Indian Journal of History of Science, 38.1 (2003) 43-57

ECLIPSE OBSERVATIONS OF PARAMEŚVARA, THE 14-15 CENTURY ASTRONOMER OF KERALA

K. CHANDRA HARI*

(Received 9 April, 2002)

The present paper is an attempt to bring to light a glorious chapter of astronomical observations in India, of which records have survived. Parameśvara had his advent at the middle of the 14th century and enriched the Kerala astronomical tradition through precise observations and astronomical experimentation. Parameśvara's eclipse observations extending over a period of five decades have been examined here in the light of modern astronomical algorithms. Sun and Moon, mean as well as true longitudes, of both Parameśvara and his disciple Nīlakaṇṭha precisely agree with those determined using the most modern algorithms.

Also the paper gives the correct interpretation of the verse IV.9 of *Goladīpikā* that specifies the location of Parameśvara's village Ālattūr. Parameśvara's village near Palghat cannot be on the west of the meridian of Ujjain as is usually interpreted. Ālattūr is fact is 18 yojanas east of the meridian of Ujjain.

Key words : Eclipse observations, Parameśvara, Nīlakaṇṭha.

INTRODUCTION

Parameśvara, the great Kerala astronomer as well as astrologer, was the resident of Ālattūr (10°51'N, 76°08'E) situated on the banks of the river Nilā or Bhāratappuzha. He was a prolific writer on astronomy as well as astrology and is best known for his work *Dṛggaṇita*, which was formulated after taking into account the astronomical observations for a period of 55 years. A detailed account of his original works and commentaries are available in the *Dṛggaṇita*[1] critically edited by K.V. Sarma. His date can be gleaned from the dates of the two texts—*Dṛggaṇita* bearing Śaka 1353 (1431

*B-204, Parth Avenue, Ahmedabad-5, Gujarat

AD) and *Goladīpikā* II inscribed with Śaka 1365 (1443 AD). Further we have got the evidence of different *Kalikhaṇḍas* employed in Parameśvara's works and the list he has given of the eclipse observations to ascertain his period to be between 1360 and 1455. Parameśvara has produced three works exclusively dealing with eclipses, viz., *Grahaṇamaṇḍana, Grahaṇāṣṭaka* and *Grahaṇanyāyadīpikā* and has made a mention of the important eclipses that have taken place during 1398 to 1431 AD in a long discussion at the end of the chapter on Eclipses in his commentary *Siddhāntadīpikā* on the *Mahābhāskarīya-bhāṣya* of Govindasvāmin.

Significance of three Eclipse Records

These eclipse observations formed the basis of the refinement of the age-old Parahita system by Parameśvara[1] in 1431 AD to formulate the *Dṛggaṇita*. Parameśvara's disciple Nīlakaṇṭha also used these observations in the formulation of his work *Tantrasaṅgraha*. This record as such throws light on to certain salient features of the medieval phase of Kerala astronomy. The following statements of Parameśvara are noteworthy in this context.[2]

1. "Parahita planetary positions have been found to deviate from the observed ones. The Śāstra declares the observed positions to be the true ones. Times for auspicious rites can be fixed only by means of the true positions and the inaccurate positions are inappropriate. Hence the twice-born who are adepts in astronomy must strive for obtaining positions agreeing with observation" (*Dṛggaṇita*, 1.2-4).
2. "The planets have been observed by me for fifty-five years and they differ from the positions derived through *Parahita-gaṇitam*" (Quoted by Nīlakaṇṭha Somayāji in his *Āryabhaṭīya-bhāṣya*).
3. "Since Śaka 1315 (AD 1393) I have observed a number of eclipses; all these occurred at times prior to the computed ones. This necessitated a correction in the computational processes" (*Siddhāntadīpikā*)[3].
4. "Many more solar eclipses other than those enumerated above have been observed by me and on the basis of such detailed observations I have found the correct positions of the Sun, Moon, Higher apsis and Node[4]..."

