THE CALENDARS OF SOUTHEAST ASIA. 5: ECLIPSE CALCULATIONS, AND THE LONGITUDES OF THE SUN, MOON AND PLANETS IN BURMESE AND THAI ASTRONOMY

Lars Gislén
Dala 7163, 24297 Hörby, Sweden.
Email: larsg@vasterstad.se

and

J.C. Eade
49 Foveaux Street, Ainslie, ACT 2602, Australia.
Email: jceade@gmail.com

Abstract: Many of the calendrical records in Southeast Asia contain information on the longitudes of the Sun, the Moon and the planets—something that is valuable for the dating of these records. Both the Burmese and the Thai use calculation schemes for the longitudes of the Sun, the Moon, and the planets that are almost identical to the original *Sūryasiddhānta* schemes. After the change to the Thandeikta calendar the Burmese changed some of the parameters involved, in general following those of the modern *Sūryasiddhānta*.

Keywords: History of astronomy, calendars, eclipse calculations, longitude of the Sun, longitude of the Moon, longitude of the planets, Burmese astronomy, Thai astronomy

1 LONGITUDES OF THE SUN AND THE MOON AND THE LATITUDE OF THE MOON

The mean longitude of the Sun in the Thai and original Burmese calendars[1] is calculated using the excess of solar days in units of 1/800th of a day at the beginning of the solar year, adding the number of elapsed day of the year multiplied by 800 and dividing by 24350. The quotient gives the zodiacal sign (*rasi*) involved.[2] The remainder is divided by 811, the quotient is the degrees in the sign (*angsa*), the remainder is further divided by 811, the quotient is the arc minutes (*lipda*). The reason for the numbers 24350 and 811 is the following: a zodiacal sign contains 30 degrees that is 1/12th of 360°. A year contains 292207 parts in units of 1/800th of a day. Dividing this by 12 we get 24350, i.e. one zodiacal sign corresponds to 24350 parts of 1/800th of a day. Then one degree corresponds to 24350/30 = 811. The calculation procedure is only approximate but accurate enough and typical of the integer kind of calculations with 'magical' numbers that is used in Burma and Thailand. There are 3 arc minutes extra subtracted from the mean longitude of the Sun, the reason is given below.

Table 1: Solar and lunar *chayas*.

Angle	Solar Equation	Lunar Equation
0	0	0
15	35	77
30	67	148
45	94	209
60	116	256
75	129	286
90	134	296

The true longitude of the Sun, L_{true}, can mathematically be written as a function of the mean longitude, L_{mean}, by

$$L_{true} = L_{mean} - \arcsin[e \times \sin(L_{mean} - w)], \qquad (1)$$

where e, the eccentricity of the Sun, is 14/360, and w is the longitude position of the apogee of the Sun, taken as 80°. These are both *Sūryasiddhānta* values (Billard, 1971). The second term of this expression, the equation, is interpolated using a table given in arc minutes, the *chaya* (see Table 1), with entries for every 15 degrees of angle in the first quadrant, 0–90°. Due to the symmetry of the sine function only values in the first quadrant are needed in the table though the equation is negative in the third and fourth quadrants.

The Thai and Burmese computations for the lunar longitude may appear confusing because the Southeast Asian calendarists effortlessly switch between using solar day and lunar day units (and sometimes get confused themselves). For example, in the Burmese and in La Loubère's (1691) description the *avoman*, a, is computed from the elapsed lunar days or *tithis*, t, by the relation

$$a = [(t \times 11) + 650] \bmod 703, \qquad (2)$$

while, in Wisandarunkorn (1997) and Faraut (1910), it is computed using the elapsed *ahargaṇa*, h, by

$$a = [(h \times 11) + 650] \bmod 692. \qquad (3)$$

The *avoman* is the excess over whole *tithis* for elapsed solar days, or *ahargaṇa*. A *tithi* is 692/703 of a solar day and thus 11/703 shorter than a solar day in units of a solar day. On the other hand, a solar day is 703/692 *tithi* and thus 11/602 *tithi* longer in units of a lunar day. The difference between the two expressions above is that the first one gives the *avoman* in units of 1/703 of a solar day while the second expression gives the *avoman* in units of 1/692 of a lunar day.

In a similar way *tithis* can be converted to *ahargaṇa* and *vice versa* with the two relations:

$t = h + [(h \times 11) + 650]/692,$ (4)
and $h = t - [(t \times 11) + 650]/703.$ (5)

The *tithis* measure the elongation of the Moon from the Sun, each *tithi* corresponding to 360/30 = 12° of elongation. The *avoman* is a measure of the fraction of the *tithi*. The scheme for converting the *avoman* into a fractional lunar elongation of the day is to take the *avoman*, divide by 25, add the *avoman* to the quotient and divide by 60. This will give the fractional lunar elongation in degrees. The procedure is equivalent of multiplying the *avoman* by 1.04 and dividing by 60. In the first relation above, equation (2), the maximum value of the *avoman* is 703, corresponding to a solar day. If we multiply this by 1.04 and divide by 60 we get 12.185°, which is almost exactly the daily movement of the Moon, 360/29.530583 = 12.191°. Using the second expression for the *avoman*, a value of 692 corresponds to one *tithi*, and 692 × 1.04/60 = 11.995°, which again is almost exactly the correct value of 12° for the movement of the Moon in one *tithi*. Thus, by using the number 25 the fractional lunar longitude of the day is 'magically' produced. If the number of whole elapsed *tithis* multiplied by the daily *tithi* motion of 12° is added to this fractional longitude, the result is the mean elongation of the Moon from the Sun. Alternatively, if the *ahargaṇa* multiplied by the Moon's motion in a solar day can be added, the result will be the same.

Adding the mean solar longitude to the elongation longitude will give the mean lunar longitude. Then 40 minutes of arc are routinely subtracted from the mean longitude of the Moon as with the 3 minutes of arc were subtracted from the mean longitudes of the Sun. These corrections have no clearly obvious purpose, but an explanation can be found. The mean daily motion of the Sun is 59′ and that of the Moon is 790′. Thus, 3′ of the Sun corresponds to 24 × 3 /59 = 1.22 hours of time and 40 of the Moon corresponds to 24 × 40/790, also 1.22 hours of time. Converted to geographical longitude where 15° corresponds to one hour, 1.22 hours equate to 18.3° in longitude, which is roughly the longitude difference between Ujjain, the prime meridian of India and Western Burma, and indicates that the subtracted minutes of arc is a correction introduced when the Indian calculation methods were transferred to Burma (something already that the French astronomer Cassini noticed). One notes, however, that the operation survived in Faraut's (1910) version of the scheme, whose home ground was Cambodia, whereas the adjustment properly applies only to Burma. If it had indeed been required, the adjustment would have needed to be twice the applied amount to apply to Cambodia. It is clear, then, that the function of the adjustment was lost sight of, but it nonetheless continued to be integral to the reckoning.

The longitude of the lunar apogee is not fixed but is determined by the *uccabala*, and the current value has to be calculated using the following formula:

uccabala = (*ahargana* + 2611)mod 3232. (6)

The *uccabala* is converted to the angular position of the apogee, where 3232 days correspond to 360°. In the original *Sūryasiddhānta* it is assumed that the lunar apogee (*mandocca*) makes 488219 revolutions in 1577917800 days, i.e. the period is 1577917800/488219 = 3231.9878 days.

The true longitude of the Moon is calculated in the same way as for the Sun but now with the *Sūryasiddhānta* lunar eccentricity 31/360 (Billard, 1971) and using the current value of the lunar apogee. The equation is again given in terms of a table or *chaya* (see Table 1).

The Burmese Thandeikta scheme for the Sun and the Moon is a little different from that of the Makaranta. The mean longitude in minutes of arc of the Sun is calculated from the expression

$L_{mean} = (1000 \times k_0 + 800000 \times sutin - 6 \times sutin)/13528,$ (7)

where k_0 is the New Year *kyammat* and *sutin* is the number of elapsed days of the solar year. The last two terms express the mean daily solar movement (800,000−6)/13528 = 59.136162 minutes of arc.

The mean longitude of the Moon is calculated, as before from the *avoman* but now with the expression

$L_{mean} = tithis \times 12 \times 60 + (avoman + 7/173 \cdot \times avoman) - 52',$ (8)

which gives the longitude in arc minutes. The factor 7/173 ≈ 1/24.714 is very nearly the same as 1/25 that is used in the Makaranta scheme. The extra correction of 52′ is partly a geographical longitude correction from Ujjain and partly a secular correction. The lunar apogee is calculated using the approximation that the daily motion of the apogee is 3 × 1800/808 = 6.68317′, which is effectively the same as the Makarata and Arakanese value.

The Thandekta equations are calculated ac-

Table 2: Thandeikta solar and lunar *chayas.*

Angle (°)	Solar Equation	Lunar Equation
0	0	0
3.75	9	20
7.5	17	40
11.25	26	60
15	34	79
18.75	43	98
22.5	51	116
26.25	58	134
30	66	152
33.75	73	169
37.5	80	185
41.25	87	200
45	93	214
48.75	99	228
52.5	104	241
56.25	109	252
60	113	262
63.75	117	272
67.5	121	280
71.25	124	287
75	126	293
78.75	128	297
82.5	129	300
86.25	130	302
90	131	303

cording to the modern *Sūryasiddhānta* where the eccentricities vary in size,

$$e = e_0 - 20/(360 \times 60)\sin(L_{mean} - w), \qquad (9)$$

and e_0 is 14/360 for the Sun and 32/360 for the Moon. The solar apogee is fixed at longitude 77° 18′. This gives the following *chayas* for the Sun and the Moon (see Table 2). This table is also divided into smaller steps of 3.75°.

The latitude of the Moon is computed by assuming an inclination of the lunar orbit of 4.5° and assuming that plane geometry can be used. If the distance from the node is Δ, this would give the lunar latitude β as

$$\beta = \Delta \times \tan 4.5° \approx \Delta \times 4.5 \times \pi/180 \approx \Delta \times 4.5/60. \qquad (10)$$

It is also used when the tangent of a small angle is approximately equal to the angle expressed in radians and the value of π has been set to 3.

2 DAY LENGTH AND *LAGNA*

Day length and *lagna*, the ascendant or rising sign, are closely related. The *lagna* is used in Southeast Asian astrological records to give the time of day. Day length (Thai: *thinpraman*) can be computed using the concept of ascensional difference, that is the excess of daytime over the day length at the equinoxes. At the equinoxes the Sun for any location on the Earth moves during the daytime in the sky in a 180° section of a great circle, and the day length is 12 hours. At other times of the year the Sun will move in a parallel circle and the day length will be either longer or shorter. The ascensional difference *A*, can be computed by the formulae

$$\sin\delta = \sin\varepsilon \times \sin\lambda \qquad (11)$$
$$\text{and } \sin A = \tan\varphi \times \tan\delta, \qquad (12)$$

where λ is the ecliptic longitude of the Sun, δ the declination of the Sun, ε is the obliquity of the ecliptic (in Indian tradition assumed to be 24°), and φ is the geographical latitude of the location on Earth. The day length (in degrees) is then calculated by 180° + 2*A*. Note that *A* is negative when the declination of the Sun is negative.

The Burmese and Thai astronomers used the time units *nadi*/*nayi*/*nati* and *vinadi*/*vinati*/*bizana*. There are 60 *nadi* in a day and night and each *nadi* is equal to 60 *vinadi*, i.e. there are 3600 *vinadi* in a day and night. This makes the conversion from the angular measure degrees to *vinadi* very simple, as it is achieved by a multiplication of the degrees by 10.

The *lagna* is a concept inherited from India and is the rising sign of the ecliptic at a given time. In Western astrology it is the ascendant. In order to calculate the lagna another quantity is needed, the oblique ascension, Ω. The scheme to calculate the oblique ascension is the following:

Given the longitude of the Sun we can calculate its right ascension, α, by

$$\tan\alpha = \tan\lambda \times \cos\varepsilon. \qquad (13)$$

The oblique ascension of the Sun is then the difference between the right ascension and the ascensional difference

$$\Omega = \alpha - A. \qquad (14)$$

Table 3: The day length and oblique ascension of the Sun for a geographical latitude of 15° 45′.

