CHAPTER 3

TRIPRAŚNĀDHIKĀRAḤ

(Three Questions of Direction, Place and Time)

In this chapter we discuss finding the *lagna* (ascendant), *krānti* (declination), *akṣa* (latitude of a place), *nata* (zenith distance) and *unnata* (altitude).

Ślokas 1, 2, 3 and 4 : **The rising (durations) at Laṅkā are 278,299 (and) 323 *vināḍīs.* (are arranged) in the given and the reverse orders (alternately); the *carakhaṇḍas* of themselves (*rāśis*) are subtracted from or added to (the respective *udayamānas*). (These are) the rising (durations), at one's place, of the six (*rāśis*) from Meṣa (in the given order) and of (the six *rāśis* from) Tulā. The balance (degrees of the *rāśis*) of the *sāyana* Ravi, at the (given) instant, multiplied, by the rising (duration of that *rāśis*) and divided by 30 is the balance time of Ravi (in *palas, vināḍīs*); (this) must be subtracted from the given time in *palas.* The rising (durations) of the further (succeeding) *rāśis* are also (subtracted); the remainder (time in *palas*) divided by the (rising duration of) the unsubtractable *rāśi* (and) multiplied by 30, in degrees etc., together with the *rāśis* (starting with Meṣa) prior to the unsubtractable (*aśuddha rāśi*), reduced by *ayanāṃśa* (amount of precession of the equinox) is the (*nirayaṇa* i.e. sidereal) ascendant (i.e. *lagna*).**

The (given) time (if) less than the balance (time of *sāyana* Ravi then the same i.e. the given time in *palas*) multiplied by 30 and divided by the rising (duration in *palas*) together with (*sāyana*) Ravi, in degrees, is the (*sāyana*) ascendant (*lagna*).

Finding *udayamāna* (duration of rising) of the 12 *rāśis* at a given place and finding the *lagna* at a given time is explained in these four *ślokas* as follows.

(i) The durations of rising (*udayamāna*) of the first three *sāyana rāśis* viz. *Meṣa*, *Vṛṣabha*, and *Mithuna* at *Laṅkā* are respectively 278, 299 and 323 (in *palas*). Writing these numbers in the reverse order as well as in the given order successively we get the *udayamānas* of the remaining *rāśīs*. The *udayamānas* of the 12 *rāśis* at *Laṅkā* are given in Table 3.1.

Table 3.1 *Udayamānas* of *rāśis* at Laṅkā

Rāśi	*Udayamāna palas (vighatīs)*	*Rāśi*	*Udayamāna palas (vighaṭīs)*
Meṣa	278	*Tulā*	278
Vṛṣabha	299	*Vṛscika*	299
Mithuna	323	*Dhanus*	323
Karkaṭaka	323	*Makara*	323
Simha	299	*Kumbha*	299
Kanyā	278	*Mīna*	278

(ii) For the given place, find *cara khaṇḍas* (as explained under *Ślokas* 19 and 20 in Chapter 2). These *cara khaṇḍas* are added to or subtracted from the *udayamānas* of the 12 *rāśis* at Laṅkā to get their *udayamānas* at the given place. Add these *khaṇḍas* if the *udayamānas* are in the reverse order and subtract if they are in the given order.

(iii) Finding the *lagna* at a given time :

(a) Find *sāyana* Ravi at the given time. Express it in *rāśis*, degrees etc. The number in the *rāśi* position gives the number of elapsed *rāśis*, and degrees etc. give the elapsed part of the running *rāśi* called *bhuktāṃśas*.

(b) Subtract degrees etc. from 30°. This difference gives the *gamya* (balance) of the currently running *rāśi* called *bhogyāṃśas*.

(c) Multiply *bhogyāṃśas* by the *udayamāna* of the currently running *rāśi* and divide it by 30. The result gives *Ravi bhogyakāla* in *vighaṭīs* (or *palas*).

(d) Express the given time in *vighaṭīs* (or *palas*) and subtract *Ravi bhogyakāla.*

(e) Consider the difference obtained in the above step. Go on subtracting the *udayamānas* of next *rāśis* until it is possible to do so. These *rāśis* are called *śuddha* (subtractable) *rāśis*. The *rāśi* which remains as unsubtractable is called the *aśuddha rāśi.*

(f) Now consider the remaining portion in the step (e) [i.e., the balance from which *udayamāna* of no more *rāśi* can be subtracted]. Multiply this by 30 and divide by the *udayamāna* of the *aśuddha rāśi*. The result will be in degrees etc.

(g) To this result add the total number of *rāśis* prior to the *aśuddha rāśi.* This result which will be in *rāśis*, degrees etc. is the *sāyana lagna* at a given time. Subtracting the *ayanāmśa* from it we get the *nirayaṇa lagna*.

Example : We have the given time 11^{gh}. after sunrise on a certain day when

True *(nirayaṇa)* Sun at the sunrise = $1^R\ 3^\circ\ 6'\ 12''$

True daily motion of the Sun = $57'\ 28''$

Motion of the Sun in $11^{gh} = \dfrac{57'\ 28'' \times 11^{gh}}{60^{gh}} = 10'\ 32''$

$\therefore$ *(Nirayaṇa)* Sun at the given time = $1^R\ 3^\circ\ 6'\ 12'' + 10'\ 32'' = 1^R\ 3^\circ\ 16'\ 44''$

Ayanāṃśa = $18^\circ\ 16'\ 10''$

$\therefore$ *Sāyana* Ravi = $1^R\ 3^\circ\ 16'\ 44'' + 18^\circ\ 16'\ 10'' = 1^R\ 21^\circ\ 32'\ 54''$

In the *rāśi* position we have 1. This means that the first *rāśi* is over and the *śāyana* Ravi is in the second *rāśi* viz. *Vṛṣabha.*

The *bhuktāṃśa* = $21^\circ\ 32'\ 54''$

The *bhogyāṃśa* = $30^\circ - 21^\circ\ 32'\ 54'' = 8^\circ\ 27'\ 06''$

Now, we have

$$Ravi\ bhogyak\bar{a}la = \frac{bhogy\bar{a}\dot{m}\acute{s}a \times udayam\bar{a}na\ V\d{r}\d{s}abha}{30} = \frac{8^\circ\ 27'\ 06'' \times 255}{30}$$

$$\approx 71\ palas$$

The given time = 11^{gh} = 660 *palas*

Now, we have $660 - 71 = 589$ *palas*

We have *Mithuna rāśi* next to *Vṛṣabha*. The *udayamāna* of *Mithuna* = 305 *palas* for the given place. Subtracting 305 from 589 we get $589 - 305 = 284$ *palas*.

The duration of rising of the next *rāśi* namely *Karkaṭaka* is 341 *palas* which cannot be subtracted from 284 *palas*. Therefore, *Karkaṭaka* is the *aśuddha rāśi*.

Now, consider $\frac{284 \times 30}{341} = 24^\circ\ 59'\ 07''$

The total number of *rāśis* prior to *Karkaṭaka* is 3. Therefore adding 3 *rāśis* to the above result, we get the *sāyana lagna* = $3^R\ 24^\circ\ 59'\ 07''$.

Now, *nirayaṇa lagna* = *Sāyana lagna* – *ayanāṃśa*

$$= 3^R\ 24^\circ\ 59'\ 07'' - 18^\circ\ 16'\ 10'' = 3^R\ 6^\circ\ 42'\ 57''$$

i.e., $6^\circ\ 42'\ 57''$ of (*nirayaṇa*) *Karkaṭaka*.

Note : If the given time in *palas* is less than the *Ravibhogyakāla*, then proceed as follows to find the *lagna*.

Multiply the given time in *palas* by 30 and divide by the *udayamāna* of the *rāśi* in which the *sāyana* Ravi lies. This result will be in degrees etc. This is added to the *sāyana* Sun to get the *sāyana lagna*. Subtracting *ayanāṃśa* we get the *nirayaṇa lagna* at the given time.

Example : Suppose the given time is $1^{gh} = 60$ *palas* (after sunrise).

Śāyana Ravi = $1^R\ 21°\ 23'\ 22''$

We have Ravi *bhogyakāla* = 73 *palas*.

Since the given time is less than the Ravi *bhogyakāla*, we proceed as given below :

Śāyana Ravi is in the *Vṛṣabha rāśi* whose *udayamāna* is 255.

$$\therefore \quad \frac{\text{given time in } palas \times 30°}{udayam\bar{a}na} = \frac{60 \times 30°}{255} = 7°\ 3'\ 31''$$

$$\therefore \quad \acute{S}\bar{a}yana\ lagna = \acute{S}ayana \text{ Ravi} + 7°\ 3'\ 31''$$

$$= 1^R\ 21°\ 23'\ 22'' + 7°\ 3'\ 31'' = 1^R\ 28°\ 26'\ 53''$$

Nirayaṇa lagna = *Sāyana lagna* – *ayanāṃśa*

$$= 1^R\ 28°\ 26'\ 53'' - 18°\ 16'\ 10'' = 1^R\ 10°\ 10'\ 43''$$

i.e., 10°10'43" in *Vṛṣabha*.

***Ślokas* 5 and 6 : (The *sāyana*) Ravi's balance (*bhogya*) with elapsed part (*bhukta*) of *lagna* added to the rising times (*udayamānas*) of the intervening (*rāśis*) gives the time from the *lagna* (ascendant). If *lagna* (ascendant) and Ravi are in the same sign (*rāśi*) then their difference in degrees multiplied by the rising time (of the *rāśi*) and divided by 30 (gives the time from sunrise).**

If (the ascendant and the sun being in the same sign) the *lagna* is less (than the *sāyana* Sun, the time in *ghaṭīs*) is subtracted from the (total duration of) day and night; this gives the *ghaṭikās* from (the previous) sunrise or from (the duration of) the night (giving the time from the previous sunset). The time during night can (also) be obtained by adding 6 signs (*raśis*) to the (*sāyana*) Ravi.

Obtaining the time from the given *lagna* is explained.

(i) Consider the given *sāyana lagna* (in *rāśi*, degree etc.). Multiply the degrees etc. by the *udayamāna* of the *rāśi* of the *sāyana lagna* and divide by 30. The result gives the *bhukta* (elapsed) part of the *sāyana lagna* in *vighaṭīs* (*palas*).

(ii) Similarly, the *bhogya* (balance) part of the *rāśi* occupied by the *sāyana* Sun is determined :

Subtract the degrees etc. of the *sāyana* Sun from 30°. Multiplying this *bhogya* part of the Sun by the *udayamāna* of the Sun's *rāśi* and divide by 30°. This is in *vighaṭīs* (*palas*).

(iii) To the sum of the results of items (i) and (ii) above, add the *udayamānas* of the intervening complete *rāśis*. The resultant gives the required time (in *vighaṭīs*) from the local sunrise. When the same is divided by 60, we get the time in *ghaṭīs*.

Example : The given (*nirayaṇa*) *lagna* = $3^R\ 6^\circ\ 42'\ 57''$

Ayanāṃśa = $18^\circ\ 16'\ 10''$

(i) *Sāyana lagna* = $3^R\ 24^\circ\ 59'\ 07''$

i.e., $24^\circ\ 59'\ 07''$ in *Karkaṭaka* whose *udayamāna* = 341 *palas*.

The *bhuktāṃśa* of (*Sāyana*) *lagna* = $24^\circ\ 59'\ 07''$.

The time-equivalent of this is

$$bhukta\ palas = \frac{24^\circ\ 59'\ 07''}{30} \times 341 \approx 284\ palas$$

(ii) *Sāyana* Ravi at the sunrise = $1^R\ 21^\circ\ 22'\ 22''$

i.e., $21^\circ\ 22'\ 22''$ in *Vṛṣabha* whose *udayamāna* is 255 *palas.*

∴ *Bhogyāṃśa* of *sāyana* Ravi = $30^\circ - 21^\circ\ 22'\ 22'' = 8^\circ\ 37'\ 38''$

The time-equivalent of the *bhogyāṃśa* is

$$bhogya\ palas = \frac{8^\circ\ 37'\ 38''}{30^\circ} \times 255 \approx 73\ palas$$

(iii) In between *Karkaṭaka* and *Vṛṣabha* there is only one intervening *rāśi* viz. *Mithuna* whose *udayamāna* is 305 *palas.*

(iv) Now, adding up the results of (i), (ii) and (iii) above, we get

$$284 + 73 + 305 = 662\ palas$$

Dividing by 60, we get $11|02$ *gh.*

This is the required time from the sunrise.

Note : In case the *sāyana lagna* and the *sāyana* Sun are in the same *rāśi*, then the required time is determined as follows :

(i) If the *sāyana lagna* is greater than the *sāyana* Sun (in the same *rāśi*), then (*Lagna* – Sun) in degrees is multiplied by the *udayamāna* of their common *rāśi* and divided by 30. The result gives the time (in *palas*) *after* the sunrise.

