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Fr. Conceicao Rodrigues College of Engineering

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SCIENCE, ENGINEERING AND TECHNOLOGY IN IKS: ASTRONOMY

सविता यन्त्रैः पृथिवीमरम्णादस्कम्भने सविता द्यामदृहंत् ।
अश्वमिवाधुक्षद्धुनिमन्तरिक्षमतूर्ते बंद्ध सविता समुद्रम् ॥

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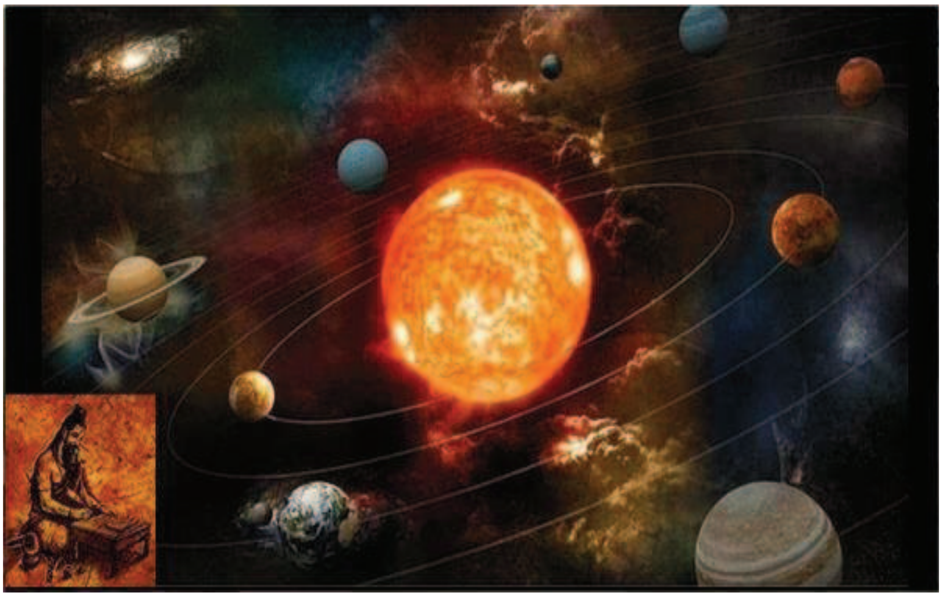


When Copernicus had his theory on heliocentric system, it was regarded as a revolutionary discovery by the scientific community.

However, historians of Vedic science have dated the Earth orbiting the Sun long before Copernicus.

MS 5297
Suryaprajnapti Sutra; astronomy. India, ca. 1500

This picture is a manuscript of Sūryaprajñapti-sūtra in Jain prākṛt on paper found in Western India dating to 1500 CE. It is a Śvetāmbara Jain text belonging to 3rd–4th BCE and is a part of the Jain canonical literature called Upāṅga Āgamas. It is an astronomical work that gives information on the sun, moon and planets and their motions.

Astronomical Instruments presented by the Maharaja of Benares to the Prince of Wales in 1876

S. R. Sarma

During his tour of India in 1875-76, the Prince of Wales (the future Edward VII, Fig. 1) was presented a highly interesting set of astronomical instruments by the Maharaja of Benares (Fig. 2), Sir Ishwari Prasad Narayan Singh, GCSI, on 5th January 1876. Before discussing these instruments and their importance for the history of astronomical instruments in India, we may dwell briefly on the opulence of the reception accorded to the Prince by the Maharaja in his Ramnagar Fort (Fig. 3), as described by the chronicler[1]:

> 'Shortly before sunset the Prince embarked in a handsome galley, [...] which was towed by a steamer to the old fort of Ramnagar, four miles up the Ganges, where the Maharaja of Benares received the Prince on a canopied and garlanded landing. It was the grandest and the most characteristic reception possible. The river-bank was blazing

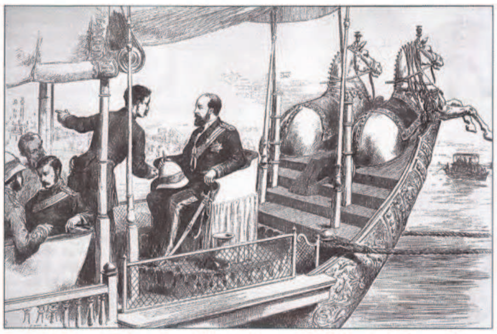


Fig. 1 *The Prince of Wales on board the state barge of the Maharaja of Benares,* The Illustrated London News, *12 February, 1876.*

List of Instruments Gifted

1	Digaṃśa-Yantra	For finding the degrees of Azimuth of a planet/star
2	Dhruva-Prota-Cakra-Yantra	For finding the degrees of declination of a planet/star.
3	Yantra-Samrāt (King of instruments)	For finding the distance (in time) from the meridian and the declination of a planet/star, and of the Sun.
4	Bhitti-Yantra (A Mural Quadrant)	For finding the Sun's greatest declination and the latitude of the place.
5	Viṣuvad-Yantra (Equinoctial Circle)	For ascertaining the distance in time) of the Sun, or of any star from the meridian.
6	Phalaka-Yantra	An instrument for finding the time after sunrise (invented by Bhāskarācārya).
7	Cakra-Yantra	For finding the altitude and zenith distance of the Sun, the longitude of planets.
8	Cāpa-Yantra and Turīya-Yantra	For finding the zenith distance and altitude of the sun.
9	Śaṅku (Gnomon)	To ascertain the points of the compass, the place of the observer (latitude, and time).
10	Armillary Sphere	Represents several celestial circles. By the threads that are fastened within the globe it is possible to determine the parts of any spherical triangle on the globe.

Indian contributions in astronomy

- The celestial entities are an integral part of all living beings on Earth. There is a strong sense of mutual ***dependence between the earthly and the celestial entities***.
- Astronomy, a study of the celestial entities and phenomena is ***interconnected with cultural practices and daily life***. Many events and planning of activities are done with reference to the celestial entities.

> - Knowledge of astronomy was widely used by all sections of Indian society.
> - The observations and computations of measures related to celestial bodies such as stars and planets have been consistently accurate and ahead of the times as observed by many.

'Kālanirṇaya' (Determination of time) was considered the purpose of astronomy. *Consulting the Pañcāṅga is a daily necessity and often the day begins with this activity*.

Indian contributions in astronomy

- Astronomy is not a study of some alien entities but an ***integral and important aspect of one's life***. Several concepts and models were developed by ancient Indians to address this requirement. This partly explains the growth and maturity of astronomical thinking in Indian society right from early times.
- ***Indians developed a systematic procedure of study, observation, data collection, codification, pattern recognition, and analysis***. This led to the development of advanced mathematics including arithmetic, geometry, algebra, trigonometry, and the basics of calculus.

> - Knowledge of astronomy was widely used by all sections of Indian society.
> - The observations and computations of measures related to celestial bodies such as stars and planets have been consistently accurate and ahead of the times as observed by many.

