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A STUDY OF THE OCCULTATIONS OF *ROHIṆĪ* (ALDEBARAN) IN CLASSICAL INDIAN ASTRONOMY

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Abstract: In Indian classical astronomy, the *Siddhāntic* texts discuss in detail conjunctions of the Sun, the Moon, the planets and important stars like *Rohiṇī* (Aldebaran), *Tiṣya* or *Puṣya* (δ Cancri), *Citrā* (Spica), *Jyeṣṭhā* (Antares), *Makhā* (Regulus) etc. The star *Rohiṇī* is given prominence, and in this paper we discuss the circumstances required for an occultation of *Rohiṇī* to occur, historical examples of such occultations and the periodicity of *Rohiṇī* occultations.

Keywords: occultation, *Rohiṇī,* Aldebaran, periodicity,

1 INTRODUCTION

Rohiṇī (Aldebaran, or α Tauri) is the brightest star that the Moon can occult. *Rohiṇī* is located entirely within the constellation of Taurus. The name *Rohiṇī* translates as the 'Reddish One', and this star is important in Indian astronomy. The aspect of *Rohiṇī* coming very close to the Moon made an impact on the ancient Indians. So, when they came up with a list of the 27 *Nakshatras* (lunar mansions), these were thought of as the daughters of Daksha Brahma, and wives of the Moon. And of these 27 wives, *Rohiṇī* is said to have been the Moon's favorite among them. This is because the Moon occults *Rohiṇī* quite regularly. In this paper we discuss the lunar occultation of *Rohiṇī*.

In his *magnum opus Abhijña Śākuntalam*, the celebrated Sanskrit poet Kalidasa, famous for similes (*Upamā*), gives a very interesting and beautiful allusion to a conjunction in the following stanza:

> It is by a piece of good luck, my lovely darling that you stand before me whose gloom of delusion has been broken by a return of memory. This has been, as it were, the star *Rohiṇī* has got conjoined with the moon at the end of a lunar eclipse.

In this paper we discuss some interesting features of *Rohiṇī* occultations.

2 MATERIALS AND METHODS

2.1 Occultations

Lunar occultation's are of two types: direct occultations and grazing occultations. In a direct lunar occultation the Moon completely occults the star for many minutes. Grazing occultations are more interesting as they offer the opportunity to:

- Help determine the heights of lunar features and the depths of lunar valleys; and
- Determine if the star is a single star or has a close companion or companions; and
- Improve information on the orbit of the Moon; and
- Improve positional information on the star.

In Indian Astronomy, the *Siddhāntic* texts discuss in detail the phenomenon of conjunctions of the Sun, the Moon and the Planets, and prominent naked eye stars like *Rohiṇī*. If one of the two bodies in conjunction is the Moon and the other is a star then there may be an occultation of that star. In the course of its sidereal revolution of 27.32 days the Moon frequently passes near stars, and when their ecliptical longitudes are equal a lunar occultation of that star will occur. Occultations are not rare events, but occultations of bright stars are somewhat rare, as visible from a given place. For instance, an occultation stated to be visible in a continent is not necessarily visible from

Table 1: The eight Occultation Series of *Rohiṇī* between 1978 and 2111.

Star Details	Series No.	First Occultation	Last Occultation	Number of Occultations
Rohiṇī (Aldebaran) α Tauri HD29139 m_v: ~0.85 Latitude: – 5° 27′ 57″	1	19 January 1978	8 April 1981	44
	2	8 August 1996	14 February 2000	48
	3	29 January 2015	3 September 2018	49
	4	18 August 2033	23 February 2037	48
	5	7 March 2052	13 September 2055	47
	6	25 September 2070	2 April 2074	48
	7	5 July 2089	19 October 2092	45
	8	24 January 2108	27 August 2111	48

from everywhere on that continent. Successive occultations of a star by the Moon occur in series, separated by periods during which the Moon does not occult the star.

2.2 The Conditions for the Lunar Occultation of a Star to Occur

The circumstances leading to an occultation can be calculated in the same manner as those for a solar eclipse. The lunar orbit has a mean inclination of 5° 08′, which can go up to 6° 21′. All stars whose ecliptical latitudes lie within these limits experience lunar occultations. Thus, Aldebaran (*Rohiṇī*), with a latitude of 5° 28′, has occultations. The larger the latitude of the star the longer is the length of each series of occultations.

In a lunar occultation the participating bodies are the Moon and the star. At the instant of conjunction (in longitude λ) of the Moon with the star, the angular semi-diameter *s*, the horizontal parallax Π and the latitude (*śara*) β_1 of the Moon are determined. The semi-diameter and the horizontal parallax of the star can be ignored since these are too small compared to those of the Moon. Let β_2 be the latitude of the star. The condition for an occultation to occur is when the absolute difference in latitudes is less than the sum of the Moon's semi-diameter and parallax, i.e., $|\beta_1 – \beta_2| < \Pi + s$. The minimum values of Π and *s* are respectively about 3223.5″ and 878.5″ and the maximum values are 3672.3″ and 1000.7″. Accordingly, the minimum and the maximum values of ($\Pi + s$) are respectively 4102.0″ and 4673.0″ i.e., 1° 8′ 22″ and 1° 17′ 53″. Thus, the lunar occultation of a star of latitude β_2 is certain if $|\beta_1 – \beta_2|$ < 1 °8′ 22″, while an occultation is not possible when $|\beta_1 – \beta_2|$ > 1° 17′ 53″, and the phenomenon is doubtful if 1° 8′ 22″ < $|\beta_1 – \beta_2|$ < 1° 17′ 53″.

In this paper, we consider the case of the occultations of *Rohiṇī*, whose mean visual magnitude is 0.85. The ecliptical co-ordinates of the star are respectively, tropical longitude (λ) = 69° 47′ 20″ and latitude (β_2) = 5° 28′ 12″.

2.3 Periodicity of Occultation Cycles of Stars

It is estimated that a star whose latitude is less than 3° 56′ has two series of lunar occultations during the sidereal period of the Moon's node. A star whose latitude lies between 3° 56′ and 6° 21′ has only one series of lunar occultations. Stars whose latitudes are greater than about 6° 21′ are never occulted by the Moon.

Aldebaran (*Rohiṇī*) will have only one series of occultations during the sidereal period of the Moon's node, which is equal to 18.6 years. The series length of these occultations is 3.529 years. For example: every month from 29 January 2015 to 3 September 2018 an occultation of Aldebaran occurred, and the next series will be from 18 August 2033 to 23 February 2037.

