

Introduction to Indian Astronomy

Part 1

Background:

Āryabhaṭa is probably the most famous Indian astronomer/mathematician. He propounded a mathematical model-based description of astronomy which became very popular and created a tradition (*paramparā*) through his work *Āryabhaṭīyam*. Such a mathematical treatise on astronomy came to be known as *siddhānta* or *siddhāntic*-astronomy. However, the discipline of astronomy prior to Āryabhaṭa very much existed, but was mostly observational. The collections of recorded observations were called *samhitā* and the developments of astronomy during this period came to be known under the title of pre-*siddhāntic*-astronomy.

A lot of astronomical knowledge is found in the Veda itself. Parāśara and Vṛddha-garga are big names in pre-*siddhāntic*-astronomy; but, unfortunately their works are not available today. We know of them because of references to them in later works by Varāhamihira and others. Prof. R. N. Iyengar and his team is doing extensive research in pre-*siddhāntic*-astronomy and has come out with the book "*Parāśaratantra*" and is currently working on *Vṛddha-garga-jyotiṣa*. Vṛddha-garga himself makes the statement "darśanaṁ gaṇitaṁ caiva yugapad-yogasādhanam" (both observation and calculation are simultaneously beneficial)

Motivation:

The source of wealth (*artha*) in an ancient society is agriculture and (overseas) trade. Agriculture requires knowledge of seasons and monsoons to know when to sow the seeds, necessitating a calendar. (Overseas) Trade necessitates knowing one's own position (as GPS helps us today).

Introduction:

Jyotiṣ means light. So, Jyotiṣa is the study of (celestial) objects that emit light. No observer can miss the Sun and the Moon. In addition to emitting light, the Sun and the Moon are also seen to move around the Earth. Our ancients noticed that the motion of the Sun and the Moon etc could also be used to keep track of time. It turns out that the celestial objects can also help in knowing one's position. In addition, owing to the motion of the Sun and other celestial objects from East to West; one can also determine the directions. Hence, Jyotiṣa also came to be known as *dig-deśa-kāla-gaṇanā-śāstra*.

Motion of the Sun:

Today, we know that the Earth revolves around the Sun. But an observer stationed on the Earth would not easily be able to tell whether the Earth revolves around the Sun or otherwise, based on naked-eye observations alone. Since the Sun is seen to rise in the East and set in the West; and also move with respect to the background stars, our ancients naturally took the Sun to be a moving celestial object (at least initially).

The time 'taken' by the Sun to complete one revolution around the Earth is called a year. Perhaps in the earliest olden days, this was called a *yuga*. Even today, we celebrate the

beginning of a new year as *yugādi*. It is well-known that the average length of an year is 365.2425 days. This is called **tropical year**.

Every day, the Sun appears to rise in the East and set in the West. This is due to the rotation of the Earth on its axis (This is mentioned by Āryabhaṭa himself). The axis of rotation of the Earth is tilted with respect to the plane of revolution of the Earth by about 23.5° . This gives rise to seasons on the Earth. The plane in which the Sun appears

