2
Ancient astronomy and its characteristics

In the post-vedic period the scope of astronomy was widened. Astronomy outgrew its original purpose of providing a calendar to serve the needs of the vedic priests and was no longer confined to the study of the Sun and Moon. The study of the five planets was also included within its scope and it began to be studied as a science for its own sake.

- K.S.Shukla (p.14)

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"Mishra Yantra" in the Jantar Mantar Observatory at Delhi built by Jai Singh in 1724

2.1 MAIN CHARACTERISTICS AND ACHIEVEMENTS OF ANCIENT INDIAN ASTRONOMY IN HISTORICAL PERSPECTIVE

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INTRODUCTION

Ancient Indian astronomy may be classified into two main categories: (1) the vedic astronomy and (2) the post vedic astronomy. The vedic astronomy is the astronomy of the vedic period i.e. the astronomy found in the vedic *saṃhitās* and *brāhmaṇas* and allied literature. The principal avocation of the people in the vedic times being the performance of the vedic sacrifices at the times prescribed by the *śāstras*, it was necessary to have accurate knowledge of the science of time so that the times prescribed for performing the various vedic sacrifices could be correctly predicted well in advance. Astronomy in those times, therefore, was essentially the science of time-determination. It centred round the Sun and Moon and its aim was to study the natural divisions of time caused by the motion of the Sun and Moon, such as days, months, seasons and years, special attention being paid to the study of the times of occurrence of new moons, full moons, equinoxes and solstices.

VEDIC ASTRONOMY

The *Ṛgveda* (1.52.11; 10.90.14), which is believed to be the earliest of the *Vedas*, describes the universe as infinite and made up of the Earth, the atmosphere and the sky. According to the *Taittiriya-saṃhitā (7.5.23), fire* rests in the Earth, the air in the atmosphere, the Sun in the sky and the Moon in the company of the *nakṣatras* (zodiacal stargroups). The *Ṛgveda* (1.105.10; 4.50.4; 10.123.1; also see *Śatapatha-brāhmaṇa*, 4.2.1) refers to the five planets as gods and mentions Bṛhaspati[1] (Jupiter) and Vena (Venus) by name[2]. It also mentions the thirty-four lights which, in all probability, are the Sun, the Moon, the five planets and the twenty-seven *nakṣatras (Ṛgveda*, 10.55.3).

The *Ṛgveda* (8.58.2; 1.95.3; 8.58.2; 1.164.14) describes the Sun as the sole lightgiver of the universe, the cause of the seasons, the controller and lord of the world (*Aitareya-brāhmaṇa* 2.7 describes sun as the cause of wind). The Moon is called *Sūrya-ras'mi* i.e. one which shines by sunlight (*Taittirīya-saṃhitā* 3.4.7.1). The Moon's path was divided into 27 equal parts, because the Moon took about 27 1/3 days in traversing it. These parts as well as the stars lying in their neighbourhood were called *nakṣatras* and given the names *Kṛttikā* etc. When the constellation called Abhijit (Lyra) was included in the list of

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nakṣatras, their number was stated as 28. Of these *nakṣatras, tiṣya* (or *Puṣya*), Aghā (or Maghā), Arjunī (or Phalgunī), Citrā and Revatī are mentioned in the *Ṛgveda* (5.54.13; 10.64.8.; 10.85.13; 4.51.2; 4.51.4). The *Taittirīya-saṃhitā* (4.4.10.1-3; see also *Atharva-saṃhitā*, 19.7.2-5; *Kāṭhaka-saṃhitā*, 39.13; *Maitrāyaṇī-saṃhitā*, 2.13.20) and the *Taittirīya-brāhmaṇa* (1.5.1; 3.1.1-2; 3.1.4-5) give the names of the 28 *nakṣatras* along with those of the deities supposed to preside over them. The *Śatapatha-brāhmaṇa* (10.5.4.5) gives the names of the 27 *nakṣatras* as well as those of the 27 *upa-nakṣatras*. The *nakṣatras* were categorized into male, female and neuter as well as into singular, dual and plural. It seems that the prominent stars of each *nakṣatra* were counted and classified in order of their brilliance.