The *Grahalāghava* of Gaṇeśa Daivagña is the most popular astronomical text among the ancient and medieval texts, and it is used in most parts of India. The *Grahalāghava* is considered to be the most comprehensive, exhaustive and easy to use *karaṇa* text in Indian astronomy. A study on the procedure of conjunctions and occultations according to this text is considered here. The first and last occultations of each series from 1970 to 2120 are given in Table 1.

2.4 The Procedure for the Occurrence of an Occultation According to the *Grahalāghava*

In Chapter 13 ('Conjunction of Planets') in the *Grahayutyadhikārah* the method of determining the instant of a conjunction of two planets is discussed by considering their true angular diameters.

Śloka 1 explains the method of determining the (true) diameters of planets whose *yuti* (conjunctions) are to be found:

Step 1: The mean diameters of the planets are given in Table 2. One *kalā* is ~1 arcminute.
Step 2: Find the *śīghrakarṇa* of the planet for which the diameter is required.

Step 3: Subtract the *śīghrakarṇa* from 11. Multiply this result by its mean diameter.
Step 4: Divide the product by 21, 12, 6, 24 and 3 for *Kuja, Budha, Guru, Śukra* and *Śani* respectively.
Step 5: If the *śīghrakarṇa* of the planet is greater than 11, subtract the above quotient from the mean diameter. If the *śīghrakarṇa* is less than 11, then add the above quotient to the mean diameter.
Step 6: The result of Step 5 divided by 3 gives the diameter of the planet in *aṅgulas*

= [Mean diameter ± (11– *śīghrakarṇa*)/n × Mean diameter]/3

where n = 21, 12, 6, 24 and 3 for *Kuja*, *Budha*, *Guru*, *Śukra* and *Śani* respectively.[1] An *aṅgula* is equivalent to about 3 arc minutes.

Śloka 2 explains whether the conjunction is over or has yet to take place:

Step 1: Of the planets for which a conjunction is to be determined, if the longitude of the planet having greater motion is larger than that of the planet having lesser motion, then this implies that the conjunction is over.
Step 2: If the longitude of the planet having retrograde motion is less than that of the planet having direct motion then the conjunction is over.
Step 3: If both planets are in retrograde motion and the longitude of the planet having the greater motion (fast moving) is less than that of the planet having slower motion (slow moving) then we have to understand that the conjunction is over.
Step 4: If the conditions of the two planets are different from the above conditions, then their conjunction is yet to take place.

Śloka 3 tells about the number of days by which the conjunction is over if it is over and the number of days for the conjunction to occur if it is yet to occur.

Step 1: If both planets are either in direct motion or in retrograde motion then divide the difference between their positions by the difference between their daily motions. The result will give the number of days after which the conjunction will occur.

Śloka 4 gives the day and time of the conjunction of the two planets and their longitudes. If the Moon's conjunction with a planet is required then, as in the case of a solar eclipse, the latitude of the Moon is corrected.

2.5 Improved *Siddhantic* Procedures for Occultations

Conjunctions of two heavenly bodies take place when their celestial longitudes are equal. Depending on the bodies involved, their conjunctions are classified as follows in the *Sūrya Siddhānta*. If the conjunction is between two planets it is called *yuddha* (war or encounter), whereas if it is between a planet and the Moon then it is called *samāgama.* In modern parlance we call this a lunar occultation. A lunar occultation also occurs if there is a conjunction between the Moon and a star (such as *Rohiṇī*), and in the *Sūrya Siddhānta* this is called *samāgama*.

Table 2: Mean diameters of the planets in *kalās*.

Planets	Mean Diameter
Kuja (Mars)	5
Budha (Mercury)	6
Guru (Jupiter)	7
Śukra (Venus)	9
Śani (Saturn)	5

2.6 Recordings of Occultations of Aldebaran

Copernicus records in the *De Revolutionibus* … his observation of an occultation of Aldebaran on 9 March 1497 at Bologna, one hour before midnight (Copernicus, 1992). The instant of this lunar conjunction was $26^h\ 15^m$ (IST); the true topical longitude (λ) of the Moon and the star was 62.833°; the Moon's latitude (β_1) was –288′; the star's latitude (β_2) was –310′; the difference in latitude was –22′; the Moon's horizontal parallax (Π) was 56.852′; and the Moon's angular semi-diameter (d) was 15.49′. The following are the circumstances of the occultation obtained using our Improved *Siddhantic* Procedures:

External Ingress = $24^h\ 07.8^m$,
Mid-occultation = $26^h\ 15^m$, and
External Egress = $28^h\ 22.2^m$

Figure 1 from *Stellarium* (on the following page) shows the conjunction of Aldebaran with the Moon for the above-mentioned date.

3 RESULTS AND DISCUSSION

3.1 Historical Recordings of Occultations of *Rohiṇī* [2]

3.1.1 24 October 899

There was an occultation on this day (see Table 3). This series started on Tuesday 20 February 899 at $08^h\ 09^m$ with a difference in latitude of 1° and ended on Saturday 20 August at 02h 10m when the difference in latitude was 1.14°.

Figure 1: The occultation of Aldebaran on 9 March 1497, seen from Bologna (courtesy: *Stellarium*).

Table 3: The occultation the 899.

Date and Day	Object near the Moon	Time in IST h m	Difference in Latitude (°)	Occultation or Not?
24 October 899, Wednesday	*Rohiṇī*	05 48	0.65	Yes

3.1.2 8 March 1063

This conjunction occurred on *śaka* 984, but there was no occultation. See Table 4.

Table 4: The conjunction of 1063.

Date and Day	Object near the Moon	Time in IST h m	Difference in Latitude (°)	Occultation or Not?
8 March 1063, Saturday	*Rohiṇī*	17 57	6.85	No

3.1.3 23 November 1067

There was an occultation on this day (see Table 5). This series started on 26 January 1067 at 14^h 10^m when the difference in latitude was 0.65° and ended on 20 February 1070 at 03^h 30^m when the difference in latitude was 1.24°.

Table 5: The occultation of 1067.

Date and Day	Object near the Moon	Time in IST h m	Difference in Latitude (°)	Occultation or Not?
23 November 1067, Friday	*Rohiṇī*	03 02	0°.49	Yes

3.1.4 8 April 1106

There was an occultation on this day (see Table 6). The start date of this series was Tuesday 25 August 1103 at 15^h 55^m, when the difference in latitude was 1.1°. The series ended on Saturday 2 March 1107 at 21^h 02^m, when the difference in latitude was 1.13°.