Sun's Longitude	Oblique Ascension	Differences	Thinpraman
0	0	244	1800
30	244	272	1868
60	516	312	1922
90	828	334	1944
120	1162	326	1922
150	1488	312	1868
180	1800	312	1800
210	2112	326	1732
240	2438	334	1678
270	2772	312	1656
300	3084	272	1678
330	3356	244	1732
360	3600	–	1800

Table 3 shows the day length and oblique ascension of the Sun for a geographical latitude of 15° 45′ where the argument in the left column is the longitude of the Sun. At sunrise the *lagna* of the Sun is of course the longitude of the Sun. As the Sun rises the oblique ascension will increase by the time converted to degrees, and the longitude of the *lagna* can be obtained by inverse interpolation from the table for oblique ascension.

Figure 1 shows the Thai way of displaying these tables. The circle is divided into twelve sectors, one for each zodiacal sign, with Aries at the top and the other signs following counter-

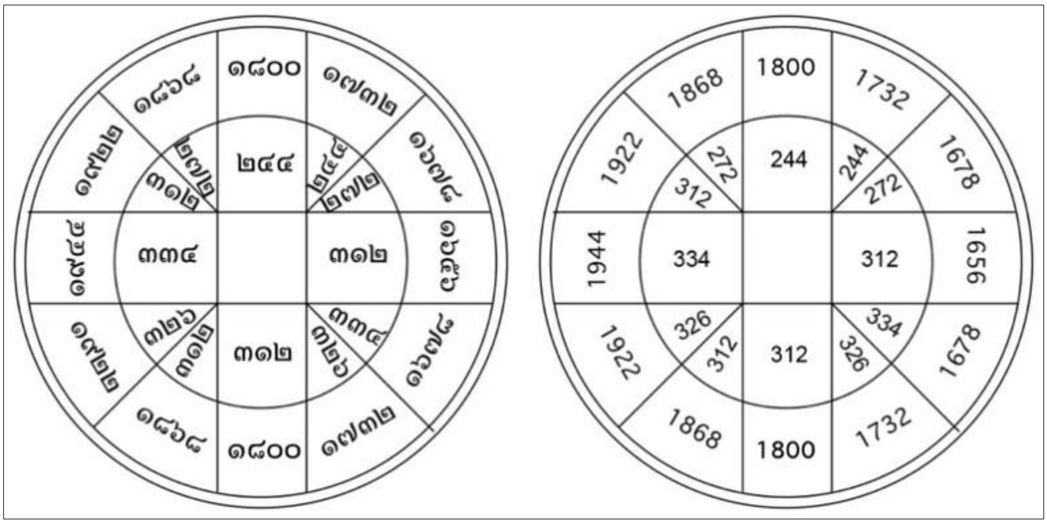


Figure 1: Thai day length and oblique ascension table (after Wisandarunkorn, 1997: 165).

clockwise around the circle. The outer band of numbers presents the day lengths in *vinadi*, the inner band shows the differences in oblique ascensions. Intermediate day lengths are found by interpolation. The oblique ascension is found, as an example will show, by starting at the top of the figure, adding the numbers in the inner band up to the given sign, and then interpolating the final addition.

Worked example: Find the daylength when the longitude of the Sun is 30° and the geographical latitude is 15° 45′. Using formula (11) we get δ = 11.73°. Formula (12) gives A = 3.36° and day length 186.8° or 1868 *vinadi*. This is also the result from the figure.

Worked example: Find the *lagna* using Figure 2 when the Sun's longitude is 70° = 2 × 30° + 10° and the time is 1 *nadi* = 60 *vinadi* (24 minutes) after sunrise. We first add differences 244 + 272 = 516 for the two signs up to 60°. The next difference is 312 and interpolating with the remaining 10° we get an additional 312/3 = 104 and a total of 516 + 104 = 620. Adding the time after sunrise, 60, we get 680. We now start subtracting the numbers in the figure as far as we can go: 680 – 244 – 272 = 164. The next difference is 312 and corresponds to a longitude difference of 30° thus interpolating we get (30 × 164)/312 = 15° 46´. The *lagna* is 60 + 15° 46′ = 75° 46′.

Figure 2 illustrates the concepts of ascensional difference, day length and oblique ascension. The figure shows the celestial sphere as seen from a place on Earth. The sky seems to rotate along an oblique axis that makes an angle of the geographical latitude with the horizontal plane. The origin of the equatorial system is γ, the vernal equinox. The Sun, S, is supposed to be just rising. In the equatorial coordinate system it has a right ascension, the angle γCP and a declination, the angle PCS. The point P has the same right ascension as the Sun at S. The angle

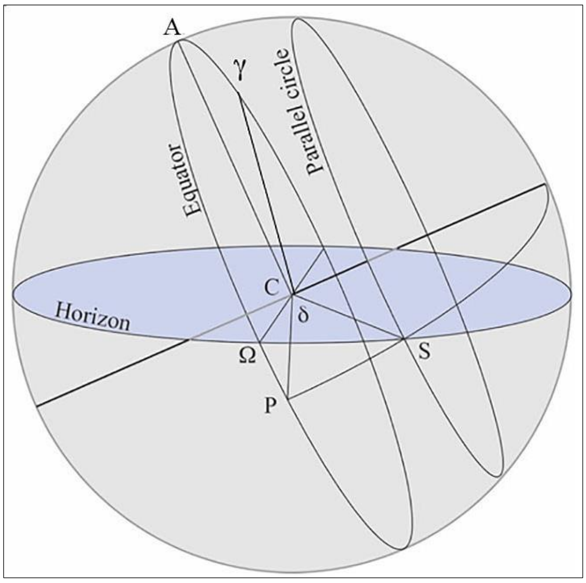


Figure 2: Ascensional difference, day length and oblique ascension (diagram: Lars Gislén).

PCA is half the day length and the angle ΩCP is the ascensional difference. Subtracting the ascensional difference ΩCP from the right ascension of the Sun, γCP gives the angle γCΩ, the oblique ascension of the Sun.

There is sometimes a simplified way of calculating the *lagna* by a standardised table (Table 4) for the rising times of the different zodiacal

Table 4: Rising times.

Sign	Rising Time(*nadis*)	Rising Time (Minutes)
Aries	5	120
Taurus	4	96
Gemini	3	72
Cancer	5	120
Leo	6	144
Virgo	7	168
Libra	7	168
Scorpio	6	144
Sagittarius	5	120
Capricorn	3	72
Aquarius	4	96
Pisces	5	120

Table 5: Planetary periods.

Mahayuga	Days	*Sūryasiddhānta*	Thai
1577917800	Rotations	Period	Period
Mercury	17937000	87.969995	8797/100
Venus	7022388	224.69818	224.7
Mars	2296824	686.999875	687
Jupiter	364220	4332.32058	12997/3 = 4332.33
Saturn	146564	10766.0667	10766
Rahu	232226	6794.7508	6795
Ketu			679

Figure 3: A Thai amulet showing Rahu eating the Sun (Gislén Collection).

sign given for instance in Wisandarunkorn (1997: 12). It is not true for any location but has the advantage that it can be used for any location.

Example: Find, using the standardised table, the *lagna* when the Sun's longitude is 70° (i.e. 10° into Gemini, thus 2 × 30° + 10°) and the time is 5 *nadi* (120 minutes) after sunrise. We first add the rising times for Aries and Taurus, 5 + 4 = 9. The next rising time is 3 *nadi*, of which we require one third and by interpolating get an additional 1 *nadi* and a total of 10 *nadi*. Adding the time after sunrise, 5 *nadi* as given, we get 15 *nadi*. We now start subtracting the numbers in the table as far as we can go: 15 – 5 – 4 – 3 = 3 *nadi*. The next rising time is 5 *nadis* and corresponds to a longitude difference of 30° thus interpolating we get (30 × 4)/5 = 24°. The *lagna* is 90°+ 24° = 114°, Cancer 24°.

3 PLANETARY LONGITUDES

For the planets the quite complicated computational scheme in *Sūryasiddhānta* is used (Billard, 1971: 76). In Faraut (1910: 214–221) the description of the scheme for Mars uses seven pages of text. The mean longitudes of the planets are computed using somewhat simplified values for the *Sūryasiddhānta* periods, see Table 5. The Thandeikta scheme uses 20383/3 = 6794.333 for the period for Rahu, the Moon's ascending node.

Table 6: Planetary parameters.

Planet	e	ρ	w
Mercury	28/360	132/360	220°
Venus	14/360	260/360	80°
Mars	70/360	234/360	110°
Jupiter	32/360	72/360	160°
Saturn	60/360	40/360	240°

Rahu was considered to be a demon that devoured the Sun during eclipses (Figure 3). It is equivalent to the Western notion of the Dragon's Head. It has a retrograde constant motion. Ketu, while borrowed from Hindu astrology, is different from its original version. Hindu astronomy considers Rahu and Ketu to be the ascending and descending lunar nodes, respectively, but Southeast Asian astrology considers Ketu to be a theoretical planet orbiting the Earth with a speed ten times that of Rahu, moving in the same retrograde direction and with only astrological significance.

The true longitudes of the five planets are computed with the complicated scheme below (Billard, 1971; Faraut, 1910). The modern mathematical formulation is given with comments. The input parameters are: the mean longitudes of the planet, L, and Sun, S. Each planet also has three fixed parameters: the eccentricity, e, the radius, ρ, of the excentre, and the longitude of the apogee, w. These parameters are shown in Table 6.

The true longitude of an outer planet is then computed using the scheme below:

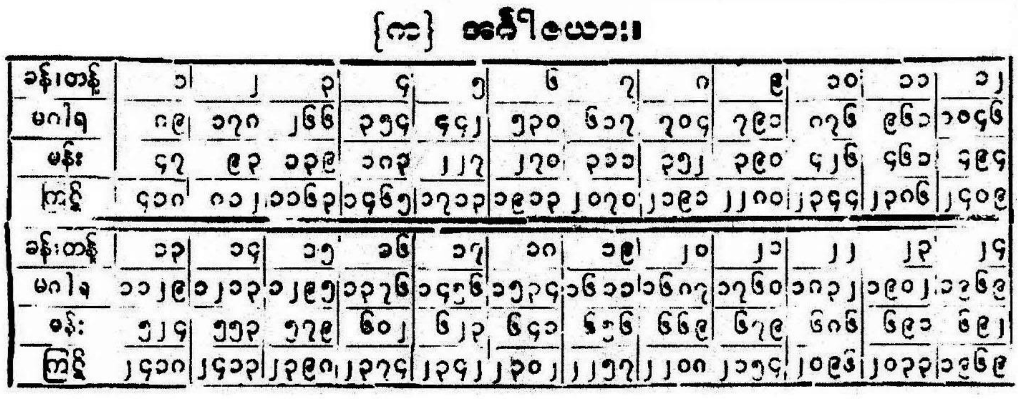
1) $\eta = S - L$, the elongation
2) $c_1 = \arcsin(\rho \times \sin\eta/\sqrt{[(1 + \rho \times \cos\eta)^2 + (\rho \times \sin\eta)^2]}$, first correction
3) $w_1 = w - c_1/2$, first corrected apogee
4) $\alpha_1 = L - w_1$, corrected anomaly
5) $c_2 = \arcsin(e \times \sin \alpha_1)$, second correction
6) $w_2 = w_1 + c_2/2$, second corrected apogee
7) $\alpha_2 = L - w_2$, second corrected anomaly
8) $c_3 = \arcsin(e \times \sin\alpha_2)$, third correction
9) $L_1 = L - c_3$, corrected mean longitude
10) $\eta_1 = S - L_1$, corrected elongation
11) $c_4 = \arcsin(\rho \times \sin\eta_1/\sqrt{[(1 + \rho \times \cos\eta_1)^2 + (\rho \times \sin\eta_1)^2]}$, fourth correction
12) $L_{true} = L_1 + c_4$, the true longitude.

For the inner planets the roles of the Sun and the planet are interchanged.

