INDIAN ASTRONOMY AND THE TRANSITS OF VENUS. 1: THE EARLY OBSERVATIONS

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Abstract: This paper, the first of two, is about sightings and astronomical observations of transits of Venus across the disk of the Sun made from the Indian region. The period covered in this first paper is from ancient times up to and including the 1769 transit. The sources of the information presented here range from some classical texts and historiographies to publications and records of institutions, and accounts by individuals. Of particular interest is the 1761 transit, which was observed from atop the Governor's house in Madras by the Reverend William Hirst, who made a significant observation. During ingress he noticed a nebulosity about the planet, which he attributed to the atmosphere of Venus, and this was duly recorded in his paper reporting the transit observation that appeared in the *Philosophical Transactions of the Royal Society* of London. However, in a recent analysis, Pasachoff and Sheehan (2012) have shown that it was not the Cytherian atmosphere that Hirst and other astronomers observed in 1761.

Keywords: transits of Venus; Indian observations of the 1761 and 1769 transits; discovery of Venus' atmosphere

1 INTRODUCTION

Transits of planets across the disk of the Sun are among the most fascinating phenomena in Solar System astronomy. As seen from the Earth, transits of only Mercury and Venus are possible. These held great importance in early telescopic astronomy when the transits, specifically of Venus, enabled astronomers to determine the solar, *p*,[1] with what was regarded as unprecedented accuracy, and thus establish the scale of the Solar System.

On the average, there are thirteen transits of the planet Mercury each century. If we refer to the transit predictions tables by Fred Espenak (2012), all transits of Mercury over a period of seven centuries, from 1601 to 2300 CE occur in the months of May or November. As the orbit of Venus (with a mean value 0.7233 AU) is much greater than that of Mercury (0.3871 AU), a transit of Venus is much rarer. In its course, Venus passes in between the Earth and the Sun and a line-up takes place every 584 days (the synodic period—the time between two successive inferior, or superior, conjunctions). However, a transit does not always occur since the orbit of Venus is inclined 3.39º to that of the Earth, so when a line-up takes place Venus is usually above or below the disk of the Sun. In the event that the line-up occurs at or very near a place where the paths cross, a transit will happen.

A transit is difficult to notice visually since the planets are much smaller than the Sun in angular dimensions. Venus (with a mean radius of 6,051.8 km) is not only larger than Mercury (at 2,437.6 km), but it is closer to the Earth at the time of its inferior conjunction. At that time, it has an angular diameter much larger than that of Mercury. Even then, compared to the ~31.5′ of the Sun (with a mean radius of 695,950 km), Venus subtends an angle of only about 1′, and while in transit appears as a small spot against the extremely bright disk of the Sun. This angular size is also at about the limit of detection by normal human eyes (for someone with 20/20 vision). There are numerous ancient claims, particularly from China, Japan and Korea, of sunspots visible to the naked eye (e.g. see Clark and Stephenson, 1978), but during a transit, Venus would only have been distinguished from a sunspot by its perfectly circular shape and its comparatively rapid motion across the Sun's disk.

Every millennium there are about twelve transits of Venus. Interestingly, these have 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 eight transits of Venus since the invention of the telescope. There was no transit in the twentieth century, following the last transit of Venus that took place more than 130 years ago, on 6 December 1882. In the twenty-first century, the first transit of Venus occurred on 8 June 2004, and this was followed by another on 5-6 June 2012; both were visible from India. In Table 1, below, is a list of post-telescopic transits.

Through the period 5000 BCE to 10000 CE, the Earth has witnessed or will witness 178 transits of Venus. A listing of literature on the various transits of Venus is available on van Gent's (2012) web-site. The map constructed by van Roode (2011) for the transit observations made from various locations on the Earth, and also the interactive Google maps of transits produced on Jubier's (2012) website, are excellent references of their kind.

This paper expands substantially on Kapoor (2012) and discusses early Hindu knowledge of planetary transits and possible naked eye observations of transits of Venus prior to 1631 before

Table 1: Historic transits of Venus (after Espanek, 2012).

Date	Transit Contact Times (UT) 1 h m	2 h m	Greatest h m	3 h m	4 h m	Minimum Sep. ″	Sun RA h	Sun Dec °	Transit GST h	Series
1631 December 07	03:51	04:59	05:19	05:40	06:47	939.3	16.912	–22.64	5.045	6
1639 December 04	14:57	15:15	18:25	21:36	21:54	523.6	16.738	–22.34	4.888	4
1761 June 06	02:02	02:20	05:19	08:18	08:37	570.4	04.957	22.69	16.988	3
1769 June 03	19:15	19:34	22:25	01:16	01:35	609.3	04.805	22.44	16.842	5
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 present-day India showing Indian localities mentioned in the text. Note that Chittagong and the area on this map previously known as 'Islamabad' (not to be confused with present-day Islamabad in Pakistan) originally were in India, but they are now in Bangladesh.

briefly mentioning Horrocks' and Crabtree's observations of the 1639 transit. The remainder of the paper discusses successful Indian observations of the transits of Venus in 1761 and 1769. For Indian localities mentioned in the text see Figure 1. A second paper, about India-based observations of the 1874 transit (Kapoor, 2014), will be published in a later issue of this *Journal*.

2 PLANETARY TRANSITS IN THE HINDU ASTRONOMICAL WORKS (THE *SIDDHĀNTAS*)?

It may seem odd but Venus (or *Shukra*) in India is male. See, for example *SriGargaSamhitā* by Garga (100 BCE–100 CE, *SriBalBhadraKhanda*, 6:13: 373-375), where Shukracharya, in his attempt to woo a beautiful Jyotishmati in penance, claims to be the Guru of the demons, and a poet. In the *Purānas* (Indian mythologies), *Shukra* is similarly identified.

While discussing planetary conjunctions (*yuti*) many Indian astronomers have considered *bheda-yuti* (occultations) of planets, as the *Siddhāntic* (astronomical) texts by Vatesvara (b. 880 CE; Selin, 1997), Bhattotpala (also Utpala; 966 CE) and Bhāskarācharya (Bhāskara II; 1114–1185 CE) bear out. An excellent review of this subject is presented by Shukla (2000: Chapter 8). In the event of a *bheda-yuti*, the particular situation occurs when the longitudinal separation between the two planets becomes smaller than the sum of their radii, with the lower planet wholly or partially covering the disk of the higher planet. The situation is then treated as akin to a solar eclipse and the computation is made accordingly for contact, immersion, emersion and separation. In his *Brhat Samhitā* (505 CE, Bhat, 1986), the Ujjain (Figure 1) astronomer, mathematician and astrologer, Varāhamihira (Figure 2, 485–587 CE; Rao, 2005), devotes a chapter *Grahayuddha* ('planet wars' = Chapter XVII) to planetary conjunctions, which are classed as occultations, grazing incidences, etc. In the *bheda-yuti*, taking the Sun as the object being occulted and assuming the occulting planet as the Moon, Vatesvara, Bhattotpala and Bhāskarācharya describe an elaborate procedure for the computation that enables one to examine if an eclipse-like situation will occur, and to determine the time of the apparent conjunction.

The planetary sequence given by Āryabhatta (476–550 CE) in his work *Āryabhatiya* (499 CE) is as follows: Earth – Moon – Mercury – Venus – Sun – Mars – Jupiter – Saturn – Fixed stars. As distinct from a usual *bheda-yuti* which can be an extreme situation only, did astronomers also look at the more likely situation where the *higher* planet happened to be the Sun? To recall, Venus transited the Sun in Vateswara's time on 23 November 910 CE. The transit commenced in India during the night, but the event ended as the Sun rose at Ujjain, the egress phase only just completed. Indian astronomers knew the inclinations of the planetary orbits to the ecliptic, as the *Sūrya Siddhānta* (ca. 400 CE by an unknown writer, and a work in progress until as late as ~1100 CE) gives these. Comparative values of the inclinations, as fixed in the various *siddhāntas*, are available in Naik and Satpathy (1998: 37). The astronomers did not factor these into their computations since the magnitudes were small. The only inclination that mattered was that of the Moon with respect to the computation of lunar and solar eclipses (Somayaji, 2000: 181-182). If, in the course of computation and observation one found that *pātas* (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 visualized. In order to have an exposure to a modern *Siddhāntic* procedure to compute planetary conjunctions, one may find Rao and Venugopal (2009) useful.

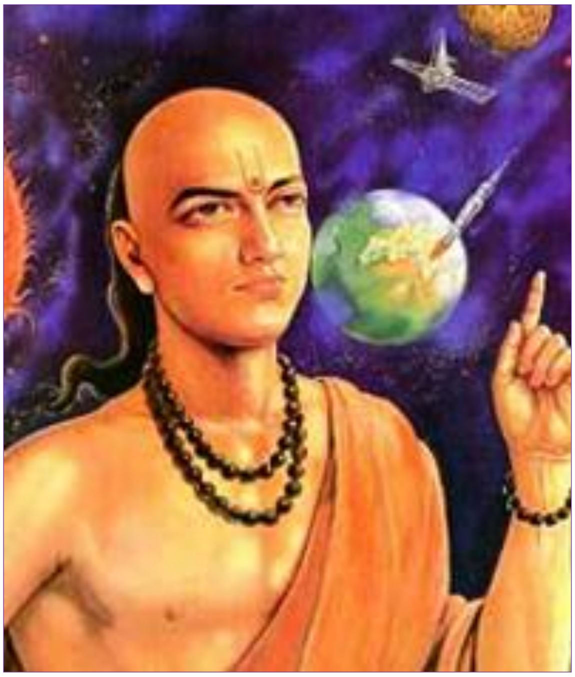

Figure 2: An artist's depiction of Varāhamihira (after indianetzone.com).

