



On mean motions in Indian astronomy

Anil Narayanan¹

Received: 23 March 2025 / Accepted: 8 August 2025 / Published online: 21 August 2025
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Abstract

Mean motions form the very core of any astronomical system. In this article, a computational study was undertaken to examine the mean motions given in the *Sūrya Siddhānta*, an ancient Indian astronomy text. The primary finding was that the mean motions of the planets specified in the text are their heliocentric mean motions, and the magnitudes specified therein are of varying accuracy when compared with modern values. The orbital periods for mean motions given in the text are exact for the Moon and the innermost planets, Mercury and Venus. Earth, Mars, and Jupiter are correct within a fraction of a day, while Saturn has a considerable error. This work also discovered that the Indian values get progressively more accurate as one travels backward in time, indicating that this mean-motion data is possibly several millennia old.

Keywords Mean motion · *Mahāyuga* · *Sūrya Siddhānta*

1 Introduction

Ancient Indian lore is replete with references to great cycles of time comprising billions of years, all of which have their basis in astronomy. Today, we find these ancient time cycles to be in reasonable agreement with our current understanding of the universe, and are wonderstruck at the acumen of the ancient astronomers, who, using only naked-eye observation, came up with these enormous frameworks of time.

Cycles of time are a natural phenomenon. There is the daily occurrence of sunrise, the moon's monthly cycle, and the seasons' yearly cycle. Some special ones are beyond these everyday mundane cycles, like the *Saros* cycle of eclipses. It would seem natural for a civilization's maturing science to seek out greater cycles of time, to determine the largest possible period in which every cyclical variation in the universe returns to its starting point. And yet, beyond the ordinary cycles of the Sun and the Moon, and perhaps a planet or two, no other civilization on Earth apart from the Indian appears to have ventured to create time-cycles that involve all astronomical elements, namely, the Sun, the Moon, all the planets, their apogees, their nodes, and the precession of the Earth. Employing this plethora of

astronomical elements results in the large number of time cycles we see in Indian astronomy, which stretch out to enormous time scales.

At the very root of this hierarchy of Indian time-cycles lies the *Mahāyuga*, of 4.32 million years. This base cycle is employed as a building block for the construction of all other greater cycles in Indian astronomy. The fundamental basis of the *Mahāyuga* is the astronomical mean motions, and in this paper, we will examine these mean motions of Indian astronomy using modern techniques. We will mainly refer to the *Sūrya Siddhānta* (Burgess, 1858), a much-revered and extant text among the various works of ancient Indian astronomy. The original treatise has been estimated to be older than 3000 BCE (Brennan, 1988; Narayanan, 2010).

2 The mean motions

Most readers are aware that heavenly bodies like the Sun, Moon, and planets do not move at a constant speed in the firmament. They appear to move faster at times and slower at other times. The mean speed of a body is defined as the average speed of the body, and this averaging in astronomy is carried out over a long period of time (many centuries); the longer the time interval, the more accurate the mean-speed value.

Once we have the mean speed of a body, we can define a hypothetical Mean-Body, which always travels at this constant mean speed, for instance, the Mean-Sun or the

✉ Anil Narayanan
anilkn_ban@hotmail.com

¹ Former Scientist, Indian Space Research Organization, 8467
Falling Leaf Rd, Springfield, VA 22153, USA

Table 1 Fundamental mean motion data in the *Sūrya Siddhānta*

Planet	Mean motion	
	Revolutions per <i>Mahāyuga</i>	Direction
Sun	4,320,000	Eastward
Mercury	17,937,060	Eastward
Venus	7,022,376	Eastward
Mars	2,296,832	Eastward
Jupiter	364,220	Eastward
Saturn	146,568	Eastward
Moon	57,753,336	Eastward
Moon apogee	488,203	Eastward
Moon node	232,238	Westward
Starry sphere	1,582,237,828	Westward

Mean-Moon. The motion of such a hypothetical body is called its mean motion. In contrast, the true motion of a body is the actual motion of the body, which, unlike the mean motion, varies with time. Thus, the True-Sun or True-Moon will at times be ahead of the Mean-Sun or Mean-Moon, and at other times will lag behind.

These fundamental constants, the heavenly bodies' mean motions, form the core of any astronomical system. A typical calculation to find a body's true position will, as a first step, determine its mean position at the required date and time using its mean motion. Then, suitable corrections are applied to this mean position to obtain the true position. With that understanding, let us examine the mean motions specified in the *Sūrya Siddhānta*.

Table 1 shows the fundamental mean-motion data of various heavenly bodies as given in the *Sūrya Siddhānta*. It depicts the number of orbital revolutions completed by these bodies in a *Mahāyuga*, and their direction of motion.