The mathematical functions, in (5) and (8), and in (2) and (11) are given by Faraut (1910) in the form of *chayas* for each planet, albeit with many printing errors and lacunae. The first func-

KÈNES	NOMBRES	DIFFÉRENCES	NOMBRES	DIFFÉRENCES	NOMBRES	DIFFÉRENCES	KÈNES
Mangkar Phoum 0	↓ 354	350	↑ 173	161	↑ 1462	736	3 Korakat Phoum
1	704	345	334	139	2198	227	4
2	1049	334	473	109	2425	33	×5
9	1383	314	582	67	2392	169	×6
10	1697	285	649	23	2223	240	×7
11	1982		↓ 672		1983		8
	Chhaya Mangkar Phoum		Chhaya Montol Phoum		Chhaya Korakat Phoum		
	Tang Mothoyom } Kho Âr } Oïch 2 / 60 } Har Kène Saupheap		È Pho } È 2 / 60 } Har Kène Pittarit	To Pho } Pho 60 } Har Kène Saupheap	Trey Âr } Trey 60 } Har Kène Pittarit		Keng Chhaya Phluk 3 / 20 / 0 } Oïch

Figure 4: Grand *chaya* for Mars (after Faraut, 1910: 216).



Argument	1	2	3	4	5	6	7	8	9	10	11	12
→	89	178	266	354	442	530	617	704	791	876	961	1046
↔	47	93	139	183	227	270	311	352	390	426	461	494
←	418	812	1163	1465	1713	1913	2070	2191	2280	2344	2386	2409
Argument	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
→	1129	1213	1295	1376	1456	1534	1611	1687	1760	1832	1902	1969
↔	524	553	579	602	623	641	656	669	679	686	691	692
←	2418	2413	2398	2374	2342	2302	2257	2208	2154	2096	2033	1969

Figure 5: Thandeikta *chaya* for Mars with transcription (after Anonymous, 1953).

tion is symmetric in the intervals [0, 90°] and [90°, 180°] such that its value for an angle in the first interval is the same as for the complementary angle in the second interval and it is only necessary to table it for the first interval, the *montol* table. The second function does not have this symmetry and is given as two separate tables, then *mangkar* and *korakat*, one for each angular interval. Figure 4 shows these tables for Mars.

The symmetric function is located in the top middle with values for 15°, 30°, 45°, 60°, 75°, and 90° in the direction of the arrows. The table then continues in descending order for angles 90° to 180°. The asymmetric function is located to the top left (0°–90°) and right (90°–180°) as shown by the arrows. The two bottom values, 1982 and 1983, should have been the same, showing that Faraut (1910) was ignorant of the astronomical background of these tables.

The Thandeikta scheme for calculating the true longitudes is the same as the one above but the eccentricities and radii of the excenters vary as function of the anomaly just as in the modern *Sūryasiddhānta* (Burgess, 2000) and the planetary *chayas* become different. Figure 5 shows the Thandeikta *chaya* for Mars corresponding to Figure 4 with transcription, taken from a Burmese manuscript (Anonymous, 1953). Each vertical of the twenty-four column represents 3.75°.

4 ECLIPSE CALCULATIONS

Eclipse calculations require the true longitudes of the Sun and the Moon. Also, the position of the lunar node has to be calculated in order to calculate the ecliptic latitude of the Moon, which is essential to know when determining the size and duration of the eclipse. These quantities are calculated for two sequential days that cover the eclipse. By interpolation, the time is found when the Sun and the Moon coincide in longitude for a possible solar eclipse or when the longitude of the Sun and the Moon differ by 180° for a possible lunar eclipse. If the Moon is sufficiently close, less than 12° to either the ascending or the descending node there can be an eclipse. A solar eclipse requires corrections for parallax. Due to the finite and different distances of the Moon and the Sun from the Earth there will be an apparent change in the relative positions of the Sun and the Moon for an observer on the Earth (topocentric) relative to the positions observed from the centre of the Earth (geocentric) that has to be taken into account and corrected for. Once these corrections are calculated and applied, the circumstance of the eclipse, sizes of the solar, lunar and shadow disks, eclipse duration, and the times for the start and end of the eclipse can be computed (Eade and Gislén, 1998; Gislén, 2015).

4.1 Parallax in Longitude

Parallax corrections are only necessary for the calculation of a solar eclipse. A lunar eclipse looks the same for all observers on the Earth where the Moon is above the horizon and the eclipse events are simultaneous for all observers and can because of this fact be used to determine geographical longitude differences between locations. It was an important tool for the French Jesuits who visited Siam in CE 1685 when they determined the longitude of Lopburi using the lunar eclipse of 11 December 1685 (Gislén, 2004; Gislén et al., 2018).

4.1.1 Thailand and Early Burma

Figure 6 shows the situation at the time of a geocentric conjunction between the Sun and the Moon. It is assumed that the Moon and the Sun move in the equatorial plane of the Earth and that we see the Earth from the North Pole. The Earth, like the Moon and the Sun, rotates anti-clockwise around C in the figure. At the geocentric conjunction, the Moon, M and the Sun, S, lie on a straight line from the centre of the Earth, C. However, for the observer at O, the sight lines to the Moon and the Sun will not coincide: there is an angle between the lines OM and OS. This is the parallax that will displace the Moon and the Sun relative to each other. In general, the parallax π, of an object is given by $\pi = \pi_0 \times \sin H$, where π_0 is the horizontal parallax, the parallax when the hour angle H is 90° and the celestial object is at the horizon. The horizontal parallax in the *Sūryasiddhānta* astronomical system is $\pi_M = 53'$ for the Moon and $\pi_S = 4'$ for the Sun, actually defined as the angle they move in 4 *nadi*. After some time, the Earth has rotated the angle ΔH and the observer, now at O', will see that the Moon and the Sun have moved a little counter-clockwise and that the new positions of the Moon, M' and the Sun, S' will coincide as seen from O' and that there is a topocentric conjunction. The angle α is given by

$$\alpha = H + \Delta H - v_M \times \Delta H/21600' + \pi_M \times \sin(H + \Delta H), \quad (15)$$

$$\alpha = H + \Delta H - v_S \times \Delta H/21600' + \pi_S \times \sin(H + \Delta H), \quad (16)$$

using the new positions M' and S' for the Moon and the Sun respectively, and assuming that the radius of the Earth is small compared to the distances to the Moon and the Sun. Here v_M and v_S are the angular daily motions of the Moon and the Sun expressed in minutes of arc. Setting these two expressions equal we get

$$\Delta H = 21600' \times (\pi_M - \pi_S)/(v_M - v_S) \times \sin(H + \Delta H). \quad (17)$$

If now the mean values for the daily motions are inserted, $v_M = 790'$, $v_S = 59'$, we get

$$\Delta H = 24°\sin(H + \Delta H). \quad (18)$$

This relation can be found also in al-Khwārizmī (Neugebauer, 1962). It is a transcendental equation for ΔH, the observer's correction to the geocentric conjunction time, and has to be solved by iteration. First ΔH is set to zero in the right member of the equation, and a new value for ΔH is computed, this value is inserted in the right member and so on. This iteration converges

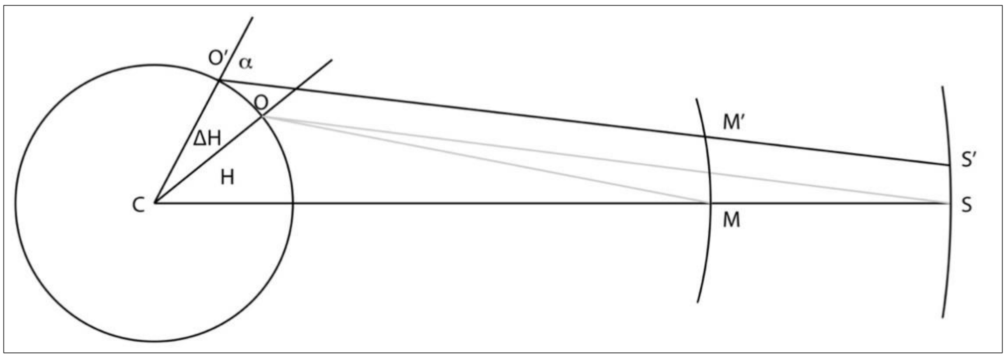


Figure 6: Parallax in longitude (diagram: Lars Gislén).

Table 7: Comparison of longitudinal parallax.

Time/ *nadis*	1st Iteration	2nd Iteration	3rd Iteration	4th Iteration	Wisandarunkorn (1997)	Faraut (1910)
0	0	0	0	0	0	-
1	6	8	9	9	9	-
2	11	15	17	18	18	-
3	16	23	25	26	26	22
4	21	29	32	33	32	29
5	26	35	38	39	37	35
6	31	40	43	43	43	40
7	35	45	47	47	46	44
8	39	48	49	50	49	47
9	43	50	51	51	50	50?
10	46	52	52	52	51	51?
11	48	53	53	53	53	52?

converges very rapidly. Expressing *H* in the time unit *nadi* (1 *nadi* = 6°) and converting ΔH to the movement in minutes of arc in longitude of the Moon by multiplying by the factor 790/360, these iterations generate the values shown in Table 7 (where the minutes of arc have been rounded to the nearest integer). The parallax correction is negative for times before noon and positive after noon.

This table compares the iteration result with two of the sources for Thai eclipse calculations. As can be seen, Wisandarunkorn (1997) agrees very well with the third and fourth iteration. Faraut's (1910) table lacks the first few values and is clearly defective at the end. Making his values start at three *nadi* and deleting some of his last values gives something similar to the second iteration.

4.1.2 Late Burma

The recipe to calculate the longitudinal parallax from the hour angle of the eclipsed bodies is given in a Burmese manual (U Thar-Thana, 1937). Figure 7 shows an extract from the manual text. Here is an English translation of the text in Figure 7:

> *Method to compute the parallax correction.*
>
> Convert the *nadi* and *vinadi* to *vinadi*. Set down the *vinadi* in two places. Multiply the upper one by 7 to make the numerator. Add 600 to the lower one to make the divisor. Divide the numerator and the denominator, the quotient is the parallax correction in *nadi*. The remainder, multiplied by 60 is the *vinadi* ….

The parallax in longitude is called *lambanata* (လမ္ဗနတ). Burgess (2000) gives the Sanskrit term as *lambana* (लम्बन), meaning 'hanging down'. In mathematical language the calculation scheme can be written as:

$$N = 7 \times V/(600 + V), \qquad (19)$$

where *V* is the hour angle (time from noon) expressed in the time unit *vinadi* and *N* is the parallax time correction in *nadi*. *V* is always taken to be positive, but the resulting *nadi* correction is added to the conjunction time if the conjunction occurs after noon otherwise it is subtracted. In order to compare it with the Thai parallax above we convert the *vinadi* into *nadi* and the time correction into minutes of arc and get Table 8 to compare with Table 7.


လမ္ဗနတနာဍီတွက်နည်း။
မချနတ နာဍီ,ဝိနာဍီကို ဝိနာဍီပုံပြု၍ နှစ်ထပ်ထား၊ အထက်ကို သတ္တ(၇)ခုမြှောက်၊ တည်ကိန်းဖြစ်၏။ အောက်ကို နဘာ,သုည,ဆ(၆၀၀)ပေါင်း၊ စားကိန်းဖြစ်၏။ တည်ကိန်းကိုတည်၊ စားကိန်းနှင့်စား၊ လဒ်ကား မချလမ္ဗနာဍီ။ သေသကို ခ,ဆ(၆၀)မြှောက်။ စားမြဲစား၊ လဒ်ကား ဝိနာဍီဖြစ်၏။ ယင်းမချလမ္ဗနာဍီ-စသည်တွင် မချနတ,နာဍီ-စသည့်ကိုနှော။ အောက်က မနေရာသည့်အတိုင်းတက်။ လမ္ဗနတနာဍီ,ဝိနာဍီဖြစ်၏။

Figure 7: Extract from a Burmese eclipse manual (after U Thar-Thana, 1937: 22).

If we compare the Thai and Burmese variants of parallax with the result from modern astronomy the Burmese formula is remarkably good (Gislén, 2015). In reality the correction varies a little with the longitude of the Sun, but the Burmese formula gives good mean values.

