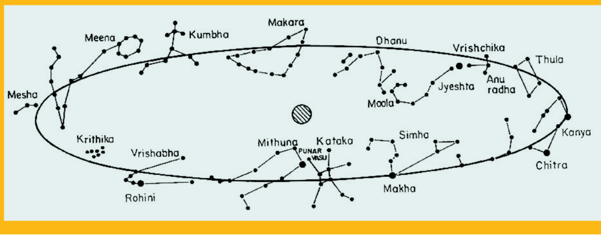
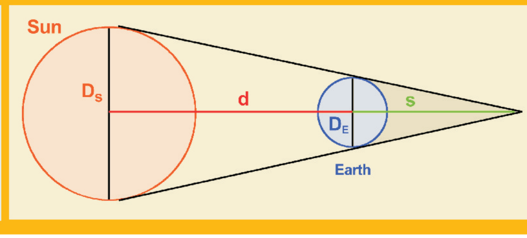




Astronomy in India: A Survey

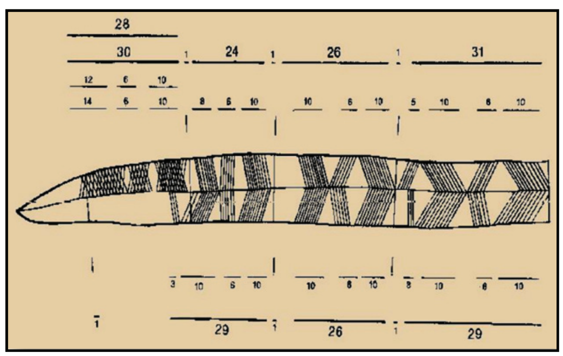
In every ancient culture, astronomy was born before mathematics: there is, in fact, no need of maths to look at the sky, observe the periodicity of the moon's phases, of a few identifiable planets, the northward or southward journey of the sunrise on the eastern horizon through the year, or to trace imaginary lines between the stars.

What do you think were the ancients' immediate needs that they thought could be met through an observation of the night sky?

The Beginnings of Indian Astronomy

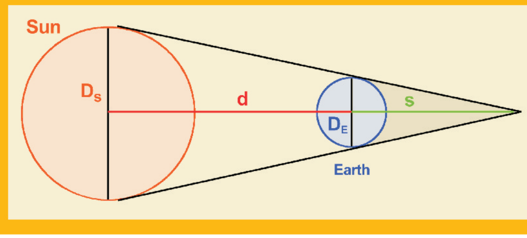
And that is indeed how the story of astronomy always begins. In India, those beginnings are not adequately documented. The first 'astronomical' objects, found in the Andamans, belong to the palaeolithic era, some 12,000 years ago; they are calendar sticks noting the waxing and waning* of the moon by incising daily notches on a wooden stick.

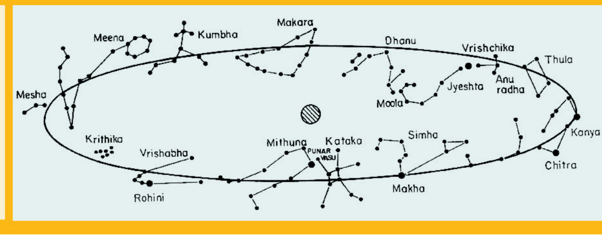
Observe this stick and interpret its various sections. How can they be related to the phases of the moon?



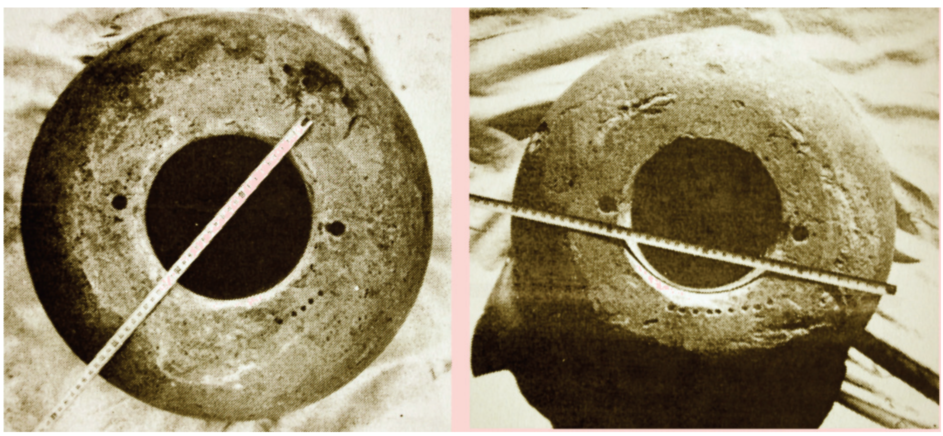
One of the calendar sticks found in the Andaman islands, apparently recording lunar phases across several months

* The apparent increase (waxing) and decrease (waning) of the moon's disc from new moon to full moon and back, in the course of a lunar month.



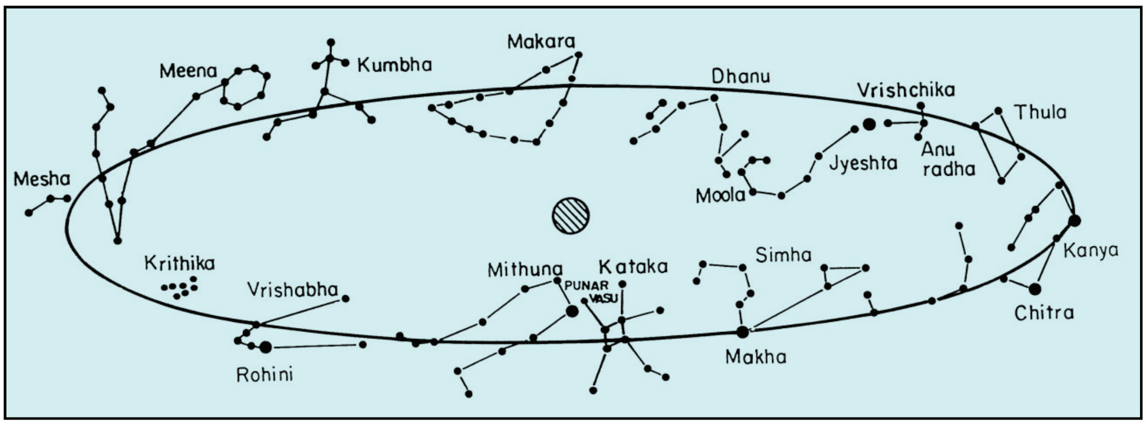


Patterns of rock art found in Kashmir, such as a double sun or concentric circles, have convinced some scholars that they were depictions of a supernova and meteor showers respectively, perhaps witnessed some 7,000 years ago. Ring-stones found at Mohenjo-daro, the largest city of the Indus civilization (2600-1900 BCE), which exhibit rows of small drilled holes, have been interpreted as calendrical devices keeping track of the sunrise at different times of the year. The perfect east–west alignment of streets in the same city has been attributed to the sighting of the star cluster Pleiades (*Kṛttikā*). While the above statements remain speculative, it is well recognized that ancient people everywhere felt a need to relate to the universe by tuning in to the rhythms of celestial objects.



Some of the ring-stones found at Mohenjo-daro, with rows of small drilled holes that appear to point to the sunset across the year. (Courtesy: Erkka Maula)

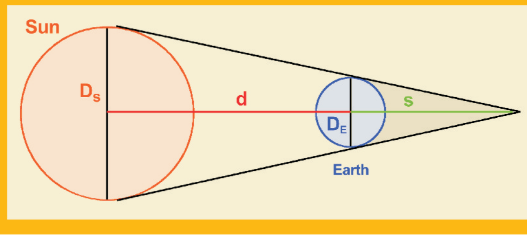
A few thousand years ago, the *Rig-Veda,* the oldest of the four Vedas, spoke of a year of 360 days divided into twelve equal parts and used a five-year *yuga* (era), probably as a first attempt to reconcile the lunar and solar years (by the addition of a month after those five years). It clearly recorded a solar eclipse, although in a metaphorical language. And it has recently been proposed that its mention of '3,339 gods' was actually a reference to the 18-year cycle of eclipses known as the saros; if so, this points to a very early tradition of astronomical observation. A few centuries later, the *Yajur-Veda* considered a lunar year of 354 days and a solar year of 365 days, and divided the year into six *ṛtus* or seasons of two months each. The *Yajur-Veda* also gave the first list of 27 *nakṣatras* or lunar mansions, that is, constellations along the path of the moon on the celestial sphere.

