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CASSINI'S 1679 MAP OF THE MOON AND FRENCH JESUIT OBSERVATIONS OF THE LUNAR ECLIPSE OF 11 DECEMBER 1685

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Abstract: On 18 February 1679 Paris Observatory astronomer Jean Dominique Cassini presented a new map of the Moon to the Academy of Sciences in Paris, and this then became the standard reference work for French astronomers who carried out selenographical observations. Among these was a contingent of Jesuit missionary-astronomers who sailed from Brest on 3 March 1685, bound for China. *En route* they were forced to spend some months in Siam (present-day Thailand) and used the map when they observed the lunar eclipse of 11 December 1685. In this paper we examine the creation of the 1679 Moon map and its use by the French Jesuit missionary-astronomers in Siam in 1685.

Keywords: Jean Dominique Cassini, Paris Observatory, 1679 map of the Moon, Siam, Lop Buri, King Narai, French Jesuit missionary-astronomers, 11 December 1685 lunar eclipse

1 INTRODUCTION

In a series of research papers we have shown how eclipses and Royal patronage played a key role in the development of astronomy in present-day Thailand (Orchiston et al., 2018; Soonthornthum, 2017). Lunar and solar eclipses largely were responsible for the birth of Western astronomy in Siam during the eighteenth century (Gislén et al., 2019; Orchiston et al., 2016; 2019a; 2019b; cf. Bhumadhon, 2000), and an association with total solar eclipses and Thai Royalty continued during the nineteenth century (Orchiston and Orchiston, 2018; 2019; cf. Aubin 2019; Euarchukiati, 2019; Hutawarakorn-Kramer and Kramer, 2017) and through into the following century (Soonthornthum et al., 2019).

In this paper we provide further details of the lunar eclipse of 11 December 1685, which was one of the two lunar eclipses responsible for the introduction of Western astronomical instruments and observational techniques into Siam. But first we discuss the 1679 map of the Moon that was used at the time by the French Jesuit astronomers.[1]

2 THE MOON MAP OF 1679

Although the story of this map was first reported by Wolf (1902: 168–172), and more recently has been precisely documented by Launay (2003) and Launay and Sheehan (2010), one can still read erroneous data about it. So let us recall briefly the exact story.

Jean Dominique Cassini (1625–1712), the first astronomer of the Cassini dynasty that was to hold the reins of Paris Observatory for 126 years, presented his new Moon map to the Paris Académie des Sciences on 18 February 1679. It was engraved on a large copper plate where the Moon was 53 cm in diameter (Figure 1). It did not show any title or signature but the craftsman who made it, Jean Patigny (*fl.* 1647–1679), is well known because his name appears regularly in *Comptes des Bâtiments du Roi* (Guiffrey, 1881).

What is striking when one looks at the map is the quality of the engraving and the beauty of the representation. However, astronomers were immediately puzzled because this did not look like the Full Moon, where the relief is masked by front lighting from the Sun. Moreover, the orientation of the map, which shows the Moon upside down as if observed through an astronomical refractor, is turned clockwise by about 30°.

On the other hand, what is also striking is a beautiful and delicate heart on the left, and a little to the right, large fragile wings, like those of a dragonfly. Just beyond the tips of these wings, Heraclides promontory appears as a figurehead, showing without any doubt a beautiful young lady whose long hair has been let loose by a breeze. Of course one wonders who this lady could be and whether it was Cassini or Patigny who put

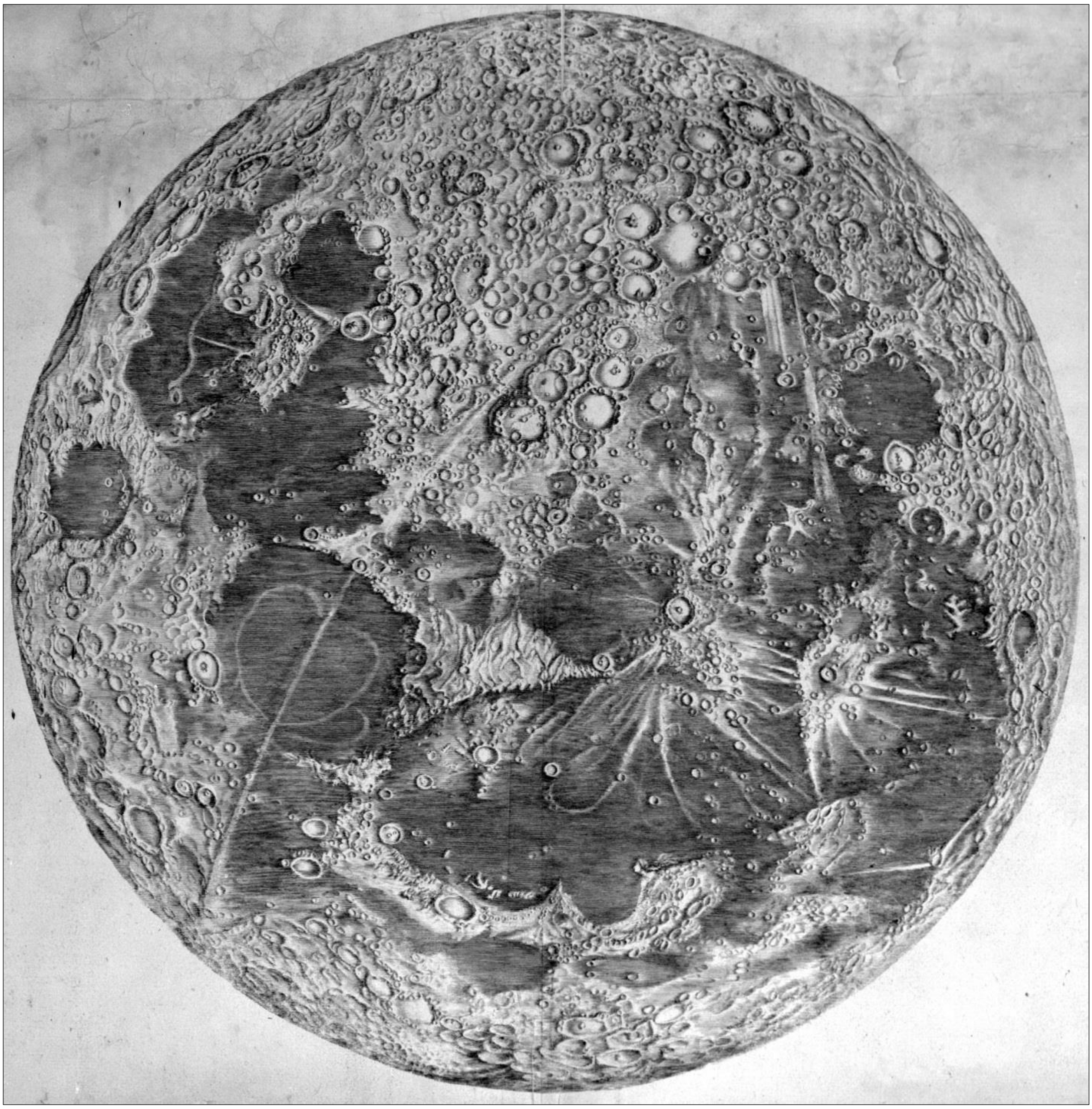

Figure 1: Cassini's map of the Moon was engraved by Jean Patigny and was first printed in 1679 (© Observatoire de Paris, First print, Inv. I 1576).

her on the map. We will return to this point later, in Sections 2.2 and 2.3.

