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A SHORT HISTORY OF HINDU ASTRONOMY & EPHEMERIS

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Abstract
We have summarized here the astronomical knowledge of the ancient Hindu astronomers. This knowledge was accumulated from before 1500 B.C. up to around 1200 A.D. In Section II we have correlated terms used by the Hindu astronomers and their equivalents in modern astronomy. In Section III we have defined the different astronomical coordinate systems and their transformation relations. In Sections IV and V we have collected the main features of solar and lunar motions in terms of modern astronomical terminology. In Section VI we have given the names of the stars mentioned by the Hindu astronomers and their modern names with the present astronomical coordinates. In Section VII we have given a short survey of Indian history with emphasis to Hindu astronomy. In Sections VIII and IX we have given short descriptions of the main sources of Hindu astronomy. In Section X the important features of Hindu astronomy have been described. All through the article we have tried to present the content in tabular forms for ready and unambiguous perception.
I Introduction

Every civilization from the antiquity to the present time has been fascinated by astronomy, study of motion of the heavenly bodies across the sky. To-day astronomy has many tools of investigation: $\gamma$-ray, X-ray, ultraviolet, visible, infra-red, microwave and radio-wave radiations emanating from the heavenly bodies. This has opened up a horizon that was not available to the ancients. They only had the visible range of the spectrum. Their studies were thus restricted to what we now call positional astronomy and did not extend to investigations of the nature of these bodies. However, extensive data about positional astronomy exist in ancient Egyptian, Babylonian, Indian and Chinese records.

Here we have summarized the knowledge that ancient Hindu Astronomers had arrived at. The time span is from circa 1500 B.C. to 1200 A.D. This is a very long span of time. The technical terms used by these people have to be collated to present astronomical vocabularies. These data were collected at places distributed over a vast region of the earth. These facts complicate the process of evaluation of correctness of these data.

In Table 2 we have given the Sanskrit names of different astronomical terms and the corresponding technical names of present-day astronomy. In writing Sanskrit words in Roman letters of alphabet we have followed the rule of transliteration recommended by the International Alphabet of Sanskrit Transliteration (IAST) given in Table 1.

In Section III we explain the different coordinate systems used to describe the position of the heavenly bodies on the Celestial Sphere. In Section IV we have described present-day knowledge of the motion of the sun and the moon, the two heavenly bodies most important to terrestrial beings. In Section V we have mentioned the different lunar and solar time periods that are of importance to astronomy. In Section VI we tabulate the fixed stars on the Celestial Sphere that were mentioned by Hindu Astronomers in their studies. In Section VII we describe the salient points of history of the Indians, their interaction with Western Asia. A map (Figure 5) gives us the idea of the region that is of importance to the development of Hindu Astronomy. The Vedas and the Siddhāntas are the main texts that tell us about the range of knowledge of the Hindu astronomers. In Sections VIII and IX we describe the salient features of these sources. In Section X the principal features of Hindu astronomy over the ages are summarized.
Table 1 Rule of transliteration from Sanskrit to Roman letters of alphabet according to International Alphabet of Sanskrit Transliteration (IAST)

| Sanskrit | Roman Letters |
|----------|---------------|
| आ | a |
| च | c |
| द | d |
| ध | dh |
| न | n |
| ख | kh |
| ध | gh |
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II Equivalence of Astronomical Terms

In all records of Hindu Astronomy we find mentions of different astronomical terms. These are given in Table 2 along with their modern equivalents.

Table 2 Technical terms in Modern Astronomy and their equivalents in Hindu Astronomy.

| Modern Astronomical Term          | Equivalent Term in Hindu Astronomy |
|-----------------------------------|-------------------------------------|
| Altitude                          | Madhyonmati                         |
| Apogee                            | Apabhū                              |
| Aps                             | Apadūraka                           |
| Aries, first point of             | Meṣādi                              |
| Astronomy                        | Jyotiṣa                             |
| Azimuth                          | Digāṁsa                             |
| Declination                      | Viṣuvalamba                         |
| Ecliptic                         | Krāntivṛttta                        |
| Equator, Celestial               | Mahāviṣuva                          |
| Equinox, Autumnal                 | Jalaviṣuva Saṁkrānti                |
| Equinox, Vernal                   | Mahāviṣuva Saṁkrānti                |
| Horizon plane                     | Dīgcakra                            |
| Hour Angle                       | Horākona                            |
| Libra, first point of             | Tūlādi                              |
| Luminary                         | Jyotiṣka                            |
| Meridian                         | Madhyarekha                         |
| Moon, Full                       | Pūrṇimā                             |
| Moon, New                        | Amābasyā                            |
| Perigee                          | Anubhū                              |
| Polaris                          | Dhruatārā                           |
| Right Ascension                  | Viṣuvaṁśa                           |
| Saros                            | Yuga                                |
| Sidereal                         | Nākṣatra                            |
| Solstice, Summer                 | Karkaṭa Saṁkrānti                   |
| Solstice, Winter                 | Makara Saṁkrānti                    |
| Sphere, Celestial                | Khagola                             |
| Zenith                           | Khamadhya                           |
| Zodiac signs                      | Rāśicakra                           |
If we go through this table we find that the Hindu Astronomers had known the basic facts of positional astronomy regarding motion of the heavenly bodies through the Celestial Sphere, the different planes of motion of the sun and the moon, and the zodiac signs of the fixed stars.
III Coordinates describing an object X

