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ANALYSIS OF THE TAMIL PARALLAX PROCEDURES IN LE GENTIL'S REPORT OF 1776

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Abstract: The Tamil procedures for computing the circumstances of eclipses were reported by the French astronomer Guillaume Le Gentil from his visit to India in the 1760's. This paper investigates these Tamil procedures for a solar eclipse, focusing on the procedures for finding the eclipse parallax which are needed to describe the local appearance of an eclipse. These procedures constitute the essential difference between a solar and lunar eclipse. The procedures are compared with the parallax procedures in Sūryasiddhānta and give similar results. It is found that there seems to be little theoretical background to the Tamil procedures, although they work rather well in practice. There are parallels with parallax procedures in Southeast Asian traditional astronomy. The Tamil calculations of the circumstances of the lunar eclipse 13 December 1769 have earlier been analyzed by Otto Neugebauer in a paper in *Isis*.

Keywords: Parallax, solar eclipse, Sun, Moon, nonagesimal, midheaven, Tamil, India, Sūryasiddhānta.

1 INTRODUCTION

In 1952 Otto Neugebauer published a paper (Neugebauer, 1952) with an analysis of the methods used by Tamil astronomers, as described in the book *Kala Sankalita* published in 1825 by amateur astronomer Lieutenant Colonel John Warren (1769–1830) (Warren, 1825). The native astronomers could, using heaps of shells on the ground and memorized tables, compute the circumstances of a lunar eclipse with astonishing accuracy. At the end of his paper Neugebauer cited a remark of Warren who regretted not having had access to an example of a solar eclipse. Neugebauer then added that he had found an additional source for Tamil astronomy in a report by Le Gentil, (1776; 1779),[1] in which the latter carefully reports the Tamil computational procedures for both lunar and solar eclipses. Neugebauer ends his paper by hinting that he would return to the Tamil procedures at a later occasion which as far as I know this never happened.

2 ECLIPSE FUNDAMENTALS

As for a lunar eclipse, the input for the computation is the elapsed Kaliyuga year, the solar month, and the day in the solar month of the eclipse. I have suppressed parts of the computation that are similar to those for a lunar eclipse, as they have already been analyzed by Neugebauer. The focus of this paper will be on the parallax procedures reported by Le Gentil and an analysis of them.

In the example reported by Le Gentil, the Kaliyuga year is 4863, the solar month 7 (Tulā), and the day 5, corresponding to the Western date 18 October 1762. There was a total solar eclipse on 17 October 1762, visible as a partial eclipse at Tirvalour. Le Gentil says (Le Gentil, 1776: 177) that Tirvalour is situated 30 leagues south of Puducherry and 5 leagues west of Nagapattinam which is close to modern Thiruvarur (10.8° N, 79.6° E). He then states that the equinoctial shadow in Tirvalour of a gnomon with a height of 720 is 144, which gives a geographical latitude of 11.3° N consistent with the data in the rising time table (see Table 1 below).

Table 1: Rising time tables (after Gislén).

Sign	Generic Rising Time Table	Ascension Correction	Rising Time Table for 11.3° N
1	278	24	254
2	299	19	280
3	323	8	315
4	323	−8	331
5	299	−19	318
6	278	−24	302
7	278	−24	302
8	299	−19	318
9	323	−8	331
10	323	8	315
11	299	19	280
12	278	24	254

The Tamil source uses several different time and angular measures. Time is measured in *nadi*, with 60 *nadi* being a night and day and corresponding to 360° in angular measure. One *nadi* corresponds to 24 minutes of Western time or 6° in hour angle. A *nadi* is divided into 60 *vinadi* and 1° then corresponds to 10 *vinadi*, making the conversion between degrees and *vinadi* very easy. I have used the sexadecimal notation *a*; *b*, *c* where *a* stands for the units, *b* for the number of 1/60ths, *c* for 1/3600ths. *Nadi* is denoted by a superscript 'n', *vinadi* by 'v' and Western hours by 'h'.