The Table clearly illustrates the astronomical significance of the *Mahāyuga* – it is the interval of time in which all these heavenly bodies, including the Moon's apogee and its node, by their mean motion, complete a whole number of revolutions and come back together at the starting point. Indeed, the word *Mahāyuga* literally means 'great joining'.

Note that the last entry in the Table pertains to the rotation of the Earth on its axis. To an observer on the Earth the west-to-east rotation of the Earth produces the illusion of the sky (the starry sphere) rotating in the opposite direction, that is, east-to-west, completing one rotation in a day. Observe that this rotation of the starry sphere carries with it the entire sky, including all the heavenly bodies. Thus, in Indian astronomy, each heavenly body has two motions – the general motion of the starry sphere, and its own particular motion.

The Sidereal Year is the time it takes the Sun to complete a revolution against the starry background, which rotates once a day from east to west. Since the Sun travels opposite

Table 2 Mean sidereal orbital periods

Planet	Mean orbital period (days)	
	<i>Sūrya-Siddhānta</i>	Modern
Sun	365.2588	365.2564
Moon	27.3217	27.3217
Moon-Apogee	3232.1	3232.6
Moon-Node	6794.4	6793.5
Mercury	87.970	87.969
Venus	224.699	224.701
Mars	686.997	686.980
Jupiter	4332.321	4332.590
Saturn	10,765.77	10,755.70

to the stars, the number of sunrises (days) in a *Mahāyuga* equals the difference of their revolutions.

Thus, days in a *Mahāyuga* = 1,582,237,828 – 4,320,000 = 1,577,917,828.

Dividing this result by the number of revolutions of the Sun in a *Mahāyuga* gives us the length of the Sidereal Year (L) as:

$$L = 1,577,917,828 / 4,320,000 = 365.2587565 \text{ days.}$$

Using the revolutions-per-*Mahāyuga* (N) as specified in Table 1, and the length of the Sidereal Year (L), we can determine the *Sūrya Siddhānta*'s mean-orbital-period (T) for each planet in days as $T = (4,320,000 \times L) / N$. The results are shown in Table 2 along with the modern values of these quantities obtained from NASA's planetary fact sheet.¹

There are two significant observations to be made from Table 2. First and foremost, the Table is a splendid acknowledgement of the precision of ancient Indian mean motion data, which, as mentioned, forms the very core of any astronomical system. The mean orbital period of the Moon in the *Sūrya Siddhānta* stands out, matching the modern value to the fourth decimal place. The others are correct to various decimal places, with only Saturn being the odd man out with a not-so-accurate value, which we will examine later in this article.

This remarkable accuracy of ancient Indian data showcases not only the proficiency of the methods of observation employed by the ancient Indian astronomer, but also the great antiquity of the Indian civilization. For example, accurately determining the mean motion of Jupiter and Saturn, the outer planets, which take 12 and 30 years to complete a single orbit, demands many centuries of recorded observations.

¹ NASA planetary fact sheet: <https://nssdc.gsfc.nasa.gov/planetary/factsheet/>



The second significant observation is that the planetary mean motions shown in Table 2 are all Heliocentric periods, not Geocentric. This is an eye-opener. Though the Indian planetary model is essentially geocentric, the fact that at its core are found heliocentric mean-motions of high precision is astonishing. We will discuss this aspect later in the article.

Before we begin our computational study of the mean motions of these heavenly bodies, it would be useful to take a short detour by looking up the masses of various planets in the solar system and their orbital placements.

3 Planetary mass, orbital radius, and stability

Figure 1 shows the relative mass and orbital distance of the various planets in the solar system, which may shed some light on the stability of their orbits. Note that the AU (Astronomical Unit) is the mean orbital radius of the Earth.

What stands out immediately in the figure is the physical division of the planets in the solar system into two distinct groups: (a) the much more minor and seemingly closely-packed four inner planets (Mercury, Venus, Earth, and Mars); (b) the four giant outer planets (Jupiter, Saturn, Uranus, and Neptune) which appear altogether on a different scale in terms of mass and orbital distance.

It is observed that Jupiter is by far the most massive body in the solar system apart from the Sun. Quite remarkably, the Indian name for this planet is ‘Guru’, which means ‘massive’ or ‘heavy’. We may expect that its motion greatly influences that of its two immediate neighbors – Mars and Saturn.

Saturn, being in close proximity with Jupiter and having a considerable mass of its own, is strongly influenced not only by the latter but also by Uranus and Neptune, so we may expect to see considerable variation in its orbital period over time.