Table 6: The occultation of 1106.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
8 April 1106, Sunday	*Rohiṇī*	14 31	0.58	Yes

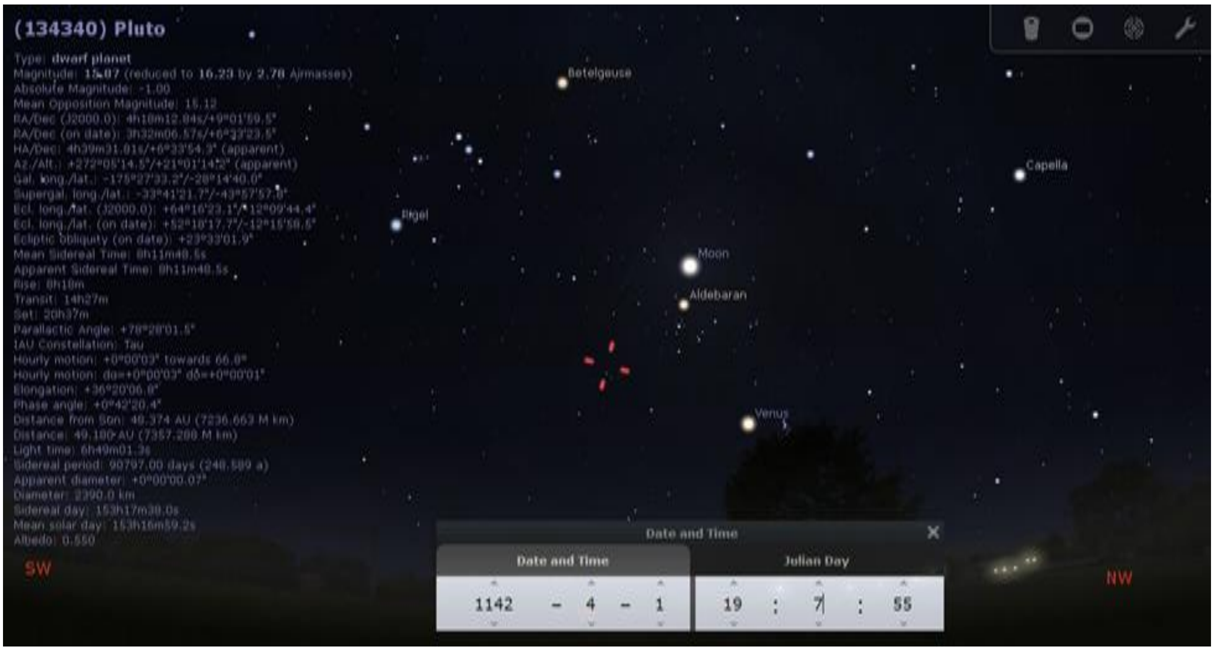

Figure 2: The occultation of *Rohiṇī* on 1 April 1142 (courtesy: *Stellarium*).

3.1.5 23 March 1132

As Table 7 indicates, no occultation occurred on this date.

Table 7: The conjunction of 1132.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
23 March 1132, Wednesday	*Rohiṇī*	00 28	10.37	No

3.1.6 5 June 1134

From our computations we found that although the Moon and *Rohiṇī* were close on Tuesday 21 June at 05^h 14^m, an occultation was not possible on that date.

3.1.7 1 April 1142

An inscription records an occultation of *Rohiṇī* on this date. We worked out the circumstances for this date and as Table 8 indicates we found that an occultation did indeed occur. Our calculations also indicate that Venus was quite near the Moon at the time (see Figure 2 above).

Table 8: The occultation of 1142.

Date	Object near the Moon	Time in IST h m	Longitude ° ′ ″	Difference in latitude (°)	Occultation or Not?
1 April 1142	*Rohiṇī*	12 23	57 31 38	0.27	Yes

This series started on Tuesday 1 October 1140 at 13^h 21^m and ended on Sunday 12 March 1144 at 02^h 25^m. Every month during this period there was an occultation of *Rohiṇī*.

3.1.8 24 June 1158

An inscription records Jupiter, the Moon and *Rohiṇī* close together (as shown in Figure 3 on the following page), however occultations were not possible for this date (Table 9) as the differences in latitude were too large.

Table 9: The conjunction of 1158.

Date	Object near the Moon	Time in IST h m	Difference in Latitude (°)	Occultation or Not?
24 June 1158	*Rohiṇī*	02 07	2.48	No
	Jupiter	22 30	2° 04′ 0″	No

Figure 3: The conjunction of *Rohiṇī*, Venus and the Moon on 24 June 1158 (courtesy: *Stellarium*).

3.1.9 13 April 1233

This inscription records that the Moon, Aldebaran (*Rohiṇī*), Venus and Mercury were in a group. We have considered this example to allow for a freak case of an occultation happening in a period of no occultations. Although no occultations did occur (see Table 10), the longitudes of the Moon, Venus and Mercury were very close.

Table 10: The conjunctions of 1233.

Date	Object near the Moon*	Time in IST h m	Longitude ° ′ ″	Difference in latitude (°)	Occultation or Not?
13 April 1233	Venus	18 25	52 36 03	1.72	No*
	Mercury	18 25	50 38 14		
	Moon	18 25	55 32 54		

* However, we notice that the Moon, Mercury and Venus were much closer around 07^h.

In this particular year (AD 1233), in all of the months except September there were no occultations (Table 11). The actual *Rohiṇī* series started on Wednesday 11 January 1234 at 22^h 06^m and ended on 1237 Tuesday March at 07^h 34^m.

Table 11: Occultations and non-occultations in 1233.

Date	Occultation or Not?	Difference in latitude (°)
28 August 1233	No	1.23
24 September 1233	Yes	1.14
22 October 1233	No	1.18

On the following page, Figure 4 from *Stellarium* shows the longitudinal conjunction of *Rohiṇī* (Aldebaran), Moon, Venus and Mercury.

3.1.10 3 April 1234

As Table 12 indicates, there was an occultation on this day.

Table 12: The occultation 1234.

