CHAPTER 1

The Mathematical and Observational Astronomy in Traditional India

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1. INTRODUCTION

The history of natural sciences is as old as the history of mankind. When people created society, they could not survive without certain knowledge of the nature in which they lived. They started to systematize the knowledge with the help of language. This system grew up to natural sciences.

Our natural sciences can be divided into two groups: modern science and traditional sciences. Some people call modern science "Western science", but it is wrong. The modern science happened to be created in Europe, but it incorporated several traditional sciences from other parts of the world during its creation, and spread over the world, where several non-Western scientists also contributed to its development, soon after its creation. So, the modern science should be considered to be the global science.

The traditional sciences in the Old World can be divided into three main traditions, namely, East Asian (predominantly Chinese), South Asian (predominantly Indian) and Ancient Mediterranean-Islamic-European science. What we are going to discuss is one branch of the South Asian Science.

Among several branches of traditional sciences, the most ancient branches are, in most cases, astronomy and medicine. India also has a very long history of astronomical sciences (*jyotiḥ-śāstra*) and medicine (*āyur-veda*).

Indian classical astronomical sciences are roughly divided into mathematical astronomy (*gaṇita-jyotiṣa*) and astrology (*phalita-jyotiṣa*).

In this chapter, I would like to discuss the history of the mathematical astronomy (and related observational astronomy) in traditional India. [For the history of Indian astronomy in the general, see Sen and Shukla (1985/2000) and Subbarayappa (2008). For the history of Hindu astronomy, the monumental work of Dikshit (English translation published in two parts in 1969 and 1981) is still the best and most reliable source. For Sanskrit astronomical works, see Pingree (1981) for an overview, and Pingree (1970–1994, incomplete) for detailed bibliographical information, and also Subbarayappa and Sarma (1985) for specimens (Sanskrit text and its English translation). For biography of Hindu astronomers, Dvivedī (1892) may still be consulted. For the exposition of the mathematical calculation in Sanskrit astronomical works, see Somayaji (1971) and Rao (2000a, 2000b). For modern astronomical analysis of Sanskrit astronomical works, see Billard (1971). There was a controversy between Billard and Pingree (see van der Waerden, 1980). For Arabic and Persian astronomical works in India, see Rahman et al. (1982). For the development of astronomy in Medieval India, see papers of Bag et al. (1990), vol. 1, Rahman (1998), Ansari (1995), (2005) and Ôhashi (2008 b). For the introduction of modern astronomy in India, Ansari (1985) gives a good survey. For the development of modern astronomy in India, Kochhar and Narlikar (1995) give a good overview. For the history of Indian science in general, see Bose et al. (1971)].

2. AN OUTLINE OF THE HISTORY OF ASTRONOMY IN INDIA

The history of Indian astronomy can roughly be divided into the following periods.

- (i) Indus valley civilisation period
- (ii) Vedic period (c.1500 BC–c.500 BC).
    - (a) Ṛg-vedic period (c.1500 BC–c.1000 BC)
    - (b) Later Vedic period (c.1000 BC–c.500 BC)
- (iii) *Vedāṅga* astronomy period
    - (a) Period of the formation of the Vedāṅga astronomy (sometime between the sixth and fourth centuries BC?)

(b) Period of the continuous use of the *Vedāṅga* astronomy (up to sometime between the third and fifth centuries AD?)

(iv) Period of the introduction of Greek astrology and astronomy

(a) Period of the introduction of Greek horoscopy (the second(?) or third century AD)

(b) Period of the introduction of Greek mathematical astronomy (sometime around the fourth century AD?)

(v) Classical Siddhānta period (classical Hindu astronomy period) (the end of the fifth century–twelfth century AD)

(vi) Coexistent period of the Hindu astronomy and Islamic astronomy (the thirteenth/fourteenth century–eighteenth/nineteenth century AD)

(vii) Modern period (coexistent period of the modern astronomy and traditional astronomy) (the eighteenth/nineteenth century onwards).

Among the above periods, we know very little about the astronomical knowledge in the Indus valley civilization period. So, let us begin with the Vedic period.

3. ASTRONOMICAL KNOWLEDGE IN THE VEDIC PERIOD

3.1. Introduction

After the period of the Indus valley civilization (c.2500 BC–c.1700 BC?), Aryans appeared in north-west India in c.1600 BC or so. The Aryans were originally pastoral people. The Aryans produced a set of Brahmanic literature called Vedas in India. There are four Vedas, namely, the *Ṛg-veda*, the *Sāma-veda*, the *Yajur-veda* and the *Atharva-veda*. Each of the four Vedas consists of the Saṁhitā, the Brāhmaṇa, the Āraṇyaka, and the Upaniṣad. Firstly, the *Ṛg-veda-saṁhitā* was produced in north-west India (present Punjab) during c.1500 BC and c.1000 BC. Let us call this period "Ṛg-vedic period". Then, the Aryans advanced towards east, and produced Later Vedic literature (Vedic literature except for the *Ṛg-veda-saṁhitā*) in north India (roughly the western part of the plain of the Ganga) during c.1000 BC and c.500 BC. Let us call this period "Later Vedic period". [For the details of the history of astronomy in this period, see Dikshit (1969) and Ôhashi (1993).]

3.2. Ṛg-vedic Period

In this period, the *Ṛg-veda-saṁhitā* was composed in north-west India (present Punjab) during c.1500 BC and c.1000 BC. [For English translation of the *Ṛg-veda-saṁhitā*, see Wilson (1850 f.) or Griffith (1889 f./1896f.).] This is the earliest literature produced by the Aryans in India. Although this is basically a religious literature, certain astronomical knowledge can be found there. The *Ṛg-veda-saṁhitā* consists of ten books (*Maṇḍalas*), and the family books (Books II–VII) are considered to be the earliest portions.

