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Astronomy of the Hindu pañcāṅga: cāndra māna

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Abstract

The Hindu pañcāṅga is a calendar that was used for timekeeping in India before the adoption of the modern calendar. This Hindu calendar has a sound astronomical basis. All the calendric elements in this calendar such as day, fortnight, month, year etc., are based on the movement of heavenly bodies, primarily the Sun and the Moon. In this article, we provide astronomical definitions of the calendric elements that are based on the movement of the Moon.

Keywords: astronomy , calendar, pañcāṅga, lunar pañcāṅga

Introduction

The Hindu pañcāṅga is used exclusively for religious purposes today. Yet, up until the end of the medieval period, the pañcāṅga served as the civil calendar in India. Time periods such as years, months, fortnights and days were reckoned using the pañcāṅga. Hence, the pañcāṅga can be considered to be a Hindu calendar. This Hindu calendar was scrupulously designed based on the movement of the heavenly bodies, specifically the Sun and the Moon.

While the pañcāṅga has survived till today as a religious artifact, the astronomy of the Hindu calendar has, by and large, been forgotten. In this article we provide the astronomical definitions of the calendric elements that are categorized as cāndra māna – the lunar portion of the Hindu calendar. These calendric elements are used to determine the dates of most of the major Hindu festivals.

This article relies on the Sūrya Siddhanta, one of the oldest astronomical treatises of the Hindu school of astronomy, as its primary source.

Preliminaries

The geocentric model

The astronomy of the Sūrya Siddhanta is based on a geocentric model of the solar system. We know now that the solar system is heliocentric, i.e., the Sun is at the centre. The Sūrya Siddhanta, on the other hand, specifies that the Earth is at the centre. This geocentric model derives its validity from the fact that, for an observer standing on the surface of the Earth, it would indeed appear as if the Earth were at the centre. To visually observe the heliocentric model, the observer would have to relocate to the surface of the Sun!

The ecliptic

The *ecliptic* is the apparent orbit of the Sun around the Earth in the geocentric model. In reality, this is the orbit of the Earth around the Sun.

The ecliptic coordinate system

The ecliptic forms the basis for the two-dimensional *ecliptic coordinate system.*[2] In this system:

- The *ecliptic longitude* of a heavenly body is the position of the body measured along the ecliptic, starting from a defined origin.
- The *ecliptic latitude* of a heavenly body is the position of the body measured perpendicular to the ecliptic with positive and negative signs representing north and south of the ecliptic respectively.

Elongation

Elongation is the angular distance of a heavenly body from the Sun, measured along the ecliptic plane. In other words, this is the difference between the ecliptic longitudes of the Sun and the heavenly body in question. It is customary in astronomical literature (and software) to record elongations east or west of the Sun, whichever is numerically smaller.

Movements of celestial bodies

It is well known that the Sun rises in the east and sets in the west causing day and night. Along with the Sun all other planets and stars too rise and set daily. Such daily movements are referred to as *diurnal* movements.

Diurnal rising and setting is an apparent movement. In reality, the Earth rotates on its axis causing this rising and setting of all heavenly bodies. Diurnal movement is of importance for clocks but when it comes to calendars, we have look beyond diurnal movement.

In the geocentric model, the Sun, the Moon, and the planets are orbiting the Earth whereas the stars are fixed in their position in space. These fixed stars serve as reliable backdrop to observe the movement of the Sun, Moon, and planets. All observations and measurements carried out with respect to these fixed stars are known as *sidereal* observations.

All observations and measurements carried out with respect to another moving body, instead of the fixed stars, are knowns as *synodic* observations, e.g., conjunction and opposition of the Moon (new moon and full moon respectively) are defined with respect to the Sun, which is also moving.

The nine measures of time

A *māna*[3] is a set of measures of time.