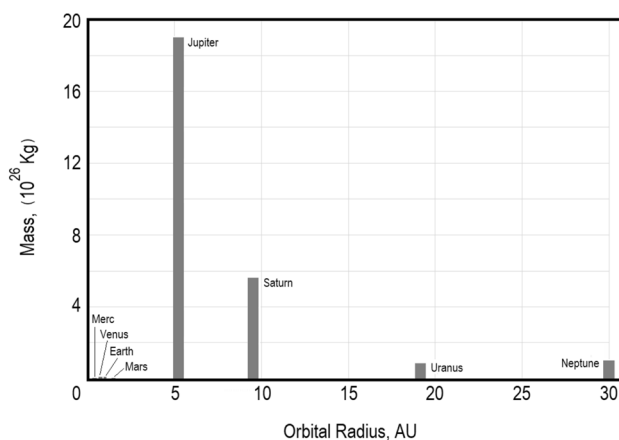


Fig. 1 Planetary mass and orbital radius in the solar system



Uranus and Neptune are not visible to the naked eye and thus were unknown to the ancients.

Among the inner planets, the Earth is the most massive. However, the mass of the inner planets appears altogether insignificant when compared to that of the outer planets, and though there may be slight disturbances caused by the outer planets on their orbits, especially on Mars and the Earth, overall, their orbits are strongly influenced by the Sun only, which is a thousand times more massive than Jupiter. After that brief detour, let us now proceed with our main topic.

4 Computational results and discussion

In this section, we will probe into the mean orbital periods of various heavenly bodies shown in Table 2 using modern computational techniques as presented in Chapter 33 of Meeus (1991). We will compute true orbital periods for each planet going thousands of years backward and forward in time to determine any temporal variations that may be found therein.

4.1 Time range and precession

We will determine orbital periods from approximately 5000 BCE to 5000 CE for each heavenly body. A couple of things may be noted: (a) the modern formulae we will employ are Tropical, that is, they are based on the movable mean equinox of the date. Since Indian astronomy employs a sidereal framework, we will convert the tropical results into sidereal by applying a correction for precession for the time interval of each orbit, using the astronomical expressions presented in chapter 21 of Meeus; (b) these modern formulae are valid only up to 4713 BCE in the past, so that date represents a threshold beyond which we cannot travel backwards in time. Going forward in time, however, has a greater range, and some of these formulae are accurate up to 10000 CE.

Let us now examine the computed results for each planet, starting with the Earth.

4.2 Earth/Sun sidereal year

It is well known that the Earth orbits around the Sun. However, to an observer on Earth, due to relative motion, it appears that the Sun orbits the Earth. Thus, the mean orbital period of the Sun given in the *Sūrya Siddhānta* is that of the Earth.

Figure 2 shows the computed variation of the Earth’s sidereal orbital period from 4700 BCE to 5300 CE. It is observed that the Earth’s motion, orbit to orbit, is far from steady; there appears to be a continual up-and-down variation from orbit to orbit. Secondly, it is clear from the plot that the Earth’s mean orbital period has been decreasing

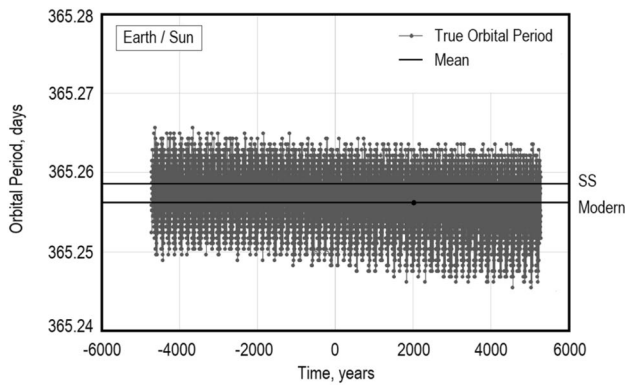


Fig. 2 Variation of the Earth’s sidereal orbital period

gradually over the past 7000 years, its current value being 365.2564 days, and it will continue to decrease for the next few millennia. The value given in the *Sūrya Siddhānta* (SS) for the Earth’s mean orbital period is 365.2587565 days, which is a little larger than the current, and it appears to match the actual mean value from a period earlier than 4000 BCE, going by the trend in the plot.