In positional astronomy, motion of a heavenly body $X$ is described in different coordinate systems. In ordinary 3-dimensional space with spherical symmetry, spherical polar coordinate system is the natural choice. On the Celestial Sphere, the real distance from the observer is not of any importance. Only the two angular coordinates fix the position of a body on the Celestial Sphere. This requires an azimuthal plane and a reference direction on this plane. For the coordinate of a place on the surface of the earth (Cartographic system) we take the terrestrial equatorial plane as the azimuthal plane and Greenwich’s meridian supplies the starting position for measuring the azimuthal angle. The topocentric (Horizon) system is suitable for direct measurement by an observer on earth’s surface. For this the local horizon plane supplies the azimuthal plane. The geocentric (Equatorial) system, which is independent of the observer’s position on earth’s surface, uses the Celestial Equator (the plane of intersection of the terrestrial equator with the Celestial Sphere) as the azimuthal plane. Description in terms of the geocentric coordinate system frees the observational data from the dependence on the position of the local observer on earth’s surface. Figure 1 shows the topocentric and the geocentric coordinate systems. To describe the motion of the planets and the stars on the Celestial Sphere, rotational and non-uniform yearly motion of earth’s motion around the sun has to be avoided. The heliocentric (Ecliptic) system takes Ecliptic (the plane of sun’s motion on the Celestial Sphere) as the azimuthal plane. Figure 2 shows the heliocentric coordinate system. In Table 3 we have compared the 3 astronomical coordinate systems and the terrestrial cartographic system. The laws of transformation from one system to another are as follows:

\[
\begin{pmatrix}
\cos \delta \cos \chi \\
-\cos \delta \sin \chi \\
\sin \delta
\end{pmatrix} =
\begin{pmatrix}
\cos \tilde{\phi} & 0 & \sin \tilde{\phi} \\
0 & 1 & 0 \\
-\sin \tilde{\phi} & 0 & \cos \tilde{\phi}
\end{pmatrix}
\begin{pmatrix}
\cos \zeta \cos \psi \\
-\cos \zeta \sin \psi \\
\sin \zeta
\end{pmatrix},
\]

\[
\begin{pmatrix}
\cos \beta \cos \lambda \\
\cos \beta \sin \lambda \\
\sin \beta
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \epsilon_0 & \sin \epsilon_0 \\
0 & -\sin \epsilon_0 & \cos \epsilon_0
\end{pmatrix}
\begin{pmatrix}
\cos \delta \cos \alpha \\
-\cos \delta \sin \alpha \\
\sin \delta
\end{pmatrix}
\]

Azimuth $\psi_0$ of a Star at setting ($\zeta = 0$) is given by $\sin(\psi_0 - 90^\circ) = \sin \delta / \cos \phi$. For the Sun at Summer Solstice (S.S.), $\delta = 23^\circ 30'$. 
Figure 1 Topocentric and Geocentric Coordinates.

$O = \text{Observer}$, $X = \text{Astronomical Object}$

$Z = \text{Zenith}$, $(\text{Khamadhya})$

$P = \text{Polaris}$, $(\text{Dhruvatārā})$

$\text{Observer’s Meridian} = \text{Great Circle through } P \text{ and } Z$

$\text{Object’s Meridian} = \text{Great Circle through } P \text{ and } X$

$N \equiv \text{North}$, $S \equiv \text{South}$, $E \equiv \text{East}$, $W \equiv \text{West}$

$N’, S’ = \text{Points of intersection of the}$

$\text{Observer’s Meridian with the Celestial Equator,}$

$\zeta = MX \equiv \text{Altitude (Madhyonnati)}, \quad \delta = RX \equiv \text{Declination (Viśuvalamba)}$

$\psi = SM \equiv \text{Azimuth (Digāṃśa)}, \quad \chi = S’R \equiv \text{Hour Angle}$

$\text{Sidereal time} \equiv \tau = \text{Hour Angle of a fixed feature } Q \text{ on the Celestial Sphere}$

$\text{Right Ascension (R.A.) of } X \equiv \alpha = \tau - \chi$

$\alpha \text{ increases towards } E \text{ from } Q, \text{ opposite to the apparent motion of the Celestial Sphere}$
\textit{Ecliptic} = Plane of the motion of the Sun on the \textit{Celestial Sphere},

\( K \) = Pole of the \textit{Ecliptic} on the \textit{Celestial Sphere},

\( \epsilon_0 \equiv \) obliquity of the \textit{Ecliptic}

\( \equiv \) with respect to the \textit{Celestial Equator}

\[ = \begin{cases} 23^\circ 30' \text{ (in 1950 A.D.)} \\ 23^\circ 51' \text{ (in 1300 B.C.)} \end{cases} \]

\( \Upsilon \text{ (V.E.)} \) and \( \Omega \text{ (A.E.)} \) = Points of intersection of the \textit{Ecliptic}

\text{and the \textit{Celestial Equator}}

\( \Upsilon \) has an involved retrograde motion with respect to the fixed stars. Its \textit{Celestial Longitude} with respect to a given fixed star decreases by about 50'' per year.

In antiquity \( \Upsilon \) was in the \textit{Constellation of Aries} (\textit{Meṣa}), but now \( \Upsilon \) has moved to the \textit{Constellation of Pisces} (\textit{Mīna}).

