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SOLAR ECLIPSE THEORY AND OBSERVATIONS IN THE 18TH CENTURY INDIA

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The status of astronomy in India in the 18th century has been a puzzling subject[1]. This is the period when Jai Singh built monumental masonry observatories in several cities like Jaipur, Delhi, Ujjain, and Benares[2]. There is evidence that he had sent missions to Europe to gain the current knowledge. However, his work does not seem to have been much influenced by the advances made in Europe. Copernican revolution was introduced in the 16th century. Telescope was introduced in the early 17th century. Newton's *Principia* was published in 1685, in the year of Jai Singh's birth. Flamsteed[3] had collected data on stars to an accuracy of 10″ by 1712.

It is enigmatic to find that these new advances in astronomy found their way into India very slowly even though accurate astronomical predictions had a very important role in Indian society. Prior to this period the development of Indian astronomy was very remarkable[4–9]. Several of the parameters and corrections needed in the calculations were known to a better accuracy than European counterparts. Bhāskara II (1150 A.D.), had introduced several novel corrections to the motion of planetary bodies some of which were introduced in the European works centuries later.

However, one should not forget the unstable conditions in India since the 13th century. This was particularly so in the early 18th century. The country was trying to recover from fanatical acts of Aurangzeb who had demolished the great learning centers of the country such as Benares. European colonization of India was slowly spreading. No wonder that foreign theories may not have been readily adopted. Jai Singh's endeavors are perhaps more noteworthy from the point of view of reviving the astronomical studies.

In order to fairly understand the 18th century astronomy one has to examine the available manuscripts and tables from this period. Of obvious importance are the solar and lunar eclipse data in view of the accuracy with which these can be calculated and in view of the importance accorded to them in the Indian religion. We have taken up some of these investigations in the present paper which is part of a current ongoing project.

Total solar eclipses are rare and awe-inspiring phenomena. At any given location the probability of a total eclipse is once in 360 years. The path of totality, umbral shadow of the moon, is only about 100 miles wide and the shadow rapidly travels from West to East. The duration of totality is only a few minutes but the partial phases may last for over an hour before and after the totality. Partial eclipses of varying maximum magnitudes are observed at locations up to several thousand miles away from the totality track. Maximum coverage decreases with the increase in the distance from the totality track.

In Table I, we have compiled a list of predicted total eclipses which should have been visible in India. The data is taken from Oppolzer's "*Canon der Finsternisse*"[10]. The criterion used for selecting the list was that at least some part of the totality track should lie between 5° N and 30° N latitudes and 65° E and 90° E longitudes. The latitude of the track changes when considered over a large geographical region. For brevity, only an approximate mean latitude on the Indian subcontinent is listed. The local solar time over the longitude region covered could differ by two hours. Therefore, the time of totality was classified into three groups, Morning, Noon, and Afternoon; totality occuring before 10 AM, between 10 AM and 2 PM, and after 2 PM local solar time respectively.

If the angular size of the Moon is smaller than that of the Sun, a thin bright ring is visible around the Moon even at the maximum phase. Such eclipses are classified as 'R', for ring. If the Moon size is bigger than that of the Sun, the eclipse is total, type 'T'. In some cases the variation in the size of the Moon during the several hours of eclipse track may cause a change in the type of the eclipse, from one location to another. Such eclipses are classified as 'RT'.

The date listed is for the Gregorian calendar. Partial eclipses of the Sun would have been visible over most of the country on these days. Further accurate data about the partial phases and the totality track can be obtained from this author by specifying the eclipse of interest.

The eclipse of 1898 is a well recorded event. Numerous expeditions to India were undertaken by foreign scientists. The expeditions turned out to be extremely successful since the day of the eclipse turned out to be completely clear. This was a comforting occasion for many investigators whose earlier eclipse expeditions had resulted in poor sky condition[11].'

Correspondence[12] of a Jessuit missionary, Father Boudier, contains reference to a solar eclipse which occurred on May 3, 1734. The date and the description of the eclipse match our tabular entries. We quote here the relevant passage from the correspondence. The original correspondence is in French, and the English translation was kindly done by a colleague[13].

> "At Delhi on May 3, beginning of a solar eclipse at 3h 57m 11s, end, a little doubtful because of the clouds, at 5h 55m 15s, non-corrected pendulum; the magnitude of this eclipse appeared to be fairly exactly 9 digits with the altitude of the upper limb of the Sun at 29 degrees 1 minute 30 seconds at 4h 18m 58s by the pendulum, from which we conclude that it is slow by 2m 48s. Therefore the commencement of eclipse at 3h 59m 59s, end at 5h 58m 3s. According to a letter of Father Gaubil, Mr. L' Abbe of Reville and Mr. Celsius, Swedish astronomer, the end of this eclipse was observed at Rome at 11h 52m 1s."

The date and the afternoon time of the eclipse match our Table. The totality track was at latitudes about 10° S of the Delhi latitude which matches with the fact that the upper limb of the Sun was showing at the maximum phase. Further work on the interpretation of this data is under progress.

