Birth and Early Development of Indian Astronomy

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1 Introduction

In the last decade or so our understanding of the origin and development of Indian astronomy and its relevance for Indian religion and culture have undergone a major shift. This shift has been caused by two factors: first, archaeological discoveries that reveal to us that the the Sarasvati river, the great river of the *Ṛgvedic* times, dried up before 1900 BCE, suggesting that this ancient text must be at least as old as that epoch; second, discovery of an astronomy in the Vedic texts. The assignment of a date to the drying up of the Sarasvati river has been a great aid to sorting the confusion regarding the chronology of the Indian texts, but it could not have come before an analysis of the excavations of the Harappan towns and settlements of the 3rd millennium BCE. On the other hand, the neglect of the astronomy of the Vedic texts was caused by the inability of the philologists and Sanskritists who studied these texts during the last two centuries to appreciate their scientific references.

Owing to the importance of the astronomy of the earliest period for understanding the entire scientific tradition in India, we will, in this essay, focus primarily on the pre-*Siddhāntic* period before Āryabhaṭa. The subsequent history of Indian astronomy is well described by the *Siddhāntas* themselves and by the many reviews that have appeared in the published literature.

The fundamental idea pervading Indian thought from the most ancient times is that of equivalence or connection (*bandhu*) amongst the adhidaiva (*devas* or stars), adhibhūta (beings), and adhyātma (spirit). These connections, between the astronomical, the terrestrial, the physiological and the psychological, represent the constant theme in the discourse of Indian texts. These connections are usually stated in terms of vertical relationships, representing a recursive system; but they are also described horizontally across hierarchies where they represent metaphoric or structural parallels. Most often, the relationship is defined in terms of numbers or other characteristics. An example is the 360 bones of the infant—which later fuse into the 206 bones of the adult—and the 360 days of the year. Likewise, the tripartite division of the cosmos into earth, space, and sky is reflected in the tripartite psychological types.

Although the Vedic books speak often about astronomical phenomena, it is only recently that the astronomical substratum of the Vedas has been examined (Kak 1992-1999). One can see a plausible basis behind many con-

nections. Research has shown that all life comes with its inner clocks. Living organisms have rhythms that are matched to the periods of the sun or the moon. There are quite precise biological clocks of 24-hour (according to the day), 24 hour 50 minutes (according to the lunar day since the moon rises roughly 50 minutes later every day) or its half representing the tides, 29.5 days (the period from one new moon to the next), and the year. Monthly rhythms, averaging 29.5 days, are reflected in the reproductive cycles of many marine plants and those of animals. The menstrual period is a synodic month and the average duration of pregnancy is nine synodic months. There are other biological periodicities of longer durations. These connections need not be merely numerical. In its most general form is the *Upaniṣadic* equation between the self (*ātman*) and the universe (*brahman*).

It is tempting to view *jyotiṣa*, the science of light and astronomy, as the fundamental paradigm for the Vedic system of knowledge. Jyotiṣa is a term that connotes not only the light of the outer world, but also the light of the inner landscape. Astronomy is best described as nakṣatra-vidyā of the *Chāndogya Upaniṣad*, but because of its popularity we will also use jyotiṣa in its narrow meaning of astronomy. As defining our place in the cosmos and as a means to understand the nature of time, astronomy is obviously a most basic science.

That astronomy reveals that the periods of the heavenly bodies are incommensurate might have led to the notion that true knowledge lies beyond empirical aparā knowledge. On the other hand, it is equally likely that it was a deep analysis of the nature of perception and the paradox of relationship of the perceptor to the whole that was the basis of Vedic thought, and the incommensurability of the motions in the sky was a confirmation of the insight that knowledge is recursive. This Vedic view of knowledge seems to have informed the earliest hymns so it does not appear to be feasible to answer the question of which came first. Neither can we now answer the question whether jyotiṣa as pure astronomy was a precursor to a jyotiṣa that included astrology.

Analysis of texts reveals that much of Vedic mythology is a symbolic telling of astronomical knowledge. Astronomy was the royal science not only because it was the basis for the order in nature, but also because the inner space of man, viewed as a microcosm mirroring the universe, could be fathomed through its insights.

1.1 Of Ceremonies, Festivals, Rites

The importance of jyotiṣa for agriculture and other secular purposes are obvious and so we begin with a brief account of rites and festivals. These ceremonies and rituals reveal that there existed several traditions of astronomical lore; these variations are marked by the different books of *Śrautasūtra*. Such variation is perfectly in accord with an age when astronomy was a living science with different scholars providing different explanations. Since our purpose is not to go into the details of the Vedic texts, we will describe ceremonies and rites selectively.

Different points in the turning year were marked by celebrations. The year, beginning with the full moon in the month Phālguna (or Caitra), was divided into three four-monthly, *cāturmāsya*, sacrifices. Another way of marking the year is by a year-long dīkṣā. The year was closed with rites to celebrate Indra Śunāśīra (Indra with the plough) to "obtain the thirteenth month;" this thirteenth month was interposed twice in five years to bring the lunar year in harmony with the solar year. This closing rite is to mark the first ploughing, in preparation for the next year. Symbolically, this closing was taken to represent the regeneration of the year.

Year-long ceremonies for the king's priest are described in the *Atharvaveda* Pariśiṣṭa; these include those for the health of horses, the safety of vehicles, and so on. There existed other royal rites such as rājasūya, vājapeya and the aśvamedha, the so-called horse sacrifice, which actually represented the transcendence by the king of time in its metaphorical representation as horse. The primary meaning of aśva as the sun is attested to in the *Ṛgveda, Nirukta*, and *Śatapatha Brāhmaṇa*.

The *Gṛhyasūtras* describe rites that mark the passage of the day such as the daily agnihotra. Three soma pressings, at sunrise, midday and sunset, were a part of the daily ritual of agniṣṭoma. Then there were the full and new moon ceremonies. Longer soma rites were done as sattras, sessions of twelve days or more.

1.2 Altars

Altar ritual was an important part of Vedic life and we come across fire altars in the *Ṛgvedic* hymns. Study of Vedic ritual has shown that the altar, adhiyajña, was used to show the connections between the astronomical, the

physiological and the spiritual, symbolically. That the altars represented astronomical knowledge is what interests us in this article. But the astronomy of the altars was not systematically spelled out although there are pointed references in many texts including the tenth chapter of *Śatapatha Brāhmaṇa*, entitled "Agnirahasya". *Ṛgveda* itself is viewed as an altar of mantras in the *Śulbasūtras*.

Altars were used in relation to two basic types of Vedic ritual: Śrauta and Gṛhya. This ritual marked specific points in the day or the year as in the soma rituals of agniṣṭoma and agnicayana. The *Śatapatha Brāhmaṇa* describes the twelve-day agnicayana rite that takes place in a large trapezoidal area, called the mahāvedi, and in a smaller rectangular area to the west of it, which is called the prācīnavaṃśa or prāgvaṃśa. The text says clearly that agnicayana represents ritual as well as knowledge.

The mahāvedi trapezium measures 30 prakrama on the west, 24 prakrama on the east, and 36 prakrama lengthwise. The choice of these numbers is related to the sum of these three equaling one fourth the year or 90 days.

The nominal year of 360 days was used to reconcile the discrepancies between the lunar and solar calendars, both of which were used. In the mahāvedi a brick altar is built to represent time in the form of a falcon about to take wing (Figure 1), and in the prācīnavaṃśa there are three fire altars in specified positions, the gārhapatya, āhavanīya, and dakṣiṇāgni. The gārhapatya, which is round, is the householder's fire received from the father and transmitted to the descendents. It is a perpetual fire from which the other fires are lighted. The dakṣiṇāgni is half-moon shaped; it is also called the anvāhāryapacana where cooking is done. The āhavanīya is square. Between the āhavanīya and the gārhapatya a space of a rough hourglass is dug out and strewn with grass; this is called the vedi and it is meant for the gods to sit on.

During the agnicayana ritual the old āhavanīya serves the function of the original gārhapatya. This is the reason why their areas are to be identical, although one of them is round and the other square. In addition eight dhiṣṇya hearths are built on an expanded ritual ground.

Agnicayana altars are supposed to symbolize the universe. Gārhapatya represents the earth, the dhiṣṇya hearths represent space, and the āhavanīya altar represents sky. This last altar is made in five layers. The sky is taken to represent the universe therefore it includes space and earth. The first layer represents the earth, the third the space, and the fifth the sky. The second

layer represents the joining of the earth and space, whereas the fourth layer represents the joining of space and sky.

Time is represented by the metaphor of a bird. The months of the year were ordinarily divided into six seasons unless the metaphor of the bird for the year was used when hemanta and śiśira were lumped together. The year as a bird had the head as vasanta, the body as hemanta and śiśira, the two wings as śarada and grīṣma, and the tail as varṣā.

The Vedic sacrifice is meant to capture the magic of change, of time in motion. Put differently, the altar ritual is meant to symbolize the paradoxes of separation and unity, belonging and renunciation, and permanence and death. The yajamāna, the patron at whose expense the ritual is performed, symbolically represents the universe.

The ritual culminates in his ritual rebirth, which signified the regeneration of his universe. In other words, the ritual is a play dealing with paradoxes of life and death enacted for the yajamāna's family and friends. In this play symbolic deaths of animals and humans, including the yajamāna himself, may be enacted.

1.3   Evolution of Vedic Thought

How did the use of altars for a symbolic representation of knowledge begin? This development is described in the *Purāṇas* where it is claimed that the three altars were first devised by the king Purūravas. The genealogical lists of the *Purāṇas* and the epics provide a framework in which the composition of the different hymns can be seen. The ideas can then be checked against social processes at work as revealed by textual and archaeological data.

As we will see later in this article, there existed an astronomical basis to the organization of the *Ṛgveda* itself; this helps us see Vedic ritual in a new light. That astronomy could be used for fixing the chronology of certain events in the Vedic books was shown more than a hundred years ago by Tilak and Jacobi. This internal evidence compels the conclusion that the prehistory of the Vedic people in India goes back to the fourth millennium and earlier. On the other hand, new archaeological discoveries show a continuity in the Indian tradition going as far back as 8000 BCE (Shaffer and Lichtenstein, 1995). These are some of the elements in accord with the view that the Vedic texts and the archaeological finds relate to the same reality. One must also note that the rock art tradition in India has been traced back to about 40000

BC (Wakankar, 1992). Whether this tradition gave birth to the Harappan tradition is not clear at this time.

Recent archaeological discoveries establish that the Sarasvatī river dried up around 1900 BCE which led to the collapse of the Harappan civilization that was principally located in the Sarasvatī region. Francfort (1992) has even argued that the Dṛṣadvatī was already dry before 2600 BCE. The region of the Sarasvatī and the Dṛṣadvatī rivers, called Brahmāvarta, was especially sanctified and Sarasvatī was one of the mightiest rivers of the *Ṛgvedic* period. On the other hand, Pañcaviṃśa Brāhmaṇa describes the disappearance of Sarasvatī in the sands at a distance of forty days on horseback from its source. With the understanding of the drying up of Sarasvatī it follows that the *Ṛgvedic* hymns are generally anterior to 1900 BCE but if one accepts Francfort's interpretation of the data on the Dṛṣadvatī then the *Ṛgvedic* period includes the period before 2600 BCE.