The fixed feature \( Q \) is taken to be the \textit{Vernal Equinox} point, \( \Upsilon \).
\[ \beta = TX = \text{Celestial Latitude}, \]
\[ \lambda = YT = \text{Celestial Longitude} \]

**Table 3** Coordinates used in different Astronomical Systems.

| Cartographic System | Topocentric Horizon system | Geocentric Equatorial system | Heliocentric Ecliptical system |
|---------------------|---------------------------|-------------------------------|-----------------------------|
| \( \phi \) = Geographical Latitude, measured from the Terrestrial Equator along the Object's Meridian, \( \bar{\phi} = 90^\circ - \phi \) = Colatitude | \( \zeta = MX = \text{Altitude (Madhyonnati)}, \text{measured from the Horizon plane towards the Zenith} \) | \( \delta = RX = \text{Declination (Vişwalamba)}, \text{measured from the Celestial Equator along the Object's Meridian} \) | \( \beta = TX = \text{Celestial Latitude}, \text{measured from the Ecliptic towards } K \) |
| \( \psi = SM = \text{Azimuth (Digāṁśa)}, \text{measured from South towards West along the Horizon plane} \) | \( \chi = S'R = \text{Hour Angle, measured from the Observer's Meridian towards West along the Celestial Equator} \) | \( \lambda = YT = \text{Celestial Longitude, measured from } \bar{\Upsilon} \text{ towards the Summer Solstice along the Ecliptic} \) |
IV Sun (Sol) - Earth (Terra) - Moon (Luna) System

To people living on the surface of the earth, the sun and the moon are the two most important heavenly bodies. In Figure 3 we show our present-day knowledge of the motion of the earth around the sun throughout the year. This heliocentric picture was, however, not available to the people of antiquity. What they observed was the Ecliptic, the plane of solar motion on the Celestial Sphere, and the difference of speed of the sun along the Ecliptic at different seasons of the year.

Figure 3 Earth’s motion around the Sun.

V.E.  $\equiv$  Vernal Equinox (Mahāviśuva Saṁkrānti)  =  21 March in 1950 A.D.
A.E.  $\equiv$  Autumnal Equinox (Jalaviśuva Saṁkrānti)  =  22 September in 1950 A.D.
W.S.  $\equiv$  Winter Solstice (Makara Saṁkrānti)  =  22 December in 1950 A.D.
S.S.  $\equiv$  Summer Solstice (Karkaṭa Saṁkrānti)  =  21 June in 1950 A.D.
Exact motion of Earth’s axis has a number of periodic terms called *nutations* $\sim 9''$.

Similarly lunar motion around the earth is shown in Figure 4. This motion, of course, tallied with observations from earth’s surface.

**Figure 4** Moon’s motion around the Earth.

Inclination of the plane of Lunar motion to the *Ecliptic* (the plane of Earth’s annual motion around the Sun) is approximately $5^\circ$.

Eccentricity of Lunar elliptic orbit is approximately 1/18.

Upper limit of the declination of the Moon has a cycle of approximately 18 years (from $18^\circ \ 10' \text{ to } 28^\circ \ 50'$).

*Perigee* = Point of closest approach,

*Apogee* = Point of farthest approach
V Lunar and Solar Cycles

The two most important cyclic motions are the lunar and the solar cycles. They provide us with the two most easily observable time periods. Since actual periods are not exactly constant all through the year due to non-uniform motion of the earth around the sun, a number of different associated periods have been used by the astronomers. These are given in Table 4.

* X transits or culminates when the Meridian of X coincides with the Meridian of the Observer.

\[
\text{Sidereal Day of } X = \text{from one transit of } X \text{ to the next transit},
\]

\[
\text{Mean Solar Day (M.S.D.)} = \text{Sidereal Day of a fictitious Mean Sun (M.S.) moving with a uniform speed on the Celestial Equator},
\]

\[
\text{Equation of time} = \alpha_{M.S.} - \alpha_S,
\]

\[
\text{Greenwich Mean Astronomical time (GMAT)} = \text{Hour Angle of M.S.,}
\]

\[
\text{Universal time (UT)} = \text{GMAT} + 12 \text{ hrs},
\]

\[
\text{Mean midnight} = 0 \text{ hr},
\]

\[
\text{Mean noon} = 12 \text{ hr}
\]

**Table 4** Different Lunar and Solar Time Periods.

| Motion       | Name (Symbol)                        | Description                                      | Present value in M.S.D. |
|--------------|--------------------------------------|--------------------------------------------------|-------------------------|
| Lunar        | **Tropical Month, }_1 {**            | Equinox to Equinox                               | 27.32158                |
|              | **Anomalistic Month, }_2 {**         | Perigee to Perigee                               | 27.53455                |
|              | **Draconic (Nodical) Month, }_3 {**  | Node to Node                                     | 27.21222                |
|              | **Sidereal Month**                   | Return to the same fixed Star                    | 27.32166                |
|              | **Synodic Month, } T {**             | \textit{New Moon} to \textit{New Moon (Amānta)} | 29.53059                |
| Solar        | **Tropical Year, }_0 {** (Sāvana Vatsara) | Equinox to Equinox                               | 365.2422                |
|              | **Sidereal Year**                    | Return to the same fixed Star                    | 365.257                 |
Hindu astronomers determined transits of heavenly bodies by Gnomon (Sun-dial) and time was measured by Clepsydra (Water-clock). Names of different subdivisions of time given in Table 5 indicate the possibility that Hindu astronomers were able to measure these short time intervals. In fact in all treatises of Hindu Astronomy accurate directions for constructing water-clocks are given [7].

Table 5 Different subdivisions of time in Hindu Astronomy.

| 1 Anupala | $\frac{1}{150}$ sec, |
| 60 Anupala | 1 Bipala | 0.4 sec, |
| 60 Pala | 1 Daṇḍa | 24 min, |
| 7.5 Daṇḍa | 1 Praharā | 3 hr, |
| 60 Bipala | 1 Pala | 24 sec, |
| 2 Daṇḍa | 1 Muhūrta | 48 min |
| 8 Praharā | 1 Divasa | 24 hr |

The unit of Muhūrta has a significance in astronomy. It is the time interval by which the time of moonrise is delayed on successive days.
VI Stars and their positions

All astromical and ephemerical calculations are based on motion of the heavenly bodies with respect to the fixed stars on the Celestial Sphere. Hindu Astronomers also used the same convention. The Celestial Sphere is mentally divided in 27 divisions and each division is assigned to the most important star there. Out of these 27 stars 12 are selected to give the names of the months. Present-day Celestial Longitudes and Latitudes of these stars are given in Table 6 Modern Astronomical names of these stars are also given.