In at least two *Siddhānta* texts we find *planetary transits* are considered, and both in independent chapters. *Dhruvamānasa,* written in 1056 CE by the astronomer and mathematician Sripati Mishra (1019–1066 CE), is a text in Sanskrit devoted to computation of planetary longitudes and eclipses (see O'Connor and Robertson, 2000). This is the first Indian astronomical work where planetary transits also are considered. Pingree (2008a) lists the names of the chapters in Sripati's *Siddhāntaśekhara* where planetary transits are mentioned. Interestingly, Sripati was just 13 years of age when Venus transited the Sun on 24 May 1032 CE, but this transit was not visible from India. However, the next transit that occurred, on 22 May 1040 CE, was. Sripati's first work, *Dhikotidakarana*, on lunar and solar eclipses, was written in 1039 CE. Therefore, as someone working on planetary longitudes and latitudes, it is likely that he would stumble upon certain critical situations amounting to a transit by a planet. Recall that Sripati's period is soon after al-Bīrūnī (973–1048 CE) visited India (during 1019-1029 CE), although he may not have been aware of the latter and his works.

Venus next transited the Sun on 23-24 November 1153 CE., at a time when the great Indian mathematician and astronomer, Bhāskarāchārya (Bhāskara II, 1114–1185 CE), also lived. He authored a number of highly-acclaimed texts on mathematics and astronomy, such as *Siddhānta Shiromani* (composed 1150 CE). The transit would not be visible from India. However, anyone who traditionally computed mean and true motions of the planets and conducted observations to follow planetary kinematics, particularly around the times of heliacal rising and setting, and their conjunctions would know about the forthcoming inferior conjunction of Venus with the Sun (*astamaya* according to *Sūrya Siddhānta*). They also would have noticed that the paths critically crossed, as in the case of a solar eclipse. Even though Bhāskarāchārya gave a procedure for computing *bheda-yuti*, we do not have any commentary from him specific to a transit of Venus event (nor even on the spectacular-looking Halley's Comet, which appeared in 1145 CE).

King Vallālasena (Ballāl Sena; ascended the throne in 1160 CE; Vallālasena, 12th century: vi) deserves mention here for his great interest in astronomy. He was a learned man who made astronomical observations, determined winter and summer solstices and considered celestial phenomena, including comets, in his tome *Adbhutasāgara* that he began in 1168 CE. 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 1168; Vallālasena, 12th century: viii). *Adbhutasāgara* is composed along the lines of the *Brhat Samhitā* and draws from Garga, Vruddha Garga, Parāshara, Varāhamihira, Yavaneswara, Brahmagupta and *Sūrya Siddhānta*, and even from the *Purānas*, the epics *Mahābhārata* and *Vālmiki Rāmāyana* etc. (Vallālasena: ix; Prasad, 1956: 205). The *Adbhutasāgara* has a chapter on *Grahayuddha* (planet wars), and mentions Venus-Sun and Mercury-Sun conjunctions (Vallālasena, 12th century: 46) and the *ayana* points (solstices) that Vallālasena 12th century: 26) says he tested out himself. In the process, whether he encountered the extraordinary Venus-Sun inferior conjunction of 1153 CE we do not know. On the other hand, in the chapter on the Sun, he refers to situations where a hole occurs in the disk of the Sun when Mercury/Venus is positioned *below* it (Vallālasena, 12th century: 46-48). There are several stanzas devoted to hole(s) in the Sun with attendant ominous repercussions, but these were naked eye sunspots. Clark and Stephenson (1978) have examined ancient Korean and Chinese records that mention sunspots, and there are references to those seen during the period of interest here, namely in 1160 CE, 1171 CE, etc. A similar indication comes from Figure 1a in Vaquero (2007), which shows sunspot numbers peaking around this time. Therefore, when Vallālasena talks about holes in the Sun, he may have only been referring to sunspots.

Centuries later, in the times of the astronomer and mathematician Kamlākara (b. ca. 1610 in Varanasi; Pingree, 2008b), there were two transits of Venus, on 7 December 1631 (visible from India) and 4 December 1639. Kamalākara (1658) is well known for his book *Siddhānta Tatva Viveka* that he composed on the pattern of the *Sūrya Siddhānta*. In the various chapters, topics such as eclipses of the Sun and the Moon, mean and true motions of the planets, planetary diameters and distances and the heliacal rising and setting, etc., are dealt with. Chapter 11 considers the phenomenon of planetary conjunctions, and includes stanzas dwelling on planetary transits. Here, certain observations by him are appropriate in the context of the transit of Venus. In stanza 28 in the chapter titled *Bimbādhikara*, which deals with planetary diameters, Kamalākara asserts that

> I do not agree with the objection raised by certain learned people to the idea that Mercury and Venus create a hole-like appearance on the Sun from whom they acquire the brightness. (Rathnasree et al., 2012; their English translation).

Indian astronomers did not know that a transit of Mercury cannot be seen with the naked eye. But what is significant is that the transit concept existed, and was contested. In fact, in the few stanzas that follow the one above, Kamalākara points out how at conjunction, Venus is quickly lost in the dazzling light of the Sun but shall be visible on the disk of the Sun's during the daytime when their separation is sufficiently small. Kamlākara is so clear on the concept that we can only wonder how he missed the two eclipse-like situations with Venus that came to pass in his younger days, but more importantly, that he thought that the 'hole' made by Venus in the Sun would be large enough as to be seen. His perceptivity is visible in yet another observation: during the moments of a solar eclipse, those living on the Moon should see the eclipse taking place on the Earth (Prasad, 1956: 215). Just consider the angular size of the spot of umbra (~200 km) and you will find him right, knowing that the circumference of the Moon's orbit that he would have used may be at variance with the modern value, but not substantially so.

3 WERE SOME EARLY TRANSITS SEEN WITH THE NAKED EYE?

In some historical records, instances have been cited suggesting that naked eye observations of some early transits of Venus were carried out, for instance by the Assyrians in the sixteenth century BCE and by medieval Arab astronomers in the years 840, 1030, 1068 and 1130 CE, etc. However, no transit occurred in any of these years, so we can safely assume that the sightings were of sunspots. The reader will find more on this in Johnson (1882) and Odenwald (2012).

The Persian polymath Abū Alī Ibn Sīnā (Figure 3; 980–1037 CE), known to early Western sources as Avicenna, records in one of his works, *Compendium of the Almagest*, that "I say that I saw Venus as a spot on the surface of the Sun." The date and place of this observation are not given. This statement has been quoted subsequently by some Muslim astronomers, for example by Nasīr al-Dīn al-Tūsī (1201–1274 CE). A transit of Venus indeed took place in Ibn Sīnā's lifetime, on 24 May 1032 CE (Julian date). Did Ibn Sīnā see this transit or did he merely see a sunspot? In recent times, this question has been addressed by Goldstein (1969) who concluded that "… this transit may not have been visible where he lived." This conclusion was based on input provided by Brian Marsden who in turn used mathematical tables prepared by Jean Meeus (1958) and gave sets of limiting terrestrial latitudes and longitudes where the first and second ingress contact would just be visible.

We have re-examined the question employing Fred Espenak's Transit Predictions and Xavier Jubier's interactive Google transit of Venus maps (Kapoor, 2013). The astronomical circumstances of the transit episode and his specific commentary on it in his monumental work *Kitāb al-Shifā* show that Ibn Sīnā could indeed have obtained a glimpse of the transit of Venus just before sunset from the place he may have observed—Isfahan or Hamadan. That also is the best time to view a transit with the naked eye, should seeing conditions permit. In other words, when Ibn Sīnā said he saw Venus on the face of the Sun, he meant it. We have also considered if Ibn Sīnā's observation could have been of a sunspot. As is apparent from some works on historical sunspot sightings, it is probable that in 1032 CE the Sun was rather quiet. So although the sunspot option cannot be dismissed altogether, it does not emerge as a cogent proposition.[2]

4 *VENUS IN SOLE VISA*: THE TRANSITS OF THE SEVETEENTH CENTURY

After the telescope, the first of the transits of Venus predicted by Johannes Kepler (1571–1630 CE) happened on 7 December 1631 CE, but the next, according to him, was not until 1761 (Whatton, 1859: 17). The Parisian astronomer Pierre Gassendi (1592–1655 CE), who had already observed the transit of Mercury on 7 November 1631, tried unsuccessfully the following month to detect Venus passing over the disk of the Sun even though he observed for the greater part of three successive days (Whatton, 1859: 17). As it happened, the final egress contact was already over at 06:47 UT before the Sun rose at Paris (where sunrise was at 07:34 UT).

Figure 3: The Persian astronomer Abū Alī Ibn Sīnā (after: crystalinks.com/Avicenna.html), who may have observed a transit of Venus in 1032 CE.

Looking through Kepler's (1627) *Tabulae Rudolphinae*, the British amateur astronomer Jeremiah Horrocks (1619–1641 CE; Applebaum, 2012; Chapman, 1990)[3] deduced that there was yet another transit situation, due on 24 November 1639 (Whatton, 1859: 43; i.e. 4 December 1639 CE Gregorian calendar). He planned and was able to observe it using the projection technique from a place fifteen miles north of Liverpool, possibly from Much Hoole. Since he came from a family of watchmakers, we can imagine how Horrocks would have striven to obtain precise observations. Horrocks also told his friend William Crabtree (1610–1644) about

Figure 4: James Gregory, 1638–1675 (after: molecular.magnet.fsu.edu/optics/timeline/people/gregory.html).

the transit and he, too, successfully observed it, from near Manchester (Whatton, 1859: 25, 44-45).

