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SURVEY OF STUDIES IN EUROPEAN LANGUAGES

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The beginnings of the study in European languages of ancient Indian astronomy can hardly be fixed with any degree of certainty. Indian astronomy appears to have reached Europe through Arabic astronomical literature during the eleventh-thirteenth century. In this transmission Spain played a crucial part. The starting point was the preparation of the Arabic version, *Az-Zij* as-*Sindhind* (*c.* 770), of one of the Indian *siddhāntas,* possibly the *Brāhmasphuṭasiddhānta* of Brahmagupta. This work, through revisions and refinements by subsequent authors such as al-Fazāri, Ya'qūb ibn Ṭāriq, al-Adamī, al-Khwārizmī, al-Hasan ibn Misbāh, an-Nairīzī, al-Majriṭī, as-Saffār and others, exerted considerable influence first among the Eastern Arabs and subsequently among the Western Arabs of Spain.[1] Maslama al-Majriṭī (fl. 1000) of Cordova edited al-Khwārizmī's astronomical tables which were translated into Latin by Adelard of Bath (*c.* 1142).[2] Lynn Thorndike published and translated an anonymous fifteenth century Latin MS Ashmole 191 II, in which computations were made for the geographical latitude of Newminster, England of the year 1428, using astronomical parameters and tables (trigonometrical sine table for $R=150$) characteristic of Hindu astronomy.[3] Thus, with the revival of learning in Latin Europe, particularly during the active period of translation from Arabic into Latin, certain Hindu astronomical elements and tradition inevitably passed into Western Europe.

SEVENTEENTH CENTURY BEGINNING

Direct study of Indian astronomy on the basis of Sanskrit manuscripts started towards the end of the seventeenth century when M. de la Loubére, French ambassador in Siam brought to Paris in 1687 a portion of a manuscript containing rules for the computation of longitudes of the Sun and the Moon. The manuscript was referred to the celebrated astronomer John Dominique Cassini, then director of the Paris observatory. The interpretation of the manuscript which did not contain any example nor any commentary proved a difficult task and called for, as Bailly put it, all the skill of the great astronomer to extract the correct astronomical elements.[4] In 1691, Cassini communicated the results of his investigations for publication in La Loubére's *Relation de Siam,* which were reprinted eight years later in the *Mémoires* of the French Royal Academy.[5]

The Siamese manuscript opened with rules for the computation of *ahargaṇa* or the number of civil days elapsed from the beginning of an era up to the date on which the mean longitude of the Sun (or the Moon) was desired. From the use of the fraction $\frac{11}{703}$ as the ratio of omitted lunar days to the total number of lunar days for the epoch, Cassini calculated the length of the synodic month as 29d 12h 44m

2.39s (703 lunar months=20,760 days). He further established the equivalence of 228 solar months (19 years) with 235 lunar months, implying that the Metonic cycle was known to the compilers of such astronomical rules. From another calculation of the era of 292207 days during which the Sun underwent 800 revolutions Cassini calculated the sidereal year length as 365d 6h 12m 36s, agreeing with the Pauliśa value of the year. The eclipse calculations suggested to him a place called 'Narsinga' (lat. 17°22'N) in the Godavari district in Orissa. Other findings included the period of revolution of the Moon's apsis as 3232 days, the Sun's equation of the centre (largest) as 2°12′ and the Moon's 4°56′. By comparing these elements with those of the *Pauliśa-siddhānta* in Varāhamihira's *Pañcasiddhāntikā,* as summarized by al-Bīrūnī in his *India,* James Burgess suggested that the Siamese manuscript was based in all probability on the *Pauliśa-siddhānta.*[6]

PROGRESS IN THE EIGHTEENTH CENTURY : LE GENTIL TO HUNTER

Cassini's work marked the recrudescence of an interest in ancient Indian astronomy among astronomers as well as scholarly circles in Europe. Early in the 18th century T. S. Bayer, in an appendix to his history of the imperial Graeco-Bactrians, furnished some information about Hindu astronomy, such as the Sanskrit and Tamilian names of planets, days of the week, months, and the twelve signs of the zodiac.[7] This brief notice assumed some importance as it was accompanied by a note by Leonard Euler on the length of the Hindu year of 365d 6h 12m 30s. About this time Beschi, in his Tamil Grammar, gave an account of calendar making in Tamil countries and also published a Tamil astronomical work under the title *Tiruchabei Kanidam.*

Le Gentil and Bailly

If the notices of Bayer and Beschi went almost unheeded M. Le Gentil's lengthy account of Hindu astronomy in the *Histoire de l'Academie Royal des Science* and in the *Mémoires* stimulated a fresh interest in the subject. Le Gentil's work on Brāhmaṇa astronomy was undertaken in strange circumstances. He was a trained observational astronomer, having received his early training at the hands of Delisle at the Collége Royal and Jacques Cassini, Cassini de Thury and Maraldi at the Paris Observatory. During the international expeditions for observing the transits of Venus in 1761 and 1769 he was deputed to India to observe the transits, important for an accurate determination of the solar parallax, but being unlucky to observe the phenome na he spent a good part of his stay in India in his researches on Brāhmaṇa astronomy.[8] He obtained his information on various astronomical tables and rules from calendar-makers in and around Pondicheri. Some of these tables were taken from the *Laghu-Āryasiddhānta,* a text then extensively used in the Madras Presidency. He dealt in detail with the methods of computing eclipses in accordance with the 'Vakyam process', developed originally for the year A.D. 499 but adapted to A.D. 1413. In these computations, the revolution of the Moon's node was taken to be 6792.36 days and the equation of the Sun's centre 5°1′. Other features of his study included the names of 27 *nakṣatras* and the identification of the principal stars or star groups associated with each of them, the relationship between planetary names and weekdays in which Śukravāra served as the beginning. Le Gentil's method of studying ancient and medieval astronomy by collecting information from calendar-makers and other practical astronomers who memorized various tables, rules and relied upon mnemonic devices and reconstructing from them correct astronomical elements and procedures was also followed by Warren; and their tables and materials have in the present century lent themselves to useful and interesting analysis.

The threads of investigations of Cassini and Le Gentil were then taken up by another capable French astronomer M. Jean Sylvain Bailly (1736-1793) whose *Traité de l'Astronomie Indienne et Orientale* served as a classic work on Hindu astronomy for many years to come. Bailly had not only the advantage of previous studies by his two distinguished compatriots, but had also the opportunity of consulting two Sanskrit manuscripts which had found their way to Paris. The first was the *Pañcāṅga Śiromaṇi* sent by Father Patouillet from India to astronomer M. Joseph de Lisle in 1750 and the second procured by the Jesuit Father Xavier du Champ in Pondicheri and sent to de Lisle via Father Gaubil in China in 1760. The provenance of the Xavier manuscript was at first supposed to be Krishnapuram, but Bailly suggested it to be Narsapur or Masulipatnam. He also associated the Patouillet MS with Narsapur, but was more inclined to relate it to Benares having the same meridian as Narasimhapur whose location again was questionable.[9]

The Xavier manuscript gave the epoch from March 10, 1491 and yielded constants good for the epoch A.D. 499 (Āryabhaṭa). The equations of the Sun and the Moon agreed with those contained in the *Sūrya-siddhānta*. Bailly calculated the lunar eclipse of July 29, 1730, the longitudes of Jupiter and Mercury for the same date and the solar eclipse of July 1731 on the basis of the tables and rules given in the manuscript and found the agreement to be good. For the Patouillet manuscript he computed the epoch to be A.D. 1569, although some of the elements conformed to A.D. 1656. The text gave the year length as 365d 6h 12m 30s, the greatest equations of centre for the Sun and the Moon as 2°10′34″ and 5°2′26″ respectively and tables of anomalies for every degree. The earth's diameter was computed as 1600 *yojanas*, and planetary distances were derived from their proportionality to their respective revolution numbers in the *yuga* by assuming the linear velocity of each planet to be the same. Bailly believed in the high antiquity of Hindu astronomy, was struck by the elegance and simplicity of its methods and rules, and expressed the view that astronomy had originated in India and was later on transmitted to the Chaldeans and the Greeks.[10] Bailly's work immediately attracted the scholarly attention of European astronomical and mathematical circles. Pierre Simon Laplace, for example, showed that the Hindu value of 12°13′13″ as the apparent and mean annual motion of Saturn at the beginning of the Kali Yuga (3101 B.C.) computed from their tables, agreed closely with the value of 12°13′14″ determined according to modern methods.[11] John Playfair of the Edinburg University published a long review of Bailly's studies with appreciative comments inviting more intensive work on the subject of Hindu astronomy.[12] Although he later on entertained doubts about the high antiquity of Indian astronomy as asserted by Bailly he freely acknowledged the impact of these early studies in following terms: "When the astronomical tables of India first became known in Europe the extraordinary light which they appeared to cast on the history and antiquity of the East made everywhere a great impression; and men engaged with eagerness in a study promising that mixture of historical and scientific research, which is, of all others the most attractive."[13] He advocated a systematic search for Sanskrit mathematical and astronomical works, all manner of descriptions and drawings of astronomical buildings (observatories) and instruments found in India, and actual observation of the skies in the company of Indian astronomers versed in their own system.

Samuel Davis on the Sūrya-Siddhānta and Jupiter's Cycle

These ideas and problems were already agitating the minds of other scholars. In India the Asiatic Society was recently founded (1784) precisely for carrying on researches of this kind into the antiquities, literature, history, sciences, arts, crafts and manufactures of the peoples of Asia in general and of India in particular. Shortly after the publication of Bailly's *Traité de l'Astronomie,* Samuel Davis in England procured, through Robert Chambers, a copy of the *Sūrya-siddhānta* with a good commentary. From the commentary he learnt of the existence of a large number of Sanskrit astronomical texts, e.g. the *Brahmasiddhānta* of the *Viṣṇudharmottarapurāṇa,* the *Paulastya-, Soma-, Vaśiṣṭha-, Ārya-, Romaka-, Parāśara-,* and *Ārṣa-siddhānta, Grahalāghava, Sākalya Saṃhitā, Siddhāntarahasya, Makaranda-sāraṇī,* and a few others. He carried out a detailed analysis of the text, giving translations of a large number of rules, in his study published in the *Asiatick Researches,* Vol. II., which included the concept of *yuga, kalpa* and other divisions of time,—*Kali, Dvāpara, Tretā* and *Satya,* revolutions executed by each planet in a *Mahāyuga* of 4,320,000 years, the canon of sines, the model of eccentric circle for converting mean longitudes of planets into true longitudes. He noted variations in planetary motions in various texts and observed that discrepancies between textual calculations and actual observations were corrected from time to time by the method of *bīja* corrections. "Accordingly, Āryabhaṭa, Brahmagupta and others", he stated, "having observed the heavens, formed rules on the principles of former shastras; but which differed from each other in proportion to the disagreements, which they severally observed, of the planets with respect to their computed places."[14]

The canon of sines, of which Davis gave the tables in sines and versed sines with respect to radius equal to 3438', was needed, he clarified, for the computation of the equation of the mean to the true anomaly. The eccentric-epicyclic geometrical models were pressed into service in Hindu astronomy 'to account for the apparent unequal motion of the planets, which they suppose to move in their respective orbits through equal distances in equal times'. The whole computational procedure was clearly described with the help of eccentric circle diagrams for solar inequality and eccentric-epicyclic model for other planets.

With regard to the value of 24° as the obliquity of the ecliptic, Davis recalled Lagrange's work suggesting the slow variation of this constant with time and expressed his view that this value true for around 2050 B.C. probably resulted from actual observation. Previously Bailly had also traversed the same ground and concluded that the Brāhmaṇas had determined it by observation about 4300 B.C. Davis also converted the Moon's mean distance in 51,570 *yojanas* from the Earth and arrived at 220,184 geographical miles or 64½ Earth-radius, somewhat wide of the mark from the modern value (226,000 miles at perigee and 252,000 miles at apogee). Davis' researches on the *Sūrya-siddhānta* proved extremely useful to later investigators, e.g. Burgess, and James Burgess did not exaggerate much when he characterized his 'On the astronomical computations of the Hindus' as 'a model of what such an essay ought to be'.[15]

Davis exhibited similar analytical approach in dealing with the subject of the twelve year cycle of Jupiter, which appeared in the third volume of the *Asiatick Researches* in 1792. This work was stimulated by an erroneous conclusion of William Marsden that Bṛhaspati's year coincided with the ordinary year.[16] Davis utilized materials from the *Āryabhaṭīya*, Varāhamihira, *Siddhānta-śiromaṇi* and *Jyotistattva*. In India a Jupiter's cycle of sixty years was widely followed. In this cycle the length of Jupiter's year is measured by the time taken by this planet to travel through one sign of the zodiac, which is 361d 0h 38m or with the *bīja* correction 361d 0h 50m. This value nearly agrees with the solar year. A cycle of sixty such years during which the planet undergoes five whole revolutions was adopted as a measure of time. A twelve-year cycle of Jupiter, that is, the time of one sidereal revolution of the planet was also adopted. Davis treated at some length of the sixty year cycle discussing rules given in the *Ārya-siddhānta* and the *Sūrya-siddhānta* for the computation of the planet's position in signs at any given date. He also gave the name of each individual year in this cycle, e.g. 1. Vijaya, 2. Jaya, 3. Manmatha,...60. Nandana.[17]

William Jones On The Hindu Zodiac

The zodiac and the question of its antiquity attracted the attention of the noted orientalist William Jones who argued that it was an indigenous development.[18] Montucla, the celebrated French historian of mathematics expressed the view that the two divisions of the zodiac, one in twentyseven lunar mansions resembling the Arab *manāzils* and the other in twelve signs of the zodiac to mark the passage of the Sun through the celestial sphere, were possibly transmitted to India through Arab intermediaries. Jones tried to show 'that the Indian zodiac was not borrowed mediately or directly from the Arabs or Greeks, and since the solar division of it in India is the same in substance with that used in Greece, we may reasonably conclude that both Greeks and Hindus received it from an older nation'. Jones' arguments were based on information obtained from Brāhmaṇa astronomers and also from Śrīpati's *Ratnamālā* containing the names of twelve signs beginning with Meṣa and ending with Mīna and describing each sign, e.g. the ram, bull, crab, lion and scorpion representing five animals bearing these names, the pair showing a damsel playing on a *vīṇā* and a youth wielding a mace, the virgin standing on a boat in water holding in one hand a lamp and an ear of corn in the other, Tulā representing a balance held by a weigher, and so on. A diagram showing twelve signs in an outer circle, nine planets (including Râhu and Ketu) in an inner circle and Mount Meru with four cardinal directions in the centre was appended. On the basis of the same *Ratnamālā* Jones listed and described twenty-seven *nakṣatras* plus Abhijit, equivalent to Arab *manāzils;* these were headed by Aśvinī and terminated by Revatī. Comparing the members of the two systems and the number of stars associated with them,

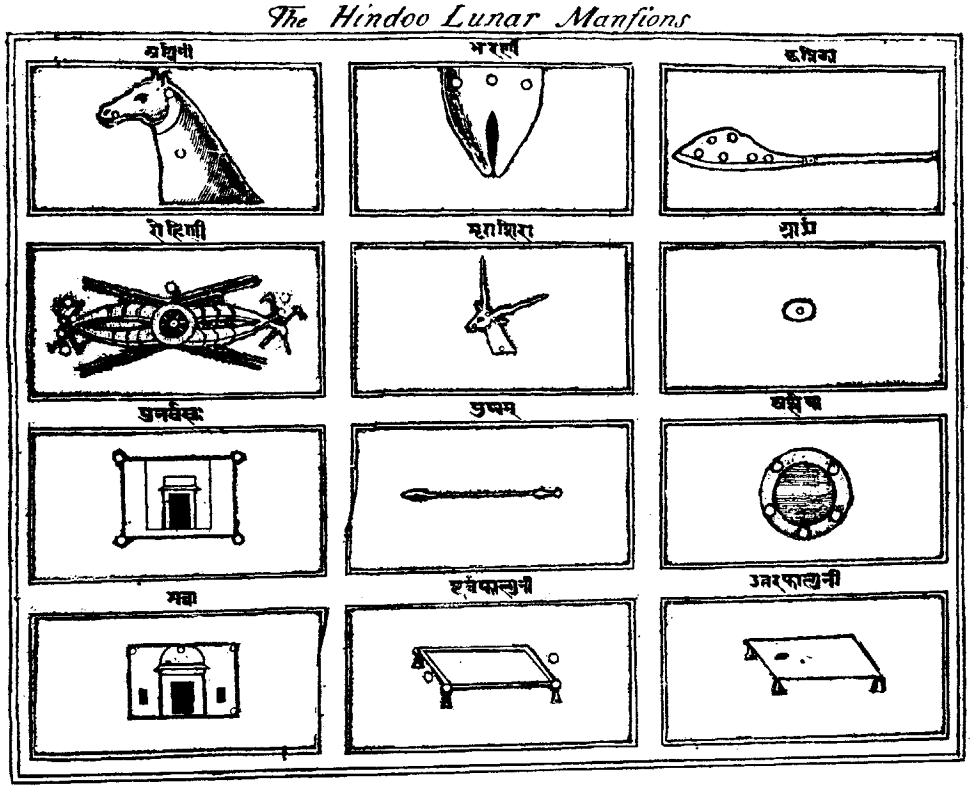

Fig. 3.1 Hindu Lunar Mansions.

he observed that there was hardly any agreement between the two systems. More importantly, twenty-seven *nakṣatras* were mentioned in Manu's Institutes, and he quoted his Brâhman informants that some of them were listed in the Vedas, 'three of which', he firmly believed from internal and external evidence, 'to be more than three thousand years old'. Thus started a great controversy on the antiquity of the zodiac and the priority of its invention which razed throughout the nineteenth century involving some of the best orientalists and historians of astronomy of the time. He also discussed the Hindu conception of the oscillation of the vernal equinox from the third of Mīna (Pisces) to the twenty-seventh of Meṣa (Aries) in the period of 7200 years, and suggested that equinox observations had been made as early as 1181 B.C.

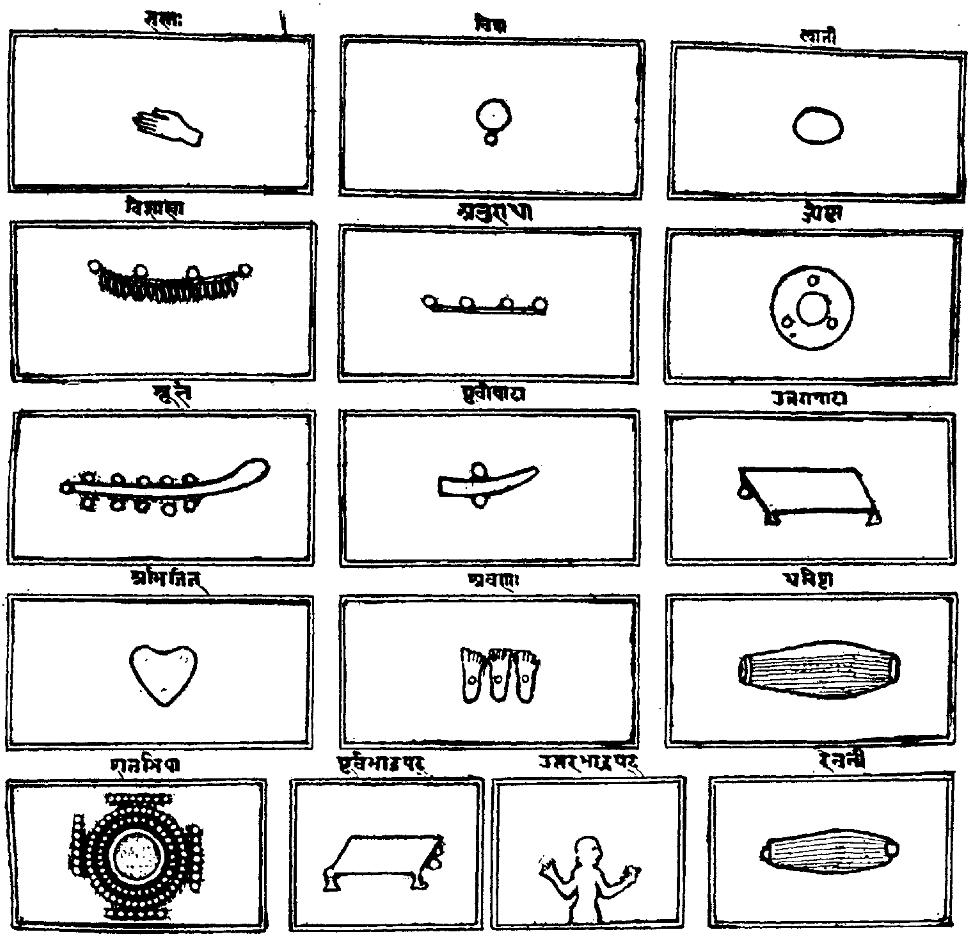

Fig. 3.1 (Contd). Hindu Lunar Mansions

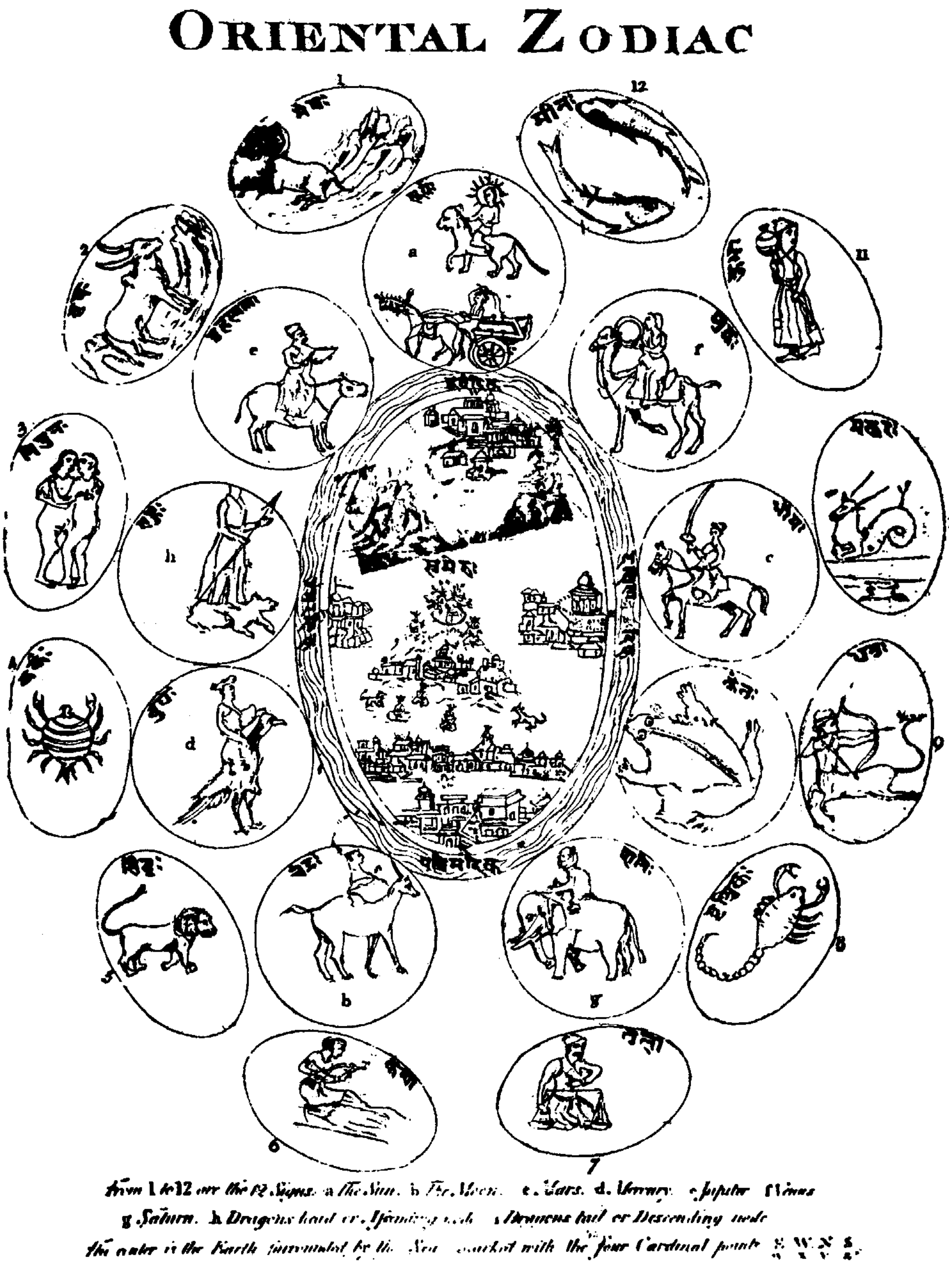

Fig. 3.2 Hindu Zodiacal Signs

JOHN BENTLEY ON THE SŪRYA-SIDDHĀNTA AND ITS DATING

The high antiquity of Hindu astronomy advocated by Bailly, Playfair and Jones on the basis of their astronomical epochs and supposed observations millennia before the Christian era did not remain unchallenged for long. In 1799 John Bentley published in the *Asiatick Researches* a study on the antiquity of the *Sūrya-siddhānta* and the formation of the astronomical cycles contained therein.[19] By utilizing the internal evidence of the text and making calculations on the basis of its own elements Bentley concluded that the *Sūrya-siddhānta* could not have been composed earlier than A.D. 1091. The text indicated that at the commencement of the Kali Yuga era (February 17-18, 3102 B.C.) all the planets were in conjunction at the first point of the Hindu sphere, and it was asserted that such a phenomenon was then actually observed. Bentley determined from the ephemerides positions of the planets from the (first point of the) Hindu sphere. These positions together with the longitudes reckoned from the vernal equinox and the data given by Bentley and Bailly are shown in Table 3.1. It at once became clear that the planets were not in conjunction at the beginning of the Kali Yuga, and such long eras could not have been determined on the basis of observations. This point has been discussed recently by van der Waerden and others, to which a further reference will be made in what follows. Even if the mean positions were determined by actual observations at a more recent date the assumption of conjunction at the beginning of the Kali Yuga was destined to introduce serious errors after the lapse of long enough time.

Table 3.1. *Planetary positions on the midnight of February* 17-18, 3102 B.C. *for the meridian of Ujjayinī (Burgess (E), I.* 29-34, *notes).*

Planet		From beginning of Hindu sphere			Longitude			Bentley			Bailly		
		°	′	″	°	′	″	°	′	″	°	′	″
Sun	—	7	51	48	301	45	43	301	1	1	301	5	57
Mercury	—	41	3	26	268	34	5	267	35	26	261	14	21
Venus	+	24	58	59	334	36	30	333	44	37	334	22	18
Mars	—	19	49	26	289	48	5	288	55	19	288	55	56
Jupiter	+	8	38	36	318	16	7	318	3	54	310	22	10
Saturn	—	28	1	13	281	36	18	280	1	58	293	8	21
Moon	—	1	33	41	308	3	50	306	53	42	300	51	16
do apsis	+	95	19	21	44	56	42	61	12	26	61	13	33
do node	+	198	24	45	148	2	16	144	38	32	144	37	41

Later astronomers were aware of this difficulty and invented the method of *bīja* correction. By this correction the original revolution numbers of the planets were suitably altered so that the figures were still divisible by 4 and the system admitted of operation with the lesser period, that is, one-fourth of the *Mahāyuga*. Davis incidentally discussed the *bija* correction, but Bentley showed that such a correction was not introduced before the sixteenth century.