Using the same methods as given by Warren in Neugebauer's paper for a lunar eclipse,

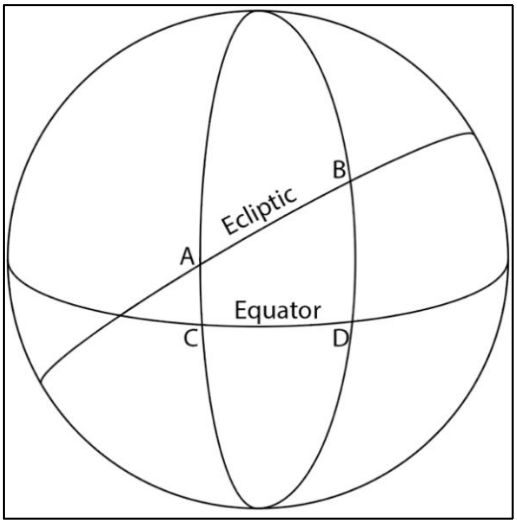


Figure 1: Rising times (diagram: Lars Gislén).

the Tamil source first computes the *ahargana*, 1776442;43,3,30 (Le Gentil, 1776: 250), the number of elapsed days at sunrise 18 October 1762 since the Kaliyuga epoch. This then leads to the Sun's true longitude at sunrise, 184;15, 53°, and the Moon's longitude 192;29,26° (ibid.). These longitudes are sidereal as is stan-dard in traditional Indian astronomy. The Tamil source uses the year length 365;15,31,15 which is standard in the Aryabhāta astronomi-cal canon as is the use of sunrise (*audayika*) as the usual origin of day (Billard, 1971).

SIGNES.		Min.
1.	♈	254
2.	♉	280
3.	♓	315
4.	♋	331
5.	♌	318
6.	♍	302
7.	♎	302
8.	♏	318
9.	♐	331
10.	♑	315
11.	♒	280
12.	♊	254

SIGNES.	MINUTES D'HEURE.
0.	00.
1.	48.
2.	38.
3.	16.

Figure 2: Ascension difference corrections (doubled) and rising times for Tirvalour (after Le Gentil, 1776: 206).

Using the elongation between the Sun and the Moon and their true daily motion, 59.45′ and 835′ respectively, the time of conjunction and the conjunction longitude are computed by interpolation (Le Gentil, 1776: 250):

Conjunction time 21;48,30^{n} after sunrise on 17 October 1672
Conjunction longitude 183;37,50°

The longitudes are converted into tropical longitudes using the Indian precession, a zig-zag function with an amplitude of 27° and a period of 7200 years. In this case, the precession is 18;57,9° and the tropical conjunction longitude becomes 202;34,59° (Le Gentil, 1776: 251).

2 THE *SŪRYASIDDHĀNTA* PARALLAX PROCEDURES

Before we analyze the Tamil parallax procedures that follow in Le Gentil's report we study them in the standard Indian astronomical work, the *Sūryasiddhānta*.

2.1 Lagna and Nonagesimal

An important quantity in Indian parallax computation is the *lagna* or rising sign or the ascendant. To calculate it you need a rising time table of the zodiacal signs for the given geographical latitude φ. This starts with a generic table for the Equator, see Figure 1, where CD is the rising time for the section AB of the ecliptic and is the difference in right ascension of these points.

For each zodiacal sign, the corresponding rising times are computed and the degrees converted to vinadis by multiplying by 10. This gives the second column of Table 1. Secondly, the ascensional differences for the geographical latitude φ and zodiacal signs are computed for the zodiacal signs. The ascensional difference measures how far sunrise and sunset deviates from 6 a.m. and 6 p.m. Their differences, converted to *vinadis*, are shown with sign in the third column of Table 1 and, when subtracted from the standard rising times, generates the rising times for the given geographyical latitude, in this case for the latitude of Tirvalour, 11.3° N. Figure 2 shows the tables given in Le Gentil's report with the differences of the ascensional differences multiplied by two and the rising time table. Le Gentil's *minutes d'heure* are *vinadis*. The procedure to arrive at twice the differences of the ascensional differences for the first three signs is described by Le Gentil (1776: 176ff):

> They know, for example, that at Tirvalor ... the length of the shadow of the gno-mon, is, on the day of the equinox, 144 parts, of which the

gnomon contains 720; they multiply 144 by 20, and divid-

Table 2: Excess in daylength.

Sign	0	1	2	3	4	5	6	7	8	9	10	11	12
Excess	0	48	86	102	86	48	0	–48	–86	–102	–86	–48	0

ing the product 2880 by 60, they get 48 minutes of an hour; this is what they call the *adi-chara-vinady*. They then divide the *asi-chara-vinady* into five parts; and take four of these parts which are called *maddia-chara-vinady*; it will be, in this example, 38 2/5. Finally one third of the *adi-chara-vinady* or 48 minutes, will give 16 minutes; which they call the *antia-chara-vinady*. (my English translation).

This seemingly strange procedure with almost the same 'magic' numbers is also described in the *Pauliśasiddānta* (Neugebauer and Pingree, 1970(I): 41; 1970(II): 20) and explained in Gislén (2021).