Cassini arrived in Paris on 4 April 1669 at the invitation of the King of France, Louis XIV, and his Comptroller General of Finances, Colbert, but it is only on 14 September 1671 that he was given an apartment in the Perrault building of the newly constructed Paris Observatory. One of his first tasks, which he began on his very first day, was to establish a detailed map of the Moon, which was needed for the calculation of longitude at sea. Cassini was an exceptional observer, but he was not a skilled draughtsman. He made drawings as a scientist not as an artist, and in order to piece these together and produce a map of the Moon he needed the help of a professional draughtsman.

It would take no less than eight years (from 1671 to 1678) for the draughtsman Jean Patigny to achieve all the preparatory drawings. Indeed, to obtain maximum precision during the observations, he could not work when the Moon was full, and during the lunar cycle he drew only the parts situated on the lunar terminator, where the contrast was strongest. The many drawings then had to be assembled, which is why the Moon map looks so amazing, with such surprising relief. This is perhaps the reason why a more realistic map (Figure 2) was prepared for observation of the 28 July 1692 lunar eclipse (*Memoires …*, 1692: Plate VI). This also contained the forty numbered features whose names were mentioned in the text and later were added to the margins of the map.

Figure 2: The 1692 map of the Moon (after Le Monnier, 1746).

Returning to the 1679 map, we do not know how many drawings Patigny made, but there are enough left in the Paris Observatory collections to give us a very precise idea about the artistic work that he did under Cassini's direction. The observations were most likely performed with the refractor that the Italian telescope-maker Giuseppe Campani (1635–1715) made for Paris Observatory in 1672. According to Danjon and Couder (1935: 645–647), this instrument had a clear aperture of 108 mm and a focal length of 11 m.

By the 1780s, it appeared to the Director of Paris Observatory, Cassini IV (1748–1845), that very few copies of the 1679 map were still available and that it was therefore necessary to have some more printed. Initially the copper plate could not be found, but eventually it was located in the depths of a store in the Royal printing workshop, and in 1787 Cassini IV was allowed to print one hundred more copies. Proceeds from the sale of these would be used to buy books for the newly created library at Paris Observatory.

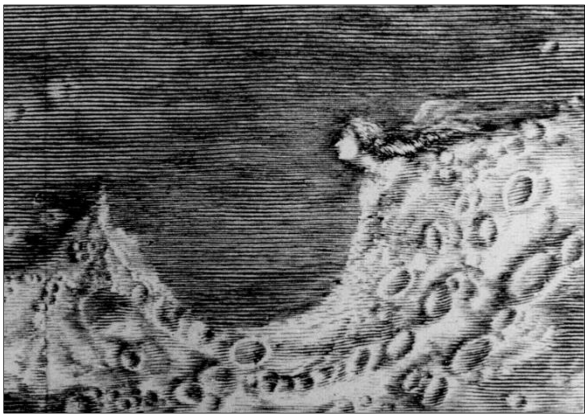

Figure 3: A close-up of the Heraclides promontory on the 1679 map of the Moon (© Observatoire de Paris).

This second set of prints was identical to the first, except for the following inscription which was printed along the lower circular edge of the map: "Carte de la Lune de Jean Dominique Cassini". Cassini IV said he did not want to spoil the copper plate by adding any names to it, and this is why in 1788 he asked the artist Jean François Jeaninet (1752–1814) to make an engraving of what he called a 'reduced map' (with the Moon only 176 mm in diameter) that included nomenclature used by the Italian Jesuit astronomer Giovanni Battista Riccioli (1598–1671). After the new batch of Moon maps was printed the large 1679 copper plate was left at the Royal printing workshop, but when the Bureau des Longitudes decided to retrieve it in 1824 they discovered that the Director of the workshop had sold it for scrap. This was—and still is—a terrible loss for French astronomy.

2.1 The Quality of the 1679 Map of the Moon

Even though the map was not realistic in its appearance when compared to what could be observed at Full Moon, the precision of the engraving was undoubtedly the best obtained up to that date. An example of the quality both of the observations and of the resulting preliminary drawings is given by the fact that evidence has been given that a feature whose centre is on the hidden face, Mare Orientale, was drawn as early as 1675, a full century earlier than hitherto attested (Sheehan et al., 2010).

2.2 The Lady's Head Shown on the 1679 Map of the Moon

Let us return to the woman's head whose engraving undeniably resulted from a deliberate decision by Cassini. This head (see Figure 3) had been regularly observed, given that the second edition of Fontenelle's *Entretiens sur la Pluralité des Mondes* (*Conversations on the Plurality of Worlds*), published in 1687 and in which a 'sixth evening' has been added, states:

> All is in a state of perpetual movement, and everything changes. Even a certain lady, who was seen in the moon through telescopes about twenty years ago, appears considerably older ... What are you telling me? Interrupted the Marchioness. It is not a jest, Madam, replied I, a figure has been observed in the Moon which resembles a woman's head, rising from among the rocks, and a change happened in that place. Some pieces of mountains have mouldered away, and left uncovered three peaks, with which one can only hardly contrive to make up the face, the nose and the chin of an old bag. (Our English translation.)

Thanks to Cassini IV, the great-grandson of Cassini I, seventy preliminary drawings made by Patigny from 1672 to 1678 were bound in 1786 to form a large folio atlas,[2] one of the treasures of the Paris Observatory library. Among the eleven drawings where the Heraclides promontory is represented, three clearly show the head of a lady. On one of them, a gorgeous young lady appears in white on a blue paper. When the copper plate was engraved by Patigny, there is no doubt that Cassini accepted, or even demanded, that a head be precisely represented, and it is likely that he thought of a real lady, whom he admired or loved. One could consider the ex-queen Christina of Sweden, or Queen Marie-Thérèse of France, but these are mere hypotheses. At that time, Cassini's daughter was less than one year old, so she is not a contender. Could the lady on the Moon map be Cassini's wife?

There is no reason to reject this hypothesis. Jean Dominique obtained French nationality in April 1673, a few months before he married Geneviève de Laistre, the daughter of a late counsellor of King Louis XIV, who signed the marriage

Table 1: Jesuit missionary-astronomers who came to Siam in 1685 with the French delegation.

Name	Birth/Death Dates	Immediate Destination after Siam
Jean de Fontenay	1643–1719	China (1688–1702)
Joachim Bouvet	1656–1730	China (1688–1697; 1699–1730)
Louis le Comte	1655–1728	China (1688–1691)
Jean-François Gerbillon	1654–1707	China (1688–1707)
Guy Tachard	1648–1712	Remained in Siam
Claude de Visdelou	1656–1737	China (1688–1702); India (1709–1737)

contract.[3] In 1679, Geneviève was 36 years old, and the year before, a pen and ink portrait of her had been made by a very young artist, who happened to be one of Jean Patigny's children.