Already in an early portion of the *Ṛg-veda-saṁhitā* (VII.103), certain calendrical knowledge is recorded. According to this portion, frogs cried at the beginning of the rainy season regularly every year, and similarly priests also performed *Soma*-rites regularly. Here, we can see that their calendrical knowledge was connected with annual monsoon, which comes regularly every year, and that the formation of calendrical knowledge was closely connected with the local climate of India and, most probably, agriculture which requires certain knowledge of seasons. It may be mentioned here that agriculture was already developed in the Indus valley civilization, and there must have been non-Aryan agriculturists, who had certain knowledge of calendar, when Aryans entered India. So, there is a possibility that Aryans acquired some agricultural and calendrical knowledge from non-Aryan people in India.

In a late portion of the *Ṛg-veda-saṁhitā* (I.25.8), the intercalary month seems to have been mentioned. According to Sāyana's commentary on this portion, the additional thirteenth month is suggested there. [For English translation of the *Ṛg-veda-saṁhitā* based on Sāyana's commentary, see Wilson (1850 f.).]

The *Ṛg-veda-saṁhitā* (X.85.2) tells that Soma (=moon) is stationed near the *nakṣatras* (lunar mansions), and the *Ṛg-veda-saṁhitā* (X.85.13) gives the names of two constellations, which were probably used to indicate the position of the Moon. However, the complete set of the name of *nakṣatras* is not recorded in the *Ṛg-veda-saṁhitā* itself.

3.3. Later Vedic Period

In the later Vedic period, the Aryans advanced towards east and composed the later Vedic literature in the area around the Doab (area between the Ganga and Yamuma rivers) during c.1000 BC and

500 BC. The society had become essentially agricultural in this stage, and several kinds of pulses and rice are mentioned in the later Vedic literature. So, a more accurate calendar must have been required.

The intercalary month is explicitly mentioned in the *Atharva-veda* (V.6.4), and the *Taittirīya-saṁhitā* (I.4.14), which is one text of the *Yajur-veda,* etc. [For English translation of the *Atharva-veda,* see Whitney (1905), and for English translation of the *Taittirīya-saṁhitā,* see Keith (1914).] The rule of intercalation is still not mentioned in the later Vedic literature. However, a 5-year cycle is mentioned in some literature, and it might have been a forerunner of the 5-year *yuga* of *Vedāṅga* astronomy which is discussed in the next section.

The complete set of *nakṣatras* (lunar mansions) is given in the later Vedic literature. The *Taittirīya-saṁhitā* (IV.4.19) gives 27 *nakṣatras,* while *Atharva-veda* (XIX.7) gives 28 *nakṣatras.* The *nakṣatras* were used to indicate the position of the full moon [(*Taittirīya-saṁhitā* (II.2.10.1) and (VII.4.8.1–2)]. This is the origin of the name of lunar months based on the name of *nakṣatras,* which is still used in modern Hindi, etc.

One year was divided into six seasons, namely, *vasanta* (spring), *grīṣma* (summer), *varṣā* (rainy), *śarad* (autumn), *hemanta* (winter) and *śiśira* (cool). This system of division is still used in modern Hindu calendars. In the *Yajur veda, Atharva veda,* etc., *hemanta* and *śiśira* were usually combined into *hemanta-śiśira,* and 1 year was divided into five seasons.

The word "*muhūrta*" appears in the *Ṛg-veda-saṁhitā* in the sense of "moment", but the *muhūrta* as 1/30 of a day first appears in the Brāhmaṇas [*Taittirīya-brāhmaṇa* (III.10.1.1–3; and 10.9.7) and *Śatapatha-brāhmaṇa* (XII.3.2.5)]. [For English translation of the *Śatapatha-brāhmaṇa,* see Eggeling (1882–1900).]

In the Vedic period, the regular calendar was symbolized in rituals. The Vedic rituals, which were developed in the later Vedic period, are divided into *Śrauta*-rituals (orthodox rituals) and *Gṛhya*-rituals (domestic rituals). The *Śrauta*-rituals are usually divided into *Havir-yajñas* (=*Havis*-offerings, offerings of any food) and *Soma-yajñas* (*Soma*-offerings). The *Havir-yajñas* include the *Agnyādheya,* the *Agnihotra,* the *Darśpaurṇamāsas,* the *Āgrayaṇa,* the *Cāturmāsyas,* the *Nirūḍha-paśubandha* and the *Sautrāmaṇī.* [This list is based on Gautama's *Dharma-sūtra* (VIII.19–20). See Bühler (1879), p. 217.] Some of these rituals are the symbols of divisions of time, that is regular calendar. Let us read the *Śatapatha-brāhmaṇa* (I.6.3.35–36):

> After Prajāpati had created the living beings, his joints (parvan) were relaxed. Now Prajāpati, doubtless, is the year, and his joints are the two junctions of day and night (i.e. the twilights), the full moon and new moon, and the beginning of the seasons.
>
> He was unable to rise with his relaxed joints; and the gods healed him by means of these havis-offerings: by means of the Agnihotra they healed that joint (which consists of) the two junctions of day and night, joined that together; by means of the full-moon and the new-moon sacrifice they healed that joint (which consists of) the full and new moon, joined that together; and by means of the (three) Cāturmāsyas (seasonal offerings) they healed that joint (which consists of) the beginning of the seasons, joined that together. (Translated by Eggeling (1882–1900), Part I, p. 173. I have changed the transliteration of Sanskrit words into modern method.)

Here, we can see that the *Agnihotra*, the *Darśapaurṇamāsas* (the full-moon and the new-moon sacrifices) and the *Cāturmāsyas* (four monthly offerings or seasonal offerings) are mentioned in connection with division of time, i.e. regular calendar.

We should also note that the *Āgrayaṇa* is the offering of first-fruits, rice in autumn, barley in spring and millet crop in rainy season.

From the above discussions, we know that the development of agriculture and the regular calendar, which was indispensable for agriculture, was symbolized in Vedic rituals, which were developed in the later Vedic period.