Bentley then argued that if the date of conjunction in the past was determined by working backwards resulting in greater computed errors in planetary positions it would be possible, by similar calculations, to arrive at a period when computed positions of the planets would more or less agree with observed values. If such a period could be found it would obviously answer for the period of composition of the treatise in question. Bentley went through the laborious exercise and gave his results in the form of a table (Table 3·2).

Table 3.2. *Bentley's table of errors in the positions of the planets as calculated for successive periods according to the Sūrya-siddhānta (seconds omitted).*

Planet	Kaliera 0 B.C. 3102	K 1000 B.C. 2102	K 2000 B.C. 1102	K 3000 B.C. 102	K 3639 A.D. 538	K 4192 B.C. 1091	When Correct
	° ′	° ′	° ′	° ′	° ′	° ′	A.D.
Mercury	+ 33 26	+ 25 10	+ 16 54	+ 8 38	+ 3 22	— 1 12	945
Venus	— 32 44	— 24 38	— 16 31	— 8 15	— 3 15	+ 1 14	939
Mars	+ 12 6	+ 9 27	+ 6 47	+ 4 8	+ 2 27	+ 0 58	1458
Jupiter	— 17 3	— 12 44	— 8 26	— 4 7	— 1 22	+ 0 41	906
Saturn	+ 20 59	+ 15 43	+ 10 28	+ 5 12	+ 1 50	— 1 45	887
Moon	— 5 53	— 3 51	— 2 9	— 0 53	— 0 19	— 0 1	1097
do apsis	— 30 11	— 23 10	— 16 8	— 9 6	— 4 36	— 0 43	1193
do node	+ 23 38	+ 17 59	+ 12 31	+ 7 3	+ 3 33	+ 0 32	1183

Averaging the results he arrived at A.D. 1091 as the possible date of composition of the *Sūrya-siddhānta*.

Bentley's approach was scientific and argument convincing but this could not be the sole criteria for determining the date of an astronomical work. He was misled by Śatānanda's statement in his *Bhāsvatī* that he was a disciple of Varāhamihira, believed that the latter was the author of the *Sūrya-siddhānta* and accordingly suggested that both the author and his work belonged to the eleventh century A.D. William Jones had already placed Varāhamihira around 499 A.D. Bentley's conclusion generated adverse crit'cism from scholars who had admired Bailley's work and did not like to see the latter work thus relegated to the background. An anonymous review of Bentley's work in the *Edinburgh Review* strongly criticised his conclusions and methods to which Bentley replied with equal vehemence and bitterness in the *Asiatick Researches*. Embittered by acrimonious controversy, Bentley refrained from publishing further studies, but continued to work on the historical development of the subject by his method of errors. These studies vitiated somewhat by his attacks on those who disagreed with him were published posthumously in the form of a book *Historical View of the Hindu Astronomy* (1825).

Astronomical Observatories

The eighteenth century travellers, scholars, astronomers, and scientists of all sorts spending some time in India did not fail to take notice of the astronomical labours of Sawai Jay Singh and the observatories he built at Jaipur, Delhi, Ujjayini and other places. Joseph Tieffenthaler (1710-1785) who lived in India from 1743 to 1785 and wrote his *Descriptio India.* (French translation by Jean Bernoulli under the title *Description Historique et Geographique de l'Inde,* Berlin, 1786) left an account of the observatories at Delhi, Muttra, and Jaipur. The observatory built at Delhi by the Rajah more or less on the plan of the Jaipur observatory had an equinoctial dial, a gnomon and several other masonry devices for observations, of which the most conspicuous was a pair of round (cylindrical) buildings graduated in hours. In Jai Singh's time this part of Delhi was fairly an open country free from obstructions from high-rise buildings and monuments and suitable for astronomical observations. The Mathura observatory was built on a hillock commanding a vast plain all around. Its principal equipments were a gnomon built of brick and lime and representing the axis of the earth, an equinoctial dial, and several other intruments representing various sections of the sphere. The Jaipur observatory, Tieffenthaler wrote, was however the most remarkable of them all, 'un ouvrage tel qu'on n'en voit jamais vu dans ce contrées, et qui frappe d'étonnement par la nouveauté et la grandeur des instrumens'.[20] This observatory, like the others, was equipped with several masonry instruments, a large number of them being various sections of the celestial sphere, equinoctial dials, horizontal sun-dial, the quadrant, the gnomon and a number of astrolabes. The imposing gnomon, the axis of the earth, was seventy royal feet in height. Some of these instruments were superficially described more with a view to excite wonder than scientific curiosity.

Shortly after Tieffenthaler, W. Barker, Commander-in-Chief of the Bengal Army examined more critically and carefully the astronomical instruments of another observatory of Jai Singh at Benares.[21] About 1797 William Hunter, a surgeon with the British Army in India and an amateur astronomer studied the astronomical works of Jai Singh, reported on the contents of an astronomical *zij* dedicated to Emperor Muhammad Shāh, and gave a more detailed account of some of the instruments of his observatories. Jai Singh had studied Hindu astronomy and mathematics and his reputation in these sciences was so high that he was chosen by the Emperor to reform the calendar. In this assignment the astronomer king constructed a new set of tables, the *Zij Muhammadshāhi,* of the preface of which Hunter gave an elegant English translation side by side with the Persian original. About the observatory at Delhi, Jai Singh informs us in this preface that he 'constructed here (at Dehly) several of the instruments of an observatory, such as had been erected at Samarcand, agreeably to the Musulman books'. Furthermore: 'But finding that brass instruments did not come up to the ideas which he had formed of the accuracy, because of the smallness of their size,...therefore, he constructed in Dar-ul-Khelafet Shah-Jehanabad, which is the seat of empire and prosperity, instruments of his own invention, such as *Jeypergās* and *Ram-junter* and *Semrāt-junter,* the semi-diameter of which is of eighteen cubits,...'[22] Besides the *Samrāṭ Yantra,* Hunter described several other instruments such as an equatorial dial provided with a gnomon in the middle and two concentric semi-circles on either side of it; an instrument named *ustuanah* designed to observe altitudes and azimuths of celestial bodies; an equatorial dial with a concave hemispherical surface 27′5″ in diameter, called the *shamlah;* and several others. The *shamlah,* representing the interior hemisphere of the heavens, was divided by fixed ribs of solid work and as many hollow spaces, the edges of which represented meridians at the distance of 15 degrees from one another.

INDIAN ASTRONOMY IN THE NINETEENTH CENTURY

Colebrooke on the Zodiac, Precession of the Equinoxes, Chronology of Astronomers

The appearance of Henry Thomas Colebrooke who combined the qualities of an able mathematician with those of an expert orientalist signalled a new period of fruitful activity in understanding the history of ancient Indian astronomy. Armed with sizable collection of Sanskrit mathematical and astronomical texts and commentaries, he reexamined the stellar zodiac question, the precession of the equinoxes, and the dating of the leading authors and commentators, apart from his major contributions to the elucidation of the mathematics of Brahmagupta and Bhāskara II.

Colebrooke revived William Jone's question regarding the antiquity of the stellar zodiac and particularly asked the question whether the Indian and the Arabian division of the zodiac had a common origin. He examined and considered the positions of the principal stars, *yogatārā,* of the *nakṣatras* and lunar mansions as given by the *Sūrya-siddhānta, Siddhānta Śiromaṇi (Marici), Grahalāghava,* Brahmagupta (as cited by Bhūdhara), besides the *Ratnamālā* previously utilized by Jones. He discussed the ancient Indian methods of observing the positions of stars with the help of an armillary sphere, as described in the *Sūrya-siddhānta,* and another method elaborated in the *Siddhānta Sundara.* Ptolemy had also used armillary spheres for astronomical observations, but by comparing the description of the Greek instrument as given in Nasir al-Dīn al-Ṭūsī's *Tahriru'l-majesti* with that of the Indian one as described in the *Siddhānta Śiromaṇi,* Colebrooke concluded that the two instruments differed in many details and the one was not the copy of the other.[23]

Each *nakṣatra* was then compared with the corresponding *manzil.* In the case of Aśvinī, for example, the *nakṣatra* comprises, according to Sanskrit texts, 'three stars figured as a horse's head; and the principal which is also the northern one, is stated by all ancient authorities, in 10°N and 8°E from the beginning of Meṣa'. The first Arabian *manzil,* Sharatān, 'comprises two stars of the third magnitude on the head of Aries, in lat. 6°36′ and 7°51′N and long. 26°13′ and 27°7′...' The principal star in the two constellations is apparently the same. Likewise the Arabian *Dabarān* is identical with the Indian Rohiṇī. But such is not the case with Abhijit and *Ẕābiḥ*, where a total disagreement is noticed. From such comparisons he concluded that the Indian asterisms generally consisted of nearly the same stars which constituted the lunar mansions of the Arabians, but in a few instances they essentially differed. Likewise the similarities of figures and designations of the twelve signs of the zodiac with those of the Greek appear to suggest that the Hindus might have taken from the Greeks the hint of this mode of dividing the ecliptic; but 'if such be the origin of it,' remarked Colebrooke, 'they have not implicitly received the arrangement suggested to them, but have reconciled and adopted it to their own ancient distribution of the ecliptic into twentyseven parts.'[24] For many years to come Colebrooke's study constituted the chief source of information of the Indian *nakṣatras* vis-a-vis the Arabian *manāzil* till the controversy was further enlivened by the researches of Biot claiming greater antiquity for the Chinese *hsius*.

More importantly, Colebrooke recognized that Varāhamihira's *dreṣkāṇas*, used in his *Vihajjātaka*, were equivalent to the decani of European astrologers. The *dreṣkāṇa* is one-third of a sign to which is allotted a regent exercising planetary influence. Each sign of the Arabian zodiac is also similarly divided into three parts, each called a *wajeh*. This is an astrological concept which originated with the Babylonians and the Egyptians and passed on to the other countries,—Greece, India. The Greek decani were discussed in Manilius, Hephaestion, Firmicus, and Psellus, and the Sanskrit equivalent, Colebrooke thought, came from the same source (see Pingree's *Yavanajātaka* discussed later). 'In the present instance', he observed, 'Varāha Mihira himself, as interpreted by his commentator, quotes *Yavanas*...in a manner which indicates that the description of the *dreṣkāṇas* is borrowed from them'.[25] This commentator Bhattotpala and others frequently cited the name of one *Yavanācārya*, and Colebrooke suspected that under this name a Grecian or an Arabian author was probably intended. He even suggested that if the work attributed to him could not be recovered it would be worth-while to collect all passages in which Yavanācārya was cited to throw further light on this important point. David Pingree's recent works to which we shall refer in what follows shows how good Colebrooke's informed guess was.

Colebrooke followed up his work on the division of the zodiac by a study of the notion of Hindu astronomers concerning the precession of the equinoxes. He traced the precession idea in Bhāskara II's *Siddhānta-śiromaṇi (Golādhyāya)*, *Sūrya-siddhānta*, *Soma-siddhānta*, *Laghu-vasiṣṭha*, *Sākalya-saṃhitā*, *Parāśara-saṃhitā*, and a few other texts. Two ideas were current,—one the retrograde revolution of the equinoxes throughout the twelve signs, and the other a libration or oscillation of the two equinoxes about the fixed points with certain limits of degrees. Besides these two basically different ideas, there was also considerable divergence of opinion on the question of the rate of precession. The first idea of precession as a revolution through the twelve signs was advocated by Bhāskara II (*Golādhyāya*, c.b.V. 17 and 18) on the authority of Muñjāla; the *krāntipāta*, the intersection of the ecliptic and the equinoctial circles is declared to undergo 30,000 revolutions in a *kalpa*. Colebrooke then notices passages in the *Sūrya-*

siddhānta, Soma-siddhānta, Laghu-vasiṣṭha and *Sākalya-saṃhitā*, which also teach a motion of the equinoxes, such motion being of the nature of a libration within the limits of 27 degrees east as well as west from the Hindu fixed points (beginnings of Aries and Libra).[26] These librations take place at the rate of 600,000 in a *kalpa*. The *siddhāntas* of Parāśara and Āryabhaṭa also advocate similar doctrine but their revolution values are slightly less. As to limits of libration Āryabhaṭa gave 24° east and west of the fixed point. Brahmagupta was silent about the precessional motion. As to the two views, the majority of Indian astronomers adhered to the libration theory of the *Sūrya-siddhānta.*

Colebrooke then discussed the libration or trepidation theory as developed by the Arab astronomers (Arzacel, Thabit ibn Qurrah), the limits in degrees of oscillations and their periods. Although somewhat out of place in this paper some of the special features of the eccentric-epicyclic models of planetary motions were pointed out. The eccentric model had already been used by Hipparchus, and Apollonius was credited with the invention of the geometry of epicycle on a deferent. Ptolemy adopted the same models to account for planetary inequalities, but introduced the new concept of the 'equant' which is absent in the Hindu treatment. What is striking, Hindu astronomers sought better accuracy by giving 'an oval form to the eccentric or equivalent epicycle, as well as to the planet's proper epicycle'.[27]

Colebrooke's *Algebra, with Arithmetic and Mensuration, from the Sanskrit of Brahmegupta and Bhāscara* was mainly concerned with the exposition of mathematics as dealt with by these two celebrated authors. But the dissertation with which he prefaced the work contained many valuable glimpses on Indian astronomy as also a critical discussion of the dating of ancient astronomers and their commentators. In Colebrooke's time Āryabhaṭa was known through references contained in Brahmagupta's works and those of Bhāskara II's scholiast Gaṇeśa and a few other commentators. Āryabhaṭa was also known to the Arabs under the abbasid Khaliphs as 'Arjabahar' or 'Arjabhar'. Piecing together such scattered and scanty information on this ancient astronomer Colebrooke suggested that Āryabhaṭa preceeded Brahmagupta and Varāhamihira by several centuries and further that, if Varāhamihira lived at the beginning of the sixth century A.D. Āryabhaṭa could have written 'as far back as the fifth century of the Christian era and was almost as ancient as Diophantus.[28] In all this he was guided to some extent by the chronology collected by William Hunter from the astronomers of Ujjayinī, which placed some of the ancient Hindu astronomers as follows: Varāhamihira—A.D. 505-6; Brahmagupta—A.D. 628–9; Muñjāla—A.D. 854; Bhaṭṭotpala—A.D. 890; Bhāskara II—A.D. 1150-1. Colebrooke also correctly noticed Āryabhaṭa as the author of an astronomical system and founder of a sect in that science, mentioning, in particular, his view about the diurnal revolution of the earth, his epicyclic planetary theory and his theory of eclipses disregarding imaginary dark planets of the mythologists and astrologers.[29]

Colebrooke possessed a manuscript copy of Brahmagupta's *Brāhmasphuṭasiddhānta,* which he interpreted as an emended text of an earlier system known as the *Brahma-siddhānta* which had ceased to agree with astronomical observations. He gave the date of his work as A.D. 628 corresponding to Śaka 550. Although Brahmagupta's mathematics was dealt with in detail in his *Algebra,* his various astronomical topics were briefly summarized in the Dissertation.[30] Finally Colebrooke provided a wealth of information about the scholiasts of Bhāskara, many of whom were well-known authors and commentators of astronomical works during medieval times,—Gangādhara, Jñānarāja, Sūryadāsa, Nṛsiṃha, Lakṣmīdāsa, Gaṇeśa, Ranganātha, Munīśvara and Kamalākara.

John Warren on the Tamil Reckoning of Time

Lt. Colonel John Warren of the Trigonometrical Survey of India prepared, during the first quarter of the nineteenth century, a number of memoirs on the various modes according to which astronomers of India, specially of the southern provinces, used to divide time. Although his main purpose was to explain the Indian calendars, and not to provide a critical exposition of Indian astronomy, his work proved useful in understanding 'the present extent of our knowledge in Hindu astronomy in these southern provinces'. The main discussion and tables centred round three distinct subjects, e.g. (a) Tamil solar year on the authority of the *Āryasiddhānta,* (b) luni-solar astronomical year and the calendar of the Telengana countries according to the *Sūrya-siddhānta,* and (c) the Muhammadan calendar on the Arabic system. Accordingly, the whole book entitled *Kāla Saṅkalita* (a compendium on the doctrine of time) comprises four memoirs and an appendix containing several explanatory notes and tables. The first memoir discusses the mean solar sidereal year *(madhyama soara māna)* used in Tamil land. The second deals with the theory and construction of the luni-solar astronomical year *(siddhānta candra māna),* on which rests the whole fabric of Hindu astronomy; here the computation of different elements is explained on the basis of the rules given in the *Sūrya-siddhānta* and at the same time the problems of the gnomon, and applications of trigonometry in finding right ascension, declination, longitude, zenith distance and amplitude of stellar bodies are fully demonstrated. The Indian cycle of sixty years is the subject of treatment of the third memoir, in which three different methods,—the first according to the *Sūrya-siddhānta,* the second on the basis of an astrological work current in the northern provinces of Bengal and the third followed in Telengana countries, are explained. The fourth memoir is devoted to the construction of the Muhammadan lunar year and the compilation of a general table showing the commencement of every year of the Hegira from the origin of the era to the lunar year corresponding to A.D. 1900.[31]

An interesting feature of the work is an exposition of the solar or *vākyam* process applied for the computation of eclipses. The elements from which the *vākyam* rules and tables are constructed are extracted from the *Ārya-siddhānta.* 'The most remarkable difference between the *vākyam* process and that of the *Sūrya-siddhānta*', Warren explained, 'is that the computations of the former are directly for the apparent, without previously obtaining the mean places of the asters, and that these refer to the time of sun rising, instead of mean midnight, as is directed in the *Sūrya-siddhānta*'.[32]

C. M. Whish On Indian Zodiac

That the concept of dividing the zodiac into twelve signs was influenced by the Greeks was already suspected by Colebrooke despite William Jone's assertion in favour of an indigenous origin. C. M. Whish utilized materials from Varāhamihira and a commentary *Prabhodana* on Śrīpati's *Ratnamālā,* in which one Yavaneśvara is again mentioned, to show that a large number of technical terms typical of Greek astrological literature found their way into Sanskrit astrological works. As an example, he cited the names of the twelve signs of the zodiac as follows: Kriya (*kpios*)—Aries; Tāvuri or Tāmbiru (*Tavpos*)—Taurus; Jituma (*△iδvμos*)—Gemini; Kulira or Karka (*Kapkivos*)—Cancer; Leya (*Λεωv*)—Leo; Pāthona (*παpθεvos*)—Virgo; Jūka (*ζvyov*)—Libra; Kaurypa (*Σkopπios*)—Scorpio; Taukṣika (*Toξoτηs*)—Sagittarius; Ākokera (*'Avyokεpωs*)—Capricornus; Hṛdroga (*Υδpoχoos*)—Aquarius; Ittha (*'Iχθvs*)—Pisces.[33] Likewise Varāha's *Horā śāstra* transliterates some of the Greek planetary names as follows: Heli (*"Hλios*) for the Sun, Himna (*'Epμηs*) for Mercury, Āra (*"Apηs*) for Mars, Koṇa (*Kpyvs*) for Saturn, Jyaus (*ζεvs*) for Jupiter and Āsphujit (*'Aφpo δiτη*) for Venus. Apart from the names of the zodiac and a few planets, several Greek terms used in geometry, astronomy and astrology were adopted almost without change in Sanskrit writings, of which the following are a few examples:—āpoklima—declination; dreṣkāṇa, dṛkāṇa, dṛkkāna or drekkāna—the chief of ten parts (out of thirty) of a sign, already discussed by Colebrooke; durudharā—the 13th yoga; harija—horizon; hibuka—the 4th lagna or astrological house; horā—hour, 24th part of a day; jāmitra—diameter, the 7th house; kendra—anomaly, argument of an equation; koṇa—angle; trikoṇa—triangle; liptā—a minute of arc; meṣuraṇa—meridian; panapharā—rising, also 2nd, 5th, 8th and 11th houses. Etymologically none of these words appear to be of Sanskrit origin. Weber who also went over these terms expressed the view that these were used in the same sense in which Paulus Alexandrinus applied them in his *Eisagoge.*[34]

Lancelot Oilkinson and Bāpudeva Śāstrī's Study Of Bhāskara II's Astromomy, Jervis on Indian Astronomy, and Hoisington's Oriental Astronomer

Between 1830 and 1850 some important contributions to the study of ancient Indian astronomy included the translation by Lancelot Wilkinson and Bāpūdeva Śāstrī of part of Bhāskara II's *Siddhānta-śiromaṇi,* Capt. J. B. Jervis' papers on metrology and calendars, J. B. Biot's work on the antiquity of lunar mansions, particularly of the Chinese *hsius* and the Indian *nakṣatras,* and Rev. Hoisington's work on Tamil astronomy. Wilkinson who spent some time in Sehore in Central India was a great enthusiast of Indian astronomy and advocated the teaching of science in schools with the help of Sanskrit text books like Bhāskara's *Siddhānta-śiromaṇi.*[35] In this connection he gave a translation of portions of the text. Later on, with the assistance of Bāpudeva Śāstrī, he published the *Golādhyāya* section of the *Śiromaṇi* and subsequently a translation with notes. A Marathi translation of the work *Siddhānta-śiromaṇi-ṭikā* had already appeared from Bombay in 1837 as had done the same work with the commentary *Siddhānta-śiromaṇi-prakāśa* from Madras in the same year. In

1844, E. Roer published a Latin translation of Bhāskara II's *Gaṇitādhyāya* in the *Journal of the Asiatic Society of Bengal.*[36]

Capt. J. B. Jarvis' work on Indian metrology drew largely upon Indian astronomical texts, e.g. *Bṛhat Cintāmaṇi* and also dealt with Hindu *Pañcāṅgas* (calendar). Rev. H. R. Hoisington's *The Oriental Astronomer* comprised a Tamil text on calendrical astronomy and a translation and proved useful in understanding the computational methods followed in Indian almanacs current in Tamil countries. Biot gave a good summary of the work in his *Etudes sur l'astronomie indienne et sur l'astronomie chnoise.*[37] Biot had already stirred the scholarly world by his views on the Chinese origin of the lunar mansions, expressed in a series of papers originally published in the *Journal des Savants* in 1840 and 1845 and initiated a controversy on the question of the priority of invention of the stellar zodiac which came to a head in the sixties of the last century, to which we shall revert in what follows.

Translation of The Sūrya Siddhānta

By the middle of the century it became possible to form on the basis of pioneering studies by men like Le Gentil, Bailly, Davis, Jones, Colebrooke, Bentley and others, a good ideas as to the contributions of ancient Hindus to the science of astronomy. These contributions established the authority of the *Sūrya-siddhānta* as the astronomical work *par excellence,* accepted unanimously by all the leading *jyotiṣa* schools in India. Yet the entire work, in original Sanskrit text as well as in English translation, was not available for easy reference and study. In 1859, the Asiatic Society of Bengal whose publication, the *Asiatick Researches* had already provided the forum for scholarly discussions on the subject, partially fulfilled this need by publishing the Sanskrit text with a commentary *Gūḍhārthaprakāśikā* under the editorship of Fitz Edward Hall and Bāpudeva Śāstrī in the *Bibliotheca Indica* series.[38] The following year appeared the long awaited English translation of the text with copious explanatory and historical notes of inestimable value. The translator Rev. Ebenezer Burgess was a devoted American missionary who lived in India in the Bombay Presidency from 1839 to 1854 and was attracted to the Sanskrit astronomical literature in connection with a project concerning 'the preparation, in the Marathi language, of an astronomical text-book for schools'. He quickly realized that 'there was nothing in existence which showed the world how much and how little the Hindus know of astronomy, as also their mode of presenting the subject in its totality, the intermixture in their science of old ideas with new, of astronomy with astrology, of observation and mathematical deduction with arbitrary theory, mythology, cosmogony, and pure imagination'. This deficiency, he thought, could well be supplied by the translation and detailed explication of a complete treatise of Hindu astronomy. As the project took shape the American Oriental Society expressed interest in the work, and its Committee of Publication extended every cooperation and assistance towards the completion of the manuscript. The distinguished orientalist Prof. Whitney was associated with the work to enrich the translation with notes and additional matter of value. Hubert A. Newton, Professor of Mathematics at the Yale College, New Haven supplied the mathematical notes and demonstration as also several comparative studies of Hindu and Greek astronomical questions. Thus was accomplished, as Biot remarked, a noble work of scholarship of positive science, a very difficult work calling for indefatiguable devotion, which almost spared nothing to facilitate an intimate understanding of the mysteries of the astronomical science of the Hindus.[39]

In addition to the notes in full utilization of previous studies, the translation was appended with additional notes and tables, calculation of eclipses, and a stellar map. As to the manuscripts relating to astronomical works made available to Burgess by the Pundits of the Sanskrit College at Puna, we are informed of the following 19 *siddhāntas*, e.g. *Brahma, Sūrya, Soma, Vaśiṣṭha, Romaka, Paulaśtya, Bṛhaspati, Garga, Vyāsa, Parāśara, Bhoja, Varāha, Brahmagupta, Siddhānta śiromaṇi, Siddhānta sundara, Tattva-viveka, Sārvabhauma, Laghu-Ārya,* and *Bṛhat-Ārya.* Nine *siddhāntas* mentioned in the Sanskrit encyclopaedia, *Śabdakalpadruma,* were also referred to, viz. *Brahma, Sūrya, Soma, Bṛhaspati, Garga, Nārada, Parāśara, Paulastya,* and *Vaśiṣṭha.* Burgess divided these works into four categories, e.g. (1) *siddhāntas* revealed by superhuman beings,—Brahma, Sūrya, Soma, Vṛhaspati, Nārada; (2) works attributed to sages,—Garga, Vyāsa, Parāśara, Vaśiṣṭha etc; (3) works by ancient authors whose dates in some cases might be uncertain,—Ārya, Varāha, Brahma, Romaka, Bhoja; and (4) later texts of known date and authorship, but of less independent and original character,—*Siddhānta śiromaṇi, Siddhānta sundara* of Jñānarāa, *Grahalāghava, Siddhānta tattvaviveka* etc.

Burgess maintained that, as far as the mean motions of the planets, the date of the last general conjunction and the frequency of its recurrence were concerned, the system of the *Sūrya-siddhānta* agreed with that of the *Sākalya-saṃhitā,* the *Soma*—and *Vasiṣṭha-siddhānta,* following the view of Bentley. *Pauliśa*—and *Laghu-Ārya-siddhāntas* also follow a more or less similar system. Planetary revolution numbers in an age sometimes differ from those of the *Sūrya-siddhānta,* but this difference is by a number which is a multiple of four. *Siddhānta-śiromaṇi* and other works, following the authority ot Brahmagupta, have somewhat different system. The starting point of planetary motions is ζ Piscium at the commencement of the Æon or *Kalpa* (4,320,000,000) so that they are again in conjunction at the end of it. Even then all systems take particular care that all planets are also in conjunction or nearly so at the beginning of the *Kali Yuga* at the moment of mean sun-rise at Laṅkā. This is illustrated by a table of mean places of planets at 6. A.M. at Ujjayinī on February18, 3102 B.C.

Burgess and Whitney believed that the scientific aspects and parameters of the *Sūrya-siddhānta* were based on Greek astronomical sources. Observational astronomy in India had not been developed to such an extent as to make possible generation of data indispensable for such computations and improvements upon them from time to time. In their view, Hindu astronomy as 'an offshoot from the Greek, planted not far from the commencement of the Christian era, and attaining its fully developed form in the course of the fifth and sixth centuries'. This transmission probably took place in connection with the lively maritime trade between the Western coast of India and Alexandria in the first centuries of the Christian era. Had the transmission taken place by way of Syrian, Persian and Bactrian Kingdoms, Rome would not have so prominently featured in the astronomical literature. Whitney and Burgess, however, failed to notice in the *Sūrya-siddhānta* or other authoritative texts traces of Ptolemy's improved system and explained this on the ground that the transmission had probably taken place before the time of Ptolemy. The discovery of the manuscripts of *Pañcasiddhāntikā* by Varāhamihira and their study by G. Thibaut and Sudhakara Dvivedi, as we shall see in what follows, have thrown further light on this question by making available a number of astronomical texts typical of the transitional period.

