Introduction to Indian Astronomy

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Sun, Moon

Very many references to Sun, Moon, Stars, Earth, Planets, Meteors etc., Eclipses

एकः सूर्यो विश्वमनु प्रभूतः। एकैवोषाः सर्वमिदं विभाति।
ṚV, 8.59.2.
The one Sun is the lord of the universe. One dawn, it lights up all this.

मित्रो दाधार पृथिवीमुत द्याम् । *YV;TS*, 3.4.11
The Sun supports the heaven and the Earth.

Many other references. The Sun is also said to control the seasons.

The Moon is spoken of in the *Vedas* as 'सूर्यरश्मि ' one which shines by the Sun's light. The dependence of Moon's phases on its elongation from the Sun is implicit in a descrip tion in *Śatapatha Brāhmaṇa*, 1.5.4.18-20.

Stars

Observation of stars necessary for performing the rites at the correct time.

यत् पुण्यं नक्षत्रं तद्वत् कुर्वीत उपव्युषं। यदा वै सूर्य उदेति। अथ नक्षत्रं नैति। यावति तत्र सूर्यो गच्छेत्। यत्र जघन्यं पश्येत् तावति कुर्वीत यत्कारी स्यात्। पुण्याह एव कुरुते।

’The auspicious star, its position has to be determined at Sunrise. But when the Sun rises, the star would not be visible (on account of the brightness of the Sun). So, before the Sun rises, watch for the adjacent star. By performing the rite with due time adjustment, one would have performed the rite at the correct time.’ *Tait. Br.*, 1.5.2.1

Names of many stars mentioned. We will take up later.

Earth

The spherical nature of the Earth is implicit in many statements in *Ṛgveda*. For instance,

पृच्छामि त्वा परमन्तं पृथिव्याः| पृच्छामि यत्र भुवनस्य नाभिः ||
इयं वेदिः परो अन्तः पृथिव्या | अयं यज्ञो भुवनस्य नाभिः ||
ṚV,1.164.34-35.

'I ask thee, where the ultimate end of the Earth is ; I ask of thee, where the centre of the Earth is.
This altar (and, for that matter, any point on the surface of the earth) is the ultimate end of the earth; this sacrifice (performed on the altar) is (again) the centre of the Earth (since the Earth is spherical).

The *Śatapatha Brāhmaṇa* describes the Earth explicitly as a sphere: परिमण्डल उ व अयं लोकः (7.1.1.37)

Planets, Comets, Meteors

The number of planets is given as five in a *Ṛgvedic* verse:

amī ye pañcokṣaṇo madhye tasthur maho divaḥ Ṛv,1.105.10.
'These mighty five(gods)are seen in the vast expanse of the sky'. (Five : Mercury, Venus, Mars, Jupiter, Saturn.)

Atharvaveda clearly distinguishes between *nakṣatras* and *graha* (planets)

Interesting reference in *Atharvaveda* about meteors and comets which are supposed to portend evil.

áṁ no bhūmir vepyamānā śaṁ ulkānirhataṁ ca ....*śaṁ no mṛtyur dhūmaketuḥ*.... *AV* 19.9.8-10
Weal for the quaking Earth, and weal for the meteor-smitten. ..... Weal for us the deadly comet .... (Weal : welfare)

Several references to eclipses ; *svarbhānu*, the *āsura* striking the Sun with darkness. Family members of Atri being well-versed in understanding eclipses.

Celestial objects and their motion as observed from Earth

Celestial objects : Stars, Sun, Moon, Planets and other extra-terresrial objects in the sky .

How do they move as seen by us ?

Do they move with respect to each other?

Intimately related to these, are the three clear time-markers in the sky: (1) Day : Time interval between two successive sunrises (2) Month : Time interval between two successive New Moons (Amavasya) or Full Moons (Poornima) (3) Year : Time required for Sun to complete one circuit around the Earth in the background of stars.

We should understand these clearly.

First : Stars : Relative positions fixed.
Constellations : Groups of stars which appear to be close to one another. Actually directions are close as seen from Earth.
Show slides Constellationsx.

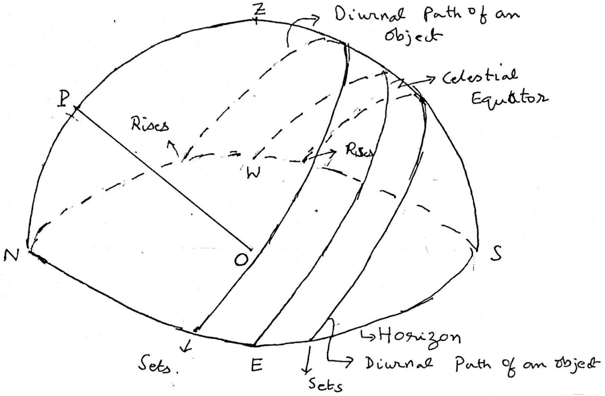
Daily Motion of celestial objects

All the celestial objects rise in the eastern part of the sky and set in the western part.

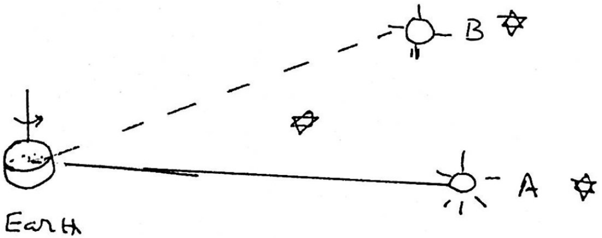
Again, after a day :

Civil day : Sunrise to Sunrise : $S\bar{a}vanadina$: 24 hours or 60 $Gha\d{t}k\bar{a}$s.