5. Nīlakaṇṭha Somayāji has spoken about Parameśvara as follows : "Parameśvara had his studentship well in mathematics and astronomy under able hands such as Rudra, Nārāyaṇa and Mā dhava. He could understand the factors that caused difference between the computed and observed planetary positions. After deliberating over the principles of earlier teachers and verifying them through observations of eclipses and planetary conjunctions, he composed his accurate work *Dṛggaṇita*".

6. Further, Nīlakaṇṭha has spoken of the use of eclipses vis-a-vis the refinement of computational methods in the following words :

"The eclipses cited in *Siddhāntadīpikā* can be computed and the details verified. Similarly, other eclipses traditionally known as well as those currently observable are to be studied. In the light of such experience future ones can be computed and predicted. Or, eclipses occurring at other places can be studied taking into account the longitude and latitude of the places and on this basis the method for true Sun, Moon, Apsis and Node can be perfected. Based on these, past and future eclipses of one's own place can be studied and verified with appropriate refinement of the technique".

It is apparent from the above that the eclipses recorded by Parameśvara have played an important role in the progress achieved by the Kerala School of astronomy.

Parameśvara's Works on Eclipses

As we have noted in the introduction, Parameśvara has produced three works on eclipses:

(1) *Grahaṇāṣṭaka* consisting of only 10 verses

(2) *Grahaṇamaṇḍana* of 100 verses and

(3) *Grahaṇanyāyadīpikā* of 85 verses.

The present author could make use of only the latter two works as references in the preparation of this paper. The *Grahaṇamaṇḍana* ('Ornament of Eclipses) is a *karaṇa* text that deals with computational aspects while *Grahaṇanyāyadīpikā* -a subsequent work—presents the underlying theory of eclipses. Both these works do not contain any information on the eclipses observed by him. The account on eclipses is available in his commentary *Siddhāntadīpikā* on the *Mahābhāskarīya-bhāṣya* of Govindasvāmin at the end of the chapter on Eclipses. Verses on the eclipses and their translations can be found on pp. 13-15 of *Indian Astronomy-A Source Book,* ed. by B.V. Subbarayappa and K.V. Sarma. The following note can be found on page 14: "The set of verses extracted and translated here form a disquisition by the author Parameśvara at the close of his commentary on *Mahābhāskarīya-bhāṣya,* ch. V, verse 77, dealing with the eclipses (See the edition of the work, Madras, 1957, pp. 321-32). Parameśvara's efforts were directed towards the refinement of the traditional constants employed in the computation of eclipses and has claimed no innovations of his own in the treatment of eclipses. But his scientific outlook is well evident from the criticism he has aired of Varāhamihira in his *Grahaṇamaṇḍana* in the following verses:

ūnātiriktakāle phalam uktaṃ pūrvaśāstradṛṣṭatvāt /
itigaditaṃ grahaṇaphale Varāhamihireṇa saṃhitāyāṃ ca //97//

śāstrādalabdha ekaḥ saṃskāro grahaṇakarmaṇi ravīndvoḥ /
astyeveti ca kalpyaḥ gaṇakavarair yuktividbhirataḥ //98//

dṛṣṭvā bahūparāgān sañcintya ca golayuktim iha gaṇakaiaḥ /
kalpyaḥ sa tu saṃskāras tasmād athavā gurūpadeśena //99//

K.V. Sarma has rendered these verses into English as follows :

(97) "Predictions of the effects (of eclipses) occurring (a little) earlier or later than the times due are given (by me) on the authority of ancient texts on the subject"—so says Varāhamihira in his (*Bṛhat-) Saṃhitā* in the section entitled 'Prediction of effects of eclipses'.

(98) "This being the case, it is to be postulated by learned astronomers well versed in (astronomical) theory that in the computation of eclipses of the Sun and Moon a correction not stated in old texts must exist.

(99) "Such a correction has to be postulated by astronomers after observing a large number of eclipses and with due consideration to the

principles of spherics, or in the light of instructions of masters (who would have arrived at such a correction in a similar manner)"[5]

Dates of Observations Available in Grahaṇamaṇḍana

The *Grahaṇamaṇḍana* makes use of the *Kalikhaṇḍa* of 1648157 days, which K.V. Sarma has indicated, as corresponding to the Kali year 4512, Kaṭaka 17, i.e., 15th July 1410 AD. Modern computation suggests that the epoch actually is 17 July 1411 AD. We can have some idea of the accuracy of computations in this manual by comparing the mean longitudes accurately determined by the Ācārya himself for the sun, moon, moon's apogee and node: *Kalidina* = 1648157 days: 17 July 1411 AD, Friday, Ujjain sunrise 05:25:36, JD (TDT) = 2236622.5201.