Controversey about the Origin of Lunar Mansions

We have seen that the Indian stellar zodiac had been the subject of an important discussion among the orientalists since the time of William Jones. Although the Greek origin of the division of the zodiac into twelve signs was generally admitted, the orientalists were almost unanimously agreed about the Indian origin of the *nakṣatras* or twenty-seven lunar mansions. In 1840, J. B. Biot, a member of the French Academy of Sciences published in the *Journal des Savants* a study on ancient Chinese astronomy in commemoration of the distinguished sinologist Ludwig Ideler,[40] in which he endeavoured to show that the lunar mansions had their origin in China and that the Indian *nakṣatras* were adopted from the Chinese system for astrological purposes. To summarize Biot's conclusions, (1) the system was first established in China around 2350 B.C. and completed and perfected about 1100 B.C.; (2) originally the Chinese *hsiu* stars were a series of single stars spread more or less along the equator, without any relation with the moon, and employed for determining meridional transits of heavenly bodies; (3) eastern nations, including India, borrowed the system from China, distorted it, and applied it to demarcate the ecliptic, by utilizing a few chance coincidences although the system was never intended for such application. In his *Études sur l'astronomie indienno* etc. Biot further observed: 'I was led, twenty years since, to recognize, and to demonstrate by palpable proof, that this singular institution, which enters into the general system of the Indian astronomy as a thing foreign to it, has its root and its explanation in the practical methods of the ancient Chinese astronomy, whence the Hindus derived it, altering its character, in order to employ it in astrological speculations'. He also attacked the indianists for their deficiency in the knowledge of astronomy and mathematics which he considered indispensable for a correct appraisal of a scientific and technical subject of this nature.

Biot's studies and remarks attracted wide attention. In Germany, the distinguished indologist Lassen found Biot's views acceptable, but Weber who was then deeply immersed in Vedic studies found these claims highly exaggerated and prepared for a fitting reply to Biot's views. Weber's efforts resulted in the publication of his two celebrated papers under the title 'Die vedischen Nachrichten von den Naxatra (Mondstationen)' published in the *Abhand. der Königl. der Wissenschaften,* in two parts, in 1860 and 1862 respectively. In the first part, devoted to historical introduction, Weber summarized Biot's opinion about the Chinese origin of Indian *nakṣatras*, and then examined the whole series of questions connected with the controversy, e.g. the chronologies of Schu-King, Schi-King, Eul-ya, Yue-ling, Tcheou-li etc.; the beginning of the 28 *hsiu* stars from the time of Lu-pou-ouey; the series beginning with the *hsiu* star *Kio* and not with *Mao;* the more ancient nature of the Indian *nakṣatra* series headed by Kṛttikā, consideration of the question whether the Chinese *hsius* could not on the contrary be borrowed from Indian *nakṣatra*s ystem; the relation between the system obtaining in West Asia and China; traces of an old Babylonian system of lunar stations in the Fihrist and in an ancient Harranian festival; the differences between the Indian *nakṣatra* and the *hsiu-manāzil* systems; the Indian origin of the *manāzil* series as well as of the system of lunar stations mentioned in the *Bundehesh*.

In the second part of his *Nachrichten*, Weber considered in detail the development of the *nakṣatra* system in the *Saṃhitās* and *Brāhmaṇas*, concentrating on the following topics, e.g., general examination of the significance of *nakṣatra* in the Vedas; the use of the word '*nakṣatra*' in the sense of star as well as in the special sense of lunar mansion; the recognition of twenty-seven *nakṣatras;* the legend of 27 *nakṣatras* as wives of the Moon; 27 *nakṣatras* marking 27 sidereal days constituting the Moon's sidereal month; the use of the system in the *Lāṭyāyana-sūtra* and *Nidāna-sūtra*, recognizing several types of years; the *nakṣatra*—rituals of the Brāhmaṇa period such as the *agnyādhānam, punarādheam, āgrayaynam, agnicayanam, nakṣatreṣṭakās* etc.; the later development of the system of 28 *nakṣatras* with the inclusion of Abhijit.

The word '*nakṣatra*' has been traced in the earliest Vedic texts and explained from Sanskrit etymological considerations. [41] An older form '*Kṣatrāṇi*' is met with in the *Śatapatha Brāhmaṇa* (2, 1, 2, 18, 19). In the *Taittirīya Brāhmaṇa* (2, 7, 18, 3) and *Atharvaveda* (7, 13, 1), the word is no longer '*kṣatra*', but '*na-kṣatra*'. In explaining '*nakṣatra*', Pāṇini refers to the irregular construction of the word '*na-kṣatra*' from the root $\sqrt{}$*kṣar* (meaning 'fliessen', 'to flow'). According to another etymological consideration $\sqrt{}$*nakṣ* signified 'the changing' (die Wandelnden) in which sense the word was used in the *Śatapatha Brāhmaṇa (tan nakṣatraṇāṃ nakṣatratvam)*.

Among the various uses found of the word in the Vedas, the most general use appears to be to signify a heavenly object or source of light and illumination. It is no wonder that the Sun itself should be described as a star (ein Gestirn) as the *Ṛgveda* (7, 81, 2) does *(nakṣatram arkivat)*. Its use in the special sense of a lunar mansion also developed during the period of the *Saṃhitās* and the *Brāhmaṇas*. This is particularly so in connection with the three *Yajus* texts where '*nakṣatra*' is used in this special sense. The *Śatapatha Brāhmaṇa* (9, 4, 1, 9) clearly states that the Moon dwells with the *nakṣatra* as a Gandharva does with the Apsarās (Der Mond stieg mit den naxatra, (wie) ein Gandharva mit Apsarasen). The *Saḍviṃśa Brāhmaṇa* (10, 5, 4, 17) echoes the same idea when it says—*tasmāt somo rājā sarvāṇi nakṣatrāṇi upaiti, somo hi retodhāḥ*, that is, 'thereupon the king Soma lives (in turn) with all the *nakṣatras;* and he is really the seedsman (samenhaltend). From these rudimentary ideas developed the well known Brāhmaṇa legend of the Moon-god Soma refusing to live with all the *nakṣatras*, daughters of Prajāpati, whereupon the latter withdrew his daughters. Weber described the legend as given in the *Kāṭhaka Saṃ.* (11, 3) as follows: "Prajāpati gave away to king Soma his daughters, the *nakṣatras*. But Soma lived only with (the *nakṣatra*) Rohiṇī. Thereupon the others who were thus deprived of his visit went to their father and complained to him of their plight. Prajāpati decided not to send his daughters back to the Moon and spoke to him (Moon) as follows, " 'You (promise to) live with all of them in the same way (*samāvat*, gleichmässig) then shall I again send them back to you'. Thereafter the Moon lives equally with all the *nakṣatras*."[42]

The *nakṣatras* also occupied an important place in several Vedic ceremonies. These ceremonies usually started with the *agnyādhāna*, that is, with the first construction of the two sacred household fires, e.g. the *gārhapatya* and the *āhavanīya*, usually during new or full moon, and were associated with *nakṣatras* such as Kṛttikās, or Rohiṇī or Mṛgaśīrṣa (*Śat. Br.* 2, 1, 2, 1, ff.). Another ceremony known as *punarādheyam* was to be observed at the double-starred *nakṣatra* Punarvasū (*etad vai punarādheyasya nakṣatraṃ yat punarvasū*, *S.TS.* 1, 5, 1.4).

Thus in India the *nakṣatra* system was firmly established in the period of the *Saṃhitās* and the *Brāhmaṇas*. When one considers the order and the beginning of the series, the identities between a limited number of stars, dissimilarities among the others, the Chinese *hsius*, Weber argued, corresponded in all probability to one of the latest stages of development of the Indian *nakṣatras*. About the changing character of the *nakṣatras*, he mentioned the case of Kṛttikā which sometimes comprised six and sometimes seven stars, the Greeks having a tradition of seven stars including a lost sister. Rohiṇī or Aldebaran was sometimes supposed to be formed of one bright star, and sometime described as including ξ Hydrae and the little group of five stars constituting the asterism Āśleṣā. For Abhijit Weber noticed the position as described in the *Taittirīya Brāhmaṇa* totally different from what obtained in the astronomical *siddhāntas*.

Weber placed some importance to the number of *nakṣatras* being sometimes given as 27 and sometimes as 28. He held that the groups were originally twenty-seven, and became twenty-eight later on with the addition of Abhijit. Thus in the various recensions of the Black Yajurveda,—*Kāṭhaka* (39, 13), *Taittirīya Saṃ.* (4, 4, 10, 1—3) and *Taittirīya Brāhmaṇa* (1, 5, 1, 1—5), 27 *nakṣatras* only are mentioned. The same number 27 is met with in the *Śatapatha Brāhmaṇa* (10, 5, 4, 5), *Pañcaviṃśa Brāhmaṇa* (23, 23), and *Kauṣitaki Āraṇyaka* (2, 16). The earliest record showing 28 *nakṣatras*, with Abhijit, is *Taittirīya Brāhmaṇa* (1, 5, 1, 3).[43]

Weber also touched upon some traces of old Babylonian tradition in respect of lunar mansions in Arabic literature and relations between West Asian and Chinese cultures. He noticed one such trace in the *Fihrist* recording an ancient Harranite custom. The Harranites followed a 27-day Moon month, and on the 27th day of such a month they observed the practice of visiting their holy temple and offering food and drink to the Moon-god. Another trace concerns the use of the word 'mazzaloth' in expression like 'the mazzaloth and all armies in the sky ("der mazzalloth und alles Heeres am Himmel") in King Josias (II. Reg. 23, 5). By an interesting philological exercise Weber proved that the word meant a 'zodiacal portrait' ("zodiacal bild"), possibly a special class of stars to mark the stations of the Moon in its periodic motion through the skies, and in time became transformed into *manzil* (pl. *manāzil*) of the Arabs, which found a place in the *Qu'rān* itself. We reproduce below a table prepared by Weber to show the correspondence of *nakṣatras* with the *hsius* and the *manāzil*.

Nakṣatra	*Manāzil*	*Hsiu*
1. Aśvinī, β, γ Ariet	1. Sharaṭān, like *nakṣ*	16. Leu, β Ariet
2. Bharaṇī, 35, 39, 41, Ariet	2. Buṭain, like *nakṣ*	17. Oei, 35 Ariet
3. Kṛttikā, η Tauri	3. Ṭuraiyā, like *nakṣ*	18. Mao, like *nakṣ*
4. Rohiṇī, α, θ, δ, ϵ Tauri	4. Dabarān, like *nakṣ*	19. Pi, ϵ Tauri
5. Mṛgaśiras, λ, φ_1, φ_2 Orionis	5. Haq'a, like *nakṣ*	20. Tse, λ Orionis
6. Ārdrā, α Orionis	6. Han'a, η, μ, ν, γ, ξ Gemin	21. Tsan, δ Orionis
7. Punarvasū, β α Geminorum	7. Ḍirā, like *nakṣ*	22. Tsing, μ Geminorum
8. Puṣya, υ, δ, γ Cancri	8. Naṭra, γ, δ Cancri and Praesepe	23. Kuei, υ Cancri
9. Āśleṣā, ϵ, δ, σ, η, ρ Hydr	9. Ṭarf, ξ Cancri, λ Leonis	24. Lieu, δ Hydr.
10. Maghā, α, η, γ, ζ, μ ϵ Leon	10. Jabha, like *nakṣ*	25. Sing, α Hydr.
11. Pūrvaphālgunī, δ, θ Leon	11. Zubra, like *nakṣ*	26. Chang, ν_1 Hydr.
12. Uttaraphālgunī, β, 93 Leon	12. Ṣarfa, β Leon	27. Y, α Crateris
13. Hasta, δ, γ, ϵ, α, β Corvi	13. 'Awwā, β, η, γ, δ, ϵ Virgin	28. Chin, γ Corvis
14. Citrā, α Virgin	14. Simāk, like *nakṣ*	1. Kio, like *nakṣ*
15. Svātī, α Bootis	15. Ghafr, i, κ, , λ Virgin	2. Kang, κ Virg.
16. Viśākhā, ι, γ, β, α Libr.	16. Zubānay, like *nakṣ*	3. Ti, α_2 Libr.
17. Anurādhā, δ, β, π Scorp.	17. Iklīl, like *nakṣ*	4. Fang, π Scorp.
18. Jyeṣṭhā, α, σ, τ Scorp.	18. Qalb, α Scorp	5. Sin, σ Scorp .
19. Mūla, λ, υ, κ, ι, θ, η ζ μ Scorp.	19. Saula, λ, υ Scorp.	6. Uei, μ_2 Scorp.
20. Pūrvāṣāḍhā, δ, ϵ Sagitt.	20. Na'āyim, γ_2, δ, ϵ, η, ϕ, σ, τ, ζ Sagitt.	7. Ki, γ_2 Sagitt.
21. Uttarāṣāḍhā, σ, ζ Sagitt.	21. Balda, π Sagitt.	8. Teu, ϕ Sagitt.
22. Abhijit, α, ϵ, ζ Lyr	22. Sa'd aḍ-ḍābih, α, β Capricorni	9. Nieu, β Capric.

23. Śravaṇa, α, β, γ Aquil	23. Sa'd Bula, ϵ, μ, ν Aquar.	10. Nu, ϵ Aquar.
24. Śraviṣṭhā, β, α, γ, δ Delphin	24. Sa'd as—Su'ūd, β, ξ Aquar.	11. Hiu, β Aquar.
25. Śatabhiṣaj, λ Aquarii	25. Sa'd al—Akhbiya, α, γ, ζ, η Aquar.	12. Goei, α Aquar.
26. Pūrvabhādrapadā, α, β Pegasi	26. First Fargh, like *nakṣ*	13. Che, α Pegasi
27. Uttarabhādrapadā γ Pegasi, α Andromedae	27. Second Fargh, like *nakṣ*	14. Pi, γ Pegasi
28. Revatī, ζ Piscium	28. Baṭn al-Ḥūt β Andromedae etc.	15. Koei, ζ Andromedae

In volume 8 of the *Journal of American Oriental Society,* William D. Whitney critically compared the opinions and arguments of Biot and Weber, and put forward his own suggestions. While noticing the two systems of 28 and 27 *nakṣatras,* Biot had described the former as the 'ancient' and the latter 'modern' *nakṣatra,* Whitney showed that such a distinction was uncalled for and had 'no foundation whatever in the facts of the Hindu Science'.[44] In the siddhāntas one looks in vain for any connected account of the system,—history, names, member, orders etc. of the asterisms, presumably because this type of information is assumed on the part of the users of the text. Whitney pointed out another error in Biot's assumption, namely, that the declination circles passing through the junction stars cut up the ecliptic into a number of positions which, according to him, constituted the ancient system of lunar mansions. Such is not the case with the Sanskrit texts. By this method Biot transferred to Indian *nakṣatras* some of the characteristics of the Chinese *hsius* so as to strengthen his arguments in favour of his own opinions. In the Chinese system the declination circles through the *hsiu* stars divide the celestial sphere into a number of zones or mansions so that any planet crossing such a declination circle enters the corresponding *hsiu* mansion. In the Hindu astronomical *siddhāntas* the position of the junction star is defined with a view to facilitate the calculation of a conjunction; such definition does not mean the commencement of the planets' continuance in the *nakṣatra.* This *nakṣatra* is indeed a space, being one-twentyseventh part of the ecliptic of 360° or 800′ arc. The Moon spends about a day in each *nakṣatra* and momentarily comes into a state of conjunction with the junction star, generally the most conspicuous in the group of stars or constellations concerned. Whitney also gave a good exposition of the Hindu system of coordinates employed to represent the celestial objects in the sphere.

Weber assumed that the *nakṣatras,* like the *hsius,* are virtually single stars, marking out the heavens and giving names to the intervals. If that was really the case, Whitney commented, the Indian system must have undergone essential variations. The *Sūrya-siddhānta,* it is true, divided the ecliptic into 27 equal portions, but if these portions were carried from one group to the next one would arrive at quite a different series. Whitney pointed out that Garga and Brahmagupta had assigned one-twenty-seventh part of the ecliptic (800′ arc) equally to only 15 *nakṣatras,* the same amount increased by half (1200′ arc) to each of 6 *nakṣatras,* and just half of the same (400′ arc) to each of the remaining 6 *nakṣatras.* On the question of 27 or 28 *nakṣatras,* the times of the *Taittirīya Saṃhitā* mentioning 27 and those of *Taittirīya Brāhmaṇa* and the *Atharvaveda* (19th book) mentioning 28 do not differ by such a great margin as to suggest the priority of either of them; possibly there was an intermingling of the two systems. Nevertheless Whitney conceded that upon Indian grounds alone the theory of the originality of the series of 27 *nakṣatras* expanding later on into one of 28, was more probable, although such a theory could not be forced by facts.[45]

Whitney arrived at the conclusion that the efforts of both Biot and Weber were of a negative character. If Biot's argument for the originality and immense antiquity of the *hsiu* system influencing countries lying farther west was entirely nugatory, Weber's attempt to prove the priority of the *nakṣatra* system leading to the *hsius* and the *manāzil* proved no less a failure. He was, therefore inclined to believe that probably some fourth people, different from all so far considered, were entitled to the honour of inventing the institution of lunar mansions, which in time diffused to other cultivated races of Asia.[46]

In the same volume of the *Journal of American Oriental Society,* Ebenezer Burgess, translator of the *Sūrya-siddhānta* traversed the same ground and expressed himself more or less in favour of the priority of the *nakṣatra* system. The system which he characterized as scientific was known in India as early as the fifteenth century B.C., and that, not as a semi-mythological fancy but as a scientific system based on astronomical observations and discoveries.[47] He agreed with Weber that the origin of 24 out of 28 *hsius* was of doubtful antiquity and that the full series of 28 did not appear in the Chinese literature earlier than 250 B.C. He pointed out that Biot's estimate of Chinese astronomy was based on exaggerated views of Romish missionaries, particularly those of Father Gaubil on which Delambre had already commented. After dealing in some detail with the coincidences and dissimilarities between the *hsius* and the *nakṣatras* he arrived at the conclusion that these two systems had no genetic relation to each other; if either was modified by the other, the modification was in this respect that the number 28 in the former was derived from the latter.[48]

Whitney had suggested the possiblity of a fourth nation outside the Indians, the Chinese and the Arabs, inventing the institution of lunar mansions. By his philogogical interpretation of 'mazzaloth', Weber was striving to show an old Babylonian connection with the Arabian *manāzil.* In 1891, Fritz Hommel, an assyriologist studied the Babylonian lunar stations, showed how their series of 24 lunar stations were derived from an original list of 36 normal stars, and concluded that these lunar and planetary stations made use of by the Babylonians at the time of the Arsacide kings could be the basis of the Arabic as well as of the Indian and Chinese series of stars and star groups delineating the ecliptic. Although he was primarily concerned with the origin and antiquity of the Arabian *manāzil,* his preference for old Babylonian as the home of invention of the most ancient system immediately attracted widespread attention. He even suggested that the lunar mansions originally numbered 24 and ultimately developed into the series of 27 or 28 farther East through processes of diffusion. Hommel's Babylonian series with corresponding *manāzil* are given below :

Babylonian series	*Manāzil*
1. Timinnu, η Tauri	aṭ-ṭuriyā, η Tauri
2. Pidnu, α Tauri	al-debarān, α Tauri
3. Şur Narkabti, β, α, ζ Tauri	al-haq'a, λ, φ', φ Orionis
4. Pū Tu'āmi, η, μ Geminorum 5. Tu'āmi, Şa re'i γ Geminorum	al-han'a, η, μ, ν, γ, ξ Geminorum
6. Tu'āmi, α, β Geminorum	aḍ-ḍirā, α, β Geminorum
7. Pulukku, γ, δ, Cancri	an-naṭra, γ, δ Cancri
8. Ris arī, ε Leonis	aṭ-ṭarf, λ Leonis
9. Şarru, α Leonis	al-jabha, α Leonis
10. Māruşa rību arkat, Şarri, ρ Leonis	az-zubra, δ, θ Leonis
11. Zibbat arī, β Leonis	aṣ-ṣarfa, β Leonis
12. Şipu arku şa ari, β Virginis 13. Şur ardati, γ Virginis	al-'awwā, β, η, γ Virginis
14. Nābu ardati, α Virginis	as-simāk, α Virginis al-ghafr, ι, κ, λ Virginis
15. Zibānītu, α, β Librae	az-zubānay, α, β Librae
16. Ris akrabi, δ, β Scorpionis	al-iklīl, δ, π, β Scorpionis
17. Ḫabrud, α Scorpionis	al-qalb, α Scorpionis
18. Mātu şa Kasil, θ Ophiuchi	as-Saula, λ, ν Scorpionis
19. Karan sug'ar, α, β Capricorni	ad-ḍābih α, β Capricorni Bula, ε, μ, ν Aquarii
20. Sug'ar, γ, δ Capricorni	as-su'ud, β, ξ Aquarii
21.	al-aḥbiya, α, ȳ, ζ , η Aquarii
22.	ad-dalwu, α, β, γ Pegasi; α Andromedae
23. Rikis nūni, η (Piscium)	al-ḥut, β Andromedae
24. Rīs Kuṣarikki, α, β Arietis	an-nath, β, γ Arietes al-buṭain, *a*, *b*, *c* Muscae

Hommel was aware that the Babylonian series of 30 or more stars differs obviously from the lunar zodiacs comprising 27 or 28 stars or star groups. He therefore argued that the Babylonian as well as Arabian and other series originally comprised 24 members only. As to the Arabian series he stated that (i) al-fargh al-awwal (α and β Pegasi) and al-farg aṣ-ṣāni (γ Pegasi and α Andromedae originally formed one mansion, (ii) aṣ-ṣarfah (β Leonis) was a later insertion, and Uttara and Pūrva phalgunī originally formed one *nakṣatra,* (iii) al-iklīl and as-zubānay was one station, and (iv) al-baldah was not possibly included in the original list.

George Thibaut, the noted indianist whose various contributions to Indian astronomy will be noticed presently found it difficult to accept Hommel's views.[49] From very early times the Babylonians had indeed a solar zodiac of twelve signs which could theoretically split into two or three parts giving rise to a series of 24 or 36 stars but no proof existed that they actually used a series of 24 stations in connection with the lunar motion. The series of 27 or 28 was employed by the Indians, the Chinese and the Arabs to follow lunar motions, and represented divisions of the ecliptic. The Babylonian zodiac of 24 or more asterisms does not appear to be divided into an equal number of parts to which the motions of the Moon and planets are referred. For such reference they used the normal stars. When the members of the Babylonian series are compared with those of the three other systems disagreements are so wide as to militate against any diffusion theory. Whenever specially bright stars were selected for inclusion in the series agreements were inevitable; for example, α Tauri, α Leonis, α Virginis, and α Scorpionis are all stars of the first magnitude. Pleiades, α, β Geminorum, α, β Librae are well defined and conspicuous stars close to the ecliptic and could not fail to be included in any series intended to mark the ecliptic. The common origin theory with Babylon as the centre of diffusion was therefore no more successful than the efforts of the sinologists and the indianists to trace the origin of the lunar mansions to the *hsius* and the *nakṣatras* respectively.

Bhāu Dāji On Āryabhaṭa, Kern On Bṛhatsaṃhitā

In the sixties of the last century, while the lunar mansions controversy was in full swing, Bhāu Dāji examined the age and authenticity of Āryabhaṭa and other notable ancient astronomers.[50] He noticed two astronomical works,—*Mahā Ārya-siddhānta* and *Laghu Āryasiddhānta*, bearing the same name as their authors. The latter work was found to be the same as the *Āryabhaṭiya*, comprising the *Daśagītikā* and the *Āryāṣṭaśata* from which Brahmagupta and others quoted extensively and whose date was given by Colebrooke as the end of the fifth century A.D. Bhāu Dāji showed that this work was by Āryabhaṭa of Kusumapura (Paṭaliputra) who was born in A.D. 476 as clearly stated in the text. The other work was a much later compilation for which Bhāu Dāji fixed the date around A.D. 1322. In 1865 H. Kern produced a critical edition of Varāha's *Bṛhatsaṃhitā*, to which he added an illuminating preface contributing to our knowledge of ancient Indian astronomers and astrologers.[51] In connection with his study Kern collected all extracts from *Āryabhaṭiya* quoted by Bhaṭṭotpala in his commentary on the *Bṛhatsaṃhitā* and later on, following the discovery of the *Āryabhaṭiya* text, published the Sanskrit text with the commentary *Bhaṭadīpikā* by Paramâdīśvara from Leiden. It is needless to mention that the availability of the text greatly facilitated investigations into his mathematics and astronomy, much of which was carried out in the present century.

Vedāṅga Jyotiṣa

The *Vedāṅga Jyotiṣa* as an astronomical appendage to the Vedas had attracted attention from the early part of the nineteenth century. Weber in 1862 and Thibaut in 1877 presented a more or less full study of the text which only served to enhance the importance of an early notice of this subject by Colebrooke. In 1805, Colebrooke, in his pioneering studies of the Vedas or sacred writings of the Hindus, commented on the *Vedāṅga Jyotiṣa* as follows: "To each Veda, a treatise, under the title of *Jyotish*, is annexed; which explains the adjustment of the calendar, for the purpose of fixing the proper periods for the performance of religious duties. It is adapted to the comparison of solar and lunar time with the vulgar or civil year; and was evidently formed in the infancy of astronomical knowledge. From the rules delivered in the treatises, which I have examined, it appears, the cycle (Yuga) there employed, is a period of five years only. The month is lunar; but at the end, and in the middle, of the quiquennial period, an intercalation is admitted by doubling one month."[52] Colebrooke also mentioned the *Jyotiṣa's* division of the zodiac into twenty-seven *nakṣatras* headed by Kṛttikā. Most importantly he noticed the placement of the colures in the *nakṣatra* circle in the important verse *svarākramete* etc. and gave a literal translation of the verse, which has been used in determining the antiquity of the astronomical knowledge embodied in the *Jyotiṣa.*

Weber, in his *Uber den Vedakalender Namens Jyotisham,* provided a complete and critical edition of the *Jyotiṣa* based on a number of manuscripts and a commentary by Somākara, together with a complete translation and explanation of the highly cryptic verses. He noted that, as an appendage of the Veda, like *śikṣā* and *chanda,* the *jyotiṣa* was available in two recensions, e.g. *Ṛk* containing 36 verses and *Yajus* with 43 or 45 verses. He noticed some Greek and Babylonian influence on the *Jyotiṣa,* particularly in its rules concerning the variation of day-lengths with seasons.[53]

Thibaut recognized the extremely corrupt form of all manuscripts containing Somākara's commentary due largely to the commentator's misunderstanding of the majority of the enigmatical rules. Somākara's chief merit consisted in his use of the *Gārgi Saṃhitā* and thereby preserving the quotations of the latter, no longer extant. The central feature of the *Jyotiṣa* is its adoption of a cycle of 5 years, beginning with the white half of the month of Māgha and ending with the dark half of the month of Pauṣa.[54] The year is obviously one-fifth of this cycle, and consists, according to verse 28, of three hundred and sixty-six days, six seasons, two *ayanas,* and twelve months considered as solar. The year meant is the tropical solar year. By comparing this with Garga's description of the quinquennial cycle, it is found that a *yuga* is composed of 1830 *sāvana* days, making the year consisting of 366 days. Weber supposed this tropical solar year to be an importation from a foreign country. Thibaut did not agree with him because both *yugas,* the Vedic as well as that of the *jyotiṣa* could not have been formed but for the knowledge of the difference of five years of 360 days and of 60 lunations from the time during which the Sun performed five tropical revolutions.