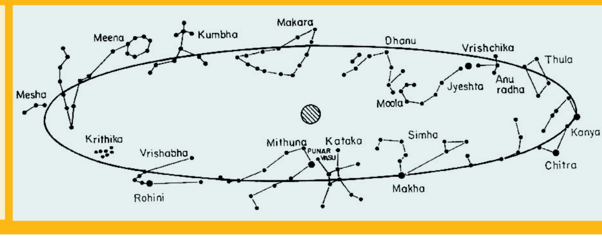


The 27 *nakṣatras*, with the earth in the centre. (Courtesy: M.S. Sriram)

How many of these nakṣatras (or constellations on the path of the moon) are you familiar with? Can you identify some of them in the sky on a clear night with the naked eye?

Because of the need to keep time for the proper conduct of rituals, calendrical astronomy grew more sophisticated in the late Vedic period, with the *Vedāṅga Jyotiṣa* of Lagadha as its representative text (and, if we may call it so, the first extant Indian scientific text). On the basis of its own astronomical data, it has been dated between the 12th and the 14th centuries BCE by most scholars. The length of the sidereal day (i.e. the time taken by the earth to complete one revolution with respect to any given star) it uses is 23 h 56 min 4.6 s, while the correct value is 23 h 56 min 4.091 s; the tiny difference is an indication of the precision reached in that early age. The *Vedāṅga Jyotiṣa* also discusses





solstices (*ayanānta*) and equinoxes (*viṣuva*) and uses two intercalary lunar months (*adhikamāsa*) to catch up with the solar calendar.* In some ways, this text remains the foundation for India's traditional luni-solar calendars.

The Early Historical Period

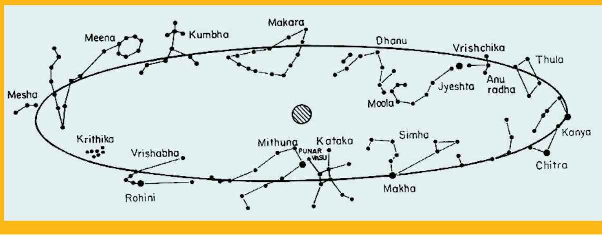
The second period extended from the 3rd century BCE to the 1st century CE and was marked by astronomical computations based on the risings and settings of planets, their revolutions, etc. Jain astronomy also developed in this period, based on a peculiar model of two sets of 27 *nakṣatras*, two suns and two moons; it nevertheless resulted in precise calendrical calculations.

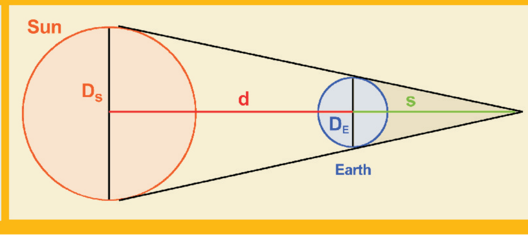
This is also the period when huge scales of time were conceived of such as a 'day of Brahmā' (or *kalpa*) of 4.32 billion years, which curiously comes close to the age of the earth (4.5 billion years). Of course, there are much longer time scales to be found in Jain texts and in the *Purāṇas*.

While some scholars have discerned Babylonian and Greek influences at play during this and the next periods, the issue remains open. Nevertheless, such influences seem clear enough in the introduction of the seven-day week a few centuries BCE (late Vedic India divided the month only into two lunar fortnights or *pakṣa*, one light and one dark), and of the zodiac of 12 signs (*rāśi*), first recorded in the *Yavanajātaka* (c. 269 CE).

Compare the Indian rāśis to the twelve signs of the European zodiac. What conclusions can you draw?

* The solar year is about 365.24 solar days, while the lunar year is, at most, 360 days. After a few years, the difference between the two will grow so much that a month needs to be added to the lunar year to restore a broad coincidence between the two systems. This is the intercalary month.





The Siddhāntic Era

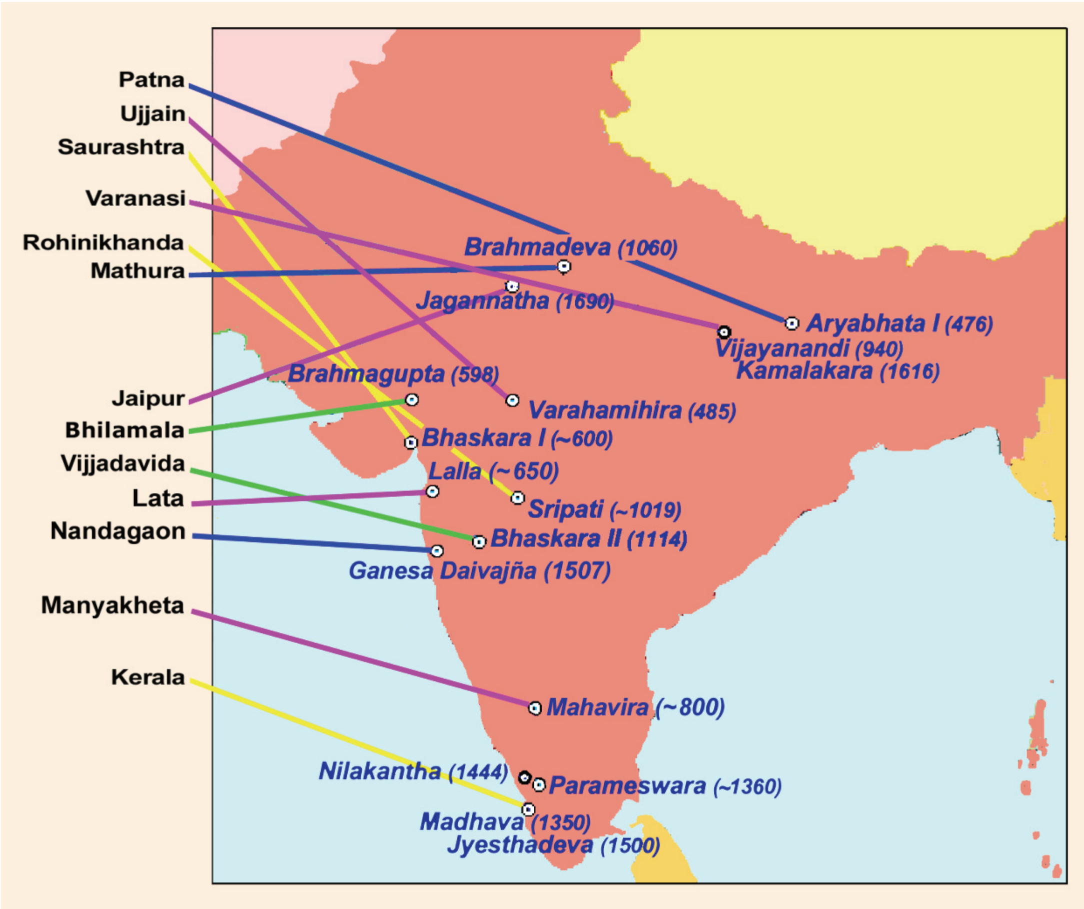
Why is this era of Indian astronomy called 'golden'? Make a list of three major contributions of that age.

There are many gaps in our knowledge after the above period and before the start of what has been called the golden age of Indian mathematics and astronomy. Beginning in the 5th century CE, this is the Siddhāntic era, when texts called *siddhāntas* were composed — a Sanskrit word meaning 'principle' or 'conclusion', but which applies here to a collection of conclusions or a treatise. Their chief characteristics were the use of trigonometric methods and epicyclic* models for the computations of planetary positions.

Find out the name of the first ever satellite launched by India. Why do you think it was so named?

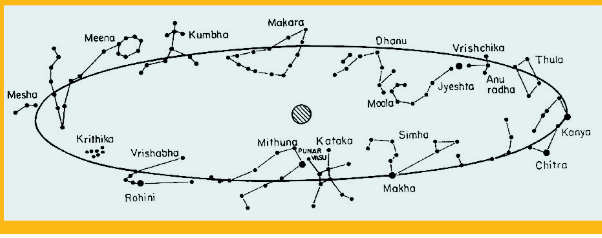
Āryabhaṭa I (born 476 CE), working near what is today Patna, ushered in this era with his *Āryabhaṭīya,* which dealt concisely but systematically with developments in mathematics and astronomy. Among other things, it discussed units of time and features of the celestial sphere, described the earth as a rotating sphere hanging in space, and produced a table of the planets' mean positions. Āryabhaṭa also gave a correct explanation for both lunar and solar eclipses, and stated that the diameter of the earth is 1,050 *yojanas* (defining the *yojana* as 8,000 average human heights or about 13.6 km); this is close to the actual dimension, though 12% too large. (His diameters for the planets and the sun are however much too small.)