It is most significant that the *Purāṇic* king-lists speak of 1924 BCE as the epoch of the *Mahābhārata* War, that marked the end of the Vedic age. This figure of 1924 BCE emerges from the count of 1500 years for the reigns prior to the Nandas (424 BCE), quoted at several places in the *Purāṇas*. Since this epoch is virtually identical to the rough date of 1900 BCE for the catastrophic drying up of the Sarasvati river, it suggests that the two might have been linked if not being the same, and it increases our confidence in the use of the Indian texts as sources of historical record.

2   Nakṣatras

The *Ṛgveda* describes the universe to be infinite. Of the five planets it mentions Bṛhaspati (Jupiter) and Vena (Venus) by name The moon's path was divided into 27 equal parts, although the moon takes about 27 1/3 days to complete it. Each of these parts was called a nakṣatra. A traditional iconic representation of the nakṣatras is shown in Figure 2. Specific stars or asterisms were also termed nakṣatras, and they are mentioned in the *Ṛgveda* and *Taittirīya Saṃhitā*, the latter specifically saying that they are linked to the moon's path. The *Ṛgvedic* reference to 34 lights apparently means the sun, the moon, the five planets, and the 27 nakṣatras. In later literature the list of nakṣatras was increased to 28. Constellations other than the nakṣatras were also known; these include the Ṛkṣas (the Bears), the two divine Dogs (Canis

Major and Canis Minor), and the Boat (Argo Navis). *Aitareya Brāhmaṇa* speaks of Mṛga (Orion) and Mṛgavyādha (Sirius). The moon is called sūrya raśmi, one that shines by sunlight.

The constellations conjoined monthly with the circuit of the sun were traditionally represented as in the outer circle of Figure 3. The inner circle of this figure shows the five planets, the sun, the moon and its ascending and descending nodes.

The *Śatapatha Brāhmaṇa* provides an overview of the broad aspects of Vedic astronomy. The sixth chapter of the book provides significant clues. Speaking of creation under the aegis of the Prajāpati (reference either to a star or to abstract time) mention is made of the emergence of Aśva, Rāsabha, Aja and Kūrma before the emergence of the earth. It has been argued that these refer to stars or constellations. Viśvanātha Vidyālaṅkāra (1985) suggests that these should be identified as the sun (Aśva), Gemini (Rāsabha), Aja (Capricorn) and Kūrma or Kāśyapīya (Cassiopeia). This identification is supported by etymological considerations. RV 1.164.2 and *Nirukta* 4.4.27 define Aśva as the sun. Rāsabha which literally means the twin asses are defined in *Nighaṇṭu* 1.15 as Aśvinau which later usage suggests are Castor and Pollux in Gemini. In Western astronomy the twin asses are to be found in the next constellation of Cancer as Asellus Borealis and Asellus Australis. Aja (goat) is defined by Nighaṇṭu 1.15 as a sun and owing to the continuity that we see in the Vedic and later European names for constellations (as in the case of the Great Bear) it is reasonable to identify it as the constellation Capricorn (*caper* goat + *cornu* horn).

Vedic ritual was based on the times for the full and the new moons, solstices and the equinoxes. The year was known to be somewhat more than 365 days and a bit less than 366 days. The solar year was marked variously in the many different astronomical traditions that marked the Vedic world. In one tradition, an extra eleven days, marked by ekādaśarātra or eleven-day sacrifice, were added to the lunar year of 354 days. According to the *Taittirīya Saṃhitā* five more days are required over the nominal year of 360 days to complete the seasons, adding that four days are too short and six days are too long. In other traditions, gavām ayana, 'the walk of cows or intercalary periods,' varied from 36 days of the lunar sidereal year of 12 months of 27 days, to 9 days for the lunar sidereal year of 13 months of 27 days to bring the year in line with the ideal year of 360 days; additional days were required to be in accord with the solar year.

The year was divided into two halves: uttarāyana, when the sun travels north, and dakṣiṇāyana, when the sun travels south. According to the *Kauṣītaki Brāhmaṇa*, the year-long sacrifices began with the winter solstice, noting the occurrence of the summer solstice, viṣuvant, after six months.

The twelve tropical months, and the six seasons, are named in the *Yajurveda*:

Madhu, Mādhava in vasanta (spring);
Śukra, Śuci in grīṣma (summer);
Nabha, Nabhasya in varṣā (rains);
Iṣa, Ūrja in śarada (autumn);
Saha, Sahasya in hemanta (winter);
Tapa, Tapasya in śiśira (freeze).

The nākṣatra names of the months began with Caitra in spring, although some lists begin with Phālguna. Since the months shift with respect to the twelve nakṣatra about 2,000 years per nakṣatra, this change in the lists indicates a corresponding long period. The lists that begin with Caitra mark the months thus:

Caitra, Vaiśākha,
Jyaiṣṭha, Āṣāḍha,
Śrāvaṇa, Bhādrapada,
Āśvina, Kārttika,
Mārgaśira, Pauṣya,
Māgha, Phālguna.

The earliest lists of nakṣatras in the Vedic books begin with Kṛttikās, the Pleiades; much later lists dating from sixth century CE begin with Aśvinī when the vernal equinox occurred on the border of Revatī and Aśvinī. Assuming that the beginning of the list marked the same astronomical event, as is supported by other evidence, the earliest lists should belong to the third millennium BCE. The *Taittirīya Saṃhitā* 4.4.10 and *Śatapatha Brāhmaṇa* 10.5.4.5 each mention 27 nakṣatras. But there was also a tradition of the use of 28 nakṣatras. The *Atharvaveda* 19.7 lists these 28 together with their presiding deities; the additional nakṣatra is Abhijit. The lists begins with Kṛttikā (Pleiades) where the spring equinox was situated at that time.

2.1 Nakṣatras and chronology

Motivated by the then-current models of the movements of pre-historic peoples, it became, by the end of the nineteenth century, fashionable in Indological circles to dismiss any early astronomical references in the Vedic literature. But since the publication of *Hamlet's Mill: An essay on myth and the frame of time* by Georgio de Santillana and Hertha von Dechend in 1969 it has come to be generally recognized that ancient myths encode a vast and complex body of astronomical knowledge. The cross-checks provided by the dating of some of the Indian myths provide confirmation to the explicit astronomical evidence related to the nakṣatras that is spelled out below. Other confirmation comes from the archaeological evidence summarized in this article.

Due to the precession of the earth's polar axis the direction of the north pole with respect to the fixed background stars keeps on changing. The period of this precession is roughly 26,000. Polaris (α Ursae Minoris) is the Pole star now but around 3000 BCE it was α Draconis which was followed later by β Ursae Minoris; in CE 14000 it will be Vega. The equinoxes and the solstices also shift with respect to the background stars. The equinoxes move along the ecliptic in a direction opposite to the yearly course of the sun (Taurus to Aries to Pisces rather than Pisces to Aries to Taurus and so on).

The vernal equinox marked an important day in the year. The sun's position among the constellations at the vernal equinox was an indication of the state of the precessional cycle. This constellation was noted by its heliacal rising. The equinoctial sun occupies each zodiacal constellation for about 2200 years. Around 5000 BCE it was in Gemini; it has moved since into Taurus, Aries, and is now in Pisces. The sun spends about 13 1/3 days in each nakṣatra, and the precession of the equinoxes takes them across each nakṣatra in about a 1000 years.

Thirteen and a half nakṣatras ending with Viśākhā were situated in the northern hemispheres; these were called devanakṣatras. The remaining nakṣatras ending with Bharaṇī that were in the southern hemisphere were called yamanakṣatras (yama: twin, dual). This classification in the *Taittirīya Brāhmaṇa* (1.5.2.7) corresponds to 2300 BCE.

As mentioned above, the list beginning with Kṛttikā indicates that it was drawn up in the third millennium BCE. The legend of the cutting off of Prajāpati's head suggests a time when the year began with Mṛgaśīrṣa in

the fifth millennium BCE. Scholars have also argued that a subsequent list began with Rohiṇī. This view is strengthened by the fact that there are two Rohiṇīs, separated by fourteen nakṣatras, indicating that the two marked the beginning of the two half-years.

The *Śatapatha Brāhmaṇa* speaks of a marriage between the Seven Sages, the stars of the Ursa Major, and the Kṛttikās; this is elaborated in the *Purāṇas* where it is stated that the ṛṣis remain for a hundred years in each nakṣatra. In other words, during the earliest times in India there existed a centennial calendar with a cycle of 2,700 years. Called the Saptarṣi calendar, it is still in use in several parts of India. Its current beginning is taken to be 3076 BCE. On the other hand, notices by the Greek historians Pliny and Arrian suggest that, during the Mauryan times, the calendar used in India began in 6676 BCE. It is very likely that this calendar was the Saptarṣi calendar with a beginning at 6676 BCE.

Around 500 CE, a major review of the Indian calendar was attempted by astronomers. Āryabhaṭa, Varāhamihira and others used the nakṣatra references that the Saptarṣi were in Maghā at the time of the *Mahābhārata* war to determine its epoch. Āryabhaṭa declared the war to have occurred in 3137 BCE (the Kaliyuga era begins 35 years after the war), and Varāhamihira assigned it 2449 BCE. It has been suggested that this discrepancy arose because the change in the number of nakṣatras from the earlier counts of 27 to the later 28 was differently computed by the two astronomers. It is quite likely that the fame of the Kaliyuga era with its beginning assigned to 3102 BCE prompted a change in the beginning of the Saptarṣi era to about the same time, viz. to 3076 BCE.

The shifting of seasons through the year and the shifting of the northern axis allow us to date several other statements in the books. Thus the *Śatapatha Brāhmaṇa* (2.1.2.3) has a statement that points to an earlier epoch where it is stated that Kṛttikā never swerve from the east. This correspond to 2950 BCE.

The *Maitrayānīya Brāhmaṇa Upaniṣad* (6.14) refers to the winter solstice being at the mid-point of the Śraviṣṭhā segment and the summer solstice at the beginning of Maghā. This indicates 1660 BCE.

The *Vedāṅga Jyotiṣa* (Yajur 6-8) mentions that winter solstice was at the beginning of Śraviṣṭhā and the summer solstice at the mid-point of Aśleṣā. This corresponds to about 1370 BCE (Sastry, 1985).

It should be noted that these dates can only be considered to be very ap-

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proximate. Furthermore, these dates do not imply that the texts come from the corresponding period; the text may recall an old tradition. A chronology of the Vedic period by means of astronomical references was attempted by the historian of science P.C. Sengupta. Amongst other evidence, Sengupta uses the description of the solar eclipse in RV 5.40.5-9 to fix a date for it. Unfortunately, this work has not received the attention it deserves.

The changes in the beginning of the Nakṣatra lists bring us down to the Common Era; at the time of Varāhamihira (550 CE) the vernal equinox was in Aśviní.

3   Ritual, geometry and astronomy

We have mentioned that the altars used in the ritual were based on astronomical numbers related to the reconciliation of the lunar and solar years. The fire altars symbolized the universe and there were three types of altars representing the earth, the space and the sky. The altar for the earth was drawn as circular whereas the sky (or heaven) altar was drawn as square. The geometric problems of circulature of a square and that of squaring a circle are a result of equating the earth and the sky altars. As we know these problems are among the earliest considered in ancient geometry.