From the units of time measurement,—*kalā, nāḍikā, muhūrta, akṣara, kāṣṭhā* etc. Thibaut calculated a day to be equal to 603 *kalā,* a *tithi* 593 $\frac{17}{62}$ *kalā,* and a *nakṣatra* day 549 *kalā.* Somākara gave the duration of a *tithi* as 562 $\frac{4}{5}$ *kalā* manifestly much shorter than what it should be. Weber also noticed this discrepancy.

The *Jyotiṣa* recognized the variation of the day-length and gave a rule for finding the relative length of the day. The length of the nycthemeron is given as 30 *muhūrtas,* that of the shortest day as 12 *muhūrtas* and that of the longest day as 18 *muhūrtas.* In the course of one *ayana* of 183 days the day-length increased by 6 *muhūrtas,* making the rate of increase per day 2/61 *muhūrtas.* From this rate the length of any day between the two solstices can be easily determined. Thibaut believed that such estimations of the longest and shortest days and the method of finding variations in day-lengths had generally prevailed in India before the impact of Greek science became obvious. The *Purāṇas*, the Jaina astronomical tracts like the *Sūryaprajñapti,* the *Paitāmaha-siddhānta* as summarized in Varāha's *Pañcasiddhāntikā* all give the same rule. One important point put forward in favour of borrowing is that variations of length of this order of magnitude are typical of latitudes in certain places of West Asia (e.g. Babylon), but it is also true of the extreme north-west corner of the sub-continent. "I am entirely of the opinion", observed Thibaut, "of Prof. Whitney who sees no sufficient reason for supposing the rule to be an imported one. It is true that the rule agrees with the facts only for the extreme north-west corner of India; but it is approximately true for a much greater part of India, and that an ancient rule—which the rule in question doubtless is, agrees best with the actual circumstances existing in the North-West of India is after all just what we should expect."[55]

The *Jyotiṣa* has dealt at considerable length with positions of the new and full moons in the *nakṣatras* during the whole quinquennial period. This question was of prime importance in Vedic times because of many sacrifices being performed on such days. In a five-year cycle there are 62 synodical *(cāndra)* months and therefore 124 *paryans,*—62 full moons and 62 new moons. On the basis of the Moon's passage in a synodical month of $29\frac{11}{62}$days and in a *pakṣa* of $14\frac{78}{124}$, Thibaut worked out the positions of all the 62 full and 62 new moons in the *yuga* in agreement with the text. In fact, the method represented another way of dividing the zodiac on the basis of 124 for readily reckoning the positions of new and full moons which served the purpose of a five-year calendar.

Jaina Astronomy

In 1865, Weber noticed a Jaina astronomical text, the *Sūryaprajñapti* and pointed out that it more or less embodied the same astronomical elements as characterized in the *Vedāṅga Jyotiṣa.*[56] Thibaut published a detailed study of the text in the *Journal of the Asiatic Society of Bengal* and showed that the system was based on a period containing 61 solar months of 30 *sāvana* days each, 62 lunar months and 67 sidereal revolutions of the Moon. These data yield 29.516129 days for the period of the Moon's synodic revolution and 27.313433 days for that of its sidereal. These periods are slightly shorter than those given in the *Sūrya-siddhānta.* In a period of 19 solar years there are 235 synodic months and 254 sidereal months of the Moon. If the corresponding number of days be worked out the Jaina text would give 14.084 days more than the *Sūrya-siddhānta* for 19 solar years, but 3.399 days and 2.093 days less than *Sūrya-siddhānta* values for the corresponding synodic and sidereal months. Thus the *Sūryaprajñapati,* like its Brāhmaṇa authority, the *Vedāṅga Jyotiṣa,* represents a less accurate system than the later *siddhāntas.*

Unlike the *Vedāṅga Jyotiṣa,* the *Sūryaprajñapti* uses a system of 28 *nakṣatras* of unequal space. Since a sidereal month consists of $819\frac{18}{20}$ *muhūrtas,* and on an average a *nakṣatra* accounts for a day, the Moon's passage through the asterisms must encompass 28 *nakṣatras,* one of them having a space of only $9\frac{18}{20}$ *muhūrtas.* But then the spaces are made unequal in such a way that one group of six (4th, 7th, 12th, 16th, 21st and 27th from *Aśvini*) are assigned $1\frac{1}{2}$ days each, another group of six (2nd, 6th, 9th, 15th, 18th, and 25th) half a day each, and the rest 1 day each. Brahmagupta has given the value of the Moon's sidereal motion in degrees, minutes etc. as 13°10′34″..88, by adopting which Burgess has calculated the *nakṣatra* spaces as follows :—[57]

6 of 19°45′52″.32 each	—	111°35′13″.92
6 of 6°35′17″.44 each	—	39°31′44″.64
15 of 13°10′34″.88 each	—	197°38′43″.19
		355°45′41″.75
Abhijit for 0.3216673 day	—	4°14′18″.25
		360° 0 0

The balance space of 4°14′18″.25 is assigned to *Abhijit.*

The peculiarities of the Jaina astronomy demanded two sets of the Sun and Moon and *nakṣatra* series, for which Brahmagupta severely criticized the Arhats.

VARĀHAMIHIRA'S PAÑCASIDDHĀNTIKĀ

Varāha's *Pañcasiddhāntikā* had been known, only in quotations and references from the early part of the nineteenth century. In 1874, G. Bühler in his search for Sanskrit manuscripts in the Bombay Presidency was rewarded with the discovery of two manuscripts of this important text. Ten years later Thibaut, in collaboration with Sudhakara Dvivedi, produced an edited text, a running translation of the cryptic verses, and an excellent introduction. Thibaut correctly assessed the importance of the work in Indian astronomical literature because of the author's predilection for historical approach. Varāhamihira, in Thibaut's judgement, was the only astronomer who realized the importance of various astronomical doctrines and systems current in his time even though some of them were defective, recorded a critical account of them, and did not hesitate to acknowledge the sources even when these were foreign. '*Pañcasiddhāntikā,*' he wrote, 'thus becomes an invaluable source for him who wishes to study Hindu astronomy from the only point of view which can claim the attention of the modern scholars, viz. the historical one.'[58]

Pañcasiddhāntikā is a *karaṇa* work in as much as it provides for a set of rules sufficient for speedy astronomical computations. It has mentioned a large number of *siddhāntas,* but selected only five most important among them, e.g. the *Sūrya-,Romaka-,Pauliśa, Paitāmaha-*and *Vaśiṣṭha-siddhānta* in order of importance. He considered the *Sūrya-*

siddhānta to be the most accurate, the next two, the *Romaka* and *Pauliśa* to be about equally correct, and the last two to be inaccurate. The five works extant in Varāha's time were not separately treated but often mixed up along with his own independent compositions. Thus in his introductory verses in ch.1 he deals with the method of computing *ahargaṇa* according to the *Romaka-siddhānta* along with an exposition of the principles of intercalation followed in the *Pauliśa-,Romaka-*, and *Sūrya-siddhānta.* Yet from the directions given at the end of the chapters Thibaut and Dvivedi had no difficulty in identifying Varāha's summary of the five *siddhāntas* as well as his own free discussions on the three fundamental questions *(tripraśna)*: the sphericity of the earth and the celestial sphere, instruments and observations, secrets of astronomy etc.

Starting with the least accurate of the five, the *Paitāmaha-siddhānta* is presented in ch. 12 in five stanzas. This *siddhānta* belongs to the category of the *Vedāṅga Jyotiṣa, Sūryaprajñapti* and *Garga Saṃhitā* and teaches a five-year luni-solar cycle comprising 5 solar years of 336 days, 60 solar, 62 synodical and 67 *nakṣatra* (sidereal revolutions of the Moon) months. The cycle commences at the moment of conjunction of the Sun and the Moon at the first point of Dhaniṣṭhā. Like the *Vedāṅga Jyotiṣa* the longest day is given as 18 *muhūrtas* and the shortest as 12 *muhūrtas*. There are some differences also. It gives a rule for calculating *Vyatipāta,* which is missing in the *Jyotiṣa* and the *Prajñapti.*

Some of the elements of the *Vaśiṣṭha-siddhānta* are discussed in chapters 2 and 18 (last chapter according to Thibaut). That the 2nd chapter embodied Vaśiṣṭha's teachings was attested by Varāha in the last stanza 13 'this is the calculation of the shadow according to the concise *Vaśiṣṭha-siddhānta*'. This chapter deals with, among other things, rules for calculating the length of the day at any time of the year, but these rules, although reminiscent of those given in the *Paitāmaha-siddhānta* and the *Vedāṅga Jyotiṣa,* give different values for the shortest and longest days. The chapter also provides rules for finding the length of the shadow, the mean longitude of the Sun and the *lagna,* which, notwithstanding their primitive nature, are superior to what *Paitāmaha* supplies. Thibaut also noted that Vaśiṣṭha operated with a sphere divided into signs, degrees and minutes in place of the ancient stellar zodiac.

Assuming that the small second chapter contained all that Vaśiṣṭha had to say, Thibaut was inclined to think that certain parts of the work were probably missing. Nevertheless he suspected, but did not definitely say, that the last chapter dealing with the courses of the planets probably contained some of the elements of Vaśiṣṭha's teachings. The rules give methods of computing the number of heliacal risings of planets in a given *ahargaṇa*. From the synodical revolutions thus found are determined the sidereal motions of the planets. Although he found many of the rules obscure and unsatisfactory, he recognized in them elements which did not differ greatly from those generally employed in Hindu astronomy.[59] The chapter itself does not provide any indication as to the sources from which the rules were compiled, but on the basis of the statement *vaśiṣṭha siddhānte śukraḥ,* he commented, "If we accept the former statement as true, it would follow that the *Vaśiṣṭha-siddhānta* possessed an accurate knowledge of the length of the planetary revolutions; for although the statement directly refers to Venus only, it is—for reasons not requiring to be set forth at length—altogether improbable that the *Vaśiṣṭha-siddhānta,* or in fact any *siddhānta,* should have been well informed about the theory of one planet only."[60]

On the question of the relationship of Varāha's *Vaśiṣṭha-siddhānta* and another work bearing the same name and known from the quotations of later authors, Thibaut particularly referred to Brahmagupta's quotation and suggested Viṣṇucandra as the author of the latter. Viṣṇucandra probably had access to the original *Vaśiṣṭha-siddhānta,* used its elements, and distorted the original teachings through a faulty understanding. The same Brahmagupta further informs us that one Vijayanandin was associated with the compilation of a *Vaśiṣṭha-siddhānta* and this Vijayanandin's name is further mentioned by Varāha himself in the last chapter in connection with planetary motions. None of the *Vaśiṣṭha-* versions compiled by Viṣṇucandra and Vijayanandin has survived. One *Laghu Vaśiṣṭha-siddhānta* (edited by Vindhyesvari Prasad Dube in 1881) which Thibaut examined did not agree with the teachings of the version summarized by Varāha, so that the question of authorship of the original *Vaśiṣṭha-siddhānta* remained an open one.

Astronomical elements of the *Romaka-siddhānta* are scattered over chapters 1, 4, 8. The *Romaka* used a *yuga* of 2850 years, containing 1050 intercalary months *(adhimāsas)* and 16547 omitted lunar days *(tithipralayas).* Reduced by 150 these elements lead to the well known metonic cycle of 19 solar years containing 235 synodical months and 7 intercalary months. Thibaut also deduced the number of natural or civil days in this *yuga* and determined the year length to be $365^{d}5^{h}\ 55'12''$, agreeing with the tropical year of Hipparchus of Ptolemy. The rules for computing the *ahargaṇa* for finding the mean longitudes of planets are given in ch. 1 and the mean longitudes of the Sun and the Moon in ch. 8. The Moon's sidereal revolution is stated to be $27^{d}7^{h}43'6.3''$. The Moon's anomalistic month is worked out to be $27^{d}13^{h}18'32.7''$ from the revolution of its *kendra* 110 times in 3031 days. For the correction of the Sun's mean motion, the longitude of its apogee is given as 75°. Although no general rule for finding the equation of the centre is provided its values for anomalies 15°, 30°, 45°, 60°, 75° and 90° are given, some of which agree closely with those of Ptolemy, as shown below :

Degree of Anomaly	15	30	45	60	75	90
Equation of Centre: Romaka	34′42″	1°8′37″	1°38′39″	2°2′49″	2°17′5″	2°23′23″
Equation of Centre: Ptolemy		1°9′		2°1′		2°23′

The Moon's equations are likewise dealt with, but the values given disagree with those by Ptolemy. The period of the revolution of the Moon's node is given as 6796 days 7 hours closely agreeing with Ptolemy's value of 3796^d 14^h etc. Other elements presented include the angular diameters of the Sun and the Moon as 30′ and 34′ respectively, the parallax in longitude of the Sun and the Moon (the difference is given), and the parallax in latitude of the Moon, that of the Sun being neglected. Another peculiarity of the *Romaka* is that the meridian of Yavanapura is adopted for *ahargaṇa* computation and that of Ujjayinī, for determining the mean places of the Sun, Moon and other planets.

Colebrooke and Bhāu Dāji, on the authority of Brahmagupta and his commentator Pṛthūdakasvāmī attributed to Śrīṣeṇa the authorship of the original *Romaka-siddhānta*. By comparing a number of manuscripts of the *Brāhmasphuṭasiddhānta.* (Bombay Government, Benares College and Royal Library of Berlin) Thibaut established that the manuscript used by Colebrooke was defective, and that Śrīṣeṇa was not an original writer but a careless compiler from various authorities. Thus he borrowed from Lāṭa rules concerning the mean motions of the Sun and Moon, and Moon's apogee and node, and the mean motions of Mercury's *śighra,* Jupiter, Venus' *śighra* and Saturn, and from Āryabhaṭa those relating to apogees, epicycles and nodes, and also the true motions of planets. As regards the *Romaka,* Śrīṣeṇa borrowed several elements from various heterogeneous sources and incorporated them in the original *Romaka-siddhānta,* and thereby transformed 'a heap of jewels' into 'a patched rag' *(śrīṣeṇena gṛhītvā ratnoccayo romaka kṛta kanthā).*[61] Thus, there was an original *Romaka-siddhānta* in many ways different from the revised and inferior text due to Śrīṣeṇa, on the authority of Brahmagupta. If Śrīṣeṇa be out, what would be the position of Lāṭadeva in connection with the *Romaka-siddhānta*? In ch.I, 3, Varāha himself mentioned Lāṭadeva as an expounder of the *Romaka-siddhānta* and also as an able astronomer who directed the computation of *ahargaṇa* from the moment the Sun had half set at Yavanapura. From this as also from Brahmagupta's references to Lāṭa, Thibaut rated him as an astronomer of no mean order, who in all probability did not write an ordinary commentary of the *Romaka,* but carried out the more difficult task of recasting the original so as to conform to a later epoch, namely Śaka 427, which Varāha adopted for his *Pañcasiddhāntikā* with Lāṭa's version of *Romaka* before him.

The elements of the *Pauliśa-siddhānta,* according to Thibaut, are discussed in chapters 1, 2, 3, 4, 5 and 6. The *ahargaṇa* rules given in ch.1 are marked by the distinction that the computations are not based on any cyclic period comprising integral numbers of years, lunar months and omitted lunar days, but are carried out directly by setting up a small aggregates of days containing approximately one intercalary month or one omitted lunar day. The rules for finding lunar positions, as discussed in ch.2, proved even more intriguing. Thibaut succeeded in interpreting these rules by applying the *Vākyam* process as obtaining among astronomers in South India and explained long ago by Bailly and John Warren. The merit of this process is that true places of the Sun and the Moon can be found without first obtaining their mean places. For this purpose four periods called *Vedam, Rasa Gherica, Calanilam,* and *Devaram* and consisting of 1600984, 12372, 3031 and 248 days respectively are used. These periods are such that the Moon can undergo complete anomalistic revolutions, e.g. *Devaram*—9 revolutions; *Calanilam*—110 revolutions; etc. For the motion of the Sun, however, the procedure appears to be based on the determination of the mean positions and applying to them the equation of centre of which a few values are given. Although no formula for finding the equation of centre is given, eccentric (or epicyclic)-cum-trigonometrical methods are indicated behind these values. The longitude of the Sun's apogee is stated to be 80°. Convenient numerical formulas for the computation of the eclipses are given, but no exposition of the theory of eclipse. Chapter 4 gives a sine table for $R=120'$, but it cannot be ascertained whether it is typical of the *Pauliśa-siddhānta* or a general table applicable for computations in accordance with the elements of the three *siddhāntas, Romaka, Pauliśa* and *Sūrya.*

Varāha's scholiast Bhaṭṭotpala and Brahmagupta's Pṛthūdakasvāmī have frequently quoted from an astronomical work bearing the same name as the *Pauliśa-siddhānta.* From the investigations of these quotations by Colebrooke it was already known that the later *Pauliśa-siddhānta* used the elements of Āryabhaṭa, the *Sūrya-siddhānta,* and later authorities had already assumed the characteristics of later *siddhānta* texts. Thibaut noted important differences between Varāha's *Pauliśa* and that of the commentators,—in the length of the year, *ahargaṇa* computations, determination of planetary places and other features, which clearly indicate that the original work underwent a number of recasts.[62]

The *Sūrya-siddhānta,* the most accurate of the five systems according to Varāha's judgement has naturally claimed the largest space, its elements being spread over chapters, 1, 9 (solar eclipses), 10 (lunar eclipses), 11 (projection of eclipses), 16 (mean motion and planets) and 17 (true motion of planets). The importance of Varāha's account of the text as known to him is obvious in as much as this is the only astronomical system to have survived to the modern times. For purposes of comparison Thibaut chose to call Varāha's account as the old *Sūrya-siddhānta* and the text that has come down to us as the modern *Sūrya-siddhānta.* The old SS. uses as its period one-twentyfourth of a *mahāyuga* of 4,320,000 years, that is, 180,000 years and gives the number of intercalary months and omitted lunar days as 66389 and 1045095, from which the number of *sāvana* days in a *mahāyuga* works out to 1577917800; in the modern SS. this number is in excess by 28 days. This difference is reflected in the length of the year, the old SS. making it as $365^d\ 6^h\ 12'\ 36''$ as against the modern SS's value of $365^d\ 6^h\ 12'\ 36.''56$.

As to the elements of the Moon, its sidereal revolutions in the *mahāyuga* have the same value in both, slightly affecting the length of the period. Some other elements are tabulated below ;

	Old SS	Modern SS
Period of revl. of Moon's apogee	$3231^d\ 23^h\ 42'16.76''$	$3232^d\ 2^h\ 14'53.4''$
Revls. of Moon's apogee in a *mahāyuga*	488,219	488,203
Revls. of Moon's node in a *mahāyuga*	232,226	232,228
Moon's greatest latitude	270′	270′

Thibaut noted that the figures of the revolutions of the Moon's apogee and node and of its greatest latitude as given in the old SS. agreed with those given by Āryabhaṭa. In the computation of the Sun's equation of centre the longitude of its apogee is an important parameter; the old SS. gives it as 80° while the modern SS. and the *Āryabhaṭīya* advise the use of 77° and 78° respectively. The old SS. does not mention any motion of the Sun's apogee; but the modern *siddhāntas* recognize such a motion albeit very slow.

For planetary revolutions Thibaut compared the values given in the two *siddhāntas,* to which we add Āryabhaṭa's values as given in his *Ārdharātrika* system:

	Old *SS.*	Modern *SS.*	Āryabhaṭa *(Ārdharātrika)*
Mercury	17,937,000	17,937,060	17,937,000
Venus	7,022,388	7,022,376	7,022,388
Mars	2,296,824	2,296,832	2,296,824
Jupiter	364,220	364,220	364,220
Saturn	146,564	146,568	146,564

While the two *Sūrya-siddhāntas* disagree in all the cases except Jupiter, the old *SS.* agrees with Āryabhaṭa and also with Pauliśa as quoted by Bhaṭṭotpala. Regarding planetary apogees and dimensions of *manda* and *śighra* epicycles, Thibaut reported agreement between the old SS. and Brahmagupta's *Khaṇḍakhādyaka* but not so in respect of the modern SS. and the *Āryabhaṭīya.* The formulae by which the two inequalities are directed to be calculated are the same in the two *siddhāntas.*

Thibaut made it clear that a correct understanding of the evolution of the five *siddhāntas* would be necessary to form a fairly accurate notion of the transition of Indian astronomy from the pre-scientific stage to its modern form. The *Paitāmaha-siddhānta,* clearly based on the *Vedāṅga Jyotiṣa, Garga Saṃhitā,* and the Jaina astronomical concepts, represented the pre-scientific stage. The *Vaśiṣṭha-siddhānta,* representing a more advanced form, probably belonged to the transitional period. The remaining three siddhāntas,—*Romaka, Pauliśa* and *Sūrya,* represented the modern phase of Hindu astronomy and were inspired by Greek teaching.[63] Thibaut thought it highly probable that the earliest Sanskrit works in which this inspiration manifested ttself were the *Pauliśa* and the *Romaka,* using the Metonic cycle, the tropical year, giving the longitude difference between Ujjayinī and Yavanapura, and computing *ahargaṇas* from the meridian of the latter. But all sorts of difficulties arise when we attempt to pinpoint the channels of transmission. The great influence and prestige of Ptolemy in the ancient world would have suggested his *Syntaxis* as the source of main inspiration in Indian astronomical renaissance, but such a conjecture is negatived by a comparison of any of the early *siddhāntas* of this transitional period with the Greek astronomical masterpiece. Whitney had suggested that the original transmission took place before Ptolemy, possibly between the time of Hipparchus and Ptolemy. Thibaut considered the possibility of the *siddhantās* deriving the Greek elements from manuals, astrological works and tracts concerning calendar making, a class of literature quite different from scientific astronomical treatises worked up by men like Hipparchus, Ptolemy or Theon. Such a conjecture, he believed, would 'help to render the whole process of transmission more intelligible.'[64] In recent years some good results have actually been achieved through investigations of the Greek and Sanskrit astrological literature of this period.

AL-BĪRŪNĪ ON INDIAN ASTRONOMY

In the seventies of the last century Edward C. Sachau, of the Royal University of Berlin edited and translated into German and English al-Bīrūnī's *Kitāb Taḥqiq mā li 'l-Hind.* The manuscript of the Arabic text was prepared in 1872, a German translation of it between 1883 and 1884, and an English translation during 1885-86. The Arabic text appeared in print in 1885-86 and the English translation two years later in 1888. The work brought to light the investigations into astronomy and other sciences of India as well as into the history, geography, literature, manners, customs and beliefs of the peoples of the sub-continent by one of the greatest of scholars and scientists produced in the Arab culture area in the medieval times. Al-Bīrūnī's scientific interests were of an encyclopaedic nature extending from astronomy, mathematics and geography to medicine, religion, philosophy and magic. As an orientalist in his endeavours to understand the contributions of the Indians in exact sciences from original sources he achieved in the beginning of the eleventh century under adverse circumstances what European orientalists with much better equipments and facilities struggled to do in the beginning of the nineteenth century. Reinaud's *Memoire geographique historique et scientifique sur l'Inde* (Paris, 1849), Steins Chneider's papers on the history of translations from Sanskrit into Arabic and their influence on Arabic literature in the *ZDMG,* Fluggel's translation of *Fihrist,* Gildemeister's *Scriptorum* and a few other works had provided some glimpses into Indo-Arabic scientific exchanges at the beginning of the Arab intellectual revival. Sachau's translation and elaborate notes provided new materials for a better understanding of the state of scientific and astronomical knowledge of the Indians before al-Bīrūnī's time.

In the foundation of Arabic literature laid between A.D. 750 and 850, Sachau observed, the literature of Greece, Persia and India were taxed to help remove the sterility of the Arab mind.[65] As far as India's contribution is concerned, it reached Bagdad in two different roads as also in two different periods. Some of the Sanskrit works were directly translated into Arabic and others travelled through Iran having been first translated from Sanskrit or Pali into Persian and subsequently from Persian to Arabic. The first period was during the reign of Khalif al-Manṣūr (A.D. 753-774) and the second in Harun al-Rashid's time (A.D. 786-808). In the first period when Sindh was under the Khalif's rule, Indian embassies visited Bagdad, and such opportunities were probably utilized for the exchange of scholars. It was in this way that the Arab scholars came in contact with Indian astronomers and first learnt of Brahmagupta's two astronomical texts *Brahmasiddhānta (Sindhind)* and *Khaṇḍa-khādyaka (Arkand)*. These two works were translated by al-Fazārī and by Ya'qub ibn Ṭāriq with the help of Indian pandits and were possibly the first works to introduce the Arab scholars into a scientific system of astronomy.[66] Muḥammad ibn Ibrahim al-Fazārī hailed from a family of scientists and technicians, his father being a reputed astrolabe-maker and was the first propagator of Indian astronomy among the Arab scholars. Al-Bīrūnī quoted from his work, informed us of his use of the word *pala* meaning a 'day-minute' and his method of computing the longitude of a place from two latitudes, and discussed his planetary cycles as derived from Indian astronomers. "These star-cycles as known through the canon of Alfazārī and Ya'qūb Ibn Ṭāriq," al-Bīrūnī wrote in his *India,* "were derived from a Hindu who came to Bagdad as a member of the political mission which Sindh sent to the Khalif Almanṣūr, A.H. 154 (=A.D. 771). If we compare these secondary statements with the primary statements of the Hindus, we discover discrepancies, the cause of which is not known to me."[67]

Ya'qūb Ibn Ṭāriq, frequently mentioned by Bīrūnī, was well versed in astronomy, chronology and mathematical geography as practised in India. Al-Bīrūnī quoted his measures of the circumference and the diameter of the zodiacal sphere in *yojanas,* which agreed with the system of Pauliśa; the radius and circumference of the earth; and discussed his method for the computation of solar days in the *ahargaṇa,* which he found as incorrect. Bīrūnī remarked, "We have already pointed out..a mistake of Ya'qub Ibn Ṭāriq in the calculation of the universal solar and *ūnarātra* days. As he translated from the Indian language a calculation the reasons of which he did not understand, it would have been his duty to examine it, and to check the various numbers of it one by the other. He mentions in his book also the method of *ahargaṇa,* i.e. the resolution of years, but his description is not correct..."[68] In his account of the order of planets, their distances and sizes (ch. LV), Bīrūnī fully utilized the data given by Ya'qūb because 'the only Hindu traditions we have regarding the distances of the stars are those mentioned by Ya'qūb Ibn Ṭāriq in his book, *The Composition of the Spheres,* and he had drawn his information from the well-known Hindu scholar who in A.H. 161, accompanied an embassy to Bagdad."[69]

In discussing the important methods, processes and doctrines, Bīrūnī did not proceed on the basis of a single standard text, but gathered his materials from a number of *siddhāntas, tantras* and *karaṇas.* Under *siddhāntas* he included those works which were straight and not crooked or changing. *Tantras* or *karaṇas* represented another class of astronomical literature, which operated upon or followed a *siddhānta.* He thought that the Hindus had five *siddhāntas,* e.g. the *Sūrya-siddhānta* composed by Lāṭa, the *Vasiṣṭha-siddhānta* by Viṣṇucandra, the *Puliśa-siddhānta* by one Puliśa, the Greek from the city of Alexandria (Saintra), the *Romaka-siddhānta* composed by Śriṣeṇa, and the *Brahmasiddhānta* by Brahmagupta, son of Jiṣṇu from Bhillamala between Multan and Anhilwara. He also mentioned Varāhamihira's *Pañcasiddhāntikā* as an astronomical handbook of small compass, but probably he did not get a copy of it as it appears from his statement: 'the name does not indicate anything but the fact that the number of *siddhāntas* is five."[70] Of these five *siddhāntas* he was able to procure the books of Puliśa and Brahmagupta from which he quoted extensively. As an example of *tantra* he mentioned the work of Āryabhaṭa and Balabhadra. Under *karaṇa,* he included Brahmagupta's, *Khaṇḍakhādyaka* representing the doctrine of Āryabhaṭa, Vijayanandin's *Karaṇa-tilaka,* Vitteśvara's *Karaṇa-sāra,* Bhānuyaśa's *Karaṇa-para-tilaka* and a number of *karaṇa* works by Utpalas. Āryabhaṭa's *Daśagitikā* and *Āryāṣṭaśata* were also mentioned under this class. Moreover, several astrological *saṃhitās,* and *jātakas* or books of nativities are mentioned as his sources. Another important aspect of Bīrūnī's researches was his intensive use of the astronomical information contained in the *Purāṇas,* of which his main sources were *Vāyu, Viṣṇu, Matsya* and *Āditya Purāṇas.*

Bīrūnī did not follow the usual chapter sequence typical of astronomical texts in arranging his topics. He introduced a large number of small chapters to discuss one astronomical topic or concept at a time such as planetary names, zodiacal signs and lunar stations (ch. XIX): shape of heaven and earth (XXVI): Laṅkā, the coupola of the earth (prime meridian) (XXV): geographical longitudes (XXXI): various kinds of day (XXXIII): four measures of time *(sāvana-māna, cāndra-māna, nakṣatra-māna, tithi)* (XXXVI): definition of *kalpa* and *caturyuga* (XLI): starcycles in a *kalpa* and *caturyuga* (L): *adhimāsa, ūnarātra, ahargaṇa* (LI): calculation of *ahargaṇa* (LII, LIII): computation of mean longitudes of planets (LIV): order of planets, their distances and sizes (LV): lunar stations (LVI): solar and lunar eclipses (LIX): *parvan* (LX): Jupiter's sixty-year cycle (LXII). The list is not exhaustive. For each subject he presented the views of different authorities, critically examined them, and gave his own verdict in a true scientific spirit.