Example : *Sāyana lagna* = $1^R\, 28°\, 26'\, 53''$ and *sāyana* Sun = $1^R\, 11°\, 23'\, 22''$ both in *Vṛṣabha*. Here, *Lagna* > Sun. We have *udayamāna* = 255 *palas* for the *Vṛṣabha rāśi*. Now,

$$\frac{(Lagna - Sun)}{30°} \times 255 = \frac{17°\ 03'\ 31'' \times 255}{30°} = 145 \ \ palas$$

i.e., $2^{gh}\ 25^{vig}$ is the required time.

(ii) If the *sāyana lagna* is less than the *sāyana* Sun (in the same *rāśi*), then (Sun – *Lagna*) in degrees is multiplied by the *udayamāna* of their common *rāśi* and divided by 30°. The result gives the time (in *palas*) *before* the sunrise.

This time is subtracted from the *rātrimāna* (the duration of the night, from the prior sunset to the sunrise) to get the required time from the preceding sunset. If the *dinamāna* (duration of the day, from the sunrise to the sunset) of the previous day is added to the above time, we get the required time reckoned from the sunrise of the previous day.

The required time after the sunset can also be obtained from the *astalagna* (by adding 6^R to the *lagna* at the previous sunrise).

***Śloka* 7 : (In the northern hemisphere) adding and subtracting the ascensional difference (*cara*) in *palas* to and from 15 *nāḍikās* (give) the half-day and half-night (respectively); the reverse (is the case) in the southern hemisphere. The difference between the half-day and the elapsed (time in) *ghaṭīs* is the *nata* (zenith distance in time unit). The *nata* subtracted from the half-day becomes the *unnata* (altitude).**

Obtaining *nata* and *unnata* is explained.

The *dinārdha*, duration of half of the day and the *ratryardha*, duration of half of the night are determined as follows :

(i) If the (*sāyana*) Sun is within 6^R from *Meṣa* (i.e., between 0° and 180°) then adding *carapalas* to 15 *gh.* we get the *dinārdha* i.e., half duration of the day time.

Similarly, subtracting the *carapala* from 15 *gh.*, we get the half duration of the night time.

[The *day time* is from the sunrise to the sunset and the *night time* is from the sunset to the next sunrise].

(ii) If the *sāyana* Sun is within 6^R from *Tulā* (i.e., between 180° and 360°), then the *carapala* is subtracted from or added to 15^{gh}. respectively to get the durations of half day time or half night time.

Example : *Carapala* = 86 *palas* = $1^{gh}\ 26^{vig}$

Assuming that the *sāyana* Sun is in the *uttaragola* (northern hemisphere), we have *dinārdha* = $15^{gh} + 1^{gh}\ 26^{vig} = 16^{gh}\ 26^{vig}$

rātryardha = $15^{gh} - 1^{gh}\ 26^{vig} = 13^{gh}\ 34^{vig}$

Nata and *unnata* of the (*sāyana*) Sun are determned as follows :

(i) *Nata* = *Dinārdha* (in gh) – Given time (gh) after sunrise.

(ii) *Unnata* = *Dinārdha* – *nata* = Given time (all in gh.).

If the given time is between the sunrise and the noon (i.e., within the first *dinārdham*) then the *nata* is *pūrva* (eastern). If the time is between the noon and the sunset (i.e., within the second *dinārdham*) then the *nata* is western.

Note : (i) *Nata* + *unnata* = *Dinārdham.*

(ii) In angle units, *nata* is the zenith distance and *unnata* is the altitude.

Zenith distance + altitude = 90°

Ślokas 8 to 12 : The half-day (in *ghaṭīs*) reduced by 5 (*ghaṭīs*) is the *hara* of mid-heaven (*madhya kāla*). The square of zenith distance (*nata* in *gh*) is separately multiplied by 50 and (the same) added with 900 and divided (by the latter); (this) reduced from the *hara* of mid-heaven (*khahara*) is the *hara* of the desired time.

If the *nati* is greater than 15 (*ghaṭīs*) then the *hara* is the *nata* subtracted from the half-day. The *carapala* divided by the first block of ascensional difference (*prathma-cara-khaṇḍa*), halved and squared and then reduced by $^1/_6$th of itself, added with 10 degrees, and multiplied by hypotenuse (*palakarṇa*) is the *hṛti*. (This) *hṛti* divided by *hara* (divisor for the given time) is the (desired) *karaṇa* (hypotenuse) in *aṅgulas*. The hypotenuse (*karṇa*) added with and reduced by 12 (respectively), are multiplied (together); the square-root (of this product) is the shadow (*dyuti*, *chāyā*); the square root of the sum of the squares of 12 and shadow is the hypotenuse. The *hṛti* divided by the *karṇa* is the (*iṣṭa*) *hara*; the mid-heaven (*madhyakālīna*) *hara* is reduced by *iṣṭa hara*, (the result) is separately multiplied by 900 and subtracted from 50; dividing (the former by the latter), its square-root is the *nata*. If the remainder (of subtracting *iṣṭa hara* from *khahara*) is greater than 10 then (*iṣṭa*) *hara* itself is the *unnatam* (altitude). Thus the determination of the shadow (of the gnomon) by the short method, devoid of sine (*jyā*) and sine-inverse (*dhanu*) of planetary operations is accomplished.

Now, obtaining the *chāyā* (shadow) from the given time and vice versa is explained.

(i) Subtract 5 from the *dinārdha ghaṭī* to get the *madhyāhna kālīna hara.*

(ii) Consider $\dfrac{(nata)^2 \times 50}{(nata^2 + 900)}$

(iii) Subtracting the result of (ii) from that of (i), we get the *iṣṭa kālīna hara.*

Note : If *nata* is greater than 15 *gh.*, then subtracting *nata* from the *dinārdham* we get the *iṣṭa hara.*

Example : *Iṣṭa ghaṭī* = $11^{gh.}$, *dinārdham* = $16^{gh}\ 26^{vig}$ and *nata* = $5^{gh}\ 26^{gh}$. We have

$$Madhy\bar{a}hna\ k\bar{a}l\bar{i}na\ hara = 16^{gh}\ 26^{vig} - 5^{gh} = 11^{gh}\ 26^{vig}$$

$$\text{Now,}\quad \frac{(5|26)^2 \times 50}{(5|26)^2 + 900} = 1\,|35\ \underline{gh}$$

$$I\d{s}\d{t}a\ k\bar{a}l\bar{i}na\ hara = 11^{gh}\ 26^{vig} - 1^{gh}\ 35^{vig} = 9^{gh}\ 51^{vig}$$

Suppose *nata* = 16^{gh}; since it is greater than 15 we have

$$I\d{s}\d{t}a\ k\bar{a}l\bar{i}na\ hara = 16^{gh}\ 26^{vig} - 16^{gh} = 0^{gh}\ 26^{vig}$$

(iv) *Hṛti* : (a) Divide the *carapala* (*CP*) by the first (*prathama*) *carakhaṇḍa* *PCK* (obtained under *Ślokas* 19 and 20 in *Spaṣṭādhikāra*) and take half of it.

(b) Square this result and subtract $\frac{1}{6}^{th}$ of this square and add 10° i.e., obtain

$$\left(\frac{CP}{2\ PCK}\right)^2 - \frac{1}{6}\left(\frac{CP}{2\ PCK}\right)^2 + 10^\circ$$

(c) Find the *palakarṇa* (or *akṣakarṇa*) *PK* from the right-angled triangle in which the *palakarṇa* is the hypotenuse and the other two sides (making the right-angle) are the *śaṅku* (gnomon) taken as *koṭi* and the *palabhā* (shadow on equinoctial midday) as the *bhuja*

i.e., $$Palakarṇa\ PK = \sqrt{(koṭi)^2 + (bhuja)^2}$$

$$= \sqrt{(śaṅku)^2 + (palabhā)^2}$$

(d) Multiply the result of (b) by the *palakarṇa PK* obtained in (c) we get

$$hṛti = \left[\frac{5}{6}\left(\frac{CP}{2\ PCK}\right)^2 + 10^\circ\right] \times PK$$

(v) Then, *iṣṭkarṇa* = *hṛti* / *iṣṭa kālīna hara*

where the numerator and the denominator are obtained in (iv) (d) and (iii).

Example : In the example considered earlier under (iii), we have

$$iṣṭa\ kālīna\ hara = 9|51\,gh.$$

$$palabhā = 5|30\ aṅg. \text{ for the given place and } śaṅku = 12\ aṅg.$$

Now, *carapalas* = 86, *prathama carakhaṇḍa PCK* = 55

(see example under *Ślokas* 19 and 20 in Chapter 2).

$$Palakarṇa\ PK = \sqrt{(5|30)^2 + 12^2} = 13|12\ aṅg.$$

Therefore, we have

$$Hṛti = \left[\frac{5}{6}\left\{\frac{86}{2\,(55)}\right\}^2 + 10^\circ\right] \times (13|12) = 138|43$$

$\therefore$ *Iṣṭa karṇa* = $\dfrac{138|43}{9|51}$ = 14|05 *aṅg.*

(vi) The shadow (*iṣṭa kālīna chāyā*) of the *śaṅku* (gnomon) for the given time on the given day is determined from the right-angled triangle with the *iṣṭa karṇa* as the hypotenuse and the *śaṅku* (12 *aṅgulas*) as the other side.

i.e., *iṣṭa chāyā* = $[(\textit{iṣṭa karṇa})^2 - (\textit{śaṅku})^2]^{1/2}$

In the example, since *iṣṭakarṇa* = 14|05 *aṅg.*, we have

Iṣṭa chāyā = $\sqrt{(14|05)^2 - (12)^2}$ = 7|22 *aṅg.*

From a given *chāyā*, we can find out the *iṣṭakāla* by the reverse process.

Example : We have *iṣṭa chāyā* = 7|22 *aṅg.* *Dinārdham* = 16|26 gh

Madhyāhna kālīna hara = 16 | 26 gh – 5 gh = 11|26 gh

$\therefore$ *Palakarṇa* = $\sqrt{(\textit{chāyā})^2 + 12^2}$

= $\sqrt{(7|22)^2 + 144}$ = $\sqrt{198|16}$ ≈ 14|5 *aṅg.*

Hṛti = 138|43 (obtained earlier).

Now,

Iṣṭahara = $\dfrac{\textit{Hṛti}}{14|5}$ = $\dfrac{138|43}{14|5}$ = 9|51 and *Madhyāhnakālīna hara* – $9|51$

$= 11|26 - 9|51 = 1|35$

Consider $\dfrac{(1|35)\times 900}{50-1|35} \approx 29|26$

Now, we have

$Nata = \sqrt{29|26} = 5|25.5\, gh$

$Din\bar{a}rdham = 16|26\ gh.$

The required time $= din\bar{a}rdham - nata$

$= 16|26 - 5|25.5 = 11|0.5\ gh.$

Note : If (*Madhyāhna kālīna hara* – *Iṣṭahara*) is greater than 10°, then *iṣṭhara* itself is *unnatam* and *nata* = *dinārdham* – *unnatam*.

Example : Suppose *iṣṭa hara* = $0|26$, *madhyhna kālina hara* (*khahara*) $= 11|26$

Now, their difference, $11|26 - 0|26 = 11 > 10$.

$\therefore$ *Unnatam* = *Iṣṭahara* = $0|26$ *gh.*

$\therefore$ *Nata* = *Dinārdham* – *Iṣṭhara*

$= 16|26 - 0|26 = 16\ gh.$

***Ślokas* 13 and 14 : The blocks of declination (*krāntikhaṇḍas*) are 362, 341, 299, 236, 150 (and) 52 for the *bhujas* (in degrees) of the *sāyana* (i.e. with *ayanāṃśa*) planets. Dividing (*bhuja*, in degrees) by 15 and adding them (elapsed *khaṇḍas*) together with the product of the remainder and (the *khaṇḍa*) to be covered divided by 15 becomes the declination (*krānti*) in *kalās* (minutes of arc) of a *sāyana* planet; its directions (northern or southern) based on the hemisphere (in which the planet lies).**

Obtaining the declination (*krānti*) of a heavenly body is explained.

(i) The six *krānti khaṇḍas* (at intervals of 15°) are 362, 341, 299, 236, 150 and 52.

(ii) Find the *bhuja* of the *sāyana* planet whose *krānti* is required.

(iii) Divide the *bhuja* by 15. Let q be the integer quotient and r be the remainder. The quotient q represents the number of *gata* (elapsed) *khaṇḍas*. The next *khaṇḍa* i.e., $(q+1)^{th}$ is called the *bhogya* (to be covered) *khaṇḍa*.