In contrast to the total solar eclipses which are visible only over a small path, the total lunar eclipses are visible over all places where the Moon happens to be above the horizon at the time of the eclipse. Since the Moon has always played an important role in the theory and the observations in the Indian astronomy, it was thought worthwhile to compile a list of predicted lunar eclipses visible from the approximate Jaipur longitude of 75° E. These lunar eclipses are listed in Table II. The data is taken from Oppolzer's Canon[10]. The date is for Gregorian calendar. Only the total lunar eclipses with the midtotality between 18:00 hr and 06:00 hr for 75° E longitude are listed. Local times for any other longitude can be obtained by using the conversion factor 15° of longitude=1 hr of time.

The beginning and end of the umbral contacts and the beginning and the end of the totality period for any eclipse can be calculated from the half durations given in the Table.

In Father Boudier's correspondence[12] mentioned earlier, there is a description of a lunar eclipse of Dec. 1, 1732. We again quote here a translation of the relevant passage[13].

> "On 1 Dec. 1732, at Jaipur, a total eclipse of the Moon (began), at 22 *garis*, 7 *pols* after sunset; beginning of emersion (end of totality) at 26 *garis* 20 *pols*, from which the middle of the eclipse was at 24 *garis 13½ pols* after sunset.
>
> Each *gari* is 24 minutes long and contains 60 *pols*. Thus mideclipse was at 9h 41m 24s after sunset. When calculated by Brame's method, that is, neglecting refraction, sunset occurred at 5h 12m 48s, consequently mideclipse was at 14h 54m 12s. According to an observation by Mr. Cassini, made at the Observatory of Paris, mideclipse was at 9h 58m 38s, from which the difference between the meridians of Paris and Jaipur is 4h 55m 34s."

The date for this eclipse in Table II is Dec. 2 because it was after midnight. Duration of totality was 4 *gari* 13 *pols*, which is 101m 12s. This is in agreement with the half duration of 51 minutes given in the Table. Adding the Observatory[14] of

TABLE I

Total solar eclipses for the Indian subcontinent in the 18th and 19th centuries. The basic data for this Table is from reference 10. *The selection criterion was that at least some part of the totality track should lie between 5°N and 30°N latitudes and 65°E and 90°E longitudes. The date is for Gregorian calendar.*

(See text for further detail)

Year	Month	Date	Latitude[a] °N	Time of day[b]	Type[c]
1731	January	8	8	A	T
1734	May	3	17	A	R
1746	March	22	27	M	R
1748	July	25	14	A	R
1753	October	26	20	A	RT
1758	December	30	23	N	R
1763	April	13	24	A	R
1774	March	12	14	A	R
1786	January	30	22	M	RT
1828	April	14	24	A	RT
1840	March	4	24	M	RT
1843	December	21	9	M	T
1847	October	9	20	A	R
1857	September	18	26	N	R
1868	August	18	15	M	R
1871	December	12	9	M	T
1872	June	6	21	M	R
1894	April	6	25	M	RT
1898	January	22	21	N	T

[a]The paths of totality run West to East. Approximate mean latitude on the continent is given.
[b]Approximate local time of the day. M=Morning, before 10 AM; N=Noon, between 10 AM and 2 PM; A=Afternoon, after 2 PM.
[c]R=Ring or annular; T=Total; RT is combination of two.

Paris longitude of 2° 20′ 15″ we find the Jaipur longitude calculated in the correspondence to be 76° 13′ 45″. The modern value for the longitude of Jaipur is 75° 49′ 19″.

TABLE II

Total eclipses of the moon in 18th century in India. Approximate local time of mideclipse for Jaipur meridian of about 75°E are given. Only the eclipses with the middle of the totality time between 6 PM and 6 AM are listed.

(See text for further detail)

Year	Month	Date	Time	Half Duration in Minutes	
				Umbral Phase	Total Phase
1704	June	17	23:26	102	21
1711	July	29	22:52	110	47
1714	November	21	18:02	112	51
1718	March	16	20:55	112	51
1718	September	9	24:52	112	51
1722	January	2	19:35	112	51
1725	October	21	23:35	112	52
1729	February	14	1:58	111	50
1732	June	8	19:07	110	48
1732	December	2	2:39	112	51
1739	July	20	21:09	103	25
1740	January	14	3:34	112	51
1743	May	8	20:28	110	49
1750	June	20	2:02	108	42
1758	July	20	21:35	110	46
1761	May	19	3:12	110	46
1765	March	7	18:33	112	51
1765	August	30	20:59	112	52
1768	December	23	20:08	112	51
1772	April	17	21:06	112	51
1772	October	11	22:13	111	50
1776	February	4	19:29	112	52
1776	July	31	5:03	110	49
1779	November	24	00:48	112	51
1783	March	19	2:34	112	52
1783	September	11	4:35	112	51
1787	January	4	4:56	112	51
1787	June	30	19:40	105	34
1790	April	29	4:58	111	50
1794	February	15	3:23	112	51
1798	May	29	23:09	102	24

In the same correspondence the time difference between Paris and Delhi is found to be 5h 0m 1s. This gives the longitude to be 77° 20′ 29″. Current value is 77° 13′ 15″. It may be worth recalling that 1 minute of angle measure is equal to 4 seconds of time and corresponds to a distance of only about 1 mile at 28° N latitude.