The fire altars were surrounded by 360 enclosing stones, of these 21 were around the earth altar, 78 around the space altar and 261 around the sky altar. In other words, the earth, the space, and the sky are symbolically assigned the numbers 21, 78, and 261. Considering the earth/cosmos dichotomy, the two numbers are 21 and 339 since cosmos includes the space and the sky.

The main altar was built in five layers. The basic square shape was modified to several forms, such as falcon and turtle. These altars were built in five layers, of a thousand bricks of specified shapes. The construction of these altars required the solution to several geometric and algebraic problems.

Two different kinds of bricks were used: the special and the ordinary. The total number of the special bricks used was 396, explained as 360 days of the year and the additional 36 days of the intercalary month. By layers, the first has 98, the second has 41, the third has 71, the fourth has 47 and the fifth has 138. The sum of the bricks in the fourth and the fifth layers equals 186 tithis of the half-year. The number of bricks in the third and the

fourth layers equals the integer nearest to one third the number of days in the lunar year, and the number of bricks in the third layer equals the integer nearest to one fifth of the number of days in the lunar year, and so on.

The number of ordinary bricks equals 10,800 which equals the number of muhūrtas in a year (1 day = 30 muhūrtas), or equivalently the number of days in 30 years. Of these 21 go into the gārhapatya, 78 into the eight dhiṣṇya hearths, and the rest go into the āhavanīya altar.

3.1 Equivalence by area

The main altar was an area of $7\frac{1}{2}$ units. This area was taken to be equivalent to the nominal year of 360 days. Now, each subsequent year, the shape was to be reproduced with the area increased by one unit.

The ancient Indians spoke of two kinds of day counts: the solar day, and tithi, whose mean value is the lunar year divided into 360 parts. They also considered three different years: (1) nakṣatra, or a year of 324 days (sometimes 324 tithis) obtained by considering 12 months of 27 days each, where this 27 is the ideal number of days in a lunar month; (2) lunar, which is a fraction more than 354 days (360 tithis); and (3) solar, which is in excess of 365 days (between 371 and 372 tithis). A well-known altar ritual says that altars should be constructed in a sequence of 95, with progressively increasing areas. The increase in the area, by one unit yearly, in building progressively larger fire altars is 48 tithis which is about equal to the intercalation required to make the nakṣatra year in tithis equal to the solar year in tithis. But there is a residual excess which in 95 years adds up to 89 tithis; it appears that after this period such a correction was made. The 95 year cycle corresponds to the tropical year being equal to 365.24675 days. The cycles needed to harmonize various motions led to the concept of increasing periods and world ages.

3.2 The Ṛgvedic altar

The number of syllables in the *Ṛgveda* confirms the textual references that the book was to represent a symbolic altar. According to various early texts, the number of syllables in the *Ṛgveda* is 432,000, which is the number of muhūrtas in forty years. In reality the syllable count is somewhat less because certain syllables are supposed to be left unspoken.

The verse count of the *Ṛgveda* can be viewed as the number of sky days in forty years or $261 \times 40 = 10,440$, and the verse count of all the Vedas is $261 \times 78 = 20,358$.

The *Ṛgveda* is divided into ten books with a total of 1,017 hymns which are placed into 216 groups. Are these numbers accidental or is there a deliberate plan behind the choice? One would expect that if the *Ṛgveda* is considered akin to the five-layered altar described in the Brāhmaṇas then the first two books should correspond to the space intermediate to the earth and the sky. Now the number that represents space is 78. When used with the multiplier of 3 for the three worlds, this yields a total of 234 hymns which is indeed the number of hymns in these two books. One may represent the *Ṛgvedic* books as a five-layered altar of books as shown in Table 1.

Table 1: The altar of books

Book 10	Book 9
Book 7	Book 8
Book 5	Book 6
Book 3	Book 4
Book 2	Book 1

When the hymn numbers are used in this altar of books we obtain Table 2.

Table 2: Hymns in the altar of books

191	114
104	92
87	75
62	58
43	191

The choice of this arrangement is prompted by the considerable regularity in the hymn counts. Thus the hymn count separations diagonally across the two columns are 29 each for Book 4 to Book 5 and Book 6 to Book 7 and they are 17 each for the second column for Book 4 to Book 6 and Book 6 to Book 8. Books 5 and 7 in the first column are also separated by 17; Books 5 and 7 also add up to the total for either Book 1 or Book 10. Another regularity is that the middle three layers are indexed by order from left to right whereas the bottom and the top layers are in the opposite sequence.

Furthermore, Books [4+6+8+9] = 339, and these books may be taken to represent the spine of the altar. The underside of the altar now consists of the Books [2+3+5+7] = 296, and the feet and the head Books [1+10] =

382. The numbers 296 and 382 are each 43 removed from the fundamental *Ṛgvedic* number of 339.

The *Brāhmaṇas* and the *Śulbasūtra* tell us about the altar of chandas and meters, so we would expect that the total hymn count of 1017 and the group count of 216 have particular significance. Owing to the pervasive tripartite ideology of the Vedic books we choose to view the hymn number as 339×3. The tripartite ideology refers to the consideration of time in three divisions of past, present, and future and the consideration of space in the three divisions of the northern celestial hemisphere, the plane that is at right angle to the earth's axis, and the southern celestial hemisphere.

Consider the two numbers 1017 and 216. One can argue that another parallel with the representation of the layered altar was at work in the group total of 216. Since the *Ṛgvedic* altar of hymns was meant to symbolically take one to the sky, the abode of gods, it appears that the number 216 represents twice the basic distance of 108 taken to separate the earth from the sky. The *Ṛgvedic* code then expresses a fundamental connection between the numbers 339 and 108.

Consider now the cosmic model used by the ancients. The earth is at the center, and the sun and the moon orbit the earth at different distances. If the number 108 was taken to represent symbolically the distance between the earth and the sky, the question arises as to why it was done. The answer is apparent if one considers the actual distances of the sun and the moon. The number 108 is roughly the average distance that the sun is in terms of its own diameter from the earth; likewise, it is also the average distance that the moon is in terms of its own diameter from the earth. It is owing to this marvellous coincidence that the angular size of the sun and the moon, viewed from the earth, is about identical.

It is easy to compute this number. The angular measurement of the sun can be obtained quite easily during an eclipse. The angular measurement of the moon can be made on any clear full moon night. A easy check on this measurement would be to make a person hold a pole at a distance that is exactly 108 times its length and confirm that the angular measurement is the same. Nevertheless, the computation of this number would require careful observations. Note that 108 is an average and due to the ellipticity of the orbits of the earth and the moon the distances vary with the seasons. It is likely, therefore, that observations did not lead to the precise number 108, but it was chosen as the true value of the distance since it is equal to 27×4,

because of the mapping of the sky into 27 nakṣatras.

The second number 339 is simply the number of disks of the sun or the moon to measure the path across the sky: $\pi \times 108 \approx 339$.

We return to a further examination of the numbers 296, 339, and 382 in the design of the *Ṛgvedic* altar. It has been suggested that 339 has an obvious significance as the number of sun-steps during the average day or the equinox, and the other numbers are likely to have a similar significance. In other words, 296 is the number of sun-steps during the winter solstice and 382 is the number of sun-steps during the summer solstice (Kak, 1994).

There also exists compelling evidence, of a probabilistic sense, that the periods of the planets had been obtained and used in the setting up of the *Ṛgvedic* astronomical code.

4   The motions of the sun and the moon

The *Vedāṅga Jyotiṣa* (VJ), due to Lagadha, is a text that describes some of the astronomical knowledge of the times of altar ritual. It has an internal date of c. 1350 BCE obtained from its assertion that the winter solstice was at the asterism Śraviṣṭhā (Delphini). Recent archaeological discoveries support such an early date, and so this book assumes great importance in the understanding of the earliest astronomy.

VJ describes the mean motions of the sun and the moon. This manual is available in two recensions: the earlier *Ṛgvedic* VJ (RVJ) and the later *Yajurvedic* VJ (YVJ). RVJ has 36 verses and YVJ has 43 verses. As the only extant astronomical text from the Vedic period, we describe its contents in some detail.

The measures of time used in VJ are as follows:

    1 lunar year = 360 tithis
    1 solar year = 366 solar days
    1 day = 30 muhūrtas
    1 muhūrta = 2 nāḍikās
    1 nāḍikā = $10\frac{1}{20}$ kalās
    1 day = 124 aṁśas (parts)
    1 day = 603 kalās

Furthermore, five years were taken to equal a yuga. A ordinary yuga consisted of 1,830 days. An intercalary month was added at half the yuga and another at the end of the yuga.

What are the reasons for the use of a time division of the day into 603 kalās? This is explained by the assertion that the moon travels through 1,809 nakṣatras in a yuga. Thus the moon travels through one nakṣatra in $1\frac{7}{603}$ sidereal days because

$$1,809 \times 1\frac{7}{603} = 1,830.$$

Or the moon travels through one nakṣatra in 610 kalās. Also note that 603 has 67, the number of sidereal months in a yuga, as a factor The further division of a kalā into 124 kāṣṭhās was in symmetry with the division of a yuga into 62 synodic months or 124 fortnights (of 15 tithis), or parvans. A parvan is the angular distance travelled by the sun from a full moon to a new moon or vice versa.

The VJ system is a coordinate system for the sun and the moon in terms of the 27 nakṣatras. Several rules are given so that a specific tithi and nakṣatra can be readily computed.

> The number of risings of the asterism Śraviṣṭhā in the yuga is the number of days plus five (1830+5 = 1835). The number of risings of the moon is the days minus 62 (1830-62 = 1768). The total of each of the moon's 27 asterisms coming around 67 times in the yuga equals the number of days minus 21 (1830-21 = 1809).

> The moon is conjoined with each asterism 67 times during a yuga.
> The sun stays in each asterism $13\frac{5}{9}$ days.

The explanations are straightforward. The sidereal risings equals the 1,830 days together with the five solar cycles. The lunar cycles equal the 62 synodic months plus the five solar cycles. The moon's risings equal the risings of Śraviṣṭhā minus the moon's cycles.

This indicates that the moon was taken to rise at a mean rate of $\frac{1,830}{1,768}$ = 24 hours and 50.4864 minutes.

4.1 Computation of tithis, nakṣatras, kalās

Although a mean tithi is obtained by considering the lunar year to equal 360 tithis, the determination of a tithi each day is by a calculation of a shift of the moon by 12° with respect to the sun. In other words, in 30 tithis it will cover the full circle of 360°. But the shift of 12° is in an irregular manner and the duration of the tithi can vary from day to day. As a practical method a mean tithi is defined by a formula. VJ takes it to be 122 parts of the day divided into 124 parts.

Each yuga was taken to begin with the asterism Śraviṣṭhā and the synodic month of Māgha, the solar month Tapas and the bright fortnight (parvan), and the northward course of the sun and the moon. The intercalary months were used in a yuga. But since the civil year was 366 days, or 372 tithis, it was necessary to do further corrections. As shown in the earlier section, a further correction was performed at 95 year, perhaps at multiples of 19 years.

The day of the lunar month corresponds to the tithi at sunrise. A tithi can be lost whenever it begins and ends between one sunrise and the next. Thus using such a mean system, the days of the month can vary in length.

4.2 Accuracy

There are other rules of a similar nature which are based on the use of congruences. These include rules on hour angle of nakṣatras, time of the day at the end of a tithi, time at the beginning of a nakṣatra, correction for the sidereal day, and so on. But it is clear that the use of mean motions can lead to discrepancies that need to be corrected at the end of the yuga.