Date	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
3 April 1234	*Rohiṇī*	21 46	0.76	Yes

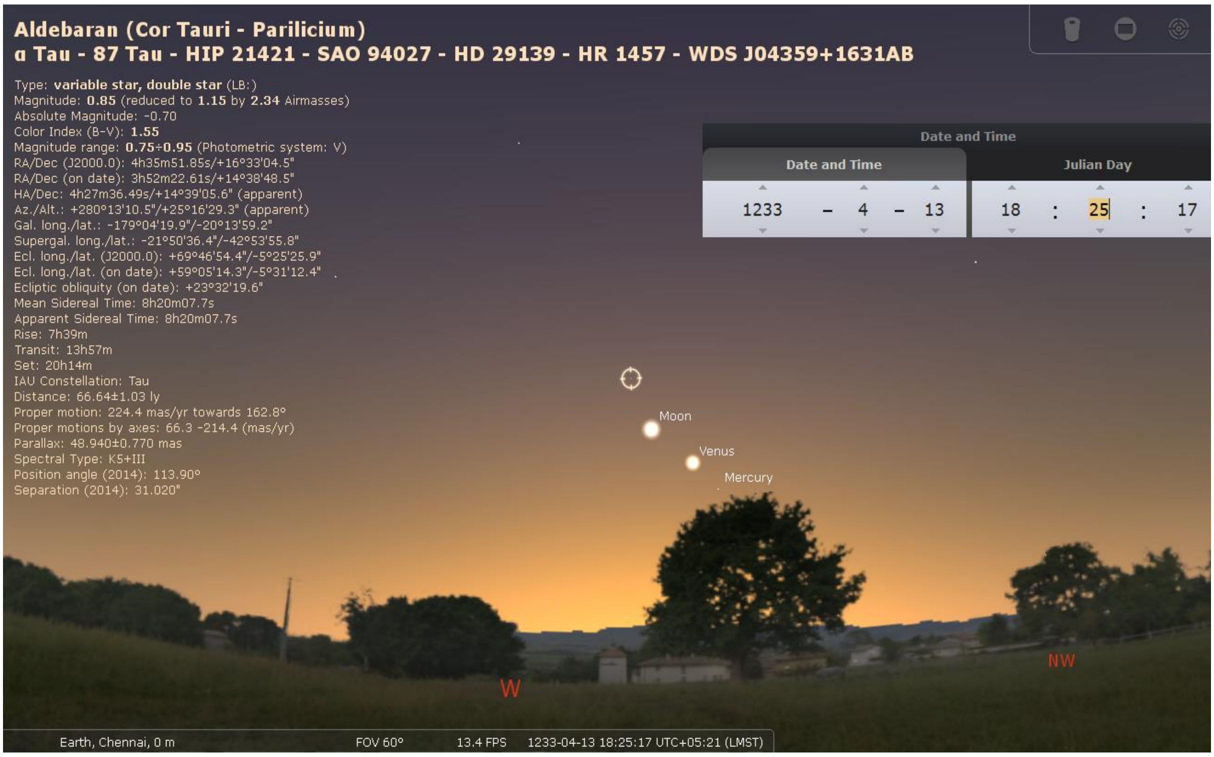

Figure 4: The conjunction of *Rohiṇī*, the Moon, Venus and Mercury on 22 October 1233 (courtesy: *Stellarium*).

Table 12: The occultation 1234.

Date	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
3 April 1234	*Rohiṇī*	21 46	0.76	Yes

3.1.11 9 November 1288

For this date we find there was no occultation; however, on 10 November there was a conjunction of *Rohiṇī* with the Moon at $08^h\ 39^m$.

3.1.12 6 March 1310,

On 6 March 1310 *Rohiṇī* was close to the Moon, but the occultation actually occurred on 7 March (Table 13). This series of *Rohiṇī* occultations started 28 February 1308 Wednesday at $06^h\ 58^m$ and ended 5 September 1311 Sunday $09^h\ 25^m$.

Table 13: The occultation of 7 March 1310.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
7 March 1310, Saturday	*Rohiṇī*	22 10^m	0.34	Yes

3.1.13 12 September 1310

On 12 September 1310 there was no occultation, but from our computation (Table 14) it occurred on Tuesday 15 September.

Table 14: The occultation of 15 September 1310.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
15 September 1310, Tuesday	*Rohiṇī*	01 07	0.38	Yes

3.1.14 8 January 1370

There was no occultation on this date, however there was a conjunction of *Rohiṇī* and the Moon at $11^h\ 50^m$.

3.1.15 2 August 1392

According to our Improved *Siddhantic* Procedures, there was no occultation on this date.

3.1.16 7 July 1404

As Table 15 indicates, there was an occultation on this date. This series started on Sunday 20 February 1401 at 23h 39m, and ended on Tuesday 23 September 1404 at $09^h\ 31^m$. We noticed during this series a freak case when there was no occultation: on Friday 13 May 1401.

Table 15: The occultation of 1404.

Date	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
6 July 1404	*Rohiṇī*	07 25	0.98	Yes

3.1.17 6 August 1455

We found there was no occultation on this date. There was a conjunction of *Rohiṇī* and the Moon at $13^h\ 18^m$ on 22 August 1467 but no occultation occurred. Saturn was retrograde, with a longitude of 14˚ 55′ 29″.

3.1.18 21 November 1515

As indicated in Table 16, there was an occultation on this date. This series began on Thursday 2 September 1512 at $00^h\ 21^m$ and ended on Sunday 9 March 1516 at $16^h\ 05^m$.

Table 16: The occultation of 1515.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
21 November 1515, Wednesday	*Rohiṇī*	07 23	0.87°	Yes

3.1.19 6 August 1531

As indicated in Table 17, there was an occultation on this date. This record also mentions *Krishna Jayanthi*, which is an important annual Hindu festival. This series started on Monday 10 July 1531 at $14^h 50^m$ and ended on Sunday 27 September 1534 ay $03^h\ 38^m$.

Table 17: The occultation of 1531.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
6 August 1531, Sunday	*Rohiṇī*	22 53	0.98°	Yes

3.1.20 27 July 1532

As Table 18 indicates, there was an occultation on this day. This record also mentions *Krishna Jayanthi*.

Table 18: The occultation of 1532.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
27 July 1532, Saturday	*Rohiṇī*	06 25	0.36	Yes

3.1.21 3 November 1533

Table 19 indicates that there was an occultation on this day

Table 19: The occultation of 1533.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
3 November 1533 Monday,	*Rohiṇī*	11 29	0.59	Yes

3.1.22 1 August 1534

According to our calculation there was Occultation on 3 August at $11^h 50^m$ with difference in latitude

0.73°. This record mentions *Krishna Jayanthi*.