4. *VEDĀṄGA* ASTRONOMY

4.1. Introduction

Towards the end of the later Vedic period, a class of works regarded as auxiliary to the Vedas was produced, which is called *Vedāṅga* (limbs of the Vedas). The *Vedāṅga* consists of six divisions, namely, phonetics, metrics, grammar, etymology, astronomy and ceremonial. It is this period when astronomy, which was called "*jyotiṣa*" in Sanskrit, was established as an independent learning. The fundamental text of this learning in this stage is the *Jyotiṣa-vedāṅga* (also called *Vedāṅga-jyotiṣa*) of Lagadha. It explains a system of astronomy for calendar making. The calendrical system of the *Jyotiṣa-vedāṅga* was used for sometime (from sometime during the sixth and fourth centuries BC up to sometime during the third and fifth centuries AD?) in India. Let us call this period "*Vedāṅga* astronomy period". The word "jyotiṣa" in modern Hindi, etc. means astrology rather than astronomy, but the original meaning of "jyotiṣa" was astronomy for making calendar, and was not astrology. This point should be kept in mind. [For the detail of the history of astronomy in this period, see Dikshit (1969) and Ôhashi (1993).]

4.2. The Jyotiṣa-vedāṅga of Lagadha

The *Jyotiṣa-vedāṅga* of Lagadha is a small monograph of astronomy written in Sanskrit. It has two recensions, namely, the Ṛg-vedic recension entitled *Ārca-jyotiṣa* and the Yajur-vedic recension entitled *Yājuṣa-jyotiṣa*. [For its text and English translation, see Sastry and Sarma (1984). And also, Mishra (2005) and Kauṇḍinnyāyana (2005) may be consulted.] Their contents are almost the same, and the existence of two recensions is probably due to the different transmissions in different Vedic schools, i.e. the Ṛg-vedic school and the Yajur-vedic school. According to Sastry and Sarma's edition, the Ṛg-vedic recension contains 36 verses, and the Yajur-vedic recension contains 43 numbered verses and 2 unnumbered verses, one of which must be an interpolation.

The name "Lagadha" is mentioned in the *Jyotiṣa-vedāṅga* itself. The Ṛg-vedic recension (v. 2) reads:

> Making obeisance to time with bent head, and saluting Goddess Sarasvatī, I shall explain the knowledge of time [enunciated] by high-souled Lagadha.

And also, the Yajur-vedic recension (unnumbered verse placed at the last) reads:

> Thus Lagadha told the explanation of months, years, *muhūrtas* (1/30 of a day), risings, syzygies, days, seasons (1/6 of a year), half years, and months. (The word 'months' which appears twice probably refers to the different kinds of months, such as solar and synodic.)

It is difficult to say whether Lagadha is the actual author or a kind of authority whom the author followed.

The beginning of the *Jyotiṣa-vedāṅga* (Ṛg-vedic recension v. 1 and 3, and Yajur-vedic recension v. 1–2) reads:

> Making obeisance with bent head to God Prajāpati, who is the supervisor of the five-year *yuga*, and has day, season, half year and month as his limbs, I, being purified *(śuci)*, shall describe systematically the correct movement of heavenly bodies, which is accepted by highest Brahmans, for the sake of the determination of the proper time of sacrifices.

The word "*śuci*", which I translated as "being purified", can also be interpreted as proper noun, that is the name of the author of this work. At present, there is no method available to investigate this problem.

From the above quotation, it is seen that the Vedic rituals had already been highly developed, and the rituals were considered to be the final purpose of astronomy. However, we should not forget that the development of astronomy was related to practical activities, such as agriculture. The rituals were only the symbols of the authority over those activities. We have seen in the previous section that some rituals were the symbols of regular calendar.

4.3. The Calendrical System of the Jyotiṣa-vedāṅga

The contents of the *Jyotiṣa-vedāṅga* are almost exclusively calendrical. The calendar described there is a kind of luni-solar calendar where two intercalary months are inserted in a 5-year cycle called "*yuga*". Two intercalary months were inserted at the middle and the end of the 5-year *yuga*. The calendrical system of the *Jyotiṣa-vedāṅga* can be summarized as follows.

1 *sāvana* day (civil day) is from sunrise to sunrise.
1 *sāvana* month is 30 *sāvana* days.
1 *tithi* is 1/30 of a synodic month.
1 synodic month is from new moon to new moon.
1 solar month is 1/12 of a solar year.
1 *ṛtu* (season) is 1/6 of a solar year.
1 solar year is from winter solstice to winter solstice.
1 solar year = 2 *ayanas* (half years),

= 6 *ṛtus* (seasons),
= 12 solar months,
= 366 *sāvana* days (civil days),
= 372 *tithis*.

1 *yuga* = 5 years,
= 60 solar months,
= 61 *sāvana* months = 1830 *sāvana* days,
= 62 synodic months = 1860 *tithis*,
= 67 sidereal months,
= 1835 sidereal days.

In the *Jyotiṣa-vedāṅga*, celestial longitude was expressed using *nakṣatra* (lunar mansion). One *nakṣatra* used therein is a segment which is equivalent to 1/27 of the ecliptic. The system of 28 or 27 *nakṣatras* already appeared in some of the later Vedic literature, as we have seen in the previous section. The *nakṣatras* described in the later Vedic literature must have consisted of the actual visible stars. The *Jyotiṣa-vedāṅga* started to use it as an artificial system of coordinates. It may be mentioned here that the systems of 28 and 27 *nakṣatras* have been used for different purposes in the later Hindu astronomy since the Classical Siddhānta period, the system of 28 *nakṣatras* as actual stars, and the system of 27 *nakṣatras* as artificial coordinates. The *Vedāṅga* astronomy may be considered to be the beginning of this division.

4.4. The Length of a Solar Year in the Jyotiṣa-vedāṅga

As we have seen in the previous section, the length of one solar year of the *Jyotiṣa-vedāṅga* is 366 days. This length may look quite inaccurate at first sight.

David Pingree conjectured that the length of one solar year of the *Jyotiṣa-vedāṅga* was originally meant to be 366 sidereal days, that is 365 civil days (see Pingree, 1973).

However, according to my study, Pingree's conjecture is untenable, and the length was definitely 366 civil days. The point is as follows.

The modern accurate value of 62 synodic months and 67 sidereal months are as follows:

62 synodic months = 1830.90 days,
67 sidereal months = 1830.55 days.

