like obfervation. This I regarded as a favourable opportunity, concluding, that if Venus had a fatellite, it muft be feen at its tranfit over the Sun's difc; accordingly, I gave notice of this to Captain Barker, of the Company's Artillery" (now Colonel Sir Robert Barker), "who took the obfervation at Pondicherry. I alfo mentioned it to the Jefuits, who obferved at the Great Mount, about 7 ½ miles S. 50 ºW. of Madras, but neither of them faw any appearance in the leaft like a fatellite. I alfo fpoke of it to Governour Pigot" (now Lord Pigot), "and Mr. Call, who with myfelf faw not the leaft fpeck attending that planet; whence we may now venture to affirm, *That Venus has not a Satellite*".

The *Transit of Venus* Opera

With great interest, we note that there is an opera *Transit of Venus* inspired by Le Gentil's fateful expeditions. It is in three Acts based on a play of the same name by the Canadian playwright Maureen Hunter and presented as 'a love story that charts a celestial course between destiny and desire' (http://www.manitobaopera.mb.ca/operas/transitofvenus.html). The opera was first produced in November 1992 at the Manitoba Theatre Centre. Its theme in brief is as below:

‘The opera explores the question of achieving your potential or being with the people you love. It follows the play’s storyline and tells of Le Gentil’s passion for what he believes is his destiny (astronomy) and Celeste’s unconsummated love for him. He and Celeste are engaged, but his quest to chart the transit of Venus takes him far from home, first for six years and then for another five years. Believing Le Gentil to be dead, Celeste turns to his assistant, Demarais for comfort and ultimately the love she so longs for. When Le Gentil finally returns, he tries to explain that he realizes his destiny to be with her, but she has moved on with her life. In the end, Le Gentil has failed in both tracking his heavenly love (Venus) and his love here on Earth’.

In his memoirs, Le Gentil put his impressions thus (Hogg 1951):

‘That is the fate which often awaits astronomers, I had gone more than ten thousand leagues; it seemed that I had crossed such a great expanse of seas, exiling myself from my native lands, only to be the spectator of a fatal cloud which came to place itself before the Sun at the precise moment of my observation, to carry off from me the fruits of my pains and my fatigues…. I was unable to recover from my astonishment, I had difficulty in realizing that the transit of Venus was finally over…’

(http://www.manitobaopera.mb.ca/transitofvenus/transitofvenus.html)

When the time of the 1874 transit drew near and the excitement began, *The New York Times* published in its July 25, 1874 edition Le Gentil’s life history, from the articles of M.W. De Fonvielle in *La Nature*, that brought forth his travails of the period 1760 to 1771 and his observations in more detail. The story revealed how he had been superseded in the Academy of Sciences (he *was* reinstated subsequently) and his property usurped back in France in his absence where his death had been announced many times (The New York Times 1874). Transit-expeditions apart, Le Gentil’s name remains etched in history

- credited with the discovery of a few deep sky objects such as the companion to the Andromeda galaxy, the Lagoon Nebula etc. and in 1961 honoured by a crater on the Moon named after him (http://messier.seds.org/xtra/Bios/legentil.html).

THE TRANSITS OF VENUS IN THE 19th CENTURY

The transit of Venus 1874

The 1761 transit produced solar parallax values that ranged from 8".28 to 10".6. In the 1769 transit observations, the value improved but ranged from 8".43 to 8".80. The last figure came close to the modern value (8."794148). The divergence in results implied large differences in the value of the distance to the Sun. That did not satisfy the astronomical world (see for more detail, Wayne Orchiston's paper in Kurtz 2004). The astronomers looked forward to the next transit pair, falling in 1874 and 1882. By this time, the techniques for angular measurements and geo-positions and instrumentation had improved while the Solar System itself had grown bigger with the discovery by Sir William Herschel of Uranus on March 13, 1781 and of Neptune on September 23, 1846 by Johann Galle and Heinrich d'Arrest. The coming transits of Venus gave rise to an excitement and scientific activity of even greater magnitude, all over. Simon Newcomb worked on the four transits results and came up with a value of 8".794 for the parallax.

In India, the transit of Dec 9, 1874 was observed from several places. As for the next one, the Sun had already set when the Dec 6, 1882 transit began; Contact I at 18:52:57 hrs (GMT+5:30) while the Sun had set; at Madras sunset time 17:40 hrs (GMT+5:30). The circumstances of the 1874 transit are as follows:

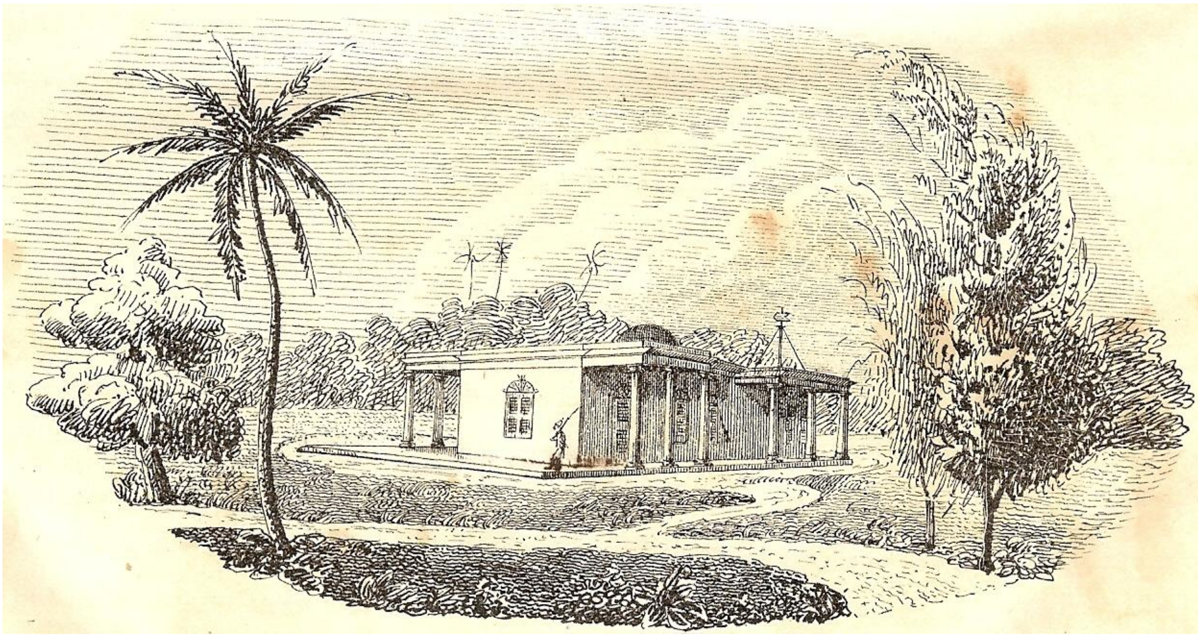
	Transit Contact Times (UT)									
Date	**I** h:m	**II** h:m	**Greatest** h:m	**III** h:m	**IV** h:m	**Minimum Sep.** "	**Sun RA** h	**Sun Dec** ° h	**GST**	**Transit Series**
1874 Dec 09	01:49	02:19	04:07	05:56	06:26	829.9	17.056	-22.82	5.182	6

The Madras Observatory made elaborate arrangements to observe the transit. However, for most part of the event, clouds frustrated the preparations. The Observatory has no publication about the observations except for a brief account that forms part of the Administration Report of the Madras Observatory for the year 1874 and Pogson's letter to *Astronomy Register* (1875, vol. 1**3**, p. 116). Let us first have a glimpse of some history.