The framework of VJ has approximations built into it such as consideration of the civil year to be 366 days and the consideration of a tithi as being equal to $\frac{122}{124}$ of a day. The error between the modern value of tithi and its VJ value is:

$$\frac{354.367}{360} - \frac{122}{124}$$

which is as small as 5×10^{-4}. This leads to an error of less than a day in a yuga of five years.

The constructions of the geometric altars as well as the Vedic books that come centuries before VJ confirm that the Vedic Indians knew that the year was more than 365 days and less than 366 days. The five year period of

1,830 days, rather than the more accurate 1,826 days, was chosen because it is divisible by 61. This choice defines a symmetry with the definition of the tithi as $\frac{61}{62}$ of the day. The VJ system was thus very accurate for the motions of the moon but it could have only served as a framework for the motions of the sun. It appears that there were other rules of missing days that brought the calendar into consonance with the reality of the nakṣatras at the end of the five year yuga and at the end of the 95 year cycle of altar construction.

Mean motion astronomy can lead to significant discrepancy between true and computed values. The system of intercalary months introduced further irregularity into the system. This means that the conjunction between the sun and the moon that was assumed at the beginning of each yuga became more and more out of joint until such time that the major extra-yuga corrections were made.

Since the Vedic astronomers were evidently aware of the many corrections that is required in the calendric system of the VJ, one might wonder about the choice of its constants. It appears that the yuga of 1,830 days, rather than the more accurate 1,826 days, was chosen because it is divisible by 61; this choice simplifies computations for a tithi defined as $\frac{61}{62}$ of the day.

5   The planets

Although it is certain that the planets had been studied by the *Ṛgvedic* people, we do not find a single place in the texts where the names are listed together. The list below brings together some of the names, together with the ascribed colours, used in a variety of places including the later *Purāṇic* literature.

MERCURY. Budha, Saumya, Rauhiṇeya, Tuṅga (*yellow*)

VENUS. Vena, Uśanas, Śukra, Kavi, Bhṛgu (*white*)

MARS. Aṅgāraka, Bhūmija, Lohitāṅga, Bhauma, Maṅgala, Kumāra, Skanda (*red*)

JUPITER. Bṛhaspati, Guru, Āṅgiras (*yellow*)

SATURN. Śanaiścara, Sauri, Manda, Paṅgu, Pātaṅgi (*black*)

Mercury is viewed as the son of the moon by Tārā, the wife of Jupiter, or the nakṣatra Rohiṇi (Aldebaran), Venus as the son of Bhṛgu and the priest of the demons, Mars as the son of the earth or Śiva, Jupiter as the son of Aṅgiras and the priest of the gods, and Saturn is seen as being born to Revatī and Balarāma or to Chāyā and the sun. Saturn is described as the lord of the planets, lord of seven lights or satellites, and the slow-goer. Since the Indian calendar was reckoned according to the constellation at the vernal equinox, one may assume the name son of Aldebaran implies that Mercury was first noted during the era of 3400-2210 BCE when the vernal equinox was in the Pleiades.

The *Jaiminigṛhyasūtra* gives the following equation between the planets and the Vedic gods: the sun is Śiva; the moon is Umā (Śiva's wife); Mars is Skanda, the son of Śiva; Mercury is Viṣṇu; Jupiter is Brahman (symbolizing the entire universe); Venus is Indra; and Saturn is Yama, the "dual" god (death). The colors assigned to the planets are from the same source.

One may speculate that the equation of Saturn and Yama arises out of the fact that the synodic period of Saturn is the "dual" to the lunar year; 378 days of Saturn and 354 days of the lunar year with the centre at the 366-day solar year.

5.1   On the identity of Mercury and Viṣṇu

Mercury's identification with the god Viṣṇu, an important figure in the *Ṛgveda*, is of particular significance. Viṣṇu is the youger brother of Indra in the *Ṛgvedic* era; and Indra is sometimes identified with the sun. The most essential feature of Viṣṇu are his three steps by which he measures out the universe (e.g. RV 1.154). Two of these steps are visible to men, but the third or highest step is beyond the flight of birds or mortals (RV 1.155, 7.99). In later mythology it is explained that Viṣṇu did this remarkable thing in the incarnation as Vāmana, the pygmy. This agrees with the identification as the small Mercury.

Now what do these steps mean? According to late tradition, Viṣṇu is a solar deity and so these three steps represent the sunrise, the highest ascent, and the sunset. Another equally old interpretation is that the three steps represent the course of the sun through the three divisions of the universe: heavens, earth, and the netherworld.

But both of these interpretations appear unsatisfactory. Neither of these

interpretations squares with the special significance attached to the third step. Nor does not explain the putative identity of Mercury and Viṣṇu.

An explanation becomes obvious when we consider the Vedic altar ritual. It appears likely that the three steps of Viṣṇu are nothing but the three revolutions of Mercury in a cycle of 261 sky days. With this supposition the period of Mercury will be 87 days. Furthermore, three synodic periods of Mercury, at 118 days a period, equal the 354 lunar days or 360 tithis. It appears that this dual relationship led to the great importance being given to the myth of the three steps of Viṣṇu. Of course, the figures for the periods are only approximate but as expected at the first determination of these numbers an attempt was made to connect them to the basic numbers of 261 and 354.

The explicit name of Budha for Mercury appears in the *Pañcaviṃśa Brāhmaṇa* (PB) which is dated definitely after 1900 BCE since it has an account of a journey to the source of Sarasvatī from the place where it is lost in the desert (PB 25.10). PB 24.18 speaks of Budha in connection with a 61 day rite. Three such rites imply a total of 183 days which equals the days exclusively devoted to the heavens. This appears to be the analog, in the field of ritual, of the three steps of Viṣṇu covering the heavens.

We note that the understanding of the motions of the planets arose at some time during the unfolding of the *Ṛgvedic* period. For example, Venus is described in early Vedic mythology in terms of the twin Aśvins, the morning and evening stars just as Homer later describes it as the pair Hesperus and Phosphorus. This commonality indicates early Indo-European basis to this myth.

The main characters in the planetary myths are Jupiter and Venus as is to be expected for the two brightest planets. Venus, in its earlier incarnation as the Aśvin twins, was seen as born to the sun. Mercury as Viṣṇu is Upendra, the younger brother of the Indra, here a personification of the sun. But once Mercury fitted into the planetary scheme, its association with Viṣṇu was forgotten. Later acccounts describe the planets in relation to each other. Our arguments showing that the period of Mercury was obtained in the third millennium BCE imply that as the determination of the period of Mercury is the hardest amongst the classical planets, the periods of the other planets had been obtained.

The literature that followed the *Ṛgvedic* age was at first concerned more with the ritual related to the earlier astronomy of the Vedic age. Once the

planetary system fell into place, the gods became supernumeraries. Now the focus shifted to their duals that inhabit the inner universe. Thus by the time of the *Śatapatha Brāhmaṇa* (second millennium BCE), the original stars of the Ursa Major were identified with the cognitive centres in the brain as in ŚB 8.1 or in more detail in BU 2.2.4.

The *Ṛgveda* and the *Śatapatha Brāhmaṇa* speak of the five planets as gods. There is also a mention of the thirty-four lights, which appear to be the twenty seven nakṣatras, the five planets, the sun and the moon. The moon is the fastest moving of the heavenly bodies, and so it is compared to the male who activates or fertilizes the other heavenly bodies with which it comes in contact. The *Ṛgveda* speaks of the five bulls of heaven, which appear to be the five planets. Being faster than the fixed stars, the planets can, in turn, be compared to bulls.

The *Taittirīya Saṃhitā* speaks of the 33 daughters of Prajāpati, personification of time here, that are given in marriage to Soma, the moon, viewed as king. These are the 27 nakṣatras, the five planets, and the sun. The sun as the bride, Sūryā, is described in the *Ṛgveda* and the *Atharvaveda*.

Since the planets move through the nakṣatras and Venus and Jupiter are brighter than any of the stars, observation of the nakṣatras presupposes a notice of the planets. The *Vedāṅga Jyotiṣa* does not mention the planets, but that is so because its concern is only the motions of the sun and the moon related to fixing the calendar.

The rivalry between the families of Aṅgirases and the Bhṛgus, mythical figures in the Ṛgveda, represents the motions of Jupiter and Venus. This is clear in later accounts where Bṛhaspati (Jupiter), the priest of the gods because its motion is closest to the ecliptic, is an Āṅgiras and Kavi Uśanas or Śukra (Venus), a Bhārgava, is the priest of the Asuras.

The idea of eclipse was expressed by the notion of Rāhu seizing the heavenly body. The fact that graha, 'seize,' is the name used for planets right from the time of *Atharvaveda* suggests that the waxing and waning of the two inferior planets, Mercury and Venus, as well as the change in the intensity of the others was known.

Although there is mention of a week of six days, called a ṣaḍaha, in the early books, it does not follow that the tradition of a week of seven days is a later one. The seven day week was in use during the time of *Atharva Jyotiṣa*.

The sidereal periods suggested by the astronomical code in the organization of the *Ṛgveda* are (Kak, 1994):

Mercury: 87 days
Venus: 225 days
Mars: 687 days
Jupiter: 4,340 or 4,350 days
Saturn: 10,816 days.

5.2 Soma

Soma, or the moon, is one of the most important deities of the *Ṛgveda*. It is related to Sūrya the way puruṣa is related to prakṛti. Soma is almost always the moon in the ninth book of the *Ṛgveda*. That very few Western scholars of the nineteenth century recognized this fact can only be explained by recalling the incorrect assumptions they labored under. Soma, as a drink, was meant to celebrate the creative function of the moon as reflected in the tides, the menstrual cycle and the growth of plants.

6 The Yuga concept

There are allusions to yugas, meant as an age, in the Vedas. In the *Aitareya Brāhmaṇa* Kali, Dvāpara, Tretā, and Kṛta are compared to a man lying down, moving, rising, and walking. The *Ṣaḍviṃśa Brāhmaṇa* mentions the four ages Puṣya, Dvāpara, Khārvā, and Kṛta. In order from Kṛta to Kali, each yuga represents a decline in morality, piety, strength, knowledge, truthfulness, and happiness. The notion of a yuga appears to have a historical basis. If we accept that a catastrophic tectonic event took place around 1900 BCE, leading eventually to a great shift in the population away from the Sarasvatī valleys, then Kaliyuga could be a memory of the beginning of that dark age. Support for this view comes from the *Mahābharata*, according to which all places were sacred in the Kṛtayuga; Puṣkara in the Sarasvatī region was the most sacred in Tretāyuga; Kurukṣetra in Dvāpara; and Prayāga at the junction of Gaṅgā and Yamuna in the Kaliyuga. This clearly marks the shift in focus of the Vedic people.

The five years of the yuga of the *Vedāṅga Jyotiṣa* are named variously; one text calling them saṃvatsara, parivatsara, idāvatsara, iduvatsara, and vatsara. It has been suggested that the 33 gods mentioned at many places

refer to a cycle of 33 years but this cannot be accepted until corroborative evidence is found. As mentioned before, a cycle of 95 years is described in the *Śatapatha Brāhmaṇa.* The yuga of 60 years appears to have emerged out of an attempt to harmonize the approximate sidereal periods of 12 and 30 years for Jupiter and Saturn, respectively. Consideration of more accurate sidereal values requires much larger periods that are seen in the later *Siddhāntic* astronomy of the Classical period.