4.2 Parallax in Latitude

4.2.1 Thailand

A rather precise theoretical expression used in Indian and early Islamic astronomy for the parallax in latitude π_β of an object in the ecliptic is the expression (Neugebauer, 1962):

$$\pi_\beta = (\pi_M - \pi_S)\sin(\delta_N - \varphi), \qquad (20)$$

Table 8: Burmese parallax correction in longitude.

Time/nadi	Correction
0	0
1	8
2	15
3	21
4	26
5	31
6	35
7	38
8	41
9	44
10	46

where δ_N is the declination of the nonagesimal, the highest point of the ecliptic, and φ the geographical latitude. Using standard trigonometrical formulae, and the relation between declination and longitude, this can be written as

$$\pi_\beta = (\pi_M - \pi_S)(\sin\varepsilon\cos\varphi\sin\lambda_N - \cos\delta_N\sin\varphi). \quad (21)$$

Here the longitude of the nonagesimal is $\lambda_N = \Lambda - 90°$, where Λ is the longitude of the ascendant, the *lagna*, and ε is the obliquity of the ecliptic, in Indian astronomy assumed to be 24°. The Thai scheme splits this expression into two terms. The first of these terms, $(\pi_M - \pi_S)\sin\varepsilon\cos\varphi\sin\lambda_N$, can be simplified using an approximation. For locations in Mainland Southeast Asia the geographical latitudes are such that the cosine term is close to 1 and varies little with the geographiical latitude. The value used for the factor $(\pi_M - \pi_S)\sin\varepsilon\cos\varphi$ is set at 19′, giving φ the value of 17.6°, presumably a kind of mean geographical latitude for the region. The function for this parallax term is given as a very crude table {9′, 16′, 19′} for arguments 30°, 60° and 90°.

The second term $\pi' = (\pi_M - \pi_S)\cos\delta_N\sin\varphi$ still depends on the declination of the nonagesimal. As δ_N lies in the interval [0, 24°], the value

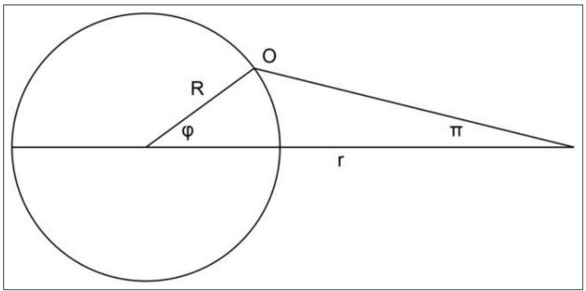


Figure 8: Geographical parallax (diagram: Lars Gislén).

of $\cos\delta_N$ will lie in the interval [0.91, 1], and the factor $(\pi_M - \pi_S)\cos\delta_N$ will lie in the interval [44.6′, 49′]. Without providing any explanation, Wisandarunkorn (1997) gives a value of 13′44″ for this second parallax term. The anonymous manuscript (Anonymous MS.) uses the value 13′ 40″. Faraut's description (1910: 176) of how to compute this parallax, 8″, is cryptic: ‘‘On retranche toujours 2, de 50 = 48, que l'on multiplie avec 2 = 96, que l'on divise par 12 = 8.'' However, there is a possible explanation, which is based on a crude approximation. Assume that the Moon and the Sun move in the equatorial plane and are located in the meridian of the observer. Figure 8 then describes the situation for the Moon. Assuming that the combined parallaxes of the Moon and the Sun are small relative to the geographical latitude, the geographical parallax is given by

$$\pi = (\pi_M - \pi_S)\sin\varphi = 49'\sin\varphi. \quad (22)$$

Wisandarunkorn (1997) gives his tables for day length and *lagna* for a geographical latitude of about 16° N. Inserting this in the formula gives a parallax of 13′ 30″. Faraut (1910) gives a table of day lengths for a geographical latitude for 9° 40′ N. Inserting this value in the formula gives a parallax of 8′ 14″. Both of these numbers are close to the values actually used by these sources.

4.2.2 Burma

The Burmese handling of the parallax in latitude is more sophisticated. The time from noon in *nadi* is multiplied by 6 in order to convert it to degrees, the hour angle. The result is then added to the longitude of the Sun. The result is a rather good approximation of the longitude of the nonagesimal λ_N, at least for locations in Burma. A table is then used to calculate the declination δ_N of the nonagesimal, using the correct relation $\sin\delta_N = \sin\varepsilon\sin\lambda_N$ with $\varepsilon = 24°$, the Indian obliquity. The parallax in latitude is then calculated using the correct expression $\pi_\beta = (\pi_M - \pi_S)\sin(\delta_N - \varphi)$, also with help of a table, where $\pi_M - \pi_S = 49'$. The agreement with a modern calculation is very good (Gislén, 2015).

5 ANALYSIS OF A THAI TRADITIONAL SOLAR ECLIPSE CALCULATION

The solar eclipse of 18 August 1868 is one of the more interesting events in Thai astronomical history and also one of the most important eclipses in the history of solar physics (see Orchiston, 2020). The duration of the totality was exceptionally long and it was the first solar eclipse where spectroscopic observations were made, leading to the discovery of helium (Nath, 2013). It was observed at several locations on the Earth, from Aden in the west to Indonesia in the east, by Austrian (Aden), English (India), German (Aden and India), French (India and Siam), and Dutch (Indonesia) astronomers (see Launay, 2012; Mumpuni et al., 2017; Orchiston et al., 2017). One of the French contingents of astronomers observed the eclipse from Wah-koa in Siam (under the black spot in Figure 9) in the presence of King Rama IV (Mongkut) of Siam (Orchiston and Orchiston, 2017). King Rama IV (Saibejra, 2006) had personally made calculations for this eclipse using Western methods, not being satisfied with the traditional way of calculating eclipses. Figure 9 shows a modern calculation of the centrality path of the eclipse. The black dot shows the size of the area on the Earth where the eclipse was total, and the red circle the area in which it was partial at the time of the totality in Wah-koa. It was total at that location about twenty minutes before noon, local time.

For eclipses the traditional Thai calculations use a special set of parameters for the Sun and the Moon. In the ordinary day-to-day calculations in South-East Asia the astronomical parameters were based on the *Sūryasiddhānta* and

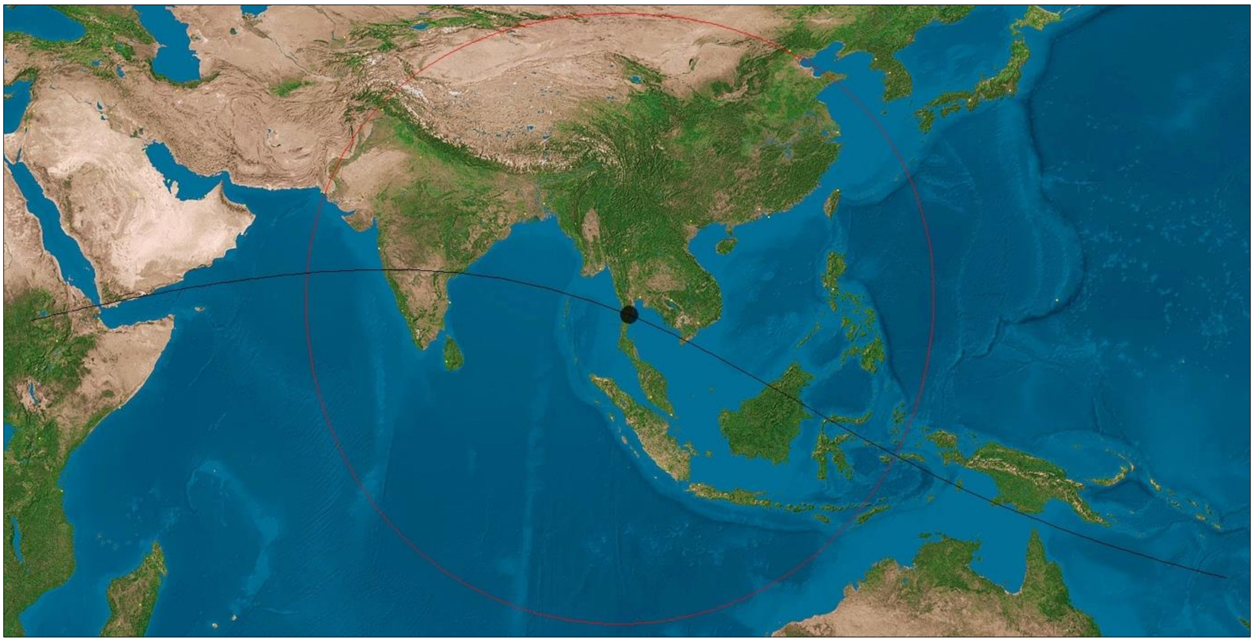


Figure 9: The solar eclipse 18 August 1868 (diagram: Lars Gislén).

midnight was used as the time reference. It is evident from the source manuscripts that the South East Asian astronomers used such day-to-day calculations to spot the occurrence of an eclipse and then switched to a more accurate set of parameters to perform the calculation of the eclipse circumstances. The parameters used for eclipse calculations are shown in Table 9 (Gislén and Eade, 2001). The precision given is 1/10000000 of a minute of arc.

The solar parameters except for the epoch longitude are exactly the values used in the *Aryabhatiya* (Billard, 1971: 77). Also, the use of 6:00 hours as the time reference points to the *Aryabhatiya*. However, the lunar parameters differ slightly from Aryabhāta's values. Billard (ibid.) describes a Hindu calendar that was introduced around CE 1000 and mentioned in the anonymous *Grahacarānibandhanasamgraha* (Haridatta, 1954). In Billiard's notation it is called k.(GCNib)B. The calendar scheme makes the following amendments to Aryabhāta's lunar parameters (Billard, 1971: 143):

Moon's longitude – (S – 444) × 9/85′, and
Moon's apogee – (S – 444) × 65/134′, and
Node – (S – 444) × 13/32′,

where S is the Śaka year. A simple check shows that this correction generates lunar parameters that precisely match those used by the Southeast Asian calendarists.[3]

Also, the epoch values correspond exactly to the values generated by the change above with the exception of that for the lunar apogee: 17651′ instead of 17641′; the Thai symbols for 4 and 5 look very similar and are easily confused. Finally, the epoch chosen for the eclipse calculations is exactly the day 1550000 current since the epoch of the Kaliyuga, 18 February 3102 BCE, certainly not a coincidence.

By a lucky coincidence, we have a Thai calculation of the 18 August 1868 solar eclipse of Wah-koa and shown in Figure 10 that was drawn from an anonymous Chiang Mai manuscript (Anonymous MS). The calculation follows exactly the traditional calculation scheme for a solar eclipse with the 63 steps given by Wisandarunkorn (1997: 190–204). The calculation in the manuscript is shown as a series of numbers accompanied by a Thai technical label that in most cases has a Sanskrit or Pali origin. A detailed transcription of the numbers in the manuscript is given here in the Appendix, in Section 12.1. Below is merely a crude layout of the calculation scheme.

The Thai date of the eclipse is written at the top of the page, 3 1/– 10 1230 Chulasakharat. The first digit 3 stands for the weekday, Tuesday. The second and third digits indicate that the day is the first of the waxing Moon in month 10, which is the month Bhadrapada in the numbering of Central Thailand. The last number is the year in the Chulasakharat Era. The first line of the calculation shows the number of years elapsed since the epoch, 725. Line 3 shows the value 265098, the number of elapsed days from the epoch. The following lines 4–15 show the

Table 9: Basic eclipse parameters.