What is of interest here is that Mercury and Jupiter were in conjunction with the Sun around this time, and that Horrocks wrote about that too (Whatton, 1859: 39). This happened around the time the telescope was waiting for the English astronomer William Gascoigne (1612–1644) to introduce a crosswire into the eyepiece, and a micrometer, so as to transform it into a powerful astronomical measuring instrument by 1640. Horrocks had discovered that the Moon's orbit was an ellipse with the centre midway between the two focus, and demonstrated that its apsides slowly advance in the direction of its motion (Whatton, 1859: 12-14). From just three observations that he made during the transit, he drew conclusions that were of unprecedented importance and recorded these in his work, *Venus in Sole Visa* … (published by Johannes Hevelius in 1662), where he described Venus on the Sun as a round body of perfect black colour; he also gave its size as 1′ 16″, a great improvement on the figure of 7′ attributed by Kepler; and he reported the angular diameter of the Sun as 31′ 30″. The event also gave Horrocks an opportunity to correct the mean motion of Venus; find its node; and correct the inclination of its orbit, to 3° 24′. He concluded that the solar parallax could not be greater than 14″, a value much smaller than the figure of 57″ that Kepler had arrived at. This new parallax value corresponded to a mean Earth-Sun distance of 15,000 Earth radii, and since this was substantially different from the prevailing one it had attendant implications for the canonical worldview. Chapman (2005: 17) provides a modern evaluation of Horrocks' observations of the 1639 transit of Venus and the deductions that he made based on these.

Figure 5: Edmund Halley, 1656–1742 (after: www.s9.com/Biography/Halley-Edmund).

It was James Gregory (Figure 4; 1638–1675) in his 1663 book *Optica Promota*, and later Edmund Halley (Figure 5; 1656–1742) in a paper published by the Royal Society in London (see Teets, 2003; van Roode, 2005), who proposed that one should be able to determine the solar parallax, *p*, and deduce a precise value for the distance from the Earth to the Sun by timing the ingress and egress of a transit of Venus from locations on the Earth that differed greatly in latitude. Horrocks' value for the solar parallax contrasts with a figure of 45″ that Halley had derived from his observations of the transit of Mercury on 7 November 1677 (Gregorian calendar) made from the island of St. Helena with a 24-foot telescope. However, Halley considered the value to be inexact since, decades later, he presented a value of 12.5″ when he proposed in his famous paper in the *Philosophical Transactions of the Royal Society* (Halley 1716:454) the method that should be used to determine parallax of the Sun from observations of the upcoming transits of Venus in 1761 and 1769 from locations far apart in latitude so that a more exact value could be derived.

5 THE TRANSITS OF VENUS IN THE EIGHTEENTH CENTURY

Unfortunately, Halley did not live to see the next pair of transits of Venus, which occurred in 1761 and 1769. As the time drew near, these rare and important astronomical events evoked great scientific interest in Europe, and observers were sent to diverse places in different parts of the globe in order to obtain long baselines. In addition, the transits were observed from many observatories in Europe. The British and the French emerged the major players in these activities, notwithstanding the fact that Europe's Seven Years' War (from 1756 to 1763) was raging when the first of the all-important transits occurred. What happened is now part of history and has been well documented by numerous authors (e.g., see various papers in Kurtz, 2005; Maor, 2000; Proctor, 1882; van Roode, 2012; Woolf, 1959; and Wulf, 2012).

5.1 The 1761 Transit of Venus

In London, the Royal Society made plans to observe the 1761 transit. One of its expeditions, led by Nevil Maskelyne (1732–1811) who would later become the Astronomer Royal, went to the island of St. Helena, while the other expedition, led by Charles Mason and Jeremiah Dixon, was destined for Sumatra, but they were forced to observe the transit from the Cape of Good Hope.

While the event would elude American astronomers as it was night-time when the transit happened, the mathematician astronomer John Winthrop (1714–1779) led Harvard's expedition to St. John's, Newfoundland, so as to catch the final phase of the transit just as the Sun rose (see Brasch, 1916).

The French, for their part, prepared four expeditions, to Siberia, Vienna and two southern locations: the astronomer Alexandre Guy Pingré (1711–1796) was sent to the island of Rodriguez in the Indian Ocean, about 1,300km east of Madagascar, while Guillaume Le Gentil (1725–1792) proceeded to India.

The Dutch clergyman Johan Mohr (1716–1775) observed the transits of 1761 *and* 1769 from Batavia, present-day Jakarta, in what then were the Dutch East Indies (see van Gent, 2005).

5.1.1 The Travails of Le Gentil

Guillaume Le Gentil, a French astronomer, originally set sail in 1760 for the French port of Pondicherry in India so that he could observe the 6 June 1761 transit of Venus. Le Gentil had been inducted into astronomy by Jacques Cassini at the Paris Observatory at a young age, and he grew to be a dedicated astronomer. His expedition was part of the international French campaign to use the 1761 transit in order to solve the solar parallax problem that confronted all leading astronomers at this time. However, Le Gentil fell victim to the Seven Years' War which engaged the two European superpowers of France and England at the time, and on 24 May 1761, when off the coast of Malabar, he learnt that the British had taken Mahe and Pondicherry (Proctor, 1882: 55). So he had to return to the Isle de France (now Mauritius) and it was on this voyage, between Point de Galle (in Ceylon, or present-day Sri Lanka) which they reached on 30 May and their arrival at the Isle de France on 23 June that with great difficulty he observed the 6 June transit from the moving ship with a cumbersome refracting telescope of fifteen feet focal length. From the times of the contacts, Le Gentil gave the total duration of the transit as 8h 27m 56 1/2s (The Transit of Venus, 1874).

Disheartened, yet determined not to give up after having ventured so far from France, Le Gentil knew that the next transit, on 4 June 1769 (local time), was also visible from India and South-east Asia, and so he decided to stay in that part of the world for the next eight years in a bid to complete his mission. So it was that he eventually arrived in Pondicherry, on 27 March 1768, more than a year before the transit. By this time the Seven Years War was over and Pondicherry once more was under French control. When Le Gentil landed, Jean Law de Lauriston, the Governor General of French territory in India, treated him well and invited him to find a suitable site and build an observatory. This facility was completed by 11 June, and a drawing of it amongst the ruins of war-torn Pondicherry is shown in Figure 6. The British in Madras then provided Le Gentil with an excellent achromatic telescope of three feet focal length so that he could observe the transit (Hogg, 1951). Le Gentil then began by precisely determining the latitude and longitude of Pondicherry.

In the course of this work he was exposed to Indian astronomy and marveled at the fine art of eclipse calculation developed by the locals and even tried to learn the technique himself. A local Tamil Brahmin then spent just 45 minutes computing the circumstances of the lunar eclipse of 30 August 1765, that Le Gentil had previously observed, and when he compared the Indian astronomer's figures with tables published by Tobias Mayer—then considered the best in Europe—he was astonished to find that the Tamil results were more accurate. Phillimore (1945: 156) has shown that it was Tamil Brahmins from Trivalour (Trivalore, now Tiruvallur near Chennai) who successfully taught Le Gentil the art of lunar eclipse calculations, 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." (cf. Banerjee, 1920: 157). However, when it came to solar eclipses, Le Gentil found the computations much more difficult to comprehend and to

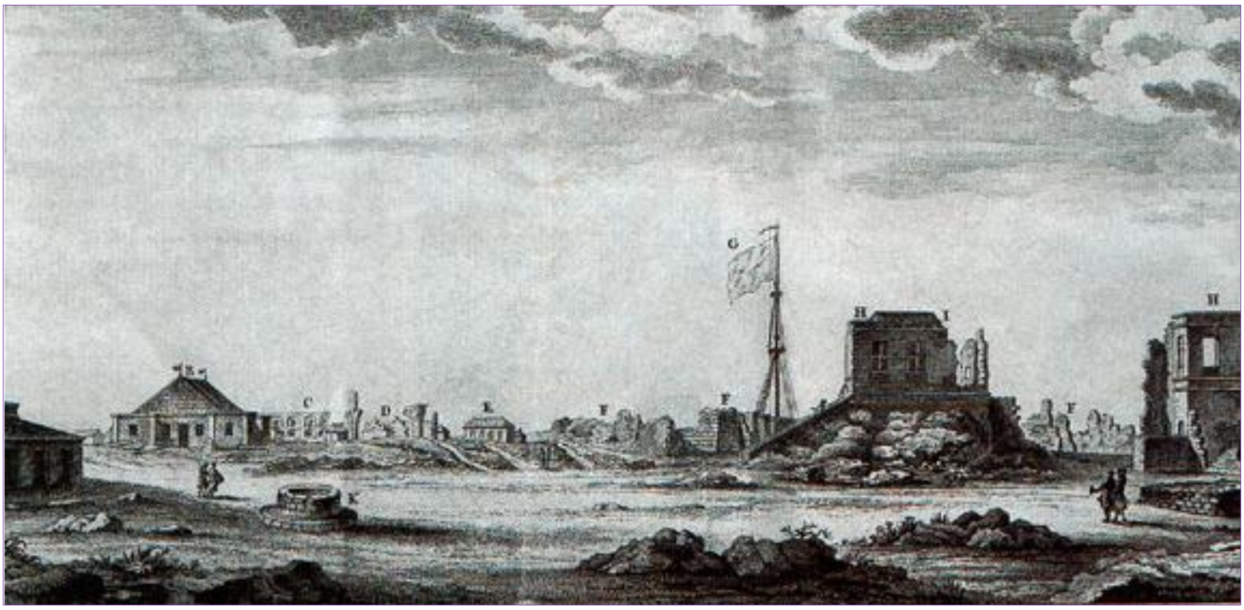

Figure 6: View of part of the ruins of Pondicherry in 1769, seen from the north. Le Gentil set up his observatory in the ruins of the former Governor's palace, the foreground structure (marked H, I) to the right of the flag pole (after en.wikipedia.org).

master. One can only wonder what the Tamil astronomers made of planetary transits once they found out that Le Gentil had come to Asia from the far side of the globe in order to observe two of them. The irony, however, was that on the vital day in 1769 Pondicherry was clouded out, so Le Gentil never got to observe his second transit of Venus and—on this occasion—record accurate contact times.

In a four-part 'essay', Helen Sawyer Hogg (1951) presents us with a wonderful peep into the life and travails of Le Gentil, based on his memoirs, *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*, which were published in two volumes in 1782. And given the disappointing outcome in 1769, Hogg (1951: 37) poignantly refers to Le Gentil's unsuccessful 11-year voyage to the Indian Ocean to observe transits of Venus as "… probably the longest lasting astronomical expedition in history."