The Madras Observatory

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 (d. 1816), an officer with the East India Company**.** The first observation on record, on the p. 164 of the MS Observations at the IIA Archives, dates 5 December 1786 and pertains to the determination of the coordinates of Masulipatam Fort Flagstaff from such observations. In 1789, the East India Company took over Petrie's observatory and it was shifted in 1792 to its new premises at Nungambakkam, designed by the Company's new Astronomer and Marine Surveyor Michael Topping (1747-96), and renamed Madras Observatory.

In his work ‘A Memoir on The Indian Surveys’, the noted geographer Sir Clements Markham (1878, p. 323-341) had thus to say for the Observatory – ‘The Madras



The Madras Observatory at Numgambakkam (from the cover of the volume IV of Taylor, 1838a; IIA Archives).

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

The Madras Observatory, Numgambakkam, during 1860-90 (IIA Archives).

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'. The Director referred to above is Norman R Pogson (1829-1891), in the seat since 1861 and until 1891. The Madras Observatory eventually evolved to the present day Indian Institute of Astrophysics. For a good detail on the Observatory's history, see Kochhar (1985a, 1985b).

Norman Pogson (1829–1891), who was Director from Feb 1861 until his death (Jun 23, 1891), started his career as an astronomer at George Bishop's South Villa Observatory where he trained under J.R. Hind. There followed fruitful days at the Radcliffe Observatory in Oxford from the close of the year of 1851 and at the Hartwell Observatory, beginning Jan 1, 1859. Although his name is well known as the 'founder' of the modern definition of the logarithmic magnitude scale (see Pogson 1856 *MNRAS* **17**,12-15), while at the Madras Observatory, he also discovered with the new eight inch Cooke equatorial five asteroids and seven variable stars. At Madras, he also re-discovered the lost asteroid Freia (1892 *MNRAS* **52**). In addition, his assistant C Ragoonatha Charry (1828-80), made a notable astronomical discovery in Jan 1867 that R Reticuli was a variable star (Markham 1878, p. 333-4; see, also, Kameswara Rao et al., 2009). Pogson was honoured with the Lalande Medal for his discovery in 1856 of the asteroid Isis (42) (that he had named after his daughter), a lunar crater in his name and an asteroid (1830) Pogson. In 1860 he

The Madras Observatory Monument (RCK: July 2011)

was elected a Fellow RAS and created on Jan 1, 1878 a Companion of the Indian Empire. One can find more on Pogson in 1892 *MNRAS* **52**.

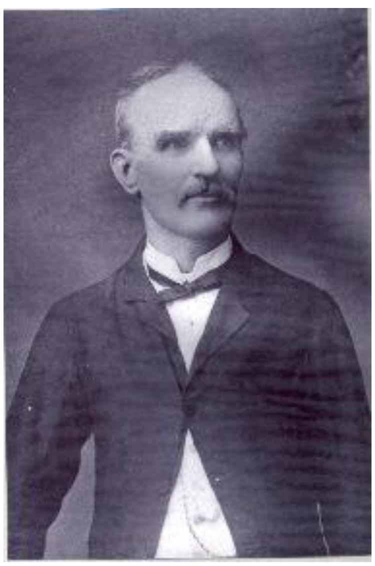
Pogson's Report on the transit of Venus 1874

Well before the transit of Venus was to take place, Pogson was concerned that it be observed from more stations in India. The following is from the *Notes* in *Nature*, March 13, 1873, p. 369-71:

'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 episode and comments form part of the Administration Report of the Madras Observatory for the year 1874 (IIA 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 equatorial 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….'

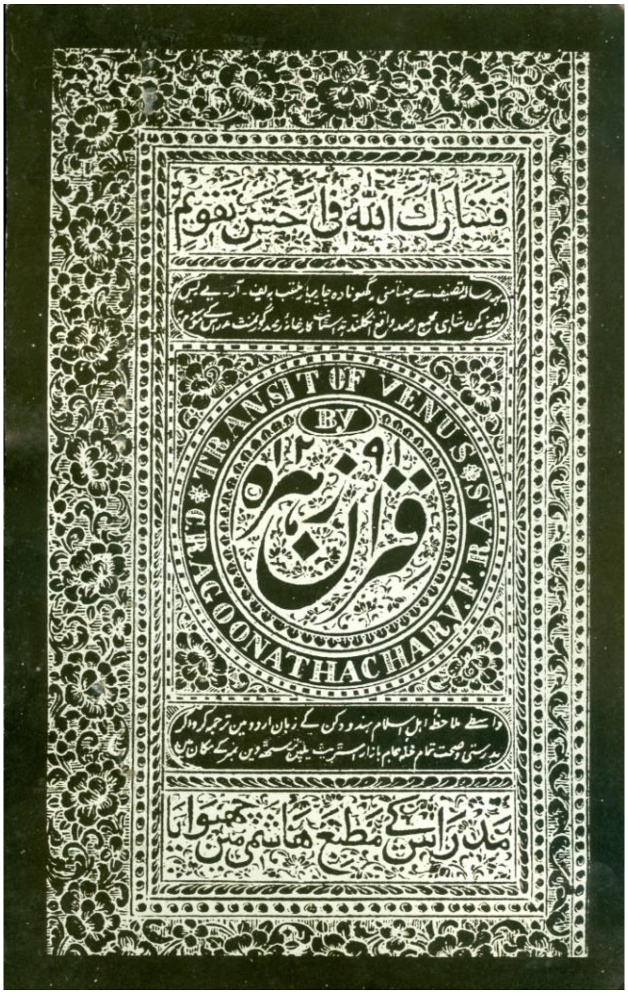

N R Pogson (1829-1891) (IIA Archives)

and further on -

'*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 solar 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 Charry, 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 midway 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'.