2.4 Why Did Cassini Dare to Include a Lady's Head on his Moon Map?

Although the identification of the lady in question remains in contention, we now know why Cassini included her on a scientific map of the Moon. In a letter dated 13 August 1677, the Paris-based scholar Henri Justel (1620–1693) reported to the German scientist Gottfried Leibniz:

> One has recently seen in the Moon the figure of a woman, what usually can be observed only on the eleventh day of the lunar cycle. Several people have seen her. It is a place on the Moon's surface that is illuminated only at this time, in such a manner that the figure can be seen. This might only be an illusion. The instrument which was used to observe it was a refracting telescope 36 [French] feet [11.7 m] long. If a 50 [French] feet long instrument had been used, perhaps nothing would have been seen. People from the Court of the King have seen her and everybody agreed that she was definitely visible. (Justel, 1677; our English translation).

Cassini therefore felt justified in including her in his map.

Justel was well aware of the fact he was reporting, and we can wonder whether he might have been one of the observers. He confirms, firstly, that the object-glass of the refractor used for the observation was undoubtedly the one made by Campani, as quoted above. Secondly, Justel knew perfectly well that high magnification could ruin some 'illusions'. This is precisely what happened, for instance, in the famous case of the canals of Mars, which were no longer seen when the planet was observed with large refractors. Justel also gave the right day in the lunar cycle when observers were most likely to see the lady's head.

Thanks to the date of his letter, we can infer that the observations Justel told Leibniz about took place on 8 August 1677. When Fontenelle claimed in 1687 that the head had been observed for more than twenty years he was not far from the truth, but he does not tell us who first observed it. Although one might assume that the early observers were all astronomers, this does not take into account the interest that Louis XIV, the celebrated 'Sun King' (see Débarbat, 2015), and his court displayed towards science, and especially astronomy.

3 SIAM AND THE 11 DECEMBER 1685 LUNAR ECLIPSE

3.1 The French Astronomers

The first chance to use the new French Moon map in Asia came in 1685 when a contingent of six French Jesuit astronomers (Table 1) observed a total lunar eclipse from Lop Buri (see Figure 4) in Siam (present-day Thailand).

The French astronomers had been

> … sent out [to Asia] by Louis XIV., under a royal patent, to carry out scientific work in the Indies and in China, in order, as the patent puts it, "to establish Security in Navigation and to improve Sciences and Arts." (Giblin, 1909: 1).

Their voyage to China was delayed in Siam, and fortuitously there was a lunar eclipse during their sojourn. Their observations of this event were facilitated by Siam's King Narai (1633–1688), who had a progressive foreign policy and a keen personal interest in astronomy (for details see Orchiston et al., 2016).

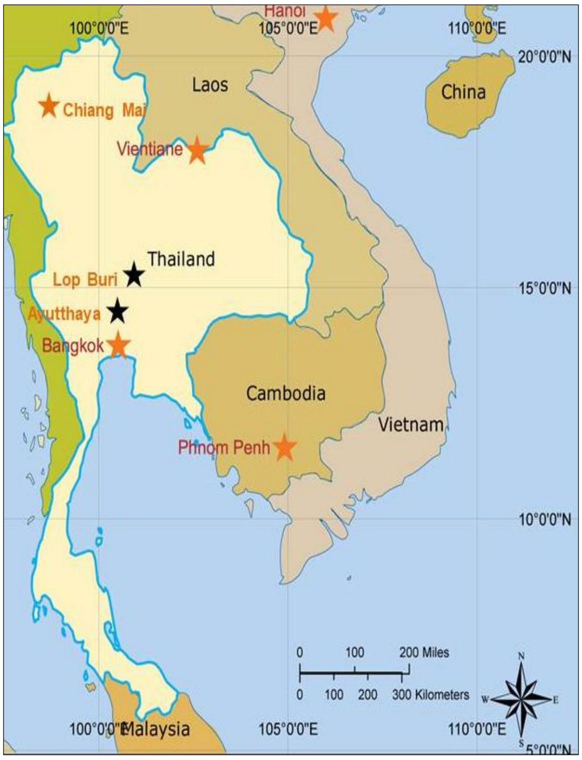

Figure 4: Thailand localities mentioned in the text, and Bangkok and Chiang Mai (map: Wayne Orchiston).

Before they left France, the six Jesuit astronomers (Landry-Delon, 2011)

> … were admitted to the Académie Royale des Sciences, and supplied with astronomical instruments on the understanding that these would be used—among other things—to determine the latitude and longitude of different geographical features and population centres. Such data would later prove invaluable when creating maps of the Asian region. As well as scientific instruments, the astronomers were supplied with tables of Jovian satellite phenomena, courtesy of Paris Observatory, and various reference books and charts. (Orchiston et al., 2016: 31).

Among these 'charts' was Cassini's new map of the Moon that would play a key role in the success of the eclipse observations in December 1685.

3.2 Observations of the Eclipse

Although Ayutthaya was the Siamese capital, King Narai liked to spend up to nine months of each year in nearby Lop Buri (Thavornthanasan, 1986), where he could enjoy a more relaxed lifestyle and

> ... pleasure trips to the forests abounding with every variety of trees and to the wild mountain scenery abounding in birds and beasts … [he] was enchanted with the romantic scenery of the region. (Smith, 1880).

Table 2: Details of the 11 December 1685 lunar eclipse.

Totality	Local Time	Moon Altitude Azimuth	Sun Altitude Azimuth
Start	04h 22m	+26° 288°	– 27° 109°
Middle	05h 15m	+15° 290°	–15° 110°
End	06h 09m	+03° 293°	–04° 113°

Near the mountains, and on the edge of an artificial lake that supplied water to the Royal Palace, King Narai maintained a 'country retreat', "... a very roomy Palace ... surrounded by brick walls fairly high." (Giblin, 1904: 11) which was about 4 km east of Lop Buri (Giblin, 1904: 22). It was from here that the King and the visiting French astronomers would observe the eclipse.

While King Narai's interest was purely motivated by curiosity and the chance to observe a notable celestial event with the aid of the newly invented telescope (see van Helden et al., 2011), the French had more scientific ambitions:

> In the 17th and partly also in the 18th century Hipparchos's old method for the determination of longitudes was renovated using the transits of craters on the edge of the shadow ... Though the accuracy of this method could not exceed more than some tenth of a minute of time, its utility was great in those times. For instance the eclipse of 1634 observed in Cairo, Aleppo and the western part of Europe, enabled the astronomers to shorten the Mediterranean Sea by 1000 km in respect to its assumed length before that time ... (Link, 1959: 10).