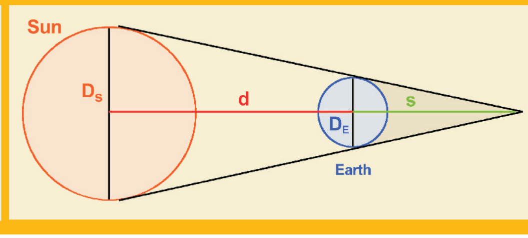
* Because they were using a geocentric system, early Greek and Indian astronomers could not explain the planets' occasional retrograde motion (as seen from the earth); they assumed that the planets moved along smaller orbits, called epicycles, whose centres revolved around the earth along larger circles (the planets' mean orbits).



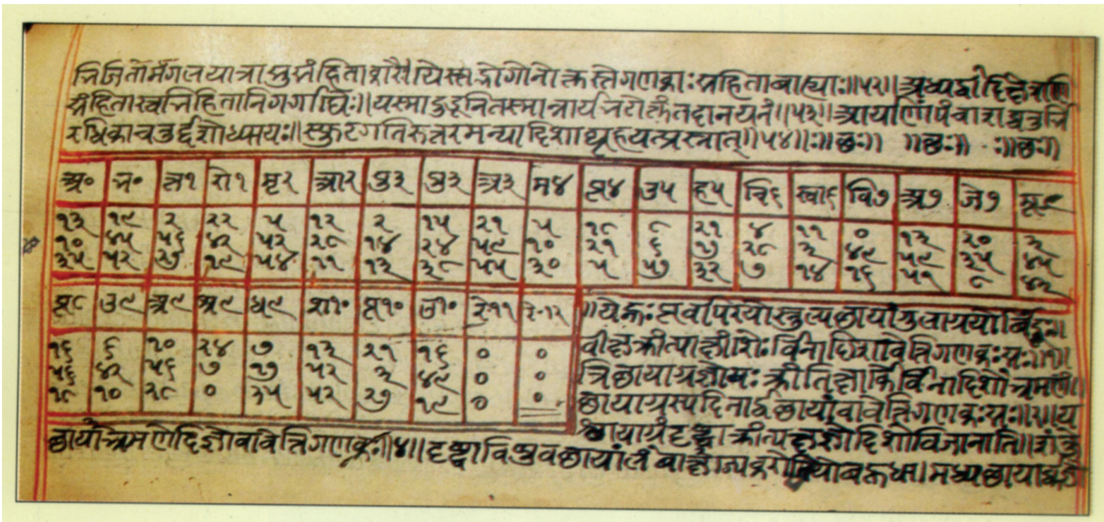
A map showing some of India's astronomers / mathematicians. Their dates of birth as well as their place of birth or work are often approximate. Note that many more names, from Baudhāyana (~ 600 BCE) to Śrīdhara (~ 800) or Āryabhaṭa II (~ 950), simply cannot be placed on the map, as the texts are silent on their locations. (Courtesy: Michel Danino, compiled from various sources)

Many brilliant astronomers followed, dealing with issues of coordinate systems, time measurement and division, mean and true positions of celestial bodies, and eclipses. Varāhamihira, Āryabhaṭa's contemporary, composed in 505 CE a collection of five astronomical texts prevalent during his time; one of the five texts, the *Sūrya Siddhānta*, was revised later and became a fundamental text of Indian astronomy; two others expounded the principles of Greek astronomy. Varāhamihira extensively discussed the





revolutions of planets, eclipses, and the zodiac, often with an astrological background. Bhāskara I (b. 600 CE), the earliest known exponent of Āryabhaṭa I, provided a very useful elucidation of Āryabhaṭa's astronomy, besides improved calculation methods.



A manuscript of a passage of Brahmagupta's *Brahmasphuta Siddhānta*.
(Courtesy: Bombay University Library)

A few years later, Brahmagupta (born 598 CE), who lived near Mount Abu, mistakenly rejected Āryabhaṭa's view of the earth as a rotating sphere, but contributed much to calculations of the mean and true longitudes of planets, conjunctions and problems of lunar and solar eclipses, applying to all these his considerable mathematical skills.[*]

Refer to Brahmagupta's objection to Āryabhaṭa in the selection of extracts from primary texts, and assess its pertinence.

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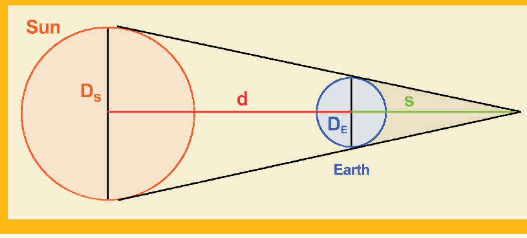
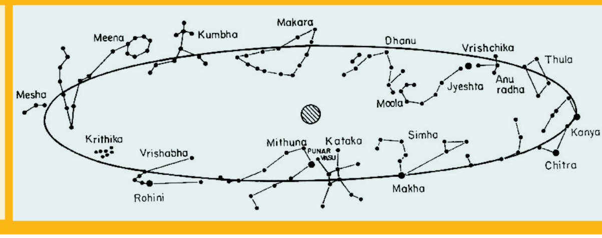
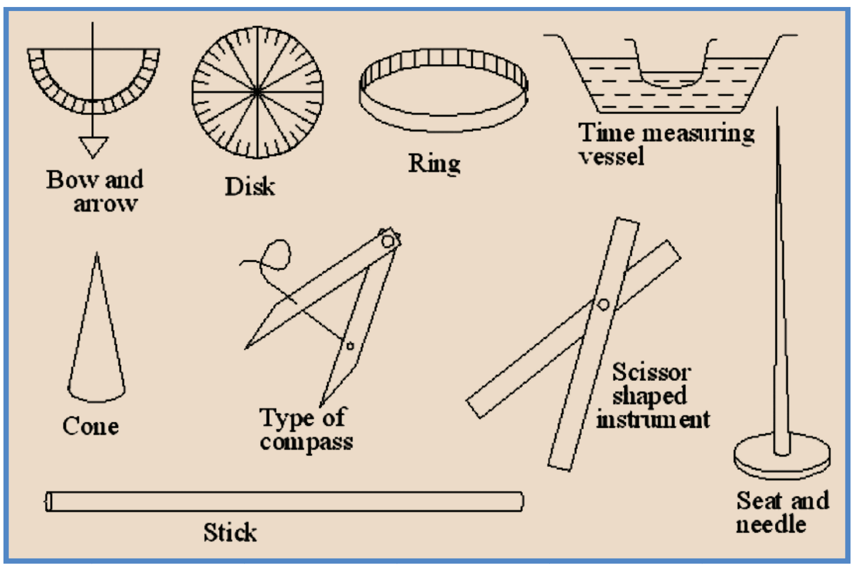
[*] The celestial longitude of a celestial body (planet or star) is the arc of the ecliptic measured eastward from the vernal equinox (Aries) to the point where the ecliptic is intersected by the great circle passing through the body. (The ecliptic is the plane of the earth's orbit.) 'Mean longitude' refers to an average value, i.e. the body's average position, while 'true longitude' refers to its actual position at a given time.





Indian astronomers could not have achieved so much without a strong tradition of observation, and the 22nd chapter of Brahmagupta's *magnum opus*, the *Brahmasphuta Siddhānta*, dealt with a variety of astronomical instruments, most of which could be easily made by any good craftsman: among them, a water clock (*ghaṭī yantra*) consisting of a bowl with a small hole at the bottom, which would sink in exactly 24 minutes (a *ghaṭī*) if placed over water; a gnomon (a short stick kept vertically for the study of the motion of its shadow); a graduated disk or half-disk; and a scissor-like pair acting as a compass. Those instruments and the computational techniques applied to them were both adopted by later scholars, beginning by Lalla of the 8th century.



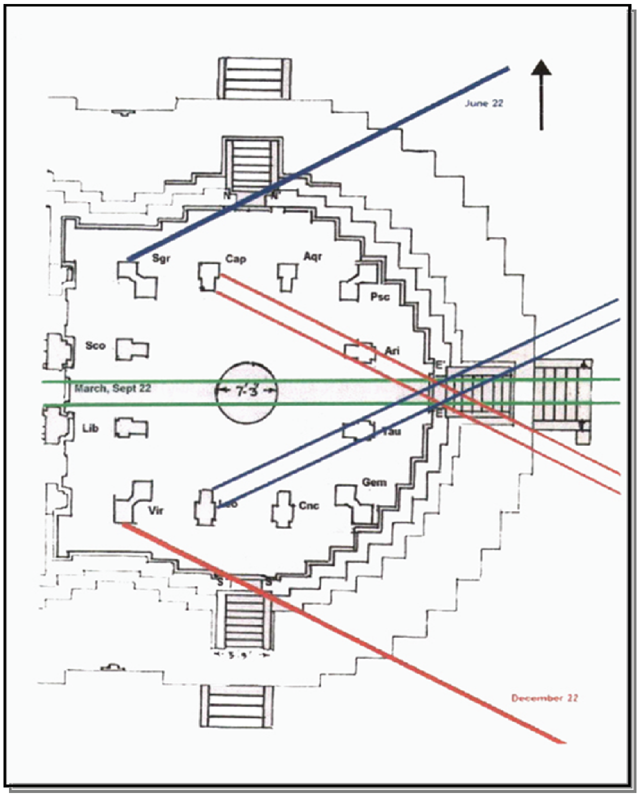
Some of the instruments described by Lalla for astronomical observations.
(Courtesy: Shekher Narveker)

Brahmagupta also authored a manual of astronomical calculations which remained popular for centuries, as testified by Al-Biruni, the Persian savant who came to India in the 11th century as part of Mahmud of Ghazni's entourage. Al-Biruni was deeply interested in Indian astronomical techniques, wrote about them at length, and translated texts by Varāhamihira and Brahmagupta into Arabic or Persian.