Using the difference table in Figure 2, the excess in daylength in *vinadis* can then be calculated (see Table 2).

The procedure to compute the *lagna* is best illustrated by an example. Suppose that the longitude of the Sun is 250° = 8 signs 10° and that the time from sunrise is 600 *vinadis*. Sign 9 has a rising time of 331 *vinadis.* The 10° correspond to 10 × 318 / 30 = 110 *vinadis*. There is a remainder 331 – 110 = 221 *vinadis* in sign 9. Subtracting this from the time from sunrise gives 600 – 221 = 379 *vinadis*. If we subtract the rising time of sign 10 there remains 379 – 315 = 64. This is less than the rising time of sign 11 and interpolating the remaining degrees in this sign gives 30 × 64 / 280 = 6.9°. Thus, the *lagna* is 10 signs 6.9° = 306;54°.

With the *lagna* known, the longitude of the *nonagesimal*, λ_N, is computed by subtracting 90°. The nonagesimal is the highest point of the ecliptic, halfway between the ascending and descending signs of the zodiac.

2.2 PARALLAX

Parallax is due to the fact that a celestial object, P (see Figure 3), at a finite distance from the Earth will be seen in slightly different directions as seen from the center of the Earth, C, and from an observer, O, on the surface of the Earth. For an object in the zenith the direction from the center of the Earth and from the observer will coincide and the parallax, π, will be zero. The horizontal parallax, π_0, is the parallax when the celestial object has a zenith distance of 90°. The basic idea in traditional Indian parallax theory is that the vertical parallax of an object, a depression vertically, is given by the horizontal parallax π_0 multiplied by the sine of the zenith distance, z, of the celestial body[3] (Burgess, 2000: 162):

$$\pi = \pi_0 \sin z \qquad (1)$$

The rigorous formula is $\sin \pi = \sin \pi_0 \sin z$. Due to the smallness of the angle π and π_0 the Indian expression is an excellent approximation.

For the horizontal parallax an effective value is used which is the difference between the Indian lunar and solar horizontal parallaxes. These parallaxes are said to be their daily mean motions during 4 *nadis* and are respectively 52′ 42″ and 3′ 56″, thus π_0 = 48′ 46″ ≈ 49′. (Burgess, 2000: 145).

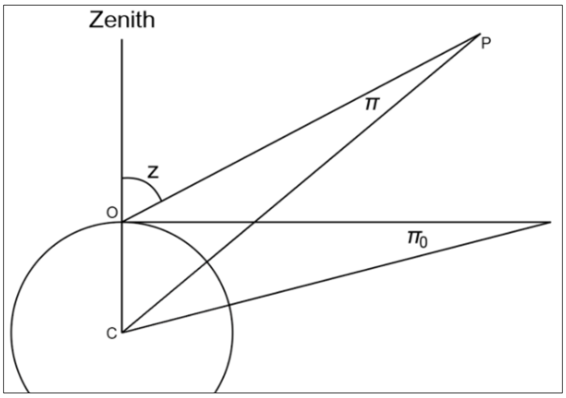
If the ecliptic lies in the local vertical plane, its highest point in the zenith is the nonagesimal and the parallax in the ecliptic will be purely parallax in longitude, π_λ, being zero if the celestial body in the ecliptic is also in the zenith (the nonagesimal) and maximum if it is in the horizon. For intermediate longitudes λ there would be a zenith distance $z = \lambda_N - \lambda$ and a parallax in longitude

$$\pi_\lambda = \pi_0 \sin(\lambda_N - \lambda) \qquad (2)$$

If the ecliptic lies in the local horizontal plane, so will the celestial body which then has a zenith distance of 90° and the parallax will be vertical and maximum and perpendicular to the ecliptic, i.e. purely parallax in latitude: $\pi_\beta = \pi_0$.

The assumption in the *Sūryasiddhānta* is that if we start with the ecliptic vertical and tilt it, the parallax in longitude gradually changing into parallax in latitude as the zenith distance z_N of the nonagesimal increases from 0° to 90°. This is described by

$$\pi_\lambda = \pi_0 \sin(\lambda_N - \lambda) \cos z_N \qquad (3)$$
$$\pi_\beta = \pi_0 \sin z_N \qquad (4)$$