4.3 Saturn

The planet Saturn has an orbital period of approximately 29.5 years (about 10,760 days). Figure 3 shows the variation in this orbital period from 4700 BCE to 4700 CE. Several sub-variations can be discerned from this plot. There is, firstly, the orbit-to-orbit (dot-to-dot) up and down primary variation. This superimposes a longer secondary variation over a period of about 1000 years. Finally, a still larger tertiary variation of approximately 9000 years can also be observed. Overall, Saturn’s orbital motion displays a considerable variation of up to 25 days over 10,000 years. This matches the expectation from our

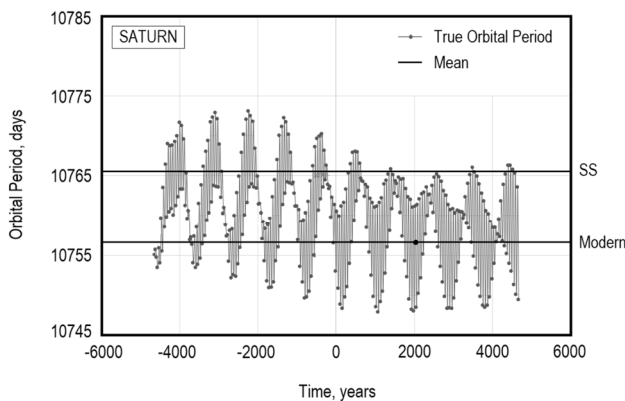


Fig. 3 Variation of the orbital period of Saturn

analysis of Fig. 1, where we noted the strong gravitational influences of Jupiter, Uranus, and Neptune on Saturn.

It is apparent from the plot that the mean orbital period of Saturn was greater in the past than it is today. Its modern value for the 2000 epoch is 10,755.70 days, while that given in the *Sūrya Siddhānta* is 10,765.77 days, which, going by the trend in the plot, appears to match the actual mean value in the neighborhood of 3000 BCE or so. It is also apparent that the cyclical variation of Saturn’s mean motion continues further backwards in time. Therefore, 3000 BCE may only represent the closest match that we can suggest, but there may be other matches for the *Sūrya Siddhānta*’s value for Saturn going further back in time, say in the 10,000–12000 BCE timeframe.

4.4 Jupiter

Jupiter, the most massive planet in the solar system, takes nearly 12 years (4332 days) to complete an orbit around the Sun. Figure 4 shows the variation of its sidereal orbital period from 4700 BCE to 4700 CE. As with Saturn, we observe a primary up-and-down variation for Jupiter and secondary and tertiary variations. It is observed that starting at about 4000 BCE, the orbital period shows a small increase, which peaks around 2000 CE and then decreases thereafter. Jupiter’s orbital period appears more stable than Saturn’s, with a variation of only 4 days in 9400 years.

The modern value of Jupiter’s mean orbital period is 4332.59 days. Going by the trend in the plot, one would expect the mean value in the past to be a bit lower than it is today, and that indeed seems to be the case, as highlighted by the value given in the *Sūrya Siddhānta*, namely, 4332.321 days. It is difficult to estimate from the plot at which epoch this Indian value would match, but it would certainly be earlier than 2000 BCE.

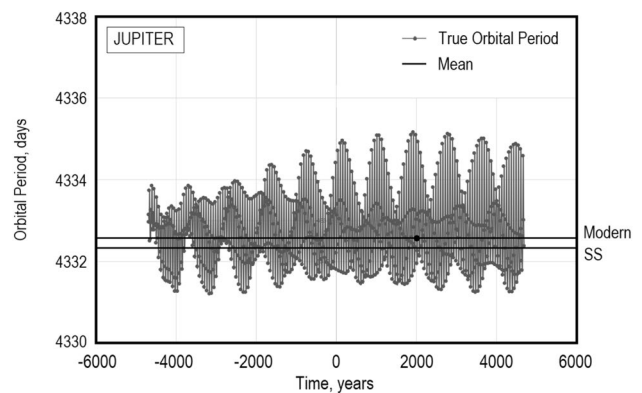


Fig. 4 Variation of the orbital period of Jupiter



4.5 Mars

Figure 5 shows a similar plot for Mars, which takes a little less than 2 years (687 days) to complete its orbit around the Sun. We notice that compared to Saturn and Jupiter, the orbital period of Mars shows little variation over thousands of years, indicating a more stable orbit than the other two. Over 9400 years, this period varies by only 1/10 of a day (686.94 to 687.04 days). The primary variation appears to dominate the motion with some secondary and tertiary variations superimposed.

There is a widening variation in time, no doubt influenced by Jupiter (see Fig. 4). The modern value of Mars’s mean orbital period is 686.971 days, which is about 3/100 of a day smaller than that given in the *Sūrya Siddhānta*, of 686.997 days. This second decimal difference is too fine to conclude anything concrete, and we can only state that the *Sūrya Siddhānta*’s value for Mars does not match the actual mean value going back up to 4713 BCE. Our current formulae, as mentioned, cannot go further into the past than this date, were a match to be available beyond 4713 BCE.