3.1.23 20 January 1537

There was a conjunction of *Rohiṇī* with the Moon at $11^h\ 43^m$, but an occultation was not possible because the latitudinal difference was 3.96°.

3.1.24 30 January 1555,

There was no occultation on this date but on 31 January at $00^h\ 18^m$ the Moon and the star were in conjunction.

3.1.25 25 November 1662

As Table 20 indicates, there was an occultation on this day. The series began on Thursday 18 August 1661 at $01^h\ 29^m$ and ended on Monday 25 February 1665 at $06^h\ 17^m$.

Table 20: The occultation of 1662.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
25 November 1662, Saturday	*Rohiṇī*	21 31	0.54	Yes

3.1.26 13 April 1679

There was no occultation for this date, however there was a conjunction at $23^h\ 41^m$.

3.1.27 20 April 1681

Table 21 indicates that there was an occultation on this day. The series began on Wednesday 6 March 1680 at $23^h\ 57^m$ and ended on Sunday 10 October 1683 at $05^h\ 36^m$.

Table 21: The occultation of 1681.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
21 April 1681, Monday	*Rohiṇī*	03 09	0.47	Yes

3.1.28 13 April 1699

According to our calculation an occultation occurred on Saturday 4 April at $10^h\ 44^m$ when the Moon's latitude was 4° 43′ and the latitude difference between the Moon and *Rohiṇī* was 0.75°.

3.1.29 19 November 1717

According to our computation (see Table 22) an occultation occurred on 19 November 1717. This series started on 6 July 1717at $5^h\ 58^m$ and ended on 20 October 1720 at $11^h\ 29^m$.

Table 22: The occultation of 1717.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
19 November 1717	*Rohiṇī*	17 35	0.93	Yes

3.1.30 12 February 1848

As Table 23 indicates there was an occultation on this day. This series started on Thursday 2 September 1847 at $00^h\ 40^m$ and ended on Monday 10 March 1851 at $05^h\ 32^m$.

Table 23: The occultation of 1848.

Date and Day	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
13 February 1848, Sunday	*Rohiṇī*	04 01	0.72	Yes

3.2 A Babylonian Record and Early East Asian Occultations

According to our calculations an occultation of Aldebaran occurred on 30 September –328 (see Table 24). This same occultation is discussed by Gonzalez (2017) in a paper where he uses lunar occultations of stars and planets to investigate Δ*T*, the rotation rate of the Earth.

Table 24: The occultation of 30 September –328.

Date	Object near the Moon	Time in IST h m	Difference in latitude (°)	Occultation or Not?
30 September –328	Aldebaran	06 42	0.15	Yes

This series started on 3 April –329 and continued until 22 February –325. We find in this series that occultations were not possible on 28 May –329 and 24 June –329 because the latitude differences were 1.31° and 1.3° respectively, but the occultation series started again on 21 July, and thereafter an occultation took place every month until the end of the series.

One of the earliest known East Asian observations of an occultation of Aldebaran occurred on 4 March 640 AD, and was observed from Japan (Stephenson, 1968). This established that the Moon was closer to the Earth than the star was.

4 CONCLUDING REMARKS

In the preceding Section we explained how to compute an occultation according to the *Grahalāghava* of Gaṇeśa Daivagña and the Improved *Siddhantic* Procedures. We also discussed the condition for a lunar occultation and the periodicity of *Rohiṇī* occultations, and we noted that a star whose ecliptical latitude is <3° 56′ has two series of lunar occultations during the sidereal period of the Moon's node. A star whose latitude lies between 3° 56′ and 6° 21′ has only one series of lunar occultations. Thus, *Rohiṇī* will have only one series of occultations, lasting 3.529 years, during the 18.6-year sidereal period of the Moon's node.

We also presented apparently unusual possibilities where in the midst of a series of occultations there are one or two cases when no occultations occur. Conversely, there also are cases where occultations occur in the midst of a series of non-occultations.

Finally, in the above section we included a few historically important *Rohiṇī* occultations viewed from non-Indian sites, while in the Appendix we supply a list of future *Rohiṇī* occultations, for the period 2033–2111.

5 NOTES

1. At this stage it is important that we mention *Śighrocca*, the conversion from solar-centred to Earth-centred co-ordinates.
2. The references associated with occultations and conjunctions 3.1.1 to 3.1.30 above are listed individually below, where the following abbreviations are used:

   EC: *Ephigraphia Carnatica*
   EKU: *Ephigraphia Karnataka University*
   EI: *Ephigraphia Indica*.
   SII: *South Indian Inscriptions*.

   Note that when traditional dates are mentioned in the inscriptions these are listed below in brackets.

   3.1.1 EC volume XI -3 Chikkamagaluru(Karthika shu 15 Mula nakshatra).
   3.1.2 EC volume XI number 25, Angadi(*śaka* 984,*Shubhakrti*, *Phalguna shu* 5, *Rohiṇī).*
   3.1.3 EKU volume V part II number 575 AP(989 *Plavanga*, *Karthikashu* 13).
   3.1.4 EI XXXIV part VII 253-68(*Vaishakha shu* 3)
   3.1.5 EKU Appendix volume III number 276 *Karakantapura(Paridhavi*, *Chaitra shu* 5, *Shobhanayoga*, *Balavakarana*, *RohiṇīNakshatra*, *vishu sankramana*).
   3.1.6 EC XII number 78 Tiptur(1055 *śaka, Ananda*, *vaishakasu shu* 11).
   3.1.7 EKU Appendix volume III no 133 Gutti(*Dundubh*i, *chaitra shu* 3).
   3.1.8 EC XII number 1 Kunigilu(*Ishvara*, *Ashadhaba* 11)
   3.1.9 EC XII number 31 Kadaba(*śaka* 1156, *Vijaya, Vaishakhashu* 2, *Rohiṇī, ekaadashastanavagraha).*
   3.1.10 EC VII 29(121) Basaralu(*śaka* 1157, *vaishakha shu* 2, *sarohini prityoga)*
   3.1.11 EC XII 33(*Virodhi*, *Rohiṇī*.,)
   3.1.12 EC V no 11, K R Pete(*Sadharana*, *Chaitra shu* 5)
   3.1.13 EC XIV (152)(*Sadharana*, *Bhadrapada ba* 1, *Rohiṇī).*
   3.1.14 SII Vol I no 88, Kanchipuram, Tamil Nadu(*Rohiṇī, Keelaka, Makara, shu* 7).
   3.1.15 EC VII no 4, Hoelnarasipura(*śaka* 1314, *Angirasa*, *Sravana su* 14, *Bhargave uttarapade, bhoumasutayta).*