For the French astronomers, successful observations of the 11 December 1685 eclipse would reveal the longitude of Lop Buri. It also would allow them to compare and contrast the position of Lop Buri with respect to nearby Ayutthaya, which another Jesuit astronomer, Father Antoine Thomas, had successfully pinpointed in 1681 and 1682 (see Orchiston et al., 2016; 2018; 2019b).

The 1685 eclipse was visible in the morning on 11 December (see Table 2), with the start of totality occurring well before the beginning of astronomical twilight. At this time, the Moon was low in the sky about 20° north of due west. At mid-totality, astronomical twilight had just begun, and in the east there would have been a minor twilight glow on the horizon 20° south of east.

French observations of the eclipse were carried out from a waterside terrace, with three Galilean telescopes, while local time was provided by "… a spring clock very trustworthy and regulated by the Sun …" (Tachard, 1686).[4] Meanwhile,

> We prepared for the King a very long telescope of 5 feet [length] in a window of a saloon which opened on the corridor [terrace] in which we were. The Penumbra being well advanced the King was informed and came at once to the window. We were seated on Persian mats, some with telescopes, others with the clock, others ready to write the time of the observation. We saluted His Majesty with a profound bow, after which the observations were begun. (ibid.).

During the eclipse King Narai also observed with a 12-ft long telescope, and he

> … expressed a special satisfaction seeing all the spots [craters, maria, highland regions, etc.] of the Moon in the Telescope, and in seeing that the plan [map] which had been drawn of it at the Paris Observatory agreed with it so well. He put several questions to us during the Eclipse. For example: Why the Moon appeared upside down in the Telescope? Why one could still see the part of the Moon which was eclipsed? What time was it at Paris? What could be the utility of such observations made at the same time at two places at such a distance apart? &c. (ibid.).

The 'plan' mentioned in this quote refers to Cassini's Moon map of 1679, and we can imagine how King Narai would have enjoyed comparing it with the various features that he observed using the telescopes supplied by the Jesuit astronomers.

In Figure 5 we reproduce a drawing that was published by Tachard in 1686 and supposedly shows the Jesuit astronomers and King Narai observing the eclipse, in the presence of prostrated Siamese court astrologers. However, we have shown elsewhere (Orchiston et al., 2016:

Figure 5: A drawing showing King Narai and the Jesuit astronomers observing the 11 December 1685 total lunar eclipse from the King's country retreat which was on an island in the water reservoir that was located to the northeast of his palace in Lop Buri (after Tachard, 1686).

36–37) that this incorporates substantial artistic licence and cannot be accepted

> … as a realistic 'photographic' depiction of the eclipse observations, and this tallies with Michel Jacq-Hergoualc'h's evaluation. In 1986 he prepared an exhibition at the Musée de l'Orangerie in Paris which included this drawing. In his exhibition catalogue Jacq-Hergoualc'h (1986) noted that this figure and others in Tachard's 1686 tome were drawn by Pierre-Paul Sevin and engraved in Paris by Cornelius-Martin Vermeulen, even though neither was a member of the 1685 delegation to Ayutthaya and Lop Buri, or had ever visited Siam! (cf. Smithies, 2003: 191–192).

It is clear from the quotations reproduced above that Father Tachard provided a detailed account of this eclipse in his 1686 book *Voyage de Siam des Pères Jésuites Envoyés par Roi aux Indes & à la Chine.*

3.3 Analysis of the Observations

In order to use their observations of the eclipse for the calculation of Lop Buri's longitude, the Jesuit astronomers needed to select distinctive and therefore easily-identifiable features on the lunar surface and a means of accurately timing the passage of the Earth's shadow across these features. As any experienced contemporary lunar eclipse observer will testify,[5] the edge of the Earth's shadow is nebulous and therefore difficult to define, so it is important for each observer to make up their own mind about where they perceive the edge of the shadow to be, and make sure they are consistent when it comes to timing the passage of the shadow over each selected lunar feature. But first, they need a reliable time source, just as the Jesuit astronomers did back in 1685.

3.3.1 Time-Keeping at Lop Buri in 1685

Gislén (2004) has already reviewed the clocks that the Jesuits had in Lop Buri. There was a 'Great pendulum' and a 'Little pendulum', and

> The method for "rectifying" … [them] in preparation for the eclipse [on the evening of 10/11 December 1685] was somewhat involved and must have been very tedious … (Gislén, 2004: 140).

To elaborate:

> The great pendulum was checked against sol-

Table 3: The selenographical co-ordinates of the lunar features selected for observation during the 11 December 1685 lunar eclipse.

Feature	Latitude	Longitude
Riccioli	3.0 S	74.3 W
Grimaldi	5.2 S	68.6 W
Kepler	8.1 N	38.0 W
Gassendi	17.55 S	39.96 W
Heraclides	40.3 N	33.2 W
Copernicus	9.62 N	20.08 W
Plato	51.6 N	9.3 W
Menelaus	16.0 N	16.3 E
Saint Denis	2.8 N	17.3 E
Plinius	15.4 N	23.7 E
P. Acutum	1.75 N	32.75 E
Mare Crisium	17.0 N	59.1 E

ar altitude at noon on 9 and 10 December. On the 9th it was 303 seconds fast and on the 10th it was only 151 seconds fast. It was losing 152 seconds in 24 hours.

The little pendulum was then checked against the great pendulum at 3 p.m. on the 9th and at 1 p.m. on the 10th. In turn it had lost 183 seconds in the interval of 22 hours relative to the great pendulum. The value used in practice in the calculations was rounded down to 8 seconds per hour ... If the clocks had any compensating mechanism in them, clearly it still needed massive improvement.

Table 4: The selenographical co-ordinates of the lunar features selected for observation during the 11 December 1685 lunar eclipse.

Feature or Event	Calculated UT	Calculated Local Time	Tachard's Time
Immersion	20:31.4	3:20.0	3:20.0
Riccioli	20:32.4	3:21.7	3:20.8
Grimaldi	20:34.8	3:23.4	3:23.1
Kepler	20:43.4	3:32.0	3:30.5
Gassendi	20:46.6	3:35.2	3:33.6
Heraclides	20:49.0	3:37.6	3:37.7
Copernicus	20:52.0	3:40.6	3:40.0
Plato	21:00.0	3:48.6	3:50.1
Menelaus	21:11.5	4:00.1	3:59.8
Saint Denis	21:13.1	4:01.7	4:00.8
Plinius	21:15.4	4:04.0	4:03.2
P. Acutum	21:21.1	4:09.7	4:08.7
M. Crisium	21:29.7	4:18.3	4:18.8
Totality	21:36.5	4:25.1	4:23.7.

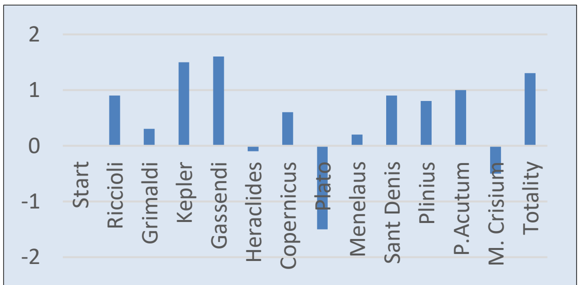

Figure 6: Plots of Modern versus Tachard times in minutes (Plot: Lars Gislén).