Some constellations other than the *nakṣatras* were also known. The *Ṛgveda* (1.24.10; 10.14.11; 10.63.10) mentions the *Ṛkṣas* or Bears (the Great Bear and the Little Bear), the two divine Dogs (Canis Major and Canis Minor), and the heavenly Boat (Argo Navis). The Great Bear was also known as *Saptarṣi* (the constellation of the seven sages) and was mentioned by this name in the *Śatapatha-brāhmaṇa*[3] (2.1.2.4) and the *Tāṇḍya-brāhmaṇa* (1.5.5). The golden Boat (Argo Navis) is mentioned in the *Atharva-veda* (5.4.4; 6.95.2) also. The *Aitareya-brāhmaṇa* (13.9) mentions the constellation of *Mṛga* or Deer (Orion) and the star *Mṛgavyādha* (Sirius), and narrates an interesting story regarding them.

Besides the Sun, the Moon, and the *nakṣatras*, mention is also made of some of the other heavenly bodies and heavenly phenomena. For example, *ulkā* (meteors) and *dhūmaketu* (comets) have been mentioned in the *Atharvaveda*(19.9.8-9, 19.9.10). Eclipses have been mentioned and described as caused by Svarbhānu or Rāhu. The *Ṛgveda* (5.40.5-9) describes an eclipse of the Sun as brought about by Svarbhānu. The *Tāṇḍya-brāhmaṇa* (4.5.2; 4.6.13: 6.6.8; 14.11.14-15; 23.16.2) mentions eclipses as many as five times. Eclipses have been mentioned in the *Atharva-veda* (19.9.10), the *Gopatha-brāhmaṇa* (8.19) and the *Śatapatha-brāhmaṇa* (5.3.2.2) also.

The day, called *vāsara* or *ahan* in the vedic literature, was reckoned from sunrise to sunrise. The variability of its length was known. The *Ṛgveda* (8.48.7) invoking Somarāja says: "O Somarāja, prolong thou our lives just as the Sun increases the length of the days." Six days were taken to form a *ṣaḍaha* (six-day week); 5 *ṣaḍahas*, a month; and 12 months, a year. As to the names of the six days of a *ṣaḍaha*, there is no reference in the vedic literature. However, the six-day week was later replaced by the present seven day week (*saptāha*) which had attained popularity and was in general use at the time of composition of the *Atharva-jyautiṣa*.

The duration of daylight, reckoned from sunrise to sunset, was divided into two parts called *pūrvāhṇa* (forenoon) and *aparāhṇa* (afternoon), three parts called *pūrvāhṇa*, *madhyāhna*, and *aparāhṇa*, four parts called *pūrvāhṇa,madhyāhna, aparāhṇa* and *sāyāhna,*[4] and five parts called *prātaḥ, saṅgava, madhyāhna, aparāhṇa* and *sāyāhna* (*Śatapatha-brāhmaṇa*, 2.2.3.9). The days and nights were also divided into 15 parts each, and these parts were called *muhūrta*. The *muhūrtas* falling during the days of the light and dark fortnights as well as those falling during the nights of the light and dark fortnights were given specific names (*Taittirīya-brā hmaṇa* 3.10.1.1-3). The fifteen days and nights of the light fortnight as well as the fifteen days and nights of the dark fortnight were also assigned special names, (*Taittirīya-brāhmaṇa* 3.10.1.1-3; 3.10.10.2).

On the analogy of a civil day, a lunar day was also sometimes reckoned from one moonrise to the next and the name *tithi* was given to it (*Aitareya-brāhmaṇa*, 32.10). The use of the term *tithi* in the sense in which it is used now occurs in the *Vedāṅga-jyautiṣa*. (*Ārca-jyautiṣa*, 20,21,31; *Yājuṣa-jyautiṣa* 20-23 , 25, 26). It does not occur in the vedic *saṁhitās* and *brāhmaṇas*, but there are reasons to believe that *tithis* were used even in those times.

The year, generally called by the terms *samā*, *vatsara* and *hāyana* in the vedic literature, was seasonal or tropical and was measured from one winter solstice to the next, but in due course it was used in the sense of a sidereal year. In the early stages, therefore, the names of the seasons were used as synonyms of a year. The *Kauṣītaki-brāhmaṇa* (19.3) gives an interesting account of how the year-long sacrifice was commenced at one winter solstice and continued until the next winter solstice: "On the new moon of Māgha he (the Sun) rests, being about to turn northwards. They (the priests) also rest, being about to sacrifice with the introductory Atirātra. Thus, for the first time, they (the priests) obtain him (the Sun). On him they lay hold with the Caturviṃśa rite; that is why the laying hold rite has that name. He (the Sun) goes north for six months; him they (the priests) follow with six day rites in continuation. Having gone north for six months, he (the Sun) stands still, being about to turn southwards. They (the priests) also rest, being about to sacrifice with the Viṣuvanta (summer solstice) day. Thus, for the second time, they obtain him (the Sun). He (the Sun) goes south for six months; they (the priests) follow him with six day rites in reverse order. Having gone south for six months, he (the Sun) stands still, being about to turn north; and they (the priests) also rest, being about to sacrifice with the Mahāvrata day. Thus they (the priests) obtain him (the Sun) for the third time".