(iv) Now, consider (sum of the *gata khaṇḍas*) + (r x *bhogya khaṇḍa*)/15

This will be in *kalās* (minutes of arc). Dividing the result by 60, we get the *krānti* in degrees.

The *krānti* is north or south (positive or negative) according as the *sāyana* planet is in the northern $(0^0 < \lambda < 180^0)$ or southern $(180^0 < \lambda < 360^0)$ hemisphere (where $\lambda =$ *sāyana* longitude).

Example : *Sāyana* Sun = $1^R\ 21°\ 32'\ 54'' = 51°\ 32'\ 54''$

$\therefore$ *Bhuja* = $51°\ 32'\ 54''$ ·

Dividing *bhuja* by 15, quotient $q = 3$ and remainder $r = 6° 32' 54''$. This means that 3 *krānti khaṇḍas* viz., 362, 341 and 299 have elapsed. The next (*bhogya*) *khaṇḍa* is 236.

$$\therefore \quad krānti = (362 + 341 + 299) + \frac{6° \ 32' \ 54''}{15°} \times 236$$

$$= 1105.0271 \ kalās$$

Dividing by 60, *krānti* $= 18° 25' 01''$.

Since *sāyana* Sun $< 180°$ (i.e., in northern hemisphere), *krānti* = $18° 25' 01'' N$.

Remark : For a planet close to the ecliptic (i.e., its celestial latitude being ignored), its declination δ is given by

$$\sin \delta = \sin \lambda \sin \epsilon$$

where λ is the *sāyana* longitude of the planet and the obliquity of the ecliptic with the celestial equator ϵ is taken as $24°$.

$$\therefore \quad \delta = \sin^{-1} (\sin \lambda \sin 24°)$$

..... (1)

For $\lambda = 15°, 30°, \ldots\ldots\ldots\ldots 90°$ (at intervals of $15°$), the values of *krānti* in *kalās* (minutes of arc) and the successive differences are compared with the corresponding differences given in *Ślokas* 13 and 14 above in the *Karaṇa Kutūhalam* (*KK*) in Table 3.1.

Table 3.1 *Krānti khaṇḍas*

Aṅka	0	1	2	3	4	5	6
λ	0°	15°	30°	45°	60°	75°	90°
Krānti from (1)	0	362.56	704.04	1002.88	1237.48	1388.02	1440
Diff. from (1)	362.56	341.48	298.84	234.60	150.54	51.98	
Diff. (*KK*)	362	341	299	236	150	52	

We observe that the *krānti* values and their differences given in *KK* are very close to those obtained from (1).

***Śloka* 15 : The product of *bhuja* (and the same) reduced from 180 divided by the difference of 18 *kalās* less than 443° (i.e. 442° 42′) and the product divided by 77 is *krānti* itself without (using) blocks (*khaṇḍas*).**

Obtaining *krānti* by another method is explained.

Consider the *bhuja* B of the *sāyana* planet. Then the *krānti* is given by

$$Kr\bar{a}nti = \frac{x}{442|42 - x/77} \text{ in degrees}$$

where $x = (180^{\circ} - B)\,B$.

Example : In the example, under *Ślokas* 13 and 14, *sāyana* Sun = $1^R\ 21^{\circ}\ 32'\ 54''$. Therefore, *bhuja* $B = 51^{\circ}\ 32'\ 54''$. Using the above formula, we get *krānti* = $18^{\circ}\ 33'\ 46''$ which differs by about $8'$ from the earlier value.

***Śloka* 16 : The shadow (in *palas*, minutes of arc) added with 410 and (the sum), divided by 60 is added to the hypotenuse (*akṣakarṇa*).**

Dividing by this, the product of the shadow (*palabhā*) and 90 is the latitude (*akṣa* of the place) taken always as southern (for places in the northern hemisphere). The latitude (*akṣāmśa* in degrees) combined with the declination (*krānti* in degrees) is the *natāṃśa*.

Now, obtaining of the *akṣāmśa* (terrestrial latitude) of a place and the *natāṃśa* is explained.

(i) Mulitply the *palabhā* of the place by 90. This product is the numerator.

(ii) Add 410 to the *palabhā* and divide the sum by 60. To the result add the *akṣakarṇa*. The sum is the denominator.

(iii) The *akṣāṃśa* is given by dividing the numerator from (i) by the denominator from (ii).

i.e., $$\textit{Akṣāṃśa} = \frac{\textit{palabhā} \times 90}{\left[\dfrac{\textit{palabhā} + 410}{60} + \textit{akṣakarṇa}\right]}$$

(iv) *Natāṃśa* = *Krānti* ± *Akṣāṃśa*

The *akṣāṃśa* i.e., the latitude of the place is always with the sign opposite to its actual one (i.e., for all places in the northern hemisphere of the earth, it is taken as –ve). The sign (positive or negative) of *krānti* is taken as actually it is.

Note : In our modern convention,

$$\textit{Natāṃśa} = \delta - \phi$$

where δ is the *krānti* (declination) and ϕ is the latitude of the place.

(with ϕ +ve in the northern hemisphere and –ve in the southern hemisphere).

Example : *Palabhā* = $5|30$ *aṅgulas* and

akṣakarṇa = $13|12$ *aṅgulas*

Numerator = $(5|30) \times 90 = 495$

$$\text{Denominator } (\textit{hara}) = \frac{5|30 + 410}{60} + 13|12 \approx 20|08$$

$$\therefore \quad \textit{Akṣāṃśa} = \frac{\text{Numerator}}{\text{Denominator}} = \frac{495}{20|08} = 24^\circ\, 35'\, 10''$$

$$\textit{Natāṃśa} = \delta - \phi = 18^\circ\, 25'\, 01'' - 24^\circ\, 35'\, 10'' = 6^\circ\, 10'\, 09'' \text{ South.}$$

CHAPTER 4

CANDRAGRAHAṆĀDHIKĀRAḤ

(Computation of Lunar eclipse)

Ślokas 1, 2, and 3 : 11250 is divided by the product of *nata* reduced from 30° (and itself i.e. *nata*), (the quotient) reduced by 10° is *Ravihara*; reducing 1/10th (of *Ravihara* from itself gives) Candra's (*Vidhu's hara*). Division of the (*manda*) *phala* (of each) by the respective *hāra* (is its *nataphalam*). Ravi's *nataphala* is positive or negative according as (Ravi is in) the west or east; Candra's *nataphala* is positive and negative for (its position in the) east (and west). Thus (the Sun and the Moon made more accurate) by the (*nata*) *phala* reduction is (applied in the computations of) eclipses and *tithi*. The *nata* obtained by successive *jyā* (*R* sine) is acceptable to Brahmagupta (Jiṣṇu's son). The *Valana-dṛk-nata-karma* based on *utkramajyā* (*R* versine), (followed) by others, is not his (Brahmagupta's) opinion.

Obtaining of the *nataphala* of the Sun and the Moon is explained.

(i) Subtract the *nata* from 30° and multiply the difference by the *nata*. Divide 11250 by the above result. The resultant is in *amśas* (degrees) etc. Subtracting 10° from this we get Ravi *hara*.

(ii) Subtracting $1/10^{th}$ of the Ravi *hara* from itself, we get Candra *hara*.

i.e., Candra *hara* = $9 \times$ Ravi $hara/10$.

(iii) Dividing the *mandaphalas* of the Sun and the Moon respectively by the Ravi *hara* and Candra *hara*, we get the *nataphalas* of the Sun and the Moon.

(iv) If the *nata*, considered in (i), is western (*paścima* when the Sun is in the western hemisphere), the *nataphala* of the Sun is taken as positive and as negative otherwise (i.e., if the Sun is in the eastern hemisphere). In the case of the Moon, its *nata phala* will have the positive or negative sign opposite to that of the Sun.

(v) The positions of the Sun and the Moon and hence the *tithi* are corrected with their respective *nata phalams*.

Example : *Vikrama Samvat* 1677, *Śālivāhana śaka* year 1542, *Mārgaśīrṣa śukla* 15 (*paurṇimā*), Wednesday, corresponding to December 9, 1620 A.D. (G). We have *Ayanāṃśa* = $18^\circ\ 17'\ 42''$, *Pūrṇimā* (ending) : $11|52$ *gh.* after sunset. *Rātryardham* (half night duration) = $16|49$ *gh.*

The difference = $16|49\, gh. - 11|52\, gh. = 4|57\, gh.$

i.e., *prāṅnatam* = $4|57$ *gh.* (eastern)

(**Note** : *Prāk* = east; *prāk* + *natam* = *prāṅnatam*).

(i) We have $Nata \times (30^\circ - nata) = (4|57)(25|03) \approx 124$

Now, $\dfrac{11250}{124} = 90^\circ\ 43'\ 33''$

(ii) Ravi *hara* = $90^\circ\ 43'\ 33'' - 10^\circ = 80^\circ\ 43'\ 33''$

Candra *hara* = Ravi *hara* $- \dfrac{1}{10} \times$ Ravi *hara*

$= 80^\circ\ 43'\ 32'' - 8^\circ\ 4'\ 21'' = 72^\circ\ 39'\ 11''$

(iii) Sun's *mandaphalam* = $0° \, 38' \, 04''$

Candra *mandaphalam* = $4° \, 19' \, 52''$

Dividing the results of (iii) respectively by those of (ii), we get

$$\text{Ravi } nataphalam = \frac{0° \, 38' \, 04''}{80° \, 43' \, 33''} = 0° \, 0' \, 28''$$

$$\text{Candra } nataphalam = \frac{4° \, 19' \, 52''}{72° \, 39' \, 11''} = 0° \, 3' \, 34''$$

Because of the *prāṅ nata* of Ravi his *nataphalam* is negative and hence, the Candra *nataphalam* is positive.

The *nata* corrected positions of the Sun and the Moon at the sunset are:

True Sun = $8^R \, 0° \, 04' \, 17''$, True Moon = $1^R \, 27° \, 35' \, 18''$.

We shall find the actual instant of ending of the *pūrṇimā tithi* (i.e., the opposition of the Sun and the Moon) :

We have $(\text{Sun} + 6^R) - (\text{Moon})$

$$= 2^R \, 0° \, 04' \, 17'' - 1^R \, 27° \, 35' \, 18'' \approx 2° \, 29' = 149'$$

Moon's true daily motion – Sun's true daily motion

$$= 829' \, 35'' - 61' \, 21'' = 768' \, 14''$$

$\therefore$ Time required for the end of *Pūrṇimā* = $\dfrac{149'}{768' \, 14''} \times 60 \, gh. = 11|38 \; gh.$

after the sunset.

***Śloka* 4 : The elapsed (*gata*) and that to be covered (*gamya* parts in *ghaṭīs*) are multiplied by the daily motion (in *kalās*) and divided by 60; this is subtracted from and added to the *cara* corrected positions of the Sun and the Moon to get their positions equal in *kalās* (for *amāvāsyā*).**

Now, obtaining the true positions of the Sun and the Moon at the end of the full-moon day (*paurṇimā*) is explained.

The elapsed (*gata*) or to be covered (*gamya*) *ghaṭīs* are multiplied by the true daily motion (in *kalās*) of a planet and divided by 60 to get the motion in *kalās*. In the case of *gamya* the motion is added to and in the case of the *gata* subtracted from the position of the planet (at the sunrise or the sunset as the case may be). In the case of the Sun and Moon, their positions are thus made equal (in *kalās*). In the case of *amāvāsyā* (new moon) for the solar eclipse the *rāśis* etc. of the Sun and the Moon are made equal and in the case of *paurṇimā* these differ by 6^R (*i.e.*, 180°).

Example : *Gamya* (or *eṣya*, to be covered) = 11|38 *gh.* after the sunset.

Sun's true daily motion = 61′ 21″

Moon's true daily motion = 829′ 35″

Sun's motion in 11|38 *gh.* $= \dfrac{11|38}{60} \times 61'\,21'' = 11'\,53''$

Since the motion is *gamya*, it is added to the position at sunset. Thus

Sun's position at the opposition

$$= 8^R\ 0°\ 04'\,17'' + 11'\,53'' = 8^R\ 0°\ 16'\,10''$$

Moon's position at the opposition = $2^R\ 0°\ 16'\,08''$

(the difference in seconds of arc is neglected).

Pāta (Moon's node) = $4^R\,1°\,38'\,15''$

[According to the modern convention, subtracting the above *pāta* from 12^R, we get *Rāhu* = $7^R\,28°\,21'\,45''$].

***Śloka* 5** : Finding the *śara* (latitude) of the Moon is explained.

Add the true positions of the Moon and the *pāta*, take the *jyā* (i.e., 120 sin) of the *bhuja* of the sum and then multiply by 3 and divide by 4. The result gives the *śara* of the Moon in *aṅgulas*.