The Age of the Vedas from Astronomical Considerations

In the closing years of the last century H. Jacobi and B. G. Tilak interpreted certain passages of the *Ṛgveda* and the *Brāhmaṇas* as indicating the positions of the solstices and equinoxes in the stellar zodiac and suggesting from the known rate of precession the date of these texts. Jacobi's explanation of the 'frog hymn' in the *Ṛgveda,* VII, 103, 9, placing this *Saṃhitā* in the fifth millennium B.C. originally appeared in the *Festschrift* on the occasion of Prof. Roth's jubilee, translated into English By J. Morison for the *Indian Antiquary* (23, 154-159, June 1894). Tilak's paper entitled 'Orion' was presented at the Ninth International Oriental Congress, an abstract of which was published in the volume of the Congress. Bühler put on record that the honour of having found the new method of utilizing astronomical facts, mentioned in Vedic literature, belonged to Jacobi and Tilak jointly, though the latter had published his results earlier.[71]

The 'frog hymn' runs as follows: "They observe the sacred order of the year, they never forget the proper time, those men, as soon as in the year the rain time has come, the hot glow of the sun finds its end." Jacobi interpreted this hymn as indicating the beginning of the year with the rainy season on the basis of which terms '*varṣa*' or '*abda*' (rain-giving) were coined for the year.[72] From the *Sūryasūkta,* X. 85, 13 and its variant in the *Atharvaveda,* XIV, 1, 13, Jacobi further suggested that the summar solstice from which the early Ṛgvedic year began was then in Phalgunī. When the Sun at the summer solstice was in Phalgunī, the full-moon was in Bhadrapadā or Prauṣṭhapadā thus coinciding with the onset of the rainy season (Fig. 3.3). In this scheme the positions of the autumnal and vernal equinoxes would clearly be at the *nakṣatras* Mūla and Mṛgaśiras. At the autumnal equinox in Mūla

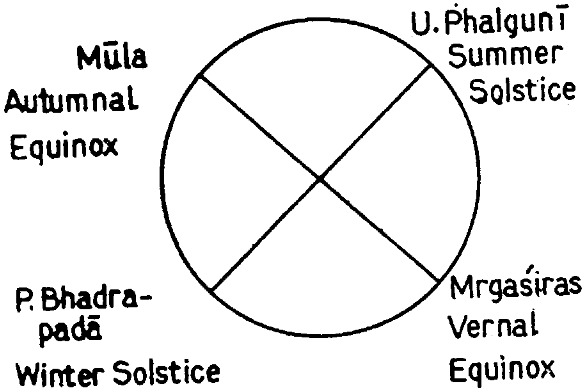

Fig. 3.3

the corresponding month from the full-moon in Mṛgaśiras was *Agrahāyaṇa,* which was the first month of the *śarad* year reckoned from the autumnal equinox. Moreover, Mūla was probably the first *nakṣatra* at one time which agrees with its etymological meaning "root-beginning". Its other name *vicṛtau* meaning 'dividers' points in the same direction. No less significant is the meaning of the preceding *nakṣatra* as Jyeṣṭha meaning the 'oldest', that is to say, the *nakṣatra* that kills or closes the old year.[73] Jacobi also suggested another year, the *himā* year, starting with the winter solstice in the month of *Phālguna,* because this month has often been described as the mouth (*mukhaṃ vā etat saṃvatsarasya yat phalgunī pūrṇamāsāt, Pañc. Br.* 5, 9.9).

Jacobi gave a table of longitudes of the principal stars of the *nakṣatras* for the years A.D. 560, 0 B.C., 1000 B.C., 2000 B.C., 3000 B.C., and 4000 B.C. In 4000 B.C. the longitudes of stars marking the equinoxes and the solstices were as follows: Mṛgaśiras—5°38; U. Phalgunī—93°.32; Mūla—186°.26; and P. Bhadrapadā—275°. 16. Therefore such a Vedic year and year beginning appear to have obtained a few centuries earlier than this date.

Tilak proceeded in a different way. In the *Vedāṅga Jyotiṣa* the year was no doubt made to commence with the winter solstice. The various sacrifices like the *gavām* *ayana* also commenced from the winter solstice day. This also appears to be the case from the use of the term *uttarāyaṇa* which meant the phenomenon of the Sun's turning north at the winter solstice. Here Tilak pointed out that in an earlier time this was not the case. The middle day of the annual *satra* is called the *viṣūvān* day, and this *viṣūvān* is the equinoctial day when the day and night are equal in length. Tilak then draws attention to the words '*devayāna*' and '*pitṛyāna*' frequently occurring in the *Saṃhitās, Brāhmaṇas* and *Upaniṣads*. These two paths, according to Tilak, represent the two halves of the ecliptic, *devayāna* representing the *uttarāyana* with which the three *deva* seasons, e.g. spring, summer and rains are associated, and *pitṛyāna* answering for the other half connected with the three *pitṛ* seasons *śarad, hemanta* and *śiśira*. The commencement of the former was thus marked by the vernal equinox and that of the latter by the autumnal one. "We must, therefore, hold," observed Tilak, "that *devayāna* in those days was understood to extend over the six months of the year, which comprised the three seasons of spring, summer and rains, i.e. from the vernal to the autumnal equinox, when the Sun was in the northern hemisphere or to the north of the equator."[74]

Having established that there were at least two year beginnings in the Vedic times, one at the vernal equinox and the other at the winter solstice, Tilak examined the question of the correlation of the *nakṣatra* series with the vernal equinox. He showed that in the *Vedāṅga Jyotiṣa* the vernal equinox was placed in the last quarter of Bharaṇī, from which a natural conclusion would follow that the vernal equinox coincided with Kṛttikā at the time of the *Taittiriya Saṃhitā*. Moreover, different statements of the *Taittirīya Saṃhitā* and *Brāhmaṇa* pointed to the same conclusion: "*firstly*, the lists of the *nakṣatras* and their presiding deities, given in the *Taittirīya Saṃhitā* and *Brāhmaṇa* all beginning with Kṛttikās; *secondly*, an express statement in the *Taittirīya Brāhmaṇa*, that the Kṛttikās are the mouth of the *nakṣatras*; *thirdly*, a statement that the Kṛttikās are the first of the *Deva Nakṣatras*, that is, as I have shown before, the *nakṣatras* in the northern hemisphere above the vernal equinox; and *fourthly*, the passage in the *Taittirīya Saṃhitā* above discussed, which expressly states that the winter solstice fell in the month of *Māgha*. The vernal equinox is referred to the Kṛttikās directly or indirectly in all these passages.."[75] On this basis, the date of the *Taittirīya Saṃhitā*, as shown by Whitney in his notes to the translation of the *Sūrya-siddhānta*, worked out to be 2350 B.C. If the placement of the corresponding asterism be taken to be 10°51′ from the initial point in the zodiacal circle, the date would be reduced by 792 years, or to about 1426 B.C.

Tilak then proceeded to prove the existence of another hidden internal evidence in the Vedic literature which pointed to a still remoter antiquity. This evidence is connected with certain passages in the *Taittiriya Saṃhitā* stating that the Citrā and Phalgunī full-moons (*citrā-pūrṇa-māsa* and *phalguni-pūrṇa-māsa*) were the beginnings of the year. He argued that the year beginning with the full-moon in Phālguna meant the coincidence of the winter solstice with the asterism Uttara Bhadrapadā, the summer solstice in Uttara Phalgunī, the vernal equinox with Mṛgaśiras and the autumnal equinox with Mūla, In other words, Tilak arrived at the same positions of the equinoxes and colours *vis-à-vis* the *nakṣatra* (Fig. 3·3) as did Jacobi from his consideration of the 'frog-hymn'. In analogy with the Kṛttikā, the Mṛgaśiras was then the mouth of the *nakṣatras*. Although no textual support in favour of this could be provided, the corresponding month of *Agrahāyaṇa,* also known as Mārgaśīrṣa was then possibly the first month of the year inasmuch as *āgrahāyaṇī* literally means 'commencing the year'.[76] Significantly enough the asterism Mūla was then 180° further from Mṛgaśiras. "I should rather suggest," continued Tilak, "that Mūla was so called because its acronycal rising marked the commencement of the year at the time when the vernal equinox was near Mṛgaśiras and winter solstice fell on the Phālgunī full-moon."[77] This is the same scheme as was hit upon independently by Jacobi, pointing to the antiquity of the Vedic literature in the neighbourhood of 4000 B.C.

Bühler welcomed these contributions as providing evidence for year-beginnings on various dates in the Vedic times. If the high antiquity of the Vedic literature following from astronomical considerations were somewhat hard to accept, Jacobi and Tilak's work provided support to the findings of research workers in the field of Brahmanical, Buddhist, and Jaina literature that the Indo-Aryan history extented very considerably beyond 1500 B.C.[78]

Whitney completely disagreed with the views expressed in these two papers. The authors, in his view, brought forward nothing that could force to change the hitherto current views on the antiquity of the sacred literature of the Indians. All inferences drawn from the *Brāhmaṇas* regarding year beginnings appeared to him 'helplessly weak support for any important theory.' As to Tilak's *devayāna* and *pitṛyāna* there was nothing so far brought to light in the *Ṛgveda* that would admit of *ayanas,* equinoxes and solstices being regarded as distances and points. That *agrahāyaṇa* itself designated the asterism Mṛgaśiras and proved to have been the first asterism of a series beginning and ending with the year was, according to Whitney, by no means to be credited in the absence of any passage exhibiting such use.[79]

Thibaut also disagreed with the views of Jacobi and Tilak, but before doing so he analyzed the same passages of the *Taittiriya Saṃhitā* and *Tāṇḍa Brāhmaṇa* with a view to proving that these admitted of a different interpretation. In the process he gave a masterly analysis of the Vedic months, years, solstices, *gavām ayana* and other relevant sacrificial rites which throw some light on the knowledge of astronomy in the Vedic times. About the Kṛttikā and Mṛgaśiras series simultaneously leaving their traces in the same Vedic texts, from which their two different degrees of antiquities separated by about 2000 years could be inferred, Thibaut observed, "It is certainly not antecedently probable that the Brāhmaṇa texts exhibited by us should, within their short compass, contain records of observations separated from each other by several thousands of years."[80] His other objections may be summarized as follows: (1) The month *Phālguna* as the mouth of the year occurs in several places of the *Brāhmaṇas* and has no more significance than a mere opinion: (2) solstices in Vedic India were looked upon as marking the beginning of the year: (3) in the Brāhmaṇa period full-moon in Phalgunī could not have coincided with the vernal equinox; (4) in India, vernal equinox did not in any way mark an important point in the revolution of the seasons; accordingly, equinoxes or anything connected with them are nowhere in the Vedic literature referred to either directly or indirectly; (5) the beginning of the spring of the *Brāhmaṇas* is thus in no way connected with the vernal equinox.

Thus by the end of the nineteenth century the study of ancient Indian astronomy was placed on a firm footing through the discovery of several important manuscripts and publication of their critical editions and translations. Most of the important authors and their commentators of the classical and medieval periods were reviewed and brought to light. The extent and quality of pre-scientific astronomical knowledge during Vedic times became crystallized. The study of Varāha's *Pañcasiddhāntikā* threw a flood of light on the transition of Indian astronomy from the pre-scientific to the scientific stage. Reinaud's notices and Sachau's translations of Al-Bīrūnī's investigations revealed the reception of Indian astronomy in the Arab countries during the early medieval period. Thus, was laid a solid and broad foundation for the history of astronomy in India from which to attempt further refinements and more detailed studies in the new century opened up. An admirable summary of the progress of knowledge in ancient India's contribution to astronomy, astrology and mathematics was given by Thibaut in the *Grundriss* in 1899.[81]

PROGRESS IN THE TWENTIETH CENTURY

Vedic Knowledge of Planets

Weber did not notice the mention of planets in any texts earlier than the *Taittirīya Āraṇyaka.* This raised the question whether the Vedic Hindus were acquainted with the planets. The seven *ādityas* mentioned in the *Ṛgveda* (IX. 114. 3) were interpreted by Oldenberg as referring to five planets in addition to the Sun and the Moon. Ludwig likewise interpreted the number 34 mentioned in the *Ṛgveda* (X. 55-4; I. 162.18) as the sum of 27 *nakṣatras,* 5 planets and the Sun and the Moon. In the *Orion,* Tilak showed that the words *śukra, manthin* and *vena* were sometimes mentioned in the *Ṛgveda* and the *Brāhmaṇas.* In his paper on Bṛhaspati and Tiṣya, Fleet quoted passages from the *Ṛgveda* and the *Taittirīya Brāhmaṇa* to prove that Bṛhaspati mentioned in them clearly referred to planet Jupiter. Thus, he gave *Ṛgveda,* 4.50.4 in English translation as follows: "Bṛhaspati, when first being born from a great light or brightness in the highest heaven, seven mouthed, of a powerful nature, seven rayed, with a deep sound blew away the darkness."[82] In the *Taittirīya Brāhmaṇa* (3.1.1.5.), Bṛhaspati is mentioned in connection with the *nakṣatra* Tiṣya in an astronomical sense, as follows: "Bṛhaspati, when first being born, came into existence over against the *nakṣatra* Tiṣya—he the best of the gods, victorious against hostile armies: let us be free from fear in all directions." These two verses are clearly related. Bṛhaspati again is the regent or presiding deity of the *nakṣatra* Tiṣya or Puṣya. This *nakṣatra* comprises three stars according to some and one according to others, and its principal star has been identified with δ Cancri in the constellation of Cancer (Praesaepe). This star cluster is usually visible to the naked eye as a misty nebular patch and is occasionally marked by the appearance of a new star or a nova. Fleet suggests that, when the *Brāhmaṇa* observation was recorded, Jupiter was quite close to Praesaepe in which a new star appeared with an exceptional outburst producing great light in the highest heaven. "In short," observed Fleet, "In these two passages, certainly, I would find a distinct mention of a planet in the Vedas; the planet in this case being Bṛhaspati, Jupiter."[83] In support of his interpretation, Fleet also quoted *Ṛgveda* verse 5.54.13 referring to the occasional disappearance of the star-cluster Praesaepe.

Keith did not believe that the Vedic Hindus were aware of the planets. According to him their *nakṣatra* system was borrowed from some other nation. Although he admitted that Fleet's arguments were ingeneous he gave a different construction to the passages and concluded that the new evidence adduced by him did not really help towards providing the Vedic knowledge of the planets.[84]

The Vedic Calendar

In 1912 R. Shamasastry carried out an investigation of several passages in the *Saṃhitās*, *Brāhmaṇas* and *Sūtra* literature to understand the efforts made in the Vedic times to evolve a workable calendar.[85] The term 'Vedic Calendar', he admitted, would be an anachronism because clear references to a calendar were wanting in the Vedas proper; but such was not the case in the *sūtra* literature which clearly recorded various attempts made to evolve calendars, which could be appropriately designated 'sūtraic calendars'. Nevertheless, allusions to a calendar, he maintained, were not altogether wanting in the Vedas. These allusions are to be found in the frequent use of the term *ekāṣṭakā* day, which meant the eighth day of the dark half of the month of *Māgha*, marking the beginning of the new year. Moreover, there are distinct references to the thirteenth month used for purposes of intercalation so as to make the lunar reckoning agree with the natural time.

The onset of the *ekāṣṭakā* day is hailed in the *Atharvaveda* (III, 10) as—'Hither hath come the year, thy spouse, O sole Aṣṭakā, do thou provide our long lived progeny with abundance of wealth.' *Tāṇḍyamahābrāhmaṇa* (V. 9.2.) has it: "What is called the *ekāṣṭakā* (day) is the wife of the year; when the night of this day arrives, (Prajāpati) lies with her. Hence, commencing with the (true) beginning of the year, (sacrificers) observe the rite of initiation." These and similar other verses make it clear that the year, possibly solar, used to begin on the eighth day of the dark half of the month of Māgha. The *ekāṣṭakā* day, Shamasastry suggested, was a lunar day. The lunar year from one *ekāṣṭakā* to the other comprised 354 lunar days. There was also a *sāvana* year of 360 days commencing on the *ekāṣṭakā* day which consequently needed an adjustment of 6 days between these two kinds of years. This was done by means of intercalation.

The practice of intercalation through the introduction of a thirteenth month was as old as the *Ṛgveda*. *Rv.* i.25.8 states, "He who, accepting the rites (dedicated to him) knows the twelve months and their productions, and that which is supplementarily engendered *(upajāyate)*." The word *upajāyate* means, according to

Sāyana's commentary, 'the thirteenth or additional month which is produced of itself, in connection with the year'. The *Atharvaveda* (XIII, 3.8) explicitly mentions the thirteenth month *(trayodaśaṃ māsaṃ yo nirmimite)*. In the Black *Yajurveda*, the thirteenth month is called a creeping month *(saṃsarpa)*, 'thou art the month of saṃsarpa; and thou art the receptacle of sin' (i.4.14). These and similar references in the *Brāhmaṇas* make it abundantly clear 'that the Vedic poets kept a calendar with far more scientific precession than we are pleased to credit them with.' Shamasastry argued that the idea of a thirteenth month could not have dawned upon the Vedic poets unless they had been familiar with the true lengths of several kinds of years. The intercalation by a thirteenth month was preceded by the practice of adjusting the two kinds of year by introducing sets of intercalary days, e.g. 9,11,12,21, etc.

The *Nidāna-sūtra* of the *Sāmaveda* provides evidence of different types of years and of different Vedic schools practising intercalation in various ways. In fact, the *sūtra* uses the term *gavām ayana* in the sense of a year containing a number of intercalated days inserted either in the middle or at the end. Literally the term means 'cow's walk', i.e. a series of intercalary days. Thus :

(a)	Synodic lunar year of 354 days Sidereal solar year of 366 days	*dvādaśāha* or period of 12 days to be added to every lunar year.
(b)	Sidereal lunar year of 351 days (13 months of 27 days each) *Sāvana* year of 360 days	9 intercalary days to be added.
(c)	*Sāvana* year 360 days Solar year of 365 ¼ days	21 days to be added to every fourth sāvana year.

Besides, there were a few other types of years, e.g. a sidereal lunar year of 324 days (27×12), sidereal solar year of 366 days and pseudo solstitial year of 378 days. Of the various forms of calendars used in the Vedic times, the principal ones appear to be the following :

(a) The sidereal lunar year of 351 days, with 9 or 15 days intercalated according as it was to be adjusted to the *sāvana* year of 360 days or to the sidereal year of 366 days.

(b) The synodic lunar year of 354 days intercalated with 12 days as stated above.

(c) The cycle of three *sāvana* years each of 360 days, intercalated with 18 days in every third or fourth *sāvana* year, for adjustment to the sidereal solar year of 366 days.

Berriedale Keith agreed with Shamasastry that there was a Vedic year of 360 days vouched for by the *Ṛgveda* and further that the Vedic Hindus were aware of the need for intercalation and practised it for keeping the seasons in check. 'The most that we can say on this head is that there are traces of a tendency to intercalate a month every fifth or sixth year, but that even for this the evidence is not cogent.'[86] He disagreed with Shamasastry's interpretation of *gavām ayana* as an intercalary period made up of any number of intercalary days, because this sense of the term was not hinted at by any ancient authority.

KAYE'S HINDU ASTRONOMY, ĀRYABHAṬA STUDIES BY P. C. SENGUPTA AND EUGENE CLARK

During the first three decades of the present century, George Rusby Kaye generated further interest in the study of mathematics and astronomy in ancient and medieval India. His researches in astronomy concerned spherical astronomy, Vedic astronomical dieties, Jai Singh's observatories and related subjects. In a publication of the Archaeological Survey of India he carefully described the metal and masonry instruments associated with the observatories built by the astronomer king,—astrolabes among the metal instruments, and *Samrāṭ yantra, Jai prakāś, Rāmyantra, digaṃśa yantra, nāḍivalaya yantra, ṣaṣṭyaṃśa yantra, rāśi valaya* and a few others. In another publication of the same Survey he traced the development of Hindu astronomy, noticing the labours of early investigators such as Cassini, Le Gentil, Bailly, Laplace, Davis, Jones, Bentley and Colebrooke; pre-scientific astronomy in the Vedic *Saṃhitās, Jātakas,* epics and the *Purāṇas;* special topics such *nakṣatras,* solstices and equinoxes, precession, Jupiter's cycle; a number of prominent astronomers like Puliśa, Āryabhaṭa, Varāhamihira and Brahmagupta; mathematical astronomy involved in such topics as ascensional difference, epicycles and equations of centre, parallax, and eclipses. Despite the merit of Kaye's diligent researches and prolific writings his works suffered somewhat for his strong bias in favour of foreign influence in the development of astronomy and mathematics in India.

It was no wonder that the challenge thrown up by the writings of Kaye should be taken up by Indian as well as some foreign scholars. From about the middle of the twenties Bibhuti Bhusan Datta, Sukumar Ranjan Das, Prabodh Chandra Sengupta, Walter Eugene Clark and a few others started a series of investigations on ancient Indian astronomy. Datta dealt with the question of two Āryabhaṭas,—the elder Āryabhaṭa and his younger name sake of Kusumapura, which influenced Kaye, Smith and others to advance doubts about the authorship and date of composition of *Gaṇita,* a section of *Āryabhaṭīya.* He compared al-Bīrūnī's references to passages attributed to Āryabhaṭa with those of the extant *Āryabhaṭīya,* noticed the work of *Ārya-siddhānta* by an author of the same name whom Dikshit and Sewell placed in A.D. 950, and proved the error of Kaye in attributing the *Gaṇita* section of the *Āryabhaṭīya* to Āryabhaṭa of Kusumapura and placing the latter in the 10th century A.D.

Intensive researches on Āryabhaṭa developed after the publication by Kern of the *Āryabhaṭīya* with the commentary by Parameśvara. The mathematical chapters of the work were studied by Rodet, Kaye, Datta and Ganguli. The whole work was translated into English by P. C. Sengupta in 1927 and Walter Eugene Clark in 1930. Sengupta made a special study of Āryabhaṭa's astronomical system and translated in English, with a short introduction, Brahmagupta's *Khaṇḍakhādyaka,* based on Āryabhaṭa's mid-night system. He further developed the idea that Āryabhaṭa was possibly the father of Indian epicyclic astronomy. According to him, astronomer Pradyumna made a special study of the superior planets, while Vijayanandin likewise studied the peculiarities of the inferior planets. Both these astronomers flourished before the time of Āryabhaṭa and did for Indian astronomy what Hipparchus had done for the Greek. Āryabhaṭa utilized the work of Pradyumna and Vijayanandin, determined afresh some of the astronomical constants, and constructed the Indian epicyclic astronomy, 'as far as it can be called so', which inspired later Indian astronomers. 'Thus the position of Āryabhaṭa in India,' observed Sengupta, 'was the same as that of Ptolemy in Alexandria. This explains the reason why Āryabhaṭa is held in so great esteem by all Indian writers.'[88] Sukumar Ranjan Das, in a series of papers of an expository nature, discussed such problems of Indian astronomy as parallax, precession and libration of the equinoxes, lunar and solar eclipses, astronomical instruments, the Jaina calendar, and motion of the earth as conceived by ancient Indian astronomers.