Epoch CE 10 October 1142 = 28 Asvina 504 Chulasakarat Era		
Basic Eclipse Parameter	Epoch longitude (arc mins)	Mean daily motion (arc mins)
Solar longitude	12260	59.1361716
Lunar longitude	11339	790.5810032
Solar apogee	4680	0
Lunar apogee	17461	6.6818670

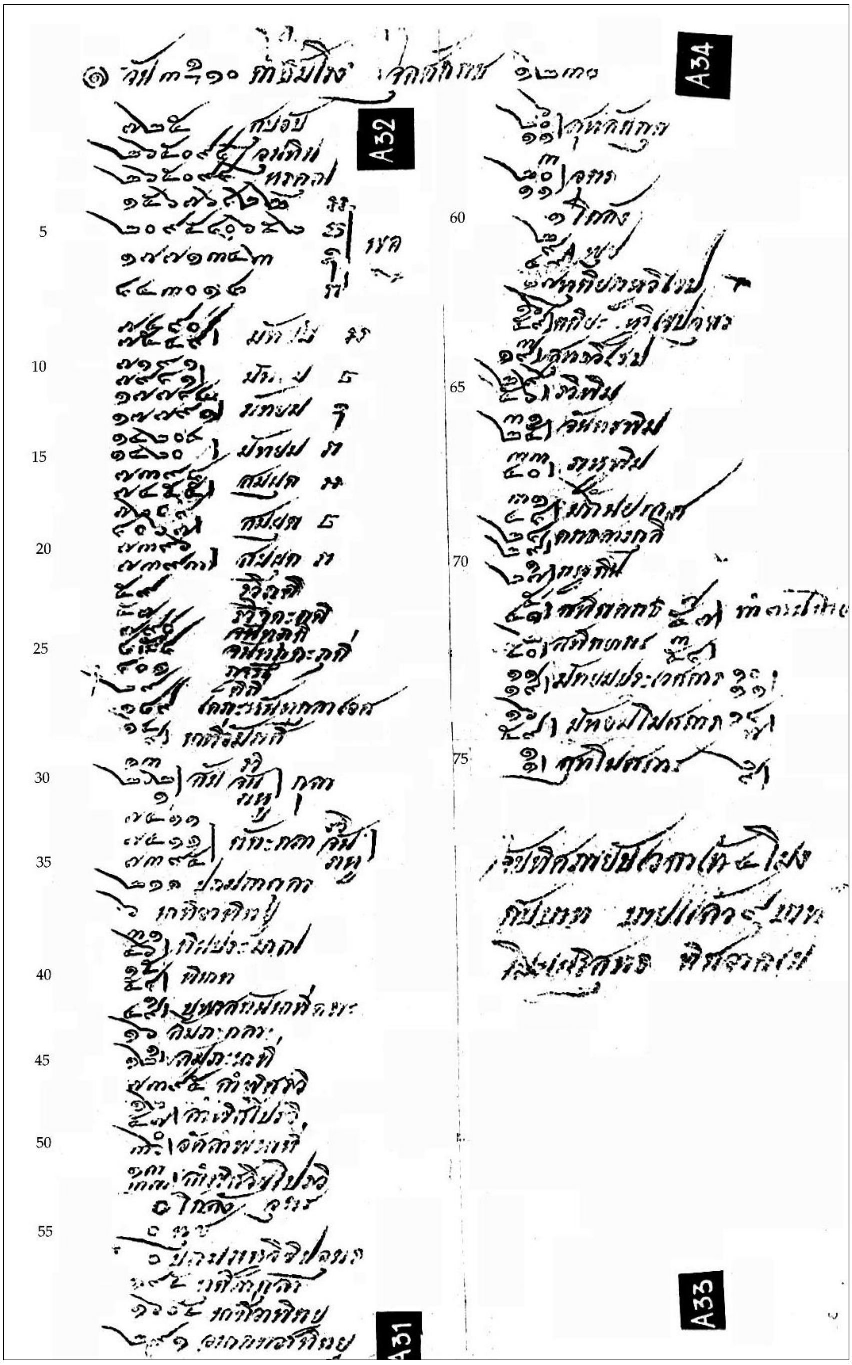


Figure 10: Traditional Thai solar eclipse calculation.

calculated mean longitudes of the Sun, the Moon, the Moon's apogee, and the node respectively for this day and the day following, the eclipse occurring within this time. Lines 16–26 calculate the true longitudes, the true elongation and the true daily motions. After having checked if an eclipse is possible, line 28, the conjunction time and longitudes are interpolated in lines 29–35. The eclipse is assumed possible if the Moon is within 12° of the lunar node, both for solar and lunar eclipses. The lengths of day and night are calculated in lines 36–41. In lines 42–45 the longitude parallax corrections are calculated and in 46–49 applied to the conjunction time and conjunction longitude. Lines 50–57 calculate the first approximation to the lunar latitude using the Moon's distance from the node. After having calculated the *lagna* and the nonagesimal (lines 58–63), the parallax corrections to the latitude are calculated to give the apparent latitude, 3′ 19″, line 64. Lines 65–70 calculate the sizes of the solar and lunar disks and the size of the eclipse. Finally, the last lines compute the eclipse duration and the times of the start and end of the eclipse.

The calculation of the semiduration of the eclipse uses a scheme that is special for Thai eclipse calculations. It has not been possible to determine the origin of this scheme, but it is very crude and may be quite ancient. The lunar latitude in minutes of arc is subtracted from 31′, the sum of the mean lunar and solar disk radii, and with this argument Table 10 is entered and the duration interpolated.

For the eclipse, the computed lunar latitude is 3′ 19″. Subtracting this from the sum of the mean solar and lunar radii, 31′, we get 31′ – 3′ 19″ = 27′ 41″. Interpolation in the table gives the duration as 5 *nadi* 41 *vinadi*, the actual value given in the manuscript.

There is a similar table to use for lunar eclipses where the lunar latitude is subtracted from 54′, which is the sum of the mean radii of the disks of the Moon and the mean shadow disk radius, where the disk radius of the shadow is taken to be 2.5 times that of the radius of Moon's disk. The table used for lunar eclipses is shown as Table 11. Faraut (1910) has a similar table, but for unknown reasons it has slightly different numbers.

According to the traditional calculation above for Bangkok, the eclipse is not total. The reason is that the parallax correction in latitude is too large, the real effective parallax correction in latitude being only of the order of 2′. The geocentric lunar latitude is about –2′, which gives a topocentric latitude of zero and a total eclipse. The reason for the error is that in order to compute the *lagna* correctly it is necessary to use the tropical longitude of the Sun, i.e. including the precession, which in this case is 21° 51′, and this is not done. The neglect of the precession in the calculation can be due either to its having fallen out of the instructions or that the instructions were out-dated. Recalculation with the precession included gives indeed a total eclipse.

6 A BURMESE LUNAR ECLIPSE CALCULATION

Burmese solar eclipse calculations are much more complex (Gislén, 2015). They use the modern *Suryasiddhānta* parameters. The precision of the calculation is in seconds of arc, precession is included, and the duration of the eclipse is calculated using an iterative scheme that corrects for the changing ecliptic latitude of the Moon during the eclipse.

The layout for a lunar eclipse is shown in Figure 11. The first two numbers in the top left column give the year, first one in the Burmese era, 1296 (၁၂၉၆), then in the Kaliyuga era 5035 (၅၀၃၅). The Gregorian date of the eclipse is 26 July 1934. The following lines show the new year *kyammat,* 85 (၈၅), the new year weekday (1 (၁) = Sunday), and the number of elapsed days of the year, 102 (၁၀၂). Then follow the calculated mean longitudes of the Sun, the Moon, the apogee and the node. The longitudes are also given here with a precision of seconds of arc.

Table 10: Solar eclipse duration.

Argument	Duration/*Nadi*
0	0
1	1
3	2
6	3
12	4
20	5
31	6

Then the true longitudes are calculated, top centre column, lines 2 and 3, and the true daily motion and the true motion in elongation, right column line 2. The rest of the top right column is devoted to a computation of the tropical longitude of the Sun, day length and the noon shadow (see Section 7 below).

The bottom left column calculates the conjunction times and the conjunction longitudes. Knowing the angular distance between the Moon and the node, in this case the ascending node, the lunar latitude is calculated assuming an inclination of 4.5″ of the lunar orbit relative to the ecliptic. This value of the inclination of the lunar orbit is standard in many Indian astronomical texts.

Also standard in both Thailand and Burma is the calculation of the sizes of the lunar and shadow disks. These sizes are assumed to be proportional to the daily motion, *v,* of the stellar object, i.e. the diameter, *D*, is assumed to be

$$D = D_{mean} \times v_{true}/v_{mean}. \qquad (23)$$

Given the apparent radii, *r* and *R*, of the Moon and the shadow respectively and the lunar latitude, β, the first approximation to the (half) duration, *d*, is calculated using the Pythagorean theorem:

$$d = \sqrt{\{(R - r)^2 - \beta^2\}} \qquad (24)$$

for the total phase and

$$d = \sqrt{\{(R + r)^2 - \beta^2\}} \qquad (25)$$

for the partial phase. If $R - r < \beta$, the first relation will not give a real number and the eclipse is only partial. The geometry of the eclipse is shown in Figure 12.

The latitude of the Moon is not constant during the eclipse and using the computed dura-

Table 11: Lunar eclipse duration.

Argument	Duration/Nadis
0	0
1	1
2	2
4	3
7	4
11	5
15	6
21	7
28	8
40	9
54	10

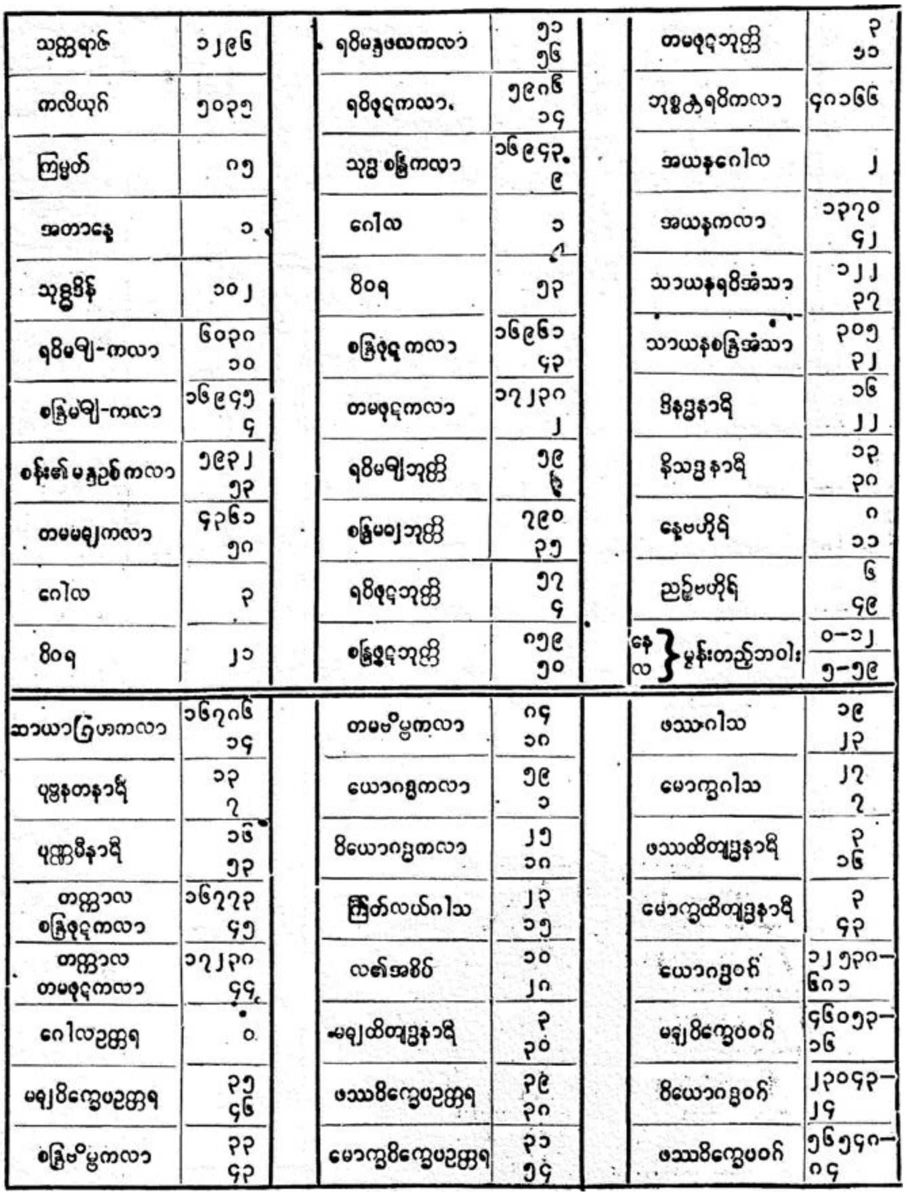


Figure 11: Burmese lunar eclipse calculation.

tion as a first approximation, new values of the lunar latitude are computed for the beginning and end of the eclipse and new semi-durations are calculated and taken as final. This calculation is correct mathematically, is very similar to the calculations done in the modern *Sūryasidddhānta* (Burgess, 2000), and is much more sophisticated than the Thai calculation.