The excitement of a 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 the Mars oppositions was better, convenient and accurate. His reference to Kerguelen is in respect of the Royal Observatory's expedition to the Kerguelen islands in the Antarctic Ocean that was led by the Rev. Stefen Perry. Failure in observations due to bad weather notwithstanding, Pogson still provided valuable help to other observers stationed elsewhere through telegraphic determination of the 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'. His longitude work was published subsequently in 1884 (Pogson 1884).

Of the two observers Pogson mentions, Elizabeth Isis Pogson was his daughter who worked at the Observatory as assistant astronomer (1873 *Nature*, p. 513) whereas Ragoonatha Chary was the First Assistant to the Astronomer. Ragoonatha Chary came from almanac makers' family and when just around eighteen had joined the Observatory in 1847 during T G Taylor's time (see Kameswara Rao et al 2009). Pogson (1861 Proceedings of Madras Government Public Department, Madras) has spoken highly of him. As the transit date drew near, a 38-page pamphlet by C Ragoonatha Chary entitled 'Transit of Venus' was brought out in 1874 in English, Kannada and Urdu. Through several figures, the pamphlet beautifully explains the transit to the lay public. The English version was presented as dialogue but the style differed when he presented the versions in the local languages. The *pamphlet*, as he called it, was printed but was not published as such. It includes his passionate address at the Pacheappa's Hall, Madras on the 13th April, 1874 to a large gathering of 'Native Gentlemen'. Here, he urges them for support to a modern *Siddhanta* that he wished to bring out, establishment of an Observatory for which he offered a few crucial equipments of his own and formation of a society on the lines of the Royal Astronomical Society. On the occasion of the Transit of



The cover page of the Urdu version of Ragoonatha Chary's pamphlet on the 'Transit of Venus' (IIA Archives).

Venus 2012, the Indian Institute of Astrophysics is planning to re-print the English edition of the *pamphlet*.


C Ragoonatha Chary (1828-80) (IIA Archives)

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

A brief account of the observations of the transit from various stations in India is available in Markham (1878, p. 339-40). He writes that from Masauri (Mussoorie) in the Shivalik hills, 6765 ft above the mean sea, the transit was observed by J B N Hennessey (1829-1910) of The Great Trigonometrical Survey. At the Survey of India's Geodetic Branch Office Compound in Dehradun, the Hennessey Observatory, originally established in 1884 to carry out photoheliography taking 30 cm images of the Sun, still exists, with a dome but sans its equipment and deserving resuscitation. Henessey's main objective was to observe the transit of Venus from a considerably high altitude above the sea. He used an 'equatoreal' provided by the Royal Society, an alt-azimuth, a mountain barometer and a thermometer. He had rated his chronometers and also determined his latitude and longitude for the purpose. At Mary Villa, the point where he placed the equatoreal was appropriately named - *Venus Station* (30º 27' 36''.3N, 78º 3' 3''.2E). He determined time measuring zenith-distances of the stars Aldebaran and Altair. He got fine weather for his observations. Henessey noticed the beginning only after the planet had made its dent on the Sun's disc. 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, vide Tennant 1877 p. 41 also).

The black-drop however was noticed clearly by Colonel Walker who, 16 km south of him, made the observations from *Dehra Doon*, a place at 2200 feet at the foothills.

The Rev. H D James observed the transit from Chakrata, a place in the Shivaliks at an elevation of 7300 feet (30º 43'N, 77º 54'E) with a telescope of his own - by Smith and Beck, an object-glass 3 1/2 inches and focal length 4 feet. In the course of observations, he was attended by his son Henry. About the Reverand, Hennessey says 'His station is distinctly visible from Mussoorie on a clear day'. As cited by Hennessey from his correspondence with Mr. James: —

'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. In his note to the Rev James, Hennessey says 'I had seen a ring of light, but no "pear-drop" or other ligament, at internal contacts.'

The Rev. James subsequently wrote him,

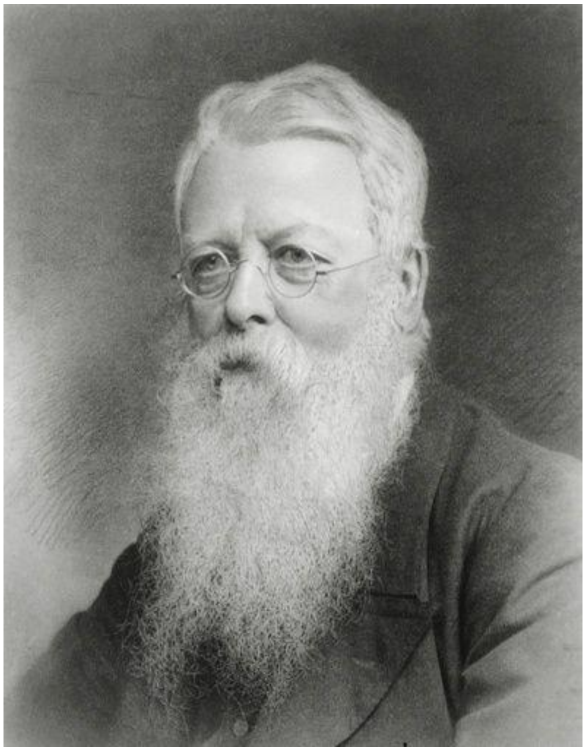
'When about half her orb had entered (alluding to ingress) my attention was attracted to the other half yet on the dark sky: to me it was dark; hence I infer that ray field was not so light as it ought to have been. Its outline, up to this time quite invisible to me, became now illumined with a fringe 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 complemented his observations in a later communication also (Hennessey 1879).

Col. J F Tennant and Capt Strahan's observations

Capt J F Tennant (1829-1915) had headed the Madras Observatory during the brief span from Oct 13, 1859 until 1960 when Norman Pogson took over its reins as Astronomer beginning Feb 1861. He had made observations of the Donati's comet during the period Oct 5-12, 1858 from Mussoorie (30º17' 19''N, 5h 12m 17.7sE) and of the Halley's Comet on May 16, 1910 made from 'somewhere in the Himalayas' (Tennant 1910, *The Observatory*, **33**, July p. 297), located at an elevation of 7500 feet. Most likely, the 'somewhere' of the comet observations is *Lal Tibba*, Mussoorie. Now Colonel, Tennant took charge of observing the transit of Venus 1874 from two stations, at Roorkee and Lahore where Capt George Strahan R.E. (Royal Engineer) was sent. At Roorkee, Tennant had Capt Campbell, R.E., Capt Waterhouse, R.E., Seargent Harrold R.E., Lance Corporal George and Private Fox as part of the team, later joined by Capt Heaviside R.E. who had also brought along Royal Society's telescope by Slater. Tennant set up a solar observatory by installing a photoheliograph, a 6-inch equatorial by Messrs. Cooke and Sons of York with a double image micrometer duly sheltered in a circular building with revolving roof, an alt-azimuth, a portable transit instrument and chronograph.