The *śara* is northern or southern according as the (Moon + *Pāta*) is so.

Remark : We have the Moon's latitude β given by

$$\beta = 270 \sin (M + P) \text{ in } kal\bar{a}s \qquad \ldots (1)$$

$$= \frac{270 \times 120 \sin (M + P)}{120 \times 3} \; a\dot{n}gulas$$

$$= \frac{3}{4} \; Jy\bar{a} \; (M + P) \; a\dot{n}gulas$$

Note : (i) Here, $P = 12^R - R$ where R is the actual position of Rāhu.

(ii) 1 *aṅgula* = 3 *kalās.*

(iii) The maximum latitude of the Moon is taken as $270'$ i.e., $4.5°$. The modern known value is about $5°\,8'$.

(iv) *Bhuja jyā* is also called *Dorjyā.*

Example : *Pāta* = $4^R\,1°\,36'\,15''$, Moon = $2^R\,0°\,16'\,08''$

$\therefore\quad M + P = 6^R\,1^\circ\,52'\,23''$

$\therefore\quad Bhuja \text{ of } (M + P) = 1^\circ\,52'\,23''$

$$\therefore\quad \acute{S}ara = \frac{3}{4}\; Jy\bar{a}\; (M + P) = \frac{3}{4} \times 120 \times \sin(1^\circ\,52'\,23'')$$

$$\approx 2|57 \text{ } a\dot{n}gulas$$

Since $M + P > 6^R$, it is in the southern hemisphere. Therefore,

$\acute{S}ara = 2|57$ *aṅg.* south.

***Ślokas* 6 and 7 (first half) : The six *rāśis* from *Karka* and from *Makara* (respectively) are the southern (*dakṣiṇa*) and the northern (*uttara*) journey (*ayana* of the Sun.) The blocks (of differences, *khaṇḍas*) of the latitude (*śara* of the Moon) are 70, 65, 56, 43, 27 and 9. From these the latitude can be obtained here, even like the declination (*krānti*) in minutes of arc (*kalās* and) dividing by 3 in *aṅgulas* etc.**

The *uttara* (north) and *dakṣiṇa* (south) *ayanas* (solstices) are explained. Also, another method for obtaining the *śara* of the Moon is explained.

For a planet lying within 6 *rāśis* from (*sāyana*) *Makara* (Capricorn) it is *uttarāyaṇa* (northern course) and 6 *rāśis* from (*sāyana*) *Karka* (Cancer) it is *dakṣiṇāyana* (southern course).

The six *khaṇḍas* for finding the *śara* are 70, 65, 56, 43, 27, 9. The *śara* is determined from these *khaṇḍas* by the process similar to the one for finding the *krānti* (*Ślokas* 13 and 14 in Chapter 3). The *śara* thus obtained is in *kalās*. Dividing the same by 3 we get it in *aṅgulas*.

The *khaṇḍas* are compared with the differences of the actual *śara* values in *kalās* obtained from equation (1).

Table 4.1 *Śara khaṇḍas*

Aṅka	0	1	2	3	4	5	6
$M+P$	0°	15°	30°	45°	60°	75°	90°
Śara from (1)	0′	69′.88	135′	190′.92	233′.83	260′.80	270′
Diff. from (1)	69′.88	65′.12	55′.92	42′.91	26′.97	9′.20	
Diff. from (*KK*)	70′	65′	56′	43′	27′	9′	

Example : *Sapāta* Candra, $M + P = 6^R\, 1°\, 52'\, 23''$

$$Bhuja \text{ of } (M+P) = 1°\, 52'\, 23''$$

Dividing by 15°, quotient $q = 0$, remainder $r = 1°\, 52'\, 23''$.

The *bhogyakhaṇḍa* = 70′.

$$\therefore \quad \acute{S}ara = 0 + \frac{1°\, 52'\, 23''}{15°} \times 70' = 8'\, 44''$$

Dividing by 3, we have

$$\acute{S}ara = 2|55 \ \text{aṅgulas.}$$

Note : We had obtained the *śara* as 2|57 *aṅg.* by the earlier method under *Śloka* 5.

Ślokas **7 (second half) and 8 : The Moon's (*angular*) diameter (*bimbam*) is its (*daily*) motion divided by 74, (the diameter) of the Sun is that (its daily motion) multiplied by 2 and divided by 11. The shadow's diam-**

eter (*bhū-bhā*) is the Moon's daily motion multiplied by 3 and divided by 67 reduced by one-seventh of the Sun's motion.

The node (*pāta*) through the shadow (cone) eclipses the (full) Moon and the sphere of the Moon eclipses the Sun.

Obtaining the *bimbas* (diameters) of the Moon etc. in *aṅgulas* is explained.

(i) Moon's *bimbam* = (Moon's true daily motion/74) *aṅgulas*

(ii) Sun's *bimbam* = $(\text{Sun's true daily motion}) \times \frac{2}{11}$ *aṅg.*

(iii) Earth shadow's *bimbam*

$$= \left(\text{True motion of Moon} \times \frac{3}{67}\right) - \left(\frac{\text{True motion of Sun}}{7}\right) \text{ aṅg.}$$

In the lunar eclipse the Moon is the *chādya* (eclipsed) and the earth's shadow is the *chādaka* (eclipser). In the solar eclipse, the Sun is the *chādya* and the Moon the *chādaka*.

Example : Moon's true daily motion = 829′ 35″

Sun's true daily motion = 61′ 21″

Therefore, we have

(i) Moon's *bimbam* = $\frac{829' 35''}{74} = 11|12$ *aṅg.*

(ii) Sun's *bimbam* = $\frac{61' 21'' \times 2}{11} = 11|09$ *aṅg.*

(iii) *Bhūbhā bimbam* (Shadow's diameter)

$$= \frac{3}{67} \times 829' 35'' - \frac{1}{7} \times 61' 21'' = 28|22 \ \textit{aṅg.}$$

Remark : In Indian astronomical texts, the usual procedure for obtaining the true diameters of the Sun and the Moon is as follows :

$$\text{True diameter} = \frac{\text{Mean diameter} \times \text{True daily motion}}{\text{Mean daily motion}}$$

We have

Sun's mean daily motion = 59′ 08″

Moon's mean daily motion = 790′ 35″

Sun's mean diameter = 32′ 31″

Moon's mean diameter = 32′

$$\therefore \text{ Sun's true diameter} = \frac{32' 31''}{59' 08''} \times (\text{True daily motion}) \ \textit{kalās}$$

$$= \frac{32' 31'' \times 2}{59' 08'' \times 3 \times 2} \times (\text{True daily motion}) \ \textit{aṅg.}$$

$$= \frac{2}{10.91} \times (\text{True daily motion}) \ \textit{aṅg.}$$

$$\approx \frac{2}{11} \times (\text{True daily motion of Sun}) \ \textit{aṅg.}$$

Moon's true diameter = $\frac{32'}{790'\,35''} \times$ (Moon's true daily motion) *kalās*

$$= \frac{32'}{790'\,35'' \times 3} \times \text{(Moon's true daily motion)}\ \textit{aṅg.}$$

$$= \frac{\text{Moon's true daily motion}}{74.117}\ \textit{aṅg.}$$

$$\approx \frac{\textit{Moon's true daily motion}}{74}\ \textit{aṅg.}$$

***Śloka* 9 : Half of the sum of the diameters of the eclipses and the eclipsing (bodies) reduced by the (Moon's) latitude is the measure of obscuration (*channam, grāsamāna*). The *channam* reduced by the (diameter of) the eclipsed (body) is *khacchannam* (or *khagrāsa*).**

Obtaining the *grāsamāna* is explained.

$$\textit{Grāsamāna} = \frac{(\textit{Chādya bimbam} + \textit{Chādaka bimbam})}{2} - \textit{Śara} \text{ in } \textit{aṅgulas}$$

Khagrāsa (or *Khachannam*) = *Grāsamāna* – *Chādya bimbam*

If there is *khagrāsa* (as positive) i.e., if the *grāsamāna* is greater than the *chādya bimbam*, then there will be a total eclipse.

Example : *Chādya bimba* (Moon's diameter) = 11|12 *aṅg.*

Chādaka bimbam (Shadow's diameter) = 28|22 *aṅg.*

Moon's *śara* = 2|57 *aṅg.*

$$\therefore \; Gr\bar{a}sam\bar{a}na = \frac{11|12 + 28|28}{2} - 2|57 \; a\dot{n}g. = 16|50 \; a\dot{n}g.$$

$$\therefore \; Khagr\bar{a}sa = 16|50 - 11|12 = 5|38 \; a\dot{n}g.$$

Therefore, the *lunar eclipse is total.*

***Śloka* 10 : Twice the (Moon's) latitude together with and (the sum) multiplied by the measure of obscuration (*channam*), the square-root of this multiplied by 180 and divided by the difference of the (daily) motions (of the Moon and the Sun) is the half-duration (*sthiti)* in *ghaṭikās* etc. From the *khacchannam* the half-duration of totality (*marda*) is obtained.**

Sthiti and *vimarda* are explained. In the case of a lunar or solar eclipse, the *sthiti* (half-duration of the eclipse) is given by

$$Sthiti = \frac{[(\acute{S}ara \times 2 + Channam) \times Channam]^{1/2} \times 180}{(\text{Moon's daily motion} - \text{Sun's daily motion})}$$

In the case of *total* eclipse, replace *channam* by *khagrāsa* in the above expression to get *vimarda* i.e., the half duration of *totality* in the case of eclipse. The *sthiti* and *vimarda* obtained here are *madhya* (mean) *sthiti* and *vimarda.*

Example : *Śara* = 2|57 *aṅgulas, Channam* = 16|50 *aṅg.*

Moon's daily motion – Sun's daily motion = $829'35'' - 61'21'' = 768'14''$.

$$\text{Half duration, } sthiti = \frac{[\{(2|57) \times 2 + (16|50)\}(16|50)]^{1/2} \times 180}{768'\,14''} \; gh.$$

i.e., *Sthiti* = 4 | 35 *gh.*

Now, *Khachannam* = 5 | 35 *aṅg.*

∴ Half-duration of totality (called *vimarda* or *marda*),

$$vimarda = \frac{[\{(2\,|\,57) \times 2 + (5\,|\,35)\}((5\,|\,35)]^{1/2} \times 180}{768'14''}\ gh.$$

i.e., *vimarda* = 1|53 *gh.*

***Ślokas* 11, 12 and 13 : If the sum of (the longitudes of) the Moon and its node is in the odd quadrant (I or III), the latitude (*śara* of the Moon) divided by 48 in *nāḍīs* etc. is added to and subtracted from the half-duration (*sthiti*), kept in two places, respectively for the commencement (*sparśa*) and the end (*mokṣa*). For the even quadrants (II or IV), the reverse (operation) is done to the half-duration (*sthiti*); (the case of) totality (*marda*) is as in *sthiti*. From the sunrise and the sunset (respectively for the solar and the lunar eclipses) the time is to pass (*gamya*) for the middle at the end of the fortnight.**

The (*sparśa*) *sthiti* and the (*vi*)*marda* subtracted from this (the middle) are the commencement of the eclipse (*sparśa*) and of the totality (*sammīlanam* respectively). The addition of the (*mokṣa*) *sthiti* and the *marda* to that (the middle) gives the end of the eclipse (*mokṣa*) and of totality (*unmīlanam*).

Obtaining the *sthiti* and *vimarda* for the beginning and ending of an eclipse and of totality is explained.

(a) If the *sapāta Candra* ($M + P$) is in an *odd* quadrant (I or III), then

$$\text{(i) } Sparśa\ sthiti = \left[Madhya\ Sthiti + \frac{Śara}{48} \right] gh.$$

(ii) *Mokṣa sthiti* = $\left[\textit{Madhya Sthiti} \; - \; \frac{\acute{S}ara}{48} \right] gh.$

(b) If the *sapāta Candra* $(M + P)$ is in *even* quadrant (II or IV), then

(i) *Sparśa sthiti* = $\left[\textit{Madhya Sthiti} \; - \; \frac{\acute{S}ara}{48} \right] gh.$

(ii) *Mokṣa sthiti* = $\left[\textit{Madhya Sthiti} \; - \; \frac{\acute{S}ara}{48} \right] gh.$

In the above formulae, by replacing the *madhya sthiti* by (*madhya*) *vimarda* (or *marda*) *ghaṭikās*, we obtain the *sparśa vimarda* and the *mokṣa vimarda*.

The same expressions hold good in the case of a solar eclipse also.