Ayanāṃśa of Parameśvara

It can be understood from Nīlakaṇṭha's remarks in *Jyotirmīmāṃsā* that Parameśvarācārya had precisely fixed the *ayanāṃśa*[6] to be 15° in Kali year 4536 or AD 1435. If we adopt this, the *ayanāṃśa* for AD 1411 turns out to be 14°36'.

Planets	Parameśvara's Sidereal λ	Col. 2+14°49'	Col.2+14°36'	Modern mean λ	Modern True λ	True λ of Parameśvara's
Sun	108°15'07"	123°04'07"	122°51'07"	122°42'07"	121°44'45"	121°44'40"
Moon	60°17'1"	75°06'01"	74°53'01"	74°27'43"	75°43'	75°49'45"
Apogee	65°23'18"	80°12'18"	79°59'18"	79°52'36"	75°45'22"	—
Node	331°41'04"	346°30'04"	346°17'04"	346°04'12"	—	—

By comparison of columns 3 and 4 with column 5 it appears that the mean Sun of Parameśvara and modern λ differed by 9 minutes of arc when contrasted using his own *ayanāṃśa*. But the true Sun of Parameśvara is precisely equal to the modern true Sun, a fact that reflects the ingenuity of Parameśvara. Column (3) suggests that the traditional value of *ayanāṃśa* was in surplus by nearly 13 minutes (after accounting for the difference in equation of center) and Parameśvara rightly and precisely fixed the siddhantic *ayanāṃśa* to be 15° in AD 1435. It is possible that at the time of writing *Grahaṇamaṇḍana* in 1411 AD, Parameśvara probably had only the traditional value of 14°49' at hand and under such circumstances the sāyana longitudes of Parameśvara would have been in error by a quarter-degree. As regards the accuracy of the results of this treatise on eclipses, Parameśvara himself has made the following observation in the concluding part :

iti pūrvaśāstrayuktyā siddhamidaṃ grahaṇakarma nirdiṣṭam,
kālo'nena ca siddhaḥ kadācid iha bhidyate svalpam /

"Thus has been enunciated the computation of eclipses according to principles derived from the ancient texts. The times (of contact etc.) as obtained from this (calculation) may, at times, differ slightly (from observation)".

The fact that Parameśvara could fix the *ayanāṃśa* to be 15° in AD 1435 –a value that made the true Sun to be as precise as the observation and modern true λ, by correcting the *ayanāṃśa* by (–) 13 minutes—is ample testimony for the diligent observations and use of the same for correcting the computational process.

Solar Eclipses Observed from the Sandy Beach of River Nila

Parameśvara has recorded altogether eight solar and five lunar eclipses that had occurred during his times. The solar eclipses have been examined below with planetarium software based on the VSOP87 theory.

Location of Parameśvara's Village

As regards the actual location of Parameśvara's village, precise information is available in Parameśvara's work *Goladīpikā*:

samarekhāyāḥ paścād aṣṭādaśa yojanāntare grāme
svarakṛtaṣaṭ-tuliteskṣe vasatā...[*Goladīpikā* IV. 91]

Scholars[7] have interpreted this verse to mean a place 18 yojanas west of Ujjain of longitude 75°43'E at the latitude of 10°51 N, *i.e.*, nearly one degree west of Ujjain (74°43'E), which is impossible for his Ālattūr, near Palghat. Actual, Parameśvara's village (Ālattūr) was situated 18 yojanas ahead of the Ujjain meridian and it had a sine latitude of 647, which corresponds to north latitude 10°51′. So 18 *yojanas* ahead of Ujjain means one degree east of Ujjain or 76°43'E as per the diameter of earth specified by Parameśvara in *Grahaṇanyāyadīpikā* .