Sidereal day : Star-rise to star-rse : 23 hours 56 min. $N\bar{a}k\d{s}atradina$.



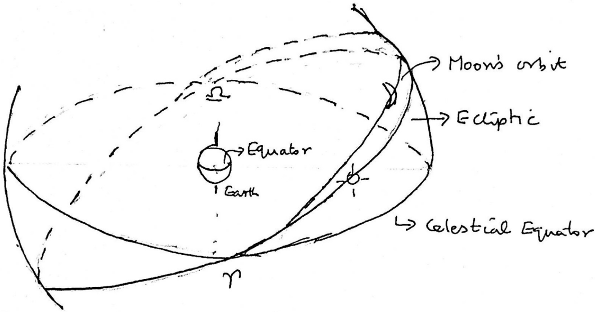
Eastward motion of Sun, Moon and Planets w.r.t. stars



On some day, Sun's position is in direction of star A.
One day later, it is in direction of star B, east of A.
Angle between these two directions is nearly one degree.

Similarly, Moon and planets also have eastward motion w.r.t. stars. Amount varies.
For Moon, it is nearly 13 degrees per day.

Motion of the Sun, Moon etc in the Stellar background: Ecliptic



Celestial Equator : *Viṣuvadvṛtta* .
Ecliptic : *Krāntivṛtta* or *Krāntimaṇḍala* ; Also *Apamaṇḍala*. Inclined to the equator at an angle nearly $23\frac{1}{2}$ degrees.

Sun moves along the ecliptic in eastward (anti-clockwise) direction. Northern and southern motions of the Sun. Solstices and equinoxes.
Moon's orbit inclined to the ecliptic at an angle nearly 5 degrees.

Planetary orbits also close to the ecliptic.

Northern, Southern motions of the Sun; Equinoxes

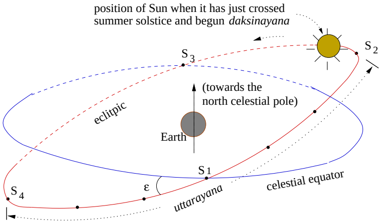
Taittirīya saṁhita (6.5.3) observes:

tasmād ādityaḥ ṣaṇmāso dakṣinenaiti ṣaṭuttareṇa
'Thus the Sun moves southwards for six months and northwards for six months.'

The equinoctial day (*viṣuvat*) in *Aitareya Brāhmaṇa* (18.4)

ekaviṁśaṁ etad ahar upayanti viṣuvantam madhye saṁvatsarasya
'The *ekaviṁśa* [rite] is performed on the [equinox] day, occuring in the middle of the year.

Solstices find mention in many places, example, *Kauṣīki Brāhmaṇa*. At solstices where the Sun turns northwards or southwards, it 'rests'.



Rāśi division of the ecliptic

One circuit of the Sun along the ecliptic : Year.$\approx$ 365.25 days.

Convenient to divide the ecliptic into 12 equal segments. Each segment spans 30° and corresponds to one month. These segments are the *rāśi*s and named as : *Meṣa, Vṛṣabha, Mithuna, Kaṭaka, Simha, Kanyā, Tulā, Vṛścika, Dhanu, Makara, Kumbha*, and *Mīna rāśis*. Constellations of stars are situated in each *rāśi* as shown.

Solar month (*Sauramāsa*): $\frac{1}{12} \times$ Year $\approx \frac{365.25}{12}$ on the average.

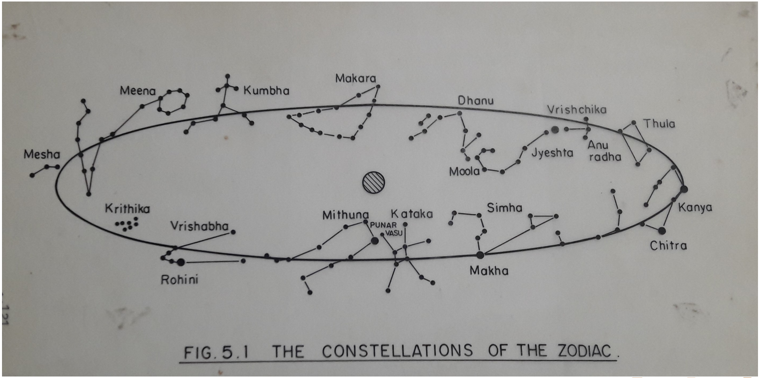


FIG. 5.1 THE CONSTELLATIONS OF THE ZODIAC.