> In preparation for the eclipse observation the little pendulum was again "rectified" by the great pendulum, at 3 p.m. on the 10th, and at that time the great pendulum by our calculation was then only 151–152·3/24 ≈ 132 seconds fast. (Gislén, 2004: 140).

It was the little pendulum that would be transported to King Narai's country retreat for the eclipse observations.

3.3.2 Selection of Lunar Features to be Timed During the Eclipse

The French selected 12 different lunar features they would observe during the December 1685 eclipse, and the locations of these are listed in Table 3.

Most of these were easily identified, but three of the lunar features mentioned by Tachard (1868) required some research. Heraclides was identified as Promontorium Heraclides located at the north edge of Mare Iridium, at lunar longitude 33.2° W, latitude 40.3° N, while P. Acutum was identified as Promontorium Acutum at 32.75° E and 1.75° N on the southern edge of Mare Tranquilitatis. Both are clearly marked in the 1692 French lunar map shown here in Figure 2. Finally, Tachard's Saint Denis was found to be identical to the crater Dionysius (see https://www.britannica.com/biography/Dionysius-the-Areopagite).

3.3.3 Observations of the Features During the Eclipse

Tachard recorded apparent local solar time for his observations. He recorded

> … the local time for the "doubtful" beginning of the eclipse as 3:16:08, 3:20:00 for the "certain" beginning and 4:23:45 for the total immersion, including the one minute correction for the error of the pendulum clock. Modern calculation gives for these events respectively 3:21 and 4:26. (Gislén, 2004: 141).

Tachard also provided a list of times when the Earth's shadow crossed the local features listed in Table 3 during the eclipse (cf. Gouye, 1692), and we used a Java program based on the theory outlined by Meeus (1972) to compute these ourselves. The calculated eclipse times obtained from the Java program are shown in the second and third columns in Table 4, while Tachard's values are listed in the right hand column. We rounded Tachard's times to the nearest tenth of a minute.

Given the difficulty of timing the diffuse shadow edge, the results are really quite impressive. To illustrate this, the difference in minutes between our modern calculated timings and those of Tachard is displayed in Figure 6. There is a tendency for the Jesuit timings to be slightly early, by about 0.5 minute. This could be due to

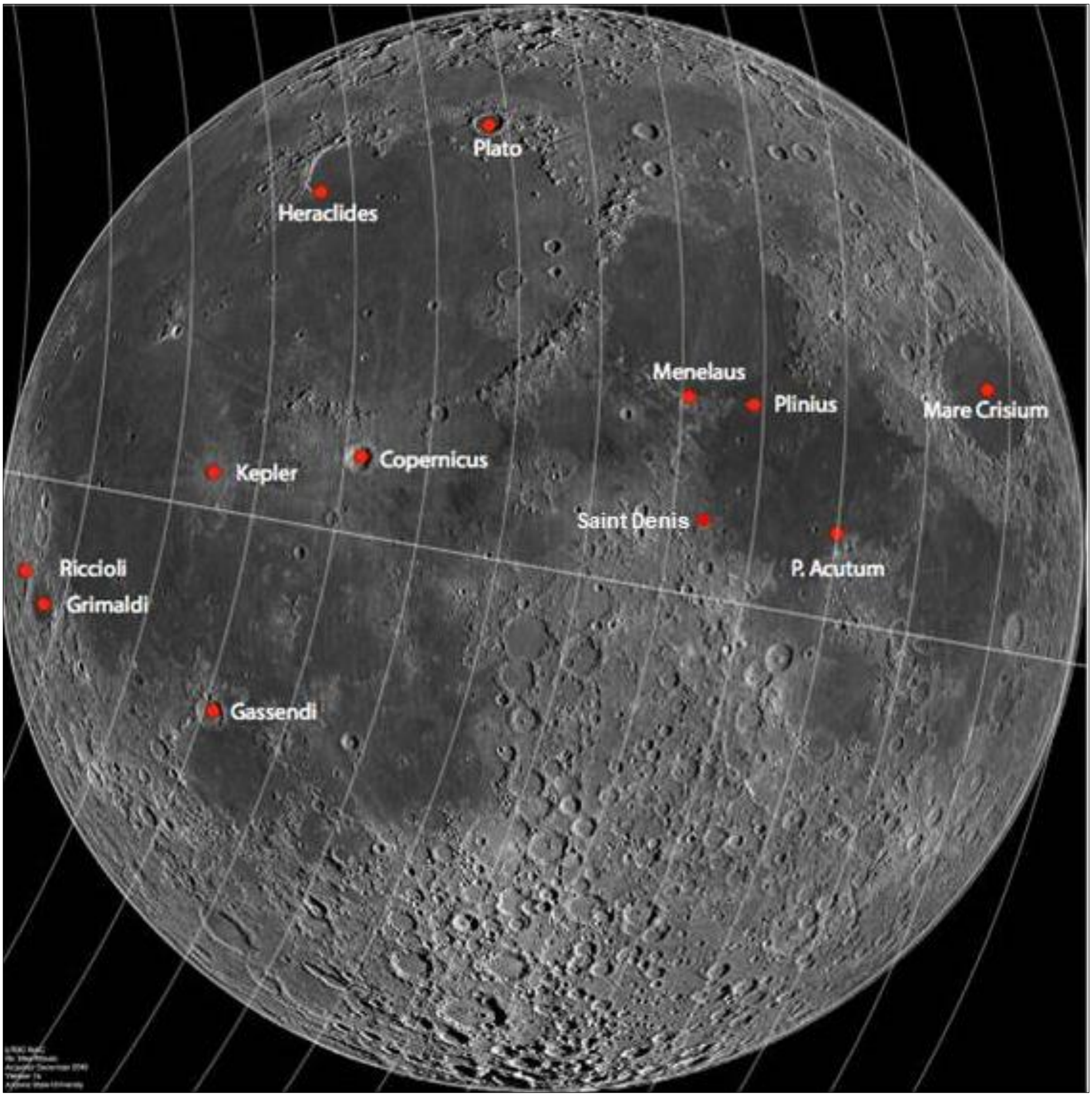

Figure 7: A reconstruction of the 11 December 1685 lunar eclipse, as seen from King Narai's country retreat at Lop Buri (Image: Lars Gislén).

a clock error (the clock had to be moved to the observing site before the observations), or more likely it is due to the Jesuits having a different criterion for what they considered to be the shadow edge. Plato is a little off, and we believe that there is an error in this observation or in the subsequent reporting of the time.

To give an indication of the motion of the shadow path across the Moon and the different lunar features observed by the Jesuit astronomers, we prepared Figure 7. The progress of the shadow is marked by the succession of thin white circular arcs, shown at five-minute intervals, and the various lunar features are shown by red dots. For this reconstruction we could not use a copy of the 1679 lunar map, so the background image is a mosaic of high resolution photographs taken by NASA's Lunar Reconnaissance Orbiter Camera in 2010. Note that in order to see the actual appearance of the eclipse, as viewed from Lop Buri in December 1685, readers should rotate this picture clockwise by 90°.