Modern Astronomical Data of Solar Eclipses Recorded by Parameśvara

Location : 10°51'N, 76°43'E (Āllattur) UT+05:00								
							End	
Date	Eclipse	Visibility	Beginning	Maximum	Magnitude	Moon/Sun	Time	Sun's altitude
9 Nov. 1398	Annular	Partial	08:18	09:56	0.906	0.938	11:57	60°
19 Oct. 1408	Hybrid	Partial	15:27	16:36	0.551	1.001	17:37	0°.9
1 Feb. 1413	Total	Partial	07:39	08:47	0.675	1.045	10:04	47°.4
23 Jan. 1422	Total	Partial	07:11	07:43	0.141	1.035	08:18	23°.5
8 Aug. 1431	Annular	Partial	06:41	07:56	0.674	0.946	09:26	49°.7
2 Feb. 1432	Partial	Partial	07:59	08:25	0.070	1.014	08:53	32°.3
10 Nov. 1425	—	No Eclipse						
19 Aug. 1430	—	No. Eclipse						
		Location: 14°32'N, 74°20'E (Gokarnam) UT+04:57						
10 Nov. 1425	Partial	Partial	15:24	15:59	0.087	0.946	16:32	11°.9
19 Aug. 1430	Partial	Partial	06:45	07:18	0.077	0.935	07:53	29°.5

Observational Data of Parameśvara [10°51'N, 76°43'E]

No.	*Kalidina*	Date	Beginning Gnomon shadow	Beginning Time	End	Duration (Parameśvara)	Modern Data Beginning	Modern Data End
1.	1643524	9 Nov. 1398	11	08:13	11:49	3^h36^m (9 nāḍikās)	08:18	11:57
2.	1647156	19 Oct. 1408	—	—	17:31	—	15:27	17:37
3.	1648722	1 Feb. 1413	24	07:45	—	—	07:39	10:04
4.	1652000	23 Jan. 1422	35	07:15	—	—	07:11	08:18
5.	16555484	8 Aug. 1431	—	—	—	—	06:41	09:26
6.	1655662	2 Feb. 1432	15	08:05	—	—	07:59	08:53
7.	1653387	10 Nov. 1425	No. eclipse	—	—	—	No eclipse	—
8.	1655130	19 Aug. 1430	No eclipse	—	—	—	No eclipse	—

Discussion on Eclipses

Solar eclipse of Kalidina 1643524

This *ahargaṇa* corresponds to the sunrise prior to the eclipse and the data is Nov. 09, 1398: Gnomon shadow at the beginning is 11. Beginning of the eclipse therefore will be at 5.666 *naḍikas* (2^h16^m) after sunrise, i.e., at $05{:}57+2^h16^m = 08{:}13$. Duration is 9 *naḍikas* or 3^h36^m, which puts the end of the eclipse at 11:49. With modern algorithms the eclipse had its beginning at 08:18 LMT and ended at 11:57 LMT—hence the duration will be 3 hours 39 minutes as against 3^h36^m or 9 *naḍikas* mentioned by Parameśvara. Upper transit of the Sun as per modern algorithms happened at 11:46 and this agrees well with Parameśvara's observation that the end of the eclipse took place after noon.

Nīlakaṇṭha's Observations on this Eclipse

Nīlakaṇṭha has referred to this eclipse in *Jyotirmīmāṃśa* and has given the mean and true sun along with mean moon and its apogee. Translation of Nīlakaṇṭha's detailed account is available on pages 15-16 of the *Indian Astronomy–A Source Book*[8] and the following information can be extracted out of it: Introductory part of Nilakaṇṭha's disquisition is quoted below followed by data relevant to our present discussion:

"The *Bhaṭa*-correction enunciated through the verse commencing with the expression *vāghbhavona* is referred to here as *śakābda-saṃskāra*. Since the system of Parameśvara (AD 1360-1455) is posterior to that of *Siddhāntaśekhara* (of Śrīpati, AD c. 1000), the mean positions of planets computed according to the former would accord (better) with observation. Hence, for (the eclipses) enumerated (by Parameśvara) in his *Siddhāntadīpikā* and of those observed and enumerated by me in various contexts, compute: (i) the mean Sun etc., as directed by Parameśvara (ii) their true positions as directed by Śrīpati, and (iii) by the special process explained by me in my (*Bhāṣya*) on the *Kālakriyā* and *Golapādas* of the *Āryabhaṭīya*. Taken as the first case the following instance : on "Kali day 16,43,524..."