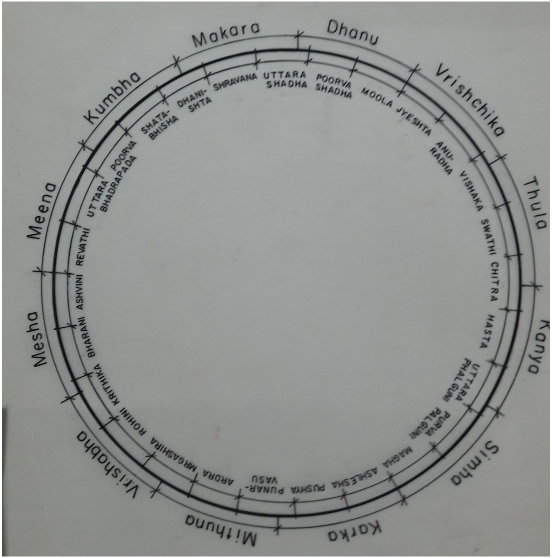
The 27 *nakṣatras*

The Moon's sidereal period is close to 27.32 days, that is, the Moon covers nearly $\frac{1}{27}$ th part of the ecliptic per day. It is natural to divide the ecliptic into 27 equal divisions, also called *nakṣatras* : Each day asssociated with a *nakṣatra* ($\frac{360}{27} = 13\frac{1}{3}^{\circ}$) in which Moon is situated. .
They are:
Aśvini, Bharaṇi, Kṛittikā, Rohiṇi, Mṛgaśira, Ārdrā, Punarvasu, Puṣya, Āśleṣa, Maghā, Pūrva Phālguṇi, Uttara Phālguṇi, Hasta, Citrā, Svāti, Viśākhā, Anurādhā, Jyṣṭhā, Mūlā, Pūrvāṣāḍhā, Uttaāṣāḍhā, Śravaṇa, Dhaniṣṭhā, Śatabhiṣaj, Pūrvābhādrā, Uttarābhādrā, and Revati
Full list headed by *Kṛittikā* in *Taittirīya saṁhita*, 4.4.10.1-3 ; also *Atharvaveda* and other places.

Lunar month : It is the time interval between successive Conjunctions of Sun, Moon: (Same direction from Earth: $Am\bar{a}v\bar{a}sya$) or Oppositions (Opposite directions : $P\bar{u}r\d{n}im\bar{a}$) . $\approx$ 29.5 days.

So we have: Day ; Year ($Var\d{s}a,\ Sa\d{m}vatsara$) $\approx$ 365.25 days ; Month ($Saura$: $\frac{365.25}{12}$ days , or $C\bar{a}ndra$:$\approx$ 29.5 days).

Rāśi and *Nakṣatra* division of Ecliptic: One more picture



Year and Months in Vedic period

द्वादशारं नहि तज्जराय ववर्ति चक्रं परि ध्यां ऋतस्य |
आ पुत्रा अग्ने मिथुनासो अत्र सप्त शतानि विंशतिश्च तस्थुः ||
'The wheel (of time), formed with twelve spokes, revolves round the heavens, without wearing out. O Agni, on it are 720 sons (viz., days and nights)' *Ṛ*V, 1.164.11

Remember Konark! A year has 12 months and 360 days (5 or even 5.25 days are added later; to be discussed later).

The months and seasons are discussed in *Taittirīya saṁhitā* :

मधु माधव (वसन्त), शुक्र शुचि (ग्रीष्म), नभस् नभस्य (वर्ष), ईष ऊर्जा (शरद्), सहस् सहस्य (हेमन्त), तपस् तपस्य (शिशिर)
Tait. saṁ . 1.4.14 and 4.4.11.

Concept of $Adhikam\bar{a}sa$ already there*. Mention of 2 more months than the 12, ($samsarpa$, $amhaspati$ in 1.4.14. The latter is perhaps a *kṣaya māsa*. [* To align lunar months and solar year; 12 lunar months $\approx 12 \times 29.5 = 354$ days.]

Advent of *Vedāṅga Jyotiṣa*

A 5-year *yuga* cycle in *Taittirīya* and *Vājasaneyi saṁhitas*. (when the Sun and the Moon return together at the same position after 5 years). As we saw, there are rudiments of a calendar with intercalary months and 27 *nakṣatras* as markers of Moon's movement. However, descriptions: qualitative.

It is in *Vedāṅga Jyotiṣa* that we have a definite quantitative calendrical system. Two rescensions: *Ṛg* and *Yajur* : ascribed to sage Lagadha. In one of the verses, it says:

स्वराक्रमेते सोमार्कौ यदा सार्कं सवासवौ ।
स्यात्तदादि युगं माघस्तपश्शुक्लोऽयन ह्यदक् ॥

When the Sun and Moon occupy the same region of the zodiac together with the asterism of *Vāsava* (*Śraviṣṭhā*) at that time begins the *yuga*, and the synodic month of *Māgha*, the solar month called *Tapas*, the bright fortnight (of *Māgha*) and their northward course (*Uttarāyana*).

So, winter solstice: beginning of the asterism *Śraviṣṭhā* (Delfini) segment. This corresponds to some time between 1370 BCE and 1150 BCE. Might have been written a little later.

Vedāṅga Jyotiṣa calendar

Clearly, the *yuga* concept mentioned. The whole calendar is summarised thus:

त्रिशत्यह्नां सषट् षष्टिरब्दः षट् चर्तवोऽयने ।
मासा द्वादश सौराः स्युः एतत् पञ्चगुणं युगम् ॥
सावनेन्दुस्त्रुमासानां षष्टिः सैक द्विसप्तिका।
ध्युत्रिंशत् सावनः सार्धः सूर्यः स्त्रुणां स पर्ययः ॥

Three hundred and sixty six days form the solar year. In the year, there are six *ṛtu*s and two *ayana*s, (i.e. northward and southward courses of the Sun). There are 12 solar months in the year. Five years make a *yuga*.
In a *yuga* there are, respectively, 61, 62 and 67 (i.e. 60+1, 60+2, and 60+7) *sāvana* months, lunar(synodic) months, and Moon's cycles. The *sāvana* month contains 30 days. This plus half (i.e. 30 1/2) make a solar month. The number mentioned here (viz. 60) is the number of solar months in a *yuga*.

Vedāṅga Jyotiṣa(VJ) calendar

What this means is the following. The *Vedāṅgajyotiṣa yuga* consists of 60 solar months, 62 lunar months, 67 sidereal months, and 60 x 30 1/2 = 1830 civil days. Hence,

A sidereal year = 1830/5 = 366 days (actual: 365.2564 d).

A lunar month = 1830/62 = 29.516 days (actual : 29.5306 d).

A sidereal month = 1830/67 = 27.301 days (actual: 27.321 d).