Note : The *madhya sthiti* is the mean half duration of the eclipse (obtained from *Śloka* 10 of this chapter). The results (i) and (ii) above provide the corrected first and second halves of the eclipse which are not equal.

The five timings of an eclipse are determined as follows :

(1) Beginning of the eclipse :

Sparśa kāla = *Parvānta* – *Sparśa sthiti*

(2) Beginning of the totality :

Sammīlana kāla = *Parvānta* – *Sparśa marda*

(3) Middle of the eclipse :

Madhya kāla = *Parvānta*

(4) End of totality :

Unmīlana kāla = *Parvānta* + *Mokṣa marda*

(5) End of the eclipse :

Mokṣa kāla = *Parvānta* + *Mokṣa sthiti*

Here, *parvānta* is the ending moment of the bright fortnight (*śukla pakṣa*) i.e., of the full moon day (*paurṇimā*). The beginning and the ending of the totality of a total eclipse are called respectively *sammīlana* and *unmīlana*.

Example (1) : Continuing the example considered in the earlier *ślokas*, we have

Parvānta = $11|38$ *gh.*, *Madhya sthiti* = $4|35$ *gh.*

Śara = $2|57$ *aṅg.*, *Madhya marda* = $1|55$ *gh.*

We have, therefore, the corrected *sthitis* and *mardas* as follows :

(i) *Sparśa sthiti* = $4|35 + \frac{2|57}{48} = 4|38$ *gh.*

(ii) *Mokṣa sthiti* = $4|35 - \frac{2|57}{48} = 4|32$ *gh.*

(iii) *Sparśa marda* = $1|55 + \frac{2|57}{48} = 1|58$ *gh.*

(iv) *Mokṣa marda* = $1|55 - \frac{2|57}{48} = 1|52$ *gh.*

The five timings are as follows :

(1) *Sparśa kāla* = $(11|38 - 4|38)$ *gh.* = 7 *gh.*

(2) *Sammīlana kāla* = $(11|38 - 1|58)$ *gh.* = $9|40$ *gh.*

(3) *Madhya kāla* (middle) = $11|38$ *gh.*

(4) *Unmīlana kāla* = $(11|38 + 1|52)$ *gh.* = $13|30$ *gh.*

(5) *Mokṣa kāla* = $(11|38 + 4|32)$ *gh.* = $16|10$ *gh.*

Duration of the eclipse

= *Sparśa sthiti* + *Mokṣa sthiti*

= $(4|38 + 4|32)$ *gh.* = $9|10$ *gh.*

Duration of totality of the eclipse

= *Sparśa marda* + *Mokṣa marda*

= $(1|58 + 1|52)$ *gh.* = $3|50$ *gh.*

We now consider a modern example below.

Example (2) : Lunar eclipse which occurred on September 27, 1996, Friday. On that day at 5.30 a.m. (IST) we have

True Sun = $160°\ 21'\ 01''$, True Moon = $338°\ 44'\ 27''$

Rāhu = $164°\ 10'\ 14''$ [**Note** : Rāhu = $360°$ – *Pāta*]

Sun's true daily motion = $58'\ 51''$

Moon's true daily motion = $861'$

Rāhu's daily motion = – $3'\ 11''$

(i) The instant of opposition (*parvānta*) = $8^h\ 24^m$ a.m. (IST)

At the *parvānta* (i.e., $8^h\ 24^m$ a.m.), we have

True Sun = $160°\ 28'\ 08''$, True Moon $M = 340°\ 28'\ 29''$, Rāhu, $R = 164°\ 09'\ 51''$.

(ii) Diameters of the Moon and the earth's shadow :

Moon's diameter = $\dfrac{861}{74} = 11|38$ *aṅg.*

Earth's shadow diameter = $\left(\dfrac{861 \times 3}{67} - \dfrac{58|51}{7}\right)$ *aṅg.* = $30|29$ *aṅg.*

(iii) Moon's latitude (*śara*) :

$$\textit{Śara} = 90 \sin (M - R) \text{ aṅg.}$$

$$= 90 \sin [176°\ 18'\ 38''] \text{ aṅg.} = 5|47 \text{ aṅg.}$$

[**Note** : sin $(M - R)$ = sin $(M + P)$ where P = *Pāta*]

(iv) *Grāsa* (obscuration) :

We have

(a) *Grāsa* (*Channam*) = $\frac{1}{2}(11|38 + 30|29) - 5|47 = 15|16$ *aṅg.*

(b) *Khagrāsa* = *Grāsa* – Moon's diameter

$= 15|16 - 11|38 = 3|38$ *aṅg.*

(v) Mean half-duration of eclipse and totality :

(i) *Sthiti* = $\frac{\sqrt{[(2(5|47) + (15|16)]\,(15|16)} \times 180}{(861 - 58|51)} = 4|32$ *gh.*

(ii) *Marda* (or *Vimarda*)

$$= \frac{\sqrt{[2(5|47) + 3|38]\,(3|38)} \times 180}{(861 - 58|51)} = 1|40 \ gh.$$

(vi) Corrected half-durations of the beginning and the ending of the eclipse and totality :

We have $\frac{\acute{S}ara}{48} = 0.1204861 gh. \approx 7$ *vig.*

Here, *Vyagu*, $M - R = 176°\ 18'\ 38''$ which is in II quadrant i.e. even quadrant.

Note : Our $(M - R)$ is the same as Bhāskara's *sapātacandra* $(M + P)$ noting that $R = (360° - P)$.

(a) *Sparśa sthiti* = $4^{gh}\ 32^{vig} - 7^{vig} = 4^{gh}\ 25^{vig} \cong 1^{h}\ 46^{m}$

(b) *Mokṣa sthiti* = $4^{gh}\ 32^{vig} + 7^{vig} = 4^{gh}\ 39^{vig} \cong 1^{h}\ 51^{m}\ 36^{s}$

(c) *Sparśa marda* = $1^{gh} 40^{vig} - 7^{vig} = 1^{gh}\ 33^{vig} \cong 0^{h}\ 37^{m}\ 12^{s}$

(d) *Makṣa marda* = $1^{gh}\ 40^{vig} + 7^{vig} = 1^{gh}\ 47^{vig} \cong 0^{h}\ 42^{m}\ 48^{s}$

(vii) The five timings (in IST) of the eclipse :

(a) *Sparśa kāla* = $8^{h}\ 24^{m} - 1^{h}\ 46^{m} = 6^{h}\ 38^{m}$ *a.m.*

(b) *Sammīlana kāla* = $8^{h}\ 24^{m} - 0^{h}\ 37^{m}\ 12^{s} = 7^{h}\ 46^{m}\ 48^{s}$ *a.m.*

(c) *Madhya* (middle) *kāla* = $8^{h}\ 24^{m}$ *a.m.*

(d) *Unmīlana kāla* = $8^{h}\ 24^{m} + 0^{h}\ 42^{m}\ 48^{s} = 9^{h}\ 06^{m}\ 48^{s}$

(e) *Mokṣa kāla* = $8^{h}\ 24^{m} + 1^{h}\ 51^{m}\ 36^{s} = 10^{h}\ 15^{m}\ 36^{s}$

Note : According to the *Indian Astronomical Ephemeris*, the respective timings are $6^{h}\ 42^{m}\ 3^{s}$, $7^{h}\ 49^{m}\ 3^{s}$, $8^{h}\ 24^{m}\ 04^{s}$, $8^{h}\ 59^{m}\ 4^{s}$ and $10^{h}\ 06^{m}\ 3^{s}$.

***Ślokas* 14, 15 and 16 : The zenith distances (*nata* in *ghaṭīs*) at the commencement (*sparśa*) and at the end (*mokṣa*) multiplied by 90 and divided by half of he day-length are the *natāṃśas*.**

Its *jyā* (120 sine of the *natāṃśas*) multiplied by the latitude (*akṣa* of the place) and divided by the radius (120) are the deflections (*akṣa valanas* at *sparśa* and *mokṣa*), due to latitude, which are north for eastern *nata* and otherwise (south for the western *nata*).

The *āyana* (valana) in degrees is the *kotijyā* (120 cosine) of the (*bhuja* of the) planet (i.e. the Sun or the Moon) divided by 5. The direction of the *āyana* (*valana*) is that of the *sāyana* planet.

The *jyā* (120 sine) of the sum or the difference (of the two *valanas* as the case is) multiplied by the sum of the half-diameters (of the eclipsed and the eclipsing bodies) and divided by the radius (*trijyā*, 120) are the corrected deflections (*sphuṭa valanam*) in *aṅgulas*.

The directions (of the *sphuṭa valanam*) at *sparśa* and *mokṣa* (respectively for the eclipses of the) Sun and the Moon are of opposite directions.

Finding of *akṣavalana, āyana valana* and hence *spaṣṭa valana* at the beginning and end of an eclipse is explained.

(a) (i) The *nata* at *sparśakāla* is multiplied by 90 and divided by *rātryardha* (half duration of night) in the case of a lunar eclipse and by *dinārdham* (half duration of day) in the case of a solar eclipse.

The samething is done for the *mokṣa kāla* by considering the *nata* at the *mokṣa kāla.*

The result gives the *natāmśa* at the *sparśa kāḷa* (or *mokṣa kāla* as the case may be).

(ii) Find the *jyā* (i.e. 120 sine) of the *natāmśa* and multiply by the *akṣāmśa* (terrestrial latitude) of the place and divide by the *trijyā* (radius) 120. The result is *akṣa valana.* This is determined for the *sparśa* and *mokṣa kālas* separately.

(b) (i) Obtain the *bhuja* of *sāyana* Candra at the *sparśa* and *mokṣa kālas.*

Consider the *koṭi* of this *bhuja* (*i.e.*, $90^\circ - bhuja$) and find the *jyā* of this *koṭi* i.e., obtain 120 sin $(90^\circ - bhuja)$ or 120 cos (*bhuja*). Dividing this by 5 we get *āyana valana.*

$$\bar{A}yana\ valana = \frac{R \cos(bhuja)}{5} \text{ where } R = 120.$$

This is determined separately for the *sparśa* and *mokṣa kālas.*

The direction of the *āyana valana* is the same as that of the *sāyana Candra.*

The direction of *akṣa valanam* is north or south according as the *nata* is eastern or western.

(c) The *spaṣṭa valanam* is obtained as follows.

Take the *algebraic* sum of the *akṣa* and *āyana valanas.* Find its *jyā* and multiply it by half of the sum of the diameters of the *chādya* (eclipsed) and *chādaka* (eclipser) bodies. Divide the result by 120 to get the *spaṣṭa* (corrected) combined *valanam.*

The direction of the corrected *valanam* is the same as that of the algebraic sum mentioned above.

The corrected *valanam* is found out separately for the *sparśa* and *mokṣa kālas.*

Note : The *akṣa valanam* and the *āyana valanam* are the angular deflections caused respectively by the latitude of the place and the obliquity of the ecliptic. The corrected combined *valanam* represents the directions, with respect to the east-west, of the obscuration at the beginning and the end of the eclipses.

Example : In Example (1) above, we have *sparśa kāla* = 7^{gh} (after sunset)

(a) *Candra dinārdham* (i.e., the actual *rātryardham* after the sunset) = 16|49 *gh.*

Difference of the above timings = $(16|49 - 7)$ *gh.* = $9|49$ *gh.*

Multiplying the difference by 90 and dividing by $16|49$ we get

$$\frac{(9|49) \times 90}{16|49} = 52|32|13.$$

Jyā $(52|32|13) \approx 95|02$ (according to Sumatiharṣa).

Multiplying by the *akṣāṃśa* (latitude) $24° \ 35' \ 09''$ of the place, and dividing by 120, we get $\dfrac{(95|02) \times (24|35|09)}{120} = 19|28$

i.e. *Akṣa valana* (at the *sparśa kāla*) = $19° \ 28' \ N$.

Similarly, considering the *nata* at the *mokṣa kāla* $16|10$ *gh.* we get

Akṣa valana (at the *mokṣa kāla*) = $1° \ 29' \ 44'' \ N$

(b) At the *sparśa kāla*, *sāyana* Candra = $2^R \ 17° \ 19' \ 20''$

Its *bhuja* = $77° \ 19' \ 20''$ and *koṭi* = $90° - 77° \ 19' \ 20'' = 12° \ 40' \ 40''$.

Jyā $(12° \ 40' \ 40'') \approx 26|20$. Dividing by 5, we get $5|16$

i.e., *Āyana valanam* (at *sparśa kāla*) = $5° \ 16' \ \dot{N}$.

Similarly, considering the *sāyana* Candra at the *mokṣa kāla viz.*, $2^R\ 19°\ 26'\ 26''$, *Āyana valanam* (at *mokṣa kāla*) = $4°\ 21'\ 24''\ N$.