The *Purāṇas* talk of a kalpa, a day of Brahmā which is taken to equal 12,000 thousands of divine years, each of which equals 360 human years, for a total of 4,320 million human years. Kṛta, Tretā, Dvāpara, and Kali are supposed to last 4,000, 3,000, 2,000, 1,000 divine years respectively. In addition, there are sandhyās (twilights) of 800 (two twilights of 400 years), 600, 400, 200 on the yugas, in order, to give a total span of 12,000 divine years. Brahmā, the creator of time, is a personification of the beginning of the sustaining principle, to be taken either as Viṣṇu or Śiva. Each day of Brahmā is followed by a night of the same duration. A year of Brahmā equals such 360 day and nights, and the duration of the universe is the span of 100 Brahmā years. The largest cycle is 311,040,000 million years. We are supposed to be in the 55th year of the current Brahmā. The large cycle is nested in still larger cycles. Within each kalpa are fourteen secondary cycles, called manvantaras, each lasting 306,720,000 years. In each manvantara, humans begin with a new Manu. We are now in the seventh manvantara of the kalpa, started by Manu Vaivasvata.

A kalpa equals a thousand mahāyugas, each of which has the four yugas Kṛta, Tretā, Dvāpara, and Kali. Each manvantara may be divided into 71 mahāyugas. While the yugas, as defined in the *Purāṇic* literature of the first millennium CE have extremely large periods in multiples of the 'years of the gods,' it is likely that the four yugas were originally 4,800, 3,600, 2,400, and 1,200 ordinary years, respectively.

7 Astronomy from Lagadha to the Siddhāntas

In this section we review the development of astronomy between two specific dates, roughly from 1300 BCE to 500 CE. Although this development is best understood by an examination of the Vedic and post-Vedic texts, note that not all scientific knowledge of those early times were committed

to writing or, if written down, has survived. There are gaps in the sequence of ideas and these were filled based on preconceived notions rather than a sound approach. New evidence of the past two decades has contradicted the old 19th-century model of the rise of the Indian civilization and the new, emerging paradigm has significant implications for the understanding of the development of astronomy in India.

Let R_s represent the distance between the earth and the sun, R_m be the distance between the earth and the moon, d_s be the diameter of the sun, d_m be the diameter of the moon, and d_e be the diameter of the earth. According to PB, $R_s < 1000\ d_e$, and we take that $R_s \approx 500d_e$.

It was further known that the moon and the sun are about 108 times their respective diameters from the earth. This could have been easily determined by taking a pole and removing it to a distance 108 times its height to confirm that its angular size was equal to that of the sun or the moon. Or, we can say that $R_s \approx 108d_s$ and $R_m \approx 108d_m$.

Considering a uniform speed of the sun and the moon and noting that the sun completes a circuit in 365.24 days and the moon 12 circuits in 354.37 days, we find that

$$R_m \approx \frac{354.37 \times 500}{365.24 \times 12}d_e$$

or $R_m \approx 40d_e$.

By using the relationship on relative sizes that $R_s \approx 108d_s \approx 500d_e$, we know that $d_s \approx 4.63 \times d_e$.

Assuming that the diameter of the earth was at some time in the pre-*Siddhāntic* period estimated to be about 900 yojanas, the distance to the moon was then about 36,000 yojanas and that to the sun about 450,000 yojanas. It also follows that the relative dimensions of the sun and the moon were taken to be in the ratio of 12.5 : 1. Knowing that the angular size of the sun and the moon is about 31.85 minutes, the size of the sun is then about 4,170 yojanas and that of the moon is about 334 yojanas.

A theory on the actual diameters of the sun, the moon, and the earth indicates a knowledge of eclipses. The RV 5.40 speaks of a prediction of the duration of a solar eclipse, so relative fixing of the diameters of the earth, the moon, and the sun should not come as a surprise.

Also note that the long periods of Jupiter and Saturn require that the sun be much closer to the earth than the midpoint to the heavens, or push

the distance of the heavens beyond the $1000d_e$ of PB and perhaps also make the distance of the sun somewhat less than $500d_e$. We do see these different modifications in the models from later periods.

The idea that the sun is roughly 500 or so earth diameters away from us is much more ancient than Ptolemy from where it had been assumed to have been borrowed by the Indians. This greater antiquity is in accordance with the ideas of van der Waerden, who ascribes a primitive epicycle theory to the Pythagoreans. But it is more likely that the epicycle theory is itself much older than the Pythagoreans and it is from this earlier source that the later Greek and Indian modifications to this theory emerged which explains why the Greek and the Indian models differ in crucial details.

Did the idea that $R_s \approx 500d_e$ originate at about the time of PB, that is from the second millennium BCE, or is it older? Since this notion is in conflict with the data on the periods of the outer planets, it should predate that knowledge. If it is accepted that the planet periods were known by the end of the third millennium BCE, then this knowledge must be assigned an even earlier epoch. Its appearance in PB, a book dealing primarily with ritual, must be explained as a remembrance of an old idea. We do know that PB repeats, almost verbatim, the Ṛgvedic account of a total solar eclipse.

It is certain that the synodic periods were first computed because the longest period, the 780 days of Mars, is not too much larger than twice the sun's period. With Mars as the furthest body in a primitive model, the sun's distance will have to be reduced to about 0.47 of the furthest point. In order to accommodate the stars, the sun will be brought even nearer. When the sidereal orbits of the planets were understood, sometime in the Vedic period, the space beyond the sun had to be taken to be vast enough to accommodate the orbits of Jupiter and Saturn. The non-circular motions of the planets would require further changes to the sizes of the orbits and these changes represent the continuing development of this phase of Indian astronomy.

The theory that $R_s \approx 500d_e$ was so strongly entrenched that it became the basis from which different Greek and later Indian models emerged. Ptolemy considers an R_s equal to $600d_e$ whereas Āryabhaṭa assumes it to be about $438d_e$. Thus the Greek and the later Indian modifications to the basic idea proceeded somewhat differently.

The ideas regarding the distance of the sun hardly changed until the modern times. The contradictions in the assumption that the luminaries move with uniform mean speed and the requirements imposed by the assumed

size of the solar system led to a gradual enlargement of the models of the universe from about twice that of the distance of the sun in *PB* to one 4.32×10^6 times the distance of the sun by the time of Āryabhaṭa. This inflationary model of the universe in *AA* makes a distinction between the distance of the sky (edge of the planetary system) and that of the stars which is taken to be a much smaller sixty times the distance of the sun. "Beyond the visible universe illuminated by the sun and limited by the sky is the infinite invisible universe" this is stated in a commentary on *AA* by Bhāskara I writing in 629 CE (Shukla, 1976). The *Purāṇic* literature, part of which is contemporaneous with Āryabhaṭa, reconciles the finite estimates of the visible universe with the old *Ṛgvedic* notion of an infinite universe by postulating the existence of an infinite number of universes.

The sizes of the planets

The ideas on planet sizes can be seen to evolve from those in the *Purāṇas* to the *Siddhāntas.* The *Purāṇas* confusingly combine two different theories, one related to the departure from the ecliptic by the moon and the other on the sidereal periods. The planets are listed in the correct sequence, supporting the view that the planet periods were known. The order of the angular sizes are correctly shown as Venus, Jupiter, Saturn, Mars, Mercury although the fractions stated are not accurate. Venus and Jupiter are taken to be $\frac{1}{16}$th and $\frac{1}{64}$th the size of the moon whereas the correct fractions are $\frac{1}{20}$ and $\frac{1}{40}$. Saturn and Mars were taken to be $\frac{1}{4}$th smaller than Jupiter and Mercury still smaller by the same fraction (VaP 53.66-67).

Table 3: The planet angular sizes in fractions of the size of the moon

Planet	correct size	Purāṇa	Aryabhaṭa
Mercury	$\frac{1}{120}$	$\frac{1}{112}$	$\frac{1}{15}$
Venus	$\frac{1}{20}$	$\frac{1}{16}$	$\frac{1}{5}$
Mars	$\frac{1}{100}$	$\frac{1}{84}$	$\frac{1}{25}$
Jupiter	$\frac{1}{40}$	$\frac{1}{64}$	$\frac{1}{10}$
Saturn	$\frac{1}{80}$	$\frac{1}{84}$	$\frac{1}{20}$

By the time of Āryabhaṭa the *relative* sizes of the planets were better

estimated (Table 3). But the angular sizes of the planets are too large by a factor of 4 excepting Mercury which is too large by a factor of 8. Overall, the *Purāna* figures are more accurate and it appears that Āryabhaṭa's overestimation by a factor of 4 may have been colored by his ideas on optics.

8   The two halves of the year

The *Brāhmaṇas* recognize that the speed of the sun varies with the seasons. The year-long rites of the *Brāhmaṇas* were organized with the summer solstice (*viṣuvant*) as the middle point. There were two years: the ritual one started with the winter solstice (*mahāvrata day*), and the civil one started with the spring equinox (*viṣuva*). Vedic rites had a correspondence with the different stages of the year and, therefore, astronomy played a very significant role. These rites counted the days upto the solstice and in the latter half of the year, and there is an asymmetry in the two counts. This is an astronomical parameter, which had hitherto escaped notice, that allows us to date the rites to no later than the second millennium BCE.

The *Aitareya Brāhmaṇa* 4.18 describes how the sun reaches the highest point on the day called viṣuvant and how it stays still for a total of 21 days with the viṣuvant being the middle day of this period. In the *Pañcaviṃśa Brāhmaṇa* (Chapters 24 and 25), several year-long rites are described where the viṣuvant day is preceded and followed by three-day periods. This suggests that the sun was now taken to be more or less still in the heavens for a total period of 7 days. So it was clearly understood that the shifting of the rising and the setting directions had an irregular motion.

ŚB 4.6.2 describes the rite of *gavām ayana*, the "sun's walk" or the "cows' walk." This is a rite which follows the motion of the sun, with its middle of the viṣuvant day.

The *Yajurveda* (38.20) says that the āhavanīya or the sky altar is four-cornered since the sun is four-cornered, meaning thereby that the motion of the sun is characterized by four cardinal points: the two solstices and the two equinoxes.

The year-long rites list a total of 180 days before the solstice and another 180 days following the solstice. Since this is reckoning by solar days, it is not clear stated how the remaining 4 or 5 days of the year were assigned. But this can be easily inferred.

Note that the two basic days in this count are the viṣuvant (summer solstice) and the mahāvrata day (winter solstice) which precedes it by 181 days in the above counts. Therefore, even though the count of the latter part of the year stops with an additional 180 days, it is clear that one needs another 4 or 5 days to reach the mahāvrata day in the winter. This establishes that the division of the year was in the two halves of 181 and 184 or 185 days.

Corroboration of this is suggested by evidence related to an altar design from the *Śatapatha Brāhmaṇa* (ŚB 8.6) which is shown in Figure 4. This altar represents the path of the sun around the earth. The middle point, which represents the earth and the atmosphere is at a slight offset to the centre. This fact, and the fact that the number of bricks in the outer ring are not symmetrically placed, shows that the four quarters of the year were not taken to be symmetric.

This inequality would have been easy to discover. The Indians used the reflection of the noon-sun in the water of a deep well to determine the solstice days.