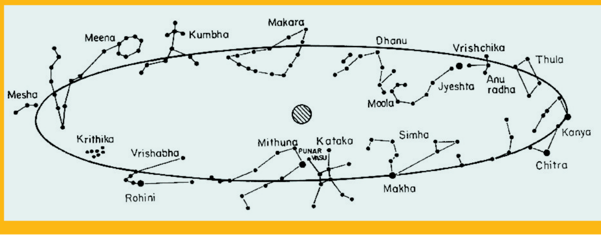
Bhāskara II (b. 1114), better known as Bhāskarāchārya, brought important innovations to both astronomical and mathematical techniques, discussing in particular the mean and true positions of planets, the triple problem of time, direction and place, the risings and settings and conjunctions of the planets, eccentric and epicyclic theories for their motions of planets, and a large number of astronomical instruments. Over all, Bhāskarāchārya greatly improved upon the formulas and methods adopted by earlier Indian astronomers.

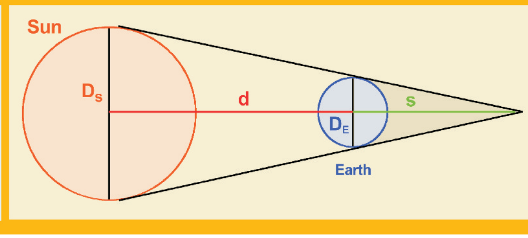
Inscription of 1128 CE recording King Ratnadeva's donation of a village to astronomer Padmanābha for predicting a total lunar eclipse. Over 350 such inscriptions, from 440 to 1859, have been traced out. (Courtesy: B.V. Subbarayappa)

During those centuries, astronomy's interface with the general public was mostly through calendars and *pañcāṅgas* (almanacs), and the prediction of eclipses, which had great religious and social significance. Indeed, an astronomer's fame was guaranteed if he could accurately predict the occurrence, nature and duration of eclipses, and numerous inscriptions record a king's reward to such an astronomer. Another interface was architecture, and many temples show clear astronomical alignments with events such as the sunrise at solstices and equinoxes.



The Sringeri temple, whose *mandapa* is dedicated to the twelve *rāśis* or signs of the zodiac; some of the pillars are aligned to the sunrise on the two solstices. (Courtesy: B.S. Shylaja)





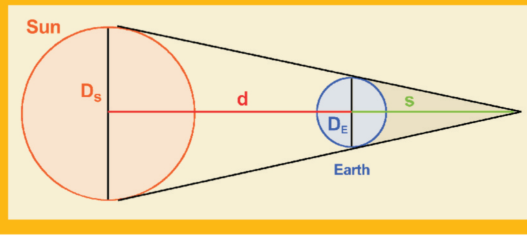
The Kerala School

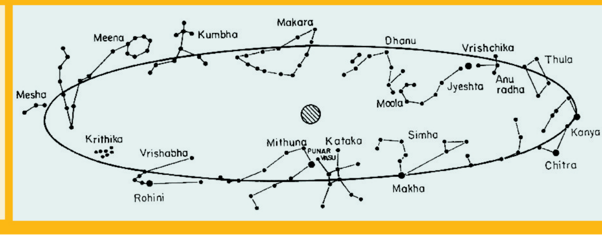
The widespread belief that there was virtually no progress in Indian astronomy and mathematics after Bhāskara II is based on a general ignorance of the intense developments that took place in the southern state of Kerala. The so-called 'Kerala School of astronomy and mathematics' flourished there from the 14th to the 17th century, when networks of knowledge transmission in north India were severely disrupted in the wake of repeated invasions.

Parameśvara (c. 1362-1455), an author of some thirty works, was one of the foremost astronomers of this School, and the founder of the *dṛk* system, which improved computations of eclipses and the positions of the planets and proved to be very popular. He emphasized the need to regularly correct formulas to bring them closer to actual observations, and was said to have studied eclipses and their parameters over a period of 55 years. He was followed by Nīlakaṇṭha Somayājī (1444-1545), who, in his landmark *Tantrasaṅgraha,* carried out a major revision of the older Indian planetary model for the inferior planets, *Budha* (Mercury) and *Śukra* (Venus), and described them, along with *Maṅgala* or *Kuja* (Mars), *Bṛhaspati* or *Guru* (Jupiter) and *Śani* (Saturn), as moving in eccentric orbits around the sun. This achievement of the Kerala school of astronomy is truly remarkable in the light of the fact that Nīlakaṇṭha preceded Copernicus (1473-1543), the propounder of the heliocentric theory in Europe. It seems unlikely, however, that Indian heliocentrism directly influenced European advances in the field.

Other Post-Siddhāntic Developments

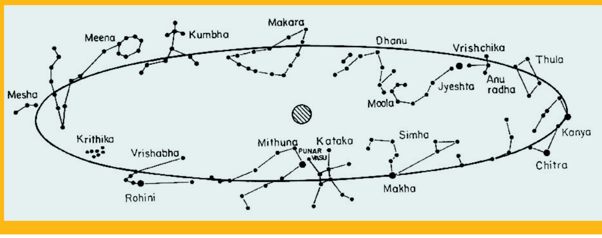
About the same time, a complex interface with Islamic astronomy took place, which, among other benefits, brought instruments such as the astrolabe to India. The famous and massive *yantramantra* or Jantar Mantar observatories built in the early 18th century

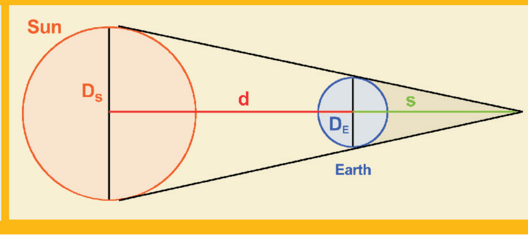




by the Maharaja of Jaipur, Sawai Jai Singh (1688-1743), represent a convergence between Indian, Arabic and European astronomy.

Two views of New Delhi's Jantar Mantar. (Courtesy: Michel Danino)





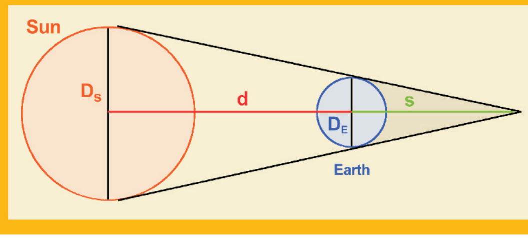
In a general way, Indian astronomers were more interested in efficient methods of computation than in theoretical models. Some of the techniques used to calculate planetary positions and eclipses yielded remarkably precise results and impressed by their speed European astronomers such as Le Gentil, a French savant who stayed in Puducherry for two years to observe a solar transit of Venus in June 1769.

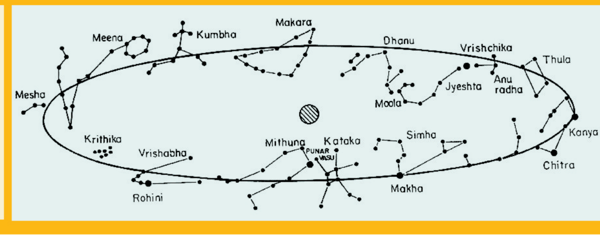
Although traditional tables and even calculation methods survived well into the nineteenth century (witness the case of the Odiya astronomer, Sāmanta Candraśekhara Simha, who was completely insulated from European astronomy and authored in 1869 a voluminous *Siddhānta*), the introduction of modern astronomy brought to a close India's own developments in this science. But India, in many ways, had contributed to the growth of the new science, as some of the techniques developed by Indian astronomers and mathematicians had been relayed to Europe centuries earlier through the Arabs. Indeed, Indian astronomy interacted not only with Islamic (or *Zīj*) and European astronomies, but also with Chinese astronomy, in complex interplays that invariably enriched both players.