$$\sin^2 z_N = \sin^2 z_M - \sin^2\Delta \qquad (7)$$

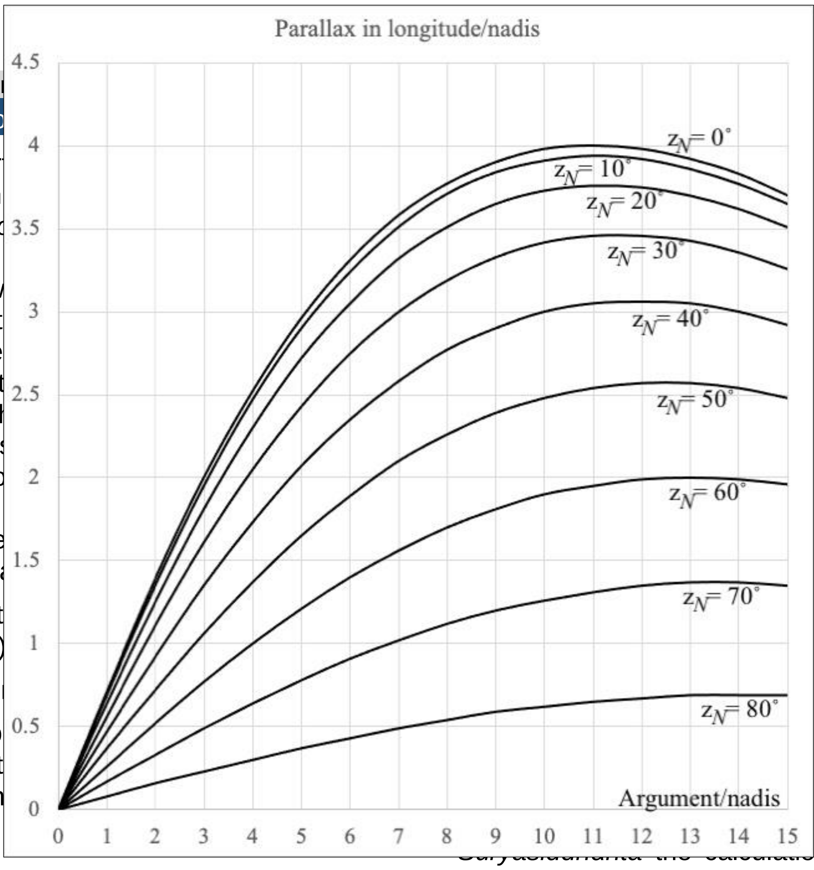


Figure 3: Par

2.2.1 Calculatio

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As before φ is the geographical latitude. Denoting $\sin \Delta = \sin(\lambda_M - \lambda_N) = \sin \varLambda \sin \varepsilon / \cos \varphi$ the *Sūryasiddhānta* (Burgess, 2000: 166) then has

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Figure 4: Longitudinal parallax in Sūryasiddhānta (diagram: Lars Gislén).

3 THE TAMIL PARALLAX PROCEURES

We now present the parallax procedures as reported by Le Gentil, together with an analysis.

3.1 Parallax in Longitude

With the tropical conjunction longitude λ and the conjunction time after sunrise the *lagna* is found as 328;55,43° (Le Gentil, 1776: 253). The Tamil procedure then calculates the difference between the *lagna*, Λ, and the conjunction longitude, multiplies it by 5 and divides by 30. This operation converts the difference from angle in degrees to time in *nadi*. Then it subtracts 15 *nadis* from the result (Le Gentil, 1776: 255). Expressed in degrees this is $\Lambda - \lambda - 90°$ $= \lambda_N - \lambda$, i.e. the correct argument for computing the parallax in longitude according to the *Sūryasiddhānta*. The rule given by Le Gentil is: Subtract 15 from the difference of the l*agna* and the Sun's longitude, if it is larger than 15, otherwise keep it. This rule is certainly wrong, as it would not result in a continuous parallax function although in this case it gives the correct result. The result of the operation is 6;3,0,0^n (Le Gentil, 1776: 253). It is denoted by *d* below.

The Tamil procedure then deviates from the *Sūryasiddhānta*. The parallax time correction in *nadi* is determined by the formula $\pi_\lambda = 60 \times (20 - d) \times d / 1468$. Inserting the actual value of *d* results in a parallax of 3;26,58^n (Le Gentil, 1776: 254). The formula is a quadratic function of *d* with a maximum 4.087 at 10 *nadi*. I have no explanation of the factor 1468 in the formula, and a better value would actually have been about 1800. There is a similarity with the corresponding *Sūryasiddhānta* function for $z_N \approx 0°$ and also with a model for longitudinal parallax that assumes that the Sun and Moon move in the equatorial plane of the Earth as used in Thai eclipse calculations (Gislén, 2019, see the Appendix). For the actual solar eclipse $z_N \approx 28°$. In Figure 5 the gray curve shows the *Sūryasiddhānta* parallax for $z_N = 28°$ and the black curve is the Tamil parallax function being about 0.6 nadi (15 minutes) too large in the present case. The horizontal scale is in *nadi* from the nonagesimal. The vertical scale is the parallax in *nadi*.