4.6 Venus

Figure 6 shows the case for Venus, whose orbital period is about 225 days. The plot appears to exhibit little variation over 9400 years, which signifies a very stable orbit. The modern value of Venus’s mean orbital period is 224.701 days, which differs from that given in the *Sūrya Siddhānta*, of 224.699 days, by the astonishingly slight difference of only 2/1000 of a day.

The plot does show a small decreasing trend going backwards in time, and if it were to continue, a match for the *Sūrya Siddhānta* value could possibly be found in the neighborhood of 8000–10000 BCE.

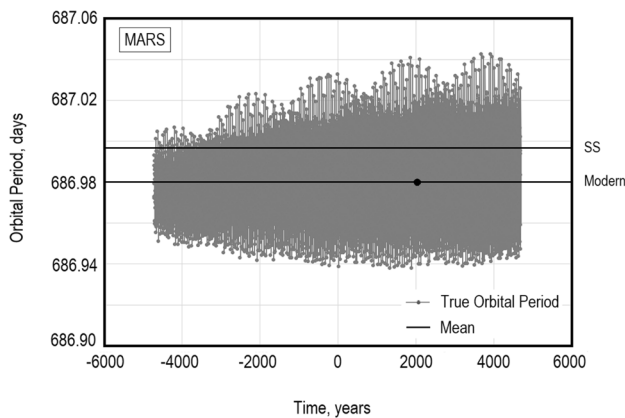


Fig. 5 Variation of the orbital period of Mars

4.7 Mercury

Figure 7 depicts the variation of the orbital period of the innermost planet, Mercury, over 9400 years. Like Venus, there appears very little variation in the plot, highlighting the extraordinary stability of its orbital period. Like Venus, this stability of Mercury’s orbital period over time is reflected in its modern mean value of 87.969 days, which differs from the ancient value given in the *Sūrya Siddhānta*, of 87.970 days, by only 1/1000 of a day.

Going backwards in time in the plot, there appears to be the beginnings of an upward trend starting around 3000 BCE. If that trend were to continue, a match for the ancient value may perhaps be found around 8000–10000 BCE, similar to the case for Venus.

After the visible planets, let us look at the results for the Moon’s orbital parameters next.