Table 6 Names of Nakṣatras in Vedāṅga Jyotisā, Sūrya Siddhānta, corresponding names in Modern Astronomy and their Celestial Longitudes and Latitudes in 1950 A.D. The names of the Lunar months are according to the stars written in bold face letters.

| Serial Number | Name of Nakṣatra in Vedāṅga Jyotisā | Name of Nakṣatra in Sūrya Siddhānta | Principal Star | Celestial Longitude | Celestial Latitude |
|---------------|-------------------------------------|-------------------------------------|----------------|---------------------|---------------------|
| 1.            | Kṛttikā | Kṛttikā | η - Tauri | 59° 17' 39" | + 4° 2' 46" |
| 2.            | Rohiṇi | Rohiṇi | α - Tauri | 69° 5' 25" | - 5° 28' 14" |
| 3.            | Mrgaśirṣa | Mrgaśirṣa | λ - Orionis | 83° 0' 31" | - 13° 22' 32" |
| 4.            | Ardrā | Ardrā | α - Orionis | 88° 3' 22" | - 16° 1' 59" |
| 5.            | Punarvasu | Pusyā | β - Geminorum | 112° 31' 29" | + 6° 40' 51" |
| 6.            | Tiṣya | Pusyā | δ - Cancri | 128° 1' 23" | + 0° 4' 32" |
| 7.            | Aśreṣa | Aśleṣa | ε - Hydræ | 131° 38' 59" | - 11° 6' 25" |
| 8.            | Maghā | Maghā | α - Leonis | 149° 8' 1" | + 0° 27' 48" |
| 9.            | Pūrva Phalguni | Phalguni | δ - Leonis | 160° 36' 52" | + 14° 19' 58" |
| 10.           | Uttara Phalguni | Uttara Phalguni | β - Leonis | 170° 55' 23" | + 12° 16' 13" |
| 11.           | Hasta | Hasta | δ - Corvi | 192° 45' 23" | - 12° 11' 31" |
| 12.           | Citrā | Citrā | α - Virginis | 203° 8' 37" | - 2° 3' 4" |
| 13.           | Svāti | Svāti | α - Bootis | 203° 32' 8" | + 30° 46' 3" |
| 14.           | Viśakhā | Viśakhā | α - Librae | 224° 23' 7" | + 0° 20' 19" |
| Serial Number | Name of Nakṣatra in Jyotiṣa Sūrya Siddhānta | Principal Star | Celestial Longitude | Celestial Latitude |
|---------------|---------------------------------------------|----------------|---------------------|--------------------|
| 15            | Anurādhā Anurādhā | δ - Scorpii | 241° 52' 23" | - 1° 58' 49"
| 16            | Rohiṇi, Jyeṣṭhā Jyeṣṭhā | α - Scorpii | 249° 3' 51" | - 33° 33' 50"
| 17            | Viḍṭau, Mūlabarhaṇī Mulā | λ - Scorpii | 263° 53' 14" | - 13° 46' 56"
| 18            | Pūrvāṣāḍhā Pūrvāṣāḍhā | δ - Sagittarii | 273° 52' 55" | - 6° 27' 58"
| 19            | Uttarāṣāḍhā Uttarāṣāḍhā | σ - Sagittarii | 281° 41' 11" | - 3° 26' 36"
|               | Abhijit Abhijit | α - Lyrae | 284° 36' 54" | + 61° 44' 7"
| 20            | Sroṇā Śravāṇā | α - Aquilae | 301° 4' 16" | + 29° 18' 18"
| 21            | Sraviṣṭhā Dhaniṣṭhā | β - Delphini | 315° 38' 38" | + 31° 55' 21"
| 22            | Satabhiṣak Satabhiṣak | λ - Aquarī | 340° 52' 38" | - 0° 23' 8"
| 23            | Pūrva Proṣṭhapada Pūrva Bhādrapada | α - Pegasi | 352° 47' 19" | + 19° 24' 25"
| 24            | Uttara Proṣṭhapada Uttara Bhādrapada | γ - Pegasi | 8° 27' 32" | + 12° 35' 55"
| 25            | Revāti Revāti | ζ - Piscium | 19° 10' 40" | - 0° 12' 52"
| 26            | Aśvayuṇa Aśvīni | β - Aretis | 33° 16' 18" | + 8° 29' 7"
| 27            | Apabharāṇi Bharaṇi | 41 - Aretis | 47° 30' 19" | + 10° 26' 48" |
VII  Summary of Indian History

Hindu Astronomy developed through about two thousand years and this development took place not at a fixed region. Parallel development of Astronomy also took place at Babylon and Alexandria. Figure 5 shows the part of the world and cities having importance in this historical development. Positions of modern cities near these ancient seats of astronomy are also shown.