3.1.16 EC volume VII no 113 Ullenahalli(*Tarana Jyeshta ba* 30, *Guru suryagrahana).*
3.1.17 EC volume VI no 19 Pandavapura(*Parthiva, Sravana ba* 8, *Rohiṇīnakshatra).*
3.1.18 EC VII 7 Mandya(*śaka* 1438, *Dhatu*, *karthika purnima*)
3.1.19 EKU Appendix volume III no 19 and 41 Lepakshi(*śaka1453, Khara, Sravana ba 8)*
3.1.20 EKU Appendix vol III no 248 Kalahasti(*śaka* 1454 *Nandana, Sravana ba* 10*Rohiṇī nakshatra)*
3.1.21 EKU vol I no 219 Hara(*Vijaya*, *Ashvayuja Śhu* 15).
3.1.22 EKU Appendix vol III no 12 Gurrepalli(*śaka* 1456*, Jaya, Sravana ba 8).*
3.1.23 EC volume IV 213 (59) Gundlupete(*śaka* 1458, *Durmukhi*, *Magha*, *shu* 10, *Rohiṇī*).
3.1.24 EKU Appendix vol III no 162 ragalapadu(*śaka* 1476, *pramadiicha*, *Magha shu* 7).
3.1.25 EC vol X no 43 Jamburu(*śaka* 1584, *Plava*, *Margashira shu* 15, *Uttara, Karkataka lagna*).
3.1.26 EC vol III no 119 Nanjanagudu(*śaka* 1602, *Siddharthi*, *Vaishakha shu* 3).
3.1.27 EC VI 53 to 22(*Durmathi*, *śaka* 1603, *Vaishakha shu*3).
3.1.28 EKU vol I no 53 Kenchanagudda(*Pramadhi*, *Chaitra ba* 14 *Rohiṇī. Priti yoga).*
3.1.29 EKU vol I no 36 Siriguppa(*śaka* 1639, *Hevilimbi*, *karthika ba* 2 *Rohiṇī).*
3.1.30 EC VI 9 Pandavapura(*śaka* 1770, *Keelaka*, *Ashvayuja*, *Rohini* 33).

3. The problem of eccentricity of the Moon's orbit does not arise since while determining the instant of conjunction the true positions of the bodies in conjunction are considered. Again, even here, the eccentricity of the orbit enters, without our knowledge about it, in the computation of the *mandaphala* (the equation of centre).

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8 APPENDIX

In Table 25, below, we list some future lunar occultations of *Rohinī* (Aldebaran).

Table 25: Occultations of *Rohiṇī* from 2033 to 2111.

Date and Day	Time in IST h m	Moon's Latitude ° ′	Difference in Latitude (°)
18 August 2033, Thursday	18 10	4 19	1.15
15 September 2033, Thursday	00 18	4 28	1
12 October 2033, Wednesday	08 36	4 30	0.97
8 November 2033, Tuesday	19 02	4 26	1.04
6 December 2033, Tuesday	06 04	4 23	1.08
2 January 2034, Monday	15 22	4 28	1
29 January 2034, Sunday	22 06	4 39	0.81
26 February 2034, Sunday	03 24	4 50	0.64
25 March 2034, Saturday	09 51	4 53	0.58
21 April 2034, Friday	18 43	4 45	0.64
19 May 2034, Friday	05 18	4 45	0.72
15 June 2034, Thursday	15 47	4 45	0.72
13 July 2034, Thursday	00 33	4 52	0.61
9 August 2034, Wednesday	07 10	5 01	0.45
5 September 2034, Tuesday	12 32	5 08	0.34
2 October 2034, Monday	18 45	5 07	0.35
30 October 2034, Monday	03 23	5 01	0.45
26 November 2034, Sunday	14 21	4 56	0.53
24 December 2034, Sunday	01 42	4 58	0.49
20 January 2035, Saturday	11 07	5 07	0.35
16 February 2035, Friday	17 45	5 15	0.22
15 March 2035, Thursday	23 06	5 16	0.21
12 April 2035, Thursday	05 40	5 10	0.31
9 May 2035, Wednesday	14 32	5 02	0.43
6 June 2035, Wednesday	01 04	5 00	0.46
3 July 2035, Tuesday	11 34	5 05	0.38
30 July 2035, Monday	20 23	5 12	0.26
27 August 2035, Monday	03 02	5 16	0.2
23 September 2035, Sunday	08 25	5 13	0.25
20 October 2035, Saturday	14 37	5 04	0.4
16 November 2035, Friday	23 22	4 57	0.52
14 December 2035, Friday	19 17	4 57	0.52
10 January 2036, Thursday	21 28	5 03	0.42