5.1.2 The British Observations

Like Le Gentil, the British also planned to observe the 1761 transit from India, but in this instance from several different locations, and primarily with the cooperation of the East India Company (EIC).

The EIC, which was founded in England in 1600, originally established itself in India in 1608 when the Mughal Court of Jehangīr permitted it to start a 'factory' (i.e. a secure warehouse) at Surat (see Figure 1), an important centre of the Mughal Empire for commerce with overseas nations. The EIC was eager to initiate and promote commerce between England and the East. To strengthen its trading activity on the eastern side of the Sub-continent a base was established at Masulipatam on the Coromandal Coast (Figure 1) in 1611. Later the Company established a factory, which it called Fort St. George, at Madraspatnam. The Fort, founded in 1639-1640 and completed in 1653, initially served as a transit outpost, but with the passage of time it grew in importance and eventually became the seat of the expanding British power. Apart from Fort St. George, the EIC had Fort William in Calcutta and the Bombay Castle as its other main seats of power (see Figure 1). These were independent presidencies of the EIC that were governed by a President and a Council. The latter were appointed by the Court of Directors of the EIC in England (see Bowen et al., 2003; Farrington, 2002; Keay, 2010).

Fresh from their victory in 1757 at the Battle of Plassey (Palashi) that established the rule of the EIC in Bengal, the British initiated scientific surveys in order to familiarize themselves with this new territory. This was a great strategic decision that paved the way for rich scientific and other dividends in years to come. As a result, the Trigonometrical Survey of India was founded in 1767, which should be seen as the earliest modern scientific institution in the country.

It was within this atmosphere of emerging scientific endeavour that the 1761 transit of Venus occurred. According to Love (1995: 590), the Royal Society prepared to send two astronomers to Fort Marlborough (Figure 1) to carry out observations of this transit, and the EIC decided to provide local support to them. The EIC Directors also called for volunteers to contribute observations of the transit, and also instructed 'any competent persons' in Fort St. George at the time also to conduct observations (ibid.).

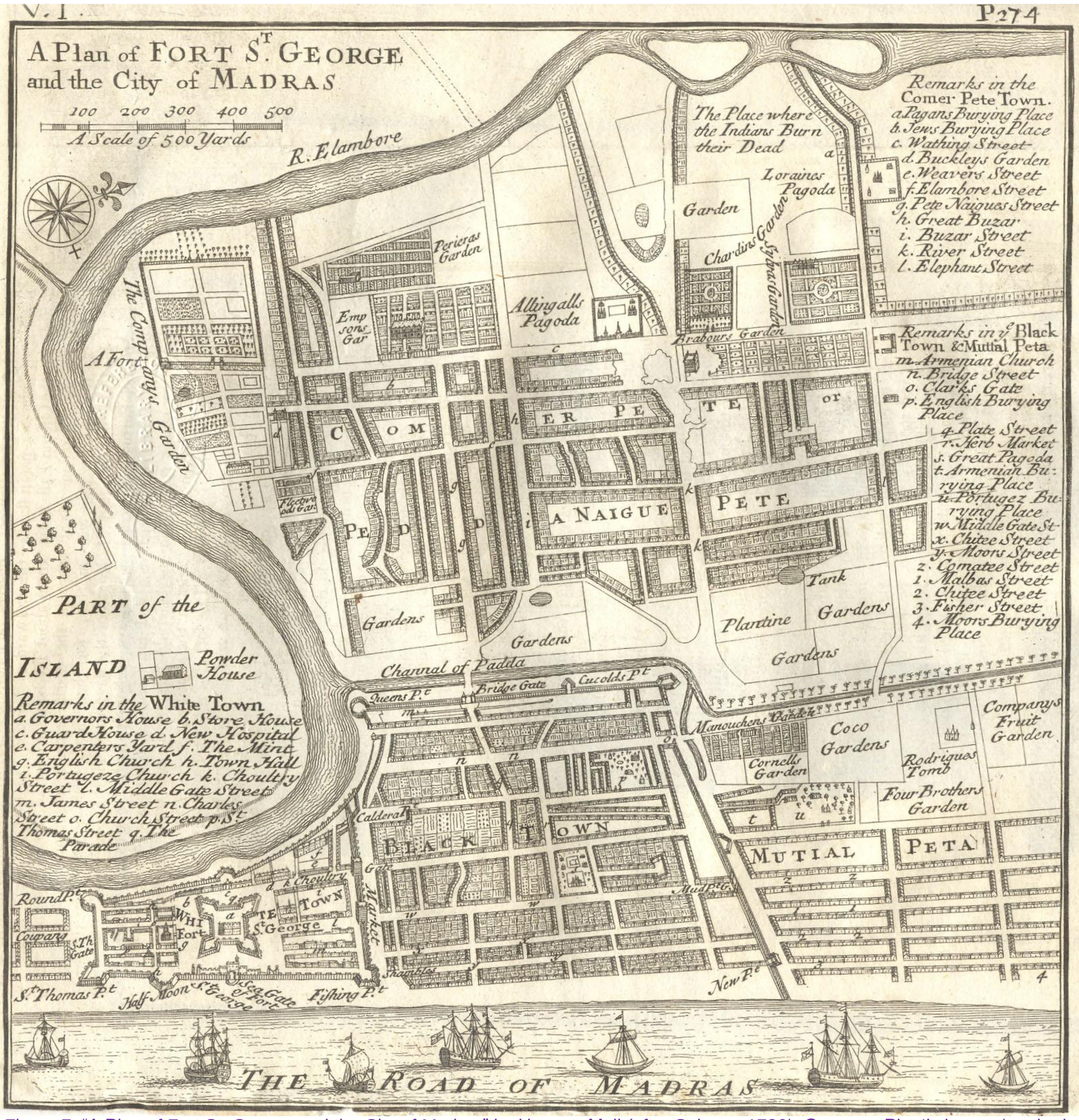

Figure 7: "A Plan of Fort St. George and the City of Madras" by Herman Moll (after Salmon, 1726). Governor Pigot's house (marked with an 'a') is the rectangular building in the White Town on the left of the picture, about half way between the shore and the river.

5.1.2.1 The Observations at Fort St. George, Madras

The 1761 transit of Venus was observed from on top of the Governor's house at Fort St. George, Madras (see Figure 7), by an astronomer, the Reverend William Hirst (d. 1774; Goodwin, 1891; The Royal Society, 2012). Hirst, a chaplain aboard one of His Majesty's ships, had been deputed by the Royal Society to conduct observations of the transit from Madras, and he mentions

> … a reflecter 2 feet long, made by Mr. Adams, of Fleetstreet, London, and lately sent, as a present, by the East India company, to the Nabob Mahommed Allah Cawn, of whom the Governor Pigot was so kind to borrow it, on this occasion. The governor himself, and, also Mr Call, a very ingenious gentleman, assisted in the observation; the former with a 4 feet reflecter, of Mr Dolond's new construction, the latter with a 2 feet reflecter, formerly belonging to Dr. Mead. (Hirst, 1761-1762).

The afore-mentioned 'Nabob Mahommed Allah Cawn' is actually Muhammed Ali, Nawab of Arcot, 'Governor Pigot' is Sir George Pigot (1719–1777) and 'Mr Call' is Captain John Call (1732–1801) who was Chief Engineer of the EIC in Fort St. George (Phillimore, 1945: 153). It was Pigot, who had gifted the 'reflecter' to the Na-wab on behalf of the Company. In his communication to the Royal Society, Hirst writes that the Jesuits for *Pondichery* calculated that the transit would begin at 06h 57m, but London calculations, reduced to the meridian of Fort St. George, gave 07h 26m 35s apparent time. In fact, when the transit occurred, the ingress contact timings were 07h 31m 10s and 7h 47m 35s, and the egress timings were 13h 39m 38s and 13h 53m 44s (apparent time). On 1 July 1761 Hirst wrote to the President of the Royal Society that he had made a significant observation, having seen at the moment of ingress a nebulosity around the planet:

> The morning proved favourable to the utmost of their wishes, which the more increased their impatience. At length, as Mr Hirst was stedfastly looking at the under limb of the Sun, towards the south, where he expected the planet would enter, he plainly perceived a kind of penumbra, or dusky shade, on which he cried out 'tis a-coming, and begged Mr. Call to take notice of it. Two or three seconds after this, namely, at 7^h 31' 10" apparent time, happened the first exterior contact of Venus with the Sun, which all the three observers pronounced the same instant, as with one voice. Mr. Hirst is apprehensive, that to be able to discern an atmosphere about a planet at so great a distance as Venus, may be regarded as chimerical; yet affirms that such nebulosity was seen by them, without presuming to assign the cause. They lost sight of this phenomenon as the planet entered the disk, nor could Mr. Hirst perceive it after the egress. (Hirst, 1761-1762).

Figure 8: Sir George Pigot, 1719–1777, painted by George Willson some time after he left Madras in 1763 and returned to England (after: en.wikipedia.org).

By the time the 1769 transit of Venus came along Hirst was back home in England, and he observed this transit from the Royal Observatory at Greenwich, where Nevil Maskelyne and several others were stationed (Maskelyne, 1769). Hirst's report (1769) on this latter transit is interesting because he reaffirms his impressions about the existence of an atmosphere around Venus (even though he did not notice it on this occasion):

> … when I took the observation of the transit of Venus at Madras, in the year 1761, I saw *a kind of penumbra or dusky shade, which preceded the first external contact two or three seconds of time, and was so remarkable, that I was thereby assured the contact was approaching, which happened accordingly ...* I may venture to say, that my observation of the transit of the present year [1769] seems to corroborate my assertion, in the account of the transit observed in India, in 1761. (His italics).

In addition to his claim to have detected an atmosphere, at ingress Hirst mentions that the planet assumed the shape of a bergamot pear, with the preceding limb of the disc clearly illustrating what is known as the 'black-drop effect'. He tried to rectify any possible defect in his telescope by checking its focus several times, but remained convinced when the same effect also was seen at egress.