Using the longitudinal parallax correction, the corrected eclipse time from sunrise is

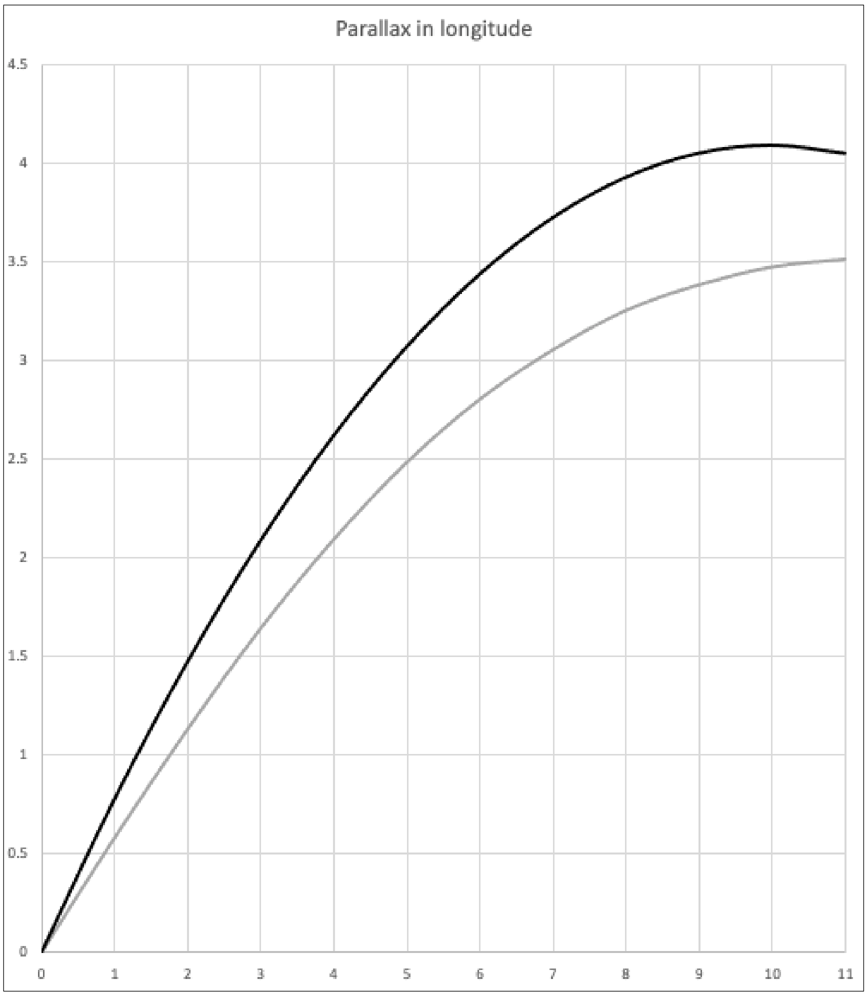

Figure 5: Comparison of parallax in longitude (diagram: Lars Gislén).

25;15,28^n. The corrected eclipse longitude of the Moon using its true daily motion is 203; 22,52° and that of the Sun is 202;38,24° (Le Gentil, 1776: 255).

The first latitude of the Moon can now be computed using a fixed table for its latitude as a function of the longitude distance from the lunar node (ibid.). This gives 38;34′ N. As in the *Sūryasiddhānta*, this latitude is given by 4.5° times the sine of the distance from the node.

3.2 Parallax in Latitude

Using the table of excess daylength and tropical longitude of the Sun, the daylength is computed, 29;23,52^n. The eclipse time from noon is then the time from sunrise minus half the day length, or 10;32,42^n (Le Gentil, 1776: 256). This is the quantity needed to compute the longitude of the midheaven. However, the Tamil procedure is a simplified *Sūryasiddhānta* version. The eclipse time from noon in *nadis* is converted into degrees by multiplying by 6 and then the tropical solar eclipse longitude is added to 265;50, 24°. This is an approximation of the longitude of the midheaven λ_M, as the Sun's longitude is measured in the ecliptic system while the time is measured in the equatorial system. A correct computation would give 261;52,31°. If the result is larger than 180°, subtract 180° giving in this case the remainder 85;50,24°. The result is called *bouja* by Le Gentil (Sanskrit *bhuja*). The approximation to the midheaven as a substitution for the nonagesimal is a recognized practice in the *Sūryasiddhānta*:

> The sine and cosine of the meridian zenith-distance are the approximate sines of the ecliptic zenith-distance and altitude. (Burgess, 2000: 167).