7 February 2036, Thursday	06 35	5 08	0.33
5 March 2036, Wednesday	13 01	5 06	0.36
1 April 2036, Tuesday	18 23	4 57	0.51
29 April 2036, Tuesday	00 51	4 48	0.67
26 May 2036, Monday	09 25	4 43	0.74
22 June 2036, Sunday	19 31	4 46	0.71
20 July 2036, Sunday	05 38	4 51	0.62
16 August 2036, Saturday	14 14	4 52	0.6
12 September 2036, Friday	20 44	4 46	0.7
10 October 2036, Friday	02 06	4 35	0.88
6 November 2036, Thursday	08 20	4 25	1.05
3 December 2036, Wednesday	16 50	4 22	1.09
31 December 2036, Wednesday	03 15	4 26	1.03
27 January 2037, Tuesday	13 38	4 29	0.98
23 February 2037, Monday	22 06	4 25	1.05
7 March 2052, Thursday	17 41	4 21	1.12
4 April 2052, Thursday	00 35	4 24	1.06
1 May 2052, Wednesday	09 55	4 21	1.11
28 May 2052, Tuesday	20 40	4 18	1.16
25 June 2052, Tuesday	07 01	4 21	1.12
22 July 2052, Monday	15 26	4 30	0.97
18 August 2052, Sunday	21 42	4 41	0.79
15 September 2052, Sunday	03 03	4 48	0.67
12 October 2052, Saturday	09 40	4 47	0.68
8 November 2052, Friday	18 53	4 45	0.76
6 December 2052, Friday	18 53	4 42	0.8
2 January 2053 Thursday	17 18	4 45	0.71
30 January 2053, Thursday	02 08	4 56	0.53
26 February 2053, Wednesday	08 15	5 04	0.39
25 March 2053, Tuesday	13 43	5 05	0.38
21 April 2053, Monday	20 39	5 00	0.47
19 May 2053, Monday	05 51	4 55	0.55
15 June 2053, Sunday	16 28	4 56	0.54
13 July 2053, Sunday	02 40	5 03	0.42
9 August 2053, Saturday	11 0 3	5 11	0.28
5 September 2053, Friday	17 20	5 15	0.21
2 October 2053, Thursday	22 42	5 12	0.39
30 October 2053, Thursday	05 15	5 05	0.39
26 November 2053, Wednesday	14 28	5 00	0.47
24 December 2053, Wednesday	01 28	5 03	0.42
20 January 2054, Tuesday	12 14	5 11	0.20
16 February 2054, Monday	20 40	5 17	0.18
16 March 2054, Monday	02 42	5 15	0.21
12 April 2054, Sunday	08 08	5 07	0.34
9 May 2054, Saturday	14 55	5 00	0.47
5 June 2054, Friday	23 43	4 58	0.5
3 July 2054, Friday	09 40	5 03	0.43
30 July 2054, Thursday	19 24	5 09	0.32
27 August 2054, Thursday	03 30	5 11	0.29
23 September 2054, Wednesday	09 40	5 05	0.38
20 October 2054, Tuesday	15 00	4 55	0.55
16 November 2054, Monday	21 38	4 47	0.68
14 December 2054, Monday	06 23	4 47	0.68
10 January 2055, Sunday	16 43	4 53	0.59
7 February 2055, Sunday	02 29	4 57	0.53
6 March 2055, Saturday	10 19	4 52	0.6
2 April 2055, Friday	16 13	4 42	0.78
27 May 2055, Thursday	04 21	4 27	1.02
23 June 2055, Wednesday	12 26	4 29	0.98
20 July 2055, Tuesday	21 30	4 33	0.92
17 August 2055, Tuesday	06 24	4 33	0.92
13 September 2055, Monday	14 02	4 25	1.05
25 September 2070, Thursday	17 39	4 17	1.18
23 October 2070, Thursday	00 43	4 17	1.19

19 November 2070, Wednesday	10 24	4 13	1.25
16 December 2070, Tuesday	21 55	4 14	1.24
13 January 2071, Tuesday	08 38	4 22	1.1
9 February 2071, Monday	16 53	4 34	0.9
8 March 2071, Sunday	22 45	4 43	0.75
5 April 2071, Sunday	04 15	4 44	0.75
2 May 2071, Saturday	11 33	4 40	0.81
29 May 2071, Friday	21 08	4 40	0.86
26 June 2071, Friday	07 33	4 40	0.8
23 July 2071, Thursday	17 27	4 49	0.65
20 August 2071, Thursday	01 25	4 59	0.49
16 September 2071, Wednesday	07 18	5 03	0.41
13 October 2071, Tuesday	12 44	5 03	0.46
9 November 2071, Monday	19 45	4 54	0.56
7 December 2071, Monday	05 16	4 52	0.6
3 January 2072, Sunday	16 15	4 58	0.5
311 January 2072, Sunday	02 30	5 08	0.33
27 February 2072, Saturday	10 16	5 15	0.22
25 March 2072, Friday	15 55	5 13	0.25
21 April 2072, Thursday	21 34	5 06	0.36
19 May 2072, Thursday	04 33	5 01	0.46
15 June 2072, Wednesday	13 26	5 01	0.45
12 July 2072, Tuesday	23 17	5 08	0.33
9 August 2072, Tuesday	08 32	5 16	0.21
5 September 2072, Monday	16 04	5 18	0.17
2 October 2072, Sunday	22 04	5 13	0.26
30 October 2072, Sunday	03 37	5 04	0.41
26 November 2072, Saturday	10 26	4 59	0.49
23 December 2072, Friday	19 19	5 01	0.44
20 January 2073, Friday	05 21	5 09	0.32
16 February 2073, Thursday	14 32	5 13	0.25
15 March 2073, Wednesday	21 15	5 09	0.32
12 April 2073, Wednesday	03 42	4 59	0.48
9 May 2073, Tuesday	09 23	4 51	0.62
5 June 2073, Monday	16 03	4 49	0.65
3 July 2073, Monday	00 08	4 53	0,58
30 July 2073, Sunday	08 55	4 58	0.49
26 August 2073, Saturday	17 25	4 58	0.5
23 September 2073, Saturday	00 47	4 51	0.62
20 October 2073, Friday	06 54	4 40	0.81
16 November 2073, Thursday	12 42	4 32	0.94
13 December 2073, Wednesday	19 20	4 32	0.94
10 January 2074, Wednesday	03 19	4 36	0.86
6 February 2074, Tuesday	12 06	4 38	0.83
5 March 2074, Monday	20 20	4 32	0.93
2 April 2074, Monday	03 40	4 20	1.13
5 July 2089, Tuesday	22 19	4 14	1.24
2 August 2089, Tuesday	07 44	4 25	1.06
29 August 2089, Monday	15 08	4 35	0.88
25 September 2089, Sunday	20 52	4 40	0.8
23 October 2089, Sunday	02 23	4 38	0.84
19 November 2089, Saturday	09 52	4 33	0.92
16 December 2089, Friday	19 41	4 34	0.91
13 January 2090, Friday	06 6^m	4 42	0.77
9 February 2090, Thursday	15 55^m	4 54	0.57
8 March 2090, Wednesday	23 08^m	5 01	0.46
5 April 2090, Wednesday	04 40	4 59	0.48
2 May 2090, Tuesday	10 25	4 54	0.57
29 May 2090, Monday	17 50	4 50	0.63
26 June 2090, Monday	02 37	4 53	0.58
23 July 2090, Sunday	12 11	5 02	0.43
19 August 2090, Saturday	20 59	5 11	0.29
16 September 2090, Saturday	04 08	5 13	0.25
13 October 2090, Friday	09 54	5 08	0.33