Al-Andalusī's Category Of Nations

In 1935, Regis Blachére translated into French Sā'īd al-Andalusī's *Kitāb Ṭabakāt al-Umam (Livre des Catégories des Nations).* The text was produced in Spain in the eleventh century and recorded some old Arabic tradition about Indian astronomy. In describing various categories of nations and their aptitudes in arts and sciences, in other words in intellectual pursuits, Sā'id stated that only eight nations were interested in, and comprehended, science. These eight peoples were the Hindus, the Persians, the Chaldeans, the Jews, the Greeks, the Romans, the Egyptians and the Arabs. In this list of eight nations which cultivated the sciences, he placed the Hindus at the head because 'Les Indous, entre toutes les nations, à travers les siecles et depuis l'antiquité, furent la source de la sagesse, de la justice et de la modération. Ils furent un peuple doné de vertus pondératrices, créature de pensées sublimes, d'apologues universels, d'inventions rares et de traits d'esprit remarquables'.[89] In astronomy he recorded the tradition of *Sindhind, Arjābhar,* and *Arkand,* the three works among many, known to the Arabs, of which only the first one, e.g. the *Sindhind* had been transmitted to the Arabs in a perfectly intelligible form. According to him, *Sindhind* meant 'infinite time' ("temps infini"); this work was adopted and lent itself to the preparation of astronomical tables by a number of Arab astronomers such as Muḥammad ibn Ibrāhīm al-Fazārī, Ḥabas ibn 'Abd Allah al-Bagdādī, Muḥammad ibn Mūsā al-Khwārizmī, al-Ḥusain ibn Muḥammad known by the name of Ibn al-Adamī. Sā'id also faithfully recorded the tradition of the arrival in Khalif al-manṣūr's court of an Indian astronomer versed in the calculations followed in the *Sindhind* and equipped with a copy of the book containing twelve chapters, dealing with astronomical equations *(ta'ādil),* sine lines *(karadajāt)* and other subjects. Al-Manṣūr ordered an Arabic translation of the Sanskrit text, and charged al-Fazārī with the task, which he accomplished under the title *as-Sindhind al-Kabir* (the *Great Sindhind*). This work was later on abridged by al-Khwārizmī who dealt with the mean longitudes *(awsāt)* after the *Sindhind,* but introduced the methods of the Persians and of Ptolemy in some astronomical matters. Even in his time, his contemporaries who had a preference for the *Sindhind* held the work in lively admiration. In Sā'id's time *Sindhind* continued to be useful to those who desired to cultivate astronomy (Les contemporains, partisans du Sindhind, marquérent toutefois une vive admiration pour ce traité et eu firent les plus grandes éloges. Ce livre n'a cessé de servir à ceux qui cultivent l'astronomie, jusqu'à nos jours).[90]

Otto Neugebauer's Contribution

In the fifties Otto Neugebauer, already distinguished for his work on cuneiform mathematical texts, published a series of papers in quick succession, which added a new dimension to researches in the history of Indian astronomy. Upon the appearance in 1953 of Louis Renou and Jean Filliozat's *L'Inde classique—Manuel des Études indiennes,* Neugebauer produced an essay review of the work, particularly of its articles on astronomy, drawing attention to the failures of sanskritists and orientalists to take note of important developments in other areas of great significance to Hindu astronomy.[91] Even after more than half a century the basic material for the general evaluation of the historical position of Hindu astronomy, he commented, was substantially the same as recorded by Thibaut in his 'Astronomie, Astrologie und Mathematik' in the *Grundriss.* This was because the relevant literature lay 'almost completely beyond the normal horizon of Sanskrit scholarship'. Greek and Babylonian influences on Hindu astronomy had been occasionally talked about more or less speculatively, but the half century provided some definite clues which had been ignored. Thibaut realized the importance of the ratio of 3:2 as longest to the shortest day in the *Pañcasiddhāntikā,* but hesitated to admit of its Babylonian origin unless the existence of such a ratio in Babylonian materials was actually demonstrated. This demonstration was provided by Kugler a year later in his *Babylonische Mondrechnung.* A few years later Franz Boll discovered in Greek astrological manuscripts fragments of tracts by one Babylonian astrologer of the name of Teucros, which passed into the writings of Abu Ma'shar; these fragments concerned constellations or spheres and were closely related to those known from Persian, Indian and Greek sources. The same constellations with their decans were identified by A. Warburg in the fifteenth century frescos in the Palazzo Schifanoja of Borso. This discovery meant that 'all the major steps of a complete cycle of transmission of astrological lore and its transformation from Hellenistic Egypt to India and back to Europe had been established.'

Thibaut had already noted in the *Pañcasiddhāntikā* the Babylonian fundamental period relation for Jupiter. Twentyfive years later P. Schnabel, in a short note in the *Zeitschrift für Assyriologie* (1924), showed that the periods of Saturn and Venus also agreed with those given in the Babylonian planetary texts of the Seleucid period. This was the background of Neugebauer's own interest in *Varāha's Pañcasiddhāntikā,* for he stated, "Matters rested at this point for another 25 years until I realized that the methods described by Thibaut in his summary of the 'third period' *(Vaśiṣṭha-siddhānta* and *Vākyam)* were identical with methods represented by two Greek papyri of the Roman imperial period and eventually with procedures of Babylonian astronomy, exactly as in the case of Kugler's and Schnabel's identifications' Earlier in his *Exact Science in Antiquity,* Neugebauer had made similar observations,"....we stand today only at the beginning of a systematic investigation of the relations between Hindu and Babylonian astronomy, an investigation which is obviously bound to give us a greatly deepened insight into the origin of both fields.....The fact that a close relationship between Babylonian linear methods and sections of the *Pañcasiddhāntikā* can be established is only one facet of the general problem of the evaluation of the role of Hindu astronomy in the history ofscience.....We have here an early historical report on source material which is no longer extant, or at least no longer extant in exactly the same form. On the other hand Varāhamihira is also one of the main sources of al-Bīrunī's report on Hindu astronomy and astrology, written about A.D. 1030. Consequently Varāhamihira occupies a central role for the study of Hindu astronomy."[92] This explains the publication by Neugebauer and Pingree of a new and critical edition of the *Pañcasiddhāntikā* with an English translation and commentary in 1970-71.

One of the early efforts of Neugebauer was directed to trace Babylonian linear and arithmetical methods in the computational procedures of calendar makers of South India for determining the times of occurrences of eclipses, recorded by Le Gentil and John Warren and already mentioned before.[93] Warren obtained his information from a calendar maker 'who showed him how to compute a lunar eclipse by means of shells placed on the ground, and from tables memorized by means of certain artificial words and syllables'. The Tamil informer (Sashia) computed for Warren the circumstances of the lunar eclipse of 1825 between May 31 and June 1. The errors were–4′ for the beginning, -23′ for the middle and -52′ for the end. The surprising thing was not the accuracy of the computational procedures, but the continuance of a tradition first found in the Seleucid cuneiform texts dated 2nd or 3rd century B.C., Roman sources of the 3rd century A.D., and Varāha's report of the 6th century A.D. Neugebauer suggested that the thriving Indo-Roman maritime trade during the first few centuries of the Christian era possibly brought about the transmission of the procedures to astronomers and almanac makers of South India. He gave a full account of the procedures with the help of Warren's tables and his own reconstructions for which the original paper must be consulted. Three years later B. L. vander Waerden examined the same materials of Warren and Le Gentil and explained some of the gaps left unexplained by Neugebauer, which will be discussed in what follows.

In another paper Neugebauer discussed the transmission of planetary theories and gave an excellent exposition of the eccentric-epicyclic model.[94] If the geometry of the true positions of the planet be worked out by first applying the apsis *(manda)* correction and then the conjunction *(śighra)* one without making any approximation, the correction δ being the difference between the true and mean longitudes $(\lambda - \lambda)$, will be given by :

$$\sin \delta = \frac{\gamma \sin \gamma - e \sin \alpha}{\sqrt{(\gamma \sin \gamma - e \sin \alpha)^2 + (R + e \cos \alpha + \gamma \cos \gamma)^2}}$$

where α = anomaly, γ = argument, e = eccentricity, r = radius of the *sighra* epicycle, and R = radius of the deferent circle. Clearly, the equation involving both the corrections is unusable for tabulation for which the *śighra* and *manda* corrections, σ and μ respectively are computed separately by introducing certain approximations. One approximation introduced by the Hindu astronomers was to transfer the position of the mean planet as modified by the *manda* correction to the deferent circle and then draw the *śighra* epicycle with this transferred point as centre. The second approximation is to ignore the eccentricity for the *manda* correction compared to the large value of the deferent radius, but to retain the value of the *śighra* epicycle radius while computing the *śighra* corrections, which leads to the following corrections :—

For *manda* correction,

$$R \mu = e \sin \alpha$$

For *śighra* correction,

$$\sin \sigma = r \sin \gamma$$

where $$h = \frac{h}{\sqrt{(R + \cos \gamma)^2 + (\gamma + \sin \gamma)^2}}$$

Neugebauer remarked that there was 'no compelling reason to treat the effect of the eccentricity with so much less accuracy than the effect of the anomaly, except for the fact that usually e is smaller than r'. The followers of Āryabhaṭa, however, did not insist on this approximation and retained the eccentricity in computing *manda* corrections. To neutralize the errors due to the aforesaid approximations the Hindu astronomers developed a procedure in which the *manda* and *śighra* corrections were not directly added to the mean longitude, but the corrections were introduced in stages by applying half the values of μ and σ. These procedures by half are given in all astronomical texts, of which Neugebauer has furnished an elegant geometrical exposition. The same procedure was adopted by al-Khwārizmī in constructing his planetary tables. Neugebauer also noted the Indian practice of employing variable epicycles for both these corrections, but left it unexplained.

The importance of al-Khwārizmī in relation to Indian astronomy has been recognized for a long time in as much as he syncretized Hindu mathematical and astronomical knowledge with that of the Greek and played a notable part in the second phase of the Arab intellectual revival. Al-Khwārizmī's astronomical tables, in Arabic original, have not come down to us, but survived in a Latin translation of one of its edited versions by the Spanish astronomer Maslama al-Majriṭī (about A.D. 1000). The Latin translation was probably done by Adelard of Bath. At the beginning of the present century A. Bjornbo and R. Besthorn prepared a critical edition of the text with notes and H. Suter prepared an elaborate commentary, resulting in the publication in 1914 of *Die astronomischen Tafeln des Muḥammed ibn Mūsā* from Copenhagen. Suter did not attempt to translate the Latin text in any of the modern European languages because 'it would be of little use to anyone who is not familiar with ancient and medieval astronomy'. Nearly fifty years later Neugebauer rendered a signal service to the history of Arabian and Hindu astronomy by producing an English translation and commentary of the Latin version of al-Khwārizmī's tables as edited by Suter and adding supplementary materials from a manuscript found in the Corpus Christi College, Oxford. Majriṭī's edition, according to Neugebauer, appears to be somewhat removed from the original *zīj* of al-Khwārizmī; a commentary on the tables by al-Muṭannā (c. 10th century A.D.) latinized by Hugo Sanctallensis probably used a more coherent treatise.

Be that as it may, the present English version makes it abundantly clear how the rules from Hindu astronomical treatises were utilized and juxtaposed with those from the works of Ptolemy and Theon. In the very introductory paragraph al-Khwārizmī refers to the prime meridian of Arin (Ujjayinī) as follows: "To describe all regions of the earth and to establish all (local) times would be tedious and unfeasible since, for innumerable times and for boundless regions, the meridians have been recorded (with respect to) Arin,.."[95] In chapter 7 on the mean positions of each planet we are told that such positions are given in the table for the locality of Arin, and a longitude correction will have to be made if we want to find them for any other locality. The rules for making apsis and conjunction corrections to mean longitudes of the three superior planets—Mars, Jupiter and Saturn are given in chapter 10. Before describing the geometrical epicyclic-eccentric models and developing the equations, Neugebauer opens this commentary as follows:—"Al-Khwārizmī's procedure for finding the true longitude of a planet for a given moment *t* is based on Hindu methods known to us from the *Sūrya-siddhānta, Khaṇḍakhādyaka* etc..... It is in any case certain that the underlying model was not influenced by Ptolemy's great innovation of a motion regulated from an eccentric equant. The procedure followed by al-Khwārizmī, is a slight modification of the procedures we know from Hindu sources."[96] The rules for finding the latitudes of three superior and two inner planets were compared to those of the *Āryabhaṭīya, Khaṇḍakhādyaka,* and the *Sūrya-siddhānta* and found to be based on the same model and formulae. This is also true of the calculations of ascensional difference. Al-Khwārizmī's eclipse tables would also be understood in the light of rules given in the *Khaṇḍakhādyaka,* which, set up in the modern mathematical language, revealed a close identity with the method given by Kepler for the calculation of parallaxes in latitude and longitude.[97]

Neugebauer's original insight into the historical position of Varāhamihira and his *Pañcasiddhāntikā* and David Pingree's scholarship in Sanskrit astronomical literature formed a happy combination in the production of a new and critical edition of the text, with an English translation and an excellent commentary embodying a good deal of recent researches on the subject. In their introduction to part I providing text and translation, the authorship question of the five *siddhāntas* has been further clarified. Varāha's *Paitāmaha-siddhānta* was derived from Lagadha's *Jyotiṣavedāṅga* and not from the *siddhānta* bearing the same name and forming part of the *Viṣṇudharmottarapurāṇa.* Three *Vaśiṣṭha-siddhāntas* have been recognized, e.g. (1) one *Vaśiṣṭha-siddhānta* mentioned by Sphujidvaja in his *Yavanajātaka* and dated around A.D. 269/70, (2) a *Vasiṣṭhasamāsa-siddhānta* abridged from an older and original work possibly around A.D. 499, from which Varāha summarized the lunar theory, the solar theory, the theory of *nakṣatras* and *tithis,* and the gnomon problems, and (3) a *Vaśiṣṭha siddhānta* attributed to Viṣṇucandra and compiled probably in the latter half of the sixth century A.D.[98] Sphujidhvaja's *Vaśiṣṭha* contained an earlier adaptation of the Babylonian planetary theory and the *Vaśiṣṭhasamāsa-siddhānta* dealt with Babylonian planetary theories and other astronomical elements more elaborately. Viṣṇucandra's version known mainly from Brahmagupta's *Brāhmasphuṭa-siddhānta* is a different type of work based on '*ārdharātrika* (Lāṭa) and *audayika (Āryabhaṭīya)* elements with some from Vijayanandin'. We have already discussed Thibaut's comments on this work. The *Romaka-siddhānta* is known in two versions, e.g. Varāha's account in chapters I, 8-10, III, 34-35 and VIII, based on Lāṭa's edition, and a work by Śrīṣeṇa, known from Brahmagupta. The Greek elements of the former have long been recognized, and the authors suspect that it appeared in Western India during the Śaka or Gupta rule. Śrīṣeṇa's *Romaka-siddhānta* was based on elements borrowed from Lāṭa, Vaśiṣṭha, Vijayanandin and Āryabhaṭa. For Varāha's *Pauliśa-siddhānta,* Lāṭa's commentary was again the source obviously based on Alexandrian-Greek sources. But Paulus Alexandrinus, the astrologer-author of *Eisagog* (A.D. 378) who was not known to have written on astronomy could not be the same as Puliśa, the author of this *siddhānta.* From Pṛthūdakasvāmin, Utpala and al-Bīrūnī, we know of another *Pauliśa-siddhānta,* which developed an *ārdharātrika* system and was written in the eighth century A.D. The authorship of the *Sūrya-siddhānta* as summarized by Varāha has been left an open question. Neugebauer and Pingree believe that Lāṭa was the author of the work on a tradition referred to by al-Bīrūnī, although Varāhamihira does not refer to Lāṭa in connection with this work.[99] It is admitted that the parameers tof this *Sūrya-siddhānta* conformed to those of the *ārdharātrika* system promulgated by Āryabhaṭa, and further that Lāṭadeva, Pāṇḍurangasvāmin and Niḥśanka were all pupils of Āryabhaṭa. Why this senior esteemed teacher whose system was adopted for working out the most accurate of the five *siddhāntas* should not be given the credit of authorship is not understood.

In addition to the sources mentioned above, particularly Lāṭa and Āryabhaṭa, Varāhamihira was in all probability influenced by the teachings of his father Ādityadāsa of an Iranian (Maga) lineage. Varāha mentions a Yavana teacher, possibly a Sasanian astronomer. Furthermore, what was the role of Siṃha, Pradyumna and Vijayanandin mentioned by Varāhamihira as also by Brahmagupta? Clearly the sources are far from being fully understood.

Despite its historical position the *Pañcasiddhāntikā* appears to have exercised little influence on later astronomical literature in India. Brahmagupta and al-Bīrūnī who again depended on the former carried some notices, and Śatānanda in the eleventh century utilized Varāha's *Sūrya-siddhānta* in writing his *Bhāsvati.* Some references are found in Pṛthūdakasvāmin, Utpala, and Āryabhaṭa's scholiasts Parameśvara and Nīlakaṇṭha. That is about all. Curiously enough the *Pañca-siddhāntikā* tradition turned up in China in the eighth century astronomical work *Chiu-Chih-li* by Ch'u-Ta'n Hsi-ta (A.D. 718). It is well known that during the first few centuries of the Christian era a number of Buddhist scriptures with Indian astronomical content were translated into Chinese. These early tracts probably taught Indian astronomy of the pre-siddhāntic period. The scientific astronomy characteristic of the *siddhāntas* was introduced to China in the Thang period by the three schools of Indian astronomy represented by Kāśyapa, Gautama and Kumāra.[100] The most prominent of them was probably Hsi-ta of the Gautama school, who prepared the *Chiu-Chih-li* (*nava-graha* calendrical astronomy). The text discussed a number of Indian mathematical rules as applicable to astronomy, contained a section on numerals, another section on sine tables in connection with the prediction of moon's positions, and so on. The values of the sine table agreed with those given in the *Āryabhaṭiya* and the *Sūrya-siddhānta.* Neugebauer and Pingree have now identified in the *Chiu-Chih-li* the following elements of the *Pañcasiddhāntikā* :

"I. The computation of the ahargaṇa (pp. 499-502). The Chiu-chih-li uses formulas which are the equivalents, with suitable sub stitutions for the new epoch, of the formulas in 1, 9-11 (Romaka).

II. The computation of the mean longitudes of the Sun, lunar apogee, and lunar anomaly (pp. 502-505). The rules in the Chiu-chih-li are based on the parameters in IX, 11-12 (Sūrya).

III. The computation of the solar and lunar equations (pp. 506-511). This passage is derived from IX. 7 (Sūrya).

IV. The computation of the length of day-light (pp. 511-513). The Chiu-chih-li depends on III, 10 (Pauliśa).

V. The determination of the daily progress of the Moon (p. 514). See III, 9 (Pauliśa).

VI. The determination of the daily progress of the Sun (p. 515). See III, 17 (Pauliśa).

VII. The computation of the nakṣatra, nakṣatra saṅkrānti, and tithi (pp. 515-518). See III, 16 (Pauliśa).

VIII. The computation of the longitude of the lunar node (pp. 521.522). See III, 28 (Pauliśa).

IX. The computation of lunar latitude (pp. 526-527). See IX, 6 (Sūrya).

X. The computation of the duration of a lunar eclipse (pp. 528-529). See VI, 3 (Pauliśa ?).

XI. The computation of the magnitude of a lunar eclipse (pp. 529-530). See VIII, 18 (Romaka).

XII. The computation of the duration of totality of a lunar eclipse (pp. 530-531). See VIII, 16 (Romaka)."[101]

The *Pañcasiddhāntikā's* influence among the circles of astronomers and calendar-makers in South-East Asia can be guessed from the fact that one of the two rare manuscripts of the text was copied in Stambhatīrtha (Cambay) in A.D. 1616.

The commentary given in part II is a model of modern mathematical treatment of ancient astronomical rules and procedures. Clearly the same technique which Neugebauer developed for al-Khwārizmī's astronomical tables has been followed. The sinusoidal relationships in equations of centres recorded in the *Romaka* and *Pauliśa* without rules, the full explanation of the double epicyclic model underlying the computation of planetary equations as per the *Sūrya-siddhānta* (ch. XVI), the exposition of Vaśiṣṭha's theory of planetary motions and planetary phases in keeping with Babylonian methods (ch. XVII, first 60 verses), have been very clearly and lucidly presented. The authors did not claim to have solved all the problems with this difficult text. Some of the interpretations due to the authors have been called into question, to which a further reference will be made in what follows, but their hope 'that future historians of Indian astronomy will find this volume a useful tool' has already started to bear fruit.

Mahābhāskarīya and other Works

While some of the Western scholars were thus busy in demonstrating the links of Indian astronomy to West Asian and Graeco-Alexandrian traditions, Indian scholars came forward with renewed interest to publish critical editions, translations and annotations of important astronomical source materials. In 1945 Balavantaraya Apte, edited the *Mahābhāskarīya* of Bhāskara I with Parameśvara's commentary *Karmadīpikā*. In 1957 T. S. Kuppanna Sastri brought out another edition with the commentary of Govindasvāmin in the Madras Government Oriental Series; although he did not undertake to translate the text, he produced a valuable introduction, drawing attention to the practice of the Āryabhaṭan school to retain the unabridged value of the hypotenuse in making *manda* corrections and to the *ārdharātrika* system briefly given towards the end of the treatise. The want of annotated English translations of both the *Mahābhāskarīya* and *Laghubhāskarīya* was removed by Kripa Shankar Shukla in 1960. Bhāskara I's (c. A.D. 600) importance in the history of Indian astronomy need hardly be overestimated inasmuch as he was a follower of Āryabhaṭa I, a contemporary of Brahmagupta and wrote besides the two works mentioned above a *bhāṣya* on the *Āryabhaṭīya*. In his commentary Shukla discussed in detail Bhāskara I's treatment of Āryabhaṭa's epicyclic theory and his method of determining the distance of the true planet from the centre of the deferent by successive approximations *(asakṛtkarma)*.[102]

Brahmagupta's *Khaṇḍakhādyaka,* with the commentary of Bhaṭṭotpala, was critically edited, translated and annotated by Bina Chatterjee in 1970, which supplemented the earlier editions of Probodh Chandra Sengupta (with an English translation and notes) and Babua Misra (text only). Bina Chatterjee's another work *Śiṣyadhīvṛddhida Tantra* of Lalla, with the commentary of Mallikārjuna Sūri and English translation and mathematical notes, was posthumously published in 1981. K. V. Sarma edited and/or translated a number of works by Parameśvara, e.g. *Dṛggaṇita, Goladīpikā, Grahṇāṣṭaka, Grahaṇāmaṇḍana* and *Grahaṇa-nyāyadīpikā,* each one a small astronomical tract. He also edited, with a good introduction in each case, Nīlakaṇṭha Somayāji's *Siddhānta-darpana, Golasāra, Tantrasaṅgraha,* and *Jyotirmīmāṃsā,* Haridatta's *Grahacāranibandhana,* Mādhava's *Venvāroha* and Sundarāja's *Vākyakaraṇa.* In his *History of the Kerala School of Hindu Astronomy* (1972), he briefly noticed the life and works of a large number of medieval astronomers based in Kerala, e.g. Govindasvāmin (c. 800-850), Śaṅkaranārāyaṇa (c. 825-900), Sūryadeva Yajvan (1191—c. 1250), Mādhava of Saṅgamagrāma (c. 1340—1425), Parameśvara of Vaṭaśreṇī (c. 1360—1455), Dāmodara (c. 1410—1510), Nīlakaṇṭha Somayāji (1444—1545), Jyeṣṭhadeva (c. 1500—1610), Putumana Somayāji (1660—1740) and several others and gave a detailed bibliography of Keralan astronomers and their works. Shukla and Sarma translated the *Āryabhaṭīya* with explanatory notes in 1976; at the same time the former produced a critical edition of the text with commentaries of Bhāskara I and Someśvara and the latter another edition of the same with the commentary of Sūryadeva Yajvan. The Indian Institute of Astronomical and Sanskrit Research published, under the editorship of Ram Swarup Sharma, *Brāhmasphuṭa-siddhānta* with an elaborate introduction, *Vaṭeśvara-siddhānta* with Sanskrit, Hindi and English commentary, and Jagannātha's *Samrāṭ-siddhānta,* being a Sanskrit translation from an Arabic version of Ptolemy's *Almagest.*

The Osmania Oriental Publications Bureau rendered invaluable service to the cause of the study and researches in the history of astronomy by editing and publishing al-Bīrūnī's *Al-Qānūnu'l-Masūdī,* an encyclopaedic work of considerable significance to Indian astronomy. The Bureau's other publications include *Rasā'il al-Bīrūnī* (Bīrūnī's tracts) which contains three dissertations on the questions of shadows, the Indian rule of three and calculations of the chords of the circle; *Kitāb al-'amal bi'l-aṣṭurlāb* of aṣ-Sufi with an introduction by E. S. Kennedy and Marcel Destombes; and the *Rasā'il Abū Naṣr ila'l-Bīrūnī* containing 14 tracts of Abū Naṣr on questions of mathematics, astronomy, astrolabe and miscellaneous matters. Sayyid Rizvī published in the *Islamic Culture* the text and translation of al-Bīrūnī's *Ghurrat al-Ẓijāt,* with critical notes; the *Ghurrat* was Bīrūnī's translation of Vijayānanda's *Karaṇatilaka.* Al-Bīrūnī's another important tract on the determination of latitudes and longitudes of cities, the *Kitāb taḥdīd nihāyāt al-amākin* etc., was published in the *Revue de l' Institut des Manuscrits Arabes,* Cairo, an English translation of it, with modern commentaries, being produced by Jamīl 'Alī.

YAVANJĀTAKA AND OTHER WORKS OF DAVID PINGREE

David Pingree's approach to Hindu astronomy appears to have been prompted by Neugebauer's transmission theory. In connection with his study of Tamil astronomy Neugebauer noted a basic dualism between geometric and arithmetical methods in the development of Hindu astronomy, a dualism that also characterized early Greek astronomy. "Both components", he remarked in his review of *l'Inde classique,* "are of much earlier date than the influence on India which was carried, in all probability through Hellenistic astrology which reached its full development in Alexandria during the first centuries A.D." Hitherto such views were based on papyrus fragments and surmises. In 1959 Pingree reported briefly on a Greek linear planetary text written in Sanskrit, which provided a definite evidence of Babylonian methods and parameters in an astrological context.[103] The text in question is the *Yavanajātaka* of Sphujidhvaja, dated A.D. 269/270, and contains in its last chapter 'astronomical instructions' intended to improve upon, or substitute for, those of the *Vaśiṣṭha-siddhānta.* Fragments concerning the movements in arcs of Jupiter, Mars, and Saturn are quoted, their translations given, and compared with Babylonian elements. Pingree concluded, "..for the superior planets it has been demonstrated that the methods in use among those Greek astrologers who transmitted their learning to India in the second century after Christ were still closely related to those developed in Mesopotamia in the Seleucid period."

In 1978 Pingree's *Yavanajātaka of Sphujidhaja,* with edited Sanskrit text, English translation and commentaries, appeared from the Harvard University Press, in which these planetary elements have been fully given along with those from Babylonian cuneiform texts, as follows :—"The significant ("Greek-letter") phenomena referred to in the theory of the superior planets are:

Γ = first visibility in the East = *udaya*
Φ = first stationary point = *sthitva*
Θ = opposition
Ψ = second stationary point
Ω = last visibility in West = *asta*
$\Phi \rightarrow \Psi$ = retrogression = *vakra*

Jupiter

Javanajātaka	*Babylonian* slow	medium	fast
$\Gamma \rightarrow \Phi$ 16°	16;15°	18;16,52,30°	19;30°
$\Phi \leftarrow \Psi$ —8°	—8;20°	—9;22,30°	—10°
$\Psi \rightarrow \Omega$ 21°	15;50°	17;48,45°	19°
$\Omega \rightarrow \Gamma$ 6;15°	6;15°	7;1,52,30°	7;30°
35;15°	30°	33;45°	36°

Mars

Yavanajātaka	*Babylonian* System 1	System 2
$\Gamma \rightarrow \Phi$ 162° in 288 tithis	162;40° in 280 tithis	162;24° in 275; 37 tithis
$\Phi \rightarrow \Psi$ — 34°	191;20°	$\Phi \rightarrow \Omega$ 157°
$\Psi \rightarrow \Omega$		89;19°
$\Omega \rightarrow \Gamma$ 88;30°		408;43°

With reference to $\Phi \rightarrow \Psi$, the arc of retrogression, where Sphujidhvaja has $-34°$ it is to be noted that $\Phi \rightarrow \Omega$ in system 2 (157°) minus $\Psi \rightarrow \Omega$ in system 1 (191;20°) equals -34; 20°. This is, in fact, much too high.

"Sphujidhvaja should, of course, have given the time-intervals between the occurrences of all the Greek-letter phenomena for all the planets for his presentation to have had a practical use.

		Saturn		
Yavanajātaka			*Babylonian*	
		fast	*slow*	*time-intervals*
$\Gamma \rightarrow \Phi$	8;15° in 112 tithis	9°	7;30°	120 tithis
$\Phi \rightarrow \Psi$	−8° in 100 tithis	−8°	−6;40°	112; 30 tithis
$\Psi \rightarrow \Omega$	—	9;3,45°	7;33,7,30°	120 tithis
$\Omega \rightarrow \Gamma$	—	4°	3;20°	—
	12°	14;3,45°	11;43,7,30°	

In Sphujidhvaja, before the remainder of Saturn was lost, it should have been stated that $\Psi \rightarrow \Omega$ is about 8° in 120 tithis, and $\Omega \rightarrow \Gamma$ about 3;45° in 40 tithis."[104] Similar data for inferior planets are given which have likewise been explained.