***

Match the following

ring-stones	heliocentrism
nakṣatras	water-clock
Āryabhaṭa	Jantar Mantar observatories
ghaṭī yantra	lunar mansions
Nīlakaṇṭha	Mohenjo-daro
Jai Singh	rotating earth



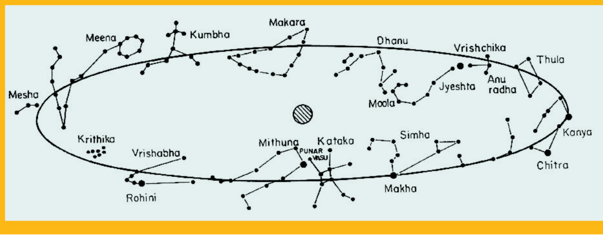


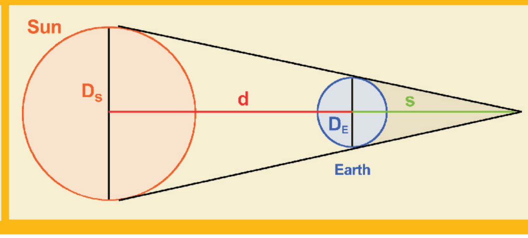
Comprehension questions

1. Write a few sentences on the inception of astronomy in India.
2. What is the astronomical content of the *Rig-Veda*?
3. Consider the following statement by the U.S. astronomer Carl Sagan (who can be viewed online, reading this out in a South Indian temple: http://www.youtube.com/watch?v=3EyAKFi3_Xg): 'The Hindu religion … is the only religion in which the time scales correspond, no doubt by accident, to those of modern scientific cosmology. Its cycles run from our ordinary day and night to a day and night of Brahma, 8.64 billion years long. Longer than the age of the Earth or the Sun and about half the time since the Big Bang.' Do you find this statement justified?
4. Spell out Āryabhaṭa's contribution to astronomy.
5. How do we know that Indian astronomers were skilled in astronomical observations?

Project ideas

- Study some of the main instruments of the Jantar Mantar (Delhi or Jaipur) and try to explain their function and principles. Your project should underline the historical importance and technical principles of the Jantar Mantar. Make a PowerPoint presentation.
- Make a list of at least ten major Indian astronomers; mention their contributions and their impact on the society around them.
- Draw a timeline for Indian astronomy, including some of its most famous representatives.





Extended activities

- Construct a sundial; observe the variations of the shadow not only in the course of the day, but in the course of the year. Indian astronomers researched the equations of the gnomon and shadow extensively; try to refer to some of their research and put it in modern terms.
- Visit the nearest planetarium and acquire a basic knowledge of astronomy, beginning with our solar system. Reflect on how much the ancients (not just in India) were able to observe and calculate despite having no telescopes.
- Learn to observe the night sky and identify the main constellations (not just the *nakṣatras*), both by their international and Indian names.

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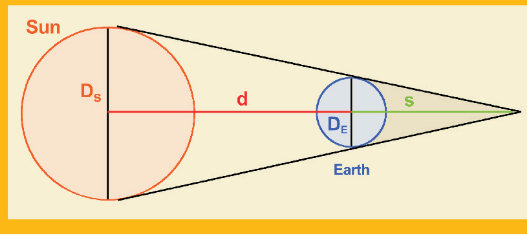

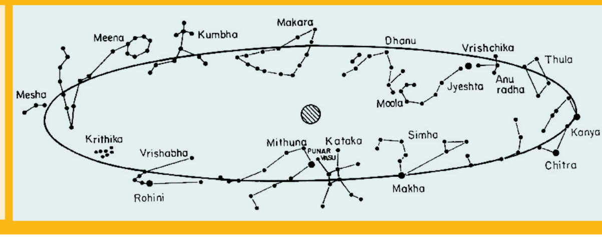

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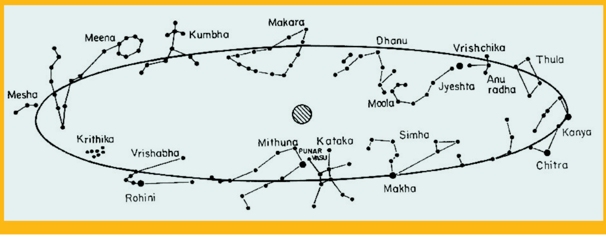
12. M.S. Sriram, K. Ramasubramanian & M.D. Srinivas, *500 Years of Tantrasangraha: A Landmark in the History of Astronomy*, Inter-University Centre & Indian Institute of Advanced Study, Shimla, 2002

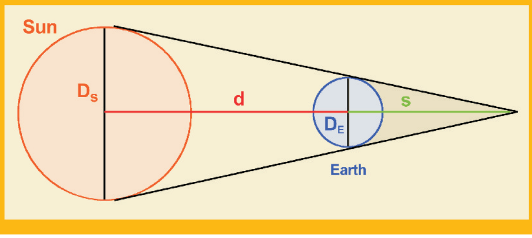
13. B.V. Subbarayappa, *The Tradition of Astronomy in India: Jyotihśāstra,* vol. IV part 4 in History of Science, Philosophy and Culture in Indian Civilization, Centre for Studies in Civilization, New Delhi, 2008

14. B.V. Subbarayappa & K.V. Sarma, eds & trs, *Indian Astronomy: A Source-Book,* Nehru Centre, Bombay, 1985

Internet Resources (all URLs accessed in May 2012)

- BBC TV series 'What the Ancients Did for Us — The Indians', especially for the sections on Indian astronomy — time keeping and the Jantar Mantar:
  www.youtube.com/watch?v=LWRhsenRZUI
- About the Jantar Mantar observatories: www.jantarmantar.org/
- About general astronomy:
  www.skyandtelescope.com/, www.euhou.net/, www.ipsindia.org/,
  www.astronomy.com/News-Observing/Astronomy%20Kids.aspx,
  www.sky-map.org,www.astronomynow.com/, etc.
- For lessons on astronomy:
  http://science.lotsoflessons.com/space/index.html,
  http://outreach.as.utexas.edu/marykay/highschool/hs.html
- For astronomy in ancient civilizations:
  www.starteachastronomy.com/archaeoastronomy.html (note that the page on India is seriously outdated),
  www.experiment-resources.com/mesopotamian-astronomy.html,
  www.laep.org/target/bridges/mayans_ancient1.html,
  http://galileo.phys.virginia.edu/classes/109N/lectures/greek_astro.htm,
  www.haystack.mit.edu/edu/pcr/resources/astronomyhistory.htm,
  http://www.astro.umass.edu/~rfinn/phys400/P400-history.pdf .





Primary Texts on Astronomy in India: A selection

Note: Indian texts of astronomy are generally of a highly technical nature. In the excerpts below, passages of a more general character have been selected. The texts are arranged more or less chronologically; the authors' dates of birth (when known) and the translator's name (when available) have been added. Brief explanatory notes follow the excerpts. (Many of these excerpts have been borrowed from B.V. Subbarayappa & K.V. Sarma, eds & trs, *Indian Astronomy: A Source-Book,* Nehru Centre, Bombay, 1985.)

Aitareya Brāhmaṇa

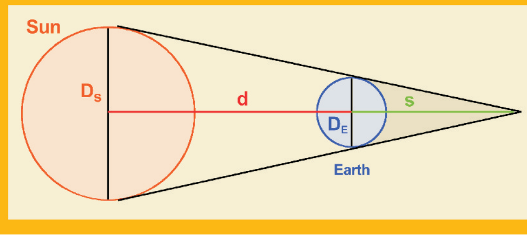
He [the sun] never sets or rises. When [people] think that he is setting, he is only turning round, after reaching the end of the day, and makes night here and day below. Then, when [people] think he is rising in the morning, he is only turning round after reaching the end of the night, and makes day here and night below. Thus, he [the sun] never sets at all. (4.11.6, 14.6)

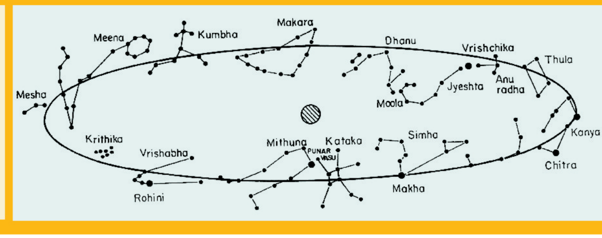
Note: This passage from a *Brāhmaṇa* (a commentary on the Veda, of uncertain date, perhaps about 1000 BCE) appears to show an awareness of the sphericity of the earth, since there is always a part of it exposed to daylight.

***

Āryabhaṭa I (b. 476 CE), *Āryabhaṭīya* (tr. K.S. Shukla)

The globe of the earth stands [supportless] in space at the centre of the circular frame of the asterisms [i.e., at the centre of the celestial sphere]





> surrounded by the orbits [of the planets]; it is made of water, earth, fire and air and is circular on all sides [i.e., spherical].
>
> Just as the bulb of a *kadamba* flower is covered all around by blossoms, so is the globe of earth surrounded by all creatures, terrestrial as well as aquatic. (4.6–7)

Note: Here, Āryabhaṭa makes a case for a spherical earth hanging in space unsupported.