The *Taittirīya-brāhmaṇa* (3.9.22) calls the year "the day of the gods", the gods being supposed to reside at the north pole.

The year was supposed to consist of six seasons and each season of two (solar) months. The relation between the seasons and months was as shown in the following Table:

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Vedic seasons (*Taitt.- saṃhitā*; 4.3.2;5.6.23;7.5.14) and months (*Taittirīya-saṃhitā*, 1.4.14;4.4.11)

Seasons	Months
1. Vasanta (Spring)	1. Madhu 2. Mādhava
2. Grīṣma (Summer)	3. Śukra 4. Śuci
3. Varṣā (Rainy)	5. Nabhas 6. Nabhasya
4. Śarada (Autumn)	7. Iṣa 8. Ūrja
5. Hemanta (Winter)	9. Sahas 10. Sahasya
6. Śiśira (Chilly Winter)	11. Tapas 12. Tapasya

Two (solar) months commencing with the winter solstice were called Śiśira; the next two months, Vasanta; and so on. Sometimes Śiśira and Hemanta were treated as one season and the number of seasons was taken as five (*Aitareya-brāhmaṇa*, 1.1; *Taittirīya-brāhmaṇa*, 2.7.10).

The lunar or synodic month was measured from full moon to full moon or from new moon to new moon (*Taittirīya-saṃhitā*, 7.5.6.1) as is the case even now. The names Caitra etc. based on the *nakṣatras* in which the Moon becomes full do not occur in the early *saṃhitās* and *brāhmaṇas* but such terms as *phalgunī-pūrṇamāsī*, *citrā-pūrṇamāsī*, etc. are found to occur in the *Taittirīya-saṃhitā* (7.4.8). They occur in the *Saṅkhāyana* and *Tāṇḍya brāhmaṇas*, the *Vedāṅga-jyautiṣa* and the *kalpa-sūtras*[5]. Twelve lunar months constituted a lunar year. In order to preserve correspondence between lunar and solar years, intercalary months were inserted at regular intervals. Mention of the intercalary month is made in the *Ṛgveda* (1.25.8), but how it was arrived at and where in the scheme of months it was introduced in that time is not known. The *Vedāṅga-jyautiṣa* prescribes insertion of an intercalary month after every 30 lunar months (*Yājuṣa-jyautiṣa*, 37). Thus a year sometimes contained 12 lunar months and sometimes 13 lunar months. The *Taittirīya-saṃhitā* (5.6.7) refers to 12 as well as 13 months of a year and calls the thirteenth (intercalary) month by the names *saṃsarpa* and *aṃhaspati* (1.4.14). The Vājasaneyi-saṃhitā (7.30;22.31) calls the intercalary month on one occasion by the name *aṃhasaspati* and on another by the name *malimluca* (22.30). In later works the synodic month with two *saṃkrāntis* is called *aṃhaspati*, the synodic month without any *saṃkrānti*, occurring before it, is called *saṃsarpa*, and the synodic month without any *saṃkrānti* occurring after it is called *adhimāsa* (intercalary month, *Tantrasaṃgraha* i.8)

Originally the lunar (or synodic) months Caitra etc. were named after the *nakṣatras* occupied by the Moon at the time of full moon. But in due course they were linked with the solar months. Thus the lunar month (reckoned from one new moon to the next) in which the Sun entered the sign Aries was called Caitra or Madhu; that in which the Sun entered the sign Taurus was called Vaiśākha or Mādhava; and so on. The lunar month in which the Sun did not enter a new sign was treated as an intercalary month.