The Sūrya Siddhanta defines nine māna as shown in Table 1. Each māna is a collection of calendric elements of durations varying from the very large to the very small.[4]

Table 1 – The nine māna of sūrya siddhanta

māna	calendric elements
brāhma māna	kalpa, parārdha
prajāpatya māna	yuga, caturyuga, manvantara
gurormāna	saṃvatsara
divya māna	divya ahōrātra, divya varṣa
saura māna	sauramāsa, ṛtu, ayana, saura varṣa
pitṛya māna	day and night of the pitṛ
cāndra māna	karaṇa, tithi, pakṣa, cāndramāsa, cāndra varṣa
sāvana mana	sāvana ahorātra
nākṣatra māna	prāṇa, vināḍi, nāḍi, nākṣatra ahorātra

The first two in the above list define calendric elements arithmetically, whereas the rest define calendric elements astronomically. In this article we focus on cāndra māna

cāndra māna

Th *cāndra māna* contains all the calendric elements that are defined using the orbital movement of the Moon relative to the Sun. The calendric elements contained in cāndra māna are:

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[2] Astronomical coordinate systems are used to locate the position of a heavenly body in the sky. All astronomical coordinate systems are two dimensional. The third dimension – distance – is only perceptible as brightness and as such, is not relevant for locating the position of the heavenly body in the sky.

[3] International Alphabet of Sanskrit Transliteration (IAST) is used throughout this article to represent Sanskrit terms.

[4] At the high end, a parārdha is a duration of 155.52 lakh crore years. At the low end, a prāṇa is a duration of 3.989 seconds.

karaṇa – lunar half-day
tithi– lunar day
pakṣa – lunar fortnight
cāndramāsa – lunar month
cāndra varṣa – lunar year

Before defining the above calendric elements, we start by defining two fundamental astronomical phenomena that underpin the design of cāndra māna:

amāvāsyā is the moment in time when the Moon's elongation is 0°. At this moment, the Moon is said to be in conjunction with the Sun. This is nothing but the New Moon.

pūrṇimā is the moment in time when the Moon's elongation is 180°. At this moment, the Moon is said to be *in opposition to* the Sun. This is nothing but the Full Moon.

pakṣa

A *pakṣa* is a fortnight.

śukla pakṣa (the silver fortnight) is the duration of time between an amāvāsyā and the succeeding pūrṇimā. pūrṇimā marks the culmination of śukla pakṣa and hence is included in śukla pakṣa. During this period, the Moon is said to be *waxing*.

kṛṣṇa pakṣa (the black fortnight) is the duration of time between a pūrṇimā and the succeeding amāvāsyā. amāvāsyā marks the culmination of kr□ ṣṇa pakṣa and hence is included in kṛṣṇa pakṣa. During this period, the Moon is said to be *waning*.

cāndramāsa

māsa is a month. *cāndramāsa* is a lunar month. There are two definitions of cāndramāsa:

amānta[5] definition :

A amānta cāndramāsa is the duration of time between two successive amāvāsyā, with the amāvāsyā marking the end of the cāndramāsa. It follows that a cāndramāsa consists of one śukla pakṣa followed by one kṛṣṇa pakṣa. This definition is widely used in southern India.

pūrṇimānta[6] definition:

A pūrṇimānta cāndramāsa is the duration of time between two successive pūrṇimā, with the pūrṇimā marking the end of the cāndramāsa. It follows that a cāndramāsa consists of one kṛṣṇa pakṣa followed by one śukla pakṣa. This definition is widely used in northern India.

Synodic orbital period of the moon

Both the above definitions of a cāndramāsa are equivalent to the synodic orbital period of the Moon. At the end of a synodic orbit, the Moon comes back to the same location with respect to the Sun (i.e., in conjunction with / in opposition to the Sun). Thus, the Moon completes one synodic orbit around the Earth during a cāndramāsa.