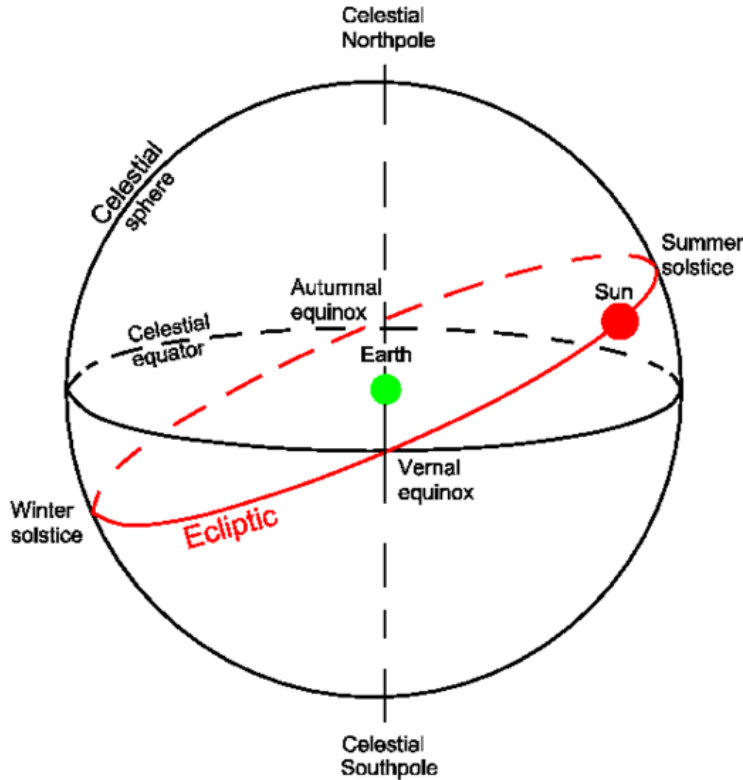


Figure 1. The axis of rotation of the Earth is shown as a dashed line. The North and South poles of the Earth is extended to 'meet' the celestial sphere at the Celestial North Pole and Celestial South Pole respectively. The Earth's equator is extended infinitely to form the celestial equator. The plane in which the Sun appears to revolve around the Earth is called 'ecliptic'

to go round the Earth is called 'ecliptic', as shown in red colour in Figure 1. The ecliptic makes an angle of 23.5 degrees with the Earth's equator. As seen in the figure, there are four cardinal points on the ecliptic, namely winter solstice, summer solstice, vernal equinox and autumnal equinox. The vernal and autumnal equinox points lie on the intersection of the ecliptic with the celestial equator. The summer solstice point is the Northern-most point of the ecliptic and the winter solstice point the Southern-most.

From the time of winter solstice till the summer solstice, the length of the day increases progressively in the Northern hemisphere. Hence, for us in India the period of *uttarāyana* begins from winter solstice and extends till summer solstice. Similarly, from the time of summer solstice till winter solstice, the length of the day decreases progressively in the Northern hemisphere. Hence, we say *dakṣiṇāyana* begins from summer solstice and extends

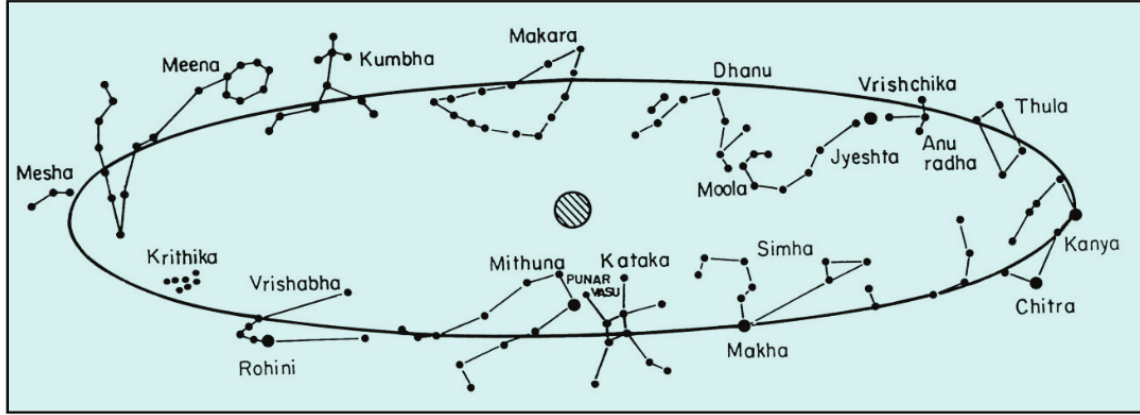
till winter solstice. Therefore, one year is divided into two *ayanas* – *uttarāyana* and *dakṣiṇāyana*. *Uttarāyana* said to be the day of the *devas* and *dakṣiṇāyana* is said to be the night of the *devas*. Notice that in the Northern hemisphere, summer solstice has the longest duration of day while winter solstice has the shortest duration of day.