On 2 October 1761 Governor Pigot (Figure 8) specifically mentioned Hirst's observations in his report to the Directors of the EIC, as per a packet to England dated 2 October 1761:

> We have the pleasure to inclose to you in this Packet a particular Account of the Observation made on the Transit of Venus the 6^{th} of June by the Reverend Mr. Hirst. This Gentleman is a Member of the Royal Society, which Circumstance, and his extreme Modesty, is the Occasion of this Account being addressed to Lord Maclesfield instead of to you. From all Accounts We have had of the Observations made in these Parts, none are to be depended on equal to this; and we wish, for your Honour and the Interest of this Worthy Clergyman, whom We recommend to you in a particular manner, that it may appear to have been the most accurate. None has equalled us in pains We can venture to assure you. (Love, 1995: 590-591).

Hirst's paper on the 1769 transit also contains another interesting observation made in 1761. In his 1769 paper Hirst reproduces an extract from his original 1761 letter to Lord Macclesfield that was not published at the time, in which he discusses his search for a satellite of Venus. Before the transit Hirst came across a paper by Mr Short in the *Philosophical Transactions of the Royal Society* where he reported observing a stellar-like object near Venus, giving rise to speculation that the planet may have a satellite. Furthermore,

> … a corroborating circumstance was added, viz, M. Cassini, in his *Elements d'Astronomie* mentions a like observation. This I regarded as a favourable opportunity, concluding, that if Venus had a satellite, it must be seen at its transit over the Sun's disc; accordingly, I gave notice of this to Captain Barker, of the Com-

pany's Artillery [now Colonel Sir Robert Barker], who took the observation at Pondicherry. I also mentioned it to the Jesuits, who observed at the Great Mount, about 7½ miles S. 50º W. of Madras, but neither of them saw any appearance in the least like a satellite. I also spoke of it to Governour Pigot [now Lord Pigot], and Mr. Call, who with myself saw not the least speck attending that planet; whence we may now venture to affirm, *That Venus has not a Satellite*.

5.1.2.2 The Bengal Observations

The report from the Bengal Council in Calcutta (now Kolkata) that was sent to the EIC Directors in England was not as enthusiastic as Pigot's missive from Fort St. George:

In consequence of your directions … We delivered copies of the Instructions relative to the Transit of Venus to such gentlemen here as were inclined to make the observation … The only reports we have received are One from Mr. Plaisted taken at Chittagong, and one from Mr. Magee taken here [in Calcutta] ... but for want of proper Instruments they are not of a sufficient exactitude to be of any material use. (Phillimore, 1945: 153).

The EIC was involved in an extensive geographical survey of Bengal, and Bartholomew Plaisted (d. 1767; Sinha, 1949: 357), who originally was trained in nautical astronomy as a sailor and developed an aptitude for determining latitude, surveyed the Chittagong coast in 1760-1761, mostly using observations of the Sun (Phillimore, 1945: 151). He observed the transit of Venus from Chittagong (Figure 1), which is now located in Bangladesh. The Astronomer Royal used Plaisted's observations to derive a longitude of 91º 45′ for Islamabad, as that area was known since the Mughal occupation (Phillimore, 1945: 153). Chittagong, along with Burdwan and Midnapore (Figure 1), had only been ceded to the EIC in the previous year.

William Magee was a notary public in Calcutta. He observed the transit, and subsequently published the contact times listed in Table 2.

Using the semi-diameter passage time as a guide, he estimated that the transit must have commenced at 08h 04m 50s, so its total duration was 6h 22m 48s. As Proctor (1882) later noted:

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. 50 m. 36 s., values which differ much more from each other than parallax will account for.

The Directors of the EIC communicated Magee's observations to the Royal Society via Charles Morton, M.D., F.R.S. Magee (1763) had noted the contact times with a "… stop-watch of Mr. Ellicott's, having no pendulum-clock or time-piece." He made a point of commenting on the behaviour and accuracy of the watch. For several days prior to the transit the sky was cloudy so Magee could not determine the accuracy of the watch, but on the day of the transit he compared its reading with "… a meridian line in the town-hall …", and did so again on 7, 8 and 9 June when the Sun was on the meridian. His contact times listed above are after due corrections. The stop-watch that Magee referred to was manufactured by John Ellicott (1706–1772), an eminent London clockmaker. It was a centre-seconds watch, and a photograph of a similar one that was made by Edward Ellicott senior in 1778 can be viewed at the website of The British Museum (2013) where it is stated that "It is unfortunate that Mr Magee did not mention the number of the Ellicott watch he used".[4]

There is something odd about the position of Magee's reported observing site in his 1763 paper in the *Philosophical Transactions of the Royal Society*. The title of this paper includes his position as "… Latitude 22º 30′, Longitude East from London nearly 92º", but since the co-ordinates of Calcutta are 22° 34′ N, and 88° 22′ E. this would suggest that he did not observe from there but rather from a site about 25 km northeast of Chittagong (which has co-ordinates of 22º 22' N and 91º 48' E). Bearing in mind the precision that Plaisted was able to achieve, no observer of the transit could have been so much in error about his location, so we have a little mystery here!

5.1.3 Observations by Some Jesuits

From Tranquebar (now Tharangambadi) in Tamil Nadu (see Figure 1), the transit was observed by some Jesuit priests. Van Roode (2011) has identified the site where the observations were made, near the present-day St. John Primary School. The reports of their observations, together with those made from the "Government

Table 2: Contact times recorded in Calcutta by William Magee (after Magee, 1763).

Observation	Time h m s
Centre of Venus on the Sun's limb at ingress	08 12 54
Interior contact at ingress	08 20 58
Interior contact at egress	14 11 34
Centre of Venus on the Sun's limb at egress	14 19.38
Egress ends	14 27.38

Table 3: Contact times recorded in Tranquebar and Madras (after The same observed …, 1762).

Observation	Madras h m s	Tranquebar h m s
First external contact of Venus with the Sun	07 28 28	07 29 39
Total emersion on the disk of the Sun	07 45 13	07 46 52
Beginning of emersion from the disk of the Sun	13 37 01	13 40 25
Total emersion of Venus's from the disk of the Sun	13 53 07	13 56 34

House, at Madrass", subsequently were published in the *Gentleman's Magazine* in 1762 (Observations of the transit …) and 1764 (Chandlee, 1764), without identifying the observers, but according to Wulf (2012: 207-216) they were British. A later report in the *Gentleman's Magazine* (The same observed …, 1762) gives the contact times for both locations, and these are listed in Table 3. Note that the Madras contact times listed here differ slightly from those that were communicated by Hirst (1761-1762).

What is worth a read is Chandlee's (1764) analysis of the transit event in the *Gentleman's Magazine* where, beginning with Doctor Halley's proposition for transit observations to be made from locations far apart, he comments on the various reports on the transit, including those from Madras and Tranquebar, as giving nothing more than the timings. He asks "… whether the necessary observations were made in places pertinent to the Doctor's design of obtaining the Sun's horizontal parallax …" He laments "… not one of them that I have yet seen, has attempted to say what her [i.e. Venus'] Latitude was at that time, or at any other interval of that transit …" Chandlee (1764) eventually presents that when, using the Tranquebar timings, he goes on to compute and construct, in a very simple but logical manner, the circumstances of the Transit of 1769 for London:

> … from which Times, if we subtract from 30 to 40 minutes, we shall have the Times of beginning, &c. for several places in *Ireland.* Here it is evident, that the Transit of 1769, instead of being, of such short duration, only touching, as it were, the upper limb of the Sun, and invisible to *Europe*, will be as large as that of 1761, come as near the Sun's center, the beginning for a good while visible to the west coast of *Europe* …

Chandlee's (1764) contact times can be comparpared with those predicted by Espenak (2012) for the 1769 transit; and differ by only 16 minutes.

5.1.4 Discussion

The 1761 transit produced widely-differing values for *p*, the solar parallax (Verdun 2004). For instance, the French results ranged from 8.6″ to 10.6″ (Débarbat, 2005: 43).

Table 4: Solar parallax values published by Short in 1762.

Site	*p* (″)
Grand Mount	8.07
Tranquebar	8.36
Madras	9.71
Calcutta	10.34

In a detailed analysis, the Scottish telescope-maker and astronomer James Short (1762; 1764) calculated *p* by reducing the contact times reported by different stations to the meridian of Greenwich. These observations included also those made at Calcutta, Pondicherry, Tranquebar, Madras and Grand Mount, Madras. The last station is identified as "… a place about 8 miles to the S. West of Madrass." (Short, 1762). No details of the activities or observers at Pondicherry and Grand Mount are available. Actually, the Grand Mount, mentioned here refers to the St. Thomas Mount (Parangimalai), a little 300-ft high hillock in Madras which is where the Jesuit Fr. Duchoiselle made his transit observations, and Van Roode (2011) identifies St Thomas Church, near the Grand Mount, as his observing site. The values of *p* that Short (1764: 305) initially derived from the observations of the Indian stations showed considerable variation (see Table 4), but from a careful reanalysis of all of the observations Short (1764) subsequently published a mean solar parallax value of 8.56″.

Wulf (2012: 207-216) provides a detailed list of 1761 transit observers of various nationalities in the Indian region. We find the following people listed who independently observed the transit but did not submit formal reports: Messrs Martin, Ferguson and Robert Barker, three British observers in Pondicherry; a Mr Harding in Bombay; and John Knott in Chittagong. Hirst (1769) also mentions a "Capt. Robert Barker of the Company's Artillery …" Hirst (1761-1762) also was aware that there were Jesuit observers in Pondichery, but he does not name them.

The only Jesuit observer I have been able to identify is Gaston-Laurent Coeurdoux (1691–1779), who was in Pondicherry at the time, and Ines Zupanov, an authority on the French Jesuits in Pondicherry, agrees with this (pers. comm., 2013). Coeurdoux had observed the 'great comet' of March-April 1759, which a few years later would become known as 'Halley's Comet'. Meanwhile, the 'Mr. Martin' mentioned above would have to be Claude Martin (1735–1800) who was an officer in the French army and later joined the army of the East India Company after the French lost Pondicherry to the British on 16 January 1761.