Periods bigger than a year are also met with in the vedic literature. They were called *yuga*. One such yuga consisted of 5 solar years. The five constituent years of this *yuga* were called saṃvatsara, parivatsara, idāvatsara, anuvatsara and idvatsara. The *Ṛgveda* (7.103.7-8) mentions two of these, viz. *saṃvatsara and parivatsara*. The *Taittirīya-saṃhitā* (5.5.7.1-3), the *Vājasaneyi-saṃhitā* (27.45;30.16) and the *Taittirīya-brāhmaṇa* (3.4.11; 3.10.4), mention all the five names, with some alteration. The *Taittirīya-saṃhitā* calls them saṃvatsara, parivatsara, idāvatsara, iduvatsara and vatsara; the *Vājasaneyi-saṃhitā*, saṃvatsara, parivatsara, idāvatsara, idvatsara and vatsara and the *Taittirīya-brāhmaṇa*, saṃvatsara, parivatsara, idāvatsara, idvatsara and vatsara respectively. The names Kṛta, Tretā, Dvāpara and Kali which are used in later astronomy as the names of longer *yugas* are also used in the vedic literature to indicate different grades, each inferior to the preceeding. But Dvāpara, as a unit of time, is found to be used in the *Gopatha-brāhmaṇa* (1.1.28).

The earliest work which exclusively deals with vedic astronomy is the *Vedāṅga-jyautiṣa*. It is available in two recensions, *Ārca-jyautiṣa* and *Yajuṣa-jyautiṣa*. Both the recensions are essentially the same; a majority of the verses occurring in them being identical. The date of this work is controversal, but the situation of the Sun and Moon at the beginning of the *yuga* of five years mentioned in this work, according to T.S.Kuppanna Sastry, existed about B.C. 1150 or about B.C. 1370, according as the first point of *nakṣatra Śraviṣṭhā* stated there means the first point of the *nakṣatra*-segment *Śraviṣṭhā* or the *nakṣatra*-group *Śraviṣṭhā* (Sastry 1984,3,p.13). This work defines *jyotiṣa* (astronomy) as the science of time-determination and deals with months, years, muhūrtas, rising *nakṣatras*, new moons, full moons, days, seasons and solstices. It states rules to determine the *nakṣatra* occupied by the Sun or Moon, the time of the Sun's or Moon's entry into a *nakṣatra*, the duration of the Sun's or Moon's stay in a *nakṣatra*, the number of new moons or full moons that occurred since the beginning of the *yuga*, the position of the Sun or Moon at the end of a new moon or full moon day or *tithi*, and similar other things. It gives also the measure of the water-clock, which was used to measure time, and tells when an intercalary month was to be added or a *tithi* was to be omitted. In short, it gives all necessary information needed by the vedic priest to predict times for the vedic sacrifices and other religious observances.

The five-year *yuga* of the *Vedāṅga-jyautiṣa* contained 61 civil, 62 lunar and 67 sidereal months. The year consisted of 366 civil days which were reckoned from sunrise to sunrise. After every thirty lunar months one intercalary month was inserted to bring about concordance between solar and lunar years. Similarly to equate the number of *tithis* and civil days in the *yuga* of five solar years, the thirty full moon *tithis* which ended between sunrise and midday were omitted. There were six seasons of equal duration in every year, each new season beginning after every 61 days. Besides *tithis* and *nakṣatras*, the *yoga* called Vyatipāta was also in use.

The five-year *yuga* was taken to commence at the winter solstice occurring at the beginning of the first *tithi* of the light half of the month Māgha. Since the Sun and Moon were supposed to occupy the same position at the beginning of each subsequent *yuga* and all happenings in one *yuga* were supposed to be repeated in the subsequent *yugas* in the same way, the calendar constructed on the basis of the *Vedāṅga-jyautiṣa* was meant to serve for a long time.

The *Vedāṅga-jyautiṣa* astronomy suffered from two main defects. Since there are actually 1826.2819 days in a *yuga* of five solar (sidereal) years and not 1830 as stated in the *Vedāṅga-jyautiṣa*, therefore if one *yuga* was taken to commence at a winter solstice the next one commenced about four days later than the next winter solstice and not at the next winter solstice. Similarly, since there are actually 1830.8961 days in a period of 62 lunar months and not 1830 as stated in the *Vedāṅga-jyautiṣa*, therefore there was a deficit of about one *tithi* in the *yuga* of five solar years. These discrepancies must have been rectified but we do not know when and how this was done.