> Just as a man in a boat moving forward sees the stationary objects [on either side of the river] as moving backward, so are the stationary stars seen by people at Laṅkā [on the equator], as moving exactly towards the west. (4.9)

Note: Āryabhaṭa now explains that the earth is rotating in space, and its rotation is causing the apparent rotation of the celestial sphere. (Laṅkā, in Indian astronomy, refers to the equator, not to Sri Lanka.)

> The moon is water, the sun is fire, the earth is earth, and what is called shadow is darkness (caused by the earth's shadow). The moon eclipses the sun and the great shadow of the earth eclipses the moon. (4.37)

Note: While it is incorrect to say that the moon is 'water', Āryabhaṭa's explanation for solar and lunar eclipses is perfectly correct. See a figure of the earth's shadow and related calculations in the module on **Mathematics in India**.

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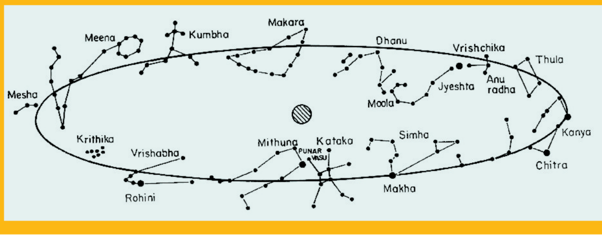
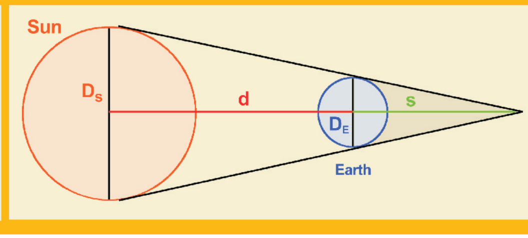
Varāhamihira (b. ~ 485 CE), *Bṛhat Saṃhitā* (tr. M.R. Bhat)

> We shall now explain the aphorisms, i.e., rules or qualifications for an astronomer.





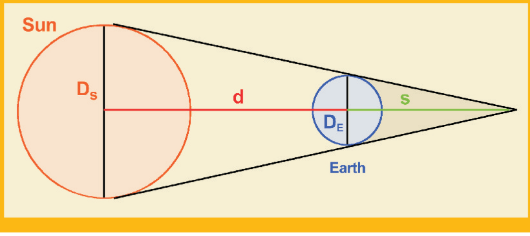
Among the astronomical calculations, the astronomer should be conversant with the various sub-divisions of time such as the *yuga,* year, solstice, season, month, fortnight, day and night, *jāma* [a period of 90 minutes] *muhūrta* [48 minutes], *nāḍī* [or *ghaṭī,* 24 minutes] *prāṇa* [time required for one inhalation], *truṭi* [a very small unit of time] and its further subdivisions, as well as with the ecliptic [or with geometry] that are treated of in the five Siddhāntas entitled *Pauliśa, Romaka, Vāsiṣṭha, Saura* and *Paitāmaha.*

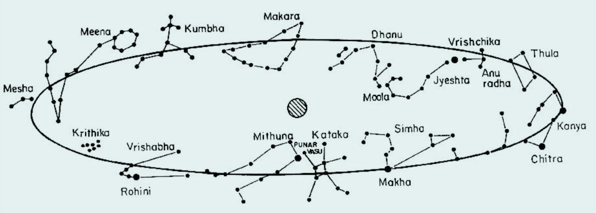
He should also be thoroughly acquainted with the reasons for the existence of the four systems of measurement of time, viz. *Saura* or the solar system, *Sāvana,* or the terrestrial time, i.e. the time intervening between the first rising of any given planet or star and its next rising, *Nākṣatra* or sidereal, and *Cāndra* or lunar, as well as for the occurrence of intercalary months and increasing and decreasing lunar days.

He should also be well-versed with the calculation of the beginning and ending times of the cycle of sixty years, a *yuga* [a five-year period], a year, a month, a day, a *horā* [hour], as well as of their respective lords.

He should also be capable of explaining, by means of arguments, the similarities and dissimilarities as well as the appropriateness or otherwise of the different systems of measurement of time according to the solar and allied systems.

Despite differences of opinion among the Siddhāntas regarding the expiry or ending time of an *ayana* [solstice], he should be capable of reconciling them by showing the agreement between correct calculation and what has been actually observed in the circle drawn on the ground by means of the shadow of the gnomon as well as water-instruments.





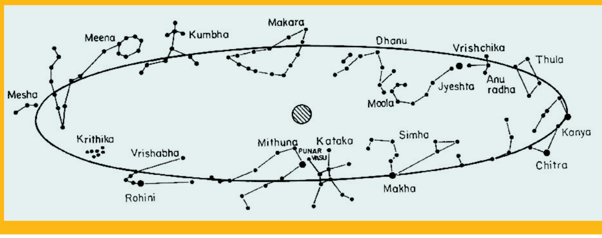
He should also be well acquainted with the causes that are responsible for the different kinds of motions of the planets headed by the sun, viz. fast, slow, southerly, northerly, towards perigee and apogee.

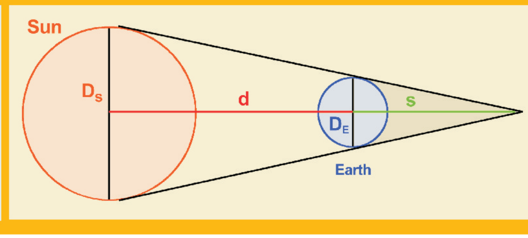
He must be able to forecast, by calculation, the times of commencement and ending, direction, magnitude, duration, intensity and colour at the eclipses of the sun and the moon, as well as the conjunctions of the moon with the five *tārāgrahas* [non-luminous planets, i.e. Mercury, Venus, Mars, Jupiter and Saturn] and the planetary conjunctions.

He should also be an expert in determining accurately for each planet, its motion in *yojanas* [a linear unit equivalent to about 13.6 km], its orbit, other allied dimensions etc., all in terms of *yojanas.*

He must be thoroughly acquainted with the earth's rotation [on its own axis] and its revolution along the circle of constellations, its shape and such other details, the latitude of a place and its complement, the difference in the lengths of the day and night [*lit.* diameter of the day-circle], the *carakhaṇḍas* of a place, rising periods of the different signs of the zodiac at a given place, the methods of converting the length of shadow into time [in *ghaṭīs*] and time into the length of shadow and such other things, as well as those to find out the exact time in *ghaṭīs* that has elapsed since sunrise or sunset at any required time from the position of the sun or from the Ascendant, as the case may be. (2. 1-12)

Note: Varāhamihira provides here a long description of the minimum qualifications expected of an astronomer, especially a command of time measurement, planetary motion and eclipses.





Varāhamihira (b. ~ 485 CE), *Pañcasiddhāntikā* (tr. T.S. Kuppanna Sastry)

> The circumference of the earth is 3,200 *yojanas.* When situated on the equator the sun is visible from pole to pole at all latitudes [making the day and night equal]. (13.18)

Note: Varāhamihira proposes a measurement for the earth's circumference. The *yojanas* was usually taken to be 8,000 human heights (Kautilya in his *Arthaśāstra* and Āryabhaṭa specifically adopted this definition); if we take an average height to be 1.7 m, we get a circumference of about 43,500 km, which is a fair approximation of the actual dimension (40,074 km). Interestingly, a few years before Varāhamihira, Āryabhaṭa took the earth's diameter to be 1,050 *yojanas*; this is equivalent to a circumference of about 3,300 *yojanas*, i.e. a slightly larger size. We do not know how these savants reached such numbers.

***

Brahmagupta (b. 598), *Brahmasphuṭa Siddhānta* (tr. K Ramasubramanian)

> If the earth were to be spinning at the rate of one minute (*kalā*) in four seconds (*prāṇa*) then what, where and why would they [birds] leave? Further, in a rotating earth, how would the arrows shot up fall in the same place? (11.17)

Note: Brahmagupta disagrees here with Āryabhaṭa's theory of a rotating earth: if it were true, birds leaving their nests would be unable to return to them, since they would have moved with the earth, or that an arrow shot vertically would not fall back to the same spot. There was no theory of frames of reference to answer those questions, and Brahmagupta's view prevailed — even though it was Āryabhaṭa who was right.