This approximation is also used in Burmese traditional astronomy (Gislén, 2019) and, considering the approximations in the next steps of the calculations, is not very critical. It avoids making the tedious calculation of a new *lagna* using the corrected eclipse time from sunrise and corrected solar longitude, and a new calculation of z_N. Such a calculation would give *lagna* Λ = 353;18° and a longitude for the nonagesimal of λ_N = 263;18°, which only differs from the approximate value above by about 2°.

Using the *bhuja* as an argument and the table for excess daylength, the ascensional difference, A = –100^v of the midheaven is computed by interpolation (Le Gentil, 1776: 256ff).

Then the following formula is used to obtain the parallax in latitude:

$$\pi_\beta = 2 \times (A \times 6 \times 60 / 144 - 114' \, 14'') / 25 \qquad (8)$$

With the numbers in Le Gentil's text this gives –29;8′. The corrected latitude of the Moon is then 38;34′ – 29;8 = 9;26′.

Effectively, the factor multiplying A (in *vinadi*), 6 × 60 / (144 × 25) = 1/10, converts this term to arc minutes. The extremal values of A are ±102^v for Tirvalour and the first term then gives an extremal contribution to π_β of ±20.40′. The first term will be a nearly sinusoidal function with this amplitude. The second term, presumably a geographical latitude constant, gives the contribution –9.14′, thus the extremal values of π_β are –29.54′ and +10.36′. From the *Sūryasiddhānta* we have, using the midheaven instead of the nonagesimal:

$$\pi_\beta = \pi_0 \sin(\delta_N - \varphi) \approx \pi_0 \sin(\delta_M - \varphi) \qquad (9)$$

The last expression is a very good approximation for the rigorous expression. Using the *Sūryasiddhānta* approximation and the geographical latitude of Tirvalour (9) gives the corresponding extrema –28.32′ and +10.77′ differing only by at most about 1′ from the Tamil result. The same kind of approximation is used in Burmese traditional eclipse calculations (Gislén, 2019). See Figure 6, which shows the parallax in latitude in arc minutes as a function of the longitude of the cumulating point in degrees. The Tamil function is the black curve, the *Suryasiddhanta* function the grey one. The agreement is very good, with only small deviations at the extrema.

A possible explanation for the Tamil formula is the following. We can develop Equation (9) into

$$\pi_\beta = \pi_0 (\sin \delta_M \cos \varphi - \cos \delta_M \sin \varphi) \qquad (10)$$

In the last term, δ_M lies in the interval 0° to 24° and cos δ_M in the interval 0.91 to 1. Using the mean value for cos δ_M and inserting the geographical latitude φ = 11.3°, the contribution of the last term to the parallax is 9.16′, very close to the Tamil second term 9.14′ in (8). In the first term, cos φ ≈ 0.98, and the contribution to the parallax will be a sinusoidal function with an amplitude of 19.5′, very similar to the first term in the Tamil formula. A similar approximation is used in Southeast Asian eclipse calculations (Gislén, 2019).

4 CONCLUDING REMARKS

There seems to be little theoretical background for the Tamil parallax procedures. They differ in style from the earlier parts of the lunar and solar eclipse calculations which are mainly based on memorized tables. Instead the parallax procedures use mathematical expressions that give satisfactory agreement with more elaborate theoretical models but are faster and easier to use and remember. They also use short-cuts and approximations that facilitates the computation as when the ascensional difference table is used instead of a sine table. However, the procedure for parallax in longitude is crude. The traditional astronomy in Southeast Asia is much influenced by early Indian astronomy. It is therefore not surprising to see parallels in the parallax calculations.