There is one more work on *jyotiṣa* belonging to the later vedic period It is known as *Atharva-jyautiṣa*. This work describes the *muhūrtas*, *tithis*, *karaṇas*, *nakṣatras* and week days and prescribes the deeds that should be performed in them. The names of the lords of the week days stated in this work viz. Āditya (Sun), Soma (Moon), Bhauma (the son of Earth), Bṛhaspati, Bhārgava (the son of Bhṛgu) and Śanaiścara (the slow-moving planet) are undoubtedly of Indian origin and must have been in use in India from very early times[6].

POST-VEDIC ASTRONOMY

In the post-vedic period the scope of astronomy was widened. Astronomy outgrew its original purpose of providing a calendar to serve the needs of the vedic priests and was no longer confined to the study of the Sun and Moon. The study of the five planets was also included within its scope and it began to be studied as a science for its own sake. While further improvement of luni-solar astronomy continued, astronomers now devoted their attention towards the study of the planets which were known in the vedic period and were now well known. In the initial stages their synodic motion was studied. Astronomers noted the times of their first and last visibility, the duration of their appearance and disappearance, the distance from the Sun at the time of their first and last visibility, the times of their retrograde motion, the distances from the Sun at the times of their becoming retrograde and reretrograde, and so on. Study was also made of their motion in the various zodiacal signs under different velocities called *gatis* (viz. very fast, fast, mean, slow, very slow, retrograde, very retrograde and reretrograde) and along their varying paths called *vīthis*. The synodic

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motion of a planet was called *grahacāra* and it was elaborately recorded in the astrological works particularly the *saṁhitās*, the earlier works of the Jainas, the earlier *purāṇas*, and the earlier *siddhāntas* such as the *Vaśiṣṭha-siddhānta* and the *Pauliśa-siddhānta*. These records were analysed and in the beginning crude methods or empirical formulae were evolved to get the longitudes of the planets. Later on a systematic theory was established which gave rise to the astronomy of the later *siddhāntas*.

Of the astronomical works written in this period, the *Vaśiṣṭha-siddhānta* is the earliest. *Vaśiṣṭha* and his teachings have been mentioned in the *Yavana-jātaka* of *Sphujidhvaja Yavaneśvara* which was written about 269 A.D. From the summary of the *Vaśiṣṭha-siddhānta* in the *Pañca-siddhāntikā* of Varāhamihira we learn that this work made improvement in the luni-solar astronomy and besides describing the synodic motion of the planets gave empirical formulae for knowing the positions of the planets Jupiter and Saturn. The *Vedāṅga-jyautiṣa* sidereal year of 366 days was replaced by Vaśiṣṭha by the sidereal year of 365.25 days (Neugebauer & Pingree 1971, ii.1). To obtain the Sun's longitude use was made of a Table giving the Sun's motion in the various zodiacal signs (Neugebauer & Pingree 1971, ii.1). The Moon's longitude was obtained in a special way. One anomalistic revolution of the Moon was divided into 248 equal parts called *pada*, each *pada* corresponding to 1/9 of a day. The period of the Moon's one anomalistic revolution was called *gati*, and that of 110 anomalistic revolutions *ghana*. It was assumed that the Moon moved through 111 revolutions -3/4 signs +2 mins. in one *ghana* and 1 rev. (185-1/10) mins. in one *gati*. First the Moon's anomalistic motion since the epoch was obtained in terms of *ghanas*, *gatis* and *padas*, and then the Moon's motion corresponding to this was obtained and added to the Moon's position at the epoch (Neugebauer & Pingree 1971, ii.2-6). To obtain the Moon's motion for p *padas* in the first half of its anomalistic revolution, the formula used was:

Moon's motion for p *padas* in the first half of its

anomalistic revolution = p degrees+[1094+5 (p-1)]p/63 mins.

And to obtain the Moon's motion for p *padas* in the second half of its anomalistic revolution, the formula used was:

Moon's motion for p *padas* in the second half of its

anomalistic revolution = p degrees+[2414-5 (p-1)]p/63 mins (Neugebauer & Pingree 1971,ii.6).