If one solar year is 366 days, one *yuga* becomes 1830 days, and this number is harmonious with the above value. However, if one solar year is 365 days, one *yuga* becomes 1825 days, and nearly 6 days' error is produced regarding the syzygies, etc. If we recall that this calendrical system was used for the determination of time of rituals, including the new and full moon offerings, 6 days' error is by no means permissible, because the difference of lunar phase in 6 days is too much. Therefore, I conclude that the length of 1 year of the *Jyotiṣa-vedāṅga* was definitely 366 days.

Let us see an interesting description of the observation of the new and full moon in the *Śāṅkhāyana-śrauta-sūtra* (I.3.3–6), one of the *Vedāṅga* literature of ceremonial.

> There are two days of full moon and two days of new moon. The two days of full moon are: (1) the day on which the moon appears full about the setting of the sun, and (2) the day on which (it appears full) after the setting of the sun. The two days of new moon are: (1) the day on which they remark 'tomorrow it will not be visible', and (2) the day on which it is not visible. (Translated by Caland (1953), p. 5)

From the above quotation, we can see that the date of the new moon and full moon was determined quite accurately. The date of the full moon was determined by the observation of the rising time of the moon as well as the lunar phase. This is an accurate method.

From the above consideration, we can see that this calendar could be used successfully at least for 5 years as far as the lunar phase was concerned. A few days' error of lunar phase is easily detectable even by laymen, but a similar error of season is not. So, the inaccuracy of the length of the solar year was not a big problem at that time. [For more detail, see Ôhashi (1993).]

4.5. The Date of the Jyotiṣa-vedāṅga

The date of the composition of the *Jyotiṣa-vedāṅga* was sometimes inappropriately estimated to be the twelfth to fourteenth century BC or so. In the *Jyotiṣa-vedāṅga* (Ṛg-vedic recension v. 5, and Yajur-vedic recension v. 6), the point of the winter solstice is considered to be at the first point of the lunar mansion "Śraviṣṭhā". From this fact and some other data, Kuppanna Sastry, for example, estimated that the date of the *Jyotiṣa-vedāṅga* is sometime around 1150 BC and 1370 BC, using the amount of the precession (See Sastry and Sarma, 1984).

The above estimation, however, cannot be relied, because a small amount of observational error produces ambiguity of hundreds of years. And also, it is difficult to believe that the *Jyotiṣa-vedāṅga* is earlier than the later Vedic period if we compare the developed system of astronomy in the *Jyotiṣa-vedāṅga* and the developing knowledge of astronomy in the Vedic literature.

From historical considerations, such as the comparison of astronomical knowledge with other sources, I think at present that the date of the *Jyotiṣa-vedāṅga* is sometime between the sixth and fourth centuries BC or so. [For more detail, see Ôhashi (1993).]

4.6. The Place of the Composition of the Jyotiṣa-vedāṅga

The place of the composition of the *Jyotiṣa-vedāṅga* was sometimes inappropriately estimated to be at the latitude 35°N or so. This estimation is based on the following verses. One verse (Ṛg-vedic recension v. 7 and Yajur-vedic recension v. 8) reads:

> The increase of daytime and decrease of night-time is [the time equivalent of] one *prastha* of water [in the clepsydra per day] during the northward course [of the sun]. They are in reverse during the southward course. [The total difference is] 6 *muhūrtas* during a half year.

Another verse (Ṛg-vedic recension v. 22 and Yajur-vedic recension v. 40) reads:

> [The number of days] elapsed in the northward course or remaining in the southward course is doubled, divided by 61, and added to 12. The result is the length of daytime [in terms of *muhūtras*].

The above rule can be expressed as follows:

$$T = \left(12 + \frac{2}{61}n\right), \tag{1}$$

where T is the length of daytime in terms of *muhūrtas* and n is the number of days elapsed from or remaining until the winter solstice. One *muhūrta* is 1/30 of a day. This is a kind of linear zigzag function, where the length of daytime changes by one *muhūrta* during one solar month.

According to this formula (1), the proportion of daytime and night-time is 2:3 at the time of winter solstice. This is the proportion observed at the latitude 35°N or so. This latitude is far north from the western part of the plain of the Ganga (around 25°N–29°N or so), where later Vedic people resided. Although this latitude 35°N, which passes through Kashmir, was not inaccessible for ancient Indian people, David Pingree conjectured that this value was borrowed from Mesopotamia during the Achaemenid occupation of the Indus valley (see Pingree, 1973).

According to my study, however, Pingree's conjecture is not tenable, and formula (1) is not based on the observation at the latitude 35°N. I think that the formula (1) is based on observations at the latitude 27–29°N or so. The reason is as follows. A source belonging to later Vedic literature tells that Vedic people observed the sun (most probably the direction of sunrise) which moves constantly during its northward and southward courses, and considered that it is stationary around the solstices.

Let us see an interesting quotation from Vedic literature. The *Kauṣītaki-brāhmaṇa* (XIX.3) reads:

> On the new moon of Māgha he rests, being about to turn northwards; these also rest, being about to sacrifice with the introductory Atirātra; thus for the first time they obtain him; on him they lay hold with the Caturviṁśa, that is why the laying hold rite has its name. He goes north for six months; him they follow with six-day periods in forward arrangement. Having gone north for six months he stands still, being about to turn southwards; these also rest, being about to sacrifice with the Viṣuvant day; thus for the second time they obtain him. He goes south for six months; him they follow with six-day[(1)] periods in reverse order. Having gone south for six months he stands still, being about to turn north; these also rest, being about to sacrifice with the Mahāvrata day; thus for the third time they obtain him. In that they obtain him thrice, and the year is in three ways arranged, verily (it serves) to obtain the year. ... (Translated by Keith (1920), p. 452. I changed the transliteration of Sanskrit words

into the modern method.) (Note: (1) In the original translation, the word "six-day" is misprinted as "six-month".)

From the above quotation, we know that the Sun was considered to move constantly northwards or southwards, but to be stationary around the solstices. I suppose that Vedic people observed the position of sunrise or sunset.