(c) At the *sparśa kāla*, the combined *valanam* is

Akṣa valanam + *Āyana valanam* = $19°\ 28'\ N + 5°\ 16'\ N = 24°\ 44'\ N$

At the *mokṣa kāla*, the combined *valanam* is

Akṣa valanam + *Āyana valanam* = $1°\ 29'\ 44''\ N + 4°\ 21'\ 24''\ N = 5°\ 51'\ 08''\ N$.

We have, $\frac{1}{2}$ (Sum of diameters of the *chādya* and *chādaka*)

$$= \frac{1}{2}(11|12 + 28|22) = \frac{1}{2}(39|34) = 19|47$$

At the *sparśa kāla*, we have

$$Spaṣṭa\ valanam = \frac{[Jyā\ (24°\ 44')] \times (19|47)}{120} = 8|13|09\ aṅgulas$$

At the *mokṣa kāla*,

$$Spaṣṭa\ valanam = \frac{[Jyā\ (5°\ 51'\ 08'')] \times (19|47)}{120} = 2|8|05\ aṅgulas$$

and both are northern.

Śloka 17 : If the *latitude* (*śara* of the Moon) is obtained from (the Moon + *Pāta* in) the *odd* quadrant then one-third of the half-duration (*sthiti*) is subtracted and added (respectively) for the beginning (*sparśa*) and

the *mokṣa*. In the case of the *even* quadrant, the reverse are the directions (i.e. added and subtracted respectively).

Finding the *śara* at the *sparśa kāla* and at the *mokṣa kāla* is explained.

If the *madhya grahaṇa kālika śara* is (the Moon's latitude at the middle of the eclipse) obtained from the *sapāta* Candra $(M + P)$ in the odd quadrant, then

$$Spar\acute{s}a\ \acute{s}ara = \acute{s}ara - \frac{Madhya\ sthiti}{3}$$

$$Mok\d{s}a\ \acute{s}ara = \acute{s}ara + \frac{Madhya\ sthiti}{3}$$

If the *sapāta* Candra is in the *even* quadrant, then

$$Spar\acute{s}a\ \acute{s}ara = \acute{s}ara + \frac{Madhya\ sthiti}{3}$$

$$Mok\d{s}a\ \acute{s}ara = \acute{s}ara - \frac{Madhya\ sthiti}{3}$$

Another method (*Prakārāntara*) :

Find the Moon (M) and the *Pāta* (P) for the instants of *sparśa* and *mokṣa* from their positions at the *parvānta* and using their true daily motions. Then

$$\acute{S}ara = \frac{3}{4} \times Jya\,(M + P)\ \ a\dot{n}g.$$

Example : Continuing from Example (1) considered earlier the mean half duration, we have

Madhya sthiti = 4|35 *gh.* and *śara* at the middle of the eclipse = 2|57 *aṅgulas*.

Sapāta Candra, (*M* + *P*) = $6^R\ 1^\circ\ 52'\ 23''$ which lies in III quadrant i.e., odd quadrant.

$$\therefore \textit{Sparśa śara} = 2|57 - \frac{4|35}{3} = 1|26 \ \textit{aṅgulas}$$

$$\text{and } \textit{Mokṣa śara} = 2|57 + \frac{4|35}{3} = 4|28 \ \textit{aṅgulas}$$

By the second method :

At the *sparśa kāla*, Moon = $1^R\ 29^\circ\ 11'\ 38''$ and *Pāta* = $4^R\ 1^\circ\ 35'\ 53''$

$\therefore M + P = 6^R\ 0^\circ\ 47'\ 31''$

Bhuja of (*M* + *P*) = $0^\circ\ 47'\ 31''$

$$\therefore \textit{Śara} = \frac{3}{4}\ \textit{Jyā}\ (0^\circ\ 47'\ 31'') = 1|14 \ \textit{aṅgulas}$$

At the *mokṣa kāla*, *śara* = 4|35 *aṅgulas*

We observe a small difference between the values obtained from the two methods.

***Ślokas* 18 and 19 : After constructing a circle with the half-diameter of the eclipsed body as the radius, (another) circle with half the sum of**

the diameters (of the eclipsing and the eclipsed bodies) as the radius is constructed. On the outer circle the desired commencement deflection (*spārśika valanam*) from the east and the ending deflection (*mokṣa valanam*) from the west are marked (for the lunar eclipse) like a chord (*jyā*). For the solar eclipse the same are marked from the west and the east. [The commencement (*sparśa*) and the end (*mokṣa*) latitudes (of the Moon, *śara*) are drawn in the shape of chords from the respective end *valanas*].

The geometrical projection (*parilekhā*) of an eclipse is described.

With a fixed point on the level ground as the centre draw a circle with radius equal to half the sum of the diameters of the *chādaka* and the *chādya*.

Then, a second circle with the centre is drawn whose radius is equal to half the *bimbam (diameter)* of the *chādya* (eclipsed) body.

Through the centre draw the two (perpendicular) lines along the north - south and the east - west directions.

The first circle is called the *mānaikyārdha vṛtta*. On this (outer circle) mark the points representing the *spārśika valanam* from the east and the *mokṣa valanam* from the west.

In the case of the solar eclipse, consider the *spārśika* and *mokṣa valanams* respectively from the west and the east.

The (positive and negative) signs i.e., north and south directions of the *valanam* are the same as those of the *śara* at the beginning and the end of the eclipse.

Śloka 20 : **From the centre of the circle the latitude (*śara*) at the middle (*madhya* of the eclipse) in its direction (and the other two for *sparśa* and *mokṣa*) are marked. Circles are drawn with half the diameter of the eclipsing body and the points of the commencement (*sparśa*) and**

the end (*mokṣa*) latitude (*śara*) as the centres. [The point of contact of this circle and the circle with half of the diameter of the eclipsing body (*chādraka*) as the radius is the point at which the eclipse commences.]

From the point of the middle of the eclipse, measuring the *śara* (of the middle of eclipse) in its direction, three points representing the *śara* values (respectively at the *sparśa, madhya* and *mokṣa*) are marked.

With the point of *sparśa śara* as the centre draw a circle with radius equal to that of the *chādaka*. The point where this circle touches the circle representing the eclipsed body (i.e. the inner circle) is the point of *sparśa* (commencement of the eclipse).

Similarly, the point of contact of the the circle having the point of *mokṣa śara* as the centre (and the radius of the *chādaka*) with the circle of the *chādya* (i.e. the second circle is the point of *mokṣa*.

A similar circle with *madhya śara* is also drawn.

(i) If this circle covers the *chādya circle* (inner circle) and goes beyond, then the eclipse is *total.*

(ii) If it covers a portion of the inner circle then the eclipse is *partial.*

(iii) If the circle does not cut the inner circle, there will be no eclipse.

***Śloka* 21, 22 and 23** : Find the obscuration *(grāsamāna)* for a given time.

The arc joining the three *śara* points (of the beginning, the middle and the end) will be in the shape of a bow (*dhanur ākāra*). The path from the point of *madhya śara* to that of the *sparśa śara* is called the "path of getting eclipsed" (*grahaṇa mārga*). The path from the point of the middle *śara* to that of the *mokṣa śara* is called the "path of release" (*mokṣa mārga*).

Draw another circle with the same centre (as that of the *chādya* circle) and radius equal to half the *difference* of the diameters of the *chādya*

and *chādaka*. Take the points of intersection of this circle with the *grahaṇa mārga* and the *mokṣa marga*. With these as centres and the radius equal to that of the *chādaka* (eclipser) draw circles. The points of contact of these two circles with the *chādya* circle respectively give the points of the beginning and the end of totality (i.e., *sammīlanam* and the *unmīlanam*).

The given time (*iṣṭakāla* from the commencement of the eclipse) multiplied by the measure (in *aṅgulas*) of the path (of eclipse or release, as the case is) and divided by the *sthiti* is the obscuration (*grāsa*) at the given time.

Finding the amount of obscuration *(grāsa)* at a given time *(iṣṭakāla)* :

(a) If the given time is between the *sparśa* and the middle of the eclipse (i.e., if the time interval from *sparśa* is less than the *sparśa sthiti*) then

$$\textit{Grāsa}\text{ at }\textit{iṣṭakāla} = \frac{\textit{Iṣṭakāla} - \textit{Sparśakāla}}{\textit{Sparśa sthiti}} \times \textit{Mārgamāna}$$

(b) If the given time is between the middle of the eclipse and the *mokṣa*, then

$$\textit{Grāsa} = \frac{\textit{Mokṣakāla} - \textit{Iṣṭakāla}}{\textit{Sparśa sthiti}} \times \textit{Mārgamāna}$$

CHAPTER 5

SŪRYAGRAHAṆĀDHIKĀRAḤ

(Computation of Solar Eclipse)

Śloka 1 : For the instant of newmoon (*darśānta*) the tropical ascendant (*sāyana lagna*) reduced by three signs (*tribhoṇa*) is worked out. Its declination (*krānti*) in *palas* reduced from or added to (the latitude of the place, *akṣa*), for the different or the same directions, is the *natāṃśa*; the same reduced from ninety (degrees) is the *unnatāṃśa*.

Obtaining of *nata, unnata, vitribhalagna* is explained.

(i) Find the true Sun, true Moon and *lagna* for the instant of the *darśānta* (i.e. new moon).

Add *ayanāṃśa* to the *(nirayaṇa) lagna* to get the *sāyana lagna*. Subtract 3 *rāśis* from it to get the *(sāyana) vitribha* (or *tribhoṇa*) *lagna*.

(ii) Find the *krānti* (declination) of the (*sāyana*) *vitribha lagna*.

(iii) Then, *nātāṃśa* = *krānti* – *akṣāṃśa* = $\delta - \phi$ where δ = declination of the *tribhoṇalagna* and ϕ = latitude of the place.

Conventionally, for a place in the northern hemisphere its latitude is taken as *southern*. However, the above definition, with the *modern* convention, is clear.

(iv) *Unnatāṃśa* = 90° – *natāṃśa*.

Example : *Samvat* 1657, *Śā.Śa.* 1522, *Aṣāḍha kṛṣṇa amāvāsyā*. The *darśānta* (end of *amāvāsyā*) = 29|24 *gh.*, *Ayanāṃśa* = $17^\circ\ 57'\ 20''$.

At the instant of the *darśānta*, we have

True Sun = $3^R\ 0°\ 35'\ 08''$ (*nirayaṇa*)

∴ *Sāyana* Sun = $3^R\ 18°\ 32'\ 28''$

Sāyana lagna = $8^R\ 25°\ 14'\ 58''$

∴ *Vitribha lagna* = $5^R\ 25°\ 14'\ 58''$

Akṣāṃśa (of the place), $\phi = 24°\ 35'\ 09''\ N$.

Krānti of *Vitribha lagna*, $\delta = 1°\ 54'\ 58''\ N$.

Natāṃśa = $\delta - \phi = 1°\ 54'\ 38'' - 24°\ 35'\ 09'' = 22°\ 40'\ 31''$ South.

∴ *Unnatāṃśa* = $90° - 22°\ 40'\ 31'' = 67°\ 19'\ 29''$.

***Ślokas* 2 and 3 : The Rsine (*jyā*) of the difference of the *tribhonalagna* and the (longitude of the) Sun divided by 30 is the (mean, *madhya*) elongation (*lambana*) in *ghaṭīs*. That multiplied by *R*sine of *unnatāṃśa* and divided by 120 is the corrected (*sphuṭa*) elongation; this is added to or subtracted from the instant of new moon (*darśānta*) according as the *tribhonalagna* is greater or lesser than the Sun.**

The *R*sine (*jyā*) of *natāṃśa* added with 1/12th of itself and (the sum) divided by 8 is *nati* in *aṅgulas* etc. in the direction of the *natāṃśa*.

Obtaining of *lambana* and *nati* is explained.

(i) ***Lambana*** :

Let *SR* = *Sāyana* Ravi, *SVL* = *Sāyana vitribha lagna* at the *darśānta*. Find the *bhuja* of (*SR* – *SVL*), denoted by *Bhuja*.

Then *madhya lambana* (mean elongation) is given by

$$Madhya\ lambana = \frac{Jy\bar{a}\ (Bhuj\bar{a})}{30}\ ghaṭ\bar{\imath}s$$

Then the corrected (*sphuṭa*) *madhya lambana* is given by

$$Sphuṭa\ \ lambana\ = \frac{(Madhya\ lambana) \times (Jy\bar{a}\ \text{of}\ Unnat\bar{a}ṃś\bar{a})}{120}$$

ghaṭīs.

i.e. *sphuṭa lambana* = 4sin(*SR* - *SVL*) cos $(\delta - \phi)$ *ghaṭīs.*

If *SVL* > *SR* and the *darśānta* is in the western hemisphere (i.e., between the noon and the sunset), then the *sphuṭa lambana* is *added* to the *darśānta* (*ghaṭīs*).