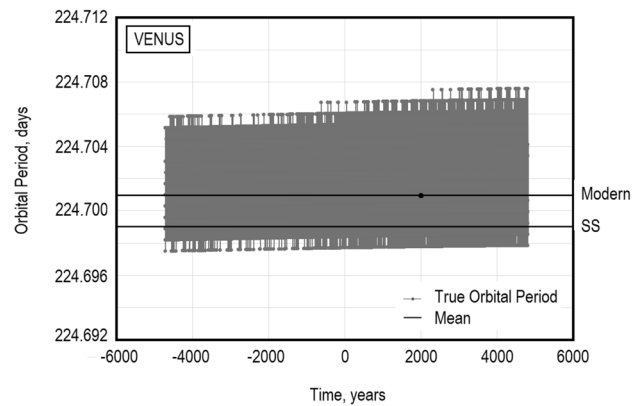


Fig. 6 Variation of the orbital period of Venus

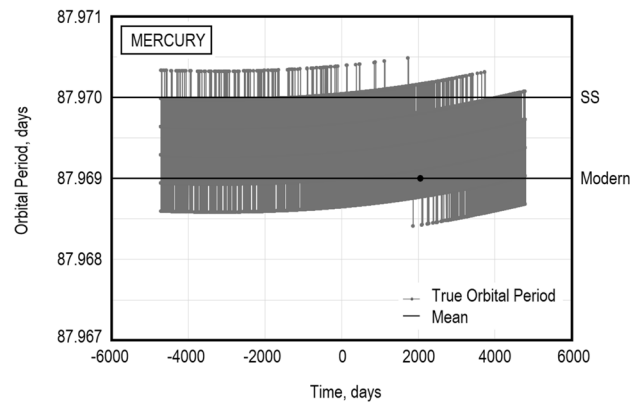


Fig. 7 Variation of the orbital period of Mercury



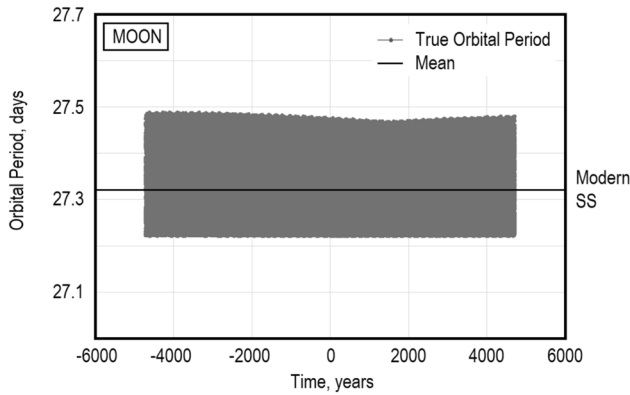


Fig. 8 Variation of the orbital period of the Moon

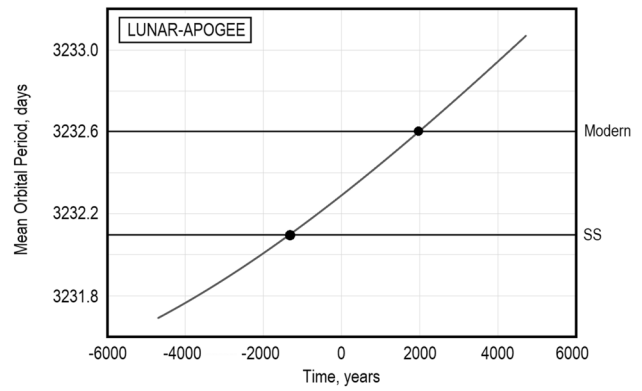


Fig.10 Variation of the Moon’s mean apsidal precession period

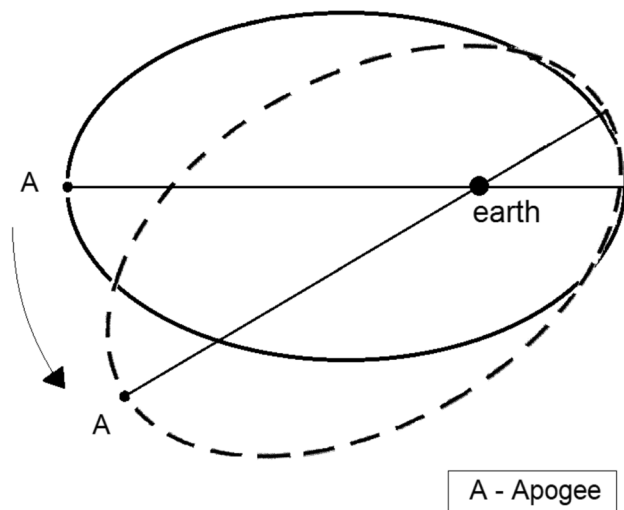


Fig. 9 Apsidal precession of the Moon’s orbit

4.8 Moon

While the other heavenly bodies are largely influenced by the Sun, the motion of the Moon is strongly affected by two bodies – the Earth and the Sun. Figure 8 shows the Moon’s orbital period variation over 9400 years. We note from the figure that the orbital period can vary by as much as 1/3 of a day, which is a considerable variation for a small 27-day cycle. This relatively large variation, as mentioned, is due to the dual influences of the Earth and the Sun on the Moon’s orbit.

That said, it is remarkable to observe that the Moon’s orbital period displays an exceptional steadiness in variation over the extended time range of 9400 years, as seen in the plot. Except for a small dip centered around 1500 CE, the plot is pretty much a rectangle. This steadiness is also reflected in the minuscule difference between this parameter’s modern and ancient values. The modern mean value

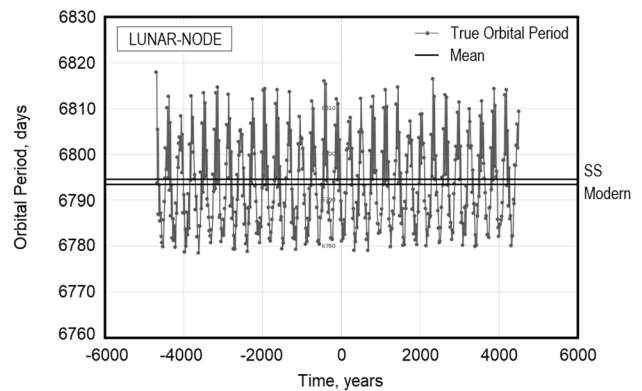


Fig. 11 Variation of the Moon’s nodal precession period

of the Moon’s orbital period is 27.321661 days, which, quite remarkably, is only 1 s smaller than that given in the *Sūrya Siddhānta*, namely, 27.321674 days.