This lunar eclipse was partial. The beginning of the eclipse was not visible from Yangoon as the Moon had not yet risen, and the middle of the eclipse occurred about 10 minutes after sunset. Comparing the calculated times with a modern ephemeris the agreement is very good, the error being only about five minutes.

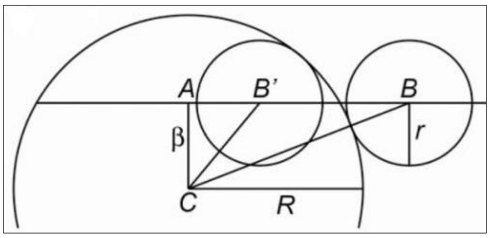


Figure 12: Eclipse geometry (diagram: Lars Gislén).

7 SHADOW CALCULATIONS

These calculations are specific for Burma where there are instructions in astronomical manuals of how to do such calculations (Gislén and Eade, 2014). However, there are a few examples also from the Thai region:

> … in the third month, on the fourth day of the waning moon … when the shadow (of the gnomon) cast by the morning sun measured fifteen feet, in the rksa of Citra, in the year seven hundred thirty-one of the Era.

> … the eighth day of the day of the waxing moon of the first month, Thursday, the auspicious day and time, in the afternoon when the shadow of the gnomon marked exactly six padas.

It is difficult to evaluate these records as there are too many unknown facts. The height of the gnomon is not known, and being a Thai record it is not known if the solar longitude and day length are corrected for precession. It seems that the shadow calculations or observations had mostly astrological significance and were of little practical use. Some records even give 'Moon shadows'. They appear in horoscopes, but also accompany eclipse calculations (Gislén, 2015).

Primitive shadow calculations appear already in Mesopotamia (Neugebauer, 1975(1): 544; Ôhashi, 2011). More sophisticated are the Indian calculation schemes using the formula

$$d/(2t) = (s - s_0)/G + 1, \qquad (26)$$

where s_0 is the noon shadow length, G, the gnomon height, s the shadow length, t the time from sunrise or sunset, and d the day length (Abraham, 1981). The same formula can also be found in the *Romakasiddhānta* in Varahamihira's *Pañcasiddhantika* (Neugebauer, 1970; Sastry, 1993). Using a half day length $D = d/2$ and measuring time T from noon $T = D - t$, we can rewrite this expression as it is used in the Burmese calculations:

$$s = s_0 + G \times T/(D - T). \qquad (27)$$

It is easy to see that this expression makes sense. At noon, $T = 0$, and $s = s_0$, the noon shadow. At sunrise or sunset, the denominator is zero and the shadow becomes infinite as it should.

However, in an astronomically correct calculation the factor G is not constant but will depend on the longitude λ of the Sun and the geographical latitude φ, as well as on the gnomon height. There is also a dependence on the time T from noon. In the Burmese scheme the dependence on the geographical latitude is neglected since this variation is not excessive in the Mainland Southeast Asia area (Mauk, 1971; Thi, 1936). The noon shadow depends on the declination of the Sun (in turn being a function of the solar longitude), and on a geographical latitude φ, which cannot be neglected there. The half day length will depend on the longitude of the Sun and the geographical latitude. We are then left with the formula

$$s = s_0(\lambda,\varphi) + G(\lambda,T) \times T/(D(\lambda,\varphi) - T). \qquad (28)$$

The calculation of the noon shadow, s_0, and the half day length is done by having a table for a set of towns in Southeast Asia. Table 12 below shows a table for Yangoon with a transcription. What is tabulated is the difference between the noon shadow and the equinoctial noon shadow, the *bawa* (ဘာဝါ).

The number to the far right, 126, is the equinoctial noon shadow for Yangoon, using a gnomon with height $G = 7$ subdivided into 60 subunits. The equinoctial noon shadow is $G \tan \varphi$, where φ is the geographical latitude. Thus, $\tan \varphi = 126/420$, giving $\varphi = 16° 42'$, which is close to the modern geographical latitude 16° 52′.

The column on the left in the table stands for multiples 1, 2, and 3 of 30° of the solar latitude. The next column is used for calculating the day length, and shows the excess *vinadi* to be added or subtracted to the equinox half day length of 15 *nadi* or 900 *vinadi*. In this column, due to symmetry, multiple 2 is equivalent to 4, 8, and 10, and multiple 1 is equivalent to 5, 7, and 11. The numbers in the last two columns show the *bawa*. You start going up the first column then back down, continue up the last column and then back down remembering that there is a hidden row with zeros at the top for solar longitude 0° and 180°. The *bawa* is to be added or subtracted from the equinoctial shadow, depending on the declination of the Sun.

For the multiplier $G(\lambda,T)$ there is a special double-entry table for longitude and *nadi* from noon, as shown in the upper Table 13. The column numbers are the *nadi* from noon.

Example. Calculate the shadow three *nadi* after noon in Yangoon when the Sun's longitude is 60° = 2 × 30°. The excess day length from Table 13 is 69 and as the Sun is north of the equator the excess is added to the equinox half day length of 900 *vinadi* to give 969 *vinadi*. The *bawa* is 155. As the Sun is moving north in declination the noon shadow becomes shorter and we should take the difference between the *bawa* and the equinoctial shadow to get the noon shadow: 155–126 = 29. From top Table 13, with arguments 60° for the Sun (Taurus) and

Table 12: Shadow table for Yangoon.

	၁	၃၆	၉၀	၁၀၁	
ရန်ကုန်မြို့	၂	၆၉	၁၅၅	၁၉၄	၁၂၆
	၃	၇၇	၁၈၀	၂၃၅	

	1	36	90	101	
Yangoon	2	69	155	194	126
	3	77	180	235	

Table 13: Multiplier tables (after Thi, 1936).

Nadis		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Capricorn		61	124	168	216	251	280	307	325	338	345	349	350	325			
Aqu	Sag	63	133	176	220	250	280	305	321	331	335	337	337	310			
Pis	Sco	79	134	187	232	267	291	309	320	324	325	320	312	301	288		
Aries	Libra	89	162	236	283	312	330	339	340	335	328	317	303	286	267	268	
Tau	Virgo	178	304	363	395	408	415	402	391	375	313	338	318	296	309	251	
Gem	Leo	571	599	582	563	590	509	484	456	430	409	375	349	322	301	270	229
Cancer		455	522	539	530	515	494	471	450	427	402	372	351	326	302	267	241
Nadis		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Capricorn		69	128	178	219	254	281	304	321	335	346	354	359	363			
Aqu	Sag	69	127	176	216	249	275	296	312	324	333	339	343	346			
Pis	Sco	72	132	181	220	250	273	290	302	310	315	317	317	316	315		
Aries	Libra	92	165	220	258	284	301	311	316	318	317	313	309	303	296	288	
Tau	Virgo	168	273	329	356	368	371	369	363	355	346	335	325	313	302	290	
Gem	Leo	499	532	524	507	487	467	446	427	407	389	371	354	337	321	306	291
Cancer		449	506	509	498	481	464	445	427	409	391	374	358	342	327	312	298

three *nadi*, we get the multiplier 363, where 3 *nadi* is equal to 180 *vinadi*. Using formula (25) we get the shadow of a 420 unit gnomon as

$$s = 29 + 363 \times 180/(969 - 180) = 112. \qquad (29)$$

By inverting the relation it is possible to get an expression for the multiplier

$$G(\lambda,T) = (s - s_0) \times (D(\lambda,\varphi) - T). \qquad (30)$$

The bottom Table 13 shows the result for $G(\lambda,T)$ from a modern calculation for geographical latitude 22°, with a result that is rather similar to the Burmese table. However, it is not known how the Burmese constructed their table.

Using equation (28) it is possible to solve for the time after noon:

$$T = D(s - s_0)/(G + s - s_0). \qquad (31)$$

This can be used to find the time, given the shad-ow length—a procedure that is found in some manuscripts. However, the quantity *G* is itself a function of time. The problem is solved by iteration, first *G* is set to 7 (or 420) and a preliminary time, *T*, is computed. A new *G* is taken from the multiplier table using this time and a second approximation time can be calculated that can be used to find a new *G*, and so on.

In the Burmese calculations the scheme is also used to calculate Moon shadows by, instead of using *D* for half the length of the night, letting *T* be time from midnight and using the longitude of the Moon. This neglects the fact that the Moon does not move on the ecliptic. Such Moon shadows are obviously purely artificial, and show that the system had become a kind of 'number magic'.

8 PRECESSION

For the shadow and day length, and also for *lagna* correct calculations, it is necessary to use the tropical longitude of the Sun, i.e. to take precession into account. However, it seems that Thai calculations ignore precession, something that seems very probable also for the earlier Burmese Makaranta calculations. The Burmese Thandeikta scheme uses the Indian model for precession that assumes that the correction for precession is a zig-zag function with an amplitude of 27° and a period of 7200 years. The zig-zag function starts at zero 88 years before the epoch of the Kaliyuga epoch and decreases linearly and becomes –27° after 1800 years. It then increases linearly to +27° for 3600 years, then decreases linearly to reach zero 1800 years later. In order to compute the correction for precession the following scheme is used.

The year in the Burmese era is converted to the Kaliyuga era by adding 3739. The epoch constant of 88 years is added. The result is divided by 1800 and the remainder is saved. The quotient tells which part of the zig-zag function that is actual. For all reasonable historic eras this part is where this function is positive and rising. The remainder is multiplied by 9 and divided by 10. The reason for these two numbers is that the zig-zag function increases linearly by 27° in 1800 years. 27° is 27 × 60 = 1620′. 1800 times 9/10 is precisely equal to this number. The quotient will then be the number of minutes of arc of precession. The remainder is multiplied by 6, and gives the seconds of arc of precession. The quotient is divided by 60. The quotient will be the degrees of the correction for precession, the remainder is the minutes of arc. The extreme of the zig-zag function is 1800. Multiplied by 9 and divided by 10 and then by 60 gives 27°, the amplitude of the correction for precession. The rate of precession is 27/18 = 1.5° per century, not far from the correct modern value of about 1.4° per century.

Example: Compute the correction for precession for the year 1297 in the Burmese era.

1297 + 3739 + 88 = 5124.
5124/1800 = 2, remainder 1524
1524 × 9/10 = 1471, remainder 6, 6 × 6 = 36
1471/60 = 22, remainder 51
The correction for precession is 22° 51′ 36″.

9 CONCLUDING REMARKS

The astronomical calculations show a great influence from Indian astronomy, in particular from the original *Sūryasiddhānta*. The later Burmese Thandeikta calculations are adaptations of the modern *Sūryasiddhānta* and show more sophistication in, for instance, the eclipse calculations. The Thai eclipse calculations use methods taken from the Indian *Aryabhāta* canon.

10 NOTES

1. This is the fifth paper in a series reviewing the traditional calendars of Southeast Asia. The first paper (Gislén and Eade, 2019a) introduced the series; Paper #2 (Gislén and Eade, 2019b) was about Burma, Thailand, Laos and Cambodia, with emphasis on the first two nations; Paper #3 (Lân, 2019) was about Vietnam; and Paper #4 (Gislén and Eade, 2019c) about Malaysia and Indonesia.
2. For specialist terms used in this paper see the Glossary in Section 12.3.
3. For example, in the Aryabhata canon the lunar apogee makes 232226 rounds during a period of 4320000 years, or 1577917500 days (Billard, 1971: 78). This gives a mean motion of 232226/1577917500 × 360 × 60 = 6.6831950 minutes of arc per day. The correction per year is –65/134′. The daily correction will then be –65/134 × 4320000/ 1577917500 = –0.0013280′. Thus, the corrected mean motion is 6.6831950 – 0.0013280 = 6.6818670, the value used in Table 9.