J F Tennant (1829-1915) (IIA Archives)

Just when the transit began, with the Sun low, Tennant noticed the planet only four or five seconds after the Contact I. However, he could observe the ingress in progress as also the Contacts III and IV at egress. Tennant initiated 'micrometer measures of the cusps, obtaining sixteen measures of the chord joining the cusps at ingress' as also at egress (Tennant 1875a). At the first internal contact, no black-drop or distortion was seen that he had expected, the same at egress. He even sent over a telegram to Capt Strahan about the same. He measured the diameter of the planet, first horizontal so that it was free of refraction as also atmospheric boiling and later in declination and in Right Ascension (RA) too. The value in RA exceeded slightly that in declination, refraction corrected. He found a mean value of 63".948 ± 0."0603, for Venus as a sphere (Tennant 1875b). Capt Waterhouse, assisted by 'Serjeant Harold', took 109 photographs while the transit was in progress and at the time of egress. Capt Campbell observed the transit with the great theodolite.

Capt. Strahan set up equipment in Lahore at Mr Elphinstone's house belonging to the Maharaja of Kashmir. He had a 6-inch telescope by Mr. Simms and two chronometers, a Solar and a Sidereal. Ingress was not visible here but with a favourable weather, he made his observations as the transit progressed. He too did not see the black drop effect at egress as such but more importantly noticed the planet's atmosphere; to quote from his report and notes presented in Tennant (1877) -

'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 (1877; see also Tennant 1875a and 1875b) presented a detailed report of the observations of the transit made under his charge and duly reduced in an 1877 report together with the plan of the observatory he set up; the transit date printed in the Report is December 8, 1874. In fact, after the transit expeditions, Col Tennant had proposed a solar observatory at Shimla for spectroscopy and photography and observations of Jupiter's satellites. The proposal somehow fell through. However, arrangements were made for the pictures of the Sun to be taken on a daily basis under Col. Walker's superintendence.

As we get it from Proctor (1882, p. 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'.

The most interesting part to note here is the 'amateur astronomers' who, unfortunately, are not identified.

Capt. A C Bigg-Wither's observations

Capt. A C Bigg-Wither (1844-1913), an Engineer with the Indus Valley Railway, observed the transit of Venus on December 9, 1874 from his observatory in *Mooltan* in Punjab (30º11'5"N, 4h45m59.5sE; Multan, now in Pakistan) where many gathered to watch the event. He was a keen astronomer since his younger days and had maintained a personal observatory for 45 years where he would carry out any kind 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' (1914 *MNRAS* **74**, 269-271). Some detail about him is available at http://ocotilloroad.com/geneal/bigg-wither1.html.

On the crucial day, Bigg-Wither observed the transit with a telescope equatorially mounted, 4-inch objective of 5 feet focal length by Cooke with powers from 55 to 300 and solar diagonal eyepiece, while the Sun rose with half the planet's orb already moved into the disk of the Sun (Bigg-Wither 1883). He got a fine weather but even at the time of Contact II, the Venus-Sun pair was still very close to the horizon. Yet he was able to observe the black-drop effect and gave Real Internal Contact time as 12h17m8s Mooltan Sidereal Time just when he saw the 7" wide black band break. As the transit progressed, he watched carefully if he could find 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). Over the disk of the Sun he also looked around the planet, though in vain, for any spot caused by a possible satellite. At the time of egress, he was surprised to notice no traces of the black drop effect. However, just as the planet reached the limb of the Sun, Bigg-Wither (1883) writes,

> '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 wondered how this crescent formed; it was not there at the ingress. He had not noticed any of this at the time of egress when he observed the transit of Mercury on Nov 5, 1868 with the same telescope while in England. The last external contact (Contact IV) of Venus happened at 16h30m1s that Bigg-Wither says actually differed quite much from the calculated time.

Fr. Lafont's observations

Founded in 1860, the St Xavier's College in Calcutta made seminal contribution to the promotion of science and technical education. The Belgian Father Eugene Lafont (1837-1908) of the Society of Jesus worked beginning in 1875 to establish the first spectro-telescopic observatory at the St. Xavier's College that he had joined in 1865 to teach. Here he had already established a meteorological observatory in 1867. He participated in Italian astronomer Pietro Tacchini's expedition to observe the transit of Venus on Dec 9, 1874 from Muddapore (Madhupur) in Bihar, discovering in the process presence of water vapour in the atmosphere of the planet (Biswas 1994). Tacchini had persuaded him to establish an astronomical observatory at the College and in 1877 he installed a 23 cm Steinheil equatorial telescope and an 18 Merz equipped with a Browning spectroscope, a coelostat etc. and erected a rotating dome, 22 feet in diameter, on the terrace (Udias 2003). At the Xavier's, he was joined in Nov 1874 by a mathematician and astronomer Father Alphonse de Penaranda. The latter until his death in 1896 participated in astronomical observations by Father Lafont. These include the solar eclipse of May 17, 1882 (magnitude 0.48 at mid-eclipse at 08:45 UT at Calcutta), the Mars-Saturn conjunction of Sept 20, 1889, the Jun 17, 1890 annular solar eclipse observed from Bhagalpur (magnitude 0.973, annularity 3m27.9s, post-meridian; *Eclipse Predictions by Fred Espenak, NASA's GSFC*), the May 10, 1891 transit of Mercury, the occultation of Jupiter by a Full Moon on Oct 6, 1892 in the constellation of Pisces and several others.

Fr Eugene Lafont (1837-1908) (**Wikimedia Commons**)

Biswas (1994) details Father Lafont's scientific work at the Xavier's and his contribution with Dr Mahendralal Sirkar (1833-1904) towards founding the Indian Association for the Cultivation of Science in 1876. Also mentioned are their observations of movement of a comet. There is no information available to enable its identification. For a comet to be so noteworthy, we feel, that could be about the bright daytime comet of 1882 that became famous as the Great September Comet (C/1882 R1). Of the Venus transit expedition to Muddapore, Fr. Lafont wrote thus (Biswas 2003) –

'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'.