The mean synodic orbital period of the Moon is 29.53 days.[7]

Sidereal orbital period of the moon

Geometrically speaking, completion of one sidereal orbit would indicate an angular movement of 360°. At the end of a sidereal orbit the Moon comes back to the same location in space where it started, with respect to the fixed stars, thus completing a 360° rotation.

The sidereal orbital period of the Moon is 27.32 days. This is shorter than the synodic orbital period for the following reason:
Assume the Moon is in conjunction with the Sun (i.e., amāvāsyā). After 27.32 days the Moon will complete one sidereal orbit and return to the starting position, but it is not in conjunction with the Sun now because the Sun has moved forward in its orbit around the earth.[8] It takes the Moon an additional 2.2 days to catch-up with the Sun and reach the next conjunction.[9]
This sidereal orbital period of the Moon is central to the design of a calendric element known as *nakṣatra*.

cāndra varṣa

varṣa is a year.

cāndra varṣa is a lunar year consisting of twelve lunar months. The names of these twelve cāndramāsa, in order, are:

caitra māsa	vaiśākha māsa
jyeṣṭha māsa	āṣāḍha māsa
śrāvaṇa māsa	bhādrapada māsa
āśvina māsa	kārttika māsa
mārgaśīrṣa māsa	pauṣa māsa
māgha māsa	phālguna māsa

The beginning of a cāndra varṣa (i.e., the moment after phālguna amāvāsyā) is celebrated as *cāndra māna yugādi.*

5 amāvāsyā-anta, i.e., ending with amāvāsyā. We use this definition in the rest of this article.
6 pūr□ imā-anta, i.e., ending with pūrṇimā.

7 Since the Sun's orbit is elliptical, the actual synodic period will vary around this mean value.
8 by ~27° (since the Sun moves ~1° per day).
9 since the Moon moves ~12° per day.

Duration of a cāndra varṣa

The following equations derive the duration of a cāndra varṣa:

1 cāndramāsa	=	1 synodic orbit of the Moon
1 cāndra varṣa	=	12 cāndramāsa
	=	12 synodic orbits of the moon
	=	12 x 29.53 days
	=	354.36 days

Reason for twelve cāndramāsa

The Moon orbits the Earth ~12 times faster than the Sun does.

Synodic orbital period of the Moon	=	29.53 days
Sidereal orbital period of the Sun	=	365.256 days
Ratio of lunar and solar orbital periods	=	29.53 **:** 365.256
	=	1 **:** 12.37

This means that by the time the Sun completes one sidereal orbit (i.e., in one sidereal solar year), the Moon would have completed twelve synodic orbits and started off on its thirteenth orbit.

This is the reason that twelve lunar months was chosen to make a lunar year. By choosing a dozen, the duration of a lunar year was brought as close to a solar year as possible without exceeding it.

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tithi

A *tithi* is the time taken by the Moon to advance 12° from the Sun, as measured by its elongation, starting from amāvāsyā. It follows that śukla pakṣa is made up of fifteen tithi (180° divided by 12°); kṛṣṇa pakṣa is also made up of fifteen tithi; and a cāndramāsa is made up of thirty tithi.

Since the duration of a cāndramāsa is 29.53 days and a cāndramāsa is made up of thirty tithi, it follows that the duration of each tithi is approximately one day. Since the lunar and solar orbits are elliptical, the angular velocity of the Moon and the Sun are not uniform throughout their orbit.[10] As a result, the duration of a tithi is not fixed; it fluctuates around twenty-four hours.

Thus, a tithi can be considered to be a *lunar day*[11] but it must be emphasised that a tithi has absolutely no correlation with sunrise. A tithi can start and end at any time of the day (or night).