3.4 The Longitude and Latitude of King Narai's Country Retreat at Lop Buri

Gislén (2004: 142) used Tachard's value for the crater Plato and his own calculations to obtain the longitude of the Lop Buri country retreat:

> Tachard's value for middle of Plato corrected for clock error is 3:49:05 + 0:01:00 ≈ 3:50. The modern value for this event is 22:08:15 ≈ 22:08, referred to the Greenwich meridian, thus the longitude difference is 15 (24 + 3:50 – 22:08) = 15 6:42 = 100.5° …

As Gislén (ibid.) pointed out, this is quite a good result, given that the currently-accepted longitude of Lop Buri is 100° 38′ 42″ east of Greenwich (see Figure 8).

However, Gislén (ibid.) was less than impressed with the way in which the French went about determining the longitude of Lop Buri based on their 1685 eclipse observations.

One approach was to compare the local times of the start and the end of the eclipse with comparable times recorded in Paris. But there were problems: as we saw in Section 3.3.3, Tachard was uncertain about precisely when the eclipse began (primarily because of the nebulous nature of the shadow edge).

That said, there were even more problems in determining the end of the eclipse, as this was "… described in a rather ambiguous way …" (Gislén, 2004: 142), because 'vapours' near the horizon did not allow a clear view. Nonetheless, Tachard (1686) recorded "… the beginning of the Emersion … at 6h 1m 11sec or rather,

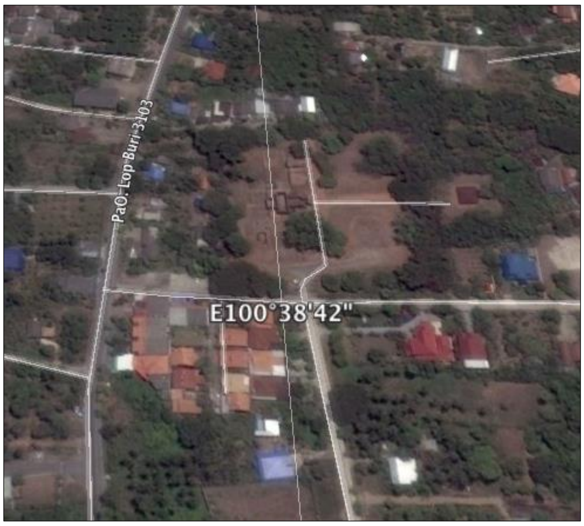

Figure 8: An aerial photograph showing the 100° 38′ 42″ E longitude line and the ruins of King Narai's country retreat.

at 6h 9m …" which he then corrected to 06h10m 25s because of the clock error of 1m 25s. Gislén (2004: 143) computed the time of emersion as 06h 09m, which agrees well with Tachard's time, but "… one wonders why the original emersion time of 6:01:11 was changed to 6:09. *I belive* [*sic*] *this observation was faked*. (Gislén, ibid.; our italics). He explains: Tachard had access to Cassini's immersion and emersion times recorded at Paris Observatory, and when he compared his Lop Buri results with those obtained by Cassini, he came up with the following longitude time differences:

> Immersion: 24 + 4:23:45–21:49:30 = 6:34:15
> Emersion: 24 + 6:10:25–23:36:18 = 6:34:07
>
> *It is highly improbable that Tachard could get two values so close by chance* using time measurements that, as we have seen above, have errors of the order of minutes. Note that the emersion was hindered by "vapors of the Horizon" and with the moon just a few degrees above the horizon, a very difficult observational situation. (Gislén, 2004: 143; our italics).

These concerns notwithstanding, the above-listed immersion and emersion figures converted to a longitude for Lop Buri of 98° 32′ E of Paris, which

> Tachard explicitly remarks … exactly agrees with the value of an earlier measurement [by Father Antoine Thomas, from Ayutthaya] using the lunar eclipse of 21 February 1682. (Gislén, 2004: 143).

Gislén (ibid.) regards this coincidence as yet another 'miracle'!

In fact, the longitude value Tachard derived for Lop Buri was expressed with reference to the island of El Hierro, not Paris. El Hierro is the smallest and westernmost of the Canary Islands in the Atlantic Ocean and for centuries was regarded by those from most non-English speaking nations as the 'edge of the known world' and therefore the ideal site for the prime meridian. It was referred to as the 'Meridian Island', and was 20° 23′ 09″ W of Paris.

As we have seen, determination of the longitude of King Narai's country retreat at Lop Buri was a challenging exercise, but finding its latitude was relatively simple, and Tachard (1689) published a figure of 14° 48′ 17″ N. The currently-accepted value is very close to this, at 14° 48′ 00″ N.

3.5 Details of the Observing Site

The 'country retreat' where the eclipse observations took place was located on the western boundary of King Narai's water reservoir:

> … a short excursion into the country, less than a league [from King Narai's palace in Lop Buri] will take us to the Tale Chupsawn, the reservoir built by King Narai. Reference to a map made up by sheets of the cadastral survey will show just how this small artificial lake is situated with regard to the town … The reservoir is enclosed by a heavy earth embankment, nearly 4½ miles long. This bank is about 12 to 13 feet high, and the area available for the storage of water is roughly one square mile ... Within the reservoir and near the western embankment on a small elevated piece of ground stand the ruins of the King's country residence. (Giblin, 1904: 22).

When we first wrote about these eclipse observations (Orchiston et al., 2016) we could not locate any copies of the aforementioned cadastral map showing the boundaries of the water reservoir and the precise location of King Narai's country retreat, but a copy has now come to hand, and was used to create the map in Figure 9.

Meanwhile, signs of buildings and foundations surrounded by dense vegetation on aerial photographs clearly indicate the site of the country retreat and the adjacent water reservoir (e.g. see Figure 8), and through fieldwork carried out in 2014 and 2015 and published literature the third and fourth authors of this paper were able to identify the room where King Narai was located during the eclipse, and the site of the waterside terrace used by the Jesuit astronomers (see Figure 9). Further details are provided in Orchiston et al. (2016: 36–38).

4 CONCLUDING REMARKS

It turned out that the successful observations at Lop Buri of the 11 December 1685 eclipse were the catalyst that led to an explosion of Western astronomical activity in Siam. As outlined in Gislén et al. (2019) and Orchiston et al. (2016; 2018; 2019a; 2019b), subsequently a second continent of French Jesuit astronomers arrived, a substantial brick observatory—named Wat San Paulo—was built at Lop Buri, and a variety of astronomical observations were carried out, before King Narai's premature death in July 1688 led to the expulsion of the Jesuit astronomers from Siam. Today all that remains as a reminder of their pioneering exploits are ruins of King Narai's palace and his country retreat in Lop Buri and the Wat San Paulo observatory.