Compared to what was deduced by Horrocks from his observation of the 1639 transit and assumed by Halley in 1716 in his transit of Venus proposal, the 1761 transit results were a step in the right direction, but the spread in the values of the solar parallax far exceeded Halley's expectations.

Muthiah (2011: 1002-1005) quotes an interesting observation made by Nirupama Raghavan,[5] that the Valleswarar Temple on South Mada Street in Mylapore (Madras)—believed to have been built about 300 years ago by a community called Sengunathars—was possibly consecrated on 6 June 1761, the day of the transit of Venus. This temple is dedicated to *Velli* (*Shukra* – Venus). *Sukra* is, of course, male.

5.2 The 1769 Transit of Venus

The next transit of Venus occurred on 3-4 June 1769, and since the plan was to carry out observations from widely-separated locations, some astronomers were destined to embark on long and arduous voyages. But the Seven Years War was over, which helped, and the astronomers knew what was in the offing and so were better prepared than in 1761.

In 1768, the Royal Society in London petitioned King George III to fund scientific expeditions to observe the up-coming transit of Venus. Undoubtedly, the most famous expedition undertaken was to Tahiti in the Pacific, led by James Cook (1728–1779). A comparatively young and relatively unknown junior officer, Cook was promoted to the rank of Lieutenant and given command of His Majesty's Bark *Endeavour*. Cook also served dual roles, for he was one of the two official astronomers on the expedition; the other was Charles Green. Both astronomers were supplied with the latest instruments by the Royal Society and the Royal Observatory. See Orchiston (2005) for a detailed account of Cook's Tahitian expedition. Meanwhile, the Royal Society also organized expeditions to Ireland, Cornwall, Norway and Hudson's Bay.

The French also prepared to observe the transit, from home and from abroad (e.g. see Débarbat, 2005).

Subsequently, Thomas Hornsby (1771) published a value for the solar parallax of 8.78″ on the basis of British and selected other international observations of the transit in 1769, and this just happens to be very close to the currently-accepted value of 8.794148″ (Dick et al., 1998). Meanwhile, the French derived a number of different parallax values (based on different suites of observations) and these ranged between 8.43″ and 8.80″, leading to intensive scrutiny in the quest for a precise value (see Débarbat, 2005).

5.2.1 Indian Observations of the 1769 Transit

Love (1995: 591) documents how, on 22 January 1768, the Royal Society once again sought help from the East India Company (EIC) regarding the up-coming 1769 transit of Venus:

> In obedience to the Orders of the Royal Society, I take the liberty to apply to you in their name, and Solicit your concurrence in an affair of some importance to the Advancement of Science and the honor of this Country. The next Transit of the Planet of Venus over the Disc of the Sun, which is expected on the June 3rd, 1769, will afford the only means of ascertaining some of the principal and hitherto unknown elements in Astronomy, and of improving both Geography and Navigation. The first Phenomenon of this kind ever taken notice of was observed above a Century ago, by an Englishman, and the last, which happened in 1761, excited the Curiosity of most Nations in Europe; but on account of the War and the want or inexperience of the Observers, the fruits expected from this Observation, and foretold by the great Dr. Halley, were but partly obtained. An opportunity of the same kind will again offer itself, and as it is the last which the present and succeeding Generations will have for at least a hundred Years to come, it is to be hoped, and indeed expected, that an universal emulation will extend itself all over the Continent on so interesting an occasion. The honor of this Nation seems particularly concerned in not yielding the palm to their Neighbours, and the Royal Society intends to exert all its strength and influence in order to have this observation made with the greatest accuracy, and, if possible, in the most uniform and satisfactory manner in various parts of the British Dominions. The experience they have had of the readiness of this potent Company to forward every great and national undertaking does not permit them to doubt of their taking a share in this. They therefore hope that it will be early and earnestly recommended to such of the Company's Servants at Madras, Bombay, Bencoolen, or other Places in the East Indies as have been accustomed to Astronomical Observations to prepare for and exert themselves in this … (cf. Sinha, 1949: 114-115).

In this letter, the 'East Indies' would mean the Indian region together with the mainland southeast Asia, Indonesia and the Philippines, while 'Bencoolen' was the original name of the city of Bengkulu in Sumatra. Going by the letter's language, there seems to be an element of persuasion here, but this had the desired effect as the Directors of the EIC once again sent out requests to its staff, stressing the importance of this transit (Phillimore, 1945: 153), and

> Recommend to such of the Company's servants at Madras, Bombay, Bencoolen ... as have been accustomed to Astronomical observation to prepare for, and exert themselves in this … Instruments required,
> 1. Reflecting Telescope. 2 ft. focus, with apparatus of smoked glasses.

2. A Pendulum Clock.
3. An Astronomical Quadrant, of 1 ft, radius at least, or in lieu of it, an Equal-Altitude Instrument.

For its part, this letter also produced the desired result, for on 3/4 June 1769 the transit was observed from a number of different locations in India.

5.2.1.1 The Dinapoor Observations

Luis Degloss, the Captain of Engineers who was employed at the Dinapoor gun foundry, observed the transit from Dinapoor with three quadrants and a reflecting telescope, assisted by J. Lang and A. Stoker. At sunrise, it was cloudy but at 05h 20m 32s, "… the Sun disengaged from the clouds when Venus appeared on the ☉'s disk." (Degloss, 1770). Degloss timed the first egress contact at 07h 5m 22s and the second egress contact at 07h 23m 36s. He gave his co-ordinates as 25º 27′ N. Dinapoor (Dinapore, now Danapur; which has a latitude of 25º 38′ N and longitude of 85º 03′ E according to the *Imperial Gazette of India*, 11: 355) is very close to Patna in Bihar. Interestingly, post-transit, a dispatch from Fort William to the Court of Directors (see Sinha, 1949: 584) advised that

> The Instruments you sent out to observe the transit of Venus with did not arrive in time to be of any Service. Captain Du Gloss is the only person who hath made any observations on the Transit which agreeable to your orders are recorded on our Consultations and we have also sent you a Copy of them a Number in this Packet.

5.2.1.2 The Phesabad Observations

Captain Alexander Rose of the 52d Regiment observed the transit from Phesabad in Bengal (latitude 25º 30′ N; see Figure 1) with a telescope (of undisclosed aperture) and a stopwatch. Rose (1770) only began observing the transit at 05h 35m 57s (local time) when it was in an advanced stage. He timed the first egress contact at 06h 52m 25s and the last egress contact at 07h 10m 47s, the duration of the egress therefore being 18m 22s. These observations were contained in a report dated 20 August 1769 that Rose (1770) sent to the mathematician Dr Patrick Murdoch, F.R.S. (d. 1774; The Royal Society, 2013) who, from the times of the contacts, determined that the planet's centre was on the limb of the Sun at 07h 01m 36s. Murdoch then added his own comments: "… this compared with an observation of the central egress made at a different place will give the sun's parallax." (ibid.). Murdoch said that the stop-watch had been regulated the previous day by equal altitudes of the Sun, and he deduced the longitude of Phesabad to be 81º 45′ east of Paris. This value indicates that Rose's observing site was ~10 km south-east of Buxar in Bihar.

5.2.1.3 Observations Planned for Fort St. George Pondicherry and Masulipatam

Apparently, on this occasion there was little interest shown in the transit by those stationed at Fort St. George (Love, 1995: 591), and sensing this, the Astronomer Royal, Nevil Maskelyne, persuaded the Chief Engineer, John Call, to observe the event. However, a sudden storm on the crucial day led to a thick cloud cover, dashing any hope of making successful observations:

> The Instruments which your Honors sent for observing the Transit of Venus having arrived in time, Mr. Call with the assistance of the other Engineers undertook to adjust every preparative for an accurate observation; but after taking great pains to regulate the time-keeper, and adjust the Instruments, the expected Observation was entirely frustrated by a change of weather coming on the 3rd June, which occasioned so cloudy a morning on the 4th that the Sun was not visible till 10 o'clock; the same ill success attended Monsr. Gentil [180 n.3] sent purposely the year before from France to Pondicherry, and Mr. Stevens [92] who had fitted an apparatus at Masulipatam was equally disappointed … The Instruments for Bombay could not possibly be sent thither in time … (Phillimore, 1945: 153-154):

The 'Mr. Stephens' referred to here is William Stevens (d. 1778), who was then Engineer at Masulipatam, and employed on fortifications and works (Phillimore, 1945: 385-386).

In his memoirs, Le Gentil also talks about John Call's aborted observations:

> 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. (Hogg, 1951: 132).

We should recall that John Call assisted the Reverend William Hirst when he successfully observed the 1761 transit from Fort St. George.