Manuscript error has led to a wrong record of the mean Sun in Kaṭapayādi notation as-"*madhyaṃ sūkṣmaṃ hyarkaḥ*" which on decoding gives 0^r 11° 57' 15". This cannot be true as the reference is to a solar eclipse and Moon's mean longitude is given as *"manye vanasthaḥ"*, which is 7^r4°15'. Obviously, the Sun's mean position is 7^r 11°57'15". On page 35 of the *Jyotirmīmāṃsā*[9] also the manuscript error has made its appearance.

Examination of Nīlakaṇṭha's Values in the light of Modern Astronomy

In continuation of the introductory remarks quoted earlier, Nīlakaṇṭha has explained the accurate determination of the mean Sun, Moon, Rāhu and True Sun and has given the following values for *kalidina* of 1643524. Comparison of these values with the modern requires the *ayanāṃśa* as used by Nīlakaṇṭha, a clue towards which is available in *Jyotirmīmāṃsā* as reported earlier in the context of our discussion on *Grahaṇamaṇḍana*. Nīlakaṇṭha has referred to 15° as the *ayanāṃśa* of AD 1435 as fixed precisely by Ācārya Parameśvara and accordingly the *ayanā ṃśa* of Nīlakaṇṭha for AD 1398 will be 15° – 0°37' = 14°23' instead of the traditional value 14°36'.

Mean sun at sunrise preceding the eclipse = 21°57'15"

Mean sun (sidereal) according to modern astronomy = 236°13'11".4 – 14°23' = 221°50'11".4

Mean moon (Nīlakaṇṭha's) = 214°15'

Mean moon (sidereal) modern λ = 228°30'18" – 14°23' = 214°07'18"

Mean apogee of moon (Nīlakaṇṭha's) = 269°26'

Mean apogee of moon (sidereal) modern λ = 283°43'53" – 14°23' = 269°20'53"

Nīlakaṇṭha's true sun at the beginning of the eclipse = 220°45'12"

The modern value turns out to be: 235°8'45" – *ayanāṃśa* = 220°45'45" at 08:13 hrs.

But we have seen above that the sidereal Moon given by Nīlakaṇṭha was more by (+) 7 minutes of arc. According to modern astronomy the apogee was at 91°40' and as such the equation of center amounted to 01°10' while in the Siddhantic astronomy the equation of center was 01°18' and thus arose the error in mean Sun of Nīlakaṇṭha. But that error got nullified in the Sphuṭīkaraṇa to obtain the true longitude. The exactness that we see here in Nīlakaṇṭha's work perhaps has no parallel in the pre-telescopic era of astronomy. Nīlakaṇṭha has also given the following details about this eclipse: *Kālalagna* or *sāyana ravi* for Local Noon as 236°38' which according to modern astronomy is 236°28' and the Lagna at the beginning of the eclipse as 266°06' against the modern computational result of 265°20' for $\omega = 23.5173$ degrees. *Dṛkṣepalagna* = 176°26' [Vṛtribha]; *Sphuṭagati* of Sun 60'59" [modern value = 60'47".5]; True Moon 219°43'40" while the modern algorithms give 219°30'8.7" (sidereal) [*i.e.*, 233°53'38".7-14°23'] and the *sphuṭagati* of Moon = 749'09" [modern value = 739'26"].

These values given by Nīlakaṇṭha have got only insignificant errors when compared to modern computer derived longitudes based on the latest theories of planetary dynamics. It is apparent from the above that in terms of accuracy of the planetary longitudes the epicyclic theory was not far behind the theory of Kepler, when it was handled by researchers like Parameśvara and Nīlakaṇṭha[10].