11 REFERENCES

Abraham, G., 1981. The gnomon in early Indian astronomy. *Indian Journal of History of Science*, 16(2), 215–218.

Anonymous [ca. 1868]. Manuscript. Chiang Mai University Library (CMUL MS 18–011) (in Thai).

Anonymous, 1953. ဆင်တဲစကားပြကျမ်း. Mandalay (in Burmese).

Billard, R., 1971. *L'astronomie Indienne.* Paris, École Française d'Extrème-Orient (in French).

Burgess, E., 2000. *The Sûrya Siddhânta*. Dehli, Motolal Banarsidass (Reprint).

Eade, J.C., and Gislén, L., 1998. "The whole Moon was eaten": Southeast Asian eclipse calculation. *Journal of Southeast Asian Studies*, 29, 309–318.

Faraut, F.G., 1910. *Astronomie Cambodgienne*. Saigon, F.H. Schneider (in French).

Gislén, L., and Eade, J.C., 2001. South East Asian eclipse calculations. *Centaurus*, 43, 278–307.

Gislén, L. 2004. Analysis of the astronomical information in Thachard: "Voyage to Siam in the Year 1685". *Centaurus*, 46, 133–144.

Gislén, L., and Eade, J.C., 2014. Burmese shadow calculations. *Journal of Astronomical History and Heritage*, 17, 258–266.

Gislén, L., 2015. Burmese eclipse calculations. *Journal of Astronomical History and Heritage*, 18, 53–64.

Gislén, L., Launay, F., Orchiston, W., Orchiston, D.L., Débarat, S., Husson, M., George, M., and Soonthordthum, B., 2018. Cassini's 1679 map of the Moon and French Jesuit observations of the lunar eclipse of 11 December 1685. *Journal of Astronomical History and Heritage*, 21, 211–225.

Gislén, L., and Eade, C., 2019a. The calendars of Southeast Asia. 1: Introduction. *Journal of Astronomical History and Heritage*, 22, 407–416.

Gislén, L., and Eade, C., 2019b. The calendars of Southeast Asia. 2: Burma, Thailand, Laos and Cambodia. *Journal of Astronomical History and Heritage*, 22, 417–430.

Gislén, L., and Eade, C., 2019c. The calendars of Southeast Asia. 4: Malaysia and Indonesia. *Journal of Astronomical History and Heritage*, 22, 447–457.

Haridatta, 1954. *Grahacâranibandhana*. Madras, Kuppuswami Sastri Research Institute.

Lân, T.L., 2019. The calendars of Southeast Asia. 3: Vietnam. *Journal of Astronomical History and Heritage*, 22, 431–446.

La Loubère, S., 1691. *Du Royaume de Siam*. *Tome 2*. Paris, Jean Baptiste Coignard (in French).

Launay, F., 2012. *The Astronomer Jules Janssen: A Globetrotter of Celestial Physics*. New York, Springer.

Mauk, 1971. *Handbook for the Calculation of Thandeikhta Horoscopes*. Mandalay (in Burmese).

Mumpuni, E.S., Orchiston, W., and Steinicke, W., 2017. J.A.C. Oudermans' observations of the 18 August 1868 and 12 December 1871 total solar eclipses from the Dutch East Indies. In Nakamura and Orchiston, 357–373.

Nakamura, T., and Orchiston, W. (eds.), 2017. *The Emergence of Astrophysics in Asia: Opening a New Window on the Universe.* Cham (Switzerland), Springer.

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

Neugebauer, O., 1962. *The Astronomical Tables of Al-Khwārizmī*. København, Historisk-filosofiske Skrifter udgivet af det Kongelige Danske Videnskabernes Selskab, 4(2).

Neugebauer, O., and Pingree, D., 1970–1971. *The Pañcasiddhantika by Varahamihira.* København, Historisk-filosofiske Skrifter udgivet af det Kongelige Danske Videnskabernes Selskab, 6(1).

Neugebauer, O., 1975. *A History of Ancient Mathematical Astronomy. Three Volumes*. Berlin, Springer.

Ôhashi, Y., 2011. On Vesāṅga astronomy: the earliest systematic Indian astronomy. In Nakamura, T., Orchiston, W., Sôma, M., and Strom, R. (eds.), *Mapping the Oriental Sky*. *Proceedings of the Seventh International Conference on Oriental Astronomy*. Tokyo, National Astronomical Observatory of Japan. Pp. 164–170.

Orchiston, W., and Orchiston, D.L., 2017. King Rama IV and French observations of the 18 August 1868 total solar eclipse from Wah-koa, Siam. In Nakamura and Orchiston, 291–317.

Orchiston, W., Lee, E.-H., and Ahn, Y.-S., 2017. British observations of the 18 August 1868 total solar eclipse from Guntoor, India. In Nakamura and Orchiston, 771–793.

Orchiston, W. (ed.), 2020. *The Total Solar Eclipse of 18 August 1868: A Watershed Event in the Development of Solar Physics.* Cham (Switzerland), Springer.

Saibejra, N., 2006. King Mongkut: the Father of Thai Science. In Chen, K.-Y., Orchiston, W., Soonthornthum, B., and Strom, R. (eds.). *Proceedings of the*

Fifth International Conference on Oriental Astronomy. Chiang Mai, Chiang Mai University. Pp. 15–18.

Sastry, T.S.K., 1993. *Pañcasiddhāntika by Varahamihira.* Madras, Adyar (P.S.S.T. Science Series No. 1).

Thi, 1936. *Moon Shadow and Time Calculating Handbook*. Mandalay (in Burmese).

U Thar-Thana, 1937. *Hsin-temu thara-kjan-thi*. Mandalay (in Burmese). A pdf version of the original can be found on: http://home.thep.lu.se/~larsg/Site/UTharThaNa.pdf

Wisandarunkorn, L., 1997. *Khamphi Horasasat Thai (Profound Thai Astrology)*. Bangkok, In-print (in Thai).

12 APPENDICES

12.1 The Solar Eclipse of 18 August 1868: A Detailed Recomputation

We refer to the manuscript page shown in Figure

Table 14: Solar and lunar equations.

Anomaly/arcmins	Solar equation	Lunar equation
0	0	0
1000	37	87
2000	71	165
3000	98	230
4000	118	276
5000	128	298
5400	129	301

10. The solar and lunar equations used are given above in Table 14.

CS 1230, day 1, Tuesday, month 10 (Bhadrapada). The numbers to the left in the calculation below refer to steps in Wisandarunkon (1997: 190–200). Bold numbers are those found in the anonymous manuscript, and they all agree with numbers computed by following the steps in Wisandarunkorn. The numbers on the right give the line number in the manuscript.

<table>
<tr><td>1</td><td>Unthin = 265098, Unthin –1 = 265098 – 1 = 265097</td><td>Days since the epoch</td><td>2</td></tr>
<tr><td>2</td><td>265097 · 591361716 = 15676821|6826452 –> 15676822</td><td>Sun mean movement, truncated</td><td>4</td></tr>
<tr><td>3</td><td>265097 · 7905810032 = 209580652|2053104 –>209580652</td><td>Moon mean movement</td><td>5</td></tr>
<tr><td>4</td><td>265097 · 66818670 = 1771342|8960990 –> 1771343</td><td>Apogee movement</td><td>6</td></tr>
<tr><td>5</td><td>265097 · 31800373 = 843018|3481181 –> 843018</td><td>Node movement</td><td>7</td></tr>
<tr><td>6</td><td>(15676822 + 12268) / 21600 = 726:7490</td><td>Mean Sun 1</td><td>8</td></tr>
<tr><td>7</td><td>7490 + 59 = 7549</td><td>Mean Sun 2</td><td>9</td></tr>
<tr><td>8</td><td>(209580652 + 11339) / 21600 = 9702:7191</td><td>Mean Moon 1</td><td>10</td></tr>
<tr><td>9</td><td>7191 + 790 = 7981</td><td>Mean Moon 2</td><td>11</td></tr>
<tr><td>10</td><td>(1771343 + 17641) / 21600 = 82:17784</td><td>Apogee 1</td><td>12</td></tr>
<tr><td>11</td><td>17784 + 7 = 17791</td><td>Apogee 2</td><td>13</td></tr>
<tr><td>12</td><td>(843018 – 8014) / 21600 = 38:14204</td><td>Node 1</td><td>14</td></tr>
<tr><td>13</td><td>14204 + 3 = 14207</td><td>Node 2</td><td>15</td></tr>
<tr><td>14</td><td>(7490 – 4680) / 5400 = 0:2810</td><td>Sun's Anomaly 1</td><td></td></tr>
<tr><td>15</td><td>2810 / 1000 = 2:810</td><td>Interpolation of</td><td></td></tr>
<tr><td></td><td>71 + (98 – 71) · 810 /1000 = 92</td><td>solar equation of centre</td><td></td></tr>
<tr><td></td><td>7490 – 92 = 7398</td><td>True Sun 1</td><td>16</td></tr>
<tr><td>16</td><td>(7549 – 4680) / 5400 = 0:2869</td><td>Sun's anomaly 2</td><td></td></tr>
<tr><td></td><td>2869 / 1000 = 2:869</td><td>Interpolation of</td><td></td></tr>
<tr><td></td><td>71 + (98 – 71) · 869 /1000 = 94</td><td>solar equation of centre</td><td></td></tr>
<tr><td></td><td>7549 – 94 = 7455</td><td>True Sun 2</td><td>17</td></tr>
<tr><td>17</td><td>(7191 – 17784 + 21600) / 5400 = 2:207</td><td>Moon's anomaly 1</td><td></td></tr>
<tr><td>18</td><td>207 / 1000 = 0:207</td><td>Interpolation of</td><td></td></tr>
<tr><td></td><td>0 + (87 – 0) · 207 / 1000 =18</td><td>lunar equation of centre</td><td></td></tr>
<tr><td></td><td>7191 + 18 = 7209</td><td>True Moon 1</td><td>18</td></tr>
<tr><td>19</td><td>(7981 – 17784 + 21600) / 5400 = 2:997</td><td>Moon's anomaly 2</td><td></td></tr>
<tr><td></td><td>997 / 1000 = 0:997</td><td>Interpolation of</td><td></td></tr>
<tr><td></td><td>0 + (87 – 0) · 997 / 1000 = 86</td><td>lunar equation of centre</td><td></td></tr>
</table>

