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Research Paper

A Mathematical Study of Truepositions of Planets in An Astronomical Table - *Grahalāghava Sāriṇi*

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ABSTRACT: *An astronomical table Grahalāghava sāriṇi provided by an unknown author is most useful in the compilation ofpañcāṇgasby its makerstill date especially in Maharashtra region. In the present paper we tried to compare the values given in Grahalāghavasāriṇiwith the main text Grahalāghava by GaṇeśaDaivagña and the mathematical relations are obtained by introducing the formula for mean daily motions and for computing mandaphala(equation of a centre) and śīghraphala (equation of conjunction). Finally, an example is worked out and the results are compared with modern ephemeris.*

KEYWORDS: *equation of a centre, anomaly, equation of conjunction, mandaphala, śīghraphala,mandakendra, śīghrakendra.*

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I. INTRODUCTION:

In India we find many popular astronomical tables belonging to different schools (*pakṣas*) in different regions. These astronomical tables are named differently from region to region as *sāriṇīs, padakas, koṣtakas, vākyas*, etc. The major genres of these Indian astronomical tables belong to different *pakṣas* are namely *saurapakṣa, āryapakṣa, brāhmapakṣa* and *gaṇeśa pakṣa.* These compositions of tables are based on the major treatises by great authors of *Sūryasiddhānta* (author of this text is not known), *Āryabhaṭīyam* of Āryabhaṭa (499 A.D.), *Brahmasputasiddhānta* of Brahmagupta (628A.D.) and *Grahalāghavam* of Gaṇeśa Daivajña (1520A.D.) respectively.

1.1 The text:*Grahalāghava*(GL)

In our present work the text*Grahalāghava*is studied to obtainthe mathematical expression and the derivation for the tables *Grahalāghavasāriṇi.* An exampleis worked out according to both the text and tables to compare the result with present ephemerical values.

According to the text *Grahalāghava*composed by GaṇeśaDaivagñaof 16th century, the epoch was considered as March 19, 1520 CE, Monday the computationswere adopted to themean sunrise at Ujjain. The traditional date is *śālivāhanaśaka*1442, *caitraśuklapratipat*.

The*ahargaṇa* computed by GaṇeśaDaivagñainvolves two components called *cakra*and *ahargaṇa*, here 4016 days are considered as 1*cakra* (C).(i.e 1C=4016 days)

In *Grahalāghava*the author gives the tables for*Dhruvakas*and *Kśepakas.Kśepaka*is the mean position of a heavenly body at the time of epoch and *Dhruvakas* are the residual motion of a body in a *cakra*after the completed revolutions.

The mean position of the sun, the moon and other planets are obtained by multiplying the mean daily motion of the concerned body with *ahargaṇa*and then by subtracting the product of *Dhruvaka*and *cakra* and then by adding *Kśepaka*to it.

Table.1: *Kśepaka*and *Dhruvakas*of heavenly body

Heavenly bodies	*Kśepaka*	*Dhruvakas*
Sun	349° 41′	1°49′11″
Moon	349° 06′	3°46′11′
Moon's apogee	167° 33′	272°45′
Moon's node	27° 38′	212° 50′
Mars	307° 08′	55° 32′
Mercury's anomaly	269° 33′	123° 27′
Jupiter	212° 16′	26° 18′
Venus anomaly	230° 09′	44° 02′
Saturn	285° 21′	225° 42′

Table.2: The mean daily motion of the heavenly bodies as per the text GL:

Heavenly bodies	Mean daily motion
Sun	59′8″
Moon	13°10′35″
Moon's apogee	6′41″
Moon's node	3′11″
Mars	31′ 26″
Mercury's anomaly	3° 6′ 24″
Jupiter	5′0″
Venus anomaly	37′ 0″
Saturn	2′ 0″

The mean longitude of the heavenly body= $[(meandailymotion \times A) - (C \times D) + K]$
where A= *ahargaṇa*, C=*cakra*, D= *druvaka*, K=*kśepaka*

1.2 The table:*Grahalāghavasāriṇi.*

The author's name and period of composition of the tables *Grahalāghavasāriṇi* is unknown. But the copies of*sāriṇi*are available in oriental research libraries.For our present work we are referring the copy of the Manuscript procured from the library of Kurukṣetra University.