On the otherhand, if *SR* > *SVL* and the *darśānta* is in the eastern hemisphere (i.e., between the sunrise and the noon) then the *sphuṭa lambana* is *subtracted* from the *darśānta* to get the *lambana* corrected *darśānta*.

(ii) ***Nati*** :

$$Nati = \frac{1}{8}\left[Jy\bar{a}\ (Nat\bar{a}ṃś\bar{a}) + \frac{Jy\bar{a}\ (Nat\bar{a}ṃśa)}{12}\right] a\dot{n}g$$

$$= \frac{1}{8} \times \frac{13}{12} \times Jy\bar{a}\ (Nat\bar{a}ṃśa)\ a\dot{n}g.$$

The direction of the *nati* is the same as that of the *natāṃśa.*

Example : In the example considered, we have *Natāṃśa* = 22° 40′ 31″ S

Sāyana Ravi, *SR* = 3^R 18° 32′ 28″, *Unnatāṃśa* = 67° 19′ 29″

Sāyana Vitribha Lagna, SVL = $5^R\ 25°\ 14'\ 58''$, *Bhuja* of (*SR* − *SVL*) = $66°\ 42'\ 30''$

$$\therefore \textit{Madhya lambana} = \frac{\textit{Jyā}\ (66°\ 42'\ 30°)}{30} = 3|40\ gh.$$

Note : At this corrected *darśānta* true Sun, *tribhoṇa lagna,* etc., are found out and a further *lambana* corrected *darśānta* is obtained. This process is iterated till we obtain a convergent value of the *darśānta.*

$$\therefore \textit{Spaṣṭa lambana} = \frac{(3|40)\ \textit{Jyā}\ (67°\ 19'\ 28'')}{120} \approx 3|22\ gh.$$

The *spaṣṭa lambana* is additive since *SVL* > *SR* and the *darśānta* is in the western hemisphere (*paścima kapāla*).

Adding this to the *darśānta,* we get

$$\textit{lambana} \text{ corrected } \textit{darsānta} = (29|24 + 3|22)\ gh. = 32|46\ gh.$$

Repeating the same process for the above corrected *darśānta* viz. 32|46 *gh.*, we get the second *lambana* corrected *darśānta* as 32|49 *gh.*

We drop further iterations since the difference between the two successive *darśānta* timings is only 3 *vig.* At 32|49 *gh.*, we shall find the *nati.*

We have *natāṃśa* = $30°\ 36'\ 05''$, *unnatāṃśa* = $59°\ 23'\ 55''$.

$$\textit{Nati} = \frac{1}{8} \times \frac{13}{12}\ \textit{Jyā}\ (30°\ 36'\ 05'') = 8|15\ \textit{aṅg.}$$

Nati is always taken negative.

***Ślokas* 4 and 5 : The (nine) blocks (*piṇḍas*) of elongation (*lambana*) are 77, 141, 188, 219, 235, 240, 236, 224 and 200. The (*bhuja*) of the difference between the *tribhonalagna* and the Sun divided by 11 (gives) the elapsed block (*gata piṇḍa*).**

The difference between the to-be-covered (*gamya*) and the elapsed (*gata*) blocks is multiplied by the remainder (*bhuja* minus elapsed block) and divided by 11. (The result) divided by 60 and subtracted from or added to (the elapsed block according as) the to-be-covered (*bhogya, gamya*) block is lesser or greater (than the elapsed block) is the (mean, *madhya*) elongation (*lambana*). The corrected one (*sphuṭa lambana*), by successive approximation (*asakṛt*), and hence *nati* are obtained as (explained) earlier.

Obtaining *lambana* by another method is explained.

The nine *lambana piṇḍas* are 77, 141, 188, 219, 235, 240, 236, 224, 200. Find the *bhuja* of the difference between the *sāyana vitribha lagna* and the *sāyana* Ravi. Divide by 11 and let the quotient be q and the remainder be r. The quotient q represents the number of *piṇḍas* completed.

Multiply the remainder r by the difference $(q+1)^{th}$ *piṇḍa* minus the q^{th} *piṇḍa* and divide by 11. The result is combined (added or subtacted as the case may be) with the q^{th} *piṇḍa*. Dividing the resultant *piṇḍa* by 60, we get the *madhyama* (mean) *lambana* in *ghaṭīs*. This is corrected to get the *sphuṭa lambana* as explained earlier (in *Ślokas* 2 and 3).

Example : At the *darśānta* instant, we have

Sāyana Ravi $SR = 3^R\ 18°\ 32'\ 28''$ and *sāyana vitribha lagna*

$SVL = 5^R\ 25°\ 14'\ 58''$, $SVL - SR = 2^R\ 6°\ 42'\ 30''$, $Bhuja = 66°\ 42'\ 30''$

Dividing *Bhuja* = $66°42'30''$ by 11, we have

$q = 6$ and $r = 0°\ 42'\ 30''$.

Now, the 6th *piṇḍa* is 240 and the 7th *piṇḍa* is 236.

∴ 7th *piṇḍa* – 6th *piṇḍa* = 236 – 240 = – 4

Now, $\dfrac{r \times (-4)}{11} = \dfrac{(0°\ 42'\ 30'')\ (-4)}{11} = 0|15|27$ *vig.*

The required *piṇḍa* = 240 *vig.* – 0|15|27 *vig.* ≈ 239|44 *vig.*

Dividing by 60, we get

(*Madhya*) *Lambana* = 3|59|44 *gh.*

Jyā (*unnatāṃśa*) = *Jyā* $(67°\ 19'\ 29'')$ = $110'\ 35''$ (see eg., under *Ślokas* 2, 3)

Sphuṭa lambana = $\dfrac{(3|59|44)\,(110|35)}{120}$ *gh.* = 3|40 *gh.*

∴ *Lambana* corrected *darśānta* = 29|24 + 3|40 = 33|04 *gh.*

(The earlier obtained value is 32|49 *gh.*)

***Ślokas* 6 and 7 : The latitude is corrected (*spaṣṭa śara* of the Moon) with the *nati* and also (obtained) are the obscuration (*channam*) and the half-duration (*sthiti*) as earlier (explained in Chapter 4).**

The *lambanam*, kept separately (in two places), is added to and subtracted from the instant of the end of the *tithi* (newmoon) reduced

by and added with the half-duration (*sthiti*). The positive or negative corrected latitude (of the Moon, *spaṣṭa śara*) as also the half-duration (are obtained) by subtracting and adding repeatedly these from and to the computed values.

Finding the *śara* and *sthiti* is explained.

(i) Find the true longitudes of the Moon (*M*) and its *Pāta* (node *P*). Obtain the *jyā* of *sapāta* Candra ($M + P$) i.e., $120 \sin (M + P)$ *kalās*. Then

$$\acute{s}ara = \frac{3}{4} \times jy\bar{a}\ (M + P)\ a\dot{n}g. = 90 \sin (M + P)\ a\dot{n}g.$$

The *nati* corrected *śara* is given by

Spaṣṭa śara = *śara* + *nati*

(*Śara* and *nati* may be positive or negative. Their algebraic sum is taken).

(ii) Let d_1 and d_2 be the *bimbams* (diameters) of the Sun and the Moon.

$$\therefore\ Gr\bar{a}sa = \left[\frac{1}{2}(d_1 + d_2) - Spa\d{s}\d{t}a\ \acute{s}ara\right] a\dot{n}g.$$

Then the (mean) half-duration (*sthiti*) given by

$$Sthiti = \frac{\sqrt{(2\ \acute{s}ara + gr\bar{a}sa)\ (gr\bar{a}sa)}}{(MDM - SDM)} \times 180\ gh.$$

where *śara* is the corrected (*spaṣṭa*) *śara*, *MDM* and *SDM* are respectively the true daily motions of the Moon and the Sun.

Khagrāsa = *Grāsa* – Sun's *bimbam*.

In the case of *total* solar eclipse, the half-duration of totality *marda* is obtained by replacing *grāsa* by *khagrāsa*.

Example : We have the corrected *darśānta* = 32|49 *gh.* At this instant,

True Moon, $M = 3^R\ 1°\ 2'\ 46''$, *Pāta,* $P = 2^R\ 26°\ 21'\ 38''$

$\therefore \quad M + P = 5^R\ 27°\ 24'\ 24''$, $Bhuja = 2°\ 35'\ 36''$

However, in the printed commentary, the *bhuja* is given as $2°\ 16'\ 36''$.

$\therefore$ *Śara* $= \dfrac{3}{4} \times$ *Jyā* (2° 16′ 36″) = 3|34 *N aṅg.*

(since $M + P < 6^R$, *śara* is northern).

We have obtained *nati* = 8|15 *aṅg.* (S). Therefore *nati* corrected *śara,*

Spaṣṭa śara = 3|34 − 8|15 = 4|41 *S aṅg.*

(**Note** : *Nati* is taken always as South).

Sun's *bimbam* $d_1 = \dfrac{2 \times (56'\ 58'')}{11}$ = 10|21 *aṅg.*

Moon's *bimbam* $d_2 = \dfrac{819'\ 04''}{74}$ = 11|04 *aṅg.*

Grāsa $= \dfrac{1}{2}(d_1 + d_2)$ − *spaṣṭa śara*

= 10|42 − 4|41 = 6|01 *aṅg.*

Sthiti = 2 | 16 *gh.*

where $MDM = 819' 04''$ and $SDM = 56' 58''$ are the true daily motions of the Moon and the Sun.

Since *grāsa* < Sun's *bimbam*, the solar eclipse is *not total*.

***Śloka* 8 : The improved instants of the commencement of the eclipse and its release are obtained by applying the *lambana* (correction). The half-intervals between the middle (of the eclipse) and the beginning and the end (of the eclipse) are corrected and the rest are explained in (the context of) lunar eclipse.**

Obtaining the *sparśa* and *mokṣa* of the solar eclipse.

Subtracting the *sthiti* from and adding the *stithi* to the *darśānṭa* respectively we get the tentative instants of *sparśakāla* and *mokṣakāla*. Considering these instants as *iṣṭakālas*, determine *sāyana* Ravi, *sāyana lagna*, *nati* and *śara*. From the corrected *sthiti*, obtain the above parameters again. Thus, by successive iterations the final convergent values for *sthiti*, *darśānta*, *sparśa kāla* and *mokṣa kāla* etc. are obtained.

We shall consider a modern example.

Example : August 11, 1999, Wednesday, at Bangalore [Longitude, $77° E' 35'$; Latitude, $13° N$].

At 5-30 a.m. (IST) we have

True (*nirayaṇa*) Sun = $3^R\ 24°\ 03'\ 31''$

True (*nirayaṇa*) Moon = $3^R\ 17°\ 59'$

Sun's true daily motion, $SDM = 57' 35''$

Moon's true daily motion, $MDM = 837'$.

The instant of conjuction of the Sun and the Moon, *Darśānta* = $16^h\ 43^m\ 27^s$ IST.

At the ***darśānta*** i.e., at $16^h\ 43^m\ 27^s$ IST, we have

True Sun = $114°\ 30'\ 27''$, True moon = $114°\ 30'\ 27''$

Ayanāṃśa = $23°\ 51'$, *sāyana lagna* = $288°\ 20'$

$\therefore$ *Sāyana Vitribha Lagna* = $198°\ 20' \equiv SVL$

Declination of $SVL = -\ 7°\ 21'\ 01'' \equiv \delta$

Natāṃśa = $\delta - \phi = -\ 7°\ 21'\ 01'' - 13° = 20°\ 21'\ 01''\ S$

where $\phi = 13°\ N$, the *akṣāṃśa* (latitude) of Bangalore. Considering the numerical value of the *natāṃśa*, we have

Unnatāṃśa = $90° - 20°\ 21'\ 01'' = 69°\ 38'\ 59''$

$\therefore$ *Jyā* (*unnatāṃśa*) = $120' \sin (69°\ 38'\ 59'') = 112'\ 30''$

Finding *lambana* and *nati* :

Sāyana Ravi, $SR = 138°\ 21'\ 27''$

$$\textit{Madhya Lambana} = \frac{\textit{Jyā}\ (SVL - SR)}{30} = 3|27\ gh.$$

$$\textit{Spaṣṭa Lambana} = \frac{(3|27) \times (112|30)}{120} = 3|14\ gh.$$

i.e., $1^h\, 17^m\, 36^s$

Lambana corrected *darśānta* = $16^h\, 43^m\, 27^s + 1^h\, 17^m\, 36^s = 18^h\, 01^m\, 03^s$

i.e., $12^h\, 31^m\, 03^s$ from 5-30 a.m. IST

At the first corrected *darśānta* :

At $18^h\, 01^m\, 03^s$ (IST), we have

Sāyana Ravi *SR* = $138°\, 24'\, 32''$, *Sāyana Lagna* = $307°\, 57'$

$\therefore$ *Sāyana Vitribha Lagna*, $SVL = 217°\, 57'$

Spaṣṭa Lambana = $3|29|22$ *gh.* $\equiv 1^h\, 23^m\, 45^s$

$\therefore$ Second corrected *darśānta* = $16^h\, 43^m\, 27^s + 1^h\, 23^m\, 45^s = 18^h\, 07^m\, 12^s$

At the second corrected *darśānta* :

At $18^h\, 07^m\, 12^s$ (IST), we have

Sāyana Ravi = $138°\, 24'\, 47''$, *Sāyana Lagna* = $310°\, 26'$

$\therefore$ *Sāyana Vitribha Lagna SVL* = $220°\, 26'$

Spaṣṭa Lambana = $3^{gh}\, 29^{vig}\, 16^{pvg} \equiv 1^h\, 23^m\, 43^s$

$\therefore$ Third corrected *darśānta* = $16^h\, 43^m\, 27^s + 1^h\, 23^m\, 43^s = 18^h\, 07^m\, 10^s$.