We will now proceed to examine some astronomical manuscripts from this period. This is needed to analyze the status of Indian astronomical calculations. Because of our interest in Jai Singh, we looked for the Tables prepared for him.[15,16] Among these are *Zij Muhammad-Shahi* in Persian, *Samrāṭ-siddhānta* which is a Sanskrit version of Ptolemy's *Almagest* and *Jaivinodsarani*. Since the first two works have been widely examined, we decided to examine the original manuscript of the *Jaivinodsarani*. Relatively few copies of this work are available.[17,18] A copy of the original manuscript was obtained from the collection of the Harvard University Library.

The first page of the *Sarani* is rendered in Table III. This work was apparently written in 1735. Functions are tabulated for every 30 yrs on this first page. The solar cycle is 387; 57, 30, 4 and the lunar cycle is 29; 16, 1, 10. The functions for 1 to 30 yrs and 0 to 388 *yoga* and the equations for *candrakendra* and *ravikendra* are tabulated in the succeeding pages of the *Sarani* and are not reproduced here.

TABLE III

First page of *Jayavinodasarani*

Śaka	1657	1687	1717	1747	1777	1807
Dhruva	17	20	23	26	2	4
Yogā āvaradi	2 32 58 57	6 29 19 55	3 25 40 53	0 22 1 51	4 18 22 49	1 14 43 47
Yoge ravi kendram	304 5 41 50	305 20 40 2	306 35 38 14	307 50 36 26	309 5 34 38	310 20 32 50
Yoge candra kendram	25 19 14 8	17 2 38 48	8 46 3 28	0 29 28 8	21 28 53 58	13 12 18 38

Note: Rabi dhruvaṅka 387;57,30,4
Candra deruvaṅka 29;16,1,10

In order to analyze the tabular entries we start out with calculating the modern values for various parameters.

Let S and M denote the sedereal periods of the Sun and the Moon respectively in days. Modern values[18,19] for these are 365.25636042 days and 27.321661 days. From their definitions, following values can be obtained for the lengths of various parameters. Extra decimal places have been retained.[20]

Synodic lunar month = $29^d.530589$

Tithi T = 29.530589/30 = $0^d.984352956$ = 0; 59, 3, 40, 14, 19

Nakṣatra N = M/27 = $1^d.01191337$ = 1; 0, 42, 53, 17, 17

Yoga Y = S · M/27 (S+M) = $0^d.94148876$ = 0; 56, 29, 21, 34, 20.

By examining the tabular entries we find that 1 *Yoga* = $0^d.94148962$ = 0; 56, 29, 21, 45, 28. The value is larger by only 0.14s.

For *Yoga ravikendra* 30 yr motion is 1; 14, 58, 12. This gives a yearly motion of 0; 2, 29, 56, 24. This value is slightly more accurate than the value 0; 2, 29, 56 given in the yearly motion table or the one derived from the solar cycle of 387; 57, 30, 4. The exact solar cycle is thus 387; 57, 30, 3, 36. Using the *Yoga* to day conversion, one obtains a solar sidereal year value of $365^d.25876$. This matches the value given in the *Sūryasiddhānta*. It is larger by 0.0014 day/year or about 2 minutes/year than the true value. It is in between the values of anomalistic year of 365.25964 and the sidereal year.

Entries for *Yoga candrakendra* yield a 30 yr motion of 20; 59, 25, 50, one year motion of 7; 31, 43, 8 and the lunar cycle of 29; 16, 1, 10 *yoga*. Conversion to days gives a value of 27.554568 days for the month. This is the anomalistic month whose modern value is 27.554551 days. The two values are extremely close, the modern value being 1.47s/cycle smaller.

In order to compare these results with those from other tables of the same era, we quote here the parameters from another manuscript from this period. Pingree[17] has provided a listing of a 1741 manuscript. The writer is not known. It is classified as "Anonymous of 1741" Poleman nos. 5177, 4770, 4946. From the entries in this work one finds that:

1 *Yoga* = 0; 56, 29, 21, 42 days.

N = 1; 0, 42, 53, 20 days; Sidereal month = 27.321667 days.

T = 0; 59, 3, 40, 11, 52 days; Synodic month = 29.530583 days.

These values are extremely close to the modern values. Average length of the anomalistic month in the above work is 27.554539 days.

Thus we find that the mean motion of the Moon was known extremely accurately in 18th century astronomy. However, the solar calculations used the sidereal year cycle established in the *Sūryasiddhānta*. This cycle is larger by about 2 minutes per year compared to the true cycle.

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