Solar eclipse of Kalidina 1647156

Date is October 19, 1408: According to Parameśvara's observation, *sunset occurred at quarter nāḍi (6 minutes) after the end of the eclipse.* The partial eclipse had its beginning at 1527 LMT and end at 1737 LMT. Sunset was at 17:37, *i.e., modern algorithms make sunset and the end of the eclipse coincident.* This discrepancy can be explained as due to lack of observational aids of Parameśvara or to the atmospheric factors that affect visibility.

In respect of the other eclipses Parameśvara gives only the following information :

3. Feb. 1, 1413: gnomon shadow at first contact = 24.

4. Jan. 23, 1422: gnomonic shadow at first contact 40 or 35.

5. Wed. Aug. 8, 1431: gnomonic shadow at last contact = 5.5.

6. Feb. 2, 1432: gnomon shadow at first contact: 15, last contact: 9.5. As mentioned by Parameśvara, the eclipse magnitude was very small.

Parameśvara has also mentioned two solar eclipses, which were observable at Gokarnam (14°32N, 74°20'E), but not at his place.

7. *Kalidina* = 1653387: New moon of 10th Nov. 1425 AD, 14:31:52.12 (LMT) of Gokarnam (JD [TDT] = 2241852.9032688). The discs came in slight contact between 1524 LMT and 1632 LMT.

8. *Kalidina* = 1655130: New moon of 19 Aug. 1430 AD, 09:00:56.24 (LMT) of Gokarnam (JD [TDT] = 2243595.6733523). Discs were in slight contact between 0645 and 0753.

Parameśvara's account of lunar eclipses has the mention of *Kalidina* only and the modern astronomical data of the lunar eclipses mentioned by him are given in the Table.

Lunar Eclipses observed by Parmesvara

No.	*Kalidina*	Date and LMT of Full Moon	Beginning of phase		Max.	End of phase	
			Total	Partial		Total	Partial
1.	1655647	17.01.1432, 21:22	20:50	19:38	21:26	22:02	23:13
2.	1655293	28.01.1431, 19:14	—	17:03	19:27	—	21:51
3.	1652694	17.12.1423, 20:03	—	19:51	20:13	—	20:36
4.	1654614	21.03.1429, 04:00	03:35	02:16	03:56	04:16	05:35
5.	1653403	25.11.1425, 02:29	01:53	00:44	02:25	02:57	04:06

Mean Luni-Solar Positions Given by Parameśvara

Parameśvara's account of eclipses ends with the accurate mean positions of Sun, Moon, Moon's apogee and Node for *Kalidina* = 1651700: Saturday, March 29, 1421AD 05:47 Ujjain sunrise. JD (TDT) = 2240165.53472291.

1	2	3	5	6
Mean λ of	Paramesvara's	Col. 2 + 14°46'	Modern λ	Difference Col. 3-4
Sun	00°15'	15°01'	14°51'	10'
Moon	304°06'	318°52'	318°37'	15'
Apogee	279°57'	294°43'	294°36'	7'
Node	143°55'	158°41'	158°27'	14'

When compared with the modern values the differences average to be only 11.5 minutes of arc. Truly speaking the mean λ's of the Siddhantic tradition cannot be compared with modern mean λs as the equation of center and other corrections based on which the mean longitude is arrived at from the true observed positions are different. As for example, here in the case of Sun the difference is (+) 10 minutes of arc and this error gets nullified when true λs are compared as the siddhantic equation of center is deficient by 11.8 minutes for anomaly of nearly (–) 78°. These accurate positions were probably obtained by applying additional correction to the method outlined *Grahaṇamaṇḍana* as can be noted from the *Dṛggaṇita* II. 47-50.

Additional corrections required for the mean positions of *Grahaṇamaṇḍana,* which was not stated therein, I shall mention now: One second should be subtracted for every two hundred years from the Sun of *Grahaṇamaṇḍana* while for Moon addition of one second is required for every 41 years. For apogee the correction is (+) one second for every 135 years and in the case of Rahu one minute needs to be subtracted for every three years.