From the above facts, we are obliged to think that formula (1) of the *Jyotiṣa-vedāṅga* was not obtained by the interpolation from the observations at the solstices, but by the extrapolation from the observations of the length of daytime around the equinoxes. Practically, there are two possibilities. (1) If the formula were obtained from one *muhūrta*'s difference of the length of daytime during one solar month after the equinox, the most suitable latitude for this observation would be around 27°N. (2) If it were obtained from two *muhūrtas*' difference during two solar months, the most suitable latitude would be around 29°N. (See Fig. 1)

From the above consideration, I conclude that the *Jyotiṣa-vedāṅga* was produced at the latitude 27–29°N or so in north India (most probably the western part of the plain of the Ganga where later Vedic people resided) without apparent foreign influence [for more detail, see Ôhashi (1993)].

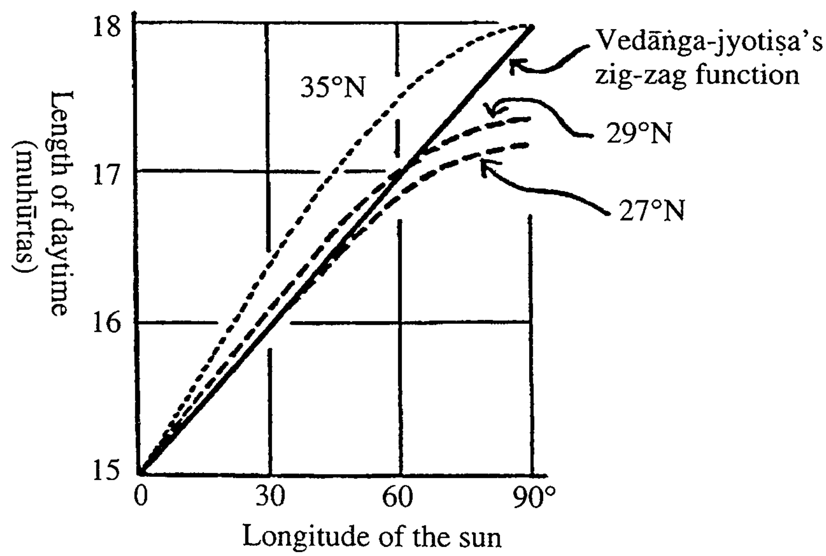


Fig. 1: *Jyotiṣa-vedāṅga*'s annual variation of the length of daytime.

4.7. Continuous Use of the Vedāṅga Astronomy

The calendrical system of the *Vedāṅga* astronomy was widely used in India for sometime (see Ôhashi, 2002b).

Besides the Brahmanical work *Jyotiṣa-vedāṅga*, a similar calendrical system is found in the *Artha-śāstra* (a political work attributed to Kauṭilya) (for its Sanskrit text and English translation, see Kangle, 1965–1972), the *Śārdūlakarṇa-avadāna* (a Buddhist work) (its Sanskrit text is published in Vaidya, 1959), the *Sūriya-pannatti* (a Jaina work) (for its Prakrit text, see Kohl, 1939; there are some other editions published in India), and so on. And also, the *Paitāmaha-siddhānta* (epoch AD 80) quoted in the *Pañca-siddhāntikā* of Varāhamihira (sixth century AD) is a text of the *Vedāṅga* astronomy.

The Jaina astronomy, which is more or less similar to the *Vedāṅga* astronomy, is recorded in some of the Jaina canonical works (*Sūriya-pannatti*, etc.). (For the Jaina astronomy, Jain (1983) and Lishk (1987) may be consulted.) The early Buddhist astronomy is similar to the *Vedāṅga* astronomy, but later Buddhists seem to have accepted Hindu Classical Astronomy (particularly the Ārdharātrika school) (see Section 9 'Indian astronomy and Asia' of the present paper).

Even after the introduction of Greek horoscopy into India in c. third century AD, the *Vedāṅga* astronomy was still used for some time. The mixture of the *Vedāṅga* astronomy and Greek horoscopy (particularly the use of zodiac) is found in the last chapter of the *Yavana-jātaka* (AD 269/270) of Sphujidhvaja, the *Vāsiṣṭha-samāsa-siddhānta* quoted in the *Pañca-siddhāntikā*, and the *Dafangdeng-dajijing Ricangfen* (Chinese translation of a Buddhist text translated by Narendrayaśa in AD 586). [See Section 5 below and Ôhashi (2002b).]

The Hindu, Jaina and Buddhist traditional cosmographies, where the Mount Meru (or Sumeru) is considered to be at the centre of the plane earth, roughly correspond to the period of the *Vedāṅga* astronomy. [For Indian traditional cosmographies, see Kirfel (1967).]

5. INTRODUCTION OF GREEK ASTROLOGY AND ASTRONOMY

5.1. Introduction of Greek Horoscopy

That the Greek horoscopy was introduced into India is shown in the *Yavana-jātaka* (AD 269/270) of Sphujidhvaja. [For its text and English translation, see Pingree (1978). Also see Shukla (1989).] The Sanskrit word "*Yavana*" means Greeks. David Pingree pointed out that this work tells that it is based on an earlier work of Yavaneśvara written in AD 149/150. However, the text regarding this date seems to be obscure. The period of the introduction of Greek horoscopy may be considered to be c. second(?) or third century AD.

Most of the content of the *Yavana-jātaka* is Greek horoscopic astrology. With Greek astrology, zodiacal signs, 7-day week, etc., were introduced in India.