In the case of Jupiter, starting from the point of zero longitude, its sidereal revolution was divided into 391 equal parts, called *padas*, divided into three unequal segments, the first segment containing 180 *padas*, the second containing the next 195 *padas*, and the third containing the remaining 16 *padas*. When Jupiter was at the end of p *padas* of the first segment, its longitude λ_1 (p) was given by the formula:

$$\lambda_1 (p) = p (1456 - p)/24 \text{ mins.};$$

when at the end of q *padas* of the second segment, its longitude λ_2 (q) was given by the formula:

$$\lambda_2 (q) = \lambda_1 (180)+q (1165+q)/24 \text{ mins.};$$

and when at the end of r *padas* of the third segment, its longitude λ_3 (r) was given by the formula:

$$\lambda_3 (r) = \lambda_2 (195)+r (1486 - r)/24 \text{ mins}$$
(Neugebauer & Pingree 1971,xvii.9-10).

Similarly, in the case of Saturn, starting with the point of zero longitude, its sidereal revolution was divided into 256 equal parts, called *padas*, divided into three segments, the first segment consisting of 30 *padas*, the second consisting of the next 127 *padas* and the third consisting of the remaining 99 *padas*. When Saturn was at the end of p *padas* of the first segment, its longitude $\lambda_1(p)$ was given by the formula:

$$\lambda_1 (p) = p (2416+2p)/27 \text{ mins.};$$

when at the end of q *padas* of the second segment, its longitude λ_2 (q) was given by the formula:

$$\lambda_2 (q) = \lambda_1 (30)+q (2519 - 2q)/27 \text{ mins.};$$

and when at the end of r *padas* of the third segment, its longitude λ_3 (r) was given by the formula:

$$\lambda_3 (r) = \lambda_2 (127)+r (2037+2r)/27 \text{ mins}$$
(Neugebauer & Pingree 1971,xvii.16-17).

The above formulae show that at the time of their formulation the longitude of Jupiter's apogee was 165.7 degrees and that of Saturn's apogee 220.8 degrees approximately. In the case of the other three planets no such empirical formulae could be devised and recourse was taken to their motion from one heliacal rising to the next.

A notable feature of the *Vaśiṣṭha-siddhānta* is that it makes use of signs which were not used up to the Vedāṅga period, and reckons the longitudes of the planets from the first point of Aries.

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Further progress in astronomy is recorded in the *Pauliśa-siddhānta*. Varāhamihira has described the *Vaśiṣṭha-siddhānta* as inaccurate but the *Pauliśa-siddhānta* as accurate (Neugebauer & Pingree 1971,i.4).

The length of the sidereal year, according to the *Pauliśa-siddhānta*, is 365 days 6 hours 12 seconds (Neugebauer & Pingree 1971, iii.1). This value is better than 365 days 6 hours given by *Vaśiṣṭha*. *Vaśiṣṭha* used approximate rules to get the longitudes of the Sun and Moon. Pauliśa, in the case of the Sun, first obtains the mean longitude and then applies correction for the equation of the centre to get the true longitude. He states a Table giving the equation of the centre for the Sun for the intervals of 30 degrees starting from the point lying 20 degrees behind the point of zero longitude (Neugebauer & Pingree 1971, iii.1-3).

According to *Vaśiṣṭha*, the Moon's motion on the first day of its anomalistic revolution when it is least is 702'; thereafter it increases and reaches the maximum value (Neugebauer & Pingree 1971, iii.4). of 879'. According to the Tables prepared by the followers of Āryabhaṭa the minimum value of the Moon's motion on the first day of its anomalistic revolution is 722' and the maximum daily motion near its perigee[7] is 859', the former being 20' greater and the latter 20' less than the values given by *Vaśiṣṭha*. The values given by *Vaśiṣṭha* are evidently gross. Pauliśa applied two corrections one after the other to the Moon's motion given by *Vaśiṣṭha* but the rules summarized by Varāhamihira have not been understood so far (Neugebauer & Pingree 1971, iii.5.8).

Pauliśa calls the Moon's ascending node by the name "Rāhu's head", and takes 6795 days as the period of its sidereal revolution. The corresponding periods, according to Āryabhaṭa, Ptolemy and modern astronomers, are 6794.7 days, 6796.5 days, 6793 days respectively. The value given by Pauliśa is evidently closer to that of Āryabhaṭa.