	7981 + 86 = **8067**	True Moon 2	19
20	21600 – 14204 = **7396**	True node 1	20
21	21600 – 14207 = **7393**	True node 2	21
22	7549 – 7490 = **59**	Mean solar motion	22
23	7455 – 7398 = **57**	True solar motion	23
24	7981 – 7191 = **790**	Mean lunar motion	24
25	8067 – 7209 = **858**	True lunar motion	25
26	858 – 57 = **801**	Motion in elongation	26
27	(7209 – 7396 + 21600)/720 = **29**:533	Distance from node <720´=12˚	27
	720 – 533 = 187	Eclipse possible	
28	(7398 – 7209) / 720 = 0:**189**	Sun-Moon elongation	28
29	189 · 60 / 801 = **14:9**	Conjunction time	29
30	14:9 · 57 /60= **13**	Sun to go	30
31	14:9 · 858/60 = **202**	Moon to go	31
32	14:9 · 3/60 = **1**	Node to go (retrograde)	32
33	7398 + 13 = **7411**	Sun: Conjunction longitude	33
34	7209 + 202 = **7411**	Moon: Conjunction longitude	34
35	7396 – 1 = **7395**	Node: Conjunction longitude	35
36	7411 / 1800 = 4:**211**	Calculation of day length	36
37	326 – 272 = 54, 54 · 211 / 1800 = **6**		37
	326 + 312 + 312 + 326 + 334 + 312 = 1922		
	1922 – 6 = 1916, 1916 / 60 = 1916 / 60 = **31:56**	Day length	38, 39
38	31:56 / 2 = **15:58**	Half day	40, 41
39		Conjunction before noon	
	15:58 – 14:9 = **1:49**	Time from noon	42, 43
	9 + (18 – 9) ·49 / 60 = **16**	Parallax in longitude	44
40	16 · 60 / 800 = **1:12**	Parallax time	45, 46
41	7411 – 16 = **7395**	Corrected longitude	47
42	14:9 – 1:12 = **12:57**	Corrected time	48, 49
43	1:12 / 2 = **0:36**	Half time correction	50, 51
44	14:9 – 0:36 = **13:3**3	Time argument for lagna	52, 53
45	(7395 – 7395) / 5400 = **0:0** (north)	Node distance	54
	0 · 60 / 800 = **0:0**	First latitude north	55
46	7395 / 1800 = 4:**195**	Lagna calculation	56
47	1800 – 195 = **1605**		57
48	Enter at 5 o'clock in the duang 326 · 1605 / 1800 = **291**		
49	13:33 · 60 = 813, 813 – 291 = 522		
	522 – 312 = 210 -> Lagna sign 6		
	210 · 30 / 312 = 20:11 degrees		
	06:20:11	Lagna	58
50	6:20:11 – 3:0:0 = **3:20:11**	Nonagesimal	59
	Sign is <6 thus parallax north	Calculation of latitude	

		parallax	
	3/3 = **1,** second quadrant -> 6 – 3:20:11 = **2:9:49**	Complementary angle	60, 61
	Sign = **2**, parallax 16´, difference 19´–16 = 3´	Interpolation	
	3 ·9:49 / 30 + 16 = 16:59 ≈**17**	Latitude parallax correction	62
51	16:59 + 0:0 = **16:59**	Second latitude north	63
52	13:40	Geographical latitude correction	
	16:59 – 13:40 = **3:19**	True latitude	64
53	57 · 31 / 59 = **29:56**	Solar disk diameter	65
54a	801 · 31 / 790 = **31:25**	Elongation diameter	66
54b	858 · 31 / 790 = **33:40**	Lunar disk diameter	67
56	(29:56 + 33:40) / 2 = **31:48**	Sum of radii	68
57	31:48 – 3:19 = **28:29**	Eclipse size	69
58	29:56 – 28:29 = **1:27**	Crescent > 0, not a total eclipse	70
59	31 – 3:19 = 27:41	Duration argument	
	5 + (27:41–20) / (31 – 20) = 5 + 7:41 / 11 = **5:41**	Interpolation	
	5:41	Eclipse duration	71
60	5:41 / 2 = **2:50**	Semiduration	72
61,62	14:9 – 2:50 = **11:19,** 14:9 + 2:50 = **16:59**	Start/end of the eclipse	73, 74
63	16:59 – 15:58 = **1:1**	Time from noon	75

In order to compute the *lagna* correctly it would be necessary to use the tropical longitude for the Sun and the Moon, i.e. including the precession which in this case is 21° 51′ = 1311′. The tropical longitude of the Sun at the conjunction will then be 1311 + 7395 = 8706. Repeating the calculation using this value gives a total eclipse. It is not clear why precession has been neglected here.

12.2 Comparison of Thai Traditional Eclipse Timings

In order to compare the quality of traditional eclipse calculations we include Tables 15 and 16, which list the calculated timings of the end of totality of a number of solar and lunar eclipses found in the records. All of these eclipses were visible (weather permitting) in Southeast Asia.

The Thai month names are abbreviated by their first three letters, and the references mentioned in column 2 in both tables are as follows:

1 Astrologers Notebook, 1808.
2 Astrologers Notebook, 1808.
3 Astrologers Notebook, 1891.
4 Astrologers Notebook, MS #159.
5 Astrologers Notebook, MS #159.
6 Wisandarunkorn, 1997.
7 Faraut, 1910.
8 Anonymous [ca. 1868].

The eclipses in bold font were visible in Southeast Asia. The quality as regards to the tim-

Table 15: Comparison of solar eclipse timings.

Date (CE)	Ref	CS Date	CS Time	Time
16 May 1817	1, 5	1 Jye 1179	13:00	12:58
9 Nov 1817	1, 5	1 Kar 11794	06:30	05:50
14 Apr 1828	1, 3	1 Vai 1190	17:00	16:51
9 Nov 1836	1, 5	30 Asv 1198	08:00	06:06
9 Oct 1847	1, 3	30 Bha 1209	15:48	15:54
18 Aug 1868	2, 8	1 Bha 1230	11:40	11:49
6 Jun 1872	–	1 Ash2 1234	09:12	08:31
11 Nov 1901	6, 7	1 Kar 1263	14:58	15:29

Table 16: Comparison of lunar eclipse timings.

Date (CE)	Ref	CS Date	CS Time	Time
14 Feb 1794	1	14 Mag 1155	03:06	02:53
22 Jul 1804	1, 4	15 Ash2 1166	22:30	22:44
5 Jan 1806	1	16 Pau 1167	05:30	05:04
21 May 1807	1, 4	15 Vai 1169	22:48	22:47
2 Sep 1811	1, 5	15 Bha 1173	04:12	04:05
22 **Aug 1812**	4, 5	15 Sra 1174	19:30	19:59
10 Apr 1819	1, 5	16 Cai 1181	17:36	18:02
3 Oct 1819	1, 5	14 Asv 1181	20:00	19:57
29 Mar 1820	5	15 Cai 1182	23:36	00:08
26 Jan 1823	1, 5	15 Mag 1184	22:12	22:33
25 Nov 1825	1, 4	16 Kar 1187	21:42	21:42
14 Nov 1826	1, 4	15 Kar 1188	20:42	20:27
20 Apr 1837	1, 3	16 Cai 1199	02:24	01:30
17 Feb 1840	1	15 Mag 1201	19:18	19:53
26 Jan 1842	1	15 Mag 1203	22:54	23:14
31 Mar 1847	1, 5	15 Cai 1209	02:36	03:09
24 Sep 1847	1, 3, 5	15 Bha 1209	20:12	20:03
14 Sep 1867	2	15 Bha 1229	05:00	05:35
22 May 1872	5	15 Jye 1234	04:30	05:15
27 Feb 1877	5	15 Pha 1238	00:24	00:23
13 Aug 1878	5	15 Sra 1240	05:24	05:28

28 Dec 1879	5	15 Pau 1241	22:12	22:21
28 Feb 1896	6	15 Pha 1257	01:49	01:11
27 Oct 1901	7	15 Asv 1263	20:50	20:45

timing is quite good: Figure 13 shows the correlation. The horizontal axis is the time after midnight for the Thai prediction, the vertical axis the time according to modern calculation. A perfect correlation would be that all the eclipse timings fell on a straight line.

The deviation from modern times has a standard deviation of 30 minutes.

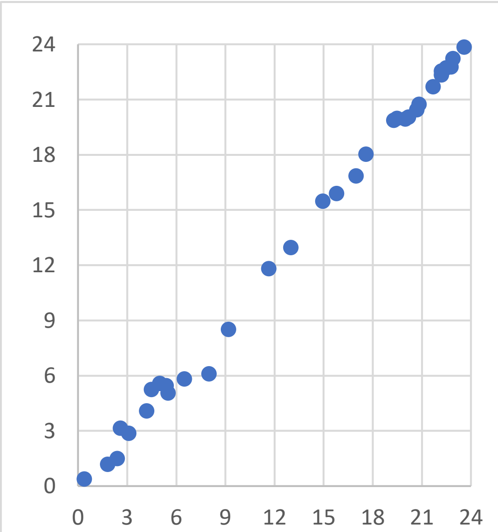


Figure 13: Eclipse timing correlations.

12.3 Glossary

ahargaṇa The number of elapsed days since the epoch.

apogee The location in a planet's orbit where it is farthest from the Earth.

ascensional difference The excess, positive or negative, over a half day length of six hours.

avoman Thai อวมาน, Burmese အဝမာန်. The excess of lunar days over solar days in units of 1/692 of a lunar day modulus 692. It increases by 11 units each solar day. It is used to determine when to add intercalary days in the calendar. Sometimes in Burmese astronomy the avoman is expressed in units of 1/703 of a solar day.

chaya Thai ฉายา, Burmese ဆယး. The original meaning of the word is 'shadow' but it is generally used as the name of a table often being a table for the correction of mean longitude to true longitude.

eccentricity A quantity that measures the deviation from circularity of a planetary orbit.

ecliptic longitude A coordinate used together with the *ecliptic latitude* and determining a position in the zodiac.

gnomon A vertical pole casting a shadow of the Sun. It can be used for determining the time of the day. In Indian astronomy the gnomon often has a length of 8 units, in Burmese astronomy it is often 7 units long.

kyammat Burmese ကမ္ဗြာတ်. A quantity that gives the excess of solar days over whole solar days.

lagna An Indian term for the ascending zodiacal sign.

lipta An Indian term for minutes of arc. Of Greek origin, *λεπτον*.

Makaranta Burmese မကာရန္တ. A Burmese calendar similar to the Thai calendar but with a Metonic intercalation with 7 intercalary years in each 19-year period.

mean longitude The ecliptic longitude of a planet calculated assuming that the planet moves with constant angular velocity. This calculation is made by reference to its revolution period and to the *ahargaṇa*. Tables of correction, the *chaya* tables, are then used to convert this mean longitude to a *true longitude*.

nadi An Indian time measure with 60 *nadi* in a day and night. In Thai it is *nathi* and in Burmese *nayi*. It corresponds to 24 minutes of an hour.

nonagesimal The highest point of the ecliptic in the local sky.

noon shadow The length of the shadow of a vertical gnomon at noon at a particular location and at a specific date.

oblique ascension An astronomical quantity used in *lagna* calculations.

parallax A nearby object will be displaced as viewed from two different points. A simple way of experiencing parallax is to view the location of a nearby object relative to the distant horizon when viewed alternatively by the left and right eyes. As the Sun and the Moon are located at different distances from the Earth two observers on different places on the Earth will not see the Sun and the Moon in exactly the same places. In solar eclipses it is necessary to correct for parallax caused by the observer not being located at the centre of the Earth.

Precession Due to the gravitational influence of the Sun and the Moon on the equatorial bulge of the Earth, the rotation axis of the Earth will trace out a cone similar to that of a spinning top on a table. This will cause the vernal equinox of the ecliptic to move slowly backwards. The rate of change in tropical longitudes due to the precession of the equinoxes, about 1° in 72 years.

rasi An Indian term corresponding to the Western zodiacal sign.

sutin The number of days that have passed since the start of the given year.

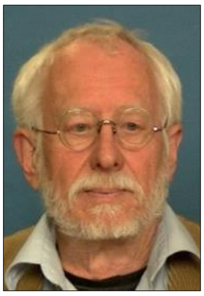
*Thandeikt*a Burmese သံဒိဋ္ဌ. The calendar used from about 1200 BE (1868 CE) in Burma.

thinpraman Thai ทินประมาณ. The length of half a day, which depends on the time of the year.

tithi Originally a time unit being a lunar day or 1/30th of a synodic month, in Southeast Asia astronomy being 692/703 of a solar day. It can also refer to the lunar day number in a month and also the relative position of the Moon relative to the Sun, the possible 360° divided into 30 tithis, each one covering 12°.

uccabala A measure of the position of the Moon's apogee. It increases by one unit a day to a maximum of 3232.

vinadi An Indian time measure being 1/60th of a *nadi*.



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 PhD in the Faculté des Sciences, at Orsay, France. He has been doing research in elementary particle physics, complex systems and applica-tions of physics in biology and with atmospheric physics. During the past twenty years he has developed several computer programs and Excel spreadsheets implementing calendars and medieval astronomical models from Europe, India and Southeast Asia (see http://home.thep.lu.se/~larsg/).

Dr Chris Eade has an MA from St Andrews and a PhD from the Australian National University. In 1986 he retired from the Australian National University, where he had been a Research Officer in the Humanities Research Centre before moving to an affiliation with the Asian Studies Faculty, in order to pursue his interest in Southeast Asian calendrical systems. In particular, research that he continued after retirement concerned dating in Thai inscriptional records, in the horoscope records of the temples of Pagan and in the published records of Cambodia and Campa.