In one of the folio the author mentions he has composed the *sāriṇi* to reduce the computational work of the text *Grahalāghava*. From this the purpose of composition is veryclear it is to reduce the tedious work of compilation of traditional *pañcāṇgas* (almanacs) by its makers.

The table consists of mean daily motion for unit days, for multiples of 10 days, for multiples of 100days from 1 to 9 and then for 1000days from 1 to 5(because 4016 days are considered as 1 *cakra*).

The *mandaphala*tables for all the heavenly bodies are provided for the argument of *mandakendra*from 1° to 90° along with the difference in *mandaphala*for every 1 degree. Similarly the*śīghraphala*tables for the five planets are provided for the argumentof *śīghrakendra*(anomaly) from 1° to 180°.

Apart from the mean daily motion,*mandaphala*and*Śīghraphala*tables, the *sāriṇi*consists of *pañcāṇga*components that is *tithi, nakśatra,yoga*and*karaṇa.*

The contents of the manuscript of*Grahalāghavasāriṇī* arelisted as below:

Sl.No	*Content*	*Folio No*
1	Mean daily motion of the Sun, the Moon, Moon's apogee, Moon's node and five Planets are given for multiple of unit days, 10days, 100days and also for 1000days	0-2
2	Mean daily motion of the Sun, the Moon, Moon's apogee, Moon's node and five Planets are given for 29 days called *madhyamānkas* along with *dvādaśa śeṣānkas* and *labdānkas,cakrānkas* and *dhruvakas* by the side of the folio	3-7
3	*Mandaphala* tables of the Sun, the Moon for manda anomaly from 0° to 90°.	8
4	*Mandaphala* tables of five planets for *manda* anomaly from 0° to 90° followed by their śīghraphala tables for *śīghra* anomaly from 0° to 180° along with that *vakrakendra* of each planet (stationary point of retrograde motion), *pūrvodayakendra* and *paşcimāstakendra* (heliacal rising in east and setting in the west) are also given in case of five planets.	9-16
5	*Tithi śeṣa samvatsara* (for arguments 1-47) and *tithi labda samvatsara* (for arguments 1-6)	17-18
6	*Tithi kṣepā* (for 12 rāśis given for 376 days)	19-21
7	*Tithi kendra phala* (for arguments 0-29, given for 58 divisions)	22-23
8	*Nakṣatra śeṣa samvatsara* (for arguments 1-47) and *nakṣatra labda samvatsara* (for arguments 1-6)	24-28
9	*Nakṣatra kṣepā* (for 12 rāśis given for 372 days)	28
10	*Nakṣatra kendra phala (*for arguments 0-29, given for 58 divisions*)*	28-29
11	*Yoga śeṣa samvatsara (*for arguments 1-47) and *yoga labda samvatsara (for arguments 1-6)*	30-33

12	*Yoga kṣepā (for 12 rāśis given for 391 days)*	34
13	*Yoga kendra phala (for arguments 0-29, given for 58 divisions)*	34-35
14	*Sankrānti śeṣa samvatsara*	36