The *Paulis'a-siddhānta* deals also with the motion of the planets, the visibility of the Moon and the eclipses. In the treatment of the planetary motion, it gives the distances from the Sun at which the planets rise or set heliacally and become retrograde and reretrograde. The following Table gives the synodic periods of the planets according to Vaśiṣṭha, Paulis'a, Āryabhaṭa, Ptolemy and modern astronomers:

SYNODIC PERIODS IN DAYS

Planet	Vaśiṣṭha	Pauliśa	Āryabhaṭa	Ptolemy	Modern
Mars	779.955	779.978	779.92	779.943	779.936
Mercury	115.879	115.875	115.87	115.879	115.877
Jupiter	398.889	398.885	398.889	398.886	398.884
Venus	583.909	583.906	583.89	584.000	583.921
Saturn	378.1	378.110	378.08	378.093	378.092

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Pauliśa's treatment of the visibility of the planets and the eclipses is very approximate.

A notable feature of the *Pauliśa-siddhānta* is the mention of the *viṣuva* and *ṣaḍaśītimukha saṃkrāntis*.

The *Pauliśa-siddhānta* was followed by the *Romaka-siddhānta*. This *siddhānta* bears the impact of the teachings of the Greek astronomers. The day is reckoned from sunset at Yavanapura (Alexandria in Egypt). To obtain the mean positions of the Sun and Moon a luni-solar *yuga* of 2850 years was defined and astronomical parameters were stated for this period (Neugebauer & Pingree 1971, i.15-16). The length of the year used in this work was 365.246 days (Neugebauer & Pingree 1971, viii.1). which is exactly the same as given by the Greek astronomers Hipparchus and Ptolemy. It was really the value of the tropical year but it was used in the *Romaka-siddhānta* as the value of the sidereal year. As the value of the sidereal year it was worse than that given by *Vasiṣṭha*. The longitude of the Sun's apogee stated in the *Romaka-Siddhānta* (Neugebauer & Pingree 1971, viii.2) was 75^0. This was the same as given by Hipparchus when reckoned from the point of zero longitude of Indian astronomy. The period of a sidereal revolution of the Moon's ascending node according to the *Romaka-Siddhānta* was 6796.29 days. This is also almost the same as the value 6796.5 days given by Ptolemy. The maximum equation of the centre for the Sun adopted in the *Romaka-siddhānta* (Neugebauer & Pingree 1971, viii.3,6). was $2^0 23' 23''$ and that for the Moon $4^0 56'$. The corresponding values given by Ptolemy are $2^0 23'$ and $5^0 1'$ respectively. Romaka's treatment of the solar eclipse was similar to that found in the later works on Indian astronomy but the rules given are very approximate (Neugebauer & Pingree 1971, viii.). It may be that Varāhamihira himself has condensed them. The *Romaka-siddhānta* did not deal with the planets.

Perfection in astronomy was brought about by Āryabhaṭa who carried out his observations at Kusumapura (modern Patna). He was successful in giving quite accurate astronomical parameters and better methods of calculation. Roger Billard (Billard 1971, pp.81-83) has analysed these parameters and has shown that they were based on observations made around 512 A.D.

Āryabhaṭa wrote two works on astronomy, in one reckoning the day from midnight to midnight and in the other from sunrise to sunrise, in the former dealing with the subject in detail and in the latter briefly and concisely. Both the works proved to be epoch-making and earned a great name for the author. The larger work was popular in northern India and was summarised by Brahmagupta in his *Khaṇḍakhādyaka* which was carried to Arabia and translated into Arabic. This work has been in use by the pañcāṅgamakers in Kashmir till recently. The *Sūrya-siddhānta* which was summarised by Varāhamihira and declared by him as the most accurate work was simply a redaction of the larger work of Āryabhaṭa. The smaller work of Āryabhaṭa called the Āryabhaṭīya was studied in south India from the seventh century to the end of the nineteenth century. This work was also translated into Arabic, by Abu'l Hasan al-Ahwāzī.

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Āryabhaṭa's astronomy is based on three fundamental hypotheses viz.

1 That the mean planets revolve in geocentric circular orbits

2 That the true planets move in epicycles or in eccentrics

3 That all planets have equal linear motion in their respective orbits.

Āryabhaṭa's epicyclic theory differs in some respects from that of the Greeks. In Āryabhaṭa's theory there is no use of the hypotenuse-proportion in finding the equation of the centre. Moreover, unlike the epicycles of the Greek astronomers which remain the same in size at all places, Āryabhata's epicycles vary in size from place to place.