Only its last chapter (chapter 79) is devoted to mathematical astronomy. The text tells that "the instruction of the Greeks" (*Yavana-upadeśa*) is explained there, but the developed Greek geometrical astronomy (epicyclic theory, etc.) is not found there. In contrast, according to my study, certain theory which is of the stage of Indian *Vedāṅga* astronomy is found there. Let us see the diurnal variation of the gnomon shadow. The *Yavana-jātaka* (Chapters 79 verse 32) tells that the diurnal variation of the gnomon shadow is given by the formula

$$\frac{d}{2t} = \frac{s - s'}{g} + 1, \tag{2}$$

where t/d is the fraction of daytime which has elapsed since sunrise or remaining until sunset, s is the length of the shadow of the gnomon of length g, and s' is its midday shadow (see Abraham, 1981). Let us compare formula (2) with the Mesopotamian formula. According to Otto Neugebauer, Mesopotamian shadow table in the *mul Apin* can be obtained from the following formula (Neugebauer (1975), part 1, pp. 544–545):

$$t = \frac{c}{s}, \tag{3}$$

where t is the time after sunrise which is counted in time degrees (1 day = 360°), s is the length of the shadow in terms of cubits and c is a constant. The value of the constant c is 60 at the winter solstice, 75 at the equinoxes, and 90 at the summer solstice. Strangely, the midday shadow is always 5/6 cubit.

Now, let us take up the gnomon shadow after a quarter of daytime since sunrise. According to the Indian formula (2), the length of the shadow becomes one gnomon length longer than the midday shadow. In contrast, according to the Mesopotamian formula (3), the length of the shadow becomes double of the length of the mid-day shadow. The length of the shadow of a gnomon of length 1 at the end of the first quarter of daytime after sunrise according to formulae (2) and (3) as well as the actual length of the shadow at the latitude 35°N and 23°.7N (Tropic of Cancer at that time) for a half year is graphed in Figure 2.

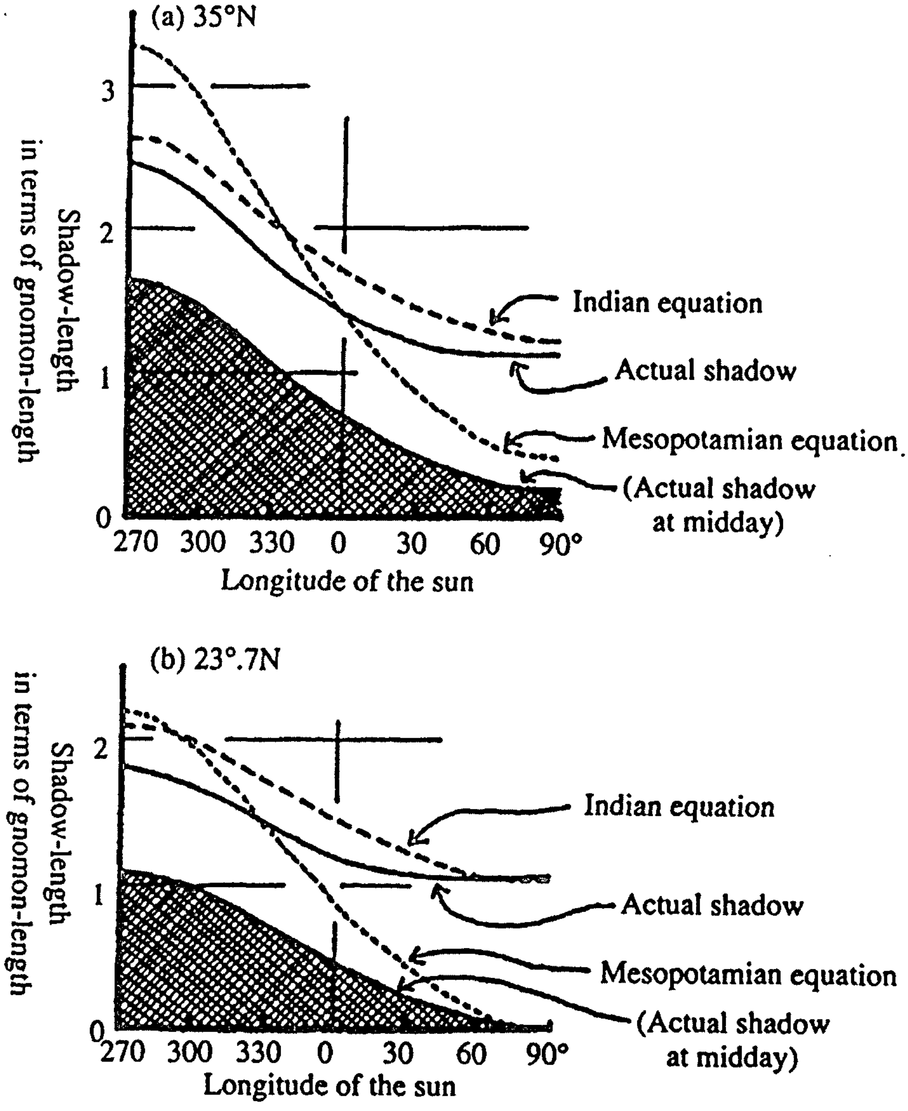


Fig. 2: Length of gnomon-shadow at the end of the first quarter of daytime.

Here, we can see that the Mesopotamian formula (3) is good around the equinox, but the Indian formula (2) gives the wrong value throughout the year at the latitude 35°N. In contrast, the Indian formula (2) is excellent around the summer solstice, but the Mesopotamian formula (3) is of no use at the latitude 23.7°N. So, I conclude that the Indian formula (2) was developed from observational data at the summer solstice in north India (particularly at the Tropic of Cancer), while the Mesopotamian formula (3) may have originated from the observational data at the equinox in Mesopotamia. In fact, the probable origin of formula (2) is found in the *Artha-śāstra* (II.20.39–40). According to the *Artha-śāstra*, which records the knowledge of the *Vedāṅga* astronomy, the gnomon shadow is given by the following formula, which gives the almost correct value at the summer solstice at the Tropic of Cancer:

$$\frac{d}{2t} = \frac{s}{g} + 1. \tag{4}$$

From the above considerations, I conclude that the *Vedāṅga* astronomy, which is based on observations in north India, was still used at this stage, even though Greek horoscopy was introduced (see Ôhashi, 2002b).