The length of day and night will be exactly equal on the days of the equinox. The equinoxes are sometimes called *viṣuvat* in Indian languages, sometimes *viṣuvat* may be loosely used for solstices too. The word *viṣuvat* comes the root *viṣ!*, meaning 'to spread'. Hence, *viṣu* is sometimes taken as the center out of which something can spread. If an year is reckoned from winter solstice to winter solstice, then the center of the year will fall on summer solstice, which was called *viṣuvat* in ancient times. Later on, *viṣuvat* came to be associated with the center of each *ayana*, and therefore became associated with the equinoxes. Now, the **tropical year** is defined as the time between two successive vernal equinoxes or between two successive winter solstice points. Note that the average length of the tropical year is 365.2425 days. The seasons on Earth are determined by this tropical year.

Parāśaratantra (pre-siddhāntic-astronomy) divides the two *ayanas* into 3 *ṛtus* (seasons) each, yielding a total of 6 *ṛtus*; namely *śiśira* (winter), *vasanta* (spring), *grīṣma* (summer), *varṣa* (rainy), *śarad* (autumn), *hemanta* (snowy). However, in the (*chāndramāna/sauramāna*) calendars in vogue today, the above alignment between the *ayanas* and *ṛtus* is not seen. Among the six *ṛtus*, *vasanta*, *varṣa* and *śarad* are most beautiful. Hence, the names of these seasons are sometimes used interchangeably with the year itself. For example, *varṣa* is also used to mean an year. Similarly, the age of a person (in years) could be said by stating that he has seen so many *vasantas* or so many *śarads*. *Vasanta* is the time when colourful leaves and flowers bloom and *śarad* is the time when the sky is clear of clouds and the Moon and stars are clearly visible. Hence, the name/expression *śarat-chandra* is used to indicate that the (full) Moon is clearly visible without any obstructions. The *Mahānārāyaṇa-Upaniṣad* says “*jīvema śaradaḥ śatam, nandāma śaradaḥ śatam, modāma śaradaḥ śatam...*” (Let us live for a hundred *śarads*, happily, with enjoyments, etc.). In the *Puruṣasūkta*, creation itself is described in terms of a *yajña* where *Vasanta* is likened to the ghee, *grīṣma* to fuel and *śarad* to oblations. During the rainy season (*varṣa-ṛtu*), it was rather difficult to travel in the olden days. Hence, people used to take up the *chāturmāsya-vrata* of staying in a place and undertake learning and contemplation under the guidance of *mahātmas* who would be following a similar lifestyle.

Motion of the Moon:

The Moon takes about 27.3 days on average to complete one revolution around the Earth. Our ancients knew that this period was between 27 and 28 days. Therefore, 27 (or 28) patterns or groups of bright stars were identified in the night sky to keep track of the movement of the Moon. These came to be known as *nakṣatras*. Note that *nakṣatra* is a technical term used for patterns of stars, and therefore *nakṣatra* is not to be confused for an individual star. For example, *Kṛttikā-nakṣatra* has six prominent constituent stars which appear in the pattern of a machete. *Bhagavān Śrī Kṛṣṇa* was born in the *Rohiṇī nakṣatra* means that the Moon was in vicinity of *Rohiṇī-nakṣatra*. In the *vibhūtiyoga* of *Bhagavad-Gītā*, where *Bhagavān Śrī Kṛṣṇa* identifies Himself with the prominent one in every group; there He identifies Himself with *Chandra* among the group of *nakṣatras* (“*nakṣatrāṇāmahaṃ śaśī*”).



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

Figure 2. The path taken by the Moon is divided into 27 *nakṣatras* to keep track of the position of the Moon

One tradition identified 27 *nakṣatras* while another identified 28 *nakṣatras*. Over time, when the period was found to be closer to 27 days rather than 28 days, one *nakṣatra* was dropped. This concept came to be codified in the *Taittiriya Samhitā* of *Yajurveda* as follows: *Dakṣa Prajāpati* had 28 daughters whom he gave in marriage to *Chandra* and asked him to care for all the 28 equally. But as time went by, *Chandra* was seen to spend more time with *Rohiṇī*. Angered by this, *Dakṣa* cursed *Chandra* to undergo *kṣaya* or to wane. When *Chandra* was about to be fully gone, he requested *Dakṣa* for pardon, and then *Dakṣa* asked *Chandra* to request *Sūrya* for help.