A short summary of the History of India and her interaction with Western Asia is given in Table 7. The earliest time in Indian History that is of importance from astronomical interest is the time of Rk-vedas. This is the oldest of all the Vedas (Section VIII) and astronomical references found here fixes its time (terminus ad quem) around 1500 B.C., when the Middle Kingdom of Egypt ended. The part of the Vedas known as Vedânga was compiled around 1200 B.C. when Egypt had the New Kingdom. Time of Gautama Buddha (end of the 6th century B.C.) is a fixed point in Indian History. Written history is available afterwards. Mahâbhârata, the great Indian epic was perhaps compiled around 400 B.C. Alexander’s invasion of the Northwestern periphery of India in 323 B.C. and Candragupta’s victory over Seleucus in 306 B.C. brought India in contact with Babylonian astronomy through the Greeks. But there is scarcely any evidence of influence of Egyptian or Babylonian astronomy on Hindu astronomy at this time. Advent of the Śakas (Scythians) in Balkh (Bactria) and their victory over the Pāradas (Parthians) in 123 B.C. would later have profound impact on Hindu astronomy and ephemeris. The Old Śaka Era started from this momentous event. With the beginning of the reign of Kanîška, the Kuśâna king, in 78 A.D. (201 in the Old Śaka Era) the New Śaka Era (omitting the 200 of the Old Śaka Era) began in India. This is the Era par excellence in Hindu astronomy and no other Era could take its place in Hindu ephemeris. The Śakas grafted Babylonian system on Hindu astronomy and by 400 A.D. the Siddhânta astronomy (Section IX) replaced the older Vedânga astronomy. Āryabhaṭa, perhaps the greatest Hindu mathematician cum astronomer, was born at Kuśumapura near Pâtaliputra (modern Patna) in 476 A.D. and his monumental work Āryabhaṭīya was compiled in 499 A.D. The next important event (6th century A.D.) of Hindu astronomy is Varāhamihira’s Pañca-siddhântikā, second only to the appearance of Āryabhâtiya. The last important contribution to Hindu astronomy came from Bhâskarâcârya of Devagiri in 1207. After Muhammad Ghouri’s conquest of Northern India at the end of the 12th century A.D. all the academic centres of excellence in Northern India were completely destroyed and starved of financial support. This saw the end of ancient Hindu astronomy.
Figure 5 India and her Western neighbors.
Table 7 History of India and her Western neighbors.

| Era | Century | Indian | West Asian |
|-----|---------|--------|------------|
| 13-th | • 1207 Siddhānta śiromaṇi of Bhāskarācārya of Devagiri, (last Indian contributor of importance) | | |
| 12-th | • 1192 Muhammad Ghouri defeats Prthvīrāja in the 2nd battle of Tarain | | |
| 11-th | • 1000 Mahmud Ghazni invades India | • 700 Beginning of Arab civilization of Baghdad, Damascus, Cordova |
| 10-th | • 966 Bhaṭṭapāla’s Gaṇitaskandha • 950 Āryabhaṭa II | • 600 End of Sassanid empire in Iran |
| 9-th | • 630 Haṇavardhana • 628 Brahmagupta of Khandakhādya & Brahmaśiddhānta | | |
| 8-th | | | |
| 7-th | • 587 Death of Varāhamihira of Paṇca siddhāntikā • 580 Śrīseṇa • 523 Death of Āryabhaṭa | | |
| 6-th | | | |
| Era | Century | Indian | West Asian |
|-----|---------|--------|------------|
| 5-th | 500 | Viṣṇucandra | 500 | 500 |
| 5-th | 499 | Composition of Āryabhaṭīya | 499 | 500 |
| 5-th | 476 | Birth of Āryabhaṭa at Pātaliputra | 476 | 476 |
| 4-th | 400 | Beginning of Siddhānta Jyotīṣa | 400 | 400 |
| 4-th | 320 | Beginning of Gupta Empire | 320 | 320 |
| 3-rd | 224 | Beginning of Sassanid Empire in Iran | 224 | 224 |
| 3-rd | 170 | Sakas reign at Ujjaini | 170 | 170 |
| 2-nd | 150 | Ptolemy of Alexandria | 150 | 150 |
| 1-st | 100 | Sātābhāhana empire ends | 100 | 100 |
| 1-st | 78 | New Śaka Era, Kanishka’s reign begins | 78 | 78 |
| 1-st | 50 | Kāṇva dynasty at Pātaliputra, Śakas rule at Puruṣapura & Mathurā | 50 | 50 |
| 1-st | 100 | Selucid rule at Babylon ends | 100 | 100 |
| 1-st | 70 | Sakas capture Takṣaśīlā | 70 | 70 |
| 1-st | 85 | Sunga reign ends | 85 | 85 |
| 1-st | 80 | Śakas occupy Afghanistan | 80 | 80 |
| B.C. | 175 | Menander captures Punjab & Sind | 175 | 175 |
| B.C. | 180 | Sunga dynasty at Pātaliputra, Selucids capture Takṣaśīlā | 180 | 180 |
| B.C. | 123 | Śakas (Scythians) defeat Paradas (Parthians) & occupy Balkh (Bactria), Old Śaka era begins | 123 | 123 |
| B.C. | 138 | End of Parthian empire in Iran | 138 | 138 |