The main achievements of Āryabhaṭa are:

1 His astronomical parameters which were well known for yielding accurate results

2 His theory of the rotation of the Earth which was described by him as spherical like the bulb of the kadamba flower

3 The introduction of sines by him

4 His value of $\pi = 3.1416$

5 Fixation of the Sun's greatest declination at 24^0 and the Moon's greatest celestial latitude at $4^0 30'$. These values were adopted by all later Indian astronomers.

6 Integral solution of the indeterminate equation of the first degree viz. $ax+c = b\ y$, a, b and c being constants.

The pattern set by the works of Āryabhaṭa was followed by all later astronomers. The works written by later astronomers differ either in the presentation of the subject matter, or in the astronomical constants which were revised from time to time on the basis of observation, or in the methods of calculation which were improved from time to time. A few new corrections which were not known in the time of Āryabhaṭa were discovered and used by later astronomers. Thus Mañjula (also called Muñjāla) discovered the lunar correction called "evection" and Bhāskara II another lunar correction called "variation".

According to Āryabhaṭa the Sun, the Moon, and the planets were last in conjunction in zero longitude at sunrise at Laṅkā[8] on Friday, February 18, B.C. 3102. This was chosen by him as the epoch of zero longitude to calculate the longitudes of the planets. The period from one such epoch to the next, according to him, is 10,80,000 years. This he has defined as the duration of a quarter *yuga*. Likewise the period of 43,20,000 years is called a yuga. At the beginning and end of this *yuga* the Moon's apogee and ascending node too are supposed to be in conjunction with the Sun, Moon and the planets at the point of zero longitude. The revolution-numbers of the planets stated by Āryabhaṭa are for this *yuga*. The astronomical parameters and the rules stated by Āryabhaṭa are sufficient to solve all problems of Indian astronomy. The main problems dealt with by Āryabhaṭa and other later astronomers are the determination of the elements of the Indian pañcāṅga, calculation and graphical representation of the eclipses of the Sun and Moon, rising and setting of the Moon and the planets, the Moon's phases and the elevation of the Moon's horns and their graphical representation, and the conjunction of the planets and stars.

The ancient Indian astronomers did not possess the telescope. They made their observations with the naked eye using suitable devices for measuring angles. Their astronomy therefore remained confined to the study of the Sun, Moon and the planets.

NOTES

1 According to the Taittirīya-brāhmaṇa 3.1.1, "Jupiter when born was first visible in the nakṣatra Tiṣya (Puṣya)".

2 Other planets are not mentioned by name in the early vedic literature. But Śani (Saturn), Rāhu (Moon's ascending node) and Ketu (Moon's descending node) are mentioned in the Maitrāyaṇī-upaniṣad, 7.6

3 According to Śatapatha-brāhmaṇa, 2.1.2,4, the Great Bear was originally called Ṛkṣa but later the name Saptarṣi was given to it:

4 Of these names the first three occur in Ṛgveda,5.76.3; and sāyam (evening) occurs in Ṛgveda,8.2.20; 10.146.3,40. Kauṭilya (Arthaśāstra, 1.19), Dakṣa and Kātyāyana divided the day and night each into eight parts.

5 Māgha is mentioned in Sāṅkhāyana-brāhmaṇa (= Kauṣītaki- brāhmaṇa) 19.3;Phālguna in Tāṇḍya-brāhmaṇa, 5.9.7-12; and Śrāvaṇa, Māgha and Pauṣa in Ārca-jyautiṣa, 5,6,32 and 34 and Yājuṣa-jyautiṣa, 5,6,and 7; and Mārgaśīrṣa and Śrāvaṇa in Āśvalāyana-gṛhyasūtra, 2.3.1. and 3.5.2. respectively.

6 As regards the origin of the week-days, see Kāne,P.V. (1974) under references.

7 Vide Candravākyāni see Kuppanna Sastri & Sarma (1962) under references. For Candrasāraṇī see Sūrya-candra-sāraṇī. Ms. No. 1657 of the Akhila Bharatīya Sanskrit Parishad, Lucknow.

8 Laṅkā is the hypothetical place on the equator where the meridian of Ujjain intersects it.

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Yājuṣa-jyautiṣa - see Vedāṅga-jyautiṣa

DISCUSSION

L.C.Jain : Could you comment on whether the Jaina Astronomy (*Sūrya Prajñapti, Candra Prajñapti* or *Tiloyapannatti*) was motivated by *Vedāṅga Jyotiṣa* or originated independently?

K.S.Shukla : It was motivated by *Vedāṅga Jyotiṣa*.

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