In the most ancient times, the region assigned to each *nakṣatra* was not constrained to be mathematically equal, but was meant to be recognized easily by naked eye observations due to their patterns. However, later on, when the influence of mathematics on astronomy increased, each *nakṣatra* came to be associated with equally divided sectors, each with an angle of $13^{\circ}20'$ (360° divided into 27 segments yields $13^{\circ}20'$). Also, *nakṣatra* stands for a unit of time. It can be defined as the time taken by the Moon to cover an angle of $13^{\circ}20'$ in its revolution around the Earth. However, the angular velocity of the Moon is not constant; hence the Moon may cover one sector faster than another.

It is observed that during one year, we get to see 12 new moons (*amāvāsya*). In Sanskrit, *amā* means 'near' (also in *amātya* for minister). So, here the Sun and Moon are together, therefore the light reflected by the Moon does not reach the Earth. Hence we see the new moon, as shown in Figure 3. After about 27.3 days, the Moon returns to this starting reference position. But in this time, the Sun would also have moved forward by about 27° (since the Sun covers 360° in about 365 days or roughly 1° per day). Since the Moon covers about $13^{\circ}20'$ in a day, the Moon will take two more days to "catch up" with the Sun. Hence, the average duration between two *amāvāsya* is about 29.5 days. Our ancients rounded this up to 30 and defined 30 *tithis* to make up one month or *māsa*. Notice that even in English, the word month comes from 'Moon' itself. This *māsa* can be divided into two halves comprising of 15 *tithis* each; one in which the Moon waxes and the other in which it wanes; called *śukla-pakṣa* and *kṛṣṇa-pakṣa*. *Śukla-pakṣa* is said to be the day for the *pitṛs* and *kṛṣṇa-pakṣa* their night. Notice that the full moon is seen when the Sun and the Moon are diametrically opposite.

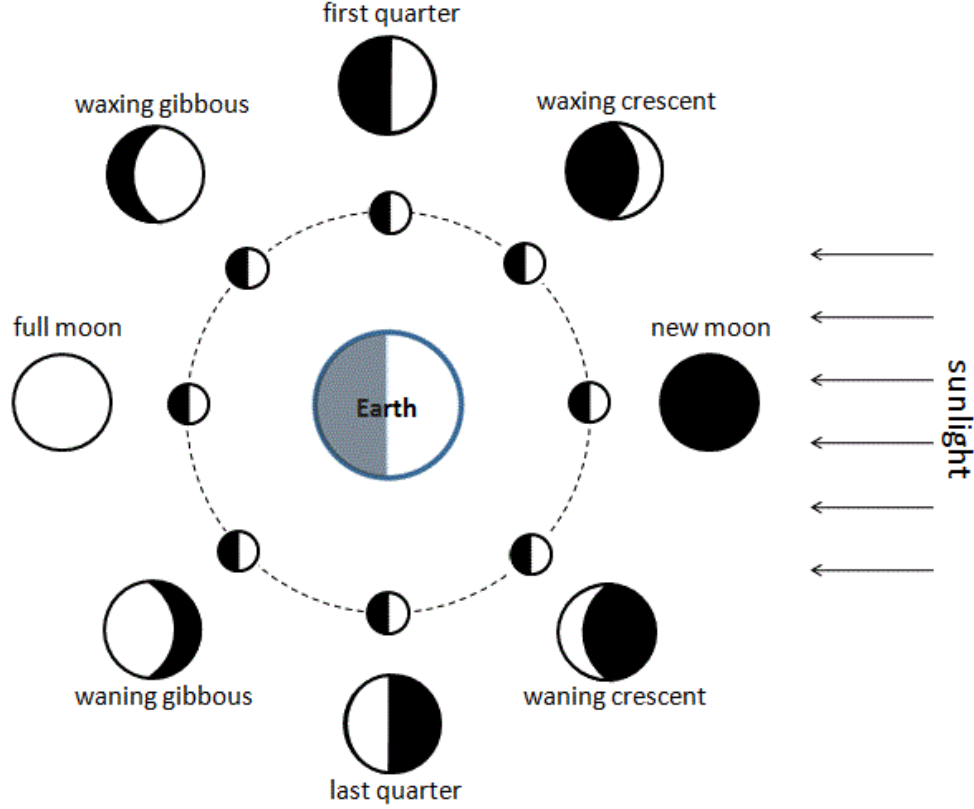


Figure 3. Phases of the Moon are caused by the relative position of the Moon with respect to the Sun.