60 solar months and 62 lunar months in 5 years. So, 2 *adhikamāsa*s in this period. So, 3 lunar years with 12 months, and 2 lunar years with 13 months in a *yuga*.

The concept of *tithi* mentioned in VJ, perhaps for the first time. *Tithi* : $\frac{1}{30}$ of a lunar month. 15 *tithis* in each *parva* (half of a lunar month).

There are short algorithms for finding *tithi*, *nakṣatra*, Sun's position in the sky, etc. So, *Vedāṅgajyotiṣa* is the first text in India to give mathematical algorithms in astronomy. There is nothing on planetary motion in this work.

Computational scheme simple, with a sid. year of 366 days; probably corrections were made regularly

Sidereal year of 366 days too long. In *Taitt.*, clear mention of *sāvana* year of 360 days increased by 5 days, or lunar year of 354 days increased by 11 days to obtain the sidereal year of 365 days. There is also mention of a cycle of 4 years with 1461 days, implying a sidereal year of 365.25 days in the *Vedic* literature elsewhere. Also, simple observations would reveal that the Sun and the Moon would not come back to the same point at the same time after 1830 days. Then why does VJ have a 366 day-sidereal year?

T.S. Kupppanna Sastry's opinion: It was meant primarily to provide a civil calendar, where convenience of division and ease of calculation is important. Difference from actuality anyway there because only mean motions of Sun, Moon considered, Certainly corrections would be introduced to obtain tolerable positions of the Sun, Moon.

Siddhāntic period and *Āryabhaṭīya* of Aryabhata

Siddhāntas : Contains systematic mathematical treatment of all the traditional astronomical problems. **Trigonometry is needed. Indians developed it in own way: closer to modern trigonometry.**

Āryabhaṭīya is the earliest available *Siddhānta* text. It is mentioned in the text itself that it was composed 3600 years after the begining of *Kaliyuga*. This corresponds to 499 CE. Further it is stated that Āryabhaṭa was 23 at the time of composition. He composed this work in *Kusumapura* which is the same as *Patalīputra* (essentially modern Patna).

Āryabhaṭīya has only 121 stanzas, and has 4 parts, namely:

Gītikāpāda, ***Gaṇitapāda***, ***Kālakriyāpāda*** and ***Golapāda***.

Gitikāpāda has only 13 stanzas and begins with the letter-numeral notation for numbers. It introduces the concepts of *Kalpa* and *Mahāyuga* and gives the revolution numbers of planets and parameters associated with them.

Gaṇitapāda and *Kālakriyāpāda*

Gaṇitapāda in 33 stanzas deals with mathematical problems such as – squaring, squareroot, cubing, cuberoot, 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, 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 even a problem related to interest calculation!

Kālakriyāpāda in 25 stanzas deals with reckoning of time, calendrical concepts, and the planetary model (epicycle and eccentric circle theories), explicit procedure for calculation of planetary positions, etc.

Golapāda ; *Āryabhatasiddhānta*

Golapāda in 50 stanzas deals with the problems of spherical astronomy such as *bhagola* (celestial sphere) 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 eclipse, solar eclipse and so on.

Āryabhaṭa has composed one more work called *Āryabhatasiddhānta*.The manuscripts of this have not been found. However several later authors have referred to this work. It was a popular work and was studies throughout India. It seems that this work discussed the astronomical instruments in some detail.

Some salient features of $\bar{A}ryabhat\bar{i}ya$

Finding the Sines using a Second-order Difference Equation.

Value of π correct to four decimal places.

The mathematical theory for finding the ”True” positions of planets , taking the non-uniform motion of planets into acount.

Problems involving spherical trigonometry

Eclipses

To put it in a nutshell, it sets up the framework for mathematical astronomy in India.

Situation of the Earth and its Spherical nature
In verse 6 of *Golapāda* Aryabhata states:

वृत्तभपञ्जरमध्ये कक्ष्यापरिवेष्टितः खमध्यगतः।
मृज्जलशिखिवायुमयो भूगोलः सर्वतो वृत्तः ॥

The globe of the Earth stands(supportless) at the centre 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.

The supportless nature of the earth and the reason for its spherical shape is elaborated in many later texts and commentaries.

Rotation of the Earth, Illumination of Planets

अनुलोमगतिर्नौस्थः पश्यत्यचलं विलोमगं यद्वत् ।
अचलानि भानि तद्वत् समपश्चिमगानि लङ्कायाम् ॥

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.

It appears that Aryabhata believed that the Sun was the only source of light in the universe and other celestial bodies, which were spherical in shape , recieved their light from the Sun. In verse 5 of $Golap\bar{a}da$ he says:

भूग्रहभानां गोलार्धानि स्वच्छायया विवर्णानि ।
अर्धानि यथासारं सूर्याभिमुखानि दीप्यन्ते ॥

Halves of the globes of the Earth, the planets and the stars are dark due to their own shadows; the other halves facing the Sun are bright in proportion to their sizes.

Cause of Eclipses; Sample Algorithm for Calculation

The constitution of the Moon, Sun and Earth, Cause of eclipses

> चन्द्रो जलमर्कोऽग्निः मृद्भूश्छायापि या तमस्तद्धि ।
> छादयति शशी सूर्यं, शशिनं महती च भूच्छाया ॥
>
> *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.*

Algorithm for half-duration of a lunar eclipse:

> तत्च्छशिसम्पर्कार्धकृतेः शशिविक्षेपवर्गितं शोध्यम् ।
> स्थित्यर्धीमस्य मूलं ज्ञेयं चन्द्रार्कदिनभोगात् ॥
>
> *From the square of half the sum of the diameters of that* ($tamas$) *and the Moon, subtract the square of the Moon's latitude , and (then) take the square root of the difference ; the result is known as half the duration of the eclipse (in minutes of arc). (The corresponding time (in* $ghaṭi$ *s etc. is obtained with the help of) the daily motions of the Sun and the Moon.*

Similar algorithms for measure of the eclipse at a given time etc. The concepts in the $golapāda$: Basis for similar chapters in later texts in India, where they are elaborated and improved.