The linear planetary theory is cursorily discussed in 62 verses of the last chapter 79 of the *Yavanajātaka*. This is obviously a difficult chapter to follow and must be learnt thoroughly before one is able to practise astrology according to the teachings of the text. Pingree has given a masterly exposition of the various verses establishing their connections with ancient Greek and Latin astrologers like Antiochus, Atheniensis, Critodemus, Dorotheus Sidonius, Firmicus, —52 names have been given, as well as with later Indian astrologers who used this text or its teachings. Here we shall only refer to a few observations of Pingree with regard to the zodiac introduced in the few opening verses of chapter 1 because it has been known for a long time that the twelve signs of the zodiac were introduced into Indian astronomy through astrological sources of foreign origin. In presenting the zodiacal scheme, its three main aspects, e.g. iconography of the signs, their melothesia, and their topothesia, are described. Iconographically Sphujidhvaja's zodiac contains several features common to the Hellenistic one, some of which were of Egyptian-cum-Hellenistic origin, e.g. the man and woman depiction in the Mithuna with the club and the lyre agreeing with the Egyptian pair Shu and Tefnut; the figure of a maiden standing in a boat and holding a torch representing Virgin etc. Pingree believes that the zodiac was possibly unknown in india before Yavaneśvara.[105]

The Egyptians had developed the idea of correlating different signs of the zodiac with specific parts of the human body so as to produce a scheme of zodiacal melothesia. Out of this idea originated the erect cosmic man and the theory of microcosm and macrocosm in medical schools which became widespread in the ancient world. Sphujidhvaja's scheme in which Aries is represented by the head of the human body, Taurus by mouth and neck, Gemini by shoulders and arms, Cancer by chest, Leo by heart, Virgo by belly and so on was derived from Egyptian concepts.

The appearance of Sanskrit works of the class of *Yavanajātaka* also fits in well with the early political and economic history of India. During the Achemenid occupation (500 B.C. to 230 B.C.) and later unsettled conditions marked by the incurisons of the Greeks, the Śakas, the Pahlavas, and the Kuṣāṇas, Indian astronomy, Pingree conjectures as others did before him, was introduced to Babylonian methods, e.g. some of the elements of the luni-solar calendar of the *Vedāṅga Jyotiṣa,* including the concept of *tithi,* variation of day-length etc. At the beginning of the first century A.D., one branch of the Śakas, the Kṣaharātas, established a kingdom in West India with Mīnanagara as their capital and Broach (Gk. Barygaza) as their main trading post between India and the Mediterranean countries. This branch succombed to another Śaka dynasty, the Western Kṣatrapas, of which the greatest king Rudradaman I ruled between A.D. 130 to 160 over a vast empire extending up to Kausambi in the north and Kalinga in the east. The Kṣatrapas were interested in astronomy, established their capital at Ujjayinī and soon raised this city as the foremost centre for astronomical work, 'the Greenwich of Indian astronomy and the Arin of the Arabic and Latin astronomical treatises.' Here in A.D. 150, Pingree informs us, Yavaneśvara, the Lord of the Greeks, translated into Sanskrit prose a Greek astrological text which had been written in Alexandria the preceeding half century.[106] This translation is not extant, but its subject matter has survived in the form of a thirteenth century palm-leaf manuscript of a versification of it carried out by Yavanarāja Sphujidhvaja in A.D. 269/270 to which a reference has just been made. In the second century A.D. another astrological text of the same type was translated into Sanskrit from a Greek original; this translation has not survived. This is known through references of Yavanarāja and Satya who utilized both the translations.

In his 'Astronomy and Astrology in India and Iran', Pingree conjectured that the concept of great cycles of time,—the *Kalpa, Mahāyuga, Yuga* etc., in which the planets and some of their nodes and apses underwent integral numbers of revolutions according to Hindu astronomy, was derived from the Babylonian sexagesimal number 2, 0, 0, 0.[107] Written decimally, this number is equivalent to 432,000 used for the *Kaliyuga;* 10 times the *Kaliyuga* is the *Mahāyuga,* and 1000 times the *Mahāyuga* the *Kalpa.* He further conjectured that this *Kalpa* of Babylonian origin was combined with the Greek epicyclic theory during the 4th or the 5th century A.D. Apart from the sub-divisions of the *Mahāyuga* in the ratios 4:3, 3:2, and 2:1, a small period of 180,000 years being 124th part of a *Mahāyuga* was tried, but without much success. In A.D. 499, Āryabhaṭa tried to solve the problem by dividing the *Mahāyuga* in four equal parts of 1,080,000 years each, but could not make it acceptable to others because of its deviation from the tradition. Pingree thinks that the Indian *yuga* system finally took shape in the Gupta period and was the result of 'the necessary theoretical knowledge and the inspiration'.

Being thus convinced of the influence of Babylonian and Greek astronomical elements Pingree's subsequent efforts were directed to explain various facts of Indian astronomy in the light of his theory of transmission. That Indian epicyclic models were inspired by the older Greek ones of Apollonius of Perga and Hipparchus has long been suspected. Pingree now attempted to show that the earliest specimen of this model, the double epicycle, appeared in the *Paitāmaha-siddhānta* of the *Viṣṇu-dharmottarapurāṇa* which he placed in the first half of the fifth century A.D. and supposed to be the source of Āryabhaṭa's system.[108] The dating and assertions are speculative and have been questioned by B. L. van der Waerden. Precession and trepidation of equinoxes have been traced in Indian astronomy in the *Jyotiṣa-vedāṅga* of Lagadha, Varāhamihira's *Pañcasiddhāntikā*, and in later astronomical siddhāntas. The appearance of these ideas in Greek literature before they did in the Sanskrit and references to one Maṇindha or Maṇittha (Gk. Manethon) led him to conjecture, even with regard to the earliest notions preserved in the *Jyotiṣa*, that 'it is not unreasonable to suppose that the *idea* of trepidation or precession was introduced into India by the Greeks, though the *parameters* chosen by the Indians are their own, and that the arguments presented in favour of the hypothesis of a motion of the colures are derived from a particular interpretation of the *Vedāṅga jyotiṣa*'.[109]

In a number of areas such as the later *Pauliśa-siddhānta*, al-Fazārī, Ya'qūb ibn Ṭāriq and several others our information has so far been fragmentary and based on the repetition of a certain tradition. In some of these Pingree collected all the traceable fragments, explained them in the form of commentaries, and critically examined some of the traditions. The later *Pauliśa-siddhānta* which al-Bīrūnī used with the help of his Pandit was compiled in Western or North-Western India, probably at Sthāniśvara, between c. A.D. 700 and 800. Besides al-Bīrūnī's Pandit, the work was known to and quoted from by Pṛthūdakasvāmin, Utpala and Āmarāja. Pingree collected all these citations in a total of 37 verses as also Bīrūnī's references, explained their astronomical elements and showed that this later *Pauliśa-siddhānta* was based on Āryabhaṭa's *ārdharātrika* system.[110] In its popularity the work rivalled that of *Khaṇḍakhādyaka,* and fell into disuse after the thirteenth century. Astronomer Muḥammad ibn Ibrāhīm al-Fazārī's fragments have been collected from Ibn al-Adamī's *Naẓm al-'Iqd,* Ṣā'id al-Andalusī's *Kitāb ṭabaqāt al-umam* al-Hāshimī's *Kitāb 'ilal al-zizāt,* Bīrūnī's *India, Chronology, al-Qānūn al-Mas'ūdi* and other tracts, al-Hamdānī's *Sifat Jazirat al-'Arab,* and a few others. Pingree has shown that the Sanskrit works in 12(?) chapters translated into Arabic was probably based on a work entitled *Mahāsiddhānta,* which was itself based on Brahmagupta's *Brāhmasphuṭa-siddhānta* with certain modifications.[111] Ya'qūb ibn Ṭāriq's fragments have been dealt with in the same manner, his principal sources being al-Hāshimī's *Kitāb,* al-Bīrūnī's *India* and other works, Abraham ben Ezra's preface to his translation of ibn al-Muthannā's *Fi 'ilal zij al-Khwārizmī*[112]

Pingree has also carried out a useful survey of Sanskrit astronomical tables in the United States, and contributed several biographical notes to the *Dictionary of Scientific Biography,* including an article on the history of mathematical astronomy in India.

Van Der Waerden on Tamil, and Other Problems of Hindu Astronomy

Shortly after the appearance in the *Orisis* of Neugebauer's study of Tamil astronomy Bartel L. van der Waerden of Zürich carried out a comparative study of the motion of the Sun as per Greek astrological tables and the Indian tables compiled by Le Gentil and Warren. In Hellenistic times the Greek astrological tables used to be constructed according to two methods, namely, the Babylonian linear method and the Alexandrian trigonometrical method. Although called Babylonian, the method of linear interpolation between extreme values involving the use of arithmetical series with first, second or third order was not limited to Babylon alone but was used by the astronomers and astrologers in Alexandria and Rome as well.[113] The Alexandrian method due to Aristarchus, Apollonius, Hipparchus and Ptolemy involved the application of geometrical models (circle, excentre and epicycle) to planetary motions and the use of trigonometrical tables. In Indian astronomy, as Thibaut had already recognized, the linear method was the characteristic of its middle period and the trigonometric one that of its third period.

With regard to the motion of the Sun as implied in the tables of Le Gentil and Warren, van der Waerden showed that a geometric model of a concentre with an equant point was used. The distance of the equant point from the centre was computed as 0; 2, 15, 19 and the direction of the equant point (the longitude of the apogee) as 78°. The concentre model (Fig. 3·4) leads to the following simple formula for the equation of centre ω :

$$\sin \omega = \frac{r \sin u}{R}$$

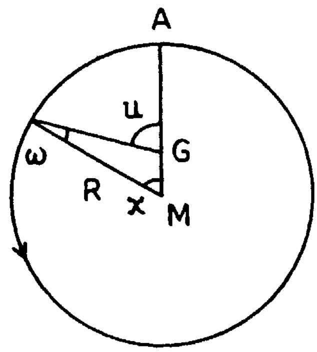

Fig. 3.4. Concentre with on equant point

Such a model was used by Eudoxus and Kallippus. Next he showed that the epicyclic theory of Āryabhaṭa and *Sūrya-siddhānta,* with the approximate value of radius also produced the same formula. Moreover, Āryabhaṭa's eccentricity *(r/R)* : $13\frac{1}{2}/360 =$ .0375 = 0; 2, 15 compared favourably with the value of 0; 2, 15, 19 obtained by Fourier analysis of the Tamil table. For the longitude of the apogee the Tamil table also used Āryabhaṭa's value of 78°.

With regard to the calculation of eclipses, the Tamil tables used four periods which Neugebauer designated by V, R, C and D. Van der Waerden showed that the period V comprising 1600984 days was not a lunar period but the *ahargaṇa*, that is, the number of days elasped from the beginning of the Kaliyuga upto May 22, 1282, at which date the Moon was in its apogee. "The whole Vākyam process," van der Waerden observed, "can be applied only to dates after May 22, 1282. For that date the computed longitude and latitude are very accurate. The Vākyam method cannot have obtained its present form before that date."[114]

Van der Waerden also analyzed the lunar latitude tables given by Le Gentil and found that the approximate trigonometrical relation $\beta = B \sin u$ (correct formula, $\sin \beta = \sin B \sin u$) was used in their compilation. Trigonometrical formula characteristic of astronomical *siddhāntas* were again the basis of computation of right and oblique ascensions tables.

Thus, the Vākyam process and other astronomical relations employed in the Tamil computation of eclipses were characteristic of Thibaut's third period of Indian astronomy when trigonometrical methods were the dominant features. In the light of this analysis the conjuncture of the transmission of Tamil countries of Babylonian linear methods in the course of Indo-Roman trade during the first few centuries of the Christian era appear highly improbable.

Motion of Venus. Following the translation by Neugebauer and Pingree of the the *Pañcasiddhāntikā*, P. B. Wirth reconsidered Vasiṣṭha's Venus theory as given in the first five verses of the last chapter (ch. XVII in NP edition and ch. XVIII in TS edition), questioned the editor's emendation of the original term '*guṇāptaiḥ*' to '*guṇāṃśāḥ*' ("and ½ (degrees)), and showed that an astronomically acceptable explanation of the velocity scheme presented in these verses did not call for such emendation.[115] Unable to refute Wirth's astronomical interpretation Pingree critized him fron linguistic point of view. Van der Waerden clarified the controversy by justifying Wirth's astronomical interpretation with reference to Egyptian planetary theory as found in 'Stobart Tables' and providing a linguistic explanation by Dr. A. Bloch, Professor of Sanskrit at the University of Basel.[116] Waerden demonstrated that if the unintelligible word '*guṇāpataiḥ*' be ignored, XVII. 1 of the *Pañc.* would simply mean, 'The progress in longitude of Venus in one synodic period is 215½ degrees.' In a subsequent verse XVII. 75, Varāha correctly gave the equivalence between revolutions and synodic periods for Venus as 1151 revolutions equalling 720 synodic periods, which meant that in one synodic period Venus moved through $1151.360°/720$ or $360+215\frac{1}{2}$ degrees, that is, the planet's longitude was $215\frac{1}{2}°$. In a like manner van der Waerden explained the direct and retrograde motions of Venus and demonstrated their perfect agreement with Egyptian planetary tables. As to the linguistic interpretation, Bloch stated as follows, 'From a linguistic point of view I still consider Pingree's interpretation"..guṇāṃśāḥ, which I take to be bahuvrīhi compound modifying pañca (aṃśāḥ) and meaning "with ⅓ (of a degree)" ((3), 37)" as highly improbable..'[117]

Origin of Great Cycles and Hindu Astronomical Yugas

Hindu astronomical *siddhāntas* of the period from A.D. 500 to modern times are based on two fundamental assumptions, e.g. (1) a yuga or a certain large period of time at the beginning and end of which all planets have the same mean longitudes, and (2) the beginning of a period in between 17 and 18 February, 3102 B.C., called the Kaliyuga era, was such that at this date the mean longitudes of planets with respect to Aries were zero. The first fundamental period, the *Mahāyuga* of 4,320,000 years was adopted by Āryabhaṭa and his followers in the beginning of the sixth century A.D. while Brahmagupta and others preferred *Kalpa* of 1000 *Mahāyugas*. Regarding the beginning of the *Kaliyuga* at the instant of conjunction of planets, Āryabhaṭa worked on two reckonings, namely, (1) that the conjunction took place in the midnight between February 17 and 18, and (2) that it happened at the sunrise of February 18; the *ārdharātrika* system was based on the first assumption and the *audayika* on the second. The advantage of developing a system on these two assumptions is that necessary corrections can be introduced by making one single observation for each planet as Āryabhaṭa did in the case of Jupiter by changing its revolution number in a *Mahāyuga* from 364, 220 in his mid-night system to 364, 224 in the sun-rise system (this meant an increase is mean longitude of Jupiter by 1°12').[118] The method was much simpler than Ptolemy's. The disadvantage is that as time goes on it does not yield mean motions of planets correctly and necessitates *bīja* corrections to be applied from time to time.

Van der Waerden investigated the question of the origin of great years in Greek, Persian, and Indian astronomy in a number of papers, and gave a final shape to his findings in a paper in the *Archive for History of Exact Sciences* (**18**, 359-384, 1978).[119] The idea of 'the eternal return of all things' at the end of a long enough period of time and of such cycles being marked by conflagration or great natural calamities have been traced to early Greek philosophers like the Pythagoreans, Namesios, and Stoic philosophers. The concept of a Great Year associated with flood and planetary conjunctions probably originated with the Babylonians, in which connection the name of Berossos, a priest of the Babylonian god of BEL is specially mentioned. He foretold that there would be a conflagration when all planets had a conjunction in Cancer and a deluge when they all met in Capricorn. He further estimated that before the Flood the sum or regnal years of mythical kings totalled 120 *saroi* or 432000 years (1 *sar* = 3600 years). In his chronological system Berossos also used other units such as

saros = 3600 years
neros = 360 years
sossos = 60 years

from which also the great year of 432000 could be obtained as 120 saroi or 1200 neroi.

As to great years mentioned in later Greek literature, van der Waerden refers to the Great Year of Orpheus comprising 120000 years, and Cassandrus' of 3600000 years. All these years are built out of factors 120 and 3600 which Berossos used in estimating the sum of regnal years before the Flood.

In India a *yuga* system is met with in the Laws of Manu and the *Mahābhārata*. The epic discusses the division of time, defines larger units like the 'year of the gods' (= 360 ordinary years), and introduces the four mundane ages, e.g. *Krita, Tretā, Dvāpara* and *Kali* with the following lengths of time :

Kritayuga	= 4800 years of the gods	=	1,728,000 years
Tretāyuga	= 3600 „ „ „	=	1,296,000 „
Dvāparayuga	= 2400 „ „ „	=	864,000 „
Kaliyuga	= 1200 „ „ „	=	432,000 „

Van der Waerden thinks that the Hindu year of the gods is the Babylonian neros, from which were derived the *Kaliyuga* by using the factor 1200 and the *Mahāyuga* by using another factor 12000.[120] Pingree, as we have seen, made a similar statement with reference to the Babylonian sexagesimal number 2, 0, 0, 0. Although the Babylonian connection is easy to infer it is more difficult to demonstrate the channels of transmission. The problem is complicated by the use of long periods or world-years in old Persian calendars and various statements of Arab astrologers-cum-astronomers suggesting Babylonian and Hellenistic transmission in Persia. Then there is the problem of who first demonstrated the possibility of planetary conjunctions in February 3102 B.C., and how and where it was done.

Three world-years are recognized in the works of Abū Ma'shar and al-Sijzī, as follows :—

(1) a World-Year of 4,320,000,000 years, ascribed to India;
(2) a World-Year of 4,320,000 years ascribed to *Aryabhaz* (Āryabhaṭa); and
(3) a World-Year of 360,000 years ascribed in some works to 'The Persians' and in others to 'the Persians and some of the Babylonians'.

While the first two world-years pose no problem and have been correctly attributed to Indian sources, the third world-year sometimes called 'Abū Ma'shar's Great Year' required a closer scrutiny. Van der Waerden drew upon al-Bīrūnī's evidence in his *Chronology* to show that Abū Ma'shar's source for his Great Year of 360,000 years was the Tables of the Shāh and that the planetary revolution numbers in this period quoted by al-Bīrūnī were taken from Persian sources. Waerden converted Āryabhaṭa's revolution numbers for his two systems for Abū Ma'shar's period and found exact agreement with the exception of Saturn, Jupiter and Mercury. Moreover, all the three systems agreed in the theory of planetary conjunctions at the first point *O* of Aries in February 3102 B.C., with the difference that the conjunction was attended with a Flood and it took place on the night just before Thursday, February 17.[121]

This brings us to the question of the Tables of the Shāh. The Arabic title of these tables is the *Zīj ash-Shāh* which in turn represented a translation of the Pahlavi original, the *Zīk-i-Shatroayār*. From Bīrūnī's statement in the Masudic canon it is known that Khurso Anūshīrvān (ruled from A.D. 531 to A.D. 579) held a conference of astronomers to revise the *Zīj ash-Shahriyār*. Van der Waerden has shown that Ibn

Yūnis in his *Hākimī Zīj* clearly mentions that the solar apogee of the Sun was observed by the Persians in A.D. 450 and again in A.D. 610; the former observation yielded 77°55' and the latter 80°. These references imply, according to Waerden, that 'a set of astronomical tables was composed about 450 or a little later, and revised under Khusro Anūshīrvān about 560.'[122] In other words, by the middle of the fifth century A.D. Sassanian Persia had developed sufficient capability so as to undertake the compilation of astronomical tables. From the *Dênkart* we know of Shāpūr I's (A.D. 240-270) interest in astronomy and the availability to Persian scholars of Ptolemy's *Almagest,* astrologer Dorotheos' hexameters and Vettius Valens' 'Anthologies'. By the time of solar apogee observations, the Persians had probably mastered the methods of computing mean conjunctions of Jupiter and Saturn and known the time interval between two successive conjunctions of Jupiter and Saturn as 20 years approximately. Waerden has shown that all this could be possible if the Persians of the fifth century A.D. had possessed a great cycle of 360,000 years in which Jupiter and Saturn revolved 30352 and 12214 times respectively and therefore suffered 18138 mean conjunctions.[123]

Now about the conjunction of planets in the month of February in the year 3102 B.C., it is easy to make sure that no such observation could have been made. In P. V. Neugebauer's *Chronological Tables* for 3102 B.C., longitudes of planets on February 18 noon were calculated as follows :—Sun—304; Moon—324 = 304+20; Mercury—289 = 304—15; Venus—318 = 304+14; Mars—302 = 304—2; Jupiter—318 = 304+14; and Saturn—277 = 304—27. The angular distance between Jupiter and Saturn alone exceeded 40°. As to records of earliest astronomical observations there are those of the visibility of Venus taken during the reign of Ammizaduga (*c.* 1582—1562 B.C.) and a few cuneiform texts from the time of Nabonassar (after 750 B.C.). The only other possibility was to compute the conjunctions backward.

According to van der Waerden, Sanskrit astronomical works do not suggest such backward computation, but Persian sources as preserved in the writings of later Arab astronomers do. In any such procedure one would obviously have to start with the slowest planets Saturn and Jupiter (in the case of the Sun and the Moon a conjunction takes place very month). In his *Book of Conjunctions,* Abū Ma'shar used Persian sources for mean motions of these two planets and showed that 18,138 mean conjunctions took place in 360,000 years, that is, one conjunction is nearly 20 years, and the mean motion from one conjunction to the next was 242°25'17" (=8 signs + 2°25'17" through the simplification of $\frac{12{,}214 \times 360°}{18{,}138}$.[124]

A Saturn-Jupiter conjunction at intervals of nearly 20 years is a 'small conjunction'. If one starts with such a conjunction in the beginning of Aries, the next two will occur in Sagittarius and Leo, and these three signs constitute 'Fire Triplicity'. After about 12 conjunctions in the 'Fire Triplicity', another series will connect the three signs of Taurus, Capricorn and Virgo and form the 'Earth Triplicity', the shift being due to a slow gain in longitude. Likewise, the 'Air Triplicity' comprising the signs Gemini, Aquarius and Libra, and the 'Water Triplicity' through Cancer, Pisces and Scorpio (Fig. 3.5). Twelve conjunctions in one and the same triplicity, van der Waerden explains, constitute a 'Middle Conjunction', four Middle Conjunctions covering all tnpiicities make up a 'Big Conjunction', and three Big Conjunctions constitute a 'Mighty conjunction', after which the cycle repeats itself.[125] On the basis of such Saturn-Jupiter conjunctions, their triplicities and cycles, one can develop long periods.

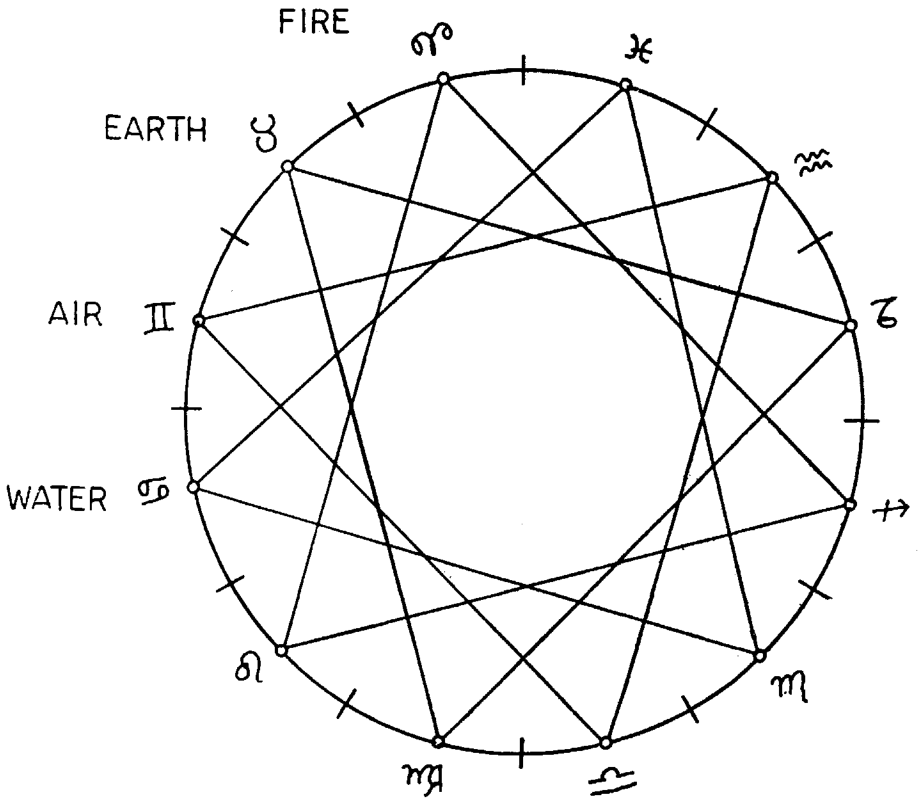

Fig. 3.5. Triplicities in Saturn-Jupiter Conjunctions.

The conjunction of 3102 B.C. taking place at the beginning of Aries was regarded as a Mighty Conjunction. Māshāllāh and other Arab astrologers who derived the method from the Persians are known to have carried out several calculations of this type to obtain long periods.

Al-Bīrūnī records in his *Chronology* that the astrologers of Babel and Chaldaea constructed astronomical tables for dating the Deluge, which Berossos had associated with Saturn-Jupiter conjunctions. "Now this conjunction occurred 229 years 108 days before the Deluge. This date they studied carefully, and tried by that to correct the subsequent times. So they found as the interval between the Deluge and the beginning of the reign of the first Nebukadnezar 2,604 years,. ." (Bīrūnī, *Chronology*, p. 28). Van der Waerden explains that if 2604 years be added to the "Era of Nabonassar" beginning on February 26, 747 B.C., as per Ptolemy, one obtains 3351 B.C. as the year of the Flood on Julian year-reckoning. The Saturn-Jupiter conjunction took place 229 years (neglecting the number of days) before that date, that is, in 3580 B.C. This year differs from 3102 B.C. by 478 years, which just accommodate 24 successive mean conjunctions of Saturn and Jupiter.[126] Other astrologers dated the Deluge differently. One such date was 3301 B.C., and counting ten such conjunctions one could arrive at 3102 B.C. But it is still hypothetical. From Bīrūnī's account of the search for a date of the Flood when all the planets were in conjunction, it appears that Abū Ma'shar Albalkhī gave this date as 3102 B.C. February 17.

The next question is: who were the astrologers of Babel and Chaldaea ? Van der Waerden thinks they could not be early Babylonians conversant with systems A and B because 'mean longitudes' were not known to them. Necessity for working with mean longitudes arose only after the development of epicyclic geometric models. Planetary tables based on epicyclic models were not available before 150 B.C.; therefore, it is surmised that 'the discovery of the conjunction of 3102 can be dated, with a certain degree of probability, between −150 and +150.' This was again the period which witnessed the spread of Hellenistic astronomy over a wide region, —Rome, Alexandria, Pergamon, Babylon etc. A number of Babylonian astronomers or astrologers such as "Teukros the Babylonian', 'Seleukos of Seleukia' versed in Greek astronomical methods are known from this period. In this Hellenistic milieu, van der Waerden conjunctures, the conjunctions of 3102 B.C. was discovered somewhere between Rome and Babylon.