9 November 2090, Thursday	15 38	5 01	0.45
6 December 2090, Wednesday	22 50	4 59	0.49
3 January 2091, Wednesday	07 41	5 04	0.4
30 January 2091, Tuesday	17 16	5 13	0.24
27 February 2091, Tuesday	01 51	5 18	0.17
26 March 2091, Monday	08 52	5 14	0.23
22 April 2091, Sunday	14 39	5 06	0.37
19 May 2091, Saturday	20 27	5 00	0.46
16 June 2091, Saturday	03 17	5 00	0.46
13 July 2091, Friday	11 12	5 07	0.36
9 August 2091, Thursday	19 40	5 13	0.25
6 September 2091, Thursday	03 55	5 13	0.25
3 October 2091, Wednesday	11 05	5 06	0.37
30 October 2091, Tuesday	17 10	4 56	0.53
26 November 2091, Monday	23 10	4 51	0.62
24 December 2091, Monday	05 53	4 53	0.58
20 January 2092, Sunday	13 42	5 00	0.47
16 February 2092, Saturday	22 08	5 02	0.43
15 March 2092, Saturday	06 15	4 56	0.53
11 April 2092, Friday	13 25	4 45	0.71
8 May 2092, Thursday	19 48	4 37	0.86
5 June 2092, Thursday	01 45	4 35	0.89
2 July 2092, Wednesday	07 58	4 39	0.82
29 July 2092, Tuesday	15 03	4 43	0.75
25 August 2092, Monday	22 15	4 41	0.78
22 September 2092, Monday	06 48	4 32	0.93
19 October 2092, Sunday	14 31	4 20	1.14
24 January 2108, Tuesday	19 40	4 16	1.21
21 February 2108, Tuesday	03 38	4 29	0.99
19 March 2108, Monday	11 22	4 36	0.87
15 April 2108, Sunday	16 47	4 34	0.9
12 May 2108, Saturday	22 52	4 30	0.97
9 June 2108, Saturday	06 23	4 29	0.99
6 July 2108, Friday	15 04	4 34	0.9
3 August 2108, Friday	23 45	4 54	0.72
30 August 2108, Thursday	08 44	4 54	0.56
26 September 2108, Wednesday	15 25	4 57	0.52
23 October 2108, Tuesday	21 17	4 53	0.58
20 November 2108, Tuesday	03 15	4 48	0.68
17 December 2108, Monday	10 29	4 48	0.67
13 January 2109, Sunday	19 20	4 56	0.53
10 February 2109, Sunday	04 26	5 06	0.36
9 March 2109, Saturday	12 34	5 11	0.28
5 April 2109, Friday	19 13	5 08	0.33
3 May 2109, Friday	01 10	5 01	0.45
30 May 2109, Thursday	07 06	4 57	0.51
26 June 2109, Wednesday	13 57	5 00	0.46
23 July 2109, Tuesday	21 48	5 09	0.32
20 August 2109, Tuesday	06 04	5 16	0.21
16 September 2109, Monday	13 57	5 16	0.2
13 October 2109, Sunday	21 04	5 10	0.3
10 November 2109, Sunday	03 16	5 02	0.4
7 December 2109, Saturday	09 21	4 59	0.48
3 January 2110, Friday	16 05	5 04	0.4
30 January 2110, Thursday	23 41	5 12	0.26
27 February 2110, Thursday	07 54	5 15	0.22
26 March 2110, Wednesday	16 00	5 10	0.31
22 April 2110, Tuesday	23 13	5 00	0.47
20 May 2110, Tuesday	05 33	4 54	0.57
16 June 2110, Monday	11 30	4 54	0.56
13 July 2110, Sunday	17 42	5 00	0.47
10 August 2110, Sunday	00 41	5 05	0.39
6 September 2110, Saturday	08 32	5 03	0.41
3 October 2110, Friday	16 39	4 55	0.55

31 October 2110, Friday	00 30	4 44	0.73
27 November 2110, Thursday	07 36	4 39	0.8
24 December 2110, Wednesday	13 40	4 41	0.78
20 January 2111, Tuesday	19 45	4 47	0.69
17 February 2111, Tuesday	02 45	4 47	0.68
16 March 2111, Monday	10 41	4 40	0.8
12 April 2111, Sunday	19 21	4 28	1.0
10 May 2111, Sunday	03 43	4 19	1.16
3 July 2111, Friday	16 36	4 21	1.12
30 July 2111, Thursday	22 26	4 23	1.08
27 August 2111, Thursday	04 53	4 20	1.14

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Padmaja has presented papers at various conferences, including a stand-alone paper on "Eclipses – inscriptional and literary references, a survey" at the 25th International Congress of History of Science and Technology, in Rio de Janeiro, Brazil, in July 2017. She has also published a succession of research papers in this journal, the *Indian Journal of History of Science* and other journals, and has co-authored books on eclipses in Indian Astronomy and transits and occultations in Indian astronomy. Currently, she is guiding PhD candidates in computational astronomy.

Professor S. Balachandra Rao has an MSc (Mathematics) from the University of Mysore and a PhD (Fluid Mechanics) from Bangalore University. He served at the National Colleges at Gauribidanur and Bangalore, teaching mathematics for 35 years, and retired in 2002 as Principal. He also served as (1) Honorary Director, Gandhi Centre of Science and Human Values, BharatiyaVidyaBhavan, Bengaluru; (2) a Member of the National Commission for History of Science, Indian National Science Academy, New Delhi; and (3) an Honorary Senior Fellow at the National Institute of Advanced Studies (NIAS) in Bengaluru.

Professor Rao has been researching Classical Indian Astronomy since 1993 under successive research projects from INSA. He has authored, singly and jointly, quite a few papers on Indian mathematics and astronomy that have been published in Indian and international journals (including *JAHH*). He has also written about 30 books, half in English and the remainder in Kannada. The more popular ones among them are: (1) *Indian Mathematics and Astronomy—Some Landmarks*; (2) *Indian Astronomy—Concepts and Procedures*; (3) *Eclipses in Indian Astronomy*; (4) *Transits and Occultations in Indian Astronomy* [titles (3) and (4) were co-authored by Professor Padmaja Venugopal]; (5) *Grahalaghavam of Ganesha Daivajna, English Translation and Notes*; (6) *Karanakutuhalam of Bhaskara II, English Translation and Notes* [titles (5) and (6) were co-authored by Professor S.K. Uma]; (7) *Astrology—Believe it or Not?*; (8) *Traditions, Science and Society*, etc. While title (7) was translated into the Kannada and Marathi languages, title (8) was rendered into Kannada, Telugu and Malayalam versions. The Kannada versions of books (7) and (8) have won awards as "The Best Works of Rational Literature" from the Kannada Sahitya Parishat (Kannada Literary Authority).