If one assumes that the two halves of the year are directly in proportion to the brick counts of 14 and 15 in the two halves of the ring of the sun, this corresponds to day counts of 176 and 189. This division appears to have been for the two halves of the year with respect to the equinoxes if we note that the solstices divide the year into counts of 181 and 184.

The apparent motion of the sun is the greatest when the earth is at perihelion and the least when the earth is at aphelion. Currently, this speed is greatest in January. The interval between successive perihelia, the anomalistic year, is 365.25964 days which is 0.01845 days longer than the tropical year on which our calendar is based. In 2000 calendar years, the date of the perihelion advances almost 35 days; in 1000 years, it advances almost a half-year (175 days). This means that the perihelion movement has a cycle of about 20000 years.

In the first millennium BCE, the earth was at perihelion within the interval prior to the winter solstice. Thus during this period the half of the year from the summer solstice to the winter solstice would have been shorter than the half from the winter solstice to the summer solstice. This is just the opposite of what is described in the rites of the *Brāhmaṇas*.

It is interesting that the Greeks discovered the asymmetry in the quarters of the year about 400 BCE. Modern calculations show that at this time the four quarters of the year starting with the winter solstice were 90.4, 94.1,

92.3, and 88.6 days long. The period from the winter solstice to the summer solstice was then 184.5 days and the perihelion occurred in mid- to late October.

The count of about 181 days from the winter to the summer solstice would be true when the perihelion occurs before the summer solstice. This will require it to move earlier than mid- to late June and no earlier than mid- to late December. In other words, compared to 400 BCE, the minimum number of months prior to October is 4 and the maximum number of months is 10. This defines periods which are from 6850 years to 17150 years prior to 400 BCE.

These periods appear too early to be considered plausible and this may reflect the fact that the measurements in those times were not very accurate. Nevertheless, it means that the first millennium BCE for the rites of the *Brāhmaṇas* is absolutely impossible.

Since the *Śatapatha Brāhmaṇa* has lists of teachers that go through more than fifty generations, we know that the period of the Brāhmaṇas was a long one, perhaps a thousand years. To be as conservative as possible, one may consider the period 2000 - 1000 BCE as reasonable for these texts. The *Vedic Saṃhitās* are then assigned to the earlier fourth and third millennia BCE.

9   The origins of the idea of epicycles

More than a hundred years ago, Burgess (1860) saw the Indians as the originators of many of the notions that led to the Greek astronomical flowering. This view slowly lost support and then it was believed that Indian astronomy was essentially derivative and it owed all its basic ideas to the Babylonians and the Greeks. It was even claimed that there was no tradition of reliable observational astronomy in India.

Using statistical analysis of the parameters used in the many *Siddhāntas*, Billard showed that the *Siddhāntas* were based on precise observations and so the theory of no observational tradition in India was wrong. This conclusion is reinforced by the fact that the Vedic books are according to an astronomical plan.

Earlier, it was believed that the mahāyuga/kalpa figure of 4,320,000, which occurs in the *Siddhāntas*, was borrowed from the astronomy[12] of the Babylonian Berossos (c. 300 BCE). But it is more logical to see it derived

from the number 432,000 related to the number of syllables in the *Ṛgveda* that is mentioned in the much earlier *Śatapatha Brāhmaṇa* (ŚB 10.4.2).

The *Siddhāntic* astronomy has features which are unique to India and it represents an independent tradition. In the words of Thurston (1994):

> Not only did Āryabhaṭa believe that the earth rotates, but there are glimmerings in his system (and other similar Indian systems) of a possible underlying theory in which the earth (and the planets) orbits the sun, rather than the sun orbiting the earth... The significant evidence comes from the inner planets: the period of the śīghrocca is the time taken by the planet to orbit the sun.

A pure heliocentrism is to be found in the following statement in the *Viṣṇu Purāṇa* 2.8:

> The sun is stationed for all time, in the middle of the day... The rising and the setting of the sun being perpetually opposite to each other, people speak of the rising of the sun where they see it; and, where the sun disappears, there, to them, is his setting. Of the sun, which is always in one and the same place, there is neither setting nor rising.

It is not certain that Āryabhaṭa was the originator of the idea of the rotation of the earth. It appears that the rotation of the earth is inherent in the notion that the sun never sets that we find in the *Aitareya Brāhmaṇa* 2.7:

> The [sun] never really sets or rises. In that they think of him "He is setting," having reached the end of the day, he inverts himself; thus he makes evening below, day above. Again in that they think of him "He is rising in the morning," having reached the end of the night he inverts himself; thus he makes day below, night above. He never sets; indeed he never sets.

One way to visualize it is to see the universe as the hollow of a sphere so that the inversion of the sun now shines the light on the world above ours. But this is impossible since the sun does move across the sky during the day

and if the sun doesn't set or rise it doesn't move either. Clearly, the idea of "inversion" denotes nothing but a movement of the earth.

By examining early Vedic sources the stages of the development of the earliest astronomy become apparent. After the *Ṛgvedic* stage comes the period of the *Brāhmaṇas* in which we place Lagadha's astronomy. The third stage is early *Siddhāntic* and early *Purāṇic* astronomy.

These three stages are summarized below:

1. *Ṛgvedic astronomy (c. 4000? - 2000 BCE)* Motion of the sun and the moon, nakṣatras, planet periods. The start of this stage is a matter of surmise but we have clues such as Vedic myths which have been interpreted to indicate astronomical events of the fourth millennium BCE.

2. *Astronomy of the Brāhmaṇas (2000 - 1000 BCE)* Astronomy represented by means of geometric altars; non-uniform motion of the sun and the moon; intercalation for the lunar year; "strings of wind joined to the sun." The *Vedāṅga Jyotiṣa* of Lagadha must be seen as belonging to the latter part of this stage. The VJ text that has come down to us appears to be of a later era. Being the standard manual for determination of the Vedic rites, Lagadha's work must have served as a "living" text where the language got modified to a later form.

3. *Early Siddhāntic and early Purāṇic (1000 BCE - 500 CE)* Here our main sources are the *Śulbasūtras*, the *Mahābhārata*, the early *Purāṇas*, the *Sūrya Siddhānta* and other texts. Further development of the śīghrocca and mandocca cycles, the concepts of kalpa. According to tradition, there existed 18 early *Siddhāntas* composed by Sūrya, Pitāmaha, Vyāsa, Vasiṣṭha, Atri, Parāśara, Kaśyapa, Nārada, Garga, Marīci, Manu, Aṅgiras, Lomaśa (Romaka), Pauliśa, Cyavana, Yavana, Bhṛgu, and Śaunaka. Of these, summaries of five are now available in the book *Pañcasiddhāntikā* by Varāhamihira, and the *Sūryasiddhānta* has come down in a later, modified form.

It is significant that the first two stages and the beginning part of the third stage are well prior to the rise of mathematical astronomy in Babylonia and in Greece. The concepts of the śīghrocca and mandocca cycles indicate

that the motion of the planets was taken to be fundamentally around the sun, which, in turn, was taken to go around the earth.

The mandocca, in the case of the sun and the moon, is the apogee where the angular motion is the slowest and in the case of the other planets it is the aphelion point of the orbit. For the superior planets, the śīghrocca coincides with the mean place of the sun, and in the case of an inferior planet, it is an imaginary point moving around the earth with the same angular velocity as the angular velocity of the planet round the sun; its direction from the earth is always parallel to the line joining the sun and the inferior planet.

The mandocca point serves to slow down the motion from the apogee to the perigee and speed up the motion from the perigee to the apogee. It is a representation of the non-uniform motion of the body, and so it can be seen as a direct development of the idea of the non-uniform motion of the sun and the moon.

The śīghrocca maps the motion of the planet around the sun to the corresponding set of points around the earth. The sun, with its winds that hold the solar system together, is, in turn, taken to go around the earth.

The antecedents of this system can be seen in the earlier texts. ŚB 4.1.5.16 describes the sun as *puṣkaramādityo*, "the lotus of the sky." ŚB 8.7.3.10 says:

> The sun strings these worlds [the earth, the planets, the atmosphere] to himself on a thread. This thread is the same as the wind...

This suggests a central role to the sun in defining the motions of the planets and ideas such as these must have ultimately led to the theory of the śīghrocca and the mandocca cycles.

The theory that the sun was the "lotus" [the central point] of the sky and that it kept the worlds together by its "strings of wind" may have given rise to the heliocentric tradition in India. The offset of the sun's orbit evolved into the notion of mandocca and the motions of the planets around the sun were transferred to the earth's frame through the device of the śīghrocca.

The *Brāhmaṇas* consider non-circular motion of the sun and, by implication, of the moon and that the sun is taken to be about 500 earth diameters away from the earth. Analysis of *Ṛgvedic* astronomy has shown that planet periods had been determined. Logically, the next step would be to characterize the details of the departure from the circular motion for the planets. In VaP 53.71 it is stated that the planets move in retrograde (*vakra*) motion.

Although the extant *Sūrya Siddhānta* (SS) is a late book, it preserves old pre-*Siddhāntic* ideas on the motions of the planets:

Forms of time, of invisible shape, stationed in the zodiac (*bhagaṇa*), called the conjunction (*śīghrocca*), apsis (*mandocca*), and node (*pata*), are causes of the motion of the planets.

The planets, attached to these beings by cords of air, are drawn away by them, with the right and lift hand, forward and backward, according to nearness, toward their own place.

A wind, called provector (*pravaha*) impels them toward their own apices (*ucca*); being drawn away forward and backward, they proceed by a varying motion.

The so-called apex (*ucca*), when in the half-orbit in front of the planet, draws the planet forward; in like manner, when in the half-orbit behind the planet, it draws it backward.

When the planets, drawn away by their apices, move forward in their orbits, the amount of the motion so caused is called their excess (*dhana*); when they move backward, it is called their deficiency (*ṛṇa*). (SS 2.1-5)

The idea of the sizes was directly related to the deviation from the ecliptic. The motions were defined to be of eight different kinds:

Owing to the greatness of its orb, the sun is drawn away only a very little; the moon, by reason of the smallness of its orb, is drawn away much more;

Mars and the rest, on account of their small size, are, by the points of focus, called conjunction and apsis, drawn away very far, being caused to vacillate exceedingly.

Hence the excess and deficiency of these latter is very great, according to their rate of motion. Thus do the planets, attracted by those beings, move in the firmament, carried on by the wind.

The motion of the planets is of eight kinds: retrograde (*vakra*), somewhat retrograde (*anuvakra*), transverse (*kuṭila*), slow (*manda*),

very slow (*mandatara*), even (*sama*), very swift (*śīghratara*), and swift (*śīghra*).

Of these, the very swift, the swift, the slow, the very slow, and the even are forms of the motion called direct (*ṛju*). (SS 2.9-13)

The Early Siddhāntas

The development of astronomical ideas from the *Vedāṅga Jyotiṣa* onwards can also by studied from the information in the Jaina books, the *Mahābhārata* and the astronomical references in the general literature. For example, the *Arthaśāstra* uses a rule for telling time that is very similar to that in VJ.

The *Pañcasiddhāntikā* of Varāhamihira summarizes five early schools of *Siddhāntic* astronomy, namely Paitāmaha, Vāsiṣṭha, Romaka, Pauliśa, and Saura manly with regard to the calculation of eclipses.