7 NOTES

1. The Jesuits were an order of the Roman Catholic religion with a long tradition in mathematics and astronomy (Udias, 2003). Jesuits first founded missions in Asia during the sixteenth century, and Jesuits and Dominicans were already in Siam in 1656 when King Narai came to power (Hutchinson, 1933) but, to our knowledge, it was only in 1681 that the first Jesuit astronomer settled in Siam.
2. This has the catalogue number Ms D 6. 40.
3. Marriage contract of Jean Dominique Cassini with Genevieve de Laistre, 10 November 1673, Archives Nationales de Paris, MC/ET/CXII/367.
4. This quotation and subsequent ones listed as 'Tachard (1686)' are actually taken directly from Giblin (1909) and are Giblin's English translations of the astronomical excerpts con-

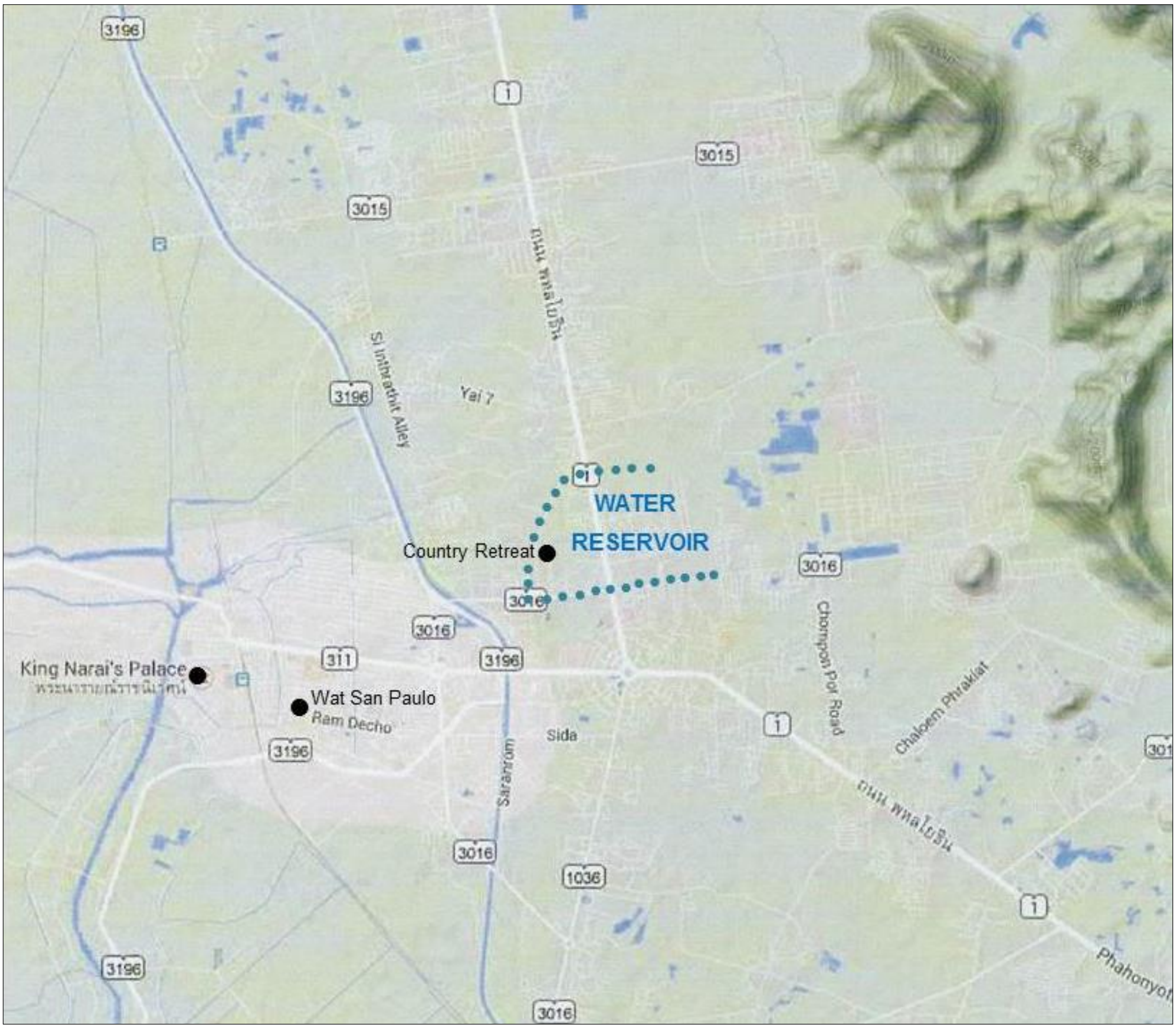

Figure 9: A map of part of Lop Buri showing the location of King Narai's water reservoir and country retreat in relation to his palace. The blue dots mark the position of the embankment (map modifications: Wayne Orchiston).

Figure 10: Ruins of the room where it is believed King Narai was located when he observed the eclipse. The foundations in the foreground mark the waterside terrace where the Jesuit astronomers were based (photograph: Wayne Orchiston).

tained in Tachard's 2-volume work *Voyage de Siam des Pères Jésuites Envoyés par le Roi aux Indes & à la Chine* (1686).

5. Of the authors of this paper, both Wayne Orchiston and Martin George have observed many lunar eclipses, some as part of Byron Soulsby's project to use these events to explore variations in shape and size of the umbra (see Soulsby 1984).

8 ACKNOWLEDGEMENTS

We are grateful to Guillaume Blanchard for bringing the Justel letter (1677) to our attention, Visanu Euarchukiati (Bangkok) for providing us with a copy of cadastral map showing King Narai's water reservoir, and Paris Observatory for permission to publish Figures 1 and 3.

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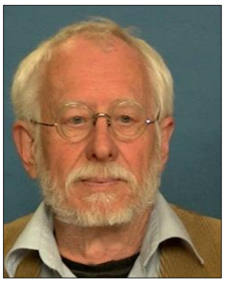
APPENDIX (Lars Gislén)

Meeus' theory (1972; 1998) needed some input parameters.

The geocentric distance to the Sun was 0.983890 AE. The equatorial horizontal parallax of the Sun was $\pi_\odot$ = 8.94″ and using a mean value of the Moon's geocentric distance from the Earth during the observation time, 406260 km, the equatorial horizontal parallax of the Moon was $\pi_☾$ = 3238.50″. With these distances the solar semidiameter was $s_\odot$ = 975.34″ and the lunar semidiameter $s_☾$ = 882.40″. Further, I used the UT times of the first and last contacts, T_1 = 20:31.0 and T_4 = 0:27.0 and the time of the maximum eclipse T_m = 22:29.2. I also need P_1 = 81.55° and P_4 = 257.92°, the first and last contact position angle measured westward from the north pole of the Moon. These angles can be calculated from the right ascensions and declinations of the Sun and the Moon at the corresponding times. I got these quantities from a very accurate commercial ephemeris program, Acyone Ephemeris. The magnitude M of the eclipse given by several sources is 1.7422.