4.9 Moon’s apogee movement

The Moon’s orbit around the Earth is practically an ellipse. Due to the influence of the Sun, the axis of this ellipse experiences a torque that causes its apogee to continually shift in space, a phenomenon known as apsidal precession, as shown in Fig. 9.

The Moon’s apsidal precession has a period of 8.85 years (about 3232 days). A direct formula to determine the position of the mean lunar apogee is known in modern times (Meeus, 1991), from which its orbital period may be obtained. Figure 10 shows the variation of this period over 9400 years. As shown in the plot, the current value of this period is 3232.6 days. The value given in the *Sūrya Siddhānta* is 3232.1 days, which appears to match the actual value from about 1370 BCE or so.



4.10 Moon's node

Yet another effect of the Sun on the Moon's orbit is nodal precession, which causes the Moon's nodes to shift continuously westwards. This nodal movement completes a full rotation with a period of 18.6 years (about 6793 days).

Figure 11 shows the variation of this period over 10,000 years. As shown in the plot, the current value of the mean nodal precession period is 6793.48 days, while the value given in the *Sūrya Siddhānta* is nearly a day longer, 6794.4 days. The plot indicates a small increasing trend with time, which implies that a match for the *Sūrya Siddhānta* value cannot be found going backwards in time, since the latter is already greater than the current. We are unable to account for this discrepancy in the *Sūrya Siddhānta* at this time. However, it may be noted from Table 3 further below that the mean motion data given by the astronomers Brāhmagupta and Nīlakaṇṭha (Ramasubramanian & Sriram, 2011) result in the Moon's nodal precession period being 6792.26 and 6792.59 days respectively, both of which represent older values than the modern.

4.11 Summary

We made some interesting discoveries in this brief computational study of astronomical mean motions. We found that some of the planetary mean motions given in the ancient Indian text are extremely precise. We also discovered that the trend of the variations of the mean motions going backward in time seems to imply that the Indian data may be several millennia old.

This concludes the main body of work in this paper. Before we end the article, let us briefly touch on a few other astronomical mean motion topics.

5 Miscellaneous

5.1 Borrowing of mean motion data

Having understood the paramount importance of mean-motions in astronomy, and the fact that it would take a long and sustained effort to determine mean motions accurately, it would seem natural to question how civilizations with fledgling astronomies, like the Arabs or the Greeks for instance, who had no significant history of recording observational data, managed to establish their astronomies.

It goes without saying, of course, that these nascent astronomies must have borrowed their mean-motion data from other people. While it is well-known that Arab mathematics and astronomy received their first impetus from India, that of Greek astronomy is not so plainly evident. It is a well-known fact, however, that the Greeks had suddenly acquired a ton of mathematics within 5–10 years of Alexander's invasion of India, including the famed thirteen books of Euclid.

It is also well-known that the ancient Greeks travelled far and wide in search of knowledge—to Egypt, to Babylon, and to India. While western scholars admit that the Greeks had borrowed their astronomical mean motions from foreign sources (Jones & Duke, 2005), they have not yet suggested a definite source.

5.2 Mean motions given by later astronomers

Next, let us look at an interesting phenomenon with regard to Indian astronomical mean motions, namely, the tweaking of these values by various Indian astronomers over the centuries.

Table 3 presents the mean-motion data given by some famous Indian astronomers in their own works, and we have added the *Sūrya Siddhānta* (SS) mean motions for reference. Many later Indian astronomers adopted the mean motions given by either Aryabhata (Clark, 1930) or Brahmagupta (Sharma, 1966). For example, Lalla

Table 3 Mean motions given by various astronomers

Planet	SS	Aryabhata	Brahmagupta	Nīlakaṇṭha
Sun	4,320,000	4,320,000	4,320,000	4,320,000
Mercury	17,937,060	17,937,020	17,936,999	17,937,048
Venus	7,022,376	7,022,388	7,022,389	7,022,268
Mars	2,296,832	2,296,824	2,296,829	2,296,864
Jupiter	364,220	364,224	364,226	364,180
Saturn	146,568	146,564	146,567	146,612
Moon	57,753,336	57,753,336	57,753,330	57,753,320
Moon apogee	488,203	488,219	488,106	488,122
Moon node	232,238	232,226	232,311	232,300
Stars	1,582,237,828	1,582,237,500	1,582,237,800	1,582,237,500



(Chatterjee, 1981) and Manjula (Shukla, 1990) have followed Aryabhata, while Śripati (Misra, 1932) and Bhāskara (Arkasomayaji, 1980) have adopted the mean motions given by Brahmagupta. It is also well-known that Aryabhata and Brahmagupta, by their own admission, were followers of the ancient *Brahma Siddhānta*, a text which is not extant anymore.