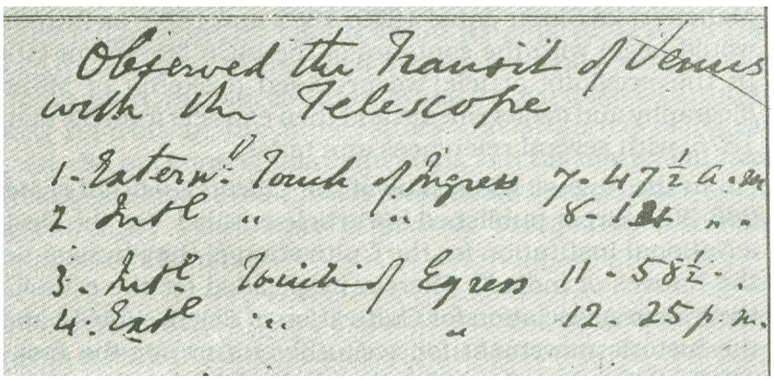
Tacchini was from the Astronomical Observatory of Palermo. He had four sets-up that had revolving cupolas. Tacchini had an equatorial spectro-telescope as also did Prof Abetti. Fr Lafont and the other observer Prof Dorna had equatorial refractors and were to record the Contact timings with rated chronometers. Despite the frustrating play of clouds, Fr Lafont and Dorna could time the Contacts I and II at ingress, as also the Contacts III and IV at egress. Soon the clouds gave way and allowed the observers their tasks. Tacchini got the signs of presence of water vapour, an observation corroborated by

Abetti. Here was the first spectroscopic confirmation of the existence of atmosphere around Venus.

Tacchini commented that 'before the second contact, Venus was visible over the chromosphere' (vide Pigatto and Zanini 2001, p. 49). Fr Lafont further says –

'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'.

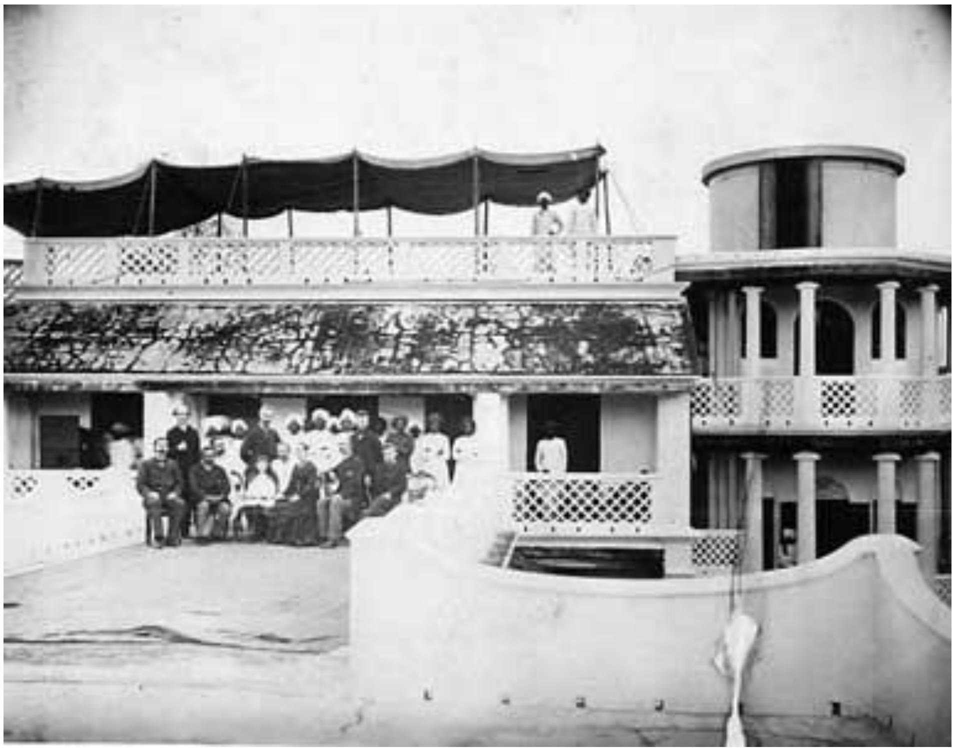
As Biswas (2003) points out, Dr Mahendralal Sircar also saw the transit with a telescope. From the entries of observations in his diary, Biswas (2000, p. 31) deduces that the total duration of the transit was 4h37m30s, slightly different from Fr Lafont's because the latter used more sophisticated equipment to time the transit.


Observed the Transit of Venus with the Telescope
1. Extern! Touch of Ingress 7-47½ a.m
2 Intl " " 8-[illegible] " "
3. Intl Touch of Egress 11-58½.
4. Extl " " 12-25 p.m.

Excerpts from the diary of Dr Mahendralal Sircar (from Biswas 2000)

Nursinga Row's observations

As a native Indian keen to pursue astronomy with modern equipment, G Venkata Jugga Row (1817-56), an affluent zemindar (land lord), was a pioneer whose personal interest saw coming up of a private observatory in the backyard of his residence in Daba Gardens at Vizagapatanam in 1840 that continued to function under his successors till the late 19th Century. He had acquired a Troughton's Transit Circle and a chronometer and optics for a 4.8 inch aperture, 5′8" focus telescope. Here he carried out astronomical and meteorological observations and even determined latitude and longitude of Vizagapatnam. On the Dolphin's Nose, he had installed a flagstaff to provide time signals to the public that used to be hauled down at nine in the morning to set the time for the station for all who lived too far to hear the report of the gun fired from the fort. He had assisted T G Taylor in the observations of the Halley's Comet and had independently published a paper in 1836 in the *Madras Journal of Literature and Science* deriving mass of Jupiter at 302 times the Earth's using motion of its satellites and Kepler's laws of planetary motion (Rao et al 2011). The figure comes close to the modern value of 317.894 times the mass of the Earth. A V Narsinga Rao (1827-92) inherited the observatory from his father-in-law Jugga Row and carried out astronomical and meteorological observations lifelong apart from initiating telescopic photographic work and maintaining the time service. To observe the solar eclipse of Aug 18, 1868, he readied the 4.8" telescope whose optics the observatory already had. He would publish his observations and maintained contact with C Piazzi Smith and W Huggins. In 1871, the Government had discontinued the time-gun firing service from Dolphin’s Nose. However, Narsinga Rao came forward to maintain it at his own expense.



Nursing Row’s Observatory, Daba Gardens, Visakhapatnam; European and Indian observers of the Transit of Venus, 1874 (adopted from the Royal Astronomical Society Library)

Earlier at this observatory, Narsinga Rao (Anglicized as Nursing Row) had observed the transit of Mercury on Nov 5, 1868 with a telescope having a 4.8 inch object glass (Nursing Row 1869). Rao’s communications to the *Monthly Notices of the Royal Astronomical Society* speak of a keen interest and knowledge of astronomy. He had observed the solar eclipses of Aug 18, 1868, Dec 12, 1871, Jun 6, 1872 and May 17, 1882 and the transits of Mercury of Nov 5, 1868, Nov 8, 1881 and May 10, 1891 and the Transit of Venus 1874.

Nursing Row observed the transit of Venus on Dec 9, 1874 with a 6-inch clock driven Cooke equatorial, 7 ½ feet focal length; clouds allowed only the last thirty minutes of the transit including the egress of Venus to be observed (Nursing Row 1875). He gave the observed sidereal times and 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’.