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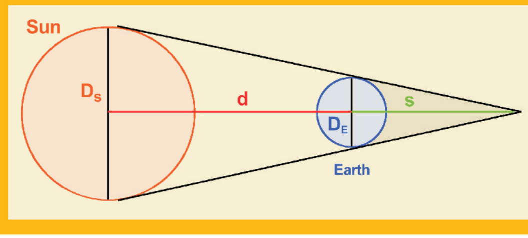
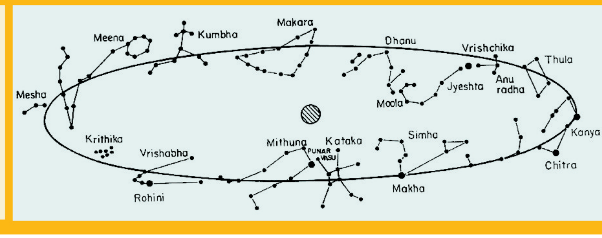




Vaṭeśvara (b. 880), *Vaṭeśvarasiddhānta*

The time-divisions:

lotus-pricking time	=	1 *truṭi*
100 *truṭis*	=	1 *lava*
100 *lavas*	=	1 *nimeṣa* (twinkling of eye)
4 ½ *nimeṣa*	=	1 long syllable
4 long syllables	=	1 *kāṣṭhā*
2 ½ *kāṣṭhās*	=	1 *asu* (respiration) = 4 seconds
6 *asus* (prāṇas)	=	1 sidereal *pala* (*caṣaka, vināḍi* or *vighaṭikū*)
60 *palas*	=	1 *ghaṭikā* = 24 minutes
60 *ghaṭikās*	=	1 day
30 days	=	1 month
12 months	=	1 year
4,320,000 years	=	1 *yuga*
72 *yugas*	=	1 *manu*
14 *manus*	=	1 *kalpa*
2 *kalpas*	=	1 day (and night) of Brahmā
30 days of Brahmā	=	1 month of Brahmā
12 months of Brahmā	=	1 year of Brahmā
1 year of Brahmā	=	72 x 14 x 2 x 30 x 12 *yugas* = 725,760 *yugas*
100 years of Brahmā	=	Life of Brahmā or *mahākalpa* (1.1.7-9)

Note: Vaṭeśvara gives here a scale of time units, beginning with the most tiny *truṭi* (equivalent to about 9 microseconds, as a simple calculation shows) and extending to cosmic time scales. We may wonder what practical use the two ends of the scale might have had, but they were mentioned by several savants — even much longer time scales.

At the very least, they show a remarkable conceptual ability. (Note that there are some variations in the smaller units from one scholar to another.)

***

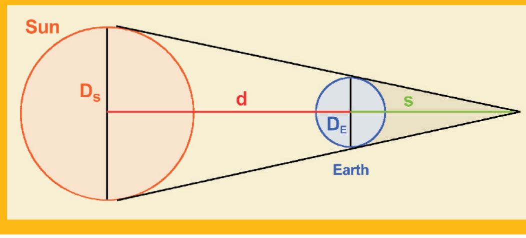
Bhāskara II (b. 1114), *Siddhāntaśiromaṇi*

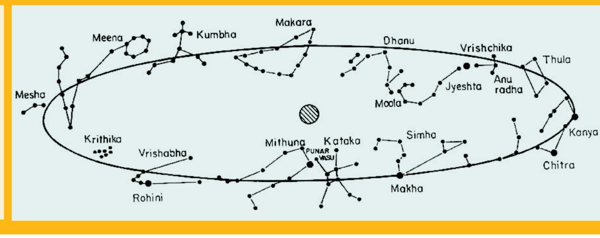
> Ancient astronomers did write, of course, treatises abounding in intelligent expression; nonetheless, this work is composed to fill some lacunae in their works. I am going to make up for the deficiencies of the older works and these improvements will be found here and there in their respective places. So I beseech the good-minded mathematicians to go through this entire work of mine (for, otherwise, they may not locate my contribution). (1.1.1.4)

Note: Bhāskarāchārya follows here a well-established Indian intellectual tradition: while acknowledging the contributions of his predecessors, he has no hesitation in proposing improvements on their work.

> A *Siddhānta* work is an astronomical treatise which deals with the various measures of time ranging from a *truṭi* up to of a *Kalpa* which culminates in a deluge, planetary theory, arithmetical computations as well as algebraical processes, questions relating to intricate ideas and their answers, location of the earth, stars and planets, and the description and use of instruments. (1.1.1.6)

Note: Bhāskarāchārya defines for us the nature of a Siddhānta text in the astronomical context. Note the last phrase, one of the many evidences found in the texts of a strong tradition of astronomical observation. In fact, many Siddhāntas included separate chapters on the 'description and use of instruments'.





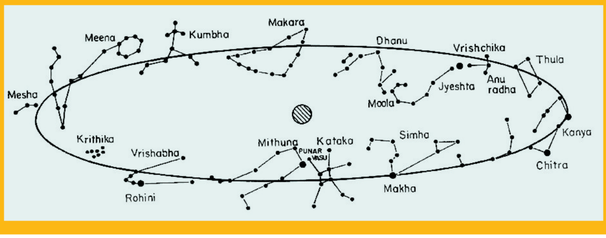
Parameśvara (b. ~ 1360 CE), *Siddhāntadīpikā (Mahabhāskarīya Bhāsyavyākhyā)*

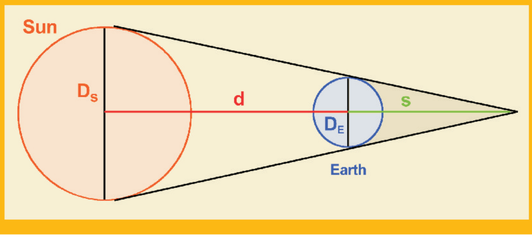
> Thus far, I have elucidated in detail (the computation of) the eclipses of the sun and the moon. But at times there are found differences both in the time (of the eclipses) and in (the extent of) the orbs (eclipsed).
>
> Beginning from Śaka (1315, i.e. A.D. 1393), I have computed and observed a large number of eclipses. However, there had uniformly been difference in the time (of the eclipses) as observed (and as computed).
>
> In those cases, the times when (the eclipses were) observed occurred before the computed times. Hence it was patent that an appropriate correction was required to be effected by expert astronomers. (5.77)

Note: Parameśvara plainly states his wide experience in computing and observing eclipses, and adds that he had to introduce 'corrections' in earlier computations. This practice was indeed standard among astronomers, and the corrections thus introduced in established formulas were called *bīja*. Such corrections became necessary in the course of time for two reasons: (1) because the formulas used were approximations, with a deviation that would grow in the course of time; (2) because the planets' parameters themselves would slightly change over centuries.

Parameśvara (b. ~ 1360 CE), *Goladīpikā* (tr. K.V. Sarma)

> [Really] the moon is the hiding object of the sun, and [the hiding object] of the moon is the huge shadow of the earth. This shadow of the earth will [always] be at the seventh sign from the sun, moving with a velocity equal to the sun's.
>
> In the case of the moon, since the eclipsed object [the moon] is faster, the beginning of the eclipse is at the east, and the end at the west. In the case of





the sun's [eclipse], due to the slower motion of the eclipsed body [the sun], these two, [the beginning and the end], are the other way.

The orb hiding the sun [the projection of the moon], is small and hence sharp horns are formed. The orb hiding the moon [the earth's shadow], is big and hence it is blunt-horned. (2. 41-43)

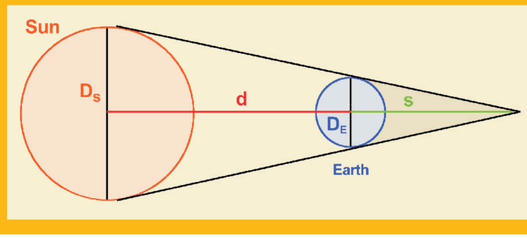
Note: Parameśvara states in brief a theory of eclipses, with the relative motions of the moon and the earth with regard to the sun.

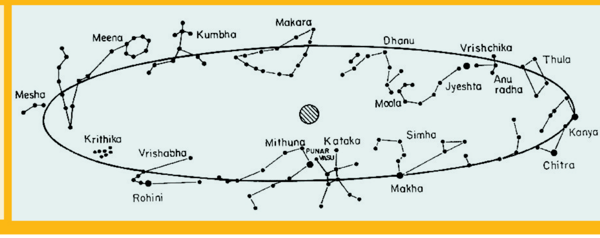
***

Nīlakaṇṭha Somayājī (b. 1444 CE), *Jyotīrmīmāṁsā*

A commentator on the *Mānasa* [*Laghumānasa* of Munjāla] has lamented: 'Indeed, the Siddhāntas, like *Paitāmaha,* differ from one another [in giving the astronomical constants]. Timings are different as the Siddhāntas differ [i.e., the measures of time at a particular moment differs as computed by the different Siddhāntas]. When the computed timings differ, Vedic and domestic rituals, which have [correct] timings as a component [of their performance] go astray. When rituals go astray, worldly life gets disrupted. Alas! We have been precipitated into a big calamity.'