Owing to the names Romaka and Pauliśa, it was assumed that the PS mostly represents Babylonian and Greek material. But such a supposition has no firm evidence to support to it. There also exists the possibility that an India-inspired astronomy could have travelled to the West before the *Siddhāntic* period.

The use of cycles was current during the time of the *Śatapatha Brāhmaṇa*. A modular arithmetic, fundamental to *Siddhāntic* astronomy, was in use in *Vedāṅga Jyotiṣa*. The 2,850 year luni-solar yuga of the *Romaka Siddhānta* (PS 1.15) is derived from the 95-year Yājñavalkya cycle of the *Śatapatha Brāhmaṇa*, as it is equal to 30×95.

Summarizing, the basic features of the *Siddhāntic* astronomy such as non-circular orbits of the sun and the moon and the specific notions of "ropes of wind" for the the planetary system were already present in the *Brāhmaṇas* and they appear in a more developed form in the primitive epicycle theory of the *Sūrya Siddhānta*. As the retrograde motions were recognized, the orbit sizes were adjusted and made smaller.

10   Pre-Siddhāntic Cosmology

Early texts consider light to be like a wind. Was any thought given to its speed? Given the nature of the analogy, one would expect that this speed was considered finite. The *Purāṇas* speak of the moving *jyotiścakra*, "the

circle of light." This analogy or that of the swift arrow let loose from the bow in these accounts leaves ambiguous whether the circle of light is the sun or its speeding rays.

We get a specific number that could refer to the speed of light in a late text by Sāyaṇa (c. 1315-1387), prime minister in the court of Emperors Bukka I of the Vijayanagar Empire and Vedic scholar. In his commentary on the fourth verse of the hymn 1.50 of the *Ṛgveda* on the sun, he says

> *tathā ca smaryate yojanānāṃ sahasre dve dve śate dve ca yojane ekena nimiṣārdhena kramamāṇa*

> Thus it is remembered: [O sun] you who traverse 2,202 *yojanas* in half a *nimeṣa*.

The same statement occurs in the commentary on the *Taittirīya Brāhmaṇa* by Bhaṭṭa Bhāskara (10th century?), where it is said to be an old *Purāṇic* tradition.

The figure could refer to the actual motion of the sun but, as we will see shortly, that is impossible. By examining parallels in the *Purāṇic* literature, we see it as an old tradition related to the speed of [sun]light.

The units of *yojana* and *nimeṣa* are well known. The usual meaning of yojana is about 9.1 miles as in the *Arthaśāstra* where it is defined as being equal to 8,000 *dhanu* or "bow," where each dhanu is taken to be about 6 feet. Āryabhaṭa, Brahmagupta and other astronomers used smaller yojanas but such exceptional usage was confined to the astronomers; we will see that the *Purāṇas* also use a non-standard measure of yojana. As a scholar of the Vedas and a non-astronomer, Sāyaṇa would be expected to use the "standard" *Arthaśāstra* units.

The measures of time are thus defined in the *Purāṇas*:

> 15 nimeṣa = 1 kāṣṭhā
>
> 30 kāṣṭhā = 1 kalā
>
> 30 kalā = 1 muhūrta
>
> 30 muhūrta = 1 day-and-night

A nimeṣa is therefore equal to $\frac{16}{75}$ seconds.

When this statement is converted into modern units, it does come very close to the correct figure of 186,000 miles per second!

Such an early knowledge of this number doesn't sound credible because the speed of light was determined only in 1675 by Roemer who looked at the difference in the times that light from Io, one of the moons of Jupiter, takes to reach the earth based on whether it is on the near side of Jupiter or the far side. Until then light was taken to travel with infinite velocity. There is no record of any optical experiments that could have been performed in India before the modern period to measure the speed of light.

Maybe Sāyaṇa's figure refers to the speed of the sun in its supposed orbit around the earth. But that places the orbit of the sun at a distance of over 2,550 million miles. The correct value is only 93 million miles and until the time of Roemer the distance to the sun used to be taken to be less than 4 million miles. The Indian astronomical texts place the sun only about half a million yojanas from the earth. We show that this figure is connected to *Purāṇic* cosmology and, therefore, it belongs, logically, to the period of pre-*Siddhāntic* astronomy.

Physical ideas in early literature

The philosophical schools of Sāṃkhya and Vaiśeṣika tell us about the old ideas on light. According to Sāṃkhya, light is one of the five fundamental "subtle" elements (*tanmātra*) out of which emerge the gross elements. The atomicity of these elements is not specifically mentioned and it appears that they were actually taken to be continuous.

On the other hand, Vaiśeṣika is an atomic theory of the physical world on the nonatomic ground of ether, space and time. The basic atoms are those of earth (*pṛthivī*), water (*āpas*), fire (*tejas*), and air (*vāyu*), that should not be confused with the ordinary meaning of these terms. These atoms are taken to form binary molecules that combine further to form larger molecules. Motion is defined in terms of the movement of the physical atoms and it appears that it is taken to be non-instantaneous.

Light rays are taken to be a stream of high velocity of tejas atoms. The particles of light can exhibit different characteristics depending on the speed and the arrangements of the tejas atoms.

Although there existed several traditions of astronomy in India, only the mathematical astronomy of the *Siddhāntas* has been properly examined.

Some of the information of the non-*Siddhāntic* astronomical systems is preserved in the *Purāṇas*.

The *Purāṇic* astronomy is cryptic, and since the *Purāṇas* are encyclopaedic texts, with several layers of writing, presumably by different authors, there are inconsistencies in the material. Sometimes, speculative and the empirical ideas are so intertwined that without care the material can appear meaningless. The *Purāṇic* geography is quite fanciful and this finds parallels in its astronomy as well.

We can begin the process of understanding *Purāṇic* astronomy by considering its main features, such as the size of the solar system and the motion of the sun. But before we do so, we will speak briefly of the notions in the *Siddhāntas*.

Āryabhaṭa in his *Āryabhaṭīya (AA)* deals with the question of the size of the universe. He defines a *yojana* to be 8,000 *nṛ*, where a *nṛ* is the height of a man; this makes his yojana (y_a) approximately 7.5 miles. Or $y_s \approx \frac{6}{5} y_a$, where y_s is the standard *Arthaśāstra* yojana. AA 1.6 states that the orbit of the sun is 2,887,666.8 *yojanas* and that of the sky is 12,474,720,576,000 *yojanas*.

There is no mention by Āryabhaṭa of a speed of light. But the range of light particles is taken to be finite, so it must have been assumed that the particles in the "observational universe" do not penetrate to the regions beyond the "orbit of the sky." This must have been seen in the analogy of the gravitational pull of the matter just as other particles fall back on the earth after reaching a certain height.

The orbit of the sky is 4.32×10^6 greater than the orbit of the sun. It is clear that this enlargement was inspired by cosmological ideas.

The diameters of the earth, the sun, and the moon are taken to be 1,050, 4,410 and 315 yojanas, respectively. Furthermore, *AA* 1.6 implies the distance to the sun, R_s, to be 459,585 yojanas, and that to the moon, R_m, as 34,377 yojanas. These distances are in the correct proportion related to their assumed sizes given that the distances are approximately 108 times the corresponding diameters.

Converted to the standard *Arthaśāstra* units, the diameters of the earth and the sun are about 875 and 3,675 yojanas, and the distance to the sun is around 0.383 million yojanas.

Purāṇic cosmology

The *Purāṇic* material is closer to the knowledge of the Vedic times. Here we specifically consider the *Vāyu Purāṇa* (VaP), *Viṣṇu Purāṇa* (ViP), and *Matsya Purāṇa* (MP). VaP and ViP are generally believed to be amongst the earliest *Purāṇas* and at least 1,500 years old. Their astronomy is prior to the *Siddhāntic* astronomy of Āryabhaṭa and his successors.

The *Purāṇas* instruct through myths and this mythmaking can be seen in their approach to astronomy also. For example, they speak of seven underground worlds below the orbital plane of the planets and of seven "continents" encircling the earth. One has to take care to separate this imagery, that parallels the conception of the seven centres of the human's psycho-somatic body, from the underlying cosmology of the *Purāṇas* that is their primary concern in their *jyotiṣa* chapters. The idea of seven regions of the universe is present in the *Ṛgveda* 1.22.16-21 where the sun's stride is described as *saptadhāman*, or taking place in seven regions.

The different *Purāṇas* appear to reproduce the same cosmological material. There are some minor differences in figures that may be a result of wrong copying by scribes who did not understand the material. Here we mainly follow ViP.

ViP 2.8 describes the sun to be 9,000 yojanas in length and to be connected by an axle that is 15.7×10^6 yojanas long to the Mānasa mountain and another axle 45,500 yojanas long connected to the pole star. The distance of 15.7 million yojanas between the earth and the sun is much greater than the distance of 0.38 or 0.4375 million yojanas that we find in the *Siddhāntas* and other early books. This greater distance is stated without a corresponding change in the diameter of the sun.

Elsewhere, in VaP 50, it is stated that the sun covers 3.15 million yojanas in a muhūrta. This means that the distance covered in a day are 94.5 million yojanas. MP 124 gives the same figure. This is in agreement with the view that the sun is 15.7 million yojanas away from the earth. The specific speed given here, translates to 116.67 yojanas per half-nimeṣa.

The size of the universe is described in two different ways, through the "island-continents" and through heavenly bodies. The geography of the *Purāṇas* describes a central continent, Jambu, surrounded by alternating bands of ocean and land. The seven island-continents of Jambu, Plakṣa, Śālmala, Kuśa, Kraunca, Śāka, and Puṣkara are encompassed, successively,

by seven oceans; and each ocean and continent is, respectively, of twice the extent of that which precedes it. The universe is seen as a sphere of size 500 million yojanas.

The continents are imaginary regions and they should not be confused with the continents on the earth. Only certain part of the innermost planet, Jambu, that deal with India have parallels with real geography.

The inner continent is taken to be 16,000 yojanas as the base of the world axis. In opposition to the interpretation by earlier commentators, who took the increase in dimension by a factor of two is only across the seven "continents," we take it to apply to the "oceans" as well. At the end of the seven island-continents is a region that is twice the preceding region. Further on, is the Lokāloka mountain, 10,000 yojanas in breadth, that marks the end of our universe.

Assume that the size of the Jambu is J yojana, then the size of the universe is:

$$U = J(1+2+2^2+2^3+2^4+2^5+2^6+2^7+2^8+2^9+2^{10}+2^{11}+2^{12}+2^{13}+2^{14})+20,000 \tag{1}$$

Or,

$$U = 32,767J + 20,000 \; yojanas \tag{2}$$

If U is 500 million yojanas, then J should be about 15,260 yojanas. The round figure of 16,000 is mentioned as the width of the base of the Meru, the world axis, at the surface of the earth. This appears to support our interpretation.

Note that the whole description of the *Purāṇic* cosmology had been thought to be inconsistent because an erroneous interpretation of the increase in the sizes of the "continents" had been used.

When considered in juxtaposition with the preceding numbers, the geography of concentric continents is a representation of the plane of the earth's rotation, with each new continent as the orbit of the next "planet".

The planetary model in the *Purāṇas* is different from that in the *Siddhāntas*. Here the moon as well as the planets are in orbits higher than the sun. Originally, this supposition for the moon may have represented the fact that it goes higher than the sun in its orbit. Given that the moon's inclination is 5° to the ecliptic, its declination can be 28.5° compared to the sun's maximum

declination of $\pm23.5°$. This "higher" position must have been, at some stage, represented literally by a higher orbit. To make sense with the observational reality, it became necessary for the moon is taken to be twice as large as the sun. That this is a jumbling up of two different theories is clear from the fact that the planets are listed in the correct sequence determined by their sidereal periods.