The indentation was perhaps because of the atmosphere of the planet.

In 1871, Nursinga Row was elected a Fellow of the Royal Astronomical Society and the following year of the Royal Geographical Society.

A V Nursing Row (1827-92) (www.avncollege.ac.in/aboutus/history.html)

Today at the Observatory site stands the Dolphin Hotel, established in 1980**.**

Samanta Chandra Sekhar and the transit of Venus

Samanta Chandra Sekhar Simha (1835-1904) from Odisha, popularly called Pathani Samanta, was a traditional *Siddhantic* (theoretical) astronomer in a relatively modern age. He devised a number of instruments to carry out astronomical observations naked-eye and put together his knowledge and experience in an invaluable tract *Siddhanta Darpana*, in Sanskrit. The work was published in 1899 by the Calcutta University. His results compare well with the true positions and movements of the celestial objects, including conjunctions etc. (see for detail Naik and Satpathy 1998). Samanta Chandra Sekhar describes, in a stanza as below, the transit of Venus of Dec 9, 1874 he predicted from his computations and observed naked eye:

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

(*Siddhanta Darpana*, **XI**, 110). A translation, by Arun Kumar Upadhyaya, is as 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 Kali year 4975 (1874 AD) there was a Solar Eclipse due to Sukra (Venus) in Vrischika Rasi (Scorpio). Then Sukra bimba (Venus shadow) was seen as 1/32 of 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’. (http://nayagarh.nic.in/sonofsoil/eminent%20person.html).

Here, the diameter in *yojana* is not absolute. The *Surya Siddhanta* (5th-12th Century) in its Ch. VII defines planetary diameter at the Moon’s mean distance, where 15 *yojanas* make an arc minute. The brighter the object the greater diameter it has; on that count Venus is 60 *yojanas* (≡ 4') and Mars 30 *yojanas*, etc (*Surya Siddhanta*, tr. Burgess, p. 170). In the *sloka*, we have a terse description of an event that Chandra Sekhar acknowledges rare among the heliacally setting and rising stars and planets. The reader may recall that in Hindu astronomy, *Kaliyuga* (the *Kali* era) commenced on a date that in modern description is the midnight of 17/18 Feb, 3102 BCE. We also note from JPL's Horizons system that Venus and the Sun were at an ecliptic longitude ~ 257º what would lay in the sector of Sagittarius even

Samanta Chandra Sekhar Simha (1835-1904) (www.iopb.res.in/~duryo/Samanta_Chandrasekhar**)**

though the luminaries lay well above Scorpio; after the IAU recognized in the 1920s the constellation boundaries, that place now falls in Ophiuchus. At the greatest transit time (04:07 UT), we get from JPL's Horizons system the respective angular diameters as 63".134 and 1949".195; that would mean a ratio of 1/30.87. What is remarkable to note here is the precision that Chandra Sekhar could achieve observing, and computing purely within the Hindu astronomical system from the astronomical constants he would have determined afresh from his own observations.

THE TRANSITS OF VENUS IN THE 21st CENTURY

About the next pair of transits of Venus, Proctor (1882, p. 231-32) concluded his book with 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'.

The transit of Venus 2004

The first of the two transits of the planet Venus in the 21st Century took place on June 8, 2004. The event was to be visible from India, in fact throughout Asia during the most convenient hours of the day. A transit of Venus is no more crucial as the only opportunity to size up the solar System with the greatest precision. Still it is significant in more ways than one. As a public interest event, its educational value is immense where institutions, the media and the internet have an important role to play.

As the smaller disk of Venus moves in front of the Sun's, the transit is marked by four contacts. For New Delhi, these phases for the event of June 8, 2004 were:

		h	m	s	
Ingress, exterior contact	IST	10	46	09.8	Contact I
Ingress, interior contact		11	05	04.5	Contact II
Least angular distance		13	48	02.5	
Egress, interior contact		16	31	36.3	Contact III
Egress, exterior contact		16	50	39.4	Contact IV

The salient features to look forward to during a transit are:

1. During the second and the third contact, it is possible to notice what has been termed as 'black drop effect'. This mysterious effect happens at those crucial times when the disk of Venus appears a bit deformed, clinging to the limb of the Sun by a thin column or thread. The breaking of this thread marks the Contact II. The Contact III happens in exactly the reverse order. This effect is a result of seeing effects due to the turbulent atmosphere of the Earth, the equipment optics and solar limb darkening.
2. There is a likelihood of the Sun showing up with sunspots. If Venus happens to pass close to or in front of one, it will mark an exciting sight.
3. A few hours before or after the transit, Venus will still be close to the Sun separated in angle by hardly a degree or so. The refraction of sunlight through the atmosphere of the planet lights it up and a ring around the tiny but dark disk of Venus can become visible. This can be noticed better if the bright disk of the Sun is blocked for only the planet to be in the field of view of an appropriate equipment.