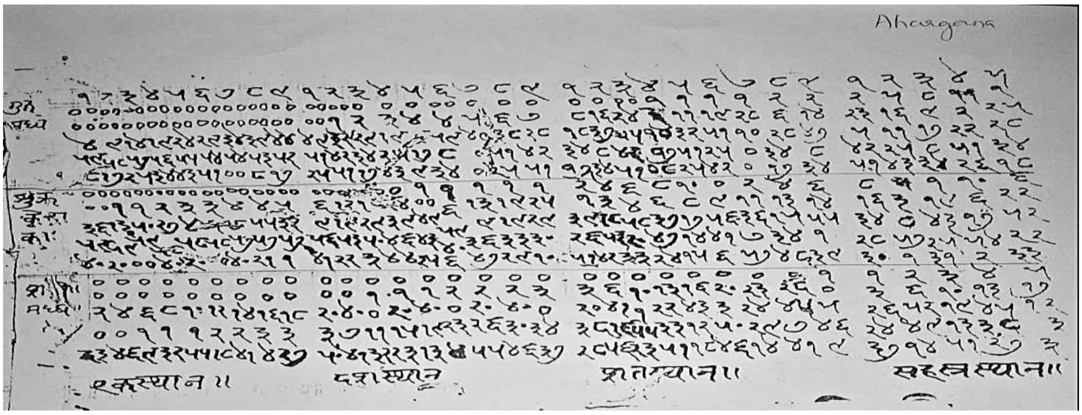

Fig .1- Mean daily motion of the Sun for multiples of 10, 100, 1000 days

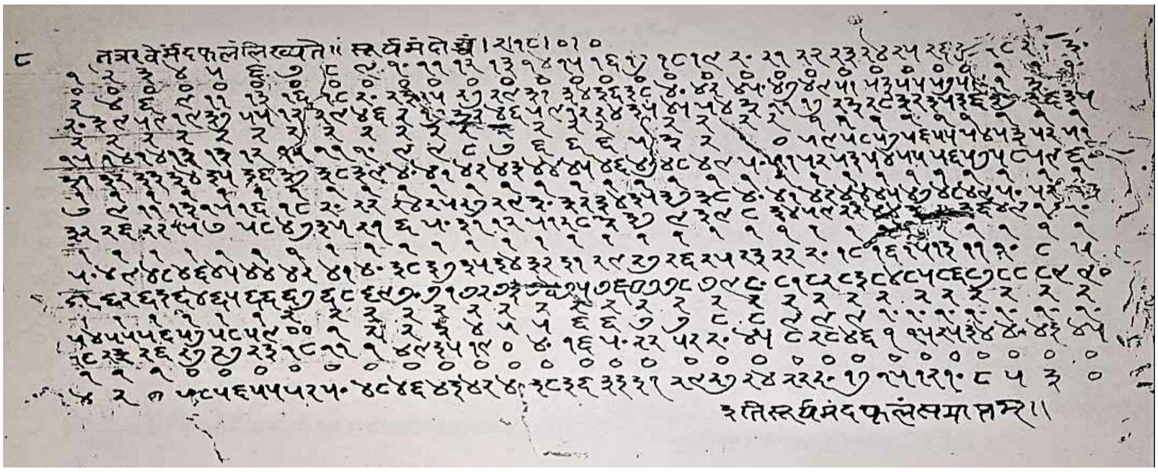

Fig 2- *Mandaphala* tables of the Sun

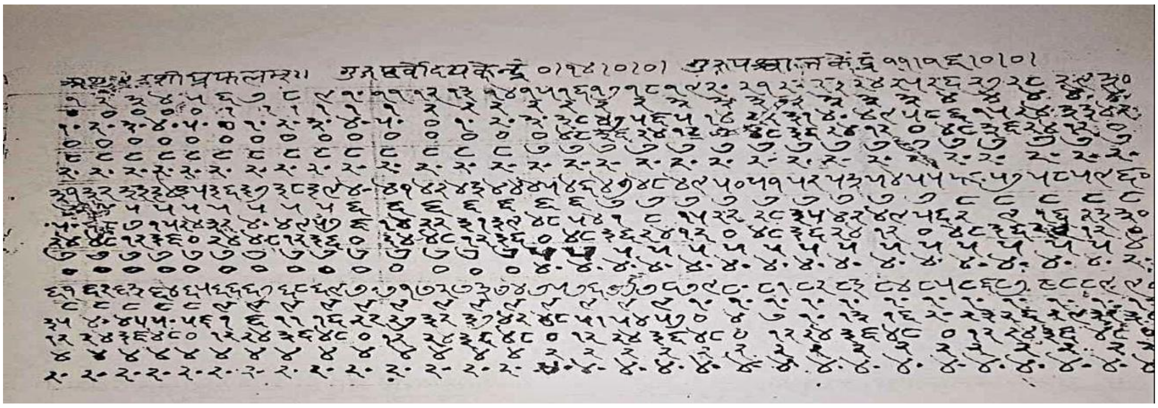

Fig 4.3- *śīghraphala* tables of *Jupiter*

II. Mathematical equations for mean daily motion of heavenly bodies.

The mean daily motion of the heavenly bodies are obtained by using the following equations

$$Sun = \left[1 - \frac{1}{70} - \frac{1}{150 \times 60}\right]^{\circ} = 0°59'8''10'''$$