Since the difference between the second and third corrected instants of *darśānta* is only 2 seconds, we take $18^h\ 07^m\ 10^s$ as the finally corrected *darśānta*.

***Nati* at the corrected *darśānta* :**

At the corrected *darśānta* = $18^h\ 07^m\ 10^s$ we have

Natāmśa = 28° 17′ 43″

$$\therefore \textit{Nati} = [\textit{Jyā}\ (28^\circ\ 17'\ 43'')] \times \frac{13}{12 \times 8} = 7|42\ \textit{aṅg.}\ (S)$$

True Moon M = 115° 19′ 06″, Rāhu R = 109° 10′ 56″

Jyā (Moon – Rāhu) = 120′ sin ($M - R$) = 12′ 50″

$$\therefore\ \textit{Śara} = \frac{3}{4}\ \textit{Jyā}\ (M - R) = 9|37\ \textit{aṅg.}\ (N)$$

∴ *Spaṣṭa śara* = *Nati* + *Śara* (algebraic sum) = – 7|42 + 9|37 = 1|55 *aṅg.*

Bimba (diameters of the Sun and the Moon) :

$$\text{Moon's diameter } d_1 = \frac{\text{Moon's true daily motion}}{74}$$

$$= \frac{837'}{74} = 11|19\ \textit{aṅgulas}$$

$$\text{Sun's diameter } d_2 = \frac{2}{11} \times \text{Sun's true daily motion}$$

$$= \frac{2}{11} \times 57'\,35'' = 10|28\ \textit{aṅgulas}$$

i.e., d_1 = 11|19 *aṅg.* and d_2 = 10|28 *aṅg.*

Bimbardha yoga = $\frac{1}{2}(d_1 + d_2) = 10|53$ *aṅg.*

Grāsa (*Channam*) = $\frac{1}{2}(d_1 + d_2)$ − *śara* = $10|53 - 1|55 = 8|58$ *aṅg.*

Sthiti = $\frac{\sqrt{(2 \times \acute{s}ara + gr\bar{a}sa) \times gr\bar{a}sa}}{(MDM - SDM)} \times 180\ gh.$ =

$2|28|26$ *gh.* ≡ $0^h\ 59^m\ 23^s$

Sparśa and Makṣa :

Sparśa kāla = *Darśānta* − *sthiti*

= $18^h\ 07^m\ 10^s - 0^h\ 59^m\ 23^s = 17^h\ 7^m\ 47^s$ (IST)

Spārśika lambana* and *nati :

Sparśa kāla = $17^h\ 7^m\ 47^s$

At that instant, we have

Sāyana Ravi *SR* = 138° 22′ 25″, *Sāyana Lagna* = 294° 27′

Sāyana Vitribha Lagna, *SVL* = 204° 27′

Declination of *SVL* = 9° 41′ 30″ *S*

Natāṃśa = 22° 41′ 30″ *S*, *Unnatāṃśa* = 67° 18′ 30″

Madhya Lambana = $3^{gh}\ 39^{vig}$

Spaṣṭa Lambana = $3^{gh}\ 22^{vig}\ 23^{pvg} \equiv 1^h\ 20^m\ 57^s$

Lambana corrected *sparśa kāla* = $17^h\ 7^m\ 47^s + 1^h\ 20^m\ 57^s$ = $18^h\ 28^m\ 44^s$.

At the lambana corrected sparśa kāla :

At $18^h\ 28^m\ 44^s$ (IST), we have

True Sun = $114^\circ\ 34'\ 39''$, True Moon = $115^\circ\ 31'\ 38''$ (both *nirayaṇa*)

Sāyana Lagna = $315^\circ\ 56'$

Sāyana Vitribha Lagna, *SVL* = $225^\circ\ 56'$

Declination of *SVL* = $-16^\circ\ 59'\ 34'' \equiv \delta$

Natāṃśa = $\delta - \phi = 29^\circ\ 59'\ 34''\ S$, *Unnatāṃśa* = $60^\circ\ 0'\ 26''$

Nati = 8|07 *aṅg. S*, *Rāhu* = $109^\circ\ 10'\ 56''$, *Śara* = 9|57 *aṅg. N*

Spaṣṭa śara = −8|07 + 9|57 = 1|50 *aṅg. N*

Grāsa (*Channam*) = 10|53 − 1|50 = 9|03 *aṅg*

Sthiti = 2|28|39 *gh.* = $0^h\ 59^m\ 28^s$

First corrected *sparśa kāla* :

Sparśa kāla = *Darśānta* – *sthiti*

$$= 18^h\ 07^m\ 10^s - 0^h\ 59^m\ 28^s = 17^h\ 07^m\ 42^s \text{ IST}$$

At the corrected *sparśa kāla* :

At $17^h\ 07^m\ 42^s$ (IST), proceeding as before, we have

Spaṣṭa Lambana = $3^{gh}\ 22^{vig} \equiv 1^h\ 20^m\ 57^s$

Lambana corrected *sparśa kāla*

$$= 17^h\ 07^m\ 42^s + 1^h\ 20^m\ 57^s = 18^h\ 28^m\ 39^s \text{ (IST)}$$

Natāṃśa = $30°\ 0'\ 27''\ S$, *Unnatāṃśa* = $59°\ 59'\ 33''$

Nati = $8|07|36$ *aṅg. S*, *Śara* = $9|56|42$ *aṅg. N*

Spaṣṭa śara = $-8|07|36 + 9|56|42 \approx 1|49$ *aṅg.*

Grāsa = $9|04$ *aṅg.*

Sthiti = $2|28|41$ *gh.* $\equiv 0^h\ 59^m\ 28^s$

Second corrected *sparśa kāla*

$$= 18^h\ 07^m\ 10^s - 0^h\ 59^m\ 28^s = 17^h\ 07^m\ 42^s \text{ (IST)}$$

Since the first and second corrected instants of *sparśa kāla* are the same, we take the finally corrected *sparśa kāla* as $17^h\ 07^m\ 42^s$ (IST)

***Mokṣa kāla* :**

We have

Mokṣa kāla = *Darśānta* + *sthiti*

$$= 18^h\ 07^m\ 10^s + 0^h\ 59^m\ 23^s = 19^h\ 06^m\ 33^s \text{ (IST)}$$

***Mokṣa kāla lambana, sthiti* etc. :**

At the *mokṣa kāla* $19^h\ 06^m\ 33^s$ (IST), we have

Sāyana Ravi, *SR* = $138°\ 27'\ 10''$

Sāyana Lagna = 326°, *Sāyana Vitribha Lagna, SVL* = 236°

Declination of *SVL* = 19° 42′ 22″ *S*

Natāṃśa = 32° 42′ 22″ *S*, *Unnatāṃśa* = 57° 17′ 38″

Madhya lambana = 3|57|55 *gh.* ≡ $1^h\ 35^m\ 10^s$

Spaṣṭa lambana = 3|20|11 *gh.* ≡ $1^h\ 20^m\ 04^s$

∴ *Lambana* corrected *mokṣa kāla*

$$= 19^h\ 06^m\ 33^s + 1^h\ 20^m\ 04^s = 20^h\ 26^m\ 37^s \text{ IST}$$

At the *lambana* corrected *mokṣa kāla* :

Natāṃśa = 36° 33′ 35″ *S*, *Unnatāṃśa* = 53° 26′ 25″

Nati = 9|40|46 *aṅg.*, *Śara* = 11|43|37 aṅg.

Spaṣṭa śara = 2|02 *aṅg.*

Grāsa = 8|51 *aṅg.*

Sthiti = 2|28|08 *gh.* ≡ $0^h\ 59^m\ 15^s$

First corrected *mokṣa kāla* = *Darśānta* + *sthiti*

$$= 18^h\ 07^m\ 10^s + 0^h\ 59^m\ 15^s = 19^h\ 06^m\ 25^m \text{ (IST)}$$

Second corrected *mokṣa kāla* :

At $19^h\ 06^m\ 25^s$ IST, we have

Sāyana Ravi = 138° 31′ 10″ ≡ *SR*, *Sāyana Lagna* = 325° 59′

Sāyana Vitribha Lagna = $235°\ 59' \equiv SVL$

Declination of $SVL = 19°\ 42'\ 08''\ S$

Natāṃśa = $32°\ 42'\ 08''\ S$, *Unnatāṃśa* = $57°\ 17'\ 52''$

Madhya lambana = $3|57|57$ *gh.* $\equiv 1^h\ 35^m\ 11^s$

Spaṣṭa lambana = $3|20|14$ *gh.* $\equiv 1^h\ 20^m\ 06^s$

Lambana corrected *mokṣa kāla*

$$= 19^h\ 06^m\ 25^s\ +\ 1^h\ 20^m\ 06^s\ =\ 20^h\ 26^m\ 31^s\ \text{(IST)}$$

At this instant i.e., at $20^h\ 26^m\ 31^s$:

We have

Natāṃśa = $36°\ 34'\ 05''\ S$, *Unnatāṃśa* = $53°\ 25'\ 55''$

Nati = $9|40|52$ *aṅg.*, *Śara* = $11|43|32$ *aṅg.*

Spaṣṭa śara = $2|2|39$ *aṅg.*

Grāsa = $8|51$ *aṅg.*

Sthiti = $2|28|07$ *gh.* $\equiv 0^h\ 59^m\ 15^s$

Second corrected *mokṣa kāla* = $18^h\ 07^m\ 10^s + 0^h\ 59^m\ 15^s$ = $19^h\ 06^m\ 25^s$ (IST).

Since the instance of the first and second corrected *mokṣa kāla* are the same, we take the finally corrected *mokṣa kāla* as $19^h\ 06^m\ 25^s$ (IST).

Further, since *grāsa* < Sun's *bimba*, the solar eclipse is *partial.*

Summary of the solar eclipse which occurred on August 11, 1999 :

Sparśa kāla (beginning) : $17^h\ 07^m\ 42^s$ IST

Darśānta (middle) : $18^h\ 07^m\ 10^s$ IST

Mokṣa kāla (end) : $19^h\ 06^m\ 25^s$ IST

at Bangalore

Note : According to the *Indian Astronomical Ephemeris*, at Bangalore, *Sparśa kāla* is $17^h\ 12^m\ 04^s$ IST and the middle at $18^m\ 12^m\ 03^s$ IST. Since the *mokṣa kāla* of the eclipse at Bangalore is after the sunset ($18^h\ 42^m\ 05^s$ IST), it is not visible.

***Śloka* 9 : One-twelfth of the Sun and one-sixteenth of the Moon, even if eclipsed, are not to the declared. The Moon is smoky (in colour) in less than half eclipse, dark in half-eclipse and reddish brown in total eclipse. The Sun (in a solar eclipse) is black.**

The colour of the eclipsed Sun and Moon is mentioned.

In a solar eclipse, if the *grāsa* is less than or equal to ${}^1\!/_{12}{}^{th}$ of the Sun's diameter (*bimbam*), then the eclipse is not predicted.

Similarly, in a lunar eclipse, if the *grāsa* is less than or equal to ${}^1\!/_{16}{}^{th}$ of the Moon's diameter (*bimbam*), the eclipse is not predicted.

In a lunar eclipse, if the magnitude is less than half then the Moon's colour is one of *smoke;* if the magnitude is $\frac{1}{2}$ then the colour is *black*. In a total lunar eclipse the Moon's colour is *reddish brown* (or tawny, *piśaṅga*). In a solar eclipse, the Sun is always *black*.