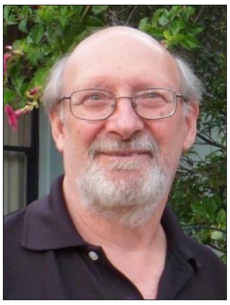
The Alcyone Ephemeris also gave me P_a = 356.79°, the position angle of the Moon's axis and the librations in latitude and longitude, b = 0.09° and l = 0.62°. Given the selenographical coordinates for the different lunar features listed in Table 3, you can then calculate the time when the lunar shadow entered that feature. These coordinates are well known and can be found in several public sources. The accuracy of Meeus' theory is of the order of one minute. The times of the immersion time and the beginning and end of the totality and the emersion were obtained by interpolating data from the Alcyone Ephemeris program from a read-out of the minute-to-minute positions of the Sun and the Moon and using the formulae in the *Explanatory Supplement to the Astronomical Ephemeris* (Gurnette and Woolley, 1961) and in Meeus (1998) and data from Espenak and Meeus (2009).

I also tried to determine the precise eclipse timings using a commercial astronomy program, 'Starry Night', where you can locate yourself anywhere on the lunar surface and view the Sun being eclipsed by the Earth. However, it turned out that it was difficult to get a timing more precise than I had before, and also the program appeared to be unstable, giving results that differed by several minutes in different runs.



Dr Lars Gislén is a former lector in the Department of Theoretical Physics at the University of Lund, Sweden, and retired in 2003. In 1970 and 1971 he studied for a Ph.D. in the Faculté des Sciences, at Orsay, France. He has been doing research in elementary particle physics, complex systems and applications of physics in biology and with atmospheric physics. During the past fifteen years he has developed several computer programs and Excel spreadsheets implementing calendars and medieval astronomical models from Europe, India and South-East Asia (see http://home.thep.lu.se/~larsg/)

Françoise Launay made her whole career as a research engineer at Meudon Observatory where she was the technical head for a large high resolution vacuum ultraviolet spectrograph installed in the very place where the astronomer Jules Janssen carried out his laboratory experiments. She was also involved in preservation of artefacts of scientific history. She had joined the team of historians at Paris Observatory as an associate researcher when she published Janssen's biography (Vuibert/Observatoire de Paris, 2008; Springer, 2012) and went on researching on astronomical instrument makers. She is now devoting herself to discovering unpublished material to document also the biographies of unknown or erroneously known Encyclopaedists and people whose names appear in the correspondences of D'Alembert (including himself!), Diderot and Condorcet.



Professor Wayne Orchiston works at the National Astronomical Research Institute of Thailand and is an Adjunct Professor of Astronomy in the Centre of Astrophysics at the University of Southern Queensland in Toowoomba, Australia. He has published extensively on historic transits of Venus and solar eclipses; historic telescopes and observatories; the history of cometary and asteroidal astronomy; the history of meteoritics; and the history of radio astronomy. While working at the National Astronomical Research Institute of Thailand his research interests have focussed on Asia, and especially Indian, Indonesian, Japanese, Philippines and Thai astronomy, and astronomical links between SE Asia and India and SE Asia and Australia. Wayne has been a member of the IAU since 1985, and has been very active in commissions dealing with history of astronomy, radio astronomy, and education and development. Currently he is the President of Commission C3 (History of Astronomy). In 1998 he co-founded the *Journal of Astronomical History and Heritage*, and is the current Editor. He also edits Springer's Series on Historical and Cultural Astronomy. He is the co-recipient of the American Astronomical Society's 2019 Donald Osterbrock Book Prize, and minor planet '48471 Orchiston' is named after him.

Mrs Darunee Lingling Orchiston is Professor Wayne Orchiston's part-time Research Assistant. She has participated in research on Thai astronomical history; Thai meteorites; and Indian, Maori and Thai ethnoastronomy. Her research papers have appeared in this journal and in a number of conference proceedings, and she has co-authored papers presented at conferences and seminars in India, Myanmar and Thailand.

Suzanne Débarbat was born in Montluçon (France) in 1928 and has a Licence ès Sciences and a Doctorat d'Etat from Sorbonne University. She spent her entire working life at the Paris Observatory, and at the time of her retirement was Director of the research groups Systèmes de Référence Spatio-temporels of the Centre National de la Recherche Scientifique and the Département d'Astronomie Fondamentale, which is now named Systèmes de Référence Temps-Espace (SYRTE). Since her retirement she has been attached to this last-mentioned Department. Suzanne's primary interest is in French astronomy, and particularly the history of Paris Observatory. She has published extensively, including the following books: *Mapping the Sky* (1988, co-edited by J.A. Eddy and H.K. Eichhorn), *Sur les Traces des Cassini: Astronomes et Observatoires du Sud de la France* (1996, co-edited by Paul Brouzeng), *Optics and Astronomy* (2001, co-edited by Gérard Simon), *Astronomical Instruments and Archives from the Asia-Pacific Region* (2002, co-edited by Wayne Orchiston, Richard Stephenson and Il-Seong Nha) and *Pierre-Simon de Laplace (1749–1827) – Le Parcours d'un Savant* (2012, co-authored by Jean Dhombres and Serge Sochon). She also contributed to the book *L'Observatoire de Paris – 350 Ans de Sciences* (2012). Suzanne was the President of IAU Commission 41 (History of Astronomy) in 1991–1994 and of the Bureau des Longitudes in 2004–2005. She is a member of the International Academy of Science.

Matthieu Husson is a CNRS researcher based in l'Observatoire de Paris. His research focus is mainly in the history of astronomy and mathematics in late medieval Europe where he currently leads two international research projects. Several years ago, Matthieu also began a new research project mainly on the archives of l'Observatoire de Paris focused on the analysis of the observational practices of seventeenth and eighteenth century observers and their relation to the past of their discipline.

Martin George is the Planetarium Manager at the Queen Victoria Museum and Art Gallery in Launceston, Tasmania, and is responsible for the Museum's planetarium and astronomy collections. He also is a Research Associate of the National Astronomical Research Institute of Thailand in Chiang Mai, and is a former President of the International Planetarium Society. Martin has a special research interest in the history of radio astronomy, and he recently completed a part-time Ph.D. on the development of low frequency radio astronomy in Tasmania through the University of Southern Queensland, supervised by Professors Wayne Orchiston and Richard Wielebinski (and originally also by the late Professor Bruce Slee). From 2005 to 2014 Martin was the Administrator of the Grote Reber Medal for Radio Astronomy, and he is a member of the IAU Working Group on Historic Radio Astronomy.

Professor Boonrucksar Soonthornthum is the former founding Executive Director of the National Astronomical Research Institute of Thailand and has D.Sc. degrees in physics and in astrophysics. He has research interests in astrophysics (especially binary stars), the history of Thailand astronomy, and astronomical education, and he has published on all of these topics. He is a long-standing member of the IAU and is currently Vice-President of Commission C1 (Astronomy Education and Development). He is very actively involved in the Astronomy Olympiad movement; and is the founder and chairman of the Southeast Asian Astronomy Network (SEAAN). Boonrucksar has arranged many international conferences, and research collaborations between NARIT and overseas institutions.