$$Moon = \left[14 - \frac{14}{17} - \frac{1}{140 \times 60}\right]^{\circ} = 13°10'\,34''\,52'''$$

$$Moon'sapogee = \left[\frac{1}{9} + \frac{1}{70 \times 60}\right]^{\circ} = 0°6'40''52'''$$

$$Moon's node = \left[\frac{1}{19}+\frac{1}{45\times 60}\right]^{\circ} = 0°3'10''52'''$$

$$Mars = \left[\frac{10}{19}-\frac{10}{73\times 60}\right]^{\circ} = 0°31'26''31'''$$

$$Mercury's anomaly or Budha \text{śīghrakendra} = \left[3+\frac{3}{28}-\frac{10}{38\times 60}\right]^{\circ} = 3°6'24''8'''$$

$$Jupiter = \left[\frac{1}{12}-\frac{1}{70\times 60}\right]^{\circ} = 0°4'59''8'''$$

$$Venus anomaly or sukras \text{īghrakendra} = \left[\frac{3}{5}+\frac{3}{181}\right]^{\circ} = 0°36'59''40'''$$

$$Saturn = \left[\frac{1}{30}+\frac{1}{156\times 60}\right]^{\circ} = 0°2'0''22'''$$

The above equations gives mean daily motion of heavenly bodies and it is the formula adopted in *Grahalāghavasāriṇi*to compute daily motions of the heavenly bodies and listed for unit days and for the multiples of 10,100,1000 days.

III. Mean and true longitude of the heavenly bodies.

The mean position of the body can be obtained by multiplying the mean daily motion of the concerned body with*Ahargaṇa*'A' and then the product of *cakra* 'C' and *druvakas*'D' is subtracted from it and thenthe *kśepaka*'K' is added to it.

$$meanlongitude = [(meandailymotion \times A) - (C \times D) + k]$$

The true position of the sun and moon requires only one major correction that is equation of centre(*mandaphala*) where as the five star planets requires one more correction called *śīghra*correction (equation of conjunction). The traditional formula to find the *mandaphala* is $MP = \frac{a}{R}\sin m$

Where 'a' is *mandaparidhi*(radius of the manda epicycle)

'R' is the circum radius of the orbit

'm' is the *mandakendra* (or) *mandaanomaly*.

GaneśaDaivagñahas dispensed the involving traditional formula and provided a new formula without involving*mandaparidhi*(radius of epicycle) and He gives different formulae for different planets to compute *mandaphala*. Based on Baskara I's, sine approximation formula.

Rsin(θ) or Jya(θ)= $\frac{(180°-\theta)\theta\times 480°}{40500-(180°-\theta)\theta}$

Where R=120(periphery of the orbit considered by Baskara I)

By using *Jya* approximation *mandaphala*of the sun=$\frac{\left(20-\frac{BMK}{9}\right)\frac{BMK}{9}}{57-\left\{\frac{\left(20-\frac{BMK}{9}\right)\frac{BMK}{9}}{9}\right\}}$

Mandaphala of the moon=$\frac{\left(30-\frac{BMK}{6}\right)\frac{BMK}{6}}{56-\left\{\frac{\left(30-\frac{BMK}{6}\right)\frac{BMK}{6}}{20}\right\}}$

*Mandaphala*of the sun and the moon are calculated by using above formulae with the *bhuja of mandakendra*(BMK) (the allied angle corresponding to *manda anomaly*).

The true longitude of the sun and the moon is taken as sum of mean longitude and *mandaphala*.

The maximum *mandaphala*attained by the sun is 2° 10'and the maximum *mandaphala*of the moon is 5°.

In *Surya siddāntha*, the true position of the star planets requires two*śīghra* and two*manda*corrections. But in *Grahalāghava* it is revised by only three corrections (there by reducing the tedious work of computing one more correction as followed in earlier texts) that is

1. Half *śīghra* correction (applied to mean body)
2. *Manda* correction (this also applied to mean body but the correction is done to half *śīghra* corrected planet)
3. Full *śīghra*correction (applied to *manda*corrected planet by taking SK_2= SK_1- *mandaphala*. Where SK_1=*śīghrocca*- mean planet, similarly MK= *mandocca*- half *śīghra* corrected planet).