Looking at the minute changes in Table 3, it would seem very unlikely that these later astronomers independently determined these mean motions from fundamental data of their own. As mentioned, the accurate determination of mean motions requires a collective effort of many centuries. Also, given that these astronomers routinely disparage the works of their contemporaries and predecessors in their own works, it would be very unlikely that they would agree to cooperate to build and maintain a common data bank of recorded observations. It appears more likely that these astronomers simply tweaked the long-held ancient mean-motion values as required to make their calculation results match their observational data for each planet.

5.3 Data updates in the *Sūrya Siddhānta*

Closely related to the above is a surprising discovery found in the *Sūrya Siddhānta*. In the very first chapter of the text, the following remarkable verse is found (Chapter I/Verse 9):

This is the same original textbook promulgated in ancient times;

Only, due to the revolution of the Ages, there is a difference of times here.

Here, then, is an open declaration by the *Sūrya Siddhānta* that even the ancient mean-motion data found therein has been updated in the past, maybe several times. Given the great antiquity of the Indian civilization, perhaps this declaration is only to be expected and should not come as a complete surprise. Nevertheless, it is interesting that the author(s) of the *Sūrya Siddhānta* have chosen to declare this in the text, to make the reader aware that even the ‘constant’ mean-motions change over the long term.

5.4 Heliocentricity

Finally, let us discuss the most remarkable thing of all, namely, the curious presence of heliocentric features in many aspects of Indian astronomy. Though the Indian planetary model is avowedly geocentric, some of its core features have intimations of heliocentricity, a prime example of which is the planetary mean motions, which, as stated, form the very core of any astronomical system.

Taking Mars as an example, the period of its heliocentric mean-motion around the Sun is 687 days, as also specified in

the *Sūrya Siddhānta*. No earth-based observation can yield this value, since the Earth is itself in motion around the Sun. For instance, the geocentric longitude of Mars on Jan 1, 2000, as seen from Earth, was 327.59°. Then, 687 days later, on Nov 18, 2001, it was at 314.91°, a substantially different value. How then did the ancients determine that the mean orbital period of Mars is 687 days?

There appears to be no easy answer to this question, and we can see that there are deeper waters here. We may conjecture that perhaps in the process of experimenting with their complex dual-pulsating planetary models based on epicycles, and correlating them with observational data, the ancient Indians frequently encountered these mysterious constants in their calculations, whose import was gradually and eventually understood. But, in whatever manner they may have been obtained, full marks to the ancient Indian astronomer for having discovered these fundamental constants of our solar system, the heliocentric mean motions.

6 Conclusions

A computational study of the astronomical mean motions of various heavenly bodies presented in the *Sūrya Siddhānta* was carried out in this paper using modern methods. The investigation was aimed not at a detailed analysis of these mean motions but only at temporal variations in these motions, with a view to determining whether the trend of these variations was opposed to, or aligned with, the ancient values given in the *Sūrya Siddhānta*. The study yielded some interesting conclusions, which may be summarized as follows:

1. The mean motions of the visible planets given in ancient Indian astronomy are the heliocentric mean motions of these bodies. It is conjectured that the ancient astronomers discovered these heliocentric values while applying their mathematical models to these planets to match calculation results with observational data.
2. A trend analysis showed that the mean motions given in the ancient *Sūrya Siddhānta* match up well with actual values going back several millennia in the past, the only exception being that for the Moon’s nodal movement.
3. Computational results on orbital variations show that the gravitational effect of the outer planets on the orbits of the innermost planets, Mercury and Venus, is very minimal, and this is well correlated by the extreme precision with which the ancient Indian mean-motion values match up with modern values for these two planets, differing by only 1/1000 and 2/1000 of a day respectively.
4. Results for Earth and Mars show a slightly greater range of variation, implying that their orbits are affected more by the giant outer planets than by the two innermost



planets. Those for Jupiter and Saturn show substantial variation in orbital mean-motion, varying by 4 and 25 days, respectively, over 10 millennia.

5. Computational results for the Moon show an exceptional stability of variation in mean-motion over 10 millennia, which is consistent with the ancient Indian mean-motion value for the Moon differing from the modern by only 1 s.
6. In summary, the mean motions presented in the *Sūrya Siddhānta* show every indication of being the result of genuine ancient observations collected over a long period of time.

Acknowledgements The author thanks the reviewer for the various suggestions for improvement, which have added value to the paper.

Author contributions Sole author.

Funding Self funded.

Data availability Not applicable.

Declarations

Conflict of interests I am the sole author of this article, and I declare that there is no conflict of interest.

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