[10] In modern science, this is codified as Kepler's second law of planetary motion

A tithi is identified by its position within a pakṣa - 1st tithi, 2nd tithi, 3rd tithi, etc. of kr□ṣṇa pakṣa / śukla pakṣa - using the equivalent Sanskrit terms, as follows:

1. prathama tithi
2. dvitīya tithi
3. tṛtīya tithi
4. caturthī tithi
5. pañcamī tithi
6. ṣaṣṭhī tithi
7. saptamī tithi
8. aṣṭamī tithi
9. navamī tithi
10. daśamī tithi
11. ekādaśī tithi
12. dvādaśī tithi
13. trayodaśī tithi
14. caturdaśī tithi
15. pūrṇimā tithi / amāvāsyā tithi

The span of each tithi is enumerated in Table 2.

pūrṇimā tithi / amāvāsyā tithi

In keeping with the above notation, the 15th tithi should have been named pañcadaśī tithi (i.e., 15th tithi). Instead, the terms pūrṇimā and amāvāsyā are reused as the identifiers of the 15th tithi of śukla pakṣa and kṛṣṇa pakṣa respectively.

Thus, the terms pūrṇimā and amāvāsyā have two usages:

- stand-alone they indicate full moon and new moon respectively
- when combined with the term *tithi* they indicate the 15th tithi of śukla pakṣa and kṛṣṇa pakṣa respectively. It is easy to see that pūrṇimā tithi ends with a pūrṇimā and amāvāsyā tithi ends with an amāvāsyā.

tithi associated with a solar day

According to the Sūrya Siddhanta tithi is a very important consideration for Hindus for performing religious ceremonies such as weddings, fasting, pilgrimages, festivals etc. At the same time, all human activity begins with sunrise and a solar day starting at sunrise naturally governs all human activities. In order to force a correlation between a tithi and a solar day, the following convention is used:

The tithi prevailing at sunrise is determined (based on the position of the Moon at sunrise). That tithi is then

[11] though in modern astronomy a lunar day indicates a day on the surface of the Moon!

associated with the entire solar day, even if astronomically the tithi changes in the middle of the day or night. Thus, the question "What is the tithi today?" is answered by determining the tithi prevailing at sunrise.

adhika tithi / kṣaya tithi

Since a tithi can exceed 24 hours, sometimes it happens that the tithi prevailing at two successive sunrises is the same.[12] In such as case, two successive solar days are associated with the same tithi. The second solar day is said to be associated with an *adhika tithi.*[13]

Since a tithi can fall short of 24 hours, sometimes it happens that an entire tithi elapses between two successive sunrises. In such as case, it appears as if the second solar day skipped a tithi and is associated with the next but one tithi. Such a skipped tithi is known as a *kṣaya tithi.*[14]

Table 2 – Span of each tithi

śukla pakṣa		kṛṣṇa pakṣa	
tithi	**elongation of the Moon**	**tithi**	**elongation of the Moon**
prathama tithi	> E0° to <= E12°	prathama tithi	>= W162° to < W180°
dvitīya tithi	> E12° to <= E24°	dvitīya tithi	>= W156° to < W168°
tṛtīya tithi	> E24° to <= E36°	tṛtīya tithi	>= W144° to < W156°
caturthī tithi	> E36° to <= E48°	caturthī tithi	>= W132° to < W144°
pañcamī tithi	> E48° to <= E60°	pañcamī tithi	>= W120° to < W132°
ṣaṣṭhī tithi	> E60° to <= E72°	ṣaṣṭhī tithi	>= W108° to < W120°
saptamī tithi	> E72° to <= E84°	saptamī tithi	>= W96° to < W108°
aṣṭamī tithi	> E84° to <= E96°	aṣṭamī tithi	>= W84° to < W96°
navamī tithi	> E96° to <= E108°	navamī tithi	>= W72° to < W84°
daśamī tithi	> E108° to <= E120°	daśamī tithi	>= W60° to < W72°
ekādaśī tithi	> E120° to <= E132°	ekādaśī tithi	>= W48° to < W60°
dvādaśī tithi	> E132° to <= E144°	dvādaśī tithi	>= W36° to < W48°
trayodaśī tithi	> E144° to <= E156°	trayodaśī tithi	>= W24° to < W36°
caturdaśī tithi	> E156° to <= E168°	caturdaśī tithi	>= W12° to < W24°
pūrṇimā tithi	> E162° to <= E180°	amāvāsyā tithi	>= W0° to < W12°

karaṇa

A *karaṇa* is the time taken by the Moon to advance 6° from the Sun as measured by its elongation, starting from amāvāsyā. A karaṇa is half a tithi.