Since 30 *tithis* are identified for one month, a *tithi* may be defined as the time taken by the Moon to lead the Sun by 12° (since $12 \times 30 = 360$). As mentioned earlier, the angular velocities of the Sun and the Moon are not uniform. Hence, the exact duration of some *tithis* may be smaller than others. For the sake of convenience, in some *sampradāyas*, the *tithi* at the time of Sunrise is taken as the *tithi* for the whole day. If a particular *tithi* begins before Sunrise on a given day and ends after Sunrise on the next day, then the said *tithi* would be prevalent for two (civil) days. For example, if *ekādaśī* begins at 5AM on a day and ends at 8AM the next day, two days will be marked as *ekādaśī* in the said method. A call has to be taken by those people who are undertaking *upavāsa*. Suppose *chaturthī* begins at 3PM on a given day and ends at 5AM next day, then in the said method, no day will be marked as *chaturthī*. If a certain festival or ceremony is to be done on *chaturthī*, again a call has to be taken as to when to perform the said ritual/s.

Note that *tithi* keeps track of the difference in the angles made by the Sun and the Moon. To provide redundancy for error correction, *yoga* is defined to keep track of the sum of the celestial longitudes of by the Sun and the Moon. 27 *yogas* are identified, similar to *nakṣatras*. *Karaṇa* is another unit of time defined as one half of a *tithi* (probably analogous to day and night). 11 *Karaṇas* are identified, four of which are fixed and seven of which vary as the *tithis* of a *māsa* proceed.

On the Seven-day week and *tārāgrahas*:

Although there are references to *saptāha* in the context of the *Aśvamedha-yāga* in the *Yajurveda*, the concept of a seven-day week (named on the *grahas* visible to the naked eye) is not seen in the *Rāmāyaṇa*, *Mahābhārata* or in any of Kālidāsa's works. Hence, the popular opinion among scholars is that the seven-day week came into being later. Also, note that the week or weekday is not directly related to an astronomical event unlike *nakṣatra* or *tithi* discussed above.

The celestial objects, namely, *Ravi* (Sun), *Chandra* (Moon), *Budha* (Mercury), *Śukra* (Venus), *Kuja* (Mars), *Guru* (Jupiter) and *Śani* (Saturn) appear to move with respect to the background stars. In the Greek tradition, these 'moving' celestial objects came to be known as 'planets' which means 'wanderers'. However, in the Indian tradition, which is arguably much older than the Greek, the 'wandering' objects were said to 'hold' different stars during their motion; and therefore came to be known as *tārāgrahas* (*tārāḥ grṇhāti iti tārāgrahaḥ*). Over time, the name *tārāgraha* was shortened to *graha* for brevity. Again, it is to be noted that *tārāgraha* or *graha* is a technical term and is not to be confused with today's understanding of planets of the solar system which orbit the Sun.

Each day of the week came to be named after the *grahas* listed above according to the following rule: The *grahas* are first arranged in increasing order of their speeds as seen from the Earth: *Śani* (Saturn, 30 years), *Guru* (Jupiter, 12 years), *Kuja* (Mars, 2 years), *Ravi* (Sun, 1 year), *Śukra* (Venus, 225 days), *Budha* (Mercury, 88 days) and *Chandra* (Moon, 27.3 days). Each of the seven *grahas* are assigned one hour out of the 24 hours per day. The *graha* which gets assigned to the first hour of a particular day, lends its name to that particular day. Since 24 leaves a remainder of 3 upon division by 7; it is easy to see that *Ravivāra* (Sunday) is followed by *Somavāra* (Monday), *Budhavāra* (Wednesday) by *Guruvāra* (Thursday) etc.