If we go by the *Kalikhaṇḍa* of 1648157, *Grahaṇamaṇḍana's* formulation took place in 1411 AD—quite early in the career of Parameśvara. The *Kalikhaṇḍa* given above in the correction mentioned falls after 10 years and hence these corrections may be the fruits of his constant observation of astronomical phenomena like eclipses.

DṚGGAṆITA EPOCH

A discussion on Parameśvara shall remain incomplete without a reference to his magnum opus—*Dṛggaṇita.* According to the information available in the text (śloka 46) the composition took place in Śaka 1353 corresponding to AD 1431. The epoch as such will be the expiry of the Kali year 4532: *Kalidina* = 1655352.34: JD[TDT] = 2243817.54490972; Thursday, March 29, 1431, 05:55 LMT [Ujjain Sunrise].

Comparison of the Mean Elements

Kalidina : 1655352 : 29 March 1431 AD, Thursday. Ujjain Sunrise 05 ; 55.

	Dṛk λ + A	Tropical λ
Sun	14°36'	14°27'
Moon	199°04'	199°12'
Apogee (Moon)	350°08'	217°44'
Rahu	329°47'	325°04'
Mars	211°31'	211°30'
Mercury	118°48'	113°11'
Jupiter	45°05'	46°06'
Venus	08°11'	07°35'
Saturn	292°50'	291°40'

Derivation of the mean longitudes from observed positions calls into play both the observational skills as well as the mathematical genius of an astronomer. Strictly speaking, the modern mean longitudes and the siddhantic *madhyamas* are not entirely the same even if the precession is accounted for. True positions decremented by the equation of center formed the siddhantic *madhyamas* while in modern astronomy the mean positions are arrived at after scores of other corrections which represent the perturbations to the mean orbit. Obviously equality cannot be looked for while comparing the epochal mean co-ordinates. But even then the contrast, siddhantic versus modern of the different epochs, have been employed by earlier scholars to gain a prima facie understanding of the merits of the siddhantic works. True picture can be gained only by comparing the true longitudes as per *Dṛggaṇita* with those of modern algorithms. Those who are adept in the Siddhantic computational processes may attempt a comparison of the *Dṛggaṇita* output with the modern true longitudes provided below:

Planet	True λ	β	δλ per day	δβ per day
Sun	16°21'	-00°00'	00°58'41"	-00'00".08
Moon	195°44'	-03°53'	12°06'45"	-42'19".53
Mercury	35°52'	02°37'	01°06'11"	06'27".13
Venus	12°22'	-01°17'	01°14'13"	01'04".14
Mars	212°09'	01°54'	-00°17'56"	-01'37".83
Jupiter	44°10'	-00°48'	00°13'19"	00'08".16
Saturn	294°39'	-00°01'	00°02'44"	-00'04".82

The *Kalikhaṇḍa* of 4532 years (of 365.2586806 days) constitutes 1655352.34 days. To remove the fraction 0.34 of a day Parameśvara introduced the *kali-dhruva* of 20'22" for mean sun, for the first time in the history of siddhantic astronomy. At no time earlier has there been a correction applied to Sun in terms of *kali-dhruva*. Perhaps, Parameśvara is the first astronomer of the Ārabhaṭan tradition of Kerala, who has postulated zero correction for the planets at the beginning of Kaliyuga. In *Dṛggaṇita* he has given: Sun: 20'22"; Moon: +3°15'2"; Mars: +3'; Mercury:(-) 3°44"; Jupiter:(-) 2°59'; Venus: (-) 4°; Saturn: + 4°8'; and Node: 182°36'.[11] Also for *Sūryasiddhānta*: Sun: + 5'35"; Moon: (-) 2'37"; Apogee: + 4°17'13"; Mars: (-) 5';

Mercury: (-) 4°; Jupiter: (-) 3°45'; Venus: (-) 4°24'; Saturn: + 4°7'; Rahu: +2°35'. Parameśvara could disregard the traditional belief of zero mean longitudes at Yugādi only because of his scientific outlook and the knowledge he had gained about planetary motions through observations of the sky.