5.2. Introduction of Greek Mathematical Astronomy

During the period (c. 2nd(?) or 3rd century AD) of the introduction of Greek horoscopy, Greek mathematical astronomy was almost unknown in India, and the *Vedāṅga* astronomy seems to have been used. So, the period of the introduction of Greek mathematical astronomy must be after the third century AD. In contrast, certain knowledge of Greek mathematical astronomy is found in some texts (*Pauliśa-*, *Romaka-* and *Saura-siddhānta*) quoted in the *Pañca-siddhāntikā* of Varāhamihira (sixth century AD) (see below). These texts show different stages of the introduction of Greek mathematical astronomy. And also, the *Āryabhaṭīya* (AD 499) of Āryabhaṭa (see below) is an established text of Classical Siddhānta period, and its stage is similar to the highest stage of the texts quoted in the *Pañca-siddhāntikā*. Therefore, Greek mathematical astronomy must have already been introduced by the end of the fifth century. During the Classical Siddhānta period, the introduction of Greek astronomy had already ceased, and further foreign influence is not found in this period. So, the period of the introduction of Greek mathematical astronomy must be before the end of the fifth century AD.

From the above evidences, we can suppose that Greek mathematical astronomy was introduced in India sometime around the fourth century AD or so. There is little source material of the development of astronomy during this period. The *Pañca-siddhāntikā* of Varāhamihira gives the most important information, although this information is fragmental, and further research of this text is necessary.

6. CLASSICAL SIDDHĀNTA PERIOD

6.1. Introduction

The Classical Hindu Astronomy period produced several famous astronomers, such as Āryabhaṭa (b. AD 476), Varāhamihira (sixth century AD), Bhāskara I (fl. AD 629), Brahmagupta (b. AD 598), Lalla (c. eighth or ninth century AD), Vaṭeśvara (b. AD 880), Mañjula (fl. AD 932), Śrīpati (fl. AD 1039/1056) and Bhāskara II (b. AD 1114), etc., and some of their works are still considered to be authoritative by modern traditional Hindu calendar makers, etc. The period (from the end of the fifth century AD to the twelfth century AD) during which they composed classical astronomical works can be called Classical Siddhānta period or Classical Hindu Astronomy period. The "Siddhānta" is the fundamental treatise of mathematical astronomy in Sanskrit (see below).

Varāhamihira wrote in his *Bṛhat-saṁhitā* that the *jyotiḥ-śāstra* (astronomical science) has three branches as follows:

(1) *Gaṇita* (mathematical astronomy),
(2) *Horā* (also called *jātaka*) (horoscopy of Greek origin) and
(3) *Saṁhitā* (study of several natural phenomena).

Among the above branches, only (1) is astronomy in strict sense, and (2) and (3) are usually considered to be astrology, although (3) treats several topics.

The Sanskrit texts of Hindu classical mathematical astronomy are divided into three types, namely, *siddhānta, tantra,* and *karaṇa.* A *siddhānta* is a fundamental treatise of astronomy, where the epoch is the beginning of the *kalpa* (traditionally considered to be the cycle of 4,320,000,000 years, except for the system of Āryabhaṭa). *Tantra* is a textbook of astronomy, where the epoch is the beginning of the

Kali-yuga (Friday 18 February 3102 BC of Julian calendar). *Karaṇa* is a handy practical work of astronomy, where the epoch is any convenient year selected by the author.

Siddhānta usually consists of two parts, i.e. the part of the calculation of the position of planets and the part of spherics. The contents of each part of the *Siddhānta-śiromaṇi* (AD 1150) of Bhāskara II, which can be considered to be a standard work, are as follows.

The *Graha-gaṇita-adhyāya* (chapter of the calculation of the position of planets) of the *Siddhānta-śiromaṇi* consists of 12 chapters as follows: (I) Mean motion of the planets, (II) True motion of the planets, (III) Three problems (direction, place, and time), (IV) New and full moon, (V) Lunar eclipse, (VI) Solar eclipse, (VII) Zenith distance of the moon, (VIII) Heliacal rising and setting, (IX) Elevation of lunar horns, (X) Conjunction of two planets, (XI) Conjunction of a star and a planet and (XII) Nodes.

The *Gola-adhyāya* (chapter of spherics) of the *Siddhānta-śiromaṇi* consists of 13 chapters as follows: (I) Praise of the spherics, (II) Nature of the sphere, (III) Cosmography, (IV) Mean motion, (V) True motion, (VI) Armillary sphere, (VII) Three questions, (VIII) Eclipses, (IX) Method to calculate the time of the rising and setting of the planets, (X) Elevation of lunar horns, (XI) Astronomical instruments, (XII) Description of the seasons and (XIII) Questions.

In this period, four major schools of mathematical astronomy were produced. These schools use more or less similar models of planetary motion, but they use slightly different astronomical constants. The four schools are as follows.

(1) *Ārdharātrika school.* The name "Ārdharātrika" means midnight, and a day begins from midnight in this school. Its fundamental texts are the *Āryabhaṭa-siddhānta* (now lost and only small fragments are extant) of Āryabhaṭa (b. AD 476) and the *Sūrya-siddhānta* (not extant in the original) summarized in the *Pañca-siddhāntikā* of Varāhamihira (sixth century AD). The earliest text of this school which is fully extant is the *Khaṇḍa-khādyaka* (AD 665) of Brahmagupta.

(2) *Ārya school.* A day begins from sunrise in this school. Its fundamental text is the *Āryabhaṭīya* (AD 499) of Āryabhaṭa.

(3) *Brāhma school.* A day begins from sunrise in this school. Its fundamental text is the *Brāhma-sphuṭa-siddhānta* (AD 628) of Brahmagupta.

(4) *Saura school.* A day begins from midnight in this school. (It may be noted here that modern Hindu traditional calendars following this school usually starts a day from sunrise.) The name "Saura" means solar, and is a derivative of the word "sūrya" (sun). Its fundamental text is the anonymous *Sūrya-siddhānta* (c. tenth–eleventh century AD), which is the most popular Sanskrit work of mathematical astronomy. This work is sometimes called "modern *Sūrya-siddhānta*", and is different from the lost *Sūrya-siddhānta* of the Ārdharātrika school.

Among the above schools, the Ārya, Brāhma and Saura schools are still followed by several makers of Hindu traditional calendars.