Indian contributions in astronomy

❖The Vedic living required methods for *fixing an auspicious time for performing various rituals and activities*. Knowledge of the cardinal directions is also ***required to set the Vedic altars***.

❖In ancient times, there were two major wealth-generating activities: ***Agriculture and Trade***. Agriculture was the main driver of the economy and wealth creation. Ability ***to predict the weather conditions and understand the mechanism of season formation*** was a key requirement to improve agricultural productivity.

Indian contributions in astronomy

❖The other economic activity is related to ***international trade***. This required a good ***understanding of the latitude, longitude, and loxodrome***. Moreover, there was a need for a calendar as well.

❖Astronomy plays a crucial role in ***navigation***. The basic idea in navigation is to *follow rising or setting location of a particular constellation for a certain period and then turn towards another constellation*. Therefore, knowledge of astronomy becomes crucial. Indians have been regularly using astronomy for *maritime purposes* and some studies suggest that details of this have been well documented.

Astronomy References in Vedic Texts and Their Dating

The concept of Yuga was introduced to synchronize the Solar and Lunar calendars.

- In the Vedāṅga Jyotiṣa the concept of Yuga consisting of 5 solar years, 67 lunar sidereal cycles, 1830 days, and 1835 sidereal days has been defined.
- Nīlakaṇtha Somayājī in 1500 CE proposed a revised model of planetary motion which closely approximates the mathematical model of planetary motion given by Kepler over a hundred years later in 1609.

No.	*Vedic Reference*	*Statement*	*Date*
1	Śatapatha-brāhmaṇa (2.1.2.3)	Kṛttikā (Pleiades) never swerve from the east.	2950 BCE
2	Maitrāyanīya-brāhmaṇa Upaniṣad (6.14)	Winter solstice at the mid-point of the Śraviṣṭhā segment and the summer solstice at the beginning of Māgha.	1660 BCE
3	Vedāṅga-jyotiṣa	Winter solstice at the beginning of Śraviṣṭhā and the summer solstice at the mid-point of Aśleṣā.	1300 BCE
4	Taittirīya-āraṇyaka (II.19.1)	Abhaya Dhruva (currently identified as alpha-Draconis) in the Śiṃśumāra Constellation is the pole star.	2800 BCE*

Indian Astronomers and Their Seminal Contributions

Sl. No.	*Details of the Work/Mathematician*	*Period, Location*	*Salient Contributions*
1	***Author not known*** – *Sūrya-siddhānta*	Prior to 6th century CE	It appears that there are several versions of it available. An ancient version is summarised in Varāhamihira's Pañcasiddhāntikā. A modern version is very popular even now among the traditional scholars and calendar makers.
2	**Varāhamihira** – *Pañca-siddhāntikā*	6th century CE	Presents an updated summary of five ancient siddhāntas.
3	**Āryabhaṭa** – *Āryabhaṭīyam*	Born 476 CE; Kusumapura, near Pataliputra, Bihar	A section on mathematics, foundations of trigonometry; Calculation of the sine function; Rotation of the Earth; Accurate algorithms for the positions of the Sun, the Moon and planets; Earth in the cosmos; Eclipses.
4	**Bhāskara I** – *Āryabhaṭīya-bhāṣya, Mahā-bhāskarīya*	7th century CE	Commentary on Āryabhaṭīyā explaining its mathematics and astronomy in detail; Develops the Āryabhaṭan system in his own texts.

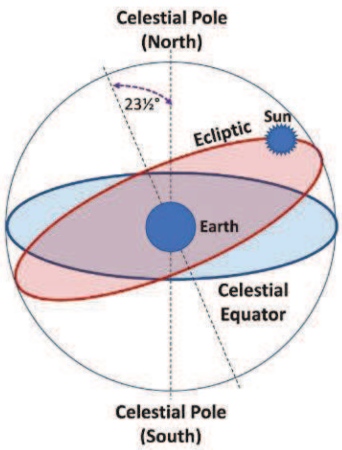
Indian Astronomers and Their Seminal Contributions

5	**Brahmagupta** – *Brāhmasphuṭa-siddhānta, Khaṇḍakhādyaka*	7th century CE	A detailed system of calculations pertaining to the Sun, the Moon, and planets; Many new algorithms and explanations in astronomy. path-breaking results in mathematics like vargaprakṛti (quadratic indeterminate equations), and cyclic quadrilaterals; Khaṇḍakhādyaka, a practical manual of Indian astronomy.
6	**Lalla** – *Śiṣyadhīvṛddhida-tantra*	8th–9th century CE	A textbook which expounds on the Āryabhaṭan system, with new algorithms.
7	**Mañjulācārya** – *Laghumānasa*	10th century CE	An explicit expression for the 'second correction' to the longitude of the Moon; Derivative of sine function and instantaneous velocity of the Sun and the Moon.
8	**Śrīpati** – Siddhānta-śekhara	11th century CE	An important text quoted by the later astronomers.
9	**Bhāskarācārya II** – *Siddhānta-śiromaṇi, Vāsanābhāṣya, Karaṇakutūhala*	Born 1114 CE	Most of the standard calculations and algorithms in Indian astronomy included, mistakes rectified, generalizations made, a calculation-manual using ready-made tables, and arithmetical simplifications.

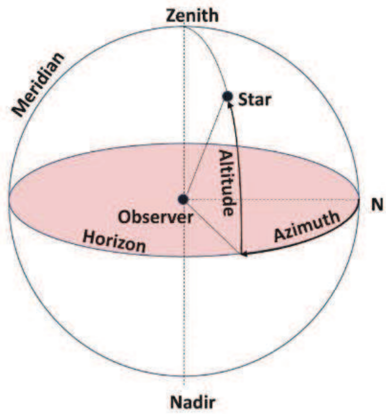
Indian Astronomers and Their Seminal Contributions

10	**Kerala School** **Mādhava of Saṅgamagrāma**– *Veṇvāroha, Sphuṭacandrāpti* **Parameśvara of Vaṭasseri**– *Dṛgganita, Bhaṭadīpika, Siddhānta-dīpikā* **Nīlakaṇṭha Somayājī or Somasutvan of Trikkantiyur**–*Tantra-saṅgraha, Āryabhaṭīya-bhāṣya* **Jyeṣṭhadeva** – *Gaṇita-yuktibhāṣā* Acuyta Pisaroti–*Sphuṭanirṇayatantra* Śankaravarman– *Ṣaḍratnamāla*	**14th–19th Century** 1340–1425 CE 1360–1455 CE 1444–1550 CE 1500–1610 CE 16th century CE 19th century CE	This school made important contributions to mathematical analysis – Derivation of infinite series for π, sine and cosine functions, much before the subject developed in Europe. A major revision of the traditional planetary theory in 1500 CE. Innovations in astronomical computations; Systematisation of the applications of spherical trigonometry to astronomy; Improved theory of eclipses.
11	**Gaṇeśa Daivajña** – *Grahalāghava*	Born 1507 CE	Simplified procedures for calculation of planetary positions, used for preparing almanacs or Pañcāṅgas even now.
12	**Kamalākara**–*Siddhānta-tattva-viveka*	Born 1616 CE	Elaborate work mostly based on Indian concepts and parameters but incorporates elements of the Greek astronomer Ptolemy's system.
13	**Candraśekhara Sāmanta** – *Siddhānta-darpaṇa*	Born 1835 CE	Important modifications in planetary parameters revised the lunar theory, designed simple instruments, reformed the traditional calendar of Odisha.
14	**Rājā Sawai Jai Singh** – *Yantrarāja-racanā, Zij Muhammad Shahi*	1688–1743 CE	Built famous observatories in several parts of North India.