6 CONCLUDING REMARKS

This review demonstrates that India contributed to the international campaigns to observe the 1761 and 1769 transits of Venus, especially during the earlier transit when clear skies allowed some uninterrupted observations. Undoubtedly, one the most interesting observations made from the Subcontinent was the reported detection by the Reverend William Hirst and his

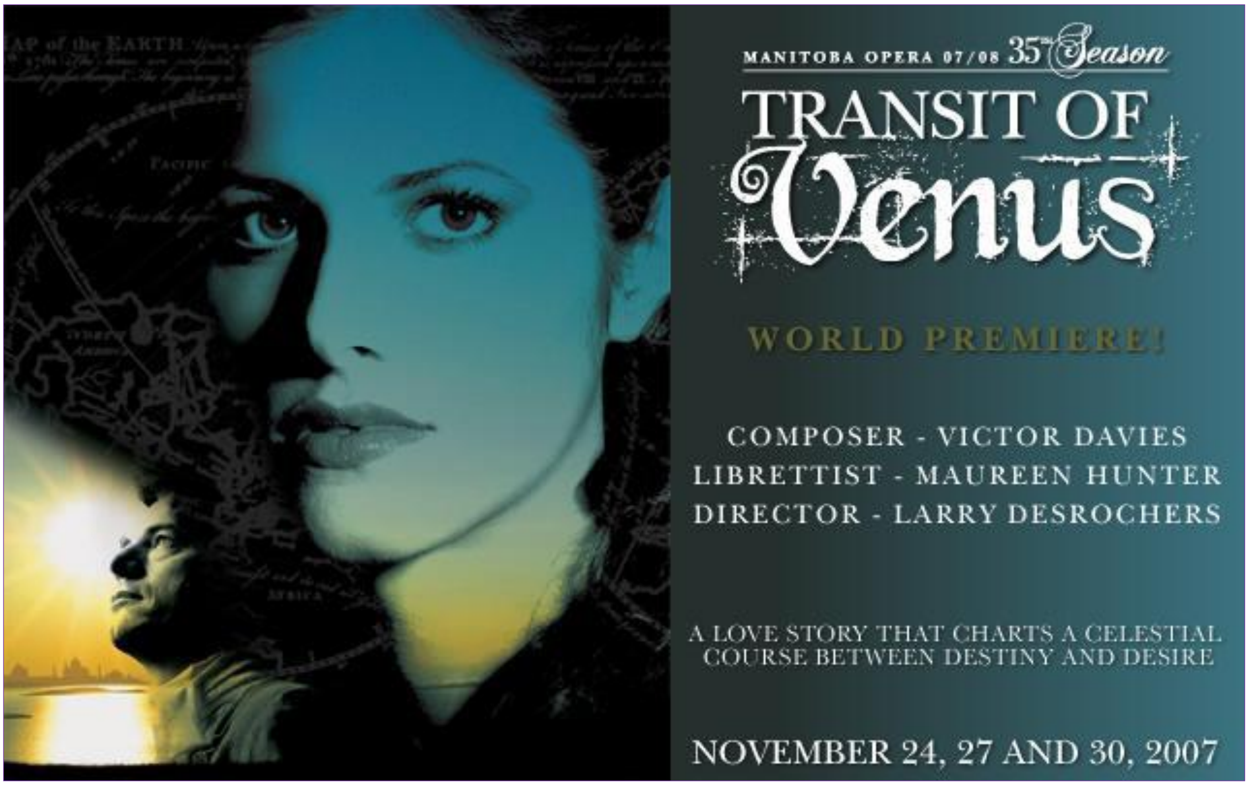

Figure 9: Advertisement for the 'Transit of Venus' opera (after: http://www.manitobaopera.mb.ca/transitofvenus/).

colleagues of an atmosphere around Venus in 1761. However, they were not the only astronomers at this time who claimed to have made such observations, and the reputed 'discovery' of the Cytherian atmosphere by the Russian astronomer Mikhail Lomonosov (1711–1765) is perhaps the best known of these (e.g. see Marov, 2005). However, recently Pasachoff and Sheehan (2012: 3) clearly demonstrated that the 'aureole' or 'dusky ring' observed around the planet was not an atmosphere:

> It has only recently become clear that these effects are produced by the smearing of the isophotic contours of the planet's disk by a combination of solar, instrumental and terrestrial-atmospheric effects.

Similarly, the black-drop effect which Hirst et al. also noticed, was not associated with Venus' atmosphere, and is now known to have been caused

> … by a combination of the point-spread function of the telescope smearing any image, in combination with the solar limb darkening, which is especially marked in the arcsecond or so nearest the limb that shows the black drop. (Pasachoff and Sheehan, 2012: 1; cf. Pasachoff et al., 2005; Schneider et al., 2004).

It is only fair to mention that at this time most astronomers assumed that other planets in the Solar System harboured life, so the appearance of an atmosphere around Venus was pretty much taken for granted (see Pasachoff and Sheehan, 2012: 5-6).

In marked contrast to Hirst's otherwise successful observing campaign is Le Gentil's unsuccessful bid to obtain accurate contact times for either the 1761 *or* the 1769 transit, and his 11-year sojourn in the Indian Ocean and in India must rank as one of the saddest tales in the saga of international eclipse and transit of Venus expeditions. Is it little wonder then that there is an opera titled *Transit of Venus* which was inspired by his fateful expeditions (see Figure 9). It is in three Acts and is based on a play with the same name by the Canadian playwright, Maureen Hunter, and presented "… a love story that charts a celestial course between destiny and desire." (Manitoba Opera, 2007).[6] In his own memoirs, Le Gentil reflects on this:

> 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 … (Hogg, 1951: 132).

As the 1874 transit of Venus drew near and public excitement grew, *The New York Times* published in its 25 July 1874 edition Le Gentil's life history, from articles by M.W. De Fonvielle in *La Nature*, that revealed his travails from the period 1760 to 1771 and his observations in more detail. The account revealed that while he was absent from France Le Gentil had been replaced at the Academy of Sciences (he was reinstated subsequently) and his property was claimed by his relatives after his death was announced many times over (*The New York Times*, 1874). Nonetheless, Le Gentil's name remains etched in astronomical history, not so much for his abortive transit observations, but rather for his discovery of a few deep sky objects, including the Lagoon Nebula and the companion to the Andromeda Galaxy. It is only fitting that he was honoured in 1961 when a crater on the Moon was named after him (see Frommert and Kronberg, 2012).

Finally, the 1769 transit of Venus was unique in that it was followed a few hours later by a total solar eclipse which was visible from the Arctic region. One can only imagine what an impact this would have had on international astronomy had the eclipse occurred a few crucial hours earlier, with the path of totality traversing more accessible northern latitudes.

6 NOTES

1. The 'solar parallax' is defined as one half the equatorial diameter of the Earth as viewed from the Sun. The currently-accepted value is 8.794148″ (Dick et al, 1998).
2. We also should mention here Mirzā Abū Ṭālib (1752–1805/6), a well known Persian astronomer and natural philosopher, who served the Nawab Asaf ad-Dawlah of Awadh. Ṭālib wrote on diverse topics in astronomy, including the phenomenon of planetary transits, and a short account of his work (in Persian) is presented by Ansari (2002). While supporting the heliocentric system through the instance of Venus and Mercury seen as dark spots transiting the disc of the Sun, Ṭālib refers to Qutbuddīn Shīrāzī (1236–1311 CE) being in the know about transits of Venus. Shīrāzī, who was a disciple of the legendary Persian astronomer Naṣīr al-Dīn al-Ṭūsī (1201–1274 CE) and trained at Marāgha Observatory, wrote on Ptolemaic planetary theory and about the transits, and he may have learnt about these from the works of Ibn Sīnā and Ibn Bājja (ca. 1095–1138/9 CE).
3. Sometimes his name is given as 'Horrox', as in the Register of Emmanuel College, Cambridge (e.g., see Whatton, 1859: 3, 5).
4. It is interesting to note that John Ellicott also observed the transit, but from London, in the company of John Dollond (Wulf, 2012).
5. Nirupama Raghavan was a student of M.K. Vainu Bappu (1927–1982) at the Kodaikanal Observatory in the 1960s, and the first woman to take up observational astronomy in India after Independence.
6. It is worth mentioning that although inspired by Le Gentil's saga, both the play and the opera are largely fictitious.

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8 REFERENCES

Ansari, S.M.R., 2002. European astronomy in Indo-Persian writings. In Ansari, S.M.R. (ed.). *History of Oriental Astronomy*. Dordrecht, Kluwer Academic Publishers. Pp. 133-144.

Applebaum, W., 2012. *Venus Seen on the Sun. The First Observation of a Transit of Venus by Jeremiah Horrocks*. Linden, Brill.

Banerjee, G.N., 1920. *Hellenism in Ancient India. Second Edition*. London, published by the author.

Bhat, M.R., 1986. *Varahamihira's Brhat Samhita, Part 1I*. Delhi, Motilal Banarsidass.

Bowen, H.V., Lincoln, M., and Rigby, N. (eds.), 2003. *The Worlds of the East India Company*. Rochester, Brewer.

Brasch, F.E., 1916. John Winthrop (1714-1779), America's first astronomer, and the science of his period. *Publications of the Astronomical Society of the Pacific*, 28, 153-170.

British Museum, The, 2013. Stop-watch / centre-seconds watch, made by Edward Ellicott senior (http://www.britishmuseum.org/research/search_the_collection_database/search_object_details.aspx?objectId=57609&partId=1&searchText=transit+venus&fromADBC=ad&toADBC=ad&orig=%2Fresearch%2Fsearch_the_collection_database.aspx&numpages=10&currentPage=1).

Chandlee, E., 1764. Some considerations on the transit of Venus over the Sun's disk. *The Gentleman's and London Magazine*, April, 201-203.

Chapman, A.A., 1990. Jeremiah Horrocks, the transit of Venus, and the 'new astronomy' in early seventeenth century England. *Quarterly Journal of the Royal Astronomical Society*, 31, 333-357.

Chapman, A. 2005. Jeremiah Horrocks, William Crabtree, and the Lancashire observations of the transit of Venus of 1639. In Kurtz, 3-26.

Clark, D.H., and Stephenson, F.R., 1978. An interpretation of the pre-telescopic sunspot records from the Orient. *Quarterly Journal of the Royal Astronomical Society*, 19, 387-410.