Here, it needs to be stated: 'O faint-hearted, there is nothing to be despaired of. Wherefore does anything remain beyond the ken of those intent on serving at the feet of the teachers [and thus gain knowledge]? One has to realise that the five Siddhāntas had been correct [only] at a particular time. Therefore, one should search for a Siddhānta that does not show discord with actual observation [at the present time]. Such accordance with observation has to be ascertained by [astronomical] observers during times of eclipses etc.





> When Siddhāntas show discord, i.e. when an early Siddhānta is in discord, observations should be made with the use of instruments and the correct number of revolutions etc. [which would give results which accord with actual observation] found, and a new Siddhānta enunciated. (p. 6)

Note: Here, Nīlakaṇṭha gently rebukes a 'faint-hearted' predecessor, who lamented that there were differences between various Siddhāntas as regards computed times (for specific configurations of the sun, the moon or the planets, for instance), and that Vedic sacrifices, which are carefully attuned to such celestial configurations, were thrown into disarray as a result. Nīlakaṇṭha observes that such differences become unavoidable in the course of time, and that the only way out it to test, verify and revise, producing a new Siddhānta whenever necessary. This is a pragmatic as well as scientific attitude.

***

Jyeṣṭhadeva (b. ~ 1500 CE), *Gaṇita-Yukti-Bhāṣā* (tr. K.V. Sarma)

> Now, all planets move in circular orbits. The number of degrees which each planet moves in its orbit in the course of a day is fixed. There again, the number of *yojana*-s moved per day is the same for all planets. For planets which move along smaller orbits, the circle would be completed in a shorter time. For those which move along larger orbits, the circle would be completed only in a longer period. For instance, the Moon would have completely moved through the twelve signs in 28 days, while Saturn will complete it only in 30 years. The length of time taken is proportional to the size of the orbit. The completion of the motion of a planet once in its orbit is called a *bhagaṇa* of that planet. The number of times that a planet completes its orbit during a *catur-yuga* is called its *yuga-bhagaṇa* [revolutions per aeon]. Now, if the Moon is seen with an asterism on a particular day, it will be seen the next day with

the asterism to the east of it. From this, it might be understood that the Moon has proper motion [relative to the stars], and that the motion is eastwards. The sequence of the signs can also be understood to be eastwards. For all these orbits, a particular point is taken as the commencing point. This point is termed as the first point of Aries (*Meṣādi*). All the circles considered in a sphere are divided into 21,600 equal parts. Each part is a minute (*ili*). They are larger in bigger circles and smaller in smaller circles, the number of parts being the same in all. The number of minutes that a planet will move along its orbit during the course of a day is fixed. If one observes the said motion placing himself at the centre of the orbit of a planet, then the motion of the planet would appear equal every day. The centre of the planetary orbit is slightly above the centre of the Earth. The observer is, however, situated on the Earth. Conceive a circle touching the planet and with the observer at its centre. The observer would find the planet that much advanced from the first point of Aries as it has advanced in the said circle. The method by which this is ascertained is called the 'computation of the true planet' (*sphuṭa-kriyā*). We state it here, deferring the specialties to later sections. (8.1)

Note: This is the beginning of Jyeṣṭhadeva's text on astronomy (which, interestingly, was written in Malayalam, not Sanskrit), the second part of his *Gaṇita-Yukti-Bhāṣā* (the first part of which is dedicated to mathematics). It is a systematic exposition of astronomical theories and practices accumulated in preceding centuries, in particular by the Kerala School of astronomy. Here, we have basic concepts of planetary motion.

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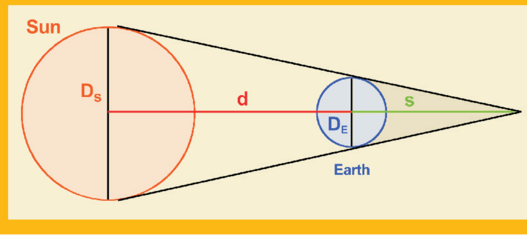
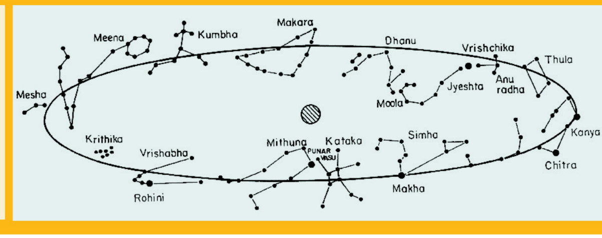




Śaṅkara Varman (b. ~ 1790 CE), *Sadratnamālā*

60 *pratatparās*	=	1 *tatparā*
60 *tatparās*	=	1 *viliptikā* (*viliptā* or *vikalā*)
60 *viliptikās*	=	1 *liptikā* (*liptā* or *kalā*)
60 *liptikās*	=	1 *lava* (or *bhāga*, a degree)
30 *lava*	=	1 *rāśi*
12 *rāśi*	=	1 celestial circle (2.4)

Note: Śaṅkara Varman gives here a few units of angular measure. Note the degree (*bhāga* or *lava*), thirty of which add up to a *rāśi* (zodiacal sign). At the other end, we find the minute (*liptikā*) and the second (*viliptikā*) of an angle, and even the 60th and 360th of a second!

***

Comprehension

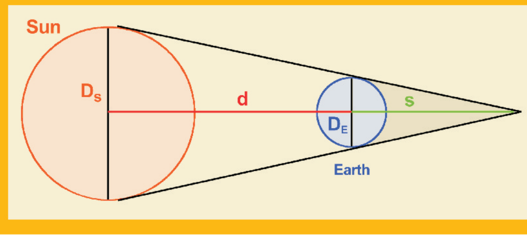
1. On the basis of your reading of the texts, complete the following table:

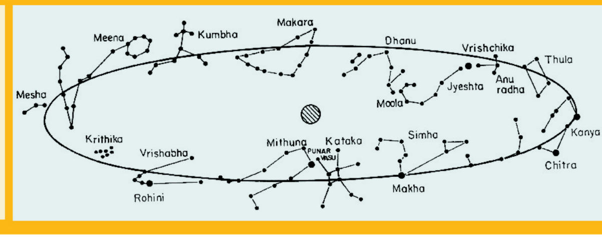
Astronomer	Period	Finding	Relevance
Āryabhaṭa			
Varāhamihira			

2. Prioritize the qualifications of an astronomer given by Varāhamihira? Give reasons. Justify your answer.

3. Among the standard astronomical instruments (see under Bhāskara II), we find the disc, the compass and the vertical stick (or gnomon); refer to the picture in the survey text. Describe some of the actual uses of these three instruments.

4. In Jyeṣṭhadeva's text on astronomy, spot elements of planetary motion which current astronomy would accept as valid.





The French astronomer Guillaume Le Gentil came to Pondicherry in 1768 to observe Venus's transit across the sun due for the following year. A mischievous cloud in an otherwise clear sky prevented his observation. However, Le Gentil's observation of Indian customs, people and astronomy, left precious testimonies.

"Brahmanas make their astronomical calculations with a singular speed and ease, without pen or pencil; they use instead cowries (kinds of shells) which they align on a board, as we do with our counters, or often on the ground.

This method of calculation seems to be advantageous in that it is swifter and more expeditious than ours, but at the same time it has a big drawback: there is no way to go back on one's calculations, still less of saving them, since one has to erase them as one proceeds. If by ill-luck one gets the result wrong, one has to start all over again.

But they very rarely make mistakes. They work in a singularly composed, untroubled and calm manner, which we Europeans are incapable of, and which protects them from the errors we would be unable to avoid in their place. It does seem that they and we must keep to our respective methods, and that theirs has been uniquely designed for them.

Their rules of astronomical calculations involve enigmatic verses which they know by heart; in that way, they have no need of tables of rules. By means of those verses which they can be seen repeating as they go along (as we repeat our formulas) and of those cowries, they calculate eclipses of the sun and of the moon with the greatest speed.

... Their tables for the sun and the moon are written on palm leaves cleanly cut to the same size. They assemble them in kinds of booklets which they consult when they want to calculate an eclipse. They use a small stylet or awl to trace on those leaves whatever signs they wish. This stylet traces a slight but visible line by tearing the thin film that covers the leaf.

What I was able to learn of the Brahmanas' astronomy boils down to five chief points: the use of the gnomon, the length of the year, the precession of equinoxes, the division of the zodiac into twenty-seven constellations, and the calculations of eclipses of the sun and the moon. ..."

"Dissertation on India, Particularly on a Few Points of the Tamil Gentiles' Astronomy", *Histoire de l'Académie Royale des Sciences,* 1772, 2nd part, pp. 174–75 (tr. Michel Danino).