A day in the Hindu calendar

A day in the Hindu calendar is identified by a triplet consisting of cāndramāsa, pakṣa, tithi.

Hindu festivals

As mentioned earlier, tithi is the determinant for all religious activities including festivals. Hence, the dates of almost all Hindu festivals are fixed based on the cāndra māna calendar. Some examples are shown in Table 3.

We have already seen that a tithi can start at any time in the day (or even in the night) but most human activity, including festival celebrations, is governed by the rising of the Sun. Hence, after the tithi starts, it is customary to wait until the next sunrise before performing the religious ceremonies associated with the festival. In general, the heads of various religious communities decide and communicate the exact pūja muhūrta.[15]

We are all aware that on the modern calendar, Hindu festivals fall on different months and days in different years. Yet, it is evident from Table 3 that they always fall on the same māsa-pakṣa-tithi in every cāndra varṣa of the Hindu calendar.[16]

[12] Very soon after sunrise the tithi will change but such a change is ignored as per the convention explained earlier.
[13] adhika tithi, i.e., extra tithi.
[14] kṣaya tithi, i.e., lost tithi.
[15] pūja muhūrta - time of prayer
[16] There are some community-specific exceptions to this statement. For instance, some communities celebrate Krishna Janmashtami according to the Hindu solar calendar.

Table 3 – Hindu festival dates

festival	cāndramāsa		pakṣa	tithi
	amānta	pūrṇimānta		
Chandramana Yugadi	caitra		śukla	prathama
Rama Navami	caitra		śukla	navamī
Akshaya Tritiya	vaiśākha		śukla	tṛtīya
Krishna Janmashtami	śrāvaṇa	bhādrapada	kṛṣṇa	aṣṭamī
Ganesha Chaturthi	bhādrapada		śukla	caturthī
Durgashtami	āśvina		śukla	aṣṭamī
Maha Navami	āśvina		śukla	navami
Vijaya Dashami	āśvina		śukla	daśamī
Dhan Teras	āśvina	kārttika	kṛṣṇa	trayodaśī
Naraka Chaturdashi	āśvina	kārttika	kṛṣṇa	caturdaśī
Lakshmi Puja	āśvina	kārttika	kṛṣṇa	amāvāsyā
Bali Padyami	kārttika		śukla	prathama
Bhai Dooj	kārttika		śukla	dvitīya
Shiva Ratri	māgha	phālguna	kṛṣṇa	caturdaśī
Holi	phālguna		śukla	pūrṇimā

Summary

The cāndra māna of the Hindu calendar defines a set of calendric elements based on the movement of the Moon relative to the Sun. The definitions of these calendric elements are summarized in Table 4.

Table 4 – Mapping from the Hindu calendar to the modern calendar

māna	Hindu calendric element	modern calendric element	astronomical definition
cāndra māna	amāvāsyā	new moon	Elongation of the Moon = 0°
	pūrṇimā	full moon	Elongation of the Moon = 180°
	śukla pakṣa	waxing fortnight	0° > Elongation of the Moon <= 180°
	kṛṣṇa pakṣa	waning fortnight	180° > Elongation of the Moon <= 360°
	cāndramāsa	lunar month	Synodic orbit of the Moon
	cāndra varṣa	lunar year	12 synodic orbits of the Moon
	tithi	lunar day	$1/30^{th}$ of a synodic orbit of the Moon
	karaṇa	half a lunar day	$1/60^{th}$ of a synodic orbit of the Moon