The distances of the planetary orbits beyond the sun are as follows:

Table 4: From the earth to the Pole-star

Interval I	yojanas
Earth to Sun	15,700,000
Sun to Moon	100,000
Moon to Asterisms	100,000
Asterisms to Mercury	200,000
Mercury to Venus	200,000
Venus to Mars	200,000
Mars to Jupiter	200,000
Jupiter to Saturn	200,000
Saturn to Ursa Major	100,000
Ursa Major to Pole-star	100,000
Sub-total	17,100,000

Further spheres are postulated beyond the pole-star. These are the Maharloka, the Janaloka, the Tapoloka, and the Satyaloka. Their distances are as follows:

Table 5: From Pole-star to Satyaloka

Interval II	yojanas
Pole-star to Maharloka	10,000,000
Maharloka to Janaloka	20,000,000
Janaloka to Tapoloka	40,000,000
Tapoloka to Satyaloka	120,000,000
Grand Total	207,100,000

Since the last figure is the distance from the earth, the total diameter

of the universe is 414.2 million yojanas, not including the dimensions of the various heavenly bodies and *lokas*. The inclusion of these may be expected to bring this calculation in line with the figure of 500 million yojanas mentioned earlier.

Beyond the universe lies the limitless *pradhāna* that has within it countless other universes.

Purāṇic cosmology views the universe as going through cycles of creation and destruction of 8.64 billion years. The consideration of a universe of enormous size must have been inspired by a supposition of enormous age.

Reconciling Purāṇic and Standard Yojanas

It is clear that the *Purāṇic* yojana (y_p) are different from the *Arthaśāstra* yojana (y_s). To find the conversion factor, we equate the distances to the sun.

$$0.4375 \times 10^6 \ y_s = 15.7 \times 10^6 \ y_p \tag{3}$$

In other words,

$$1 \ y_s \approx 36 \ y_p \tag{4}$$

The diameter of the earth should now be about $875 \times 36 \approx 31,500 \ y_p$. Perhaps, this was taken to be 32,000 y_p, twice the size of Meru. This understanding is confirmed by the statements in the *Purāṇas*. For example, MP 126 says that the size of Bhāratavarṣa (India) is 9,000 y_p, which is roughly correct.

We conclude that the kernel of the *Purāṇic* system is consistent with the *Siddhāntas*. The misunderstanding of it arose because attention was not paid to their different units of distance.

Speed of the sun

Now that we have a *Purāṇic* context, the statement that the sun has the speed of 4,404 yojanas per nimeṣa can be examined.

We cannot be absolutely certain what yojanas did Sāyaṇa have in mind: standard, or *Purāṇic*. But either way it is clear from the summary of *Purāṇic* cosmology that this speed could not be the speed of the sun. At the distance

of 15.7 million yojanas, the sun's speed is only 121.78 yojanas (y_p) per half-nimeṣa. Or if we use the the figure from VaP, it is 116.67. Converted into the standard yojanas, this number is only 3.24 y_s per half-nimeṣa.

Sāyaṇa's speed is about 18 times greater than the supposed speed of the sun in y_p and 2×18^2 greater than the speed in y_s. So either way, a larger number with a definite relationship to the actual speed of the sun was chosen for the speed of light.

The *Purāṇic* size of the universe is 13 to 16 times greater than the orbit of the sun, not counting the actual sizes of the various heavenly bodies. Perhaps, the size was taken to be 18 times greater than the sun's orbit. It seems reasonable to assume, then, that if the radius of the universe was taken to be about 282 million yojanas, a speed was postulated for light so that it could circle the farthest path in the universe within one day. This was the physical principle at the basis of the *Purāṇic* cosmology.

We have seen that the astronomical numbers in the *Purāṇas* are much more consistent amongst themselves, and with the generally accepted sizes of the solar orbit, than has been hitherto assumed. The *Purāṇic* geography must not be taken literally.

We have also shown that the Sāyaṇa's figure of 2,202 yojanas per half-nimeṣa is consistent with *Purāṇic* cosmology where the size of "our universe" is a function of the speed of light. This size represents the space that can be spanned by light in one day.

It is quite certain that the figure for speed was obtained either by this argument or it was obtained by taking the postulated speed of the sun in the *Purāṇas* and multiplying that by 18, or by multiplying the speed in standard yojanas by 2×18^2. We do know that 18 is a sacred number in the *Purāṇas*, and the fact that multiplication with this special number gave a figure that was in accord with the spanning of light in the universe in one day must have given it a special significance.

Is it possible that the number 2,202 arose because of a mistake of multiplication by 18 rather than a corresponding division (by 36) to reduce the sun speed to standard yojanas? The answer to that must be "no" because such a mistake is too egregious. Furthermore, Sāyaṇa's own brother Mādhava was a distinguished astronomer and the incorrectness of this figure for the accepted speed of the sun would have been obvious to him.

If Sāyaṇa's figure was derived from a postulated size of the universe, how was that huge size, so central to all Indian thought, arrived at? A

possible explanation is that the physical size of the universe was taken to parallel the estimates of its age. These age-estimates were made larger and larger to postulate a time when the periods of all the heavenly bodies were synchronized. The great numbers in the *Purāṇas* suggest that the concepts of mahāyuga and kalpa must have had an old pedigree and they can be viewed as generalizations of the notion of yuga.

The speed of light was taken to be 2×18^2 greater than the speed of the sun in standard yojanas so that light can travel the entire postulated size of the universe in one day. It is a lucky chance that the final number turned out to be exactly equal to the true speed. This speed of light must be considered the most astonishing "blind hit" in the history of science! But it is consistent with *Purāṇic* model of the cosmos and it is, in most likelihood, a pre-Āryabhaṭa figure.

11   The Later Siddhāntic Period

This period begins with Āryabhaṭa (born 476 CE) who established two systems by his works *Āryabhaṭīya* and *Āryabhaṭasiddhānta*. Of these, the first has exercised great influence, especially in South India, while the second is lost but elements of it are known through quotations in other texts and in criticism. These two constitute the *Āryapakṣa* and the *Ārdharātrikapakṣa*, respectively. The *Sūryasiddhānta*, which has come down to us in a later recension, is based primarily according to *Ārdharātrikapakṣa*.

The *Brāhma-sphuṭa-siddhānta* of Brahmagupta (born 598 CE) has been extremely influential in north and west India and in the Arabic world, through its translation called *Sindhind*. A rival to the Āryabhaṭa systems, this is also called the *Brahmapakṣa*.

The later improvements to these *Siddhāntas* required *bīja*-corrections. A later text by Lalla (8th-9th cent.) is based on the *Ārdharātrikapakṣa* but it also incorporates ideas from the *Brahmapakṣa*.

The *Siddhānta-Śiromaṇi* of Bhāskara II (c.1150) is the most comprehensive of the Indian *Siddhāntas*. It is based on the Brahmapakṣa. The epicyclic-eccentric theories are further developed to account for the motions of the planets.

Nīlakaṇṭha Somayāji (1444-1550) corrects the *Āryapakṣa* constants in his *Siddhānta-darpaṇa* and *Tantrasaṃgraha*. In a recent review (Ramasubra-

manian et al, 1994), it has been argued that Nīlakaṇṭha's revision of the planetary model for the interior planets Mercury and Venus led to a better equation of the center for "these planets than was available either in the earlier Indian works or in the Islamic or European traditions of astronomy till the work of Kepler, which was to come more than a hundred years later."

12 Concluding Remarks

This essay summarizes the essential points of the emerging new understanding of the rise and development of Indian astronomy. We have traced the gradual development of many ideas of astronomy in the pre-*Siddhāntic* period, but we are not in a position to completely discount all outside influences especially because considerable interaction existed in the ancient world and ideas must have travelled in several directions.

Further evidence in support of the flow of ideas from India to the West has recently become clear. Recent studies of Celtic material indicate that a calendar similar to the 5-year yuga of VJ with two intercalary months was current amongst the Druids (Ellis, 1994:230-231). The connections between the Vedic and the Druidic material must predate the rise of the astronomy in Mesopotamia, because otherwise the more direct Mesopotamian theories would have won out against the complex Vedic system. The Druids also appear to have counted in months of 27 days similar to the conjoining of the moon with the nakṣatras of Vedic astronomy. This supports the idea of transmission from India into Europe. This idea is further supported by a new analysis of a *Ṛgvedic* hymn on Vena (Kak, 1998c) which suggests that the seed ideas of the Venus mythologies of the Mesopotamians, the Greeks, and the later *Purāṇic* period are all present in the Vedic texts.

A figure from the neolithic/chalcolithic period of Indian art (5000 BCE ?) (Kak, 1998a) appears to be the prototype of the "Gilgamesh" or "hero" motif with a god or goddess holding back two beasts on either side. The beasts are without their front ends, so clearly the depiction is symbolic. David Napier (1986) has argued for a transmission of Indian motifs into Greece in the second millennium BCE. As another example consider the Gundestrup cauldron, found in Denmark a hundred years ago. This silver bowl has been dated to around the middle of the 2nd century BCE. The iconography is strikingly Indic as clear from the elephant (totally out of context in Europe)

with the goddess and the yogic figure (Taylor, 1992). The unicorn figure of European mythology appears to be based on the Indian conception of the unicorn seen in the many fine representations of it in Harappan art and also its celebration in the Vedic and Purāṇic texts as ekaśṛṅga.

According to Seidenberg's analysis (Seidenberg, 1962, 1978) Indian geometry and mathematics predate Babylonian and Greek mathematics. It is likely that the cultural processes that were responsible for the spread of Indian mathematics and art were also responsible for the spread of Indian astronomy during the pre-*Siddhāntic* period. Doubtless, there existed transmission of Western (Babylonian and Greek) ideas to India as well.

The most important conclusion of the new findings is that there existed a much greater traffic of ideas in all directions in the ancient world than has hitherto been supposed.

Abbreviations

AA   Aitareya Āraṇyaka
AB   Aitareya Brāhmaṇa
ABA   Āryabhaṭīya of Āryabhaṭa
ASS   Āpastamba Śulbasūtra
AV   Atharvaveda
BSS   Baudhāyana Śulbasūtra
BU   Bṛhadāraṇyaka Upaniṣad
CU   Chāndogya Upaniṣad
KB   Kauṣītaki Brahmaṇa
MP   Matsya Purāṇa
PB   Pañcaviṃśa Brahmaṇa
PS   Pañcasiddhāntikā
RV   Ṛgveda
ŚB   Śatapatha Brāhmaṇa
SS   Sūrya Siddhānta
ŚU   Śvetāśvatara Upaniṣad
TB   Taittirīya Brāhmaṇa
TS   Taittirīya Saṃhitā
VaP   Vāyu Purāṇa
ViP   Viṣṇu Purāṇa
VJ   Vedāṅga Jyotiṣa

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12.1 Figure captions

Figure 1. The falcon altar which represented the days in the year

Figure 2. The traditional representation of the nakṣatras

Figure 3. The Indian zodaic along with the signs for the sun, five planets, the moon and its ascending and descending nodes

Figure 4. The asymmetric orbit of the sun around the earth