Closely connected with the epoch of 3102 B.C. is the duration of the sidereal year. According to al-Bīrūnī, Egyptians and the Babylonians used a sidereal year of 365; 15, 30, which appeared in Varāhamihira's *Pauliśa-siddhānta*. The *Shāh Zij* gave the value of 365; 15, 30, 0, 30 days. Āryabhaṭa, in his mid-night system, used the value of 365, 15, 31, 30 and, in his sun-rise system, that of 365; 15, 32, 30. The transmission also took place in the same order of evaluation of the constant of sidereal year length. "The starting point of the whole development," concludes van der Waerden, "was the 'Mature Epicycle Theory' of Apollonius. Based on this theory and on trigonometrical methods, tables were calculated for the longitude of Alexandria. By the aid of these tables, several Hellenistic astrologers tried to date the Deluge by calculating conjunctions of Jupiter and Saturn in the fourth millennium B.C. One of these attempts led to the discovery of an approximate mean conjunction of all planets in 3102 B.C. Next, a new theory and new tables were fabricated, based on the assumption of a mean conjunction of all planets in February, 3102, and of an exact repetition of all planetary positions at the end of a certain "World-Year". These tables were used, with corrections, in Sassanid Persia before and after Khusto Anushīrvān. Āryabhaṭa corrected the theory, replacing the Persian World-Year of 360,000 years by a period twelve times as large, the Mahāyuga, which enabled him to adopt the theory to observations made in his own time, Other Hindu astronomers like

Brahmagupta, used the *Kalpa* of 1,000 *Mahāyugas* in order to obtain theories in which the mean longitudes, apogees and nodes of all planets were assumed to be zero at the beginning of the *Kalpa*.[127]

Roger Billard's L'astronomie Indienne

In 1971 Roger Billard published his *L'Astronomie indienne investigation des textes Sanskrits et des donnés numeriques* (Indian Astronomy,—an investigation of Sanskrit texts and their numerical data). In this investigation the author adopted the novel procedure of mathematical statistics, based in particular on the method of least squares, analyzed a large number of astronomical *siddhāntas,* and graphically represented the deviations (écarts) against time of longitudes calculated according to the texts from those obtained from modern procedures and tables. From these deviation curves he determined independently and with accuracy the dates of compositions of a number of texts. Furthermore, it was established that exact agreement between actual positions of planets and those calculated theoretically from the constants and formulae of their cannons was secured from time to time by astronomical observations quite accurate for the ancient times under consideration.

Billard recognized three periods in the development of Indian astronomy. The first period dated from the time of the Brāhmaṇas (10th—8th century B.C.) and extended up to the 3rd century B.C.; its characteristic feature was calendrical astronomy and the representative text the *Jyotiṣavedāṅga*. The second period extended from the 3rd century B.C. to the 1st century A.D. and was marked by Babylonian astronomical elements, particularly the *tithi* as a unit of time, arithmetical computations based on heliacal risings and settings of planets, their synodic revolutions etc. The third period,—the period of scientific astronomy, extended from around A.D. 400 up to modern times, was characterized by the employment of trigonometrical methods and epicyclic models for the computations of planetary positions, and produced the *Āryabhaṭīya* of Āryabhaṭa as its first typical text. Billard's main concern was with this scientific astronomy of the third period because the relevant texts and materials readily lent themselves to investigation by the statistical method he adopted.[128]

With the exception of a few texts anterior to A.D. 500, and manifestly imported, the astronomical works of this period are marked by a fantastic speculation, that of the imaginary *yuga,* in which are fitted the mean motions of planets in the form of integral numbers of revolutions and their conjunctions, and various other methods for the calculations of true positions with the help of trigonometry. In all appearances, it was, according to Billard, Āryabhaṭa who in the beginning of the sixth century A.D. was the first astronomer to have laden the scientific trigonometric astronomy with the bewildering speculation of the *yuga*. Yet this speculation was not entirely unbriddled, for it was checked and tested from time to time by a series of astronomical observations and reductions, which constituted the limits of ancient astronomical methods. Sanskrit astronomical texts themselves speak of these observations when these use terms like *dṛkprabhāvāt* (by the imposition of observation), *dṛksama* (in response to observation), *dṛṣṭigaṇitaikya* (accord between observation and calculation), and *dṛggaṇitakāraka* (that which establishes an accord between observation and calculation). Thus Āryabhaṭa was possibly moved by the idea of a Great Year of Berossos which could be suggested to him verbally; thereupon he sought for the constants of mean motions to construct the common multiples and the general conjunctions in accordance with his practical observation in A.D. 510 or very near that date.[129]

In chapter 2 of his *l'Astronomie,* Billard has given an adequate exposition of his statistical method of testing ancient astronomical texts. The first consideration is the choice of a suitable ancient element which has also its equivalent in modern computations. Such an element is the mean longitude ,$\mathcal{L}$ a linear function of time in the form

$$\mathcal{L}\ (t) = \mathcal{L}o + ct.$$

For the Sun, Moon and the five planets Mercury, Venus, Mars, Jupiter and Saturn, seven mean longitudes have to be taken into account; along with these seven elements, one should also consider the vernal equinox ♈, and the apside and node of the Moon. The same ten functions can be computed from modern theory and compared with the value obtained from ancient theories. The deviations between these two sets of values have been called 'écarts'. Billard computed two types of deviations, e.g. those of mean longitudes as defined by the above formula, and synodic deviations, the latter to be derived by combining with the longitudes of the Sun (formula is given on p. 48).

Before applying the method of Sanskrit astronomical canons, Billard first tested its reliability with respect to Ptolemy's *Almagest (Mathematical Syntaxis)*. Billard calls the *Almagest* a non-speculative treatise inasmuch as its elements were based on contemporary as well as ancient observations and consequently the mean motions of planets were precise. The epoch of the *Almagest* was taken to be February 26, A.D. 746 Julian. Between this date and February 2, A.D. 141 Julian there were records of 76 observations, mostly of lunar eclipses and a few of planets. These observations included several Babylonian records of lunar eclipses taken before A.D. 381 Julian, observations by Timocharis at Alexandria, about 10 observations utilized by Hipparchus, and about 33 observations by Ptolemy himself. Ptolemy's constants, —apogees, eccentricities, and radii of epicycles, and formulae for converting mean longitudes into true ones have also been given. Deviations of longitudes and synodics have been represented graphically against time - 500 to + 1900 (Billard's figs. 1 & 2). With the exception of Mercury and Venus, longitude deviation curves, mostly straight lines (sinusoidal for Jupiter and Saturn), lie in a narrow bundle converging to a point corresponding to A.D. 100, approximately the time of Ptolemy. The error of nearly 1° is also in keeping with Ptolemy's observational error. The year of no error, that is, —125 A.D. agrees with Hipparchus' time.[130]

The results of Billard's statistical analyses of Āryabhaṭa's two systems, the *ārdharātrika* and the *audavika,* are discussed in chapter IV. In the former the epoch is the mid-night at the beginning of the *Kaliyuga,* and the *yuga* comprises 4,320,000 years or 1577917800 civil days, while in the latter the *Kaliyuga* starts at the following sun-rise and the *yuga* is made to contain 1577917500 days. This adjustment of 300 days will be understood when one computes the number of days elapsed in 3600 years of the *Kaliyuga* era on Sunday March 21, A.D. 499 Julian 12 hour at the meridian on Ujjayinī. The days are 1314931.5 (mid-night system) and 1314931.25 (sun-rise system) satisfying the following relationship;[131]

$$\frac{1314931.5}{1577917800} = \frac{1314931.25}{1577917500} = \frac{3600}{4320000} = \frac{1}{1200}$$

The number of revolutions of the planets in a *yuga*, the longitudes of their *manda* apses, and the dimensions of their *manda* and *śighra* epicycles are then tabulated, giving details of the variability of the epicycles in the sun-rise system. Formulae for computing equations of centre and conjunction are also given. With these elements the deviations of longitudes and synodics were electronically computed for the two systems and the desired graphics for écarts against time (-500 to $+1900$) obtained. Unlike the *Almagest*, the lines of the graphics in both the Āryabhaṭa systems form a pencil spreading out rapidly from the zone of coincidence. In both cases the zone of coincidence, which is sufficiently sharp, meets the line of zero deviation shortly after A.D. 500 (around A.D. 510). In both systems the curve for Mercury is wide of the mark, but that for Jupiter which is out of step in the mid-night system aligns itself with the majority of the pencil converging on the common zone of null deviation around A.D. 510. Billard interprets these results as showing that the mid-night system was the earlier of the two canons and that, as a result of observations carried out around A.D. 510, the more accurate sun-rise system was developed by slightly changing the revolution number of Jupiter in the *yuga* and by making the dimensions of the epicycles variable. The very nature of distortion or spread away from the zone of coincidence provides a powerful tool for pin-pointing the time of emendation through observation. In Billard's own words: "Il vient tout d'abord l'importante constatation generale: ces elements astronomiques dont on verra plus encore (4, 3, 5) la caractere fantastique, reposent malgre tout sur des observations astronomiques, un ensemble unique d'observations tres rapprochees dans le temps et necessairement de tres grande qualite pour les moyens de l'epoque."[132] The same conclusion is true for other speculative astronomical *siddhāntas* produced in India. Billard was convinced not only of the fact of astronomical observations made in India from time to time, but was struck by their precision which represented the limit of accuracy attainable by the ancient instruments and methods of observation. Thus about Āryabhaṭa he unhesitatingly observed: "On ne manquera pas de remarquer l'etonnante precision de ces ensembles de position pendant la periode des observations: Cette precision etait certainement a la limite des moyens de l'astronomie ancienne, a la limite de ses instruments et de ses modeles mathematiques. C'est dire des a present qu'en depit de la speculation yuga, Aryabhata est certainement l'une des grandes figures de l'histoire de l'astronomie."[133] This view is in marked contrast to the opinions expressed by Colebrooke, Biot, Kaye and others that ancient Indians were poor in astronomical observations.

Space would not permit consideration of Billard's results for his analyses of various other texts, but a few typical results might be mentioned. It is interesting to see that in cases where the date of the text is known, his statistical dating agrees with the known date. This strengthens the reliability of his method in cases where the dating is either unknown or doubtful.

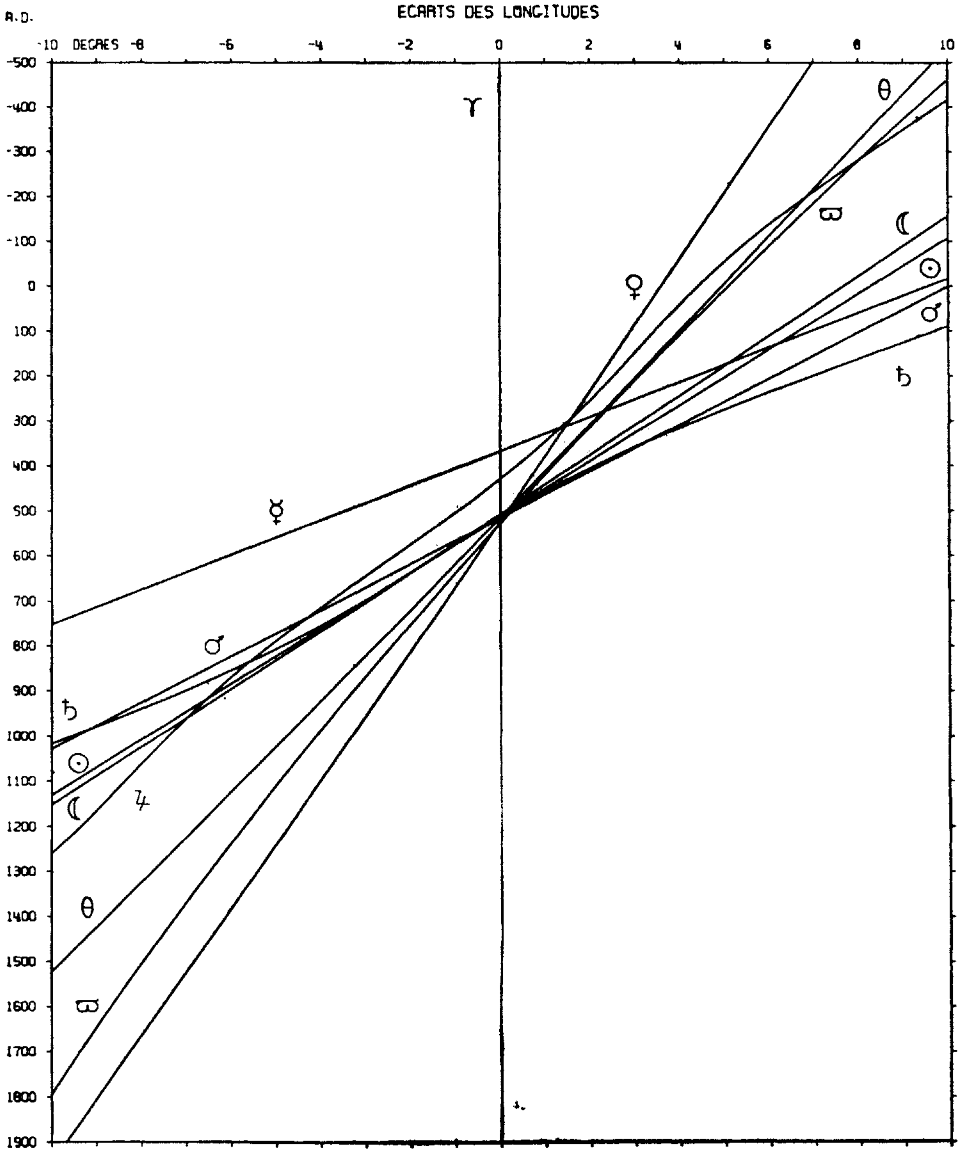

Fig. 3.6. Deviations of longitudes, K. *(S.S.)* *(ārdharātrika)* (from Billard, Fig. 3)

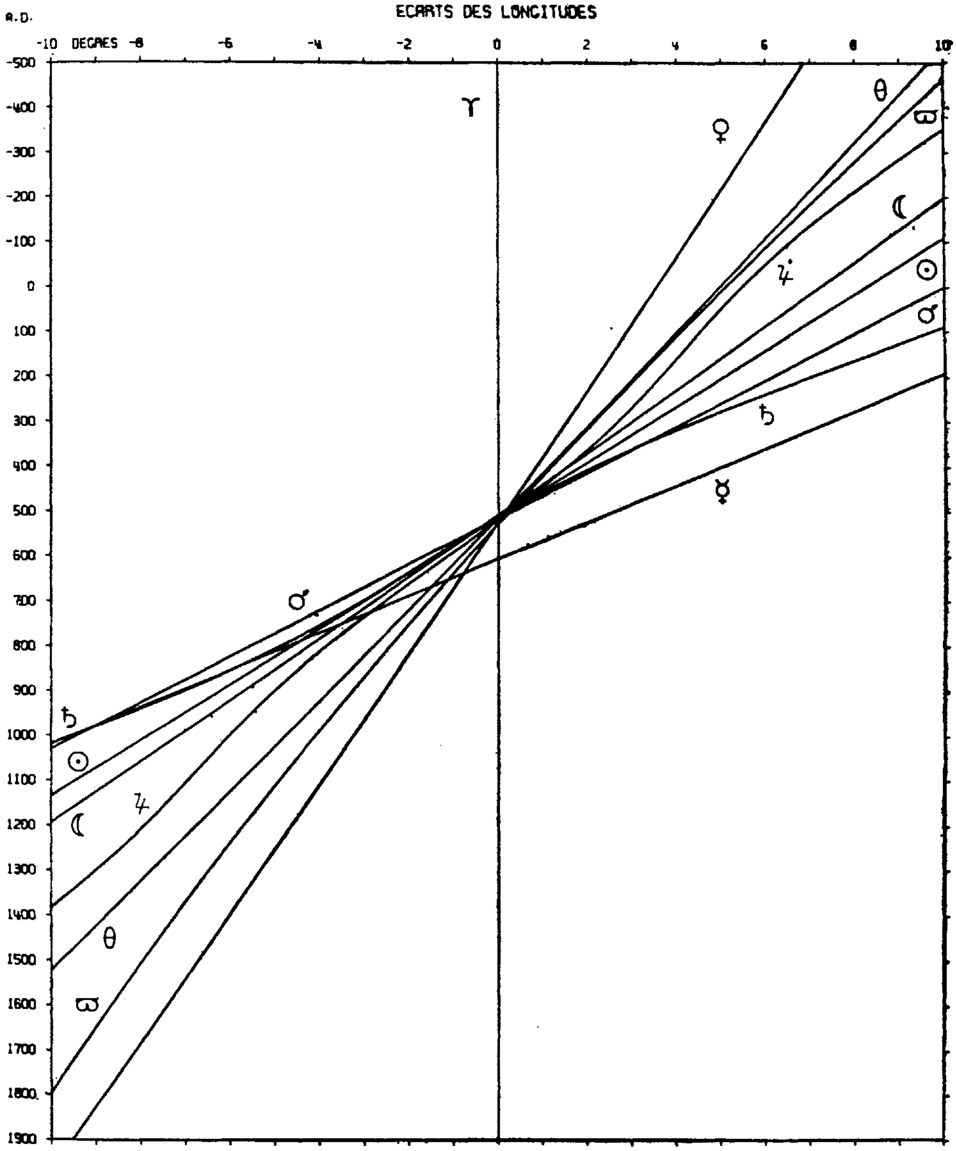

Fig. 3.7. Deviations of longitudes, K. *AB (audayika)* (from Billard, Fig. 5)

Text	*Textual evidence*	*Billard's statistical Method*	*Remarks*
Pañc. S	c. A.D. 505	490.3±6,8 to 512.1±3.6	
Brāhmasphuṭa-siddhānta	A.D. 628	555.2±14.3 to 586.5±18.0	Planetary observations anti-date the composition of the text.
Khaṇḍakhādyaka	A.D. 665	680.7±(12.3) to 729.8±9.6	
do (Āmarāja)	,,	694.5 (8.4) to 739.9±(19.5)	The work appears to have been completed or recast well after 665, possibly at the beginning of the 8th century A.D.
Laghubhāskariya by Śaṅkaranārnāyaṇa	A.D. 869	785.9±13.6 to 822.6±(0.5)	The canon could possibly be dated between A.D. 807 and 821.
Drgganita of Parameśvara	A.D. 1431	1427.2±17.0 to 1475.6±15.1	carried out a large number of observations, particularly of the eclipses.

What is refreshingly new in Billard's study is his endeavour, with the help of modern statistical-cum-computer methods, to understand the true nature, the merit, the originality and the shortcomings of an astronomical system which functioned as an active and effective institution for over fourteen centuries and maintained its vitality through periodical observations, and emendations. The work is a strange contrast to the general efforts of Western scholars directed at digging evidence in favour of their theory of the imported character of the system, its lack of originality, its absence of an observational basis and so on.

David Pingree came forward with a scathing criticism of Billard's *l'Astronomie* (*JRAS*, 1976) presumably because some of his own conclusions were diametrically opposed to those of Billard's. In 1978 he also presented the results of his studies in an article entitled 'History of Mathematical Astronomy in India' in the *Dictionary of Scientific Biography* (vol. XV, Supplement I, 1978). The views presented in Billard's *l'Astronomie*, and Pingree's *Mathematical Astronomy* are so opposed to each other's that both cannot be simultaneously right, and therefore one of them must be wrong. This peculiar situation led van der Waerden to publish in 1980 in the *Journal for the History of Astronomy* a critical review of both these treatises, which deserves close consideration.

Pingree objected to Billard's graphic demonstration that Āryabhata improved upon his earlier mid-night system by utilizing his observations made in A.D. 510. According to Pingree, Āryabhaṭa's mean motions 'apparently are computed from the assumed mean conjunction of the beginning of the Kaliyuga and the mean longitudes of the planets as found from a Greek table for exactly 3600 years later—that is, for noon of 21 March 499." Further more, "..Āryabhaṭa could only observe true, not mean longitudes. It is not an easy matter to deduce the mean longitudes from these true longitudes, and for Āryabhaṭa, with his rather clumsy and inaccurate planetary models, it would have been impossible to arrive at results as good as Billard shows his to be." On Pingree's theory of Āryabhaṭa's dependence on Greek planetary tables, van der Waerden considers it practically impossible for the following reason: "The most accurate Greek tables were the *Handy Tables* of Ptolemy: They were used in Alexandria and Byzantium in the time between Ptolemy and Āryabhaṭa. As far as longitudes are concerned, these tables are based on the *Almagest*. Now leaving aside the very difficult planet Mercury, the deviations of Ptolemy's mean longitudes in A.D. 510 are (in degrees according to Billard's calculations): Equinox—0 (by definition); Sun—2.7; Moon—2.6; Moon's node—3.1; Moon's apogee—3.0; Venus—5.2; Mars—2.6; Jupiter—1.6; Saturn—3.0. Without any doubt, pre-Ptolemaic Greek tables would give rise to still larger deviations. Usually, the errors of astronomical tables tend to increase in the course of time. By sheer accident, it may happen that for one or two planets the deviations become nearly zero for a particular year, but in Figure 5 we have nine deviations which simultaneously become extremely small in A.D. 510. The only possible explanation is that the mean longitudes were determined by accurate observations around A.D. 510."[134]

As to Pingree's other contention that Āryabhaṭa could observe true, and not mean longitudes, van der Waerden shows that it was not at all necessary for Āryabhaṭa to observe mean longitudes. Supposing that Āryabhaṭa had tables from which to calculate mean and true longitudes for his own time and he had really computed them to find discrepancies between the observed and calculated positions how would he proceed to make his system work? "He might", says van der Waerden, "make appropriate changes in the elements of the table, and calculate the positions anew. After one or two trials, he would probably get a reasonable agreement between calculation and observation. There was no need for him to calculate mean longitudes from observed positions."[135] That Āryabhaṭa really proceeded in this manner is strongly indicated in Billard's analysis of Āryabhaṭa's mid-night and sun-rise systems. In the former all mean longitudes are good for A.D. 510 except those for Mercury and Jupiter. Supposing Āryabhaṭa wanted to improve upon his Jupiter it would have been easier for him to observe the planet 'for some time, say one or two synodic periods of thirteen months each, and see what changes in the mean longitudes and other elements he had to make in order to reach a better agreement between theory and observation'. Billard actually prepared a diagram showing deviations of true longitudes of Jupiter and Saturn computed on the mid-night system from those due to modern theory and tables for the years between A.D. 507 and 513 and made it available to van der Waerden. The diagram shows for Jupiter a more or less constant deviation between—1°10′ and—1°40′ and a superimposed sine wave of period equal to that of Jupiter. The constant deviation and the sine wave could be rectified by increasing the mean longitude by the amount of deviation and at the same time changing the dimension of Jupiter's 'conjunction epicycle'. Van der Waerden says, "Now this is just what Āryabhaṭa did. In the Mid-night System, the number of revolutions of Jupiter in a *Mahāyuga* was 364, 220, but in the *Āryabhaṭīya* it was raised to 364, 224, which means that the mean longitudes for the lifetime of Āryabhaṭa were augmented by 1°12'.....In the Midnight System the circumference of this epicycle was 72 degrees, i.e. its radius was the $\frac{72}{360}$ of the radius of the deferent. In the *Āryabhaṭīya* the figure 72 was retained for the initial points of the odd quadrants of the epicycle (i.e. at the opposition and conjunction), but reduced to $67\frac{1}{2}$ at the initial points of the even quadrants, where the sine wave has its maxima and minima. This reduction of the size of the epicycle was just sufficient to eliminate the sine wave, as Billard's calculations show clearly."[136]

Observational basis is also strongly indicated in Billard's analysis of Brahmagupta's *Brāhmasphuṭasiddhānta*. Although the text was written in A.D. 628 the planetary observations underlying the system appear to have been made near the middle of the sixth century and those of the Sun and the Moon near the end of the century. Van der Waerden carried out his own calculations to confirm these conclusions. Āryabhaṭa's mean longitudes set right for A.D. 510 as explained above would deteriorate progressively (mean motions would be slow), and show up large errors in the case of Mars, Saturn, Jupiter and Venus after nearly a century. "Now Brahmagupta, or his predecessor, who corrected Āryabhaṭa's mean motions", observes van der Waerden, "never diminished, but always augmented the mean motions. He added four units to Āryabhaṭa's number of revolutions for Mars, three for Saturn, two for Jupiter and one for Venus, just in the right order. This proves that the observations, on which these corrections to Āryabhaṭa were based, were made sometime after Āryabhaṭa, say about A.D. 570."[137] That these corrections were necessitated by observations was stated by Brahmagupta himself (*Br. Sph. S.* XI, 51).

In addition to the speculative canons based on imaginary conjunction of planets in February 3102 B.C., where the errors increase with time, Billard discovered three 'non-speculative' canons (canons exempts de spéculation) independent of any such supposition. These are Lalla's *Śiṣyadhīvṛddhidatantra* (K. (Lalla)), and two versions A and B of *Grahacāranibandhanasaṃgraha* (K. (GCNibs) A, K. (GCNibs) B). The first canon of this family, K (Lalla), for example, derives its mean motions by comparing Āryabhaṭa's values correct for his time with a set of new observations made around A.D. 898. The result is that the canon yields accurate sidereal longitudes of all planets except Mercury for a period of 500 years between A.D. 400 and A.D. 900. The other two canons operated likewise between values correct for A.D. 522 (assuming Āryabhaṭa's mean values to be correct for this date) and the same observed values for A.D. 898 used by Lalla. The deviation curves in longitudes and synodics obtained for this family of three are more or less identical and resemble those for the *Almagest*. Billard says that from the view point of realism, objectivity and precision, these texts achieved what was possible in their epochs. "Le réalisme y est cette fois aussi complet qu'il pouvait l' être dans l'astronomie ancienne. La spéculation disparait enfin pour laisser place a des canons tout objectifs, tout comme le K. $Ma\theta\Sigma\upsilon\nu\tau$ *(Almagest)* (2, 2, 2) des figures 1 et 2, et de plus d'une precision qui était sans doute à la limite des moyens de l'époque."[138] Van der Waerden points out that Pingree criticizes Lalla's work to be "very crude", but "does not mention the fact that Lalla's mean motions are excellent for the whole period from A.D. 400 to 900." He also avoids noting Billard's date of A.D. 898 when actual observations were made as the basis of these non-speculative texts, and sticks to his own dating of Lalla's work in favour of eighth or early ninth century without giving any reason.

To suit his own theory Pingree devised a number of chronological schools, e.g. the *Brahmapakṣa,* the *Āryapakṣa* etc. The *Brahmapakṣa* of which the basic text was the *Paitāmaha-siddhānta* is supposed to precede *Āryapakṣa,* and the *siddhānta* which is placed in the early fifth century is assumed to be the source and inspiration of Āryabhaṭa's work, for which the last verse (IV. 50) of the *Āryabhaṭiya* is adduced as evidence. Billard considered this last verse in detail, found it to be incompatible with the spirit of the work, and unhesitatingly declared it to be an interpolation. *Paitāmaha-siddhānta*'s placement in the early 5th century has also been called into question. The revolution numbers given in this work are the same as those given by Brahmagupta. Furthermore, the calculations made by Billard and van der Waerden indicate that these numbers were based on observations made in the late sixth century.' Van der Waerden, therefore, considers Pingree's dating 'in the early fifth century as impossible.[139]

In concluding his review of the two treatises, van der Waerden observes that 'Billard's methods are sound, and his results shed new light on the chronology of Indian astronomical treatises and the accuracy of the underlying observations.'[140] We ourselves would like to conclude this survey by expressing a hope that Billard's method of computerized statistical analysis should be followed in many more studies of this kind for a better and more thorough understanding of the history of astronomy in ancient and medieval India.