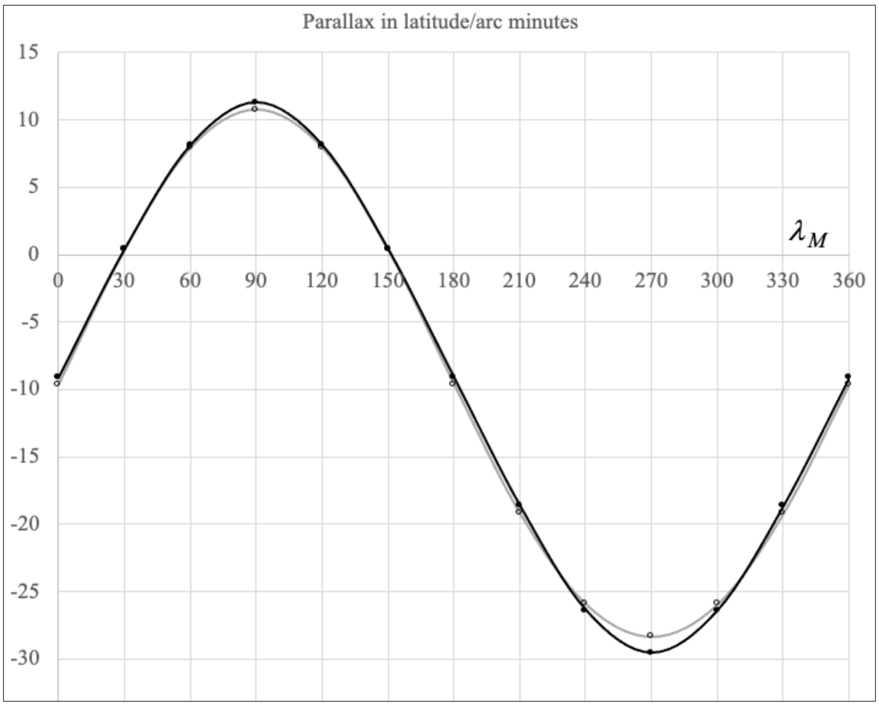

Figure 6: Comparison of the Tamil and the *Sūryasiddhānta* parallax in latitude, represented by the black and grey curves respectively (diagram: Lars Gislén).

5 NOTE

1. His full name was Guillaume Joseph Hyacinthe Jean-Baptiste Le Gentil de la Galaisière.

6 ACKNOWLEDGEMENT

I am grateful to Dr J.C. Eade for valuable comments.

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8 APPENDIX: DERIVATION OF A SIMPLIFIED LONGITUDINAL PARALLAX

We look at the situation at the time of a solar eclipse (Figure 7). It is assumed that the Sun and the Moon move in circles in the equatorial plane and that we see the Earth from the north pole and the Earth rotates counter-clockwise. At the geocentric conjunction, the Moon, M, and the Sun, S, lie on a straight line CMS from the center of the Earth. The observer is located at O with an hour angle H relative to the geocentric positions of the Moon and Sun. As seen from the observer, the direction of the sight-lines OM and OS will not coincide, there will be an angular separation or a parallax of the Sun and Moon relative to each other. As the parallax π of a single object is given by $\pi = \pi_0 \sin H$, where π_0 is the horizonal parallax, the parallax when the zenith distance H = 90°, and the celestial object is at the horizon. The effective joint parallax will be the difference of these parallaxes and is defined as the increase in elongation between the Moon and Sun during 4 *nadi*.

At some later time ΔH the observer is at O′, the Moon has moved to M′, and the Sun to S' and they are now seen to coincide in direction as seen from O′. The angle M′CM, the angle that the Moon has moved is $v_M \times \Delta H/v$ where $v_M \approx 791'$ is the Moon's mean daily angular velocity and v the daily rotation of the Earth, 21600. In the same way the angle S′CS is $v_S \times \Delta H/v$ with $v_S \approx 59'$ being the corresponding solar velocity. The angle α can be expressed in two ways, using the consideration that the local zenith distance of either luminary is the angle $H + \Delta H$ decreased by the respective angular movement during time H, and increased by its parallax at zenith distance $H + \Delta H - v_L \times \Delta H / v$. The index L is here M or S.

$$\alpha = H + \Delta H - v_M \times \Delta H / v + \pi_M \sin(H + \Delta H - v_M \times \Delta H / v) \quad (11)$$

$$\alpha = H + \Delta H - v_S \times \Delta H / v + \pi_S \sin(H + \Delta H - v_S \times \Delta H / v). \quad (12)$$

We ignore the last term inside the sine argument, since both ratios v_M/v and v_S/v are much smaller than 1. Eliminating the angle α we get

$$\Delta H = (\pi_M - \pi_S)\cdot\sin(H + \Delta H) \mathrm{x} v / (v_M - v_S) \quad (13)$$

Using the definition of the effective parallax we finally get

$$\Delta H = 4^n \cdot \sin(H + \Delta H) \quad (14)$$

This is a transcendental equation that must be solved by successive approximation (Kennedy, 1956; Kennedy and Transue,1956; Neugebauer,1962; Suter, 1914). We first set ΔH = 0 in the right member to compute ΔH that in turn is inserted in the right member and so on. The iteration process converges very rapidly, typically only four iterations are needed to reach a sufficient accuracy and gives the same result as the *Sūryasiddhānta* when the zenith distance of the nonagesimal is zero.