Conclusion

In the above is presented a succinct account of the golden period of medieval Indian as well as Kerala astronomical tradition authored by the genius of Parameśvara. His record of astronomical observations, the refinement of astronomical parameters and the accompanying work of his disciple Nīlakaṇṭha Somayaji, following the same footsteps to maximize the accuracy of planetary longitudes etc., are reflective of the past glory of Indian Science. The accuracy that we see in the Sun and Moon of Parameśvara and Nīlakantha can be inferred as the result of eclipse observations as well as experimentation with the computational techniques. Planetary longitudes of Kujādis have relatively more deviation when compared to the results of modern algorithms, obviously due to the constraints of the pre-telescopic age in the matter of observation.

Notes and References

1. *Dṛggaṇ ita,* Critically edited by K.V. Sarma, V.V.R.I., Hoshiarpur, 1963.
2. In the following translations I have given a resumé in English rather than a literal translation.
3. *Siddhāntadīpikā*, commentary on *Mahābhāskarīya-bhāṣya* of Govindasvāmin, p. 321, ed. Madras, 1953.
4. Ibid p. 331, K.V. Sarma has quoted this verse on p.xii of his Introduction to his editions and translation of *Grahaṇamaṇḍana*.
5. Sarma has added the note: "Perhaps the author has at the back of his mind Muñjāla's *Laghumānasa Gaṇita*, on which he himself has commented and which gives the correction to the Moon, known as 'Evection' and envisages the possibility of others".

6. In making a contrast of the sidereal longitudes of Parameśvara with the results of modern lunar theory we need to determine the *ayanāṃśa* of the epochs of which computations are presented. The Siddhāntic tradition takes Kali 3623 or AD 522 as the coincidence of the vernal equinox with the zero point vis-a-vis the epoch of *Āryabhaṭīya*. The extra-long solar year of Siddhāntic astronomy necessitated a rate of precession of nearly one minute per year and this amounts to one degree in sixty years. *Ayanāṃśa* of any year Y can therefore be computed as (Y-522)/60 degrees. Accordingly the *ayanāṃśa* works out to be 14°49'. First of the references to this practice can be found in *Rājamṛgāṅka* (AD 1042) of Bhoja: "*Śakaḥ pañcābdhivedonaḥ ṣaṣṭi bhaktoyanāṃśatāḥ* [(25) Madhyamavicāraḥ]. Here Śaka 445 or AD 523 is taken as the zero year. Bhāskara II had a similar computation of *ayanāṃśa* that gave for Kali 4284 the value 11°.

7. (1) Kripa Shankar Shukla, the *Sūryasiddhānta* with the commentary of Parameśvara, p. 64:

   "The latitude is given to be 10°50' north and longitude 18 *yojanas* west of the meridian of Ujjain". Published by Department of Mathematics and Astronomy, Lucknow University (1957).

   (2) K.V. Sarma, *Grahaṇamaṇḍana,* critically edited with translation, V.V.R.I., Hoshiarpur, p. xii:

   "It was, thus, 18 *yojanas* to the west of the Central (Ujjain) meridian and had a Sine latitude of 647, corresponding to 10°51', north latitude".

8. B.V. Subbarayappa and K.V. Sarma, *Indian Astronomy–A Source Book,* Nehru Centre, Bombay.

9. *Jyotirmīmāṃsā*, ed. By K.V. Sarma, Pub: V.V.R.I., Panjab University, Hoshiarpur.

10. Nīlakaṇṭha has mentioned two other eclipses. (1) *Kalidina* = 1681472: Annular eclipse at Trivandrum (Syānandūrapura) [08°29'N, 76°59'E]. New Moon: Saturday, 1st October, 1502, 13:33:58.44 LMT. Eclipse had its beginning at 1250 PM, Middle:02:34 PM and end at 04:10 PM. JD (TDT) = 2269936.8539206. (2) *Kalidina* = 1686847: Annular eclipse at Harihara of Karnataka state–exact location of this place could not be made out. At Bangalore [77°34'E, 12°58'N] the eclipse was total at 10:00 LMT. New Moon: Friday, June, 19, 1517. JD(TDT) = 2275311.736119.

11. *Indian Astronomy–A Source Book:* ed. B.V. Subbarayappa and K.V. Sarma, p. 153; Nehru Centre, Bombay.