6.2. Some Eminent Hindu Astronomers

6.2.1. Āryabhaṭa

Āryabhaṭa was an astronomer who was born in AD 476. He probably lived in Kusumapura (Pāṭaliputra) in ancient Magadha, i.e. modern Patna in Bihar. He is the earliest astronomer in the Classical Siddhānta period whose name and date are definitely known. This Āryabhaṭa is sometimes called Āryabhaṭa I by modern historians in order to differentiate from his namesake Āryabhaṭa II (author of the *Mahā-siddhānta*), whose date is controversial. However, Āryabhaṭa I is so famous that he is simply called Āryabhaṭa usually.

Āryabhaṭa composed two astronomical works, the *Āryabhaṭa-siddhānta* (now lost) and the *Āryabhaṭīya* (AD 499). [For its text and English translation, see Shukla and Sarma (1976).]

The *Āryabhaṭa-siddhānta* is a lost text belonging to the Ārdharātrika school. Only its fragments are found to be quoted in later works (see Shukla, 1967, 1977). Its fragment on astronomical instruments, published by Shukla (1967), is very interesting and gives important information about the development of astronomical instruments in India.

The *Āryabhaṭīya* (AD 499) is a celebrated work of Hindu astronomy and is the fundamental text of the Ārya school. It consists of four sections, namely, the *Gītikā* section on astronomical constants, the *Gaṇita* section on mathematics, the *Kālakriyā* section on the reckoning of time and the *Gola* section on the celestial sphere. The significance of this work is that the rotation of the earth is mentioned there. In the *Āryabhaṭīya* (I.3), Āryabhaṭa mentions the eastward rotation of the earth. This theory was, however, not accepted by other Hindu astronomers. What Āryabhaṭa told is the rotation of the earth, and not the revolution of the earth. The earth was considered to be at the centre of the universe. Therefore, Āryabhaṭa's theory is different from Copernican heliocentric theory. This difference should not be confused.

Another interesting feature of the *Āryabhaṭīya* is that the size of the epicycles of the planets changes in different anomalistic quadrants. This is quite different from simple geometrical model. The modern *Sūrya-siddhānta*, etc., also use a similar method.

Let us see the interesting history of the study of two different Āryabhaṭas.

Henry Thomas Colebrooke (1765–1837), a pioneer of the study of Indian mathematics, thought that Āryabhaṭa belongs to the fifth century, and the *Daśagītikā* and the *Āryāṣṭaśata* (both of which form what we call *Āryabhaṭīya* of Āryabhaṭa I) are the genuine works of Āryabhaṭa, but Colebrook had not seen these works (Colebrook, 1817, notes G and I).

In contrast, John Bentley, another pioneer of the study of Indian astronomy, thought that Āryabhaṭa belongs to the fourteenth century, and the *Ārya-siddhānta* (which is what we call *Mahā-siddhānta* of Āryabhaṭa II) is the genuine work of Āryabhaṭa (Bentley, 1825, part II, section III, pp. 138–156).

Wish has seen the *Āryabhaṭīya,* and mentioned its alphabetical notation of numbers in his paper (Wish, 1827).

Fitz-Edward Hall thought that the works mentioned by Colebrook and Bentley are both genuine, and suggested that there might have been two Āryabhaṭas (Hall, 1860). This is a correct suggestion.

Whitney commented on the above-mentioned paper of Hall and wrote that these two Āryabhaṭas must have been considered to be one person by Brahmagupta, who criticized Āryabhaṭa's inconsistency (Whitney, 1860). This Whitney's view is wrong, because Āryabhaṭa II is actually later than Brahmagupta.

Bhâu Dâjî pointed out that there were two Āryabhaṭas, one was born in 476 AD, and the other belongs to the 14th century, and that the work known to Brahmagupta is the *Āryabhaṭīya* of the elder Āryabhaṭa only (Bhâu Dâjî, 1865). Bhâu Dâjî was not aware that Āryabhaṭa I wrote two works. Bhâu Dâjî announced in the above-mentioned paper to publish the *Āryabhaṭīya* with the commentary of Someśvara, but it could not see the light of day.

In 1874, Kern published the Sanskrit text of the *Āryabhaṭīya* with the commentary of Paramādīśvara (= Parameśvara, fifteenth century) (Kern, 1874).

In 1896, Sankar Balakrishna Dikshit (1853–1898) suggested that Āryabhaṭa I might have written some other lost work besides the *Āryabhaṭīya* (Dikshit, 1981, pp. 58–59). Sudhākara Dvivedī (1860–1922) also suggested that Āryabhaṭa I might have written two works [Dvivedī, 1902, commentary on (XI.13)].

In 1910, Sudhākara Dvivedī published the Sanskrit text of the *Mahā-siddhānta* of Āryabhaṭa II (Dvivedī, 1910 also see Sarma, 1966).

Bibhutibhusan Datta (1888–1958), one of the pioneers of the study of the history of Indian mathematics, however, misunderstood that there might have been three Āryabhaṭas (Datta, 1926).

In 1927, Prabodh Chandra Sengupta (1876–1962) published an English translation of the *Āryabhaṭīya* (Sengupta, 1927). In 1930, Walter Eugene Clark published another English translation of the *Āryabhaṭīya* (Clark, 1930).

Sengupta also collected information of Āryabhaṭa's lost work from later works, and published a paper "Aryabhata's Lost Work" in 1930 (Sengupta, 1930). In this paper, Sengupta investigated the astronomical constants, etc. of Āryabhaṭa's lost work which uses midnight system.

Finally, Kripa Shankar Shukla (1918–2007) published a fragment of the *Āryabhaṭa-siddhānta*, Āryabhaṭa I's lost work, quoted in a later work (Shukla, 1967; also see Shukla, 1977).

In 1976, a set of the text and English translation of the *Āryabhaṭīya* as well as its text with Sanskrit commentaries, edited by K.S. Shukla and K.V. Sarma (1919–2005), was published (Shukla and Sarma 1976; Shukla, 1976; Sarma, 1976).

The date of Āryabhaṭa II (or the *Mahā-siddhