I A SURVEY OF SOURCE MATERIALS

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Fascinating phenomena in nature like the brilliant moonlit sky studded with stars, the charm of the rising and setting Sun, the waxing and waning phases of the Moon, the periodical changes in the seasons and the like should obviously have excited the curiosity of early man. The origins of astronomy in India, as elsewhere in the world, have to be traced to the inquisitive interest which such phenomena excited in him and urged him to investigate the how and why thereof. The evolution of astronomical acumen, naturally enough, passed through several stages, including the feeling of wonder, mystery, continued observation, religious speculation, cosmic interpretation, scientific enquiry, derivation of rules for computation and development as a discipline.

The present survey of source materials on Indian astronomy is intended to indicate, in a chronological manner, the primary and secondary sources bearing on the development of the science of astronomy in India from the earliest times. Astronomy, unlike certain other disciplines like architecture and metallurgy, is more a science of observation and computation and therefore the main sources of information on its history have to be sought for in recorded literature, traditional practices, instruments and observatories, the last two relating to medieval and post-medieval periods.

ARCHAEOLOGICAL SOURCES

Large-scale excavations in the different regions of the Indian sub-continent, especially in the north-western region, during the last one hundred years, have unearthed substantial archaeological materials right from the Early Stone Age through the Middle and Late Stone Age to historical times. In the Mediterranean world neolithic culture, wherein sharp stone implements were used, and the chalcolithic culture, wherein copper and bronze implements had come into vogue, are clearly distinguished. In India, however, the two are often found to co-exist. This aspect was first identified in the excavations at Mohanjo-daro and Harappa on the Indus basin, for which reason that culture was called Indus Valley civilization. Later excavations proved the existence of this culture in places far removed from the Indus basin, extending to the entire north-west of India and part of Pakistan. The area included Cutch, Saurashtra and Gujarat in the south, Sind and Baluchistan in the west, East Panjab in Pakistan and Panjab and western U.P. in India, in the north, and northern Rajasthan in the east covering in all about 80,000 square miles. A series of excavations at Harappa have determined the norms of the civilization that existed in the area for which reason it is generally given the appellation

Harappan Culture. With this culture as the basis, the archaeological finds at Mohenjo-daro (Sind), Kot Diji (Sind), Kalibangan (Rajasthan), Lothal (Gujarat) and nearly 70 other sites, at different levels, are generally classified as Harappan, pre-Harappan and post-Harappan. Many of the finds have been subjected to Carbon-14 tests which have given dates ranging from 2300 to 2000 B.C.[1] Since recent researches have shown that radio carbon dates tend to be lower beyond 1000 B.C., the date of the pre-Harappan culture might have to be shifted to a few centuries earlier, to about 2500 B.C. or earlier.

Apart from extensive material including different types of pottery, stone and metal implements, faience, glass and beads, the above excavations have unearthed massive remains of towns and fortifications and nearly 3000 inscriptions and figures on terracotta seals.[2] Since during the early days of the evolution of astronomy observations would have been restricted to simple contrivances, besides the human eye any substantial remains could not be expected from archaeological sources. It is in the orientation indicated by the remains of constructions and the interpretation of select seals that one could look for any remains of astronomical importance.[3] However, more important and informative than the archaeological sources are the astronomical traditions of the earliest times recorded and preserved in Vedic literature the early strata of which go farther back than the excavated remains indicated above.

VEDIC LITERATURE

Nature of the Vedic corpus

The extensive Vedic literature spread over nearly 300 basic texts, forms, amongst other things, the primary source of information about the earliest stages of astronomical knowledge in India. A grand monument of the hoary past of the land, the Vedas have come down in a continuous and unbroken tradition, much better preserved than the religious literature, of any other ancient civilization. While most other religious canons have been composed at some specific period by an individual or a school, the Vedas are said to be revealed to 'Seers' of different ages, and handed down intact from generation to generation by oral transmission. This literature is amenable to be divided broadly, by contents and chronology, into four, viz. the *Saṃhitās, Brāhmaṇas, Āraṇyakas-Upaniṣads* and *Vedāṅgas.*

The Saṃhitās

The *Saṃhitās* are collections of hymns, prayers, invocations, charms, sacrificial formulae and the like, selected from a vast mass of floating material and arranged and classified according to content, utility or some other consideration. For each hymn or prayer so included, such documentation as its 'Seer', the deity invoked, the metre and the purpose are also indicated. There are four *Saṃhitās,* viz. the *Ṛgveda* or 'Book of Devotional Verse', the *Yajurveda* or 'Book of Sacrificial Formulae', the *Sāmaveda* or the 'Book of Psalms' and the *Atharvaveda* or the 'Book of Mystico-therapeutic Priestcraft'. It is to be noted that the pieces contained in these 'collections' are very much older than the time of their codification into the four *Saṃhitās,* having

been composed at different periods of time aud having been current by oral tradition when the pieces were selected and arranged in a definitive order.

The *Ṛgveda* is the oldest and the most important of the *Saṃhitās*. It comprises of 10,462 verses in 1028 hymns classified into 10 *maṇḍalas* according to the subject or the seer-families of the hymns. The *Yajurveda* is current in two traditions. The *Śukla* ('White'), available in two recensions, is entirely in verse, divided into 40 chapters, and the *Kṛṣṇa* ('Black'), current in four recensions, contains a large number of theological and other discussions and explanations in prose, interspersed with verses. The *Sāmaveda,* comprises of about 2000 verses, of which 1875 have been taken out of the *Ṛgveda* and the rest from elsewhere. It is arranged into four sections and set to music for being sung during sacrifices. The *Atharvaveda,* current in two recensions, contains about 6000 verses, put under 731 hymns, arranged into 20 sections. A seventh of the hymns of the *Atharvaveda* are common to those of the *Ṛgveda* and the work is nearly as important in the matter of antiquity and contents as the *Ṛgveda* itself.

The Brāhmaṇas

Next in order are the several *Brāhmaṇa* texts allied to each of the Vedic *Saṃhitās* and dealing mainly with the sacrificial rites, the ritualistic application of select passages from the relevant Veda and the speculation of the ideas underlying them. The important *Brāhmaṇa* texts are the *Aitareya* and *Sāṅkhāyana* related to the *Ṛgveda,* the *Śatapatha* of the *Śukla-Yajurveda, Taittiriya* of the *Kṛṣṇa-Yajurveda* and *Gopatha* of the *Atharvaveda.* The *Brāhmaṇas* are important for an understanding of the social, mythological and scientific thought-currents prevalent during the Vedic age.

The Āraṇyakas-Upaniṣads

The *Āraṇyaka* texts allied to the different *Saṃhitās* are concerned with the exposition of the symbolical significance of sacrificial ceremonies, and the *Upaniṣads* concern themselves with philosophical speculations and the exposition of the ways and means for the attainment of the highest values of life. Of the *Āraṇyakas,* the *Aitareya* and *Sāṅkhāyana* are related to the *Ṛgveda* and the *Taittiriya* to the *Kṛṣṇa-Yajurveda.* About 250 *Upaniṣads* are current, but only about a score of them belong to the Vedic age, the rest being later, aligning themselves to different schools of philosophy and later religious cults. There is not much information of astronomical significance in the *Āraṇyakas* and *Upaniṣads.*

The Vedāṅgas (Ancillary Vedic texts)

While the Vedic *Saṃhitās* set out the basic hymns and the *Brāhmaṇas* the sacrifices in which they are used, another set of texts called the *Vedāṅgas* helped in a proper understanding, interpretation and application of the hymns. Of the six *Vedāṅgas, Śikṣā* concerned itself with phonetics, *Vyākaraṇa* with grammar, *Chandas* with metre, *Nirukta* with etymology, *Kalpa* with the performances of rituals and *Jyotiṣa* with astronomy. Two of the six *Vedāṅgas,* are of significance to the history of astronomy. First, *Kalpa,* which consists of practical manuals on the performance of Vedic sacrifices

and household rituals, contain sections called *Śulba-sūtras* which, among other things, mention methods of orientation and make use of geometry, irrational numbers and other mathematical ideas in the construction of sacrificial altars. The other is the *Vedāṅga Jyotiṣa,* 'ancillary Vedic astronomy', of which three texts are available, related respectively, to the *Ṛgveda, Yajurveda* and the *Atharvaveda.* The first two, containing, respectively 36 and 43 verses, are ascribed to the same author Lagadha. Their basic content is almost the same, the latter having some additional matter, and form manuals for computing the civil calendar and proper times for the performance of rituals. The work locates the summer solstice in the middle of the constellation Āśleṣā and the winter solstice at the beginning of Dhaniṣṭhā, calculating backwards from the present position of the solstices, this would give a date *c.* 1370 B.C. The *Atharva Jyotiṣa,* which is in the form of a dialogue between Pitāmaha and sage Kāśyapa, in 162 verses, is astrological in content. Mention might be made here also of another work related to the *Atharvaveda,* viz. the *Nakṣatra-kalpa,* which enumerates 28 constellations from Kṛttikā, indicates their presiding deities, their groupings according to the part of the day and the directions and rituals pertaining to them; the work is thus astrological in content.

Nature of the astronomical content in Vedic texts

Though the Vedic poets did not compose the hymns for setting out scientific information, these extensive texts contain pertinent indication of the concepts and practices relating to the astronomy of the times. Especially significant in this regard are the cosmological hymns of the *Ṛgveda* and the *Atharvaveda.* Moreover, the recording, in some of the hymns, of celestial observations enables one to compute back, within margins, the date of composition of those hymns.

The lunar year was followed and the Moon was called *māsa-kṛt* 'maker of months.'[4] A full cycle of seasons delimited the year and the beginning of the year was ascertained by the proximity of a bright star to the full-moon which is clearly visible to the naked eye. Such stars recorded in different hymns of the *Ṛgveda* as the harbingers of autumn or the autumnal equinox are Aditi (Punarvasu, Pollux, long. 113°), Dakṣa (Abhijit, Vega, long. 284°), Rudra (Ārdrā, Betelguse, long. 88°) and Rohiṇī (Aedebaran, long. 69°). This change has obviously been the result of the precession of the equinoxes. Calculating at the rate of 72 years per degree, with due allowance for error, the periods referred to should, respectively, be *c.* 6200 B.C. 5400 B.C., 4350 B.C. and 3070 B.C. which should be the dates when the respective hymns were composed. A process of intercalation had also been in vogue for the correlation of the lunar year with the year of the seasons.[5]

The Ṛgvedic hymn 1.164, on the cosmic times wheel, by sage Dīrghatamas, speaks of a wheel of time, with a year consisting of twelve lunar months and 360 lunar days (*RV* 1.164.1) and starts the year with the autumn star Agni (Kṛttikā, Alcyon, long. 59°5) which on calculation gives a date *c.* 2350 B.C. In another Ṛgvedic hymn 3.99, which also mentions Kṛttikā as the autumn star (*c.* 2350 B.C.), sage Viśvāmitra worships 3339 (371×9) *devas* and apparently refers to a period of 30 years consisting of 371 lunar months. This would give an year of 371 lunar days, working out to

365.19 solar days.[6] Incidentally, it may be noted that in the above-cited hymns (*RV* 1.164 and 3.99), the numbers used (12, 360; 371, 3339. 33 and 11) have been expressed in the decimal system. Attention might also be drawn to the *Yajurveda*[7] enumerating multiples of 10 upto thirteen digits with specific names for each.[8]

While some of the stars are mentioned in the *Ṛgveda*, the *Yajurveda* and the *Atharvaveda* give full lists of the 27 (or 28) stars commencing from Kṛttikā. A fair knowledge of calendrical science is apparent in the full treatment of *gavām ayana* and other sacrifices of different durations based on the daily progress of the Sun. The equinoxes and solstices were determined accurately.[9] The twelve lunar months are named and so also the intercalary month. For ritualistic purposes the day-time had severally been divided into two, three, four, five and fifteen equal parts, each division having a different nomenclature. Of the five planets mentioned, only Jupiter (Bṛhaspati) and Venus (Vena) are referred to by name.[10,11] The solar eclipse is described as the occultation of the Sun by Svarbhānu (Rāhu). P. C. Sen Gupta has determined the date of a total eclipse of the sun described in the *Ṛgveda* (5.40-4-9) as 3928 B.C.[12] It is interesting to note that the *Taittiriya Brāhmaṇa* (3.10.9) extols *nakṣatra-vidyā* ('science of stars') and mentions a hierarchy of scholars who cultivated the science.[13] Professional astronomers were termed *nakṣatra-darśa* 'star-gazer'[14] and *gaṇaka* 'calculator.'[15]

JAINA LITERATURE

Canonical Literature

The Jainas displayed extensive literary activity from early times and their canonical literature contain information on a wide range of subjects, religious, philosophical, social and scientific. The original texts, termed *Pūnva-s*, are said to have been lost and the Śvetāmbara sect of Jainas had them receast later in the Ardha-Māgadhī Prākṛt from existing fragments and oral tradition. Their basic canonical texts number 45 (or 50), besides a large number of subsidiary texts. The basic texts are classified as *Aṅgas, Upāṅgas, Prakirṇakas, Chedasūtras* and *Mūlasūtras*.

The *Aṅgas* are twelve in number and deal with doctrinal matter, rituals, legends and the like. They are the *Ācārāṅga, Sūtrakṛtāṅga, Sthānāṅga, Samavāyāṅga, Bhagavati* or *Vyākhyāprajñapti, Jñātṛdharmakathā, Upāsakadaśā, Antakṛtadaśā, Anuttara-aupapātikadaśā, Praśna-vyākaraṇa, Vipākasūtra* and *Dṛṣṭivāda*. Of these, the *Sthānāṅga* and *Bhagavatisūtra* contain information on mathematics and astronomy.

There are twelve *Upāṅgas* corresponding to the *Aṅgas*, but not directly related to them. These are: *Aupapātika, Rājapraśniya, Jīvājīvābhigama, Prajñāpanā, Sūryaprajñapti, Jambūdvīpaprajñapti, Candraprajñapti, Nirṇayāvali, Kalpāvataṃsikā, Puṣpikā, Puṣpacūlikā* and *Vṛṣṇidaśāḥ*. Among these, Jaina cosmogony is dealt with in *Jīvājīvābhigama* and *Jambūdvīpaprajñapti* and details of Jaina astronomy are to be found in *Sūryaprajñapti* and *Candraprajñapti*, and also in *Jambūdvīpaprajñapti*.

The third set of texts called *Prakirṇakas*, 'Miscellaneous texts', are ten in number, and like the *Pariśiṣṭas* (ancillary texts) of the Vedas, treat of numerous matters related

to the canon. One of these texts, the *Tandulaveyāliya* contains, among other things, measures of length and of time.

There are nine *Chedasūtras* which deal with the rules of conduct and life of monks and nuns, monastic jurisprudence and edificatory legends.

Extensive and highly important from the point of contents are the four *Mūlasūtras*, viz. *Uttarādhyāyana, Āvaśyaka, Daśavaikalika* and *Piṇḍa-niryukti,* of which the first one contains occasional passages ralating to mathematics and astronomy.

Two individual texts called *Cūlikāsūtras* of an encyclopaedic nature, the *Nandi-sūtra* and *Anuyogadvārasūtra,* sometimes included in the *Prakīrṇakas,* make up the Śvetāmbara canon. These texts deal with numerous topics, including topics on astronomy and mathematics, which a Jaina monk was supposed to know.

Chronology of the Jaina canon

Jaina tradition holds that the canon taught by Mahāvīra Jina was dutifully handed down for six generations and, when it tended to lapse into oblivion, a Council was called at Pataliputra when the 12 *Aṅgas* were resuscitated. When it was again thrown into disorder, another Council was held at Vallabhi in the 6th century A.D. and it was again reconstructed. Detailed analysis of the contents and language of the canon as it exists would show that the most ancient portions took shape during the third and fourth century B.C.

The Jaina canonical texts are highly repetetive and numerous passages are common to different texts. The several topics dealt with in the Jaina canons were later classified by Āryarakṣita (by Samantabhadra according to some) and arranged into four collections entitled *Caraṇānuyoga, Dharmakathānuyoga* (or *Prathamānuyoga*), *Gaṇitānuyoga* (or *Karaṇānuyoga*) and *Dravyānuyoga.* Matters relating to astronomy, mathematics, geography and allied subjects have been collected in the *Gaṇitānuyoga.*

The Jaina canons speak of astronomy as an important branch of study and as an essential equipment for a Jaina priest for computing the correct time for religious performances. The *Sūryaprajñapti, Candraprajñapti* and *Jambūdvīpaprajñapti,* give a full depiction of the astronomical concepts and practices of the Jainas. The first two texts are entirely devoted to the subject, while the third, which is an extensive work divided into seven sections, devotes its last section for astronomy; it also enumerates, in section two, forty-five divisions of time, commencing from *asaṅkhyāta,* being 'inscrutable infinitismal time', to *śīrṣaprahelikā,* which is equal to several crores of years. The astronomical material contained in all these three works is almost the same in essence.

Extensive expositions are also available for the above works. For the *Sūryaprajñapti* there is a commentary by the versatile Jaina scholiast Malayagiri (*c.* 1100-1200 A.D.) and a *Nirukti* by Bhadrabāhu, which latter is known only through quotations. *Candraprajñapti* too has been commented on by Malayagiri. For the

Jambūdvipaprajñapti, Malayagiri's commentary is known only through quotations, but a detailed commentary by Śānticandra (16th cent. A.D.) is available. Padmanandi, an author of *c.* 1000 A.D., has abridged the work in his *Jambūdvipaprajñapti-saṃgraha.*

Post-canonical Jaina Literature

Post-canonical Jaina literature is very voluminous and encompasses all disciplines. A brief mention might be made here of the more important writings relating to astronomy.

The *Tattvārthādhigama-sūtra* of Umāsvāti (A.D. 185-219) contains a section on cosmology, which deals with astronomy as well. Commentaries on this work are available by Umāsvāti himself and by later scholars. The *Trilokaprajñapti* by Yati-Vṛṣabha (between A.D. 473 and 609) is an encyclopaedic work in 7000 verses and, in its chapter seven, there is a long excursus on astronomy. It is noteworthy that the treatment of the subject here exhibits considerable parallelisms in thought and expression with the *Āryabhaṭiya.*[16] *Jyotiṣakaraṇḍaka*, possibly by an early author by name Padaliptācārya, is based on the *Sūryaprajñapti* and contains the entire gamut of Jaina astronomy. The work has been commented on by Malayagiri who quotes earlier commentaries also. The *Karaṇānuyoga* or *Gaṇitānuyoga* of the Digambara seet of Jainas is again a compilation of astronomical and mathematical material scattered in the different Jaina texts, including *Sūrya*-and *Candraprajñapti* and *Jayadharalā.*

Among later Jaina works on astronomy the undermentioned are noteworthy: *Jyotissāra* by Thakker Pheru (14th cent.) in 238 verses, divided into four chapters; *Dinaśuddhi* by Ratnaśekhara Sūri (15th cent.) in 144 verses for computing the true Sun, Moon etc., *Maṇḍalaprakaraṇa* by Vinayakuśala in 99 verses, composed in A.D. 1596, with an elaborate commentary: *Jyotiḥprakāra* by Jñānabhuṣaṇa (*c.* A.D. 1700) in seven sections, and *Candrārki* by Dinakara (16th cent.) on the computation of true Sun and Moon and its commentary by Kṛpāvijaya.

A few works on astronomical instruments produced by Jaina astronomers under Muslim inspiration are also known. These include *Yantrarāja* by Mahendra Suri (A.D. 1348) who was a courtier of Sultan Feroz Shah Tughlaq, and its commentary by Malayendu Sūri, and *Ustaralaya-yantra* by Meghalaya (*c.* A.D. 1500 in the construction and use of astrolabe, with a commentary by the author himself. Among manuals on astronomy by Jaina authors, a mention might be made of *Karaṇarāja* in ten sections by Muni Sundara (*c.* A.D. 1600). A number of *Pañcāṅga* manuals for the computation of the daily calendar are also known to be composed by later Jaina scholars.

ASTRONOMICAL SIDDHĀNTAS

Nature of the Siddhāntas

The few centuries immediately preceding and following the Christian era are of significance in the history of Indian astronomy inspite of the fact that practically no important work on astronomy of the times has come down to us intact, but for the

Jaina texts mentioned earlier. The reasons are not far to seek. This was a period when the Vedic age evolved into the classical age at the advent of Buddhism and Jainism and the direct contact with the Greeks and the Romans. The unorthodox bent of thought and new sources of knowledge should have had their impact upon the intellectual endeavours of the Vedic Indians, resulting in novel strides in all walks of life including the pursuit of sciences. In the discipline of astronomy, this period witnessed the advent of a class of texts called *siddhāntas,* characterized by a better scientific approach and more comprehensive treatment. The *siddhānta* astronomy adopted more sophisticated mathematics, incorporated the planets in the system, devised a system of coordinates for the determination of the periods of planetary revolutions and of the relative sizes of the Earth, the Sun and the Moon. The *nakṣatra* system was dispensed with and replaced by the twelve signs of the zodiac. The mean longitudes were calculated from the number of days elapsed from the beginning of long periods of time called *Kalpa* or the *Kaliyuga.* The length of the year and day-lengths were correctly determined. Planetary positions were computed using eccentrics and epicycles. The eclipses were computed with greater accuracy by correcting the results for parallax. Computations were characterized also by geometrical, arithmetical and algebraic practices, some aspects of plane and spherical trigonometry, and application of indeterminate equations.

Early Siddhāntas

According to tradition, there existed 18 early *siddhāntas* composed by Sūrya, Pitāmaha, Vyāsa, Vaśiṣṭha, Atri, Parāśara, Kāśyapa, Nārada, Garga, Marīci, Manu, Aṅgiras, Lomaśa (Romaka), Paulīśa, Cyavana, Yavana, Bhṛgu and Śaunaka. Most of these have gone out of vogue and lost, but five are available in the form of summaries or, what is more likely, extracts, in the *Pañcasiddhāntikā* of the prolific writer of astrology Varāhamihira (A.D. 578), being the *siddhāntas* of Pitāmaha Vaśiṣṭha, Pauliśa, Romaka and Sūrya. The *Sūryasiddhānta* is available also in a later modified form. The reason for the disappearance of the early *siddhāntas* is to be sought in their supercession by later *siddhāntas* characterised by greater accuracy, easier methods of calculation and comprehensiveness. The non-availability of the early *siddhāntas* in their full and original form makes it difficult to reconstruct the development of the discipline during this period.

Later Siddhāntas

The later *siddhāntas* followed, in the main, the general pattern of the earlier *siddhāntas,* but there was substantial development in the matters covered, the range of date used and the manner in which the subject was set out. For various reasons, the schools represented by the different *siddhāntas* came to be popular in different parts of the country, where texts in extension, expositions, systems of computation, practical manuals *(Karaṇas),* astronomical tables *(Koṣṭhakas),* description of instruments *(yantras)* and other miscellaneous writings, came to be composed, mainly in Sanskrit, but also in the different provincial languages.

The *Āryabhaṭīya* of Āryabhaṭa I (b. A.D. 476) is the earliest of the later *siddhāntas.* In 121 verses, divided into four chapters, it sets out: Ch. I. The astronomical

constants and the sine table; II. Mathematics required for computations; III. Division of time and rules for computing the longitudes of planets using eccentrics and epicycles; and IV. The armillary sphere, rules relating to problems of trigonometry and the computation of eclipses. The *Āryabhaṭiya* started a new school of astronomy which grew popular in South India and threw up extensive literature, both expository and original.

The *Āryabhaṭiya,* the parameters and other astronomical elements of which constituted *Āryapakṣa,* had its epoch at sunrise at Laṅkā, at the commencement of the Kaliyuga, on Friday, 18 February 310 B.C. Āryabhaṭa wrote still another work, apparently entitled *Āryabhaṭasiddhānta,* which had its epoch at midnight 17/18 February 310 B.C. and formed the basis for the *Ārdharātrikapakṣa* in Indian astronomy. The text of this work is not available now, but is known through quotations and a summary of its tenets mentioned in later works.[17]

The earliest available commentary on the *Āryabhaṭiya* is by Bhāskara I who wrote from Valabhi in Gujarat (A.D. 629), but he names earlier exponents of the school like Lāṭadeva and Pāṇḍuraṅgasvāmī. Other scholiasts of the *Āryabhaṭiya* include Someśvara (11th-12th cent.), also from Gujarat, and several from South India, including Sūryadeva Yajvan (b. 1191), Parameśvara (*c.* 1450), Yallaya (1480), Nīlakaṇṭha Somayāji (b. 1444), Raghunātha Rājā (1597), Ghaṭīgopa (*c.* 1800) and Bhūtaviṣṇu. Bhāskara I wrote also two authoritative works on the system of Āryabhaṭa, the *Mahābhāskarīya* and the *Laghubhāskarīya,* in eight chapters each. These texts too have been elaborately commented upon, the former by Govindasvāmin (*c.* 800-850) with a super commentary by Parameśvara, Sūryadeva Yajvan, Parameśvara and in *Prayogaracanā* by an anonymous author. The *Laghubhāskarīya* has been commented by Śaṅkaranārāyaṇa (A.D. 869), Udayadivākara (A.D. 1073) and Parameśvara.

The *Brāhma-sphuṭa-siddhānta* of Brahmagupta (b. 598) exerted great influence in the astronomical thought of western and northern India as works based on it would show. In 1008 (or 1022) verses, divided into 24 (or 25) chapters, it expounds the *Brahmapakṣa* and criticises the *Āryapakṣa* of Āryabhaṭa. Chapter 11 and 22 are important for the reason that in the former he criticizes the views of some of his predecessors, including Āryabhaṭa, Pradyumna, Lāṭadeva, Varāhmihira, Vijayanandin, Viṣṇucandra's *Vāśiṣṭha-siddhānta,* Śrīṣeṇa's *Romaka-siddhānta,* and the Jainas, and in the latter gives details of astronomical instruments. Pṛthudakasvāmin (*c.* 860) wrote an erudite commentary on the work, in which he quotes an earlier commentary by Balabhadra. Other commentators of *Brāhma-sphuṭa-siddhānta* are Āmarāja, Bhaṭṭotpala, Lalla, Someśvara, Śrīdatta and Varuṇa. This siddhānta was taken to Baghdad where it was translated into Arabic under the title, *Al-Zij-al-Sindhind* in A.D. 771 or 773 by Muhammad ibn Ibrahim al-Fazārī.[18]

A '*Later Pauliśa-siddhānta*', which adopts the parameters of the *Ārdharātrikapakṣa* but makes major improvisations otherwise is known from citations occurring in the works of Pṛthūdakasvāmin, Bhaṭṭotpala, Āmarāja and Al-Bīrūnī.[19]

The *Śiṣyadhivṛddhida-tantra* of Lalla (8th-19th cent.) in 12 chapters, is based on the *Ārdharātrikapakṣa* of Āryabhaṭa, but incorporates *bīja*-corrections and makes certain improvisations from the *Brāhmasphuṭa-siddhānta*. It contains an informative chapter on astronomical instruments and has been commented upon by Bhāskara II (b. 1114) and by Mallikārjuna Sūri (12th cent.).

The *Later Sūryasiddhānta*, a comprehensive work in 12 chapters, has been highly popular throughout India. It adopts the *Ārdharātrikapakṣa* but makes modifications. Among its large number of commentaries might be mentioned those of Mallikārjuna Sūri (12th cent.), in Telugu and Sanskrit, Caṇḍeśvara (12th cent.), Madanapāla (14th cent.), Parameśvara (1432), Yallaya (1472), Rāmakṛṣṇa Ārādhya (1472), Bhūdhara (1572), Tamma Yajvan (1599), Raṅganātha (1603), Nṛsiṃha (1611), Viśvanātha (1628), Kamalākara (17th cent.) and Dādābhāi [20] (18th cent.).

The *Vaṭeśvara-siddhānta* by Vaṭeśvara (A.D. 904) follows the *Āryapakṣa* and *Saurapakṣa* and gives a thorough treatment of astronomy in three sections. A point of interest in the work is that, as an ardent admirer of Āryabhaṭa, Vaṭeśvara vehemently criticizes Brahmagupta and refutes his views in ch. 10 of Sn. I of the work.

Śrīpati's *Siddhāntaśekhara* (A.D. 999), which, in 20 chapters, follows the *Brahmapakṣa* is important in that it gives rules for determining the moon's second inequality and evection. An incomplete commentary on the work by Makkibhaṭṭa is available in print.

The *Siddhānta-Śiromaṇi* (A.D. 1150) of Bhāskara II, who hailed from the Karnataka region, is by far the most comprehensive *siddhānta* work in Indian astronomy. It is based on the *Brahmapakṣa*. The work is in four parts: I. *Līlāvati* on arithmetic, II. *Bijagaṇita* on algebra, and III. *Gaṇitādhyāya* and IV. *Golādhyāya*, on astronomy. The epicyclic-eccentric theories are fully developed to account for planetary motions. The section on astronomical instruments is also more full than earlier treatises. The four parts of the work have also been studied independent of each other. All these have been supplied elucidative glosses, called *Vāsanā-bhāṣya* by the author himself. About 50 other commentaries are known for the *Līlāvati* and the other parts have also been commented by several scholiasts. The more important commentaires in *Gaṇitādhyāya* and *Golādhyāya*, which form the astronomical component of the work, are by Lakṣmīdāsa (A.D. 1501), Gaṇeśa Daivajña (17th cent.), Nṛsiṃha (1621) and Munīśvara (17th cent.).

In his short work *Siddhānta-darpaṇa*, Nīlakaṇṭha Somayāji (*b.* 1444) sets out the astronomical constants according to the *Āryapakṣa* as corrected by him and also the situation of the armillary sphere. He has also commented on this work in detail. His *Tantrasaṃgraha* in 432 verses, divided into eight chapters, however gives a full treatment of the subject.

A few *siddhāntas*, apocryphal in nature, are available in print. They are: *Vṛddha-vāsiṣṭha-siddhānta* in 13 chapters dealing with all topics of astronomy, *Vāsiṣṭha-siddhānta*,

in 95 verses divided into five chapters, *Soma-siddhānta,* a comprehensive work in ten chapters, and *Brahma-siddhānta,* in 764 verses divided into six chapters which claims to be a part of *Śākalya-saṃhitā.* There is also a *Vyāsa-siddhānta,* in three sections entitled *Bhuvanakośa, Kakṣādhyāya* and *Golādhyāya,* which claims to be part of *Vyāsasmṛti.*

Mention might be made here of a late *siddhānta* work entitled *Siddhānta-sundara* by Jñānarāja who wrote from Pārthapura on the Godāvarī in A.D. 1503. The author claims that Brahmā, Sūrya, Soma, Vasiṣṭha and Pulastya agree with his *Saurapakṣa* parameters. It is again to be noted that by Brahmā he refers to the *Brahma-siddhānta* of the *Śākalya-saṃhitā* noticed above. The work has a commentary by the author's son Cintāmaṇi (*c.* 1530).

Karaṇas

Astronomical computations based on *kalpas* and *yugas* involving large numbers being cumbersome, a genre of practical manuals, called *karaṇas,* arose and was designed to lighten the work of calculations and produce quick and more accurate results. A contemporary date at the sun-rise of which there occurred a conjunction of the Moon and its higher apsis, was chosen as the epoch[21] and the longitudes of the other planets were determined accurately for this moment to be used as zero corrections. Computations were then made with this epoch as the basis. Usually, *bija* corrections were also applied to the parameters.

The recensions of the *Pauliśa*-and *Romaka-siddhāntas* of Lāṭadeva (6th cent.) pupil of Āryabhaṭa, redacted in the *Pañcasiddhāntikā* of Varāhamihira (d. 587) are the earliest *karaṇa* texts in Indian astronomy. The *Saura-siddhānta* of the *Pañcasiddhāntikā* is also a *karaṇa* text, and according to Al-Bīrūnī this is also a work of Lāṭadeva. The epoch of all these *karaṇas* is 21 March, 505. It is interesting to note that Chapter 4 of his *Pañcasiddhāntikā,* dealing with spherical trigonometry is called *karaṇādhyāya.* Obviously, at that time, the term *karaṇa* meant only 'astronomical calculation' and *siddhāntas* included also *karaṇas.*

The *Khaṇḍakhādyaka* of Brahmagupta, of epoch 23 March 665, bases itself on the *Ārdharātrikapakṣa* of Āryabhaṭa I. The different astronomical topics are dealt with in nine chapters which form Pt. I of the work. In Pt. II corrections are given to the parameters of Part I, changing them to *Brahmapakṣa.* The work had been extremely popular in the whole of North India. It has been commented upon by Pṛthūdakasvāmin (A.D. 864), Bhaṭṭotpala (969), Āmarāja (*c.* 1200), Yamaṭa, Varuṇa and Śrīdatta. A *Khaṇḍakhādyaka-sāraṇi* is also known.

Laghumānasa of Muñjāla (10th cent.) is a *karaṇa* in six chapters using the elements both of the *Āryapakṣa* and the *Ārdharātrikapakṣa* and mentions of the second inequality in lunar motion. The work has been commented by Praśastadhara of Kashmir (A.D. 958), Sūryadeva Yajvan of the Cola country (1248), Parameśvara (1409) of Kerala and Yallaya (1482) from the Telugu country. Muñjāla had composed also a *Bṛhanmānasa,* which is lost and is known only from quotations which give its epoch as 9 March 932; the epoch of the *Laghumānasa* is likely to be the same.

Rājamṛgāṅka of king Bhoja of Dhārā, whose epoch is 21 February 1042, is not available in its original form, but only in three incomplete versions, of which one version by Rāma is available in print.

The *Karaṇaprakāśa* of Brahmadeva is based on the *Āryapakṣa,* and has its epoch on 11 March 1092. This *karaṇa* has been a popular work in south and west India and has commentaries on it by Dāmodara, Amareśa, Govinda, Śrīnivāsa Yavan and Sampatkumāra. Commentator Dāmodara has composed, on his own, two *karaṇa* texts, *Āryatulya* in 1417, based on *Āryapakṣa* and a *Sūryatulya* based on the *Sūrya-siddhānta.*

The *Bhāsvati* of Śatānanda of Puri, in 8 sections, is a popular *karaṇa* based on the *Sūrya-siddhānta* of Varahamihira's *Pañcasiddhāntikā.* It follows the *Ārdharātrikapakṣa* and has been commented on by nearly 25 scholiasts.

Bhāskara II has written also an erudite *Karaṇakutūhala,* called also *Grahagāma kutūhala* and *Brahmatulya.* This work has been very popular in the west and north-west of India. It has its epoch on 23 February 1183 and follows the *Brahmapakṣa.* Of its several commentaries the more important are those by Ekanātha (1370), Padmanābha (*c.* 1400), by Viśvanātha (1612) and by the Jaina astronomer Sumatiharṣagaṇi (1621). There is also a set of planetary tables based on this work, called *Brahmatulyasāraṇi.*

The *Grahalāghava* or *Siddhānta-rahasya* of the prolific astronomer Gaṇeśa Daivajña in 16 chapters, of epoch 18 March 1520, is a very popular *karaṇa* commented upon by the author himself and by a host of scholiasts. Several planetary tables based on *Grahalāghava* are also known.

Rāmavinoda by Rāma, a courtier of Akbar, belongs to the *Saurapakṣa* and has 11 March 1590 for its epoch. The author himself prepared a *koṣṭhaka* for the work, while there is a commentary on it by Viśvanātha (1602). Still another *karaṇa* following the same *pakṣa* is the *Sūryapakṣaśaraṇa* or *Khacarāgama* of Viṣṇu, having the epoch 7 March 1608, on which Viśvanātha wrote a commentary in 1612.

Koṣṭhakas or Sāraṇis

Alongside the *karaṇas* from about the 10th cent., a genre of ancillary Tables called *koṣṭhakas* or *sāraṇis* came into vogue, in which were charted, in columns, the planetary positions, cusps of the astrological places or other calendrical functions like *tithis, nakṣatras, yogas* etc. Since these tables were extremely handy for almanac-makers, a very large number of *koṣṭhakas* or *sāraṇis* came to be produced, based on different *karaṇas.* In some cases the authors of the *karaṇas* themselves prepared the *sāraṇis.* Every almanac-maker, priest and astrologer had to have his own copy of a *sāraṇi,* with the result that a very large number of manuscripts of this type of works is known.[22]

Diverse texts from Kerala[23]

Astronomical thought in South India, especially in Kerala, developed, from early times, certain features varying from the traditions in the rest of India. For this reason, it would be advantageous to assess, under a separate heading, the contributions of this region in the said aspects. It might be noted at the outset that Kerala had been a strong bastion of the Āryabhaṭan school of astronomy from early times. Numerals in Keralite works are expressed in the *kaṭapavādi* notation, and while the language of most of these works is Sanskrit, their commentaries are mostly in the local Malayalam language.

i. *Parahita and Dṛk Systems of Computation.*

Tradition has it that astronomers of Kerala gathered at Tirunāvāy on the Arabian coast, in A.D. 683 and formally inaugurated the *Parahita* system of astronomical computation with emendations to Āryabhaṭan elements which had till then been followed in the land. The *Grahacāranibandhana* and *Mahāmārganibandhana* of Haridatta formed the basic texts of the system. Several centuries later, when results derived from *Parahita* were found not to tally with observation, Parameśvara (1360-1455) enunciated in 1431 his *Dṛk* system of computation through his *Dṛggaṇita.* While these two basic texts provided only the basic elements and rules, in their wake, a large volume of *karaṇa* literature, treating in detail some or all the topics of astronomy, and introducing further changes, novel methodologies and the like, came to be produced. Shortly after Haridatta, but apparently unconnected with his work, Devācārya wrote in A.D. 689 his *Karaṇaratna,* a full-fledged *karaṇa,* dealing, in eight chapters, all the major topics of practical astronomy, including the determination of the longitudes of the Sun, Moon and planets, the eclipses, gnomon shadow, rising of the Moon, heliacal visibility and planetary conjunctions. Among later texts might be mentioned the *Vākyakaraṇa* (*c.* 1300) to be noticed below, the *Dṛkharaṇa* in 10 chapters of Jyeṣṭhadeva (1500-1610), *Karaṇasāra* by Śaṅkara Vāriyar (1500-60) in 4 chs. with auto-commentary, *Karaṇāmṛta* of Citrabhānu (1530), in 4 chs., having two commentaries, *Karanottama* of Acyuta Piṣāraṭi (1550-1621) in 5 chs., with autocommentary, *Bhadradīpagaṇita* of Iṭakramañceri Nampūtiri (17th cent.), *Karaṇapaddhati* of Putumana Somayāji (1660-1740), *Jyotiṣśāstrasaṃgraha* and *Saṃgrahasādhanakriyā* of Āzvāñceri Tamprākkaḷ (18th cent.) and *Sadratnamālā* of Śaṅkara Varman (1800-38). There are at least eleven different texts with the common title *Pañcabodha,* some of them with commentaries, nine texts with the title *Grahagaṇita,* two texts with the title *Kriyāsaṃgraha,* a dozen texts with the title *Vyatipataganita* and several other anonymous texts, often with commentaries.

ii. *Astronomical vākyas.* The *Parahita* and *Dṛk* based systems make use of a large number of mnemonics couched in the form of words, phrases or short sentences *(vākyas)* which, when deciphered in terms of the *kaṭapayādi* system of numeral notation, yield different astronomical tables. These *vākya*-mnemonics relate to all sorts of astronomical tables, to wit, the 248 daily longitudes of the Moon for 9 anomalistic months (well-known as the *Candravākyas* of Vararuci), 3031 daily lunar longitudes for 110 anomalistic months, 2075 *vākyas* called *Samudra-vākyas, Maṇḍala-vākyas.* or *Kujā-*

dipañcagraha-mahāvākyas for the five planets, 570 for Kuja, 528 for Budha, 231 for Guru, 165 for Bhṛgu and 551 for Śani, the different sines of arc *(iyās)*, deductive components to be used in computations and so on and so forth. Some of the *karaṇa* texts make profuse use of these mnemonic-*vākyas*. Following Haridatta's basic *Parahita* manual *Grahacāranibandhana*, the first known major text that makes use of this device is the *Vākya-karaṇa* ('*Karaṇa* utilising *vākyas*') in five chapters, apocryophally attributed to Vararuci, but composed about A.D. 1300. The work has been commented upon in great detail by Sundararāja (*c.* 1500) of Viprasadgrāma near Trichinopoly in Tamilnadu. The almanac-makers of the Tamil region of South India fully make use of the *Vākyakaraṇa* for computing their almanacs, which, therefore, are known as *Vākya-pañcāṅgas*.

iii. *Tantra texts*. Alongside the *karaṇa* texts, which were more in the nature of practical manuals, a genre of texts which aimed to be more comprehensive in the treatment of the topics, besides serving the purpose of the *karaṇas*, came to be produced. These texts followed the *Āryapakṣa*, retained the beginning of Kali, viz. 18 Feb., 3101, as the epoch, and expressed numbers in the *bhūtasaṃkhyā* notation instead of the *kaṭapayādi* notation of the *karaṇas*. To this genre belong the *Vārṣika-tantra* of Viddaṇa, son of Mallaya (before 1370), in 11 chapters, the *Tantrasaṃgraha* of the versatile astronomer Nīlakaṇṭha Somayāji (*b.* 1444) *Sphuṭanirṇaya-Tantra* of Acyuta Piśāraṭi (1550-1621) and the *Tantrasāra* of Nārāyaṇa of the Perumanam village in central Kerala. The last has been commented in Malayalam, but for the second, there are five commentaries including the elaborate *Yuktidīpikā* of Śaṅkara which takes pain to explain the rationale of the theories and the computations.

iv. *Veṇvāroha texts*. Mādhava of Saṅgamagrāma near Cochin (*c.* 1340-1425), whose investigations into the value of π and other trigonometrical functions, differentials in sines of arc etc. are well known, has devised an ingenious method to determine, at intervals of 2 hours and 40 minutes each, every day, the longitude of the Moon correct to the second, utilizing the cyclic nature of the 248 lunar *vākyas* equal to nine anomalistic months. On a parallelism between this method and the knots in a bamboo tree, he called this the *Veṇvāroha* method. For use in this computation, Mādhava also refined the lunar *vākyas* correct to the second. The *Veṇvāroha* method has been set out in two of this works, the *Sphuṭacandrāpti* and *Veṇvāroha*. The ingenuity of this method appealed to other astronomers also and we have several works of the type, including a *Dṛg-veṇvārohakriyā* of epoch 1695, and Putumana Somayāji's *Veṇvārohāṣṭaka*.

v. *Planetary tables*. Besides his work on the moon, Mādhava has worked on planetary motions as well and has determined the longitudes of the planets for long cycles of years and the results have been set out in the form of tables in his *Agaṇita-grahacāra*. Two other anonymous works of a similar nature are also known, both under the common name *Grahacāra*, one of them for the years 1845-55.

vi. *Eclipses*. Investigations on accurate computation of eclipses had the greatest appeal to Kerala astronomers, perhaps, next only to the computation of the planets

This is exemplified also by the series of observations of eclipses made and recorded by astronomers like Parameśvara and Nīlakaṇṭha. A large number of works on eclipse computation, short or long, some of them improvising new or revised elements and methodologies, are known. Among these might be mentioned: The *Grahaṇāṣṭaka* and *Grahaṇamaṇḍala* (epoch 15 July 1411) of Parameśvara, *Grahaṇanirṇaya* of Nīlakaṇṭha (b. 1444), an *Uparāgakriyākrama* based on Nīlakaṇṭha's work, another *Uparāgakriyākrama* by Nārāyaṇa (1561), *Uparāgaviṃśati* and *Uparāgakriyākrama* by Acyuta Piṣāraṭi (1550-1621), and *Grahaṇagaṇita* and *Grahaṇāṣṭaka* by Putumana Somayāji (1660-1740). A number of anonymous works on the subject are known: Two short texts under the name *Grahaṇāṣṭaka* III-IV, another under the title *Uparāgāṣṭaka* (epoch 1563), *a Grahaṇopadeśa*, three texts under the general title *Grahaṇādigaṇita* and then under the title *Grahaṇagaṇita*. Some of these texts have also commentaries, mostly in Malayalam.

vii. *Computation of the Shadow*. Still another genre of texts relate to the computation of the Moon's shadow towards determining the time and therefrom planetary positions. Of this genre of works, the undermentioned are important: *Candracchāyāgaṇita* I of Parameśvara, *Candracchāyāgaṇita* II with a detailed commentary by Nīlakaṇṭha, two more *Candracchāyāgaṇitas* (III-IV), which remain anonymous, and *Chāyāṣṭaka* of Acyuta Piṣāraṭi. Other works on the subject, all anonymous, are *Candracchāyānayanopāvaḥ*, four different tracts of the title *Chāyāgaṇita, Sūryacandracchāyāgaṇita* and two works called *Sūryacchāyādigaṇita*.

viii. *Astronomical rationale*. One of the major hurdles in the study of the history of Indian astronomy lies in the tendency of the early scientists to record the results only of their findings and fail to record, similarly, the steps that led to those results. Apart from their tendency, this was necessitated also by the fact that the results had to be recorded in as succinct a manner as possible, in the form of aphorisms or verses. An understanding of the mental working of the scientists is thus lost of posterity. This defect has been remedied to a great extent, so far as mathematics and astronomy are concerned, through a class of writings called *Yukti-s* ('rationale'). Many of these are short anonymous tracts dealing with individual items, processes or formulae and are found written on flyleaves or ends of manuscripts of astronomical works. From among full-fledged works of this class might be mentioned the *Lagnaprakaraṇa* of Mādhava (1360-1440) on the computation of the ascendant, the *Grahaṇanyāyadīpikā* of Parameśvara on eclipse computation, *Yuktibhāṣā* of Jyeṣṭhadeva, (1500-1610), an extensive work in two parts, depicting the rationales of arithmetic, algebra, geometry and trigonometory in the first part and of astronomy in the second, *Rāśigolasphuṭāniti*, according to Acyuta Pisāraṭi, giving the rationale, at length, for measuring planetary longitudes on the ecliptic, and *Nyāyaratna* of Putumana Somayāji. A fairly long tract explains the rationale of the Āryabhaṭan verses *Kakṣyāpratimaṇḍala* etc. (*Abh Kāla* 17—21). A number of minor tracts on astronomical rationale have been put together in a collection called *Gaṇitayuktayaḥ*. Among Keralite commentaries which afford expository rationale might be mentioned, the *Yuktidīpikā* on Nīlakaṇṭha's *Tantrasaṃgraha* and *Kriyākramakari* on Bhāskara's *Līlāvati*, both by Śaṅkara (1500-60), and Acyuta Piṣāraṭi's commentary on his own *Karaṇottama*.

ix. *Observation and experimentation.* A unique work in Indian astronomy is the *Jyotirmīmāṃsā* of Nīlakaṇṭha, written in 1504, wherein he stresses the importance of astronomical observation, defends the necessity of correcting parameters periodically, on the basis of observation of eclipses, of the Sun, Moon and the planets, comparing the elements of different schools etc. Perhaps, more important is his *Grahaparikṣā-krama* wherein he demonstrates some of the astronomical methods.

Yantras; Astronomical Instruments

Śaṅkaranārāyaṇa (A.D. 869), court-astronomer of King Ravi Varma of Kerala, refers, in his *Laghubhāskariya-vyākhyā* (3.20), to an observatory in the capital city, fitted with astronomical instruments, but gives no description thereof. While the gnomon *(śaṅku)*, *nāḍikā* (water clock) etc. find mention in the *Śulbasūtras* and the Jaina texts, a sustained description of astronomical instruments occurs, possibly, for the first time in the *Āryabhaṭasiddhānta* of Āryabhaṭa I (*c.* 476) .This work of Āryabhaṭa which sets out his *Ārdharātrikapakṣa* is not available, but extracts from it are preserved in later works. Thus, Rāmakṛṣṇa Ārādhya (A.D. 1472), while commenting on the *Yantrādhyāya* of the *Sūrya-siddhānta* (ch. 13) quotes 34 verses on astronomical instruments from the *Āryabhaṭasiddhānta.*[24] Some of these verses are quoted and explained also by other commentators on the *Sūrya-siddhānta* like Mallikārjuna Sūri (A.D. 1178) on verse 7.12, and Tammayajvā (A.D. 1599) on *vv* 13.20-25.[25] Ch. 14 of Varāha-mihira's *Pañcasiddhāntikā*, in 29 verses, is devoted to the subject of astronomical instruments, observations etc. Other early and medieval texts which mention the use of or deal with astronomical instruments are: *Mahābhāskarīya* ch. 3 esp. vv. 56-60 and *Laghubhāskarīya,* ch. 3, of Bhāskara I (A.D. 629), ch. 22 of *Brāhma-sphuṭa-siddhānta* of Brahmagupta (b. 598), ch. 21 of *Śiṣyadhīvṛddhida-tantra* of Lalla (8th cent.), ch. 13 of the *Sūrya-śiddhānta* (*c.* 800) *Golādhyāya* of *Vaṭeśvara-siddhānta* (904) ch. 11 of Pt. II of of the *Siddhānta-śekhara* of Śrīpati (*c.* 1050) and ch. 19 of the *Siddhānta-śiromaṇi* of Bhāskara II (1150).

The works on astronomical instruments written later generally bear the impress of Central Asian astronomy brought to India by the Muslims, which will be noticed in the next section. There are, however, a few which treat only of Hindu instruments, mostly written in Gujarat or Rajasthan. Among these might be mentioned the following: The *Yantraratnāvalī* of Padmanābha (*c.* 1400), with a commentary by the author himself. The second chapter of this work, called *Dhruvabhramaṇādhikāra* describes an instrument for ascertaining the exact time at night from the position of the pole star. Cakradhara, son of Varuṇa wrote a short work entitled *Yantracintāmaṇi,* of which four commentaries are available, one by the author himself and the others by Harisaṅkara, Paramasukha and Rāma Daivajña (1625).[26] The prolific Gaṇeśa Daivajña, son of Keśava Daivajña of Nandigrāma (1507), wrote two works on instruments, entitled *Cābukayantra* and *Pratodayantra.* An extensive work on the subject is the *Yantraprakāśa* of Rāmacandra with autocommentary, which describes as many as 27 instruments, including a *Kācaghaṭīyantra.* The texts of this genre are short and a close reading of the commentaries are always necessary to get a full idea of the form, nature and use of the instruments of the Hindu period.

ARABIC AND PERSIAN SOURCES

While the peoples of India and Iran belonged to the same Aryan stock and their religion, literature and culture had close relationship from very early times, it was only from the eighth century that scientific exchanges between India and central and west Asia took positive shape due largely to the rise of Islam. The reign of the second Abbāsid Caliph al-Mansūr (A.D. 753-74) heralded an era when considerable Indian scientific literature, especially on medicine and mathematics, including astronomy, were redacted into Arabic. The services of Indian scholars who had mastered Arabic helped in this exchange and among Arabic scholars, the names of Ibrāhīm al-Fazārī (*d.* 796 or 806), Ya'qūb ibn Ṭāriq, al-Khwārizmī (d. *c.*850), al-Kindī (d. *c.*873), Habash al-Hāṣib (d. *c.*864 or 874) are noteworthy. Many of these Arabic translations are lost, but the details thereof are preserved in the *Fihrist* or 'Index' of Abu'l--Faraj Mahammad of Baghdad, better known as Abi Ya'qūb an-Nadim (A.D. 988). Details about scholars of science and their contributions occur in Sn. II of the *Fihrist*.

Al-Bīrūni

A potential source of information about Indian and Perso-Arabic literature on astronomy and allied disciplines is the large quantum of writings left by Abdu'l-Raiḥān al-Bīrūnī (973-1050), who accompanied Sultan Maḥmūd of Ghazna during his campaigns and stayed in north-west India for the best part of 2027-30. A versatile scholar of Persian and Arabic, and also of Sanskrit, al-Bīrunī, wrote 183 works, comprising of studies, collections and translations, of which as many as 27 pertain to Indian culture, philosophies and sciences.[27] His work entitled *Kitāb fi taḥqiq mā lil-Hind min maqālatin maqbūlatin fi'l-aql au mardhūla* ('Verification of what is said about India which is accepted or rejected by reason'), *Ta'rīq al-Hind,* in short, translated into English under the title *Al-Bīrūnī's India* by Edward Sachau, is well known for the comprehensive information it supplies on contemporary India.[28] Valuable information on Indian astronomy and mathematics is contained in his undermentioned works: *Jawāmi al-Maujūd li-Khawāṭir al-Hanūd fi Ḥisāb al-Tanjim* ('Collection of the ideas of the Indians on astronomical calculations'),[29] *Al-jawābāt 'an al-masā'il al-wārida min munajjim 'l-Hind* ('Replies to questions raised by Indian astronomers'), *Al-Qānūn al-Mas'ūdi* (Book on astronomy).[30] It is worth noting that al-Bīrūnī endeavoured to transmit to Western Asia the knowledge contained in Sanskrit astronomical texts through translations into Arabic or Persian. Such texts included Brahmagupta's *Brāhmasphuṭa-siddhānta* and *Khaṇḍakhādyaka, Pauliśa-siddhānta,* Varāhamihira's *Laghujātaka* and *Bṛhatsaṃhitā*, and *Karaṇatilaka* of Vijayanandi. The worth of al-Bīrūnī's writings lies in the fact that, apart from the intrinsic value of their contents, they provide new information, corroborative evidence and help in the identification and dating of authors, works and views.

Encyclopaedias

Another authentic source of contemporary information is the *Ā'in-i-Akbari,* the Imperial Gazetteer of the times of the Mughal emperor Akbar, prepared by his

minister Abu'l-Faḍl (1551-1602). The work carries details on a variety of subjects, including an account of Indian and Arabic astronomy.

The influx of scholars from the Middle East to India and the patronage extended to them by Muslim rulers, not only in Delhi but also in the provinces, resulted in the production of a number of encyclopaedic works containing, among other things, substantial information of astronomy in its several aspects.[31] Among them the following deserve mention for the wealth of details contained therein: *Jawāharu'l-'Ulūmi-Humāyūn* composed by M. Fādil b.'Ali B.M. al-Miskīnī al-Qaḍi Samarqandī of the court of the Mughal emperor Humayun in 1555.[32], *'Uqūl-i 'Asharah* by M. Barārī Ummī b. Jamshīd (A.D. 1673),[33] and *Shahid-Ṣadiq* by Ṣādiq B.M. Ṣāliḥ al-Isfahānī al-Azadānī (A.D. 1646), of the court of emperor Shahjehan.[34]

Zij (Astronomical Tables)

The genre of astronomical tables indicating planetary positions, star charts and conversion tables with notes and explanations, on lines with the famous *Zij-iUlugh Beg* and *Zij-i Khāqānī* of Samarqand came to be produced, generally under state patronage,[35] like *Zij-i Nāsiri* (13th cent.) by Mahmud b. 'Umar dedicated to Sultan Iltutmish[36] (1246-65), *Zij-i Jāmi'* (1448-61) by Maḥmūd Shāh Khaljī[37] and *Zij-i Shahjaḥani*[38] by Faridu'd-din Mas'ud b. Hafiz Ibrahim Manajjm, Court astronomer of emperor Shahjehan (1628-58). More important, however, is the highly elaborate *Zij-i Muḥamad Shāhi*[39] (1727) prepared by Sawai Jaisingh, (1686-1743), dedicated to the Mughal emperor Muhammad Shah (1719-48). Divided into three sections, the work gives rules for the transformation of four calendars, measurement of time in 19 chapters, and motions of stars and planets and their position from a certain longitude, latitude etc. in five chapters. That this work was later revised as *Zij-i Jadid Muḥammad Shāhi* (New Astronomical tables of Muhammad Shahi) in four chapters would indicate how matters were developed further. It is interesting to note a Sanskrit version of this *Zij* had also been prepared for the use of Hindu astronomers. The Arabic and Persian Zījes studied and produced in India will be further discussed in chapter 2.

Mingling of Traditions

In the wake of the introduction of Arabic and Persian astronomical tradition into India under State patronage, there arose an effort, on the part of Hindu astronomers, to produce translations, adaptations and books of a combined tradition, the combination taking mostly the form of mere addition, explanation of one through the other, or regular coalescence. Obviously, such activities too were encouraged and patronized by the State. Such study, required bilingual dictionaries. Thus Kṛṣṇadasa, a protege of Akbar compiled a *Pārasīprakāśa* in about 1575, containing a Persian-Sanskrit dictionary of astronomical terms and a grammar of Persian in Sanskrit. Since this was inadequate for translators, Mālajit, who was honoured by Shahjehan with the title *Vedāṅgarāva,* wrote another *Pārasīprakāśa* in 1643, which gave classified lists of astronomical terms in Arabic and Persian with Sanskrit equivalents. Vrajabhūṣaṇa, son of Raghunātha, wrote in 1660 still another work of this nature entitled *Pārasīvinoda* or *Pārasīvinodānanda.*

In line with translating of Sanskrit texts into Arabic and Persian by Al-Bīrūnī and earlier in Baghdad,[40] there had also been sustained efforts to translate Arabic and Persian texts into Sanskrit. These texts included those belonging to the school of Marāgha and Samarqand, like the *Zij* of Ulugh Beg in *Ji ca Ulugbegi*, and al-Qushiji's *Risalah dar hay'at* in *Hayatagrantha*. In this vein, under the patronage of Sawai Jai Singh, Jagannātha, Paṇḍita produced *Rekhāgaṇita*, being a rendering of Euclid's *Elements of Geometry* from its Arabic version *Tahirir-u-Uqlidas* by Naṣīr-ud-din aṭ-Ṭūsī (1201) and *Siddhāntasārakaustubha* in 13 chapters, being a rendering of Ptolemy's *Almagest* from its Arabic version, also by Naṣīr-ud-din. It is worth noting here that, as against what is presumed by scholars all along, Jagannātha's *Samrāṭ-siddhānta* is really the title of an original work of the author, in five chapters, all along called *Yantrādhyāya*, and printed in continuation of the first 13 chapters, and these 13 chapters alone form the translation of the *Almagest* under the title *Siddhāntasārakaustubha*.[41] Nayanasukhopādhyāya produced, under Jai Singh's inspiration, the *Ukarā*, being a Sanskrit rendering of the Greek work *Sphaerica* of Theodosius from its Arabic rendering by Qusta bin Luqa (912 A.D.). Nayanasukhopādhyāya translated into Sanskrit also of another work *Sharah-Tazkarah Barjandi*.[42]

As instances of incorporating Western ideas into India might be cited the *Siddhāntasāryabhauma* of Munīśvara (*b.* 1603), court astronomer of Shahjehan (1628-59), and Kamalākara who wrote the *Siddhāntattvaviveka* in 1658. These astronomers composed their works in the Hindu pattern, but used therein elements of Aristotelian physics, Euclidean geometry, Islamic trigonometry and Ptolemaic astronomy as found in Ulug Beg. Among works which tried to coalesce the two traditions might be mentioned the *Siddhāntasindhu* (1628) and the *Siddhāntarāja* (1639) of Nityānanda, astronomer in the court of Shahjehan, which adopted the Islamic parameters and the *sāyana* year in computation. These innovations, however, remained confined to intellectual experimentations and did not permeate into general use among the people.

ASTROLABES AND OBSERVATORIES

With Arabic astronomy came the astrolabe (Arabic *aṣṭurlab*, Sanskritized into *ustaralava*), a handy and versatile metallic instrument, which, through the manipulation of graduated discs and circles and of a gnomon attached to it, enabled one to ascertain planetary positions, the time of the day and the like. Being a complicated precesion instrument, it used to be prepared by hereditary families of experts, with graduations and words inscribed in Persian script. As the instrument grew popular in the land, it began to be inscribed in Devanagari script, as well. Short works in Sanskrit also came to be composed describing the construction and use of astrolabes. The earliest work on the astrolabe is the *Yantrarāja* (1370), mentioned earlier based on Arabic sources, by the Jain Mahendrasūri, court astronomer of Ferozeshah Tughlaq, in five chapters entitled *Gaṇita, Ghaṭanā, Yantraracanā, Yantraśodhana* and *Vicāraṇā*. There are commentaries on the work by Malayendasūri and Gopirāja.

Other works on the subject, of a later period include those of Malayendu (with Cintāmaṇi's commentary) and by Mathurānātha and some anonymous, but by far

the most important is the *Yantrarājaracanā* by the royal astronomer Sawai Jai Singh and its rendering into verse form by Śrīnatha under the title *Yantraprabhā,* over which its modern editor Kedaranatha has added his own commentary, *Yantrarāja-prabhā.* A number of Indian astrolabes, of different types, combinations and functions, are preserved in museums and other repositories[43] and await detailed study.

The efforts of the Raja Sawai Jai Singh of Jaipur (1686-1743) towards the fostering of scientific observational practices with the combined use of Hindu, Muslim and European advances in astronomy are a saga in itself in the history of Indian astronomy. Jai Singh collected texts of all the three traditions, studied them himself and composed works, invited scholars of all the traditions and induced them to prepare original works and translations. He also invented and caused to be constructed instruments for astronomical observations. A manuscript entitled *Yantraprakāra,* preserved in the Art Gallery as No. 31 of the Maharaja's Museum at Jaipur, mentions the undermentioned instruments as designed by Jai Singh with the caption: *Śri-Mahārājādhirāja-viracita-yantrāṇi:* (1) *Jayaprakāśa-yantra,* (2) *Nāḍivalaya,* (3) *Krāntivṛttam,* (4) *Palabhāyantram,* (5) *Digaṃśayantram,* (6) *Śarayantram,* (7) *Agra-yantram,* (8) *Yāmyottaramiti,* (9) *Jatulahalaka,* (10) *Yantrarāja* (astrolabe, mentioned above), (11) *Jātuśukavataina,* (12) *Sudasphakari,* (13) *Jātuśukataina,* (14) *Śaṅkuyantra* and (15) *Pratirāśīnām Krāntivṛttāni.*[44] The main features and methods of observation of some of these instruments have been indicated by Jagannātha in the first chapter of his *Samrāṭsiddhānta.*

Three instruments, viz. *Jayaprakāśayantra, Rāmayantra* and *Samrāṭ-yantra* are stated to have been invented by him. Realising, by experience, that these metallic instruments suffered from limitations on account of their smallness, wear and tear, and the effect of weather, he constructed massive outdoor observatories, like those of Ulug Beg in Samarqand, in Delhi (1724), Jaipur (1734), Ujjain (1734), Varanasi (1737) and at Mathura on the Yamuna. Massive models of several of the instruments were also installed by him at these observatories.[45] The contribution made by Jai Singh and that inspired by him form a potential source for the study of a special phase of the history of Indian astronomy.