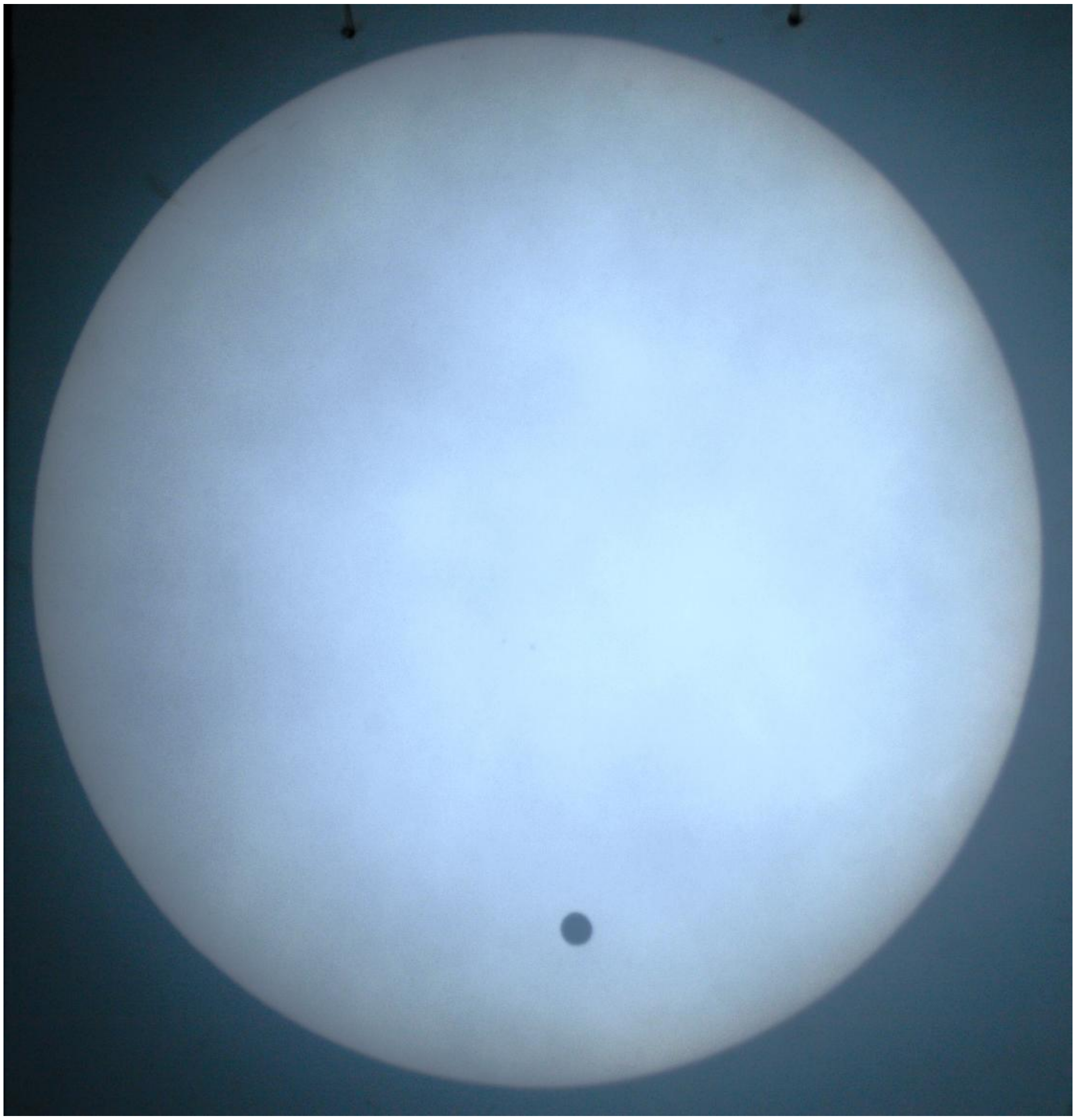
Observations planned from the Kodaikanal Observatory for the event were as follows:

a. Photographic recording of broad band (white light) frames, at about once in 30 minutes, of the full solar disk during the transit. Multiple frames were planned during ingress and egress. The timing of the circumstances of the event were recorded based on the GPS facility available at the Observatory.

b. Narrow band full disk imaging in the Chromospheric lines, the Calcium K and/or the Hydrogen alpha, close to the timings of the frames in (a) above.

c. CCD camera recording of select regions of the Franhaufer spectrum in order to look for possible spectral signatures of the atmosphere of Venus silhouetted against the solar disk.

Come June 8 and the planet passed in front of the Sun as viewed from the Earth and was well observed from a large part of the globe and extensively covered in the media. In India, the transit was witnessed live by thousands who visited the various institutions and planetaria where arrangements had been made for public viewing. Not just the scientists and students, the visitors included people of all ages, from all walks of life and from near and far.



Venus in transit on Jun 08, 2004; taken at the Solar Tower Tunnel Telescope, Kodaikanal Observatory (Indian Institute of Astrophysics photograph).

At the ARIES (Aryabhata Research Institute of Observational Sciences), Nainital, where observing facilities for solar research exist, a public viewing was organized. A large number of visitors had the glimpse of Venus silhouetted against the large image of the Sun. It was the same way at the Udaipur Solar Observatory.

At the Kodaikanal Observatory of the Indian Institute of Astrophysics, the ingress and egress were both clouded out on the day. Still, 10 broadband images and over 40 H-alpha images were taken at the Observatory that could be used to measure the effect of the atmosphere of Venus on the background chromospheric radiation. At the Solar Tower Tunnel Telescope, 35 high-resolution digital images of the full Sun were taken where a 34 cm image of the Sun is formed. At the Koramangala Campus of IIA, an arrangement was made to view a 30 cm image of the Sun on a screen in a tent formed with a 20 cm coelostat system. The event began at 10:45:31 IST. The sky was generally cloudy throughout the day but in between, the event was possible to be watched whenever the cloud cover got thinner or cleared up for a while.

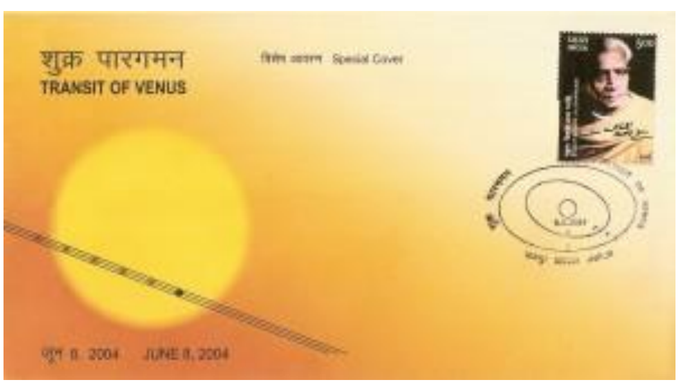
The Transit of Venus 2004 in the news (clockwise from top left: *Vijay Times* May 28, *The Times of India* Jun 9, *Hindustan*, *Deccan Herald* Jun 8, *Vijay Times* Jun 9; in the middle – *The Times of India* Jun 8, 2004; all papers from Bangalore except for *Hindustan* from Delhi).

Venus appeared against the bright image of the Sun as a dark round spot, ~1/30 its diameter transiting across it in over 6 hours. This apart, there was also installed a 35 cm Maede telescope attached with a video camera to directly record the entire event and project it through a multimedia facility. Inside the auditorium, there proceeded lectures and question answer sessions all through the hours of the transit for the benefit of the general public whose enthusiasm never abated. Towards the latter part of the day, the clouds got thicker much to the disappointment of the scientists and the visitors as they could not watch the grand egress of the planet at about 16:30 hrs onwards. The event received wide publicity in the print and electronic media while news channels had stationed outdoor broadcasting vans exclusively to cover the transit-watch live from both

The Transit of Venus was arranged to be viewed on a screen kept in a tent.

Coelostats and the solar image projection set up at the Indian Institute of Astrophysics, Koramangala Campus, Bangalore.

the campuses. A fuller description of the event, as observed from Bangalore by R C Kapoor and from Kodaikanal by S P Bagare and S S Gupta, is available in the IIA Annual Report 2004-05.



The special cover issued by the India Post on 08.06.2004. (http://www.indianstampghar.com/**).**

The transit of Venus 2012

The next transit of Venus falls on June 5– June 6, 2012. The whole event can be witnessed from north-west parts of Canada and the US, eastern and northern parts of Asia, the eastern half of Australia and the Western Pacific Ocean. It shall be visible over India, with the transit in progress when the Sun rises. In the 2004 transit picture presented here, we do not find any noticeable sunspots. However, in 2012, with the Sun getting increasingly active, the planet might have some for company.