The celestial coordinate system



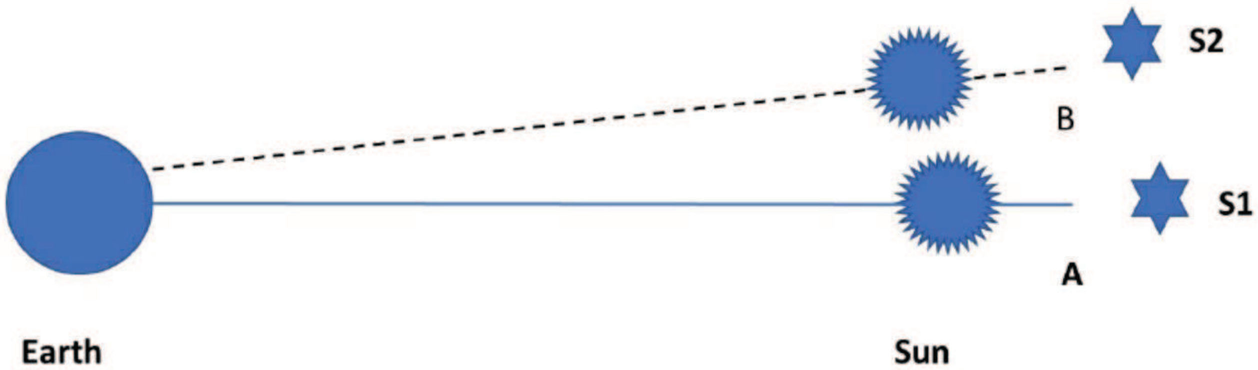
(a) Illustration of an Ecliptic



(b) Azimuth and Zenith

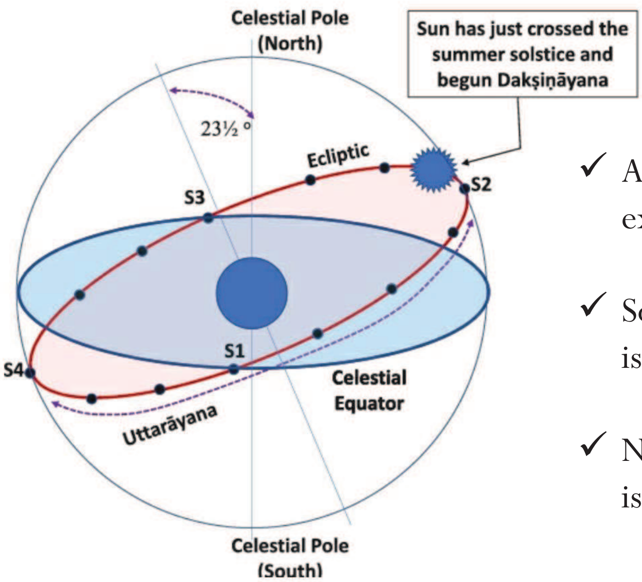
- ✓ ***Ecliptic*** is an imaginary line depicting the Sun's movement around earth.
- ✓ The ***zenith*** is an imaginary point directly 'above' a particular location (highest point), on the celestial sphere and ***nadir*** is 180° from zenith (the lowest point).
- ✓ The vector from an observer to a point of interest (such as a star or any celestial body) is projected perpendicularly onto a reference plane. The angle between the projected vector and a reference vector on the reference plane is called the ***azimuth***.

The celestial coordinate system



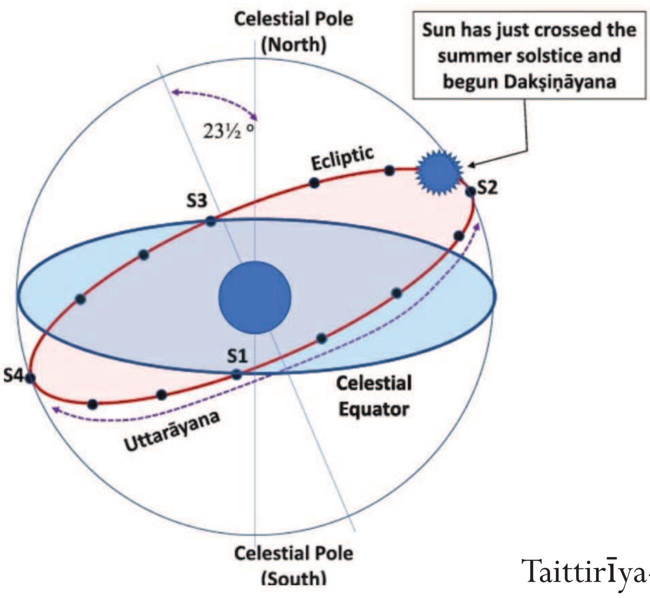
Motion of the Sun in the Background of Stars

The celestial coordinate system



- ✓ A solstic occurs when the sun's path crosses the extreme north or south points on the earth's equator.
- ✓ Southernmost point (S4) with respect to the equator is **'winter solstice**'.
- ✓ Northernmost point (S2) with respect to the equator is **'summer solstice'.**

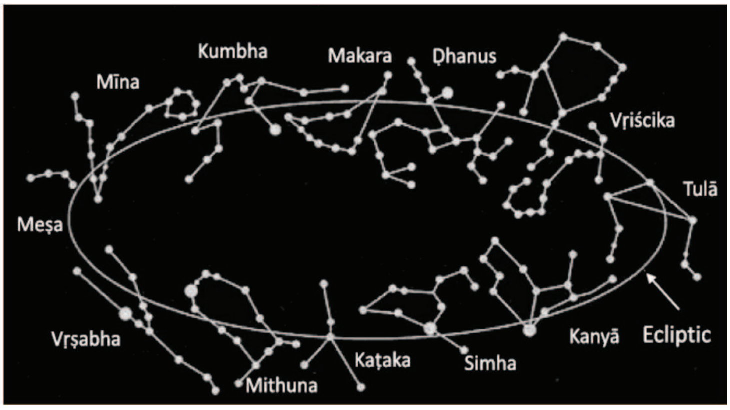
The celestial coordinate system

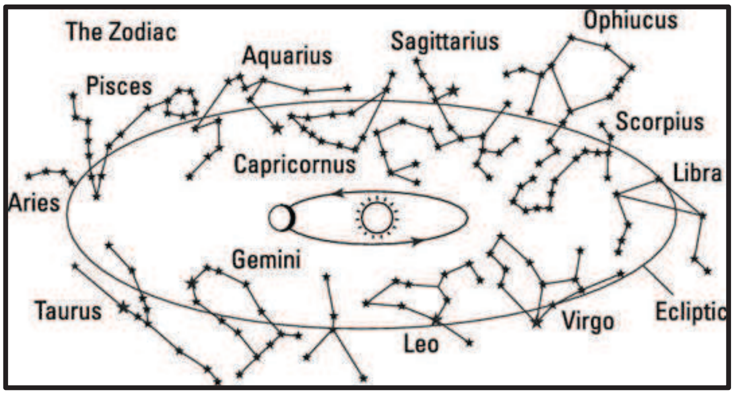


- ✓ At S1 and S3, the ecliptic intersects the equator, and these points are known as the **equinoxes**.
- ✓ When the Sun is at equinox it is **equinoctial day** (**viṣuvat**) is mentioned in Aitareya-brāhmaṇa (18.4)
- ✓ Methods to compute the nth equinox is available in Vedāṅga-jyotiṣa.
- ✓ Between S4 and S2, the Sun moves northwards (known in the Indian system as **Uttarāyaṇa**)
- ✓ Between S2 and S4, the Sun moves southwards (known as **Dakṣiṇāyana**).

Taittirīya-saṃhitā (6.5.3) observes8, 'Thus the Sun moves southwards for six months and northwards for six months'.

The Zodiac Signs on the Ecliptic





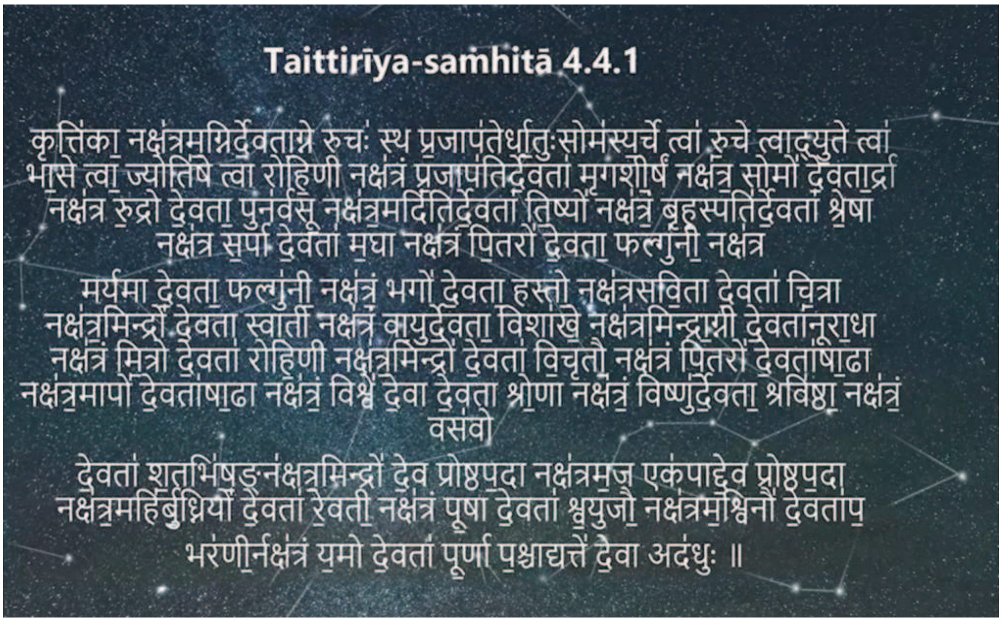
The '***sidereal period***' of an object is the time taken by it to complete one revolution in the background of stars.

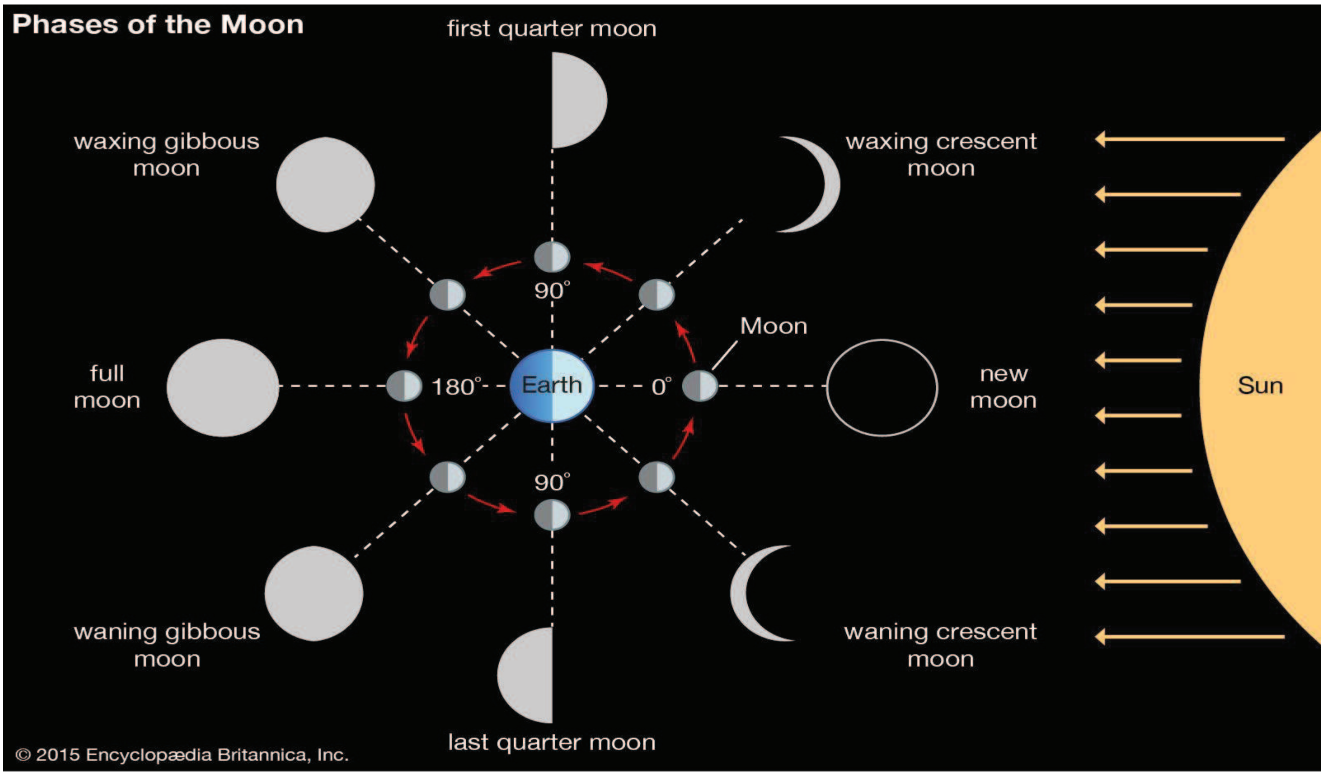
The Moon's sidereal period is close to 27.32 days, which constitutes one lunar cycle.

The 27 nakṣatras are mapped on to the 12 rāśis. Therefore, each rāśi is associated with two and a quarter (27/12) nakṣatra.

In the Indian system, the zodiac has been divided into 27 equal parts from a fixed initial point in the ecliptic in order to trace the trajectory of the Moon in the context of the stars. Each such division is known as **nakṣatra**, measuring 13° 20′ or 800 minutes of arc of the ecliptic (360/27). Each division is named after a selected star that is generally prominent or traditionally well-known and is broadly equally spaced in the zodiac.

No.	Name
1	Ashwini
2	Bharani
3	Krittika
4	Rohini
5	Mriga
6	Ardra
7	Punarvasu
8	Pushya
9	Aslesha
10	Magha
11	Purvaphalguni
12	Uttarphalguni
13	Hasta
14	Chitra
15	Swati
16	Vishaka
17	Anuradha
18	Jyeshta
19	Moola
20	Purvashada
21	Uttarashada
22	Shravana
23	Dhanishta
24	Shatataraka
25	Purvabhadrapad
26	Uttarbhadrapad
27	Revati





Moulding Engineers Who Can Build the Nation

Elements of the Indian calendar
Notion of years and months

The Notion of a Year

द्वादशारं नहि तज्जराय वर्वर्ति चक्रं परि द्यामृतस्य ।
आ पुत्रा अग्ने मिथुनासो अत्र सप्त शतानि विंशतिश्च तस्थुः ॥
dvādaśāraṃ nahi tajjarāya varvarti cakraṃ pari dyāmṛtasya |
ā putrā agne mithunāso atra sapta śatāni viṃśatiśca tasthu: ||

(Ṛgveda 1.164.11)

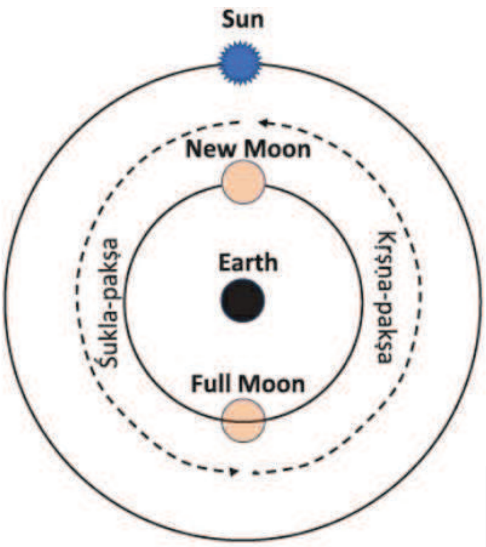
The wheel (of time), formed with twelve spokes, revolves around the heavens, without wearing out. O Agni, on it, are 720 sons (viz., days and nights)". According to this verse, a year has 12 months and 360 days.

The Vedic year consisted of 12 months, each of 30 days (known as Sāvana)

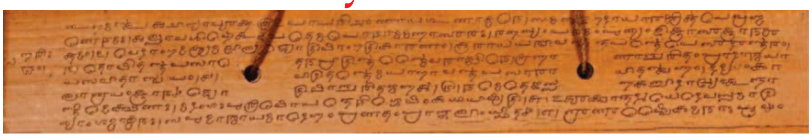
Alternative Classification of Year Cycles in the Indian Tradition

	Solar Year	*Sāvana Year*	*Lunar Year*
Year	12 Solar Months (366 days)	12 Sāvana Months (360 days)	12 Lunar Months (354 days)
Month	30.5 days	30 days	29.5 days
Yuga	60 Solar Months	61 Sāvana Months	62 Lunar Months
Remarks	Known as Saṃvatsara	Known as Idāvatsara	Known as Anuvatsara

Solar and Lunar Months



Sūrya-siddhānta



Solar month as the time taken by the Sun to traverse a rāśi,

A lunar month (cāndra-māsa) is the time interval between two new Moons (Amāvāsyā), or two full Moons (Pūrṇimā).

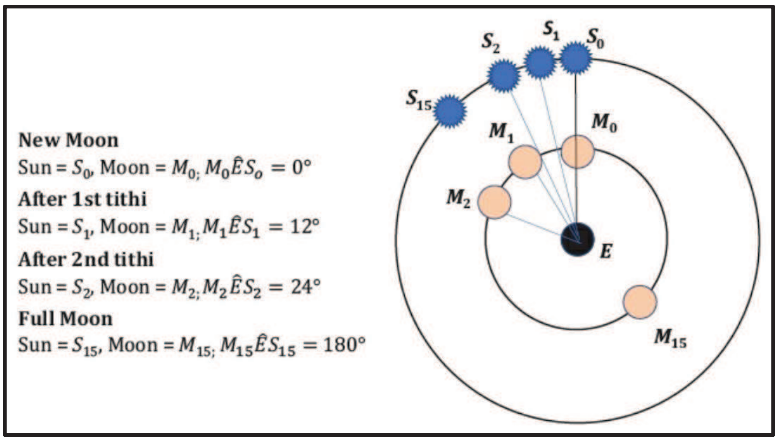
Lunar month (Pakṣas):
Śukla-pakṣa (bright fortnight) from Amāvāsyā to Pūrṇimā
Kṛṣṇa-pakṣa (dark fortnight) from Pūrṇimā to Amāvāsyā.

Lunar Months

Hindu	Gregorian
Chaitra	Mar-Apr
Vaishaka	Apr-May
Jyestha	May-Jun
Ashada	Jun-Jul
Shravan	Jul-Aug
Bhadrapada	Aug-Sep
Ashvina	Sep-Oct
Kartik	Oct-Nov
Margashirsha	Nov-Dec
Pausha	Dec-Jan
Megha	Jan-Feb
Phalgun	Feb-Mar

- Vedāṅga-jyotiṣa is the first text in India to give mathematical algorithms in astronomy
- There are short algorithms for finding tithi, nakṣatra, Sun's position in the sky, etc.

The Notion ofTithi



- Tithi captures the angular separation between the Sun and the Moon.
- It is a time-unit during which the angle between the Sun and the Moon (as viewed from the Earth) increases by 12° or its integral multiples.
- The actual duration of a particular tithi may vary from 26 hours 47 minutes to 19 hours 59 minutes.

How to Compute the Quantum of Daytime on any Day?

Vedāṅga-jyotiṣa, gives a simple arithmetical rule for the duration of the daytime (in verse 22 of the *Ṛgveda* version and verse 40 of *Yajurveda* version):

यदुत्तरस्यायनतो गतं स्याच्छेषं तथा दक्षिणोऽयनस्य ।
तदेकषष्ट्या द्विगुणं विभक्तं सद्वादशं स्याद्दिवसप्रमाणम् ॥
yaduttarasyāyanato gataṃ syāccheṣaṃ tathā dakṣiṇo'yanasya |
tad-ekaṣaṣṭyā dviguṇaṃ vibhaktaṃ sadvādaśaṃ syād-divasapramāṇam ||

According to this, the number of days which have elapsed in the northward course of the Sun (Uttarāyaṇa) or the remaining days in the southward course (Dakṣiṇāyana) doubled and divided by 61, plus 12, is the daytime (in muhūrtas) of the day taken. Hence, the duration of the daytime D_t is given by: $D_t = \left(12 + \frac{2n}{61}\right)$ muhūrtas, where n denotes the number of days elapsed in Uttarāyaṇa, or the number of days yet to elapse in Dakṣiṇāyana and muhūrta = 1/30th of a civil day (of 24 hours).

Āryabhaṭīya: Magnum Opus in Indian Astronomy

Āryabhaṭīya is the first pioneering work that established the framework for mathematical astronomy in India.

- Procedures to calculate the planetary positions, eclipses
- The times of sunrise and sunset Duration of the day
- Relation between the shadow of the Sun and the time
- Many other quantities of astronomical interest

Āryabhaṭīya and the Siddhāntic Tradition

Organisation of Āryabhaṭīya and the Issues Covered

No.	Section Name	No. of Verses	Issues Covered
1	Gītikāpāda	13 verses	The letter-numeral notation for numbers, concepts of Kalpa and Mahāyuga, revolution numbers of planets and parameters associated with them
2	Gaṇitapāda	33 verses	Square, Square root, cube, cube root, areas of a triangle, a trapezium, and general plane figures, volumes of right pyramids and spheres, value of π, methods for computing Sines geometrically, constructing a sine table, arithmetic progression, summation of first n natural numbers, the sum of their sums, sums of squares and cubes of first n natural numbers, Kuṭṭaka procedure to solve linear indeterminate equations, relative velocities of moving objects, and a problem related to interest calculation
3	Kālakriyāpāda	25 verses	Reckoning of time, calendrical concepts, planetary models (epicycle and eccentric circle theories), and explicit procedures for calculation of planetary positions, etc.
4	Golapāda	50 verses	Problems of spherical astronomy as seen at different latitudes, diurnal problems associated with the motion of the Sun, Moon, and planets on the celestial sphere, situation of the earth and its shape, brightness/darkness of planets, parallax, lunar eclipses, solar eclipses and so on.

According to Āryabhaṭa, the Earth is a sphere at the center of the framework in which stars and planets move. According to a verse in Āryabhaṭīya:

"The globe of the Earth stands (supportless) at the center of the circular frame of asterisms surrounded by the orbits (of the planets); it is made up of water, earth, fire, and air and is spherical."

According to the earlier astronomical works in India and elsewhere, the Earth was stationary, and all the celestial objects rotated in the sky, completing one rotation in one day. The celestial objects rise in the eastern part of the sky, and set in the western part, and are visible when they are above the horizon.

However, Āryabhaṭīya presented a different view. The diurnal motion of the celestial objects was mentioned in one of the verses as follows:

"Just as a man in a boat moving forward sees the stationary objects as moving backward, just so are the stationary stars seen by people at Lanka (on the equator), as moving exactly towards the west."

What is implied in this verse is that though it appears that objects in the sky are moving from east to west, they are indeed stationary, and it is the Earth which is moving (rotating) along with the entities situated on it.

Mahāyuga

✓ Kṛta
✓ Tretā
✓ Dvāpara
✓ Kali

The beginning of the current Kali-yuga was on a Friday (18 February, 3102 BCE).

Planetary Revolutions in a Mahā-yuga and the Inferred Sidereal Periods in Āryabhaṭīya

Planet	*No. of Revolutions*	*Sidereal Period*	*Modern Value*
Sun	43,20,000	365.25868	365.25636
Moon	5,77,53,336	27.32167	27.32166
Moon's Apogee	4,88,219	3231.98708	3232.37543
Moon's Nodes	2,32,226	6974.7491	6793.39108
Mecury*	1,79,37,020	87.96988	87.96930
Venus*	70,22,388	224.69814	224.70080
Mars	22,96,824	686.99974	686.97970
Jupiter	3,64,224	4332.27217	4332.58870
Saturn	1,46,564	10766.06465	10759.20100

The apparent motions of the Sun, Moon, and planets in the background of stars are not uniform.
Two corrections have to be applied to the 'mean longitude, θ_0 to obtain the 'true' (geocentric) longitude.

Manda-saṃskāra:

To obtain heliocentric longitudes of all planets

1. **Manda-saṃskāra**:

✓ This is due to the non-uniformity of motion due to the eccentricity of the planet's orbit. It is called the 'Equation of centre' in modern astronomy.

✓ This is the only correction to the Sun and the Moon (for Moon, there are some other minor corrections specified in later texts).

✓ In the case of the actual planets called **tārāgrahas** in India (traditionally only Mercury, Venus, Mars, Jupiter, and Saturn), we obtain the **true heliocentric longitude**, that is, the longitudes with respect to the Sun after the manda-saṃskāra.

Śīghra-saṃskāra:

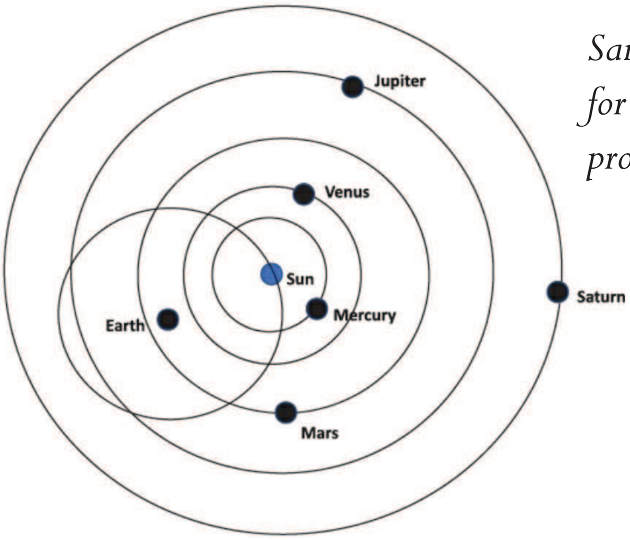
Convert the heliocentric longitudes of planets to geocentric longitudes

2. **Śīghra-saṃskāra**: This correction is done only for the planets. This converts their heliocentric longitudes (as observed from the Sun) to the geocentric longitudes (as observed from the Earth).

Nīlakaṇṭha Somayāji's Planetary Model (1500 CE)

(Tantra-saṅgraha)

According to this model, the planets move in eccentric orbits around the Sun (that is, the centers of the orbits will be slightly displaced from the Sun), which itself orbits around the Earth.



Same as Tycho Brahe's model for the planetary motion proposed around 1580 CE

Pañcāṅga – The Indian Calendar System

Pañcāṅga, as the name suggests has five components:

tithi, nakṣatra, vāra, karaṇa, and yoga.

Tithi:	Karaṇa:	Nakṣatra:	Yoga:	Vāra:
Captures the angular separation between the Sun and the Moon	Half of a tithi	The particular portion of the ecliptic in which the Moon is situated	The period during which the sum of the nirayana longitudes of the sun and the moon amounts to 13° 20' or integral multiples	The day of the week

Pañcāṅga – **Calculations:**

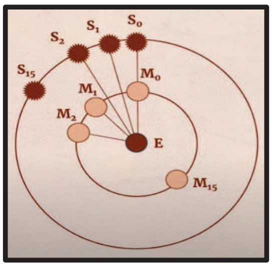
- ✓ Use Sūrya-siddhānta
- ✓ In recent times,
    - Graha-lāghava of Gaṇeśa Daivajña
    - Siddhānta-darpaṇa of Candraśekhara Sāmanta

Tithi

Let θ_M and θ_S be the true Longitudes of the Moon and the Sun in degrees respectively at any instant.

Let, $\frac{(\theta_M - \theta_S)}{12} = I + f$ where I is an integer, and f is the fractional part.

Then I is the number of tithis that have elapsed in the lunar month.



Case 1: $(\theta_M) = 60°\ 12'$ and $(\theta_S) = 19°\ 7'$, the computations are as follows:

$$\frac{(\theta_M - \theta_S)}{12} = \frac{(60°\ 12' - 19°\ 7')}{12} = \frac{41°\ 5'}{12} = 3\frac{61}{144}$$

Therefore 3 tithis have elapsed, and the current tithi is 4th, which is Caturthī in Śukla-pakṣa.

Case 2: $(\theta_M) = 201°\ 2'$ and $(\theta_S) = 219°\ 17'$. Since $\theta_M < \theta_S$ we add 360° before performing the subtraction.

$$\frac{(\theta_M - \theta_S)}{12} = \frac{(561°\ 2' - 219°\ 17°)}{12} = \frac{341°\ 45'}{12} = 28\frac{23}{48}$$

Therefore 28 tithis have elapsed, and the current tithi is 29th, which is Caturdaśī in Kṛṣṇa-pakṣa.

Karaṇa

This is **half of a tithi.** In one karaṇa, the angular separation between the Moon and the Sun increases by **6°.** There are **60 karaṇas in a lunar month**.

At any instant, the procedure to find the number of karaṇas elapsed, and the time elapsed in the current karaṇa is the same as for the tithi except that **12 should be replaced by 6.**

Case 1:

$$\frac{(\theta_M - \theta_S)}{6} = \frac{(60° 12' - 19° 7')}{6} = \frac{41° 5'}{6} = 6\frac{61}{72}$$

So, 6 karaṇs have elapsed, and the current karaṇā is 7th.

Case 2:

$$\frac{(\theta_M - \theta_S)}{6} = \frac{(561° 2' - 219° 17')}{6} = \frac{341° 45'}{6} = 56\frac{23}{24}$$

So, 56 karaṇs have elapsed, and the current karaṇa is 57th.

Nakṣatra

The ecliptic is divided into 27 equal parts called nakṣatras beginning with Aśvinī and ending with Revatī. Hence each nakṣatra corresponds to $\frac{360 \times 60}{27} = 800$ minutes along the ecliptic.

The nakṣatra at any instant refers to the particular portion of the ecliptic in which the Moon is situated.

When the longitude of the Moon in minutes is divided by 800 the quotient gives the number of nakṣatras that have elapsed, and the remainder corresponds to the minutes covered by the Moon in the present nakṣatra.

If we consider the above example, the nakṣatras for the two longitudes of the Moon will be as follows:

To find the nakṣatra, we first convert θ_M into minutes and divide it by 800.

Case 1: $(\theta_M) = 60° 12' = 3612'$.

Nakṣatra = $\frac{3,612}{800} = 4\frac{103}{200}$.

Therefore 4 nakṣatras have elapsed,

and the current nakṣatra is 5th (Mṛgaśiras).

Case 2: $(\theta_M) = 201° 2' = 12,062'$.

Nakṣatra = $\frac{12,062}{800} = 15\frac{31}{400}$.

Therefore 15 nakṣatras have elapsed,

and the current nakṣatra is 16th (Viśākhā).

Yoga

- ✓Yoga means addition, which indicates the period during which the sum (yoga) of the nirayana longitudes of the Sun and the Moon amounts to 13° 20′ or integral multiples.
- ✓The yoga at any moment can be found by **dividing the sum of the longitudes of the sun and moon at the moment by 13° 20′**.
- ✓**The quotient will give the serial number of the yoga expired** and **the remainder will give the elapsed part of the current yoga in units of arc.**
- ✓It pertains to a 27-fold division of the ecliptic. $\theta_S + \theta_M$ in degrees is found (if the number exceeds 360, we can subtract 360 from it). It is converted into minutes (by multiplying this by 60) and then divided by 800. The quotient (Q) represents the number of yogas completed, and Q + 1 represents the current Yoga.

Yoga

Case 1: $(\theta_M) = 60° \, 12'$; $(\theta_S) = 19° \, 7'$; $\theta_M + \theta_S = 60° \, 12' + 19° \, 7' = 79° \, 19'$

Converting it to minutes, we get 4759′. Dividing this by 800, we get,

$$\frac{4759}{800} = 5\frac{759}{800}.$$

Therefore, five yogas have elapsed and the current one is 6th.

Case 2: $(\theta_M) = 201° \, 2'$; $(\theta_S) = 219° \, 17'$; $\theta_M + \theta_S = 201° \, 2' + 219° \, 17' = 420° \, 19'$

After subtracting 360° from this and converting

it to minutes, we get 3619′. Dividing this by 800, we get,

$$\frac{3619}{800} = 4\frac{419}{800}$$

Therefore, four yogas have elapsed and the current one is 5th.

Vāra

Vāra is the day of the week as we know it in modern parlance.

Āryabhaṭa I was the first astronomer in the world to conceive the brilliant idea of counting continuously the days without the involvement of months and years which varies from one calendar to another. This system is named **'ahargaṇa'**, literally meaning **'count of days'.**

As per Āryabhaṭīya, the beginning of the current Kali-yuga was on a Friday (18 February, 3102 BCE).

Let A be the ahargaṇa corresponding to a given day. Divide A by 7. If the remainder is 0, the given day is a Friday, if it 1, it is a Saturday, etc. This is used to check the computed value of A.

0. Friday
1. Saturday
2. Sunday
3. Monday
4. Tuesday
5. Wednesday
6. Thursday

Suppose the ahargaṇa of the day for which we need to compute the pañcāṅga is 18,70,348. The day of the week is determined as follows: *The ahargaṇa of the day is 18,70,348. Dividing this by 7 we get a quotient of 2,67,192 and a reminder of 4. For reminder 4, the day of the week is Tuesday.*

Indian Astronomical Instruments

Gola-yantra
(The armillary sphere)
A sphere in which all movable and fixed circles are designed and serves the purpose of an astrolabe.

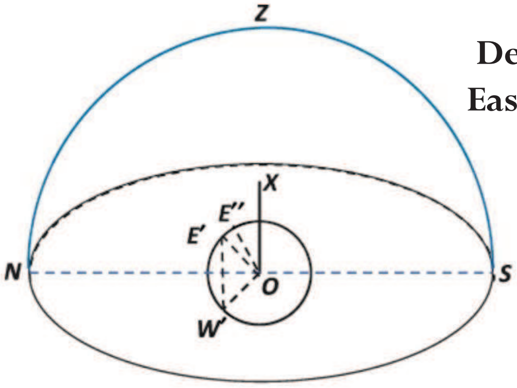
Gati- yantra
A drone (bowl-shaped) water-clock with a hole at its bottom.