...
| Era | Century | Indian | West Asian |
|-----|---------|--------|------------|
|     | ...     | ...    | ...        |
| 3-rd | 306 Candragupta defeats Seleucus | 220 Beginning of Śatavahana empire | 226 Death of Aśoka |
|     | 323 Alexander invades India | 268 Aśoka’s reign begins | 312 Seleucidean Era begins at Babylon |
| 4-th | 400 Mahābhārata | 248 Beginning of Parthian Empire in Iran | 290 Archimedes |
|     | 300 Euclid | 300 Euclid | 300 Euclid |
| B.C. | 6-th | 560 Death of Gautama Buddha | 550 Pythagoras |
|     | 640 Birth of Gautama Buddha | 560 Cyrus establishes Achaemenian Empire in Iran | 560 Cyrus establishes Achaemenian Empire in Iran |
|     | 650 Ashurbanipal rules at Babylon | End of Assyrian Empire at Babylon, End of Chaldean Empire at Babylon | End of Assyrian Empire at Babylon, End of Chaldean Empire at Babylon |
| 7-th | 728 Beginning of Assyrian Empire at Babylon | 1100 End of New Kingdom at Egypt | 1100 End of New Kingdom at Egypt |
| 8-th | 1200 Beginning of Vedaṅga Jyotiśa | 1200 Beginning of Vedaṅga Jyotiśa | 1200 Beginning of Vedaṅga Jyotiśa |
| 9-th | ... | ... | ... |
| 10-th | ... | ... | ... |
| 11-th | ... | ... | ... |
| 12-th | ... | ... | ... |
| Era   | Century | Indian | West Asian                                      |
|-------|---------|--------|------------------------------------------------|
|       | ...     | ...    | ...                                            |
| 13-th |         |        |                                                |
| 14-th |         |        |                                                |
| 15-th |         |        | • 1500 Rk – Veda (terminus ad quem)            |
|       |         | 1500   | • 1500 End of Middle Kingdom at Egypt          |
| 16-th |         |        |                                                |
| 17-th |         |        |                                                |
| 18-th |         |        |                                                |
| 19-th |         |        | • 1900 Hammurabi establishes Chaldean Empire  |
|       |         |        | at Babylon                                      |
| 20-th | Harappan civilization |        |                                                |
VIII The Vedas

The earliest reference to astronomical facts are found in the Vedas, the scripture of the Hindus. There are 4 Vedas, Rk, Sāma, Yajuh and Atharva. Each of these Vedas are divided in 4 parts, Chanda (or Saṁhīta), Brāhmaṇa, Āraṇyaka (or Upaniṣad) and Vedāṅga. Vedāṅga deals with Phonetics, Ritualistic literature, Grammar, Etymology, Metrics and Astronomy. The Saṁhīta part of Rk-veda has very scanty astronomical references. That of Yajuh has slightly more references. The Vedāṅgas (particularly of the Krṣṇa or the Black Yajuh-veda), on the other hand, has a full-fledged astronomy. The salient features of the Vedas are given in Table 8. This shows the range of academic activities pursued by the ancient Indians.
Table 8 The Vedas, their subdivisions and salient features.

| The Vedas |
|-----------|
| ↓        |
| Rk        |
| divided in 10 Manḍalas |
| ↓        |
| Sāma      |
| ↓        |
| Yajuḥ      |
| ↓        |
| Atharva   |
| ↓        |
| Krṣṇa     |
| (Black)   |
| ↓        |
| Śukla     |
| (White)   |
| ↓        |
| Chandas or Samhitā |
| Brāhmaṇa prose texts on theological matters, observations on sacrifices and their mystical significances |
| ↓        |
| Āraṇyaka or Upaniṣad meditations of forest hermits and ascetics on God, the world & mankind |
| ↓        |
| Vedaṅga or Sūtra |
| ↓        |
| Śīkṣā (Phonetics) |
| Kalpa (Ritualistic literature) |
| ↓        |
| Vyākaraṇa (Grammar) e.g. Pāṇini’s Aṣṭādhyāyī |
| ↓        |
| Nirukta (Etymology) e.g. of Yāska |
| ↓        |
| Chandas (Metrics) e.g. of Piṅgala |
| ↓        |
| Jyotiṣa (Astro—nomy) e.g. of Lagadha Rk—Jyotiṣa has 36 verses and Yajuḥ—Jyotiṣa has 43 verses |
IX The Siddhāntas

Hindu astronomy gradually developed from the Vedāṅga jyotiṣa to what are known as the Siddhāntas. There are 5 Siddhāntas: Paitāmaha, Vāsiṣṭha, Romaka, Pauliśa and Sūrya. The last one is the latest and the most developed. Texts of all the siddhāntas are not available, but Varāhamihira in the 6th century A.D. has described them in his Pañca-Siddhāntikā. Romaka and Pauliśa siddhāntas show influence of Babylonian and Egyptian astronomy. One of the earliest proponent of the Sūrya Siddhānta was Āryabhaṭa. But with time it was upgraded with accumulation of new knowledge. Solar, lunar and stellar motions were accurately described in this Siddhānta. A study of this Siddhānta shows that Hindu astronomers knew about precession of the Equinoxes, but they were lamentably unaware of the difference between the Sidereal and the Tropical years. This is not so amazing, since even European astronomers became aware of this difference only in the 17th century A.D. after Galileo, Kepler and Newton. The 5 Siddhāntas are summarized in Table 9.
Table 9 Different Siddhānta Jyotiṣas and their salient features.

| The Siddhāntas |
|---------------|
| ↓             |
| ↓             |
| ↓             |
| ↓             |
| ↓             |
| ↓             |

| Paitāmaha | Vāsiṣṭha | Romaka | Pauliṣa | Śūrya |
|-----------|----------|--------|---------|-------|
| ascribed to | ascribed to | revealed by | ascribed to | Revealed by |
| Brahmā and | Vaśiṣṭha and | Viṣṇu to Ṛṣi | the sage Pulastya; | the Sun god |
| described in | revealed | Romaśa; | refers to | to Asura |
| 5 stanzas in | by him to | Yuga = | Yavanapura, | Maya, |
| Paṅca- | Maṇḍavya | 19 × 5 × 30 yrs, | Longitudes of | who |
| Siddhāntikā | and | incorporates | Ujjainī & | propounded |
| of | described in | 19 yr cycle of | Benares | it to |
| Varāhamihira | 13 couplets | Babylon and | are given | the Ṛṣis. |
| | by | 5 yr Yuga of | with respect | It has |
| | Varāhamihira; | Vedāṅga | to | 500 verses in |
| | method of | Jyotiṣa | Alexandria, | 14 Chapters, |
| | calculating | | Lords of | does not |
| | Tithi and | | the days | show any |
| | Nakṣatra, | | are | influence of |
| | mentions | | mentioned | Ptolemy’s |
| | Rāśi | | like the | Almagest, |
| | and | | Iranian | does not |
| | Lagna | | calendar, | mention |
| | | | but the | Alexandria, |
| | | | names are | Longitude |
| | | | Indian | of Ujjainī |
| | | | | is the |
| | | | | standard |
| | | | | Meridian, |
| | | | | it is |
| | | | | continually |
| | | | | updated |
| | | | | like the |
| | | | | Landolt– |
| | | | | Bernstein |
| | | | | tables, |
| | | | | earliest |
| | | | | version |
| | | | | is by |
| | | | | Āryabhaṭa |
| | | | | 476 – 523A.D. |
X Comparison of different Astronomical systems of India before 1200 A.D.