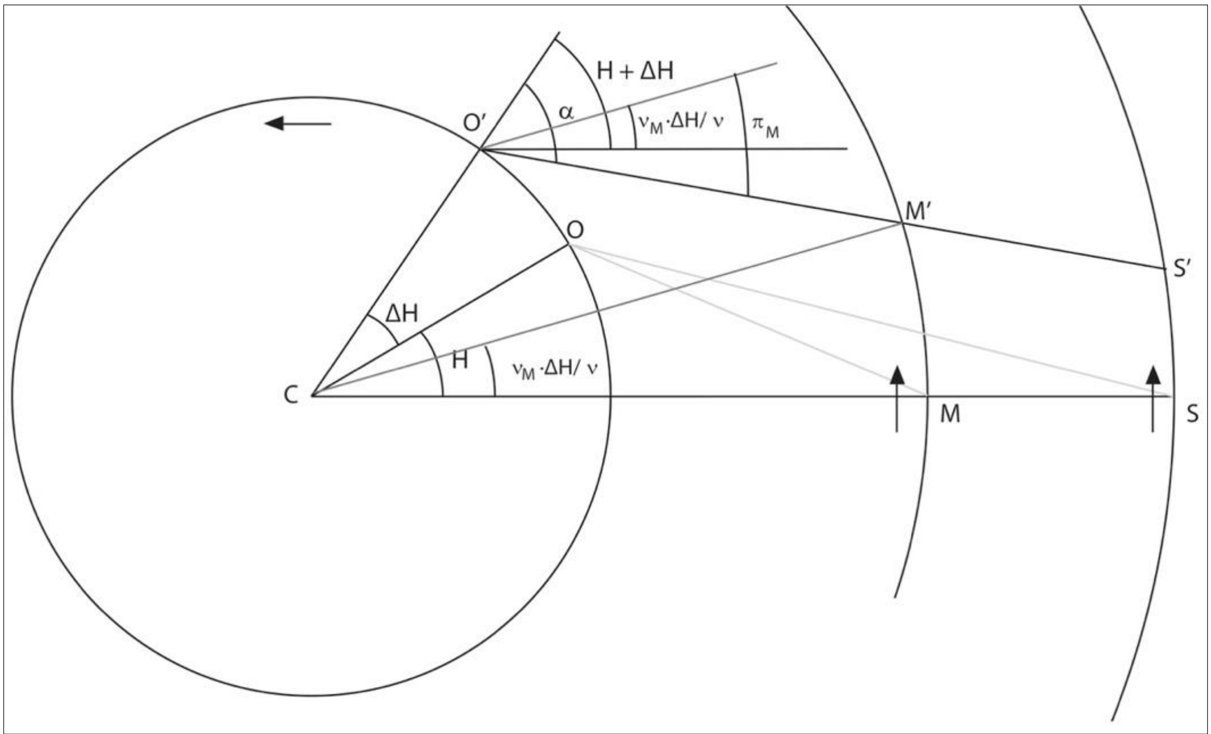
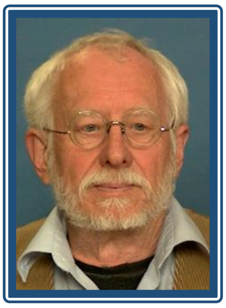


Figure 7: Solar eclipse parallax (diagram: Lars Gislén).



Dr Lars Gislén was born in Lund (Sweden) in 1938, and received a PhD in high energy particle physics from the University of Lund in 1972. He worked in 1970 and 1971 as a researcher at the Laboratoire de Physique Théorique in Orsay (France) with models of high energy particle scattering. He has also done research on atmospheric optics and with physical modelling of biological systems and evolution.

He has worked as an Assistant Professor (University Lector) at the Department of Theoretical Physics at the University of Lund, where he gave courses on classical mechanics, electrodynamics, statistical mechanics, relativity theory, particle physics, cosmology, solid state physics and system theory.

For more than twenty years he was a delegation leader and mentor for the Swedish team in the International Physics Olympiad and the International Young Physicists' Tournament.

Lars retired in 1983, and since then his interests have focused on medieval European astronomy and on the astronomy and calendars of India and Southeast Asia. He has published more than 20 research papers in this field. He has also made public several spreadsheet tools implementing a number of astronomical models from Ptolemy to Kepler as well as computer tools for the calendars of India and Southeast Asia. He is a member of the IAU.