Venus will have a date with the Sun again in 2117 on December 11 and in 2125 on December 8, and so on.

This work is in progress. Some of the pictures included here are gratefully adopted from a few websites, appropriately credited.

REFERENCES

Banerjee G N 1920 Hellenism in ancient India, Second edition, Published by the Author; London & Foreign Agents: Probsthain & Co., London (http://asi.nic.in/asi_books/10192.pdf).

Bigg-Wither A C Capt 1883 Observations of the Transit of Venus, 1874, December 8-9, as observed at Mooltan, Punjab, India, Mem Royal Astron Soc, XLVII, p. 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 Gleaning of the past and the science movement: in the diaries of Drs Mahendralal and Amritlal Sircar, The Asiatic Society, 1, Park street, Calcutta- 16.

Biswas A K (Ed.) 2003 Collected works of Mahendralal Sircar, Eugene Lafont and the science movement (1860-1910), The Asiatic Society, 1 Park Street, Kolkata 16.

Degloss L Observations made at Dinapoor, on the Planet Venus, when passing over the Sun's Disk, June 4, 1769, with three different Quadrants, and a Two-Foot reflecting Telescope. By Luis Degloss, Captain of Engineers, with the Assistance of J. Lang and A. Stoker 1770 *Phil Trans* **XIII**, p. 47 (Internet Archives: www.archives.org).

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 Royal Astronomical Society of Canada*, **99**, 170-176

Gorakh Prasad 1956, *Bharatiya Jyotish ka Itihas* (in *Hindi*), Prakashana Bureau, Uttar Pradesh Sarkar, Lucknow, p. 205

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*, **XXIII**, p. 379-384 (Internet Archives: www.archives.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*, **XXIX**, p. 297-302 (Internet Archives: www.archives.org).

Hirst W The Rev 1761-1762 *An Account of an Obfervation of the Tranfit of* Venus *over the* Sun, *on the 6th of* June 1761, *at* Madrafs; *by the Rev. Mr*. William Hirft, *Chaplain of one of his Majesty's Ships in the* Eaft Indies; *contained in a Letter wrote by him to the Right Honourable the Earl of* Macclesfield, *Prefident of the Royal Society*. *Dated Fort* St. George, 1*ft* July 1761, *Phil Trans* **52**, p. 396-8; http://gallica.bnf.fr/ark:/12148/bpt6k55857c/f430.image.

Hirst W the Rev. 1769 Account of several Pheenomena observed during the Ingress of Venus into the Solar Disc. By the Reverend W. Hirst, F. R. S. in a Letter to the Astronomer Royal, *Phil Trans*, **59**, 228-235; http://www.jstor.org/stable/10.2307/105829**.**

Hogg H S 1951 Le Gentil and the Transits of Venus, 1761 and 1769, *Journal of the Royal Astronomical Society of Canada*, **45**, 37–44, 89-92, 127-134 & 173-178 Out of Old Books, http://cseligman.com/text/atlas/LeGentil.pdf

Johnson, The Rev. S J 1882 On a Probable Assyrian Transit of Venus, *Monthly Notices of the Royal Astronomical Society*, **43**, 41.

Kapoor R C 2012 Did Ibn Sina observe the transit of Venus 1032 CE? (in preparation)

Kochhar, R.K., 1985a. Madras Observatory: The beginning. *Bulletin 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.

Kurtz D W (Ed.) 2004 Transits of Venus: new views of the solar system and Galaxy, IAU Coll. 196, Preston, UK, Cambridge University Press, Cambridge.

Majumdar R C, Pusalker A D and Majumdar A K 1989 The History and Culture of the Indian People *Vol* **5**: The Struggle for Empire, Bharatiya Vidya Bhavan, Bombay,

Markham C R 1878 The Indian Surveys IInd Ed, W H Allen & Co., London, p. 323-341 (Internet Archives: www.archives.org).

Maor Eli 2000 June 8, 2004 Venus in Transit, Princeton University Press, New Jersey.

Marov M 2004 in Kurtz D W (Ed.) 2004 Transits of Venus: new views of the solar system and Galaxy, IAU Coll. 196, Preston, UK, Cambridge University Press, Cambridge.

Mukherjee S K (Ed) 1985 History of Astronomy in India, *Indian Journal of History of Science*, **20** (INSA, New Delhi).

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

Nursing Row A V 1875 Observation of the Transit of Venus at Vizagapatam, *MNRAS* **35**, 317-8.

Orchiston W 2004 in Kurtz D W (Ed.) 2004 Transits of Venus: new views of the solar system and Galaxy, IAU Coll. 196, Preston, UK, Cambridge University Press, Cambridge.

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 & Heritage* **4:1** (2001) 43-58.

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: Printed at the Lawrence Asylum Press, by W H Moore) (Internet Archives: www.archives.org).

Proctor R A 1882 Transits of Venus, Longmans, Green, and Co., London (Internet Archives: www.archives.org).

Rao N K , Vagiswari A, Thakur Priya and Birdie C 2009 C. Ragoonatha Charry and variable star astronomy, *Journal of Astronomical History and Heritage*, **12:3**, pp. 201 – 210.

Rao N K, 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.

Rose A 1770 Transit of Venus observed in India, *Phil Trans* **XIII**, p. 78 (Internet Archives: www.archives.org).

The New York Times 1874 The transit of Venus: Le Gentil's observation in the last century, http://select.nytimes.com/gst/abstract.html?res=F30E17F7345C16738DDDAC0A94DF405B848BF0D3&scp=1&sq=The%20Transit%20of%20Venus%20From%20Nature&st=cse

Sachau E C 2003 Al Beruni's India, Asian Educational Services, New Delhi.

Selin, Helaine 1997 Encyclopaedia Of The History Of Science, Technology, And Medicine In Non-Western Cultures, Springer; (books.google.co.in).

Tennant J F 1875a Letter dated Roorkee, December 11, 1874, *MNRAS*, **35**, 209-210.

Tennant J F 1875b On the Dimensions of Venus as determined during the recent Transit, *MNRAS*, **35**, 345-47

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*, Office of the Superintendent of Government Printing, Calcutta, 1877); see also Col. J F Tennant's Letter dated Roorkee, December 11, 1874 Tennant J F 1875a *MNRAS*, **35**, 209-210 and 1882 An Examination of the Roorkee observations of the Transit of Venus, 1874, December 8, *MNRAS* **42**, 352-355 (Internet Archives: www.archives.org).

Udias A 2003 Searching the heavens and the Earth: the history of Jesuit observatories, Kluwer Academic Publishers.