Mahāyuga in *Āryabhaṭīya*

Mahāyuga of 43,20,000 years. *Kṛta, Tretā, Dvāpara* and *Kali* are all quarter of this *mahāyuga*, namely, 10,80,000 years. In most other texts, lengths of *Kṛta, Tretā, Dvāpara* and *Kali* are in the ratio: 4:3:2:1.

Why *Mahāyuga*?
All the planets make integral number of revolutions around the earth in the stellar background in orbits close to the ecliptic in a *Mahāyuga*.

The number of revolutions in the stellar background made by the planets in a *mahāyuga* are given in the texts. For *Āryabhaṭīya*, these are given in the following table. The number of civil days in a *mahāyuga* known as the *Yugasāvanadina* (D_Y) is also specified. In *Āryabhaṭīya* $D_Y = 1577917500$.

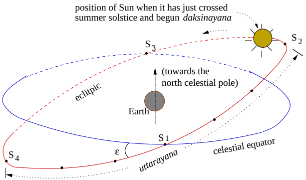
Revolution numbers in a *Mahāyuga*

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	6794.74951	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

Table 1: Planetary revolutions in a *mahāyuga* and the inferred sidereal periods in *Āryabhaṭīya*. * For Mercury and Venus: *Śīghroccas*(Heliocentric revolution numbers). *Yugasāvanadina* (D_Y) = 1577917500.

Mean Longitude and Corrections

Suppose we want to calculate the 'True longitude' of the planet, at an instant which is the (mean) Sun-rise on a day A days after the epoch [In the case of $\bar{A}ryabh\d{t}\bar{\imath}ya$, the epoch is the beginning of $kaliyuga$]. A is called the $Aharga\d{n}a$. Wor that we have to first calculate the 'Mean Longitude', λ_0.



Let N_p : Planet's Revolution number.
No. of completed revolutions for A,
$n(A) = N_p \times \frac{A}{D_Y}$,
$\lambda_0 = n(A)$ (Fractional part) $\times 360°$.

From this, the mean longitudes of planets can be calculated at any time. Normally, it is assumed that the mean longitudes are zero at the beginning of the $kaliyuga$. In $\bar{A}ryabha\d{t}\bar{\imath}ya$, this is taken to be the mean sunrise at Ujjain of February 18, 3102 BC.

Now, the apparent motion of the Sun, Moon and planets in the background of stars is not uniform. Two corrections are needed to obtain the 'true' (geocentric) longitudes. These are :

The Two Corrections

(1) *Mandasaṃskāra*. This is due to the non-uniformity of motion due to the eccentricity of the planet's orbit. 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 *tarāgraha*s in India (traditionally, only Mercury, Venus, Mars, Jupiter and Saturn), we obtain the true heliocentric longitude after *mandasaṃskāra*.

(2)*Śīghrasaṃskāra*. This converts the heliocentic logitude of the *taraagraha*s to geocentric longitudes.

It is in *Āryabhaṭīya* that the above two corrections are discussed clearly for the first time in the Indian tradition. This planetary model described by Aryabhata 'roughly' amounts to the planets orbiting around the Sun in eccentric orbits, with the Sun itself orbiting around the earth. But Aryabhata **does not state it**. We discuss the planetary models in Indian astronomy a little more later, if time permits.

Major Indian Astronomers and Texts after *Āryabhaṭīya*

Aryabhata (466 AD) *Āryabhaṭīya* (499 AD)

Varahamihira (505 AD) *Pañcasiddhāntikā*

Bhaskara I (600 AD) *Mahābhāskarīya*, *Laghubhāskarīya*, *Āryabhaṭīyabhāṣya*

Brahmagupta (591 AD) *Brāhmasphuṭasiddhānta*, *Khandakhādyaka*

Lalla (8th Century) *Śiṣyadhīvṛddhida Tantra*

Vateswara (880 AD) *Vaṭesvarasiddhānta*

Manjulacarya (932 AD) *Laghumānasa*

Sripati (11th Century) *Siddhāntaśekhara*

Bhaskaracarya II (1114 AD) *Siddhāntaśiromaṇi* with *Vāsanābhāṣya* (1152 AD), *Karaṇakutūhala*

Siddhāntaśiromaṇi: A Landmark. Marvelous commentary by himself. Existing knowledge systematised and taken forward. Even now a text book in *Jyotiṣa* departments.

Post- Aryabhatan Astronomy

Madhava (1350 AD) *Veṇvāroha, Sputacandrāpti*

Paramesvara (1370 AD) *Sūryasiddhāntavivaraṇa, Bhaṭadīpikā*, *Laghumānasavyākhyā, Dg̣gaṇita*

Nilakantha Somayaji (1465 AD) *Tantrasaṅgraha* (1500 AD), *Āryabhatīyabhāṣya* , *Jyotirmīmāmsa, Golasāra, Siddhāntadarpana*

Jyesthadeva *Gaṇita-Yuktibhāṣa* (1530 AD)

Sankara Varier (16th Cent) *Laghuvivṛti, Yuktidīpikā* : Commentaries on *Tantrasaṅgraha*

Acyuta Pisarati (16th cent) *Sphuṭanirṇayatantra*, *Rāśigolasphuṭanīti, Karaṇottama*

Putumana Somayaji *Karaṇapaddhati* (1730 AD ?)

Ganesha Daivajna (1507 AD) *Grahalāghava*

Kamalakara (1616 AD) *Siddhāntatattvaviveka*

Chandrasekara Samanta (1835 AD) *Siddhāntadarpana* (pub. 1900)

Author unknown : Modern *Sūryasiddhānta* (10th Century)

Contents of Indian Astronomy Texts

We list the chapters contained in a typical Indian text. In Sanskrit, the word for chapter is *adhikāra* or *adhyāya*.

Madhyamādhikāra : This gives the procedure for finding the *ahargaṇa*, which is the count of days from a given epoch. The revolution number of each planet in a *mahāyuga* would also be given. From this, the mean longitude of the planet or the *madhyamagraha* at any instant can be calculated.

Spaṣṭādhikāra : *Spaṣṭa* means clear or true. In this chapter, the procedure to obtain the true longitude or the *sphuta* from the mean longitude would be elaborated. This would involve two corrections, namely, *mandasaṃskāra* and *śighrasaṃskāra*. Discussed.

tripraśnādhikāra : *tripraśna*: direction (*dik*), place (*deśa*) and time (*kāla*). Various diurnal problems would be discussed: Finding north-south directions, latitude of a place, Sun's diurnal path, its declination, Sunrise/Sunset times, measurement of time (from shadow), relations among various celestial coordinates, calculation of *lagna* (point on the ecliptic which is on the horizon) at any time, etc.

Contents of *Siddhāntic* texts

Candragrahaṇādhikāra and *Sūryagrahaṇādhikāra* : These deal with lunar and solar eclipses. These include timings, durations of eclipses, duration of totality, magnitude of the eclipses, etc. All these depend very sensitively on the parameters associated with the Sun and the Moon. Indian astronomers periodically revised these after observing eclipses.

Other chapters : There would be chapters or parts of chapters on visibility of eclipses (heliacal rising and setting) and Moon's cusps. In many works there would be separate chapters on instruments for measuring time, illustrating the celestial globe, etc. There would be expositions on the mathematics used in the text, especially, spherical trigonometry. As a matter of fact, *Golādhyāya* on spherical trigonometry problems would be a major separate part of the text.

Indian astronomy texts are Algorithmic. Commentaries of texts very important.

Indian Calendar

and

Paṅcāṅga

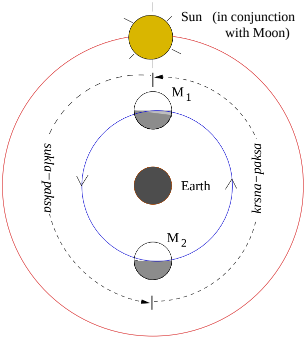
Based on True Longitudes of the Sun, Moon

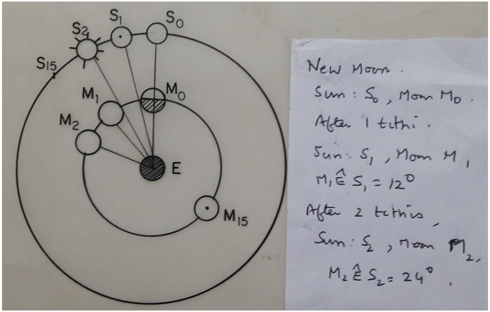
Lunar month ; *Śukla-pakṣa*, *Kṛṣṇa-pakṣa*; *Tithi*

New Moon (N): *Amāvāsyā* , Full Moon (F): *Pūrṇimā* .
N to F : *Śukla-pakṣa* (Bright Fortnight) ; F to N : *Kṛṣṇa-pakṣa* (Dark fortnight): Lunar month : N to N (*Amānta*) or F to F : *Pūrṇimānta*

Wrt Stellar background, Motion of Sun $\approx 1^\circ$ / day: Moon $\approx 13^\circ$ / day.

Tithi: Time-unit during which the angle between the Sun and the Moon increases precisely by 12°. At *Amāvāsyā* , Angle = 0°; First *tithi* begins. This ends and second *tithi* begins when Angle $= 12^\circ$. Second ends when Angle =24°, and so on. A *pakṣa* : 15 *tithis*. Lunar month: 30 *tithis*.





30 *Tithis* and their Angular Ranges

Śukla-pakṣa		*Kṛṣṇa-pakṣa*	
Name of *tithi*	Angular separation bet. Moon and Sun	Name of *tithi*	Angular separation bet. Moon and Sun
Prathamā	0° – 12°	*Prathamā*	180° – 192°
Dvitīyā	12° – 24°	*Dvitīyā*	192° – 204°
Tṛtīyā	24° – 36°	*Tṛtīyā*	204° – 216°
Caturthī	36° – 48°	*Caturthī*	216° – 228°
Pañcamī	48° – 60°	*Pañcamī*	228° – 240°
Ṣaṣṭhī	60° – 72°	*Ṣaṣṭhī*	240° – 252°
Saptamī	72° – 84°	*Saptamī*	252° – 264°
Aṣṭamī	84° – 96°	*Aṣṭamī*	264° – 276°
Navamī	96° – 108°	*Navamī*	276° – 288°
Daśamī	108° – 120°	*Daśamī*	288° – 300°
Ekādaśī	120° – 132°	*Ekādaśī*	300° – 312°
Dvādaśī	132° – 144°	*Dvādaśī*	312° – 324°
Trayodaśī	144° – 156°	*Trayodaśī*	324° – 336°
Caturdaśī	156° – 168°	*Caturdaśī*	336° – 348°
Pūrṇimā	168° – 180°	*Amāvāsyā*	348° – 360°

Lunar month ; Lunisolar or Lunar Year; *Amānta* and *Pūrṇimānta* systems

Śukla-pakṣa+ *Kṛṣṇa-pakṣa* = *cāndra-māsa* (Lunar month).
A normal lunar year has twelve lunar months. The names of the twelve lunar months are: *Caitra, Vaiśākha, Jyeṣṭha, Āṣādha, Śrāvaṇa, Bhādrapada, Āśvayuja, Kārtika, Mārgaśira, Puṣya, Māgha* and *Phālguna*. During most *Caitra* months the Moon will be close to the star *Citrā* (Spica), on the full Moon day of the month. Similarly, during most *Vaiśākha* months, the Moon will be near to the star *Viśākhā* on the full moon day in that month. This is the reason for the nomenclature.

Amānta system: A Lunar month commences with the ending moment of the New Moon day or equivalently the beginning of the *Śukla-pakṣa*.
Pūrṇimānta system : A Lunar month commences with the ending moment of the Full Moon day or equivalently the beginning of the *Kṛṣṇa-pakṣa*.

.

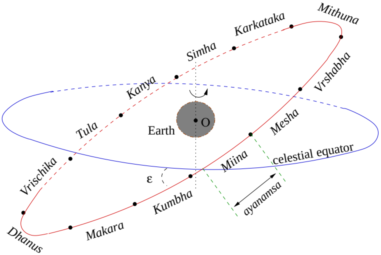
Amānta and *Pūrṇimānta* Lunisolar systems

Names of Lunar months Same. *Śukla-pakṣas* : Same name. *Kṛṣṇa-pakṣas* : Different names. *caitra-śukla-pakṣa* of the *Amānta* system will be the same as the *caitra-śukla-pakṣa* of the *Pūrṇimānta* system, though the *caitra-kṛṣṇa-pakṣa* of the *Amānta* system will be the *vaiśākha-kṛṣṇa-pakṣa* of the *Pūrṇimānta* system.

The *Amānta* system is more popular in Andhra Pradesh, Karnataka, Maharashtra, Gujarat, etc. Places in the north like Uttar Pradesh, Bihar, Rajasthan etc. follow the *Pūrṇimānta* system. As a result, the commencement of the lunar year also differs by about 15 days. The commencement of the lunar year, *yugādi* (as it is popularly called in the south), is celebrated a fortnight earlier in the north.

How about Tamilnadu, Kerala, Punjab, Bengal, North-east etc.? They follow a Solar calendar: Year and months are Solar.

Rāśi division of the Eclliptic and the Solar Year



Ecliptic is divided into 12 equal parts, each corresponding to 30°, called *rāśis*. The *rāśis* : *Meṣa*(Aries), *Vṛṣabha*(Taurus), *Mithuna* (Gemini),*Karkaṭaka*(Cancer),*Siṃha*(Leo), *Kanyā*(Virgo),*Tulā*(Libra),*Vṛścika*(Scorpio), *Dhanus*(Sagittarius),*Makara* (Capricorn),*Kumbha*(Aquarius),*Mīna*(Pisces).

The beginning point of the '*Meṣa rāśi*' known as the *Meṣādi* (first point of Aries) is a fixed point on the ecliptic , which 180° away from the star 'Spica': Different from 'Vernal Equinox'. Vernal equinox drifts continuously westwards along the ecliptic at the rate of nesrly 50″ per year, due to the 'Precession of equinoxes'. Today, the *Meṣādi* is situated nearly 24°7′48" from the vernal equinox. The solar year begins when the Sun reaches the *Meṣādi* (around April 14 nowadays), and ends when it reaches *Meṣādi* again, next time.

Solar months; Solar and Lunisolar calendars

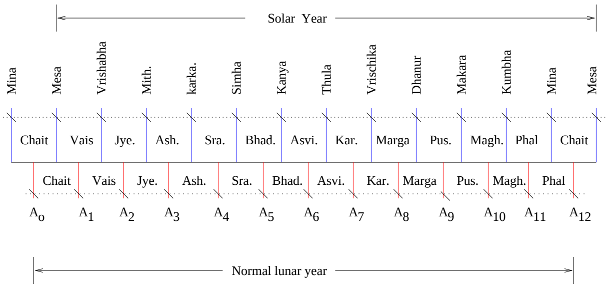
The time taken by the Sun to travel across one *rāśi*, which is a 30° segment on the ecliptic, is defined to be a *sauramāsa* or solar month. The names of the solar months are the same as those of the lunar months. The solar *caitramāsa* is the solar month during which the Sun is in *Mīna-rāśi* (Pisces sign). Similarly, the Sun is in *Meṣa-rāśi* during the *Saura Vaiśākhamāsa* and so on. So, the first month in a solar year is the *Saura Vaiśākha*, the second is the solar *Saura Jyeṣṭha*,.....12th month is *Saura Caitra*. In Tamilnadu, the solar months are Cittirai, Vaikasi, ..., Panguni.

Now, a solar sidereal year is appproximately 365.2564 days (modern value) and 12 lunar months is approximately 354.3671 days. So there is a gap of nearly 10. 89 days between them.

So, an additional month, '*adhikamāsa*' (intercalary month) has to be introduced in some lunar years to correlate the solar and lunar (lunisolar) years.

In the *amaānta* system,. a lunar year in India begins at the ending moment of the *amāvāsyā* just before the beginning of the solar year, and ends at the ending moment of the *amāvāsyā* just before the beginning of the next solar year. A lunar year has 12 or 13 months. In Indian astronomy, there is a definite procedure for inserting an *adhikamāsa* in a lunar year.