Débarbat, S., 2005. Venus transits: a French view. In

Kurtz, 41-50.
Degloss L., 1770. 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 ... *Philosophical Transactions of the Royal Society*, 60, 239.
Espenak, F., 2012. *Six Millennium Catalog of Venus Transits: 2000 BCE to 4000 CE,* NASA Eclipse Web Site(http://eclipse.gsfc.nasa.gov/transit/catalog/Ven us Catalog.html).
Farrington, A., 2002. *Trading Places: The East India Company and Asia, 1600–1834*. London, British Library.
Frommert, H., and Kronberg, C., 2012. Guillaume-Joseph-Hyacinthe-Jean-Baptiste Le Gentil de la Galazière (September 11, 1725 - October 22, 1792) (see http://messier.seds.org/xtra/Bios/legentil.html).
Garga, 100 BCE-100 CE. *SriGargaSamhita*, Gorakhpur, Geeta Press Edition (in Hindi).
Gent, R. van, 2005. Observations of the 1761 and 1769 transits of Venus from Batavia (Dutch East Indies). In Kurtz, 67-73.
Gent, R. van, 2012. Transits of Venus. (see http://www. staff.science.uu.nl/~gent0113/venus/).
Goldstein, B.R., 1969. Some medieval reports of Venus and Mercury transits. *Centaurus*, 14, 49-59.
Goodwin, G., 1891. Hirst, William. In *Dictionary of National Biography: Volume 27*. London, Smith, Elder & Co.
Halley, E. 1716. A new method of determining the parallax of the sun, or his distance from the earth. *Philosophical Transactions of the Royal Society*, 29, 454-464 (in Latin).
Hirst, W. The Rev, 1761-1762. An account of an observation of the transit of Venus over the Sun, on the 6th of June 1761, at Madrass … *Philosophical Transactions of the Royal Society*, 52, 396-398.
Hirst, W. the Rev., 1769. Account of several pheenomena observed during the ingress of Venus into the solar disc. *Philosophical Transactions of the Royal Society*, 59, 228-235.
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 and 173-178.
Johnson, S.J., The Rev., 1882. On a probable Assyrian transit of Venus. *Monthly Notices of the Royal Astronomical Society*, 43, 41.
Jubier, X., 2013. Interactive Google maps for Venus transits (http://xjubier.free.fr/en/index_transit.html).
Kamlākara Bhatt, 1658. *SiddhāntaTatvaViveka.* Delhi, Chaukhamba Sanskrit Pratishthan. Reprinted 2009 (in Sanskrit).
Kapoor, R.C., 2012. Venus in India: the Transit Tales. April 2012, Bangalore, Indian Institute of Astrophysics (http://prints.iiap.res.in/handle/2248/5757).
Kapoor, R.C., 2013. Did Ibn Sīnā observe the transit of Venus 1032 CE? *Indian Journal of History of Science*, in press.
Kapoor, R.C., 2014. Indian astronomy and the transits of Venus. 2: the 1874 event, *Journal of Astronomical History & Heritage*, in press.
Keay, J., 2010. *The Honourable Company: A History of the English East India Company*. HarperCollins UK.
Kurtz, D.W., (ed.), 2005. *Transits of Venus: New Views of the Solar System and Galaxy.* Cambridge, Cambridge University Press,.
Love, H.D., 1995. *Vestiges of Old Madras 1640-1800*, New Delhi, Mittal Publications.
Magee, William 1763. Minutes of the observation of the transit of Venus over the Sun, the 6th of June 1761, taken at Calcutta in Bengal … *Philosophical Transactions of the Royal Society*, 52, 582-583.
Manitoba Opera, 2007. *Transit of Venus* by Maureen Hunter.
Maor, E., 2000. *June 8, 2004 Venus in Transit*. Princeton, Princeton University Press.
Marov, M., 2005. Mikhail Lomonosov and the discovery of the atmosphere of Venus during the 1761 transit. In Kurtz, 209-219.
Maskelyne, N. 1769. Observations of the transit of Venus over the Sun, and the eclipse of the Sun … *Philosophical Transactions of the Royal Society*, 58, Pp. 355-365.
Meeus, J., 1958. The transits of Venus 3000 B.C. to A.D. 3000. *Journal of the British Astronomical Association,* 68, 98-108.
Muthiah, S., 2011. *A Madras Miscellany: A Decade of People, Places & Potpourri*. East West Chennai.
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.
O'Connor J.J., and Robertson E.F., 2000. *Sripati.* School of Mathematics and Statistics, University of St Andrews (see http://www-history.mcs.st-andrews.ac.uk/Biographies/Sripati.html).
Observations on the Transit of Venus over the Sun, at the Government House, at Madrass, in the East Indies, June 6, 1761, *The Gentlemen's Magazine*, 32(April), 177 (1762).
Odenwald, S., 2012. A brief history of the transit of Venus, In NASA. *Technology Through Time*, 73,
Orchiston, W., 2005. James Cook's transit of Venus expedition to Tahiti. In Kurtz, 52-66.
Pasachoff, J.M., Schneider, G., and Golub, L., 2005. The black-drop effect explained. In Kurtz, 242-253.
Pasachoff, J.M., and Sheehan, W., 2012. Lomonosov, the discovery of Venus' atmosphere, and eighteenth century transits of Venus. *Journal of Astronomical History and Heritage*, 15, 3-14.
Phillimore, R.H., 1945. *Historical Records of the Survey of India Eighteenth Century*, *Volume 1.* Dehra Dun, The Surveyor General of India, Survey of India.
Pingree, D., 2008a. Śrīpati. *Complete Dictionary of Scientific Biography.* (Encyclopedia.com. http://www. encyclopedia.com).
Pingree, D., 2008b. Kamalākara. *Complete Dictionary of Scientific Biography*. (Encyclopedia.com. http:// www.encyclopedia.com).
Prasad, G., 1956. *Bharatiya Jyotish ka Itihas*. Lucknow, Prakashan Bureau, Uttar Pradesh Sarkar (in Hindi).
Proctor, R.A., 1882. *Transits of Venus*, London, Longmans, Green, and Co.
Rao, B.S., 2005. *Indian Mathematics and Astronomy* Bangalore, Bhavan's Gandhi Centre of Science and Human Values.
Rao, B.S., and Venugopal, P, 2009. *Transits and Occultations in Indian Astronomy*. Bangalore, Bhavan's Gandhi Centre of Science and Human Values.
Rathansree, N., Shylaja B.S., Kaidala, G., and Mukherjee, A., 2012. A search for records of planetary transits in India prior to the colonial period. *Current*

Science, 103, 95-97.
Roode, S.M. van, 2005. Halley's method of durations: Its history and appliance (http://www.Transitofvenus.nl/halleysmethod.pdf).
Roode, S. van, 2011. Transit of Venus: 1639-2012 (http://maps.google.co.in/maps?hl=en&gs_rn=8&gs_ri=psyab&cp=55&gs_id=4q&xhr=t&bav=on.2,or.r_qf.&bvm=bv.44770516,d.bmk&biw=1920&bih=895&wrapid=tljp13650663025910104&q=http://www.transitofvenus.nl/transit_venus_2012.kmz&um=1&ie=UTF-8&source=websearch).
Roode, S. van, 2012. Historical observations of the transit of Venus (http://www.transitofvenus.nl/history.html).
Rose, A, 1770. Extract of two letters from the late Capt. Alexander Rofe of the 52d Regiment to Dr. Murdoch, F.R.S. *Philosophical Transactions of the Royal Society*, 60, 444-450.
Royal Society, The, 2012. Ingress of Venus and "black drop" effect during the 1769 transit of Venus, date 12 June 1769 creator William Hirst (d. 1774, British), Astronomer (https://pictures.royalsociety.org/image-rs-9606).
Royal Society, The, 2013. Library Collection: Fellow Details: Murdoch, Patrick (http://royalsociety.org/DServe/dserve.exe?dsqIni=Dserve.ini&dsqApp=Archive&dsqCmd=Show.tcl&dsqDb=Persons&dsqPos=1&dsqSearch=%28Surname%3D%27murdoch%27%29).
Salmon, T., 1726. *Modern History: or, the Present State of the Nations*. London, Bettesworth & Hitch.
Schneider, G., Pasachoff, J.M., and Golub L., 2004. TRACE observations of the 15 November 1999 transit of Mercury and the black drop effect: considerations for the 2004 transit of Venus. *Icarus*, 168, 249-256.
Selin, Helaine, 1997. *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*. Springer.
Sen, S.N. and Shukla, K.S. (eds.), 2000. *History of Astronomy in India*. *Second revised edition*. New Delhi, Indian National Science Academy.
Short, J., 1762. The observations of the internal contact of Venus with the Sun's limb, in the late transit, made in different places of Europe, compared with the time of the same contact observed at the Cape of Good Hope, and the parallax of the Sun from thence determined. *Philosophical Transactions of the Royal Society*, 52, 613-628.
Short, J., 1764. Second paper concerning the parallax of the Sun determined from the observations of the late transit of Venus, in which this subject is treated of more at length, and the quantity of the parallax more fully ascertained. *Philosophical Transactions of the Royal Society*, 53, 300-345.
Shukla, K.S., 2000. Phases of the Moon, Rising and setting of planets and stars and their conjunctions. In Sen, and Shukla, 236-275.
Sinha, N.K., 1949. Fort William-India House correspondence and other contemporary papers relating thereto (Public Series, 5, 1767-1769). Delhi, National Archives of India, Government of India.
Somayaji, A., 2000. The Yuga system and the computations of mean and true planetary longitudes, in Sen and Shukla, 162-207.
Teets, D.A., 2003. Transits of Venus and the astronomical unit. *Mathematics Magazine*, 76, 335-348.
The same observed by the Jesuits at Tranquebar. *The Gentlemen's Magazine*, April 1762, p. 177.
The transit of Venus: Le Gentil's observation in the last century. *The New York Times*, 25 July 1874.
Vallālasena, 12th Century. *Adbhutasāgara* (Hindi translation by Shivakant Jha, 2006). Varanasi, Chaukhamba Surbharti Prakashan (in Sanskrit).
Vaquero, J.M., 2007. Historical sunspot observations: a review. *Advances in Space Research,* 40, 929-941.
Verdun, A., 2004. The determination of the solar parallax from transits of Venus in the 18th century, *Archives des Sciences,* 57, 45-68.
Whatton, W.R., 1859. *Transit of Venus Across the Sun; A Translation of the Celebrated Discourse Thereupon by Jeremiah Horrocks*, Memphis, General Books.
Woolf, H., 1959. *The Transits of Venus: A Study in the Organization and Practice of Eighteenth-Century Science*. Princeton, Princeton University Press.
Wulf, A, 2012. *Chasing Venus: The Race to Measure the Heavens*. London, Random House.

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