In Table 10 we have summarize astronomical knowledge of the Hindu astronomers found in the 4 systems: Rk-Saṁhitā, Yajuḥ-Saṁhitā, Vedāṅga Jyotiṣa and Śūrya Siddhānta. This knowledge primarily encompasses the following subjects: Lunar asterism, Lunar day (Tithi), Month & Year (both Lunar and Solar), Seasons & Year (Ṛtu), and longer period of time (Yuga).

In the Rk-Saṁhitā, scanty though the knowledge is, we find mentions of lunar asterism, some specific fixed stars, lunar zodiac, lunar year of 360 days and solar year of 366 days, 3 Seasons each of 4 months (Cātmāṣya) and a 5 year Yuga. It is interesting to note that in the list of Seasons, the Rainy Season was not mentioned. This is possibly because the Hindu astronomers did not come across this season at the place where they were studying astronomy. This indicates that they were located only in the extreme North-Western corner of the country (Takṣaśila) and Afghanistan (Balkh).

During the time of the Yajuḥ-Saṁhitā astronomy was more developed. Full list of the Lunar asterism is given though it started with Krṣṭṭikā instead of Aśvinī as in later time. Lunar fortnight (Pakṣa) of 15 lunar days (Paṇcadasī tithi) was mentioned and gradually the concept of lunar month came into vogue. Northern and Southern motions of the Sun and the 6 Seasons connected with the motion of the sun along the Ecliptic was established knowledge. The Spring (Vasanta Ṛtu) consisting of 2 months was symmetrically placed about the Vernal Equinox (V.E.) point and the Solar year started when the Sun was 30° before the V.E.

Vedāṅga Jyotiṣa was a completely developed system with the numerical values of astronomical data comparing favorably with modern values. Evidence of the knowledge of the Sidereal Day, the Solstices, ratio of durations of day & night on the Summer Solstice, Lunar months, Tropical Solar Year, and longer periods of time is found in Vedāṅga Jyotiṣa. During the time of the Vedāṅga Jyotiṣa, Winter Solstice was at the Sraviṣṭhā nakṣatra (Delphini) at the longitude of 270°. Sraviṣṭhā is now at 316° 41'. This fixes the time of the Vedāṅga Jyotiṣa around 1400 B.C. Similar calculation fixes the time of compilation of the Mahābhārata as 450 B.C.

Śūrya Siddhānta has precise and logical definitions of the Lunar asterism, Tithi (Lunar Day), Solar Month, Tropical (Sāvana) year and the 6 Seasons (Ṛtu). The effect of the precession of the Equinoxes was also noted.
Table 10  Salient features of Hindu Astronomy in different ages.

| Astro-nomical features | Rk Saṁhitā | Yajuḥ Saṁhitā | Vedāṅga Jyotiṣa | Sūrya Siddhānta |
|------------------------|------------|--------------|-----------------|-----------------|
| **Lunar Asterism (Nakṣatra)** |            |              |                 |                 |
| • Custom of mentioning Nakṣatra perhaps started here | • Full list of lunar asterism is given | • Lunar asterism starts at Kṛttikā, most probably Υ | • Lunar asterism starts at Aśvinī (α− or β− Arietis), Υ was at Revati (ζ − Piscium); now Υ has shifted by ∼ 19° from ζ − Piscium |
| • Days were designated by lunar asterism | • Lunar asterism starts with Kṛttikā | • Days were named after Nakṣatra | • At Varāha−mihira's time S.S. has moved $\frac{1}{2}$ of Āśleṣā + Puṣyā, time is 1500 yrs after Vedāṅga Jyotiṣa |
| • Aghā & Arjunī were mentioned | | 1 Nakṣatra day was 1.011608 Solar day, in reality it is 1.011913 Solar day | • No knowledge of precession of the Equinoxes, but its effect has been observed |
| | | | | |
| | | | | |
| | | | | |
Table [10] (Continued)

| Astro-nomical features | Rk Saṁhitā | Yauĵha Saṁhitā | Vedāṅga Jyotiṣa | Sūrya Siddhānta |
|------------------------|------------|----------------|----------------|-----------------|
| ...                    | ...        | ...            | ...            | ...             |
| Lunar day (Tithi)      |            |                |                |                 |
| • No reference         |            |                |                |                 |
| • Perhaps individual days were denoted by the Nakṣatra, |            |                |                |                 |
| • Lunar zodiac was known |            |                |                |                 |
| • Paṅcadaśī tithi      |            |                |                |                 |
| • Knowledge of Pakṣa   |            |                |                |                 |
| • Tithi was from moonrise to moonrise during Krṣṇa pakṣa and from moonset to moonset during Śukla pakṣa |            |                |                |                 |
| • Subdivision of day was measured by Clepsydra |            |                |                |                 |
| • Ratio of day & night on S.S. is \( \frac{3}{2} \), this is true for latitude 35° N |            |                |                |                 |
| • Tithi is \( \frac{1}{30} \) of lunar month = 0.983871 days, correct value is 0.984353 days |            |                |                |                 |
| • Day is reckoned by tithi |            |                |                |                 |
| • Tithi is complete when the moon is ahead of the sun by 12° or its multiple, tithi varies from 26 hr 47 min to 19 hr 59 min |            |                |                |                 |
| • If a tithi extends to 2 solar days, then both the days are assigned the same tithi |            |                |                |                 |

28
| Astro-nomical features | Rk Saṁhitā | Yajuḥ Saṁhitā | Vedāṅga Jyotiṣa | Sūrya Siddhānta |
|------------------------|------------|---------------|-----------------|-----------------|
| **Month & Year**       | **...**    | **...**       | **...**         | **...**         |
|                        | • Year has 12 months each of 30 days (12 spoke-boards, & 360 saṅkus) | • Mentions lunar mansions with their presiding deities | • Does not mention zodiac signs | • Defines only astro-nomical solar month |
|                        | • Mentions Citrā (α – Virginis) & Aghā (α – Leonis) | • Lunar months came gradually, generally pakṣa is mentioned | • Pūrṇimānta lunar months are named after the Nakṣatras | • 1 Solar month = time of passage of the Sun through 30° of its orbit = 30.43823 days; modern value = 30.43685 days |
|                        | **...**    | **...**       | **...**         | **...**         |

1 Solar year = 12 Solar months
Table 10 (Continued)

| Seasons & Year | Astro-nomical features | Rk Saṁhitā | Yajuh Saṁhitā | Vedāṅga Jyotiṣa | Śūrya Siddhānta |
|----------------|-------------------------|-------------|---------------|------------------|------------------|
| 3 seasons (navels), Caturmāśya, each of 4 months, Grīṣma (Summer), Śarad (Autumn), Hemanta (Winter); Varṣā (Rainy) is not mentioned | • Mentions Uttarāyaṇa & Daksināyaṇa of the Sun | • In Brāhmī inscriptions of the Kuśāṇas month names are mostly seasonal: Grīṣma, Varṣā, Hemanta | • 6 Seasons (Rtu) in Tropical Year; each season consists of 2 zodiac signs; each zodiac sign covers 30° of the Ecliptic |
| Solar year of 366 days | • The Solar year has 6 Seasons: i) Vasanta (Spring) = Madhu & Mādhava | • The pakṣa is not mentioned | • Tropical Year = 365.25875 days (Varāha–mihira), 365.8756 days (Modern Astronomy) |
| | ii) Grīṣma (Summer) = Śukra & Śuci | • Astro-nomical year starts when the Sun crosses the V.E., the civil year starts on the next day | • Solar Year starts at Vaiśākhā, Lunar Year starts at Caitra |
| | iii) Varṣā (Rains) = Nabha & Nabhasya | | |
| | iv) Śarad (Autumn) = Iṣa & Urja | | |
| | v) Hemanta (Early Winter) = Sahas & Sahasya | | |
| | vi) Śīta (Winter) = Tapas & Tapasya; each Season covers 60° of the Sun’s motion along the Ecliptic; solar months are seldom mentioned | | |
| | • Tropical Solar year & Vasanta starts at −30° of the Ecliptic, | | |
Table 10 (Continued)

| Astro-nomical features | Rk Saṁhitā | Yajuḥ Saṁhitā | Vedāṅga Jyotiṣa | Śūrya Siddhānta |
|-------------------------|------------|---------------|-----------------|----------------|
| ...                     | ...        | ...           | ...             | ...            |
| Longer Periods of time  |            |               |                 |                |
| • Yuga (≡ Saros of Chaldean Astronomy) |            |               |                 |                |
| • Perhaps a 5 years Yuga |            |               |                 |                |
| • Yuga = 1830 sāvana days = 1860 tithis = 62 lunar months = 60 solar months = 67 nākṣatra months |            |                 |                |
| • Yuga begins at W.S. with the Sun and the moon at Dhaniṣṭhā |            |                 |                |
| • Mahāyuga 4.32 × 10^6 years |            |                 |                |
| • Kalpa 4.32 × 10^9 years |            |                 |                |
XI Comments on Astrology

Unlike in Babylonian civilization, astrology had no place in Hindu astronomy. This is perhaps because of Gautama Buddha’s strictures against astrological predictions of doom and disorder. This is found in the Buddhist scripture Dīgha Nikāya, Vol 1, p. 65, (Pali Text Book Society)

Some brāhmaṇas and śramaṇas earn their livelihood by taking to beastly professions and eating food brought to them out of fear. They say: "There will be a solar eclipse, a lunar eclipse, occultation of the stars, the sun and the moon will move in the correct direction, in the incorrect direction, the nakṣatras will move in the correct path, in the incorrect path, there will be precipitation of meteors, burning of the cardinal directions (?), earthquakes, roar of heavenly war-drums, the sun, the moon and the stars will rise and set wrongly producing wide distress amongst all beings, etc. "

Kautilyā Arthaśāstra also has the following stricture against astrological predictions.

"The objective (≡ artha) eludes the foolish man (≡ bālam) who enquires too much from the stars. The objective should be the nakṣatra of the objective, of what avail are the stars."

The practice of astrological prediction of human fate was perhaps imported from Babylonian civilization by the Śakas in the 1st century B.C. It is also to be noted that in the Hindu books of knowledge Astronomy was called Jyotisā whereas Astrology was called Sāmudrika Jyotisā. The epithet Sāmudrika indicates that this branch of knowledge came from beyond the boundaries of the country.
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