Nara or Sanku
(The Gnomon) made of Ivory or a metal

Indian Astronomical Instruments

Procedure for Fixing the Cardinal Direction

The simplest instrument is just a straight, vertical stick **(Sanku)** which has a pointed tip (called a **'gnomon'** in astronomy).

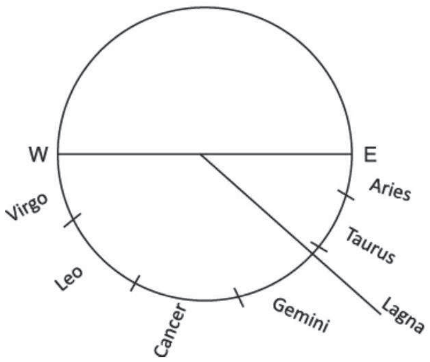


Determination of the East-West Line Using a Gnomon

- ❖ Place a Gnomon OX exactly vertical level on the ground, so that its tip at X points at the Zenith Z.
- ❖ Draw a circle with a suitable radius with the base of the gnomon O as the centre.
- ❖ Mark the points 'W' and 'E' where the tips of the shadow of the gnomon are on the circle, in the forenoon and the afternoon, respectively.

Indian Astronomical Instruments

Nadivalaya Yantra



* The spacing of zodiac markings are proportionate to their rising times at the place installation.

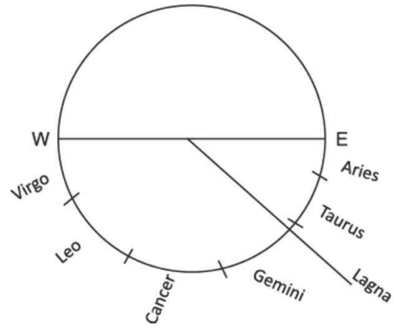
Nāḍīvalaya – A Simple Illustration

- ✓ The **Nāḍīvalaya** is a larger circular wooden disc with an axis in the centre.
- ✓ Divided into 60 ghatikas and also into 12 signs of the ecliptic with variable arcs corresponding to the periods of their risings in the place of observation.
- ✓ The disk is rotated around the axis so that the shadow of the axis falls on the mark made for the position of the Sun at sunrise.
- ✓ The number of **ghatis** will be seen between the point of sunrise to the position of the shadow which will also indicate the **lagna**.

Indian Astronomical Instruments

Nadivalaya Yantra

Nāḍīvalaya – A Simple Illustration



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1. The **Nāḍīvalaya** is a larger circular wooden disc with an axis in the centre.
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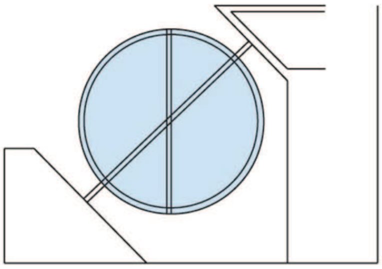
3. The disk is rotated around the axis so that the shadow of the axis falls on the mark made for the position of the Sun at sunrise.
4. The number of **ghatis** will be seen between the point of sunrise to the position of the shadow which will also indicate the **lagna**.

Astronomical Instruments Described in Siddhānta-śiromaṇi

1. **Gola-yantra, the armillary sphere:** A sphere in which all movable and fixed circles are designed. An observer can perform observations sitting within the sphere itself This instrument serves the purpose of an astrolabe. Bhāskarācārya performed lunar observations with the help of this instrument and compiled his Bījopanaya.
2. **Cakra-yantra:** A wooden or metallic wheel-like structure with an axis fixed in a hole at its centre. It was used to determine longitudes and latitudes of planets.
3. **Cāpa-yantra:** This is half the structure of Cakra yantra.
4. **Turīya-yantra:** This constitutes one quadrant of the Cakra yantra with a stick or nālika (tube) for observing celestial bodies in order to determine their zenith distances and altitudes.
5. **Nāḍīvalaya:** A cakra in the plane of the equator used to determine directly timings of rising and setting of signs.
6. **Ghatī-yantra:** A droṇa (bowl-shaped) water-clock with a hole of standardized size at its bottom.
7. **Nara or Śaṅku:** (the gnomon) made of Ivory or a metal.
8. **Phalaka-yantra:** A plank with a circle of radius 30 aṅgulas drawn on it. The circle graduated in ghaṭīs and degrees. When hanging in the plane of vertical circle, the instrument can read zenith distance directly through graduations on the circle.
9. **Dhī-yantra:** It is a simple stick instrument (augmented by a plumbline-like device to assign vertical direction). It was used to determine the heights and distances of objects by measuring the inclinations or angles of elevation at different points.

Cakra-Yantra

When the instrument is illuminated by the rays of the Sun on both sides, the shadow of the needle gives angular height of the Sun.



A Simple Representation of Cakra-Yantra

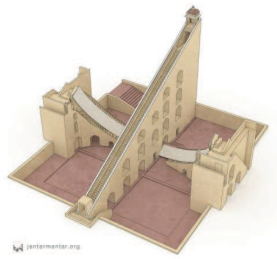
Capa Yantra

Half the structure of Cakra Yantra

Turiya Yantra

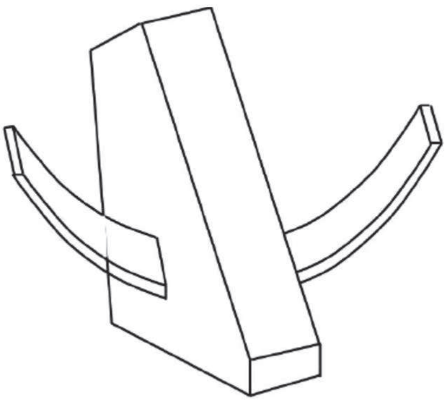
(one quadrant of the Cakra)

Jantar Mantar of Rājā Jai Singh Sawai (1686-1743 CE)



East Side of Samrāṭ-yantra 2 at Delhi Jantar Mantar

The Samrat Yantra is an enormous sundial: a 27m-high triangular wall with two semi-circular ramps that radiate like wings from its sides



A Simple Sketch of Samrāṭ-yantra

धन्यवाद
Thank you

આભાર شکریہ धन्यवाद ਤੁਹਾਡਾ ਧੰਨਵਾਦ நன்றி ధన్యవాదాలు
ಧನ್ಯವಾದ നന്ദി धन्यवाद આભાર شکریہ धन्यवाद ਤੁਹਾਡਾ ਧੰਨਵਾਦ
நன்றி ధన్యవాదాలు ಧನ್ಯವಾದ നന്ദി આભાર شکریہ धन्यवाद ਤੁਹਾਡਾ
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ਧੰਨਵਾਦ நன்றி ధన్యవాదాలు धन्यवाद ਤੁਹਾਡਾ ਧੰਨਵਾਦ
நன்றி ధన్యవాదాలు