The *Mandocca's*of the planets are fixed according to *Grahalāghavam* except for the Moon.

Table.3: The *Mandocca'*sof the planets

Planet	***Mandocca***
Sun	78°
Mars	120°
Mercury	210°
Jupiter	180°
Venus	90°
Saturn	240°

For exterior planets the mean sun itself is considered as *śīghrocca* where as for the interior planets mean sun acts as the mean body. Hence *Budhaśīghrakendra*and *Śukraśīghrakendra* are computed by using the formulae evolved in earlier section.

For the computation of true position of the star planets we require two more tables containing the values called *śīghrāṅka* and *mandānka*. The *śīghrāṅkas* are given at the intervals of 15° from 0° to 180° of the *śīghrakendra.*

Table.4:*Śīghrāṅkas*of planet

Planets	0	1	2	3	4	5	6	7	8	9	10	11	12
Mars	0	58	117	174	228	279	325	365	393	400	368	249	0
Mercury	0	41	81	117	150	178	199	212	212	195	155	89	0
Jupiter	0	25	47	68	85	98	106	108	102	89	66	36	0
Venus	0	63	126	186	246	302	354	402	440	461	443	326	0
Saturn	0	15	28	39	48	54	57	57	53	45	33	18	0

The *Mandāka's* are provided at the intervals of 15° from 0° to 90° of the *mandakendra.*

Table 5 : *Mandāṅkas* of planet

planets	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Mars	0	29	57	85	109	124	130
Mercury	0	12	21	28	33	35	36
Jupiter	0	14	27	39	48	55	57
Venus	0	06	11	13	14	15	15
Saturn	0	19	40	60	77	89	93

The m*andakendra* is taken as
MK=MK, if $0° < MK < 90°$
MK=180°-MK, if $90° < MK < 180°$
MK=MK-180°, if $180° < MK < 270°$
MK=360°-MK, if $270° < MK < 360°$
But the śīghrakendra is taken as
SK=SK, if $0° < SK < 180°$
SK=360°-SK,if $180° < SK < 360°$

According to *Grahalāghavasāriṇi* the maximum *mandaphala* of the sun, the moon, and the five planets are attained at 90°. Whereas the maximum *Śīghraphala*attained by the planets differs from each planet.

Table 6:- Maximum *Śīghraphala*.

Heavenly body	*Śīghrakendra*	Maximum *Śīghraphala*
Mars	135°	40° 0' 0"
Mercury	105° to 120°	21° 12' 0"
Jupiter	105°	10° 48' 0"
Venus	135°	46° 6' 0"
Saturn	90° to 104°	5° 42' 0"

Table 7:-Maximum *Mandaphala*

Heavenly bodies	Maximum *mandaphala*
Sun	2° 10' 45"
Moon	5° 1' 40"
Mars	13° 36' 0"
Mercury	5° 42' 0"
Jupiter	1° 30' 0"
Saturn	9° 18' 0"

IV. Comparison of true position of heavenly body

An example is worked out by taking a date as 28-02-2025, the mean and true longitudes of the sun, the moon and the 5 planets were found out by using the formulae provided in earlier sections and the same is compared with modern ephemerical values.

Heavenly bodies	True position according to *Grahalāghava*	True position according to *Grahalāghava sāriṇi*	True position according to Modern ephemeris
Sun	340° 05′	340° 05′	340° 05′
Moon	345° 31′	345° 31′	345° 31′
Mars	107° 09′	107° 09′	107° 09′
Mercury	355° 21′	355° 21′	355° 21′
Jupiter	72° 12′	72° 12′	72° 12′
Venus	10° 48′	10° 48′	10° 48′
Saturn	350° 42′	350° 42′	350° 42′

V. Conclusion:

- From the previous calculations, it is clear that the values obtained from *Grahalāghava sāriṇi*is similar to its main text. That means that the author of *sāriṇi*has followed the same parameters that is adopted by the author of main text.
- But when compared with modern ephemeris the value of the *sāriṇi* differs. Hence to obtain the present ephemeral values we have to change the peripheries of epicycle and also the *druvakas.*
- According to all traditional astronomical authors the parameters has to be revised by time to time to obtain the correct values.

If incorporate the revision in parameters then the tables are worth for calculating the almanac for present day as per the modern ephemeris.

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