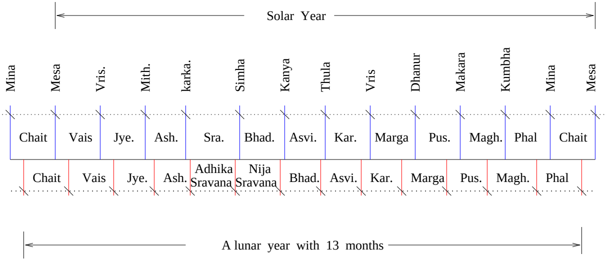
A Normal Lunar year (12 months)



Vertical lines above with markings *Mīna, Meṣa,...*: *Saṅkramaṇas* or *Saṅkrāntis* or Solar transits.
$A_0, A_1, \ldots$:New Moons. A_0: New Moon just before *Meṣa saṅkrānti*.
Here, there is a *saṅkramaṇa* in every Lunar month. This makes it a "Normal" Lunar Year with 12 months.

Next, we consider an Year, in which a lunar month will not include a *saṅkrānti*.

A Lunar year with an *adhikamāsa* (13 months)



Some times, No *saṅkrānti* between two *amāvāsyās*. Or, Two *amāvāsyās* within a solar month. **Then the lunar year will have 13 months**. In the Fig. above, *Śravaṇa* is the solar month in which there are two *amāvāsyās*.

The extra month is called an *adhikamāsa* (intercalary month). By convention, the name of the *adhikamāsa* is the same as the name of the solar month with two *amāvāsyās*. The true (=*nija*) lunar month with the same name follows this *adhikamāsa*.

In the case above, the lunar month following the *Aṣāḍha-māsa* is the *Adhika-śrāvaṇa*. This is followed by *Nija-śrāvaṇa*.

Paṅcāṅga

Traditionally the five elements of the *paṅcāṅga* are (1) *Tithi*, (2) *Nakṣatra*, (3) *Vāra* (Weekday), (4) *Yoga*, and (5) *Karaṇa*.

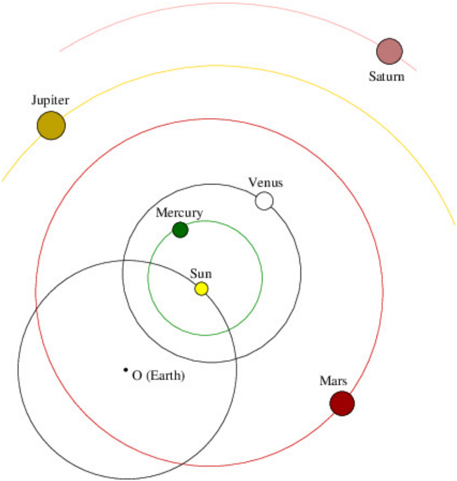
Vāra : Usual meaning . *Yoga* : related to the sum of the longitudes of the Sun and Moon. *Karaṇa* : Half a *Tithi*.

Names of Solar year , Luni-solar year, their beginning times are specified.

Festival days.

There are various other listings in an actual *pañcāṅga*: Details reg. planetary positions; Eclipses; Auspicious times, etc.

Nīlakaṇṭha Somayājī's "Quasi- Heliocentric" Planetary Model (1500 CE)



Planets move in eccentric orbits around the Sun, which itself orbits the Earth.

Summary

1. References to Celestial objects in the Vedic period. Earth is round .

2.The three primary time markers: Day, Month and Year. Diurnal motion of celestial objects. Motion in the Stellar background.

3.Ecliptic . *Rāśi* and *Nakṣatra* divisions of the ecliptic.

4. *Vedāṅga Jyotiṣa* calendar.

5. *Siddhāntas*. *Āryabhaṭīya*: Beginning of Mathematical astronomy. Salient features.

6. Post- *Āryabhaṭīya Siddhāntic* astronomy. Contents of a *Siddhānta*.

7. Calendar: Solar year, Lunar month, *Adhikamāsa*. *Pañcāṅga*: *Tithi*, *Nakṣatra* etc.

8. Nīlakaṇṭha's 'quasi-heliocentric' model.

References

- ”Facets of Indian Astronomy” ,by K.V. Sarma, Edited by Siniruddha Dash, Rashtriya Sanskrit Vidyapeeth, Tirupati, 2009
- ”*Vedāṅga Jyotiṣa* of Lagadha” , , with edition, translation and notes, T.S. Kuppanna Sastry and K.V. Sarma, INSA, New Delhi, 1985..
- ”History of Astronomy in India”, Edited by S.N. Sen and K.S. Shukla, Second revised edition, INSA, New Delhi, 2000.
- ”*Tantrasaṅgraha* of Nilakantha Somayaji”, Translation and Notes by K. Ramasubramanian and M.S. Sriram, Hindustan Book Agency, New Delhi and Springer, 2011.
- ”History of Indian Astronomy” - A Handbook, Edited by K.Ramasubramanian, Aniket Sule, Mayank Vahia, SandhI, IIT, Bombay, TIFR, Mumbai, 2016. [Especially, the article, ”Astronomy in Vedic texts” by R.N. Iyengar, pp.107-169.]
- ”The Mathematical and Observational Astronomy in Traditional India”, Y. Ohashi, 1993.
- Mathematics and Astronomy in India before 300 BCE” , A.K. Dutta and M.S. Sriram, to be published.

- "Man and the Universe" (An Elementary Account of Indian Astronomy), M.S. Sriram, 1993.
- "*Pañcasiddhāntikā* of Varāhamihira" , with edition, translation and notes, T.S. Kuppanna Sastry and K.V. Sarma, P.P.S.T. Foundation, Madras, 1993.
- "*Āryabhaṭīya* of Āryabhaṭa", edited with translation, K.S. Shukla and K.V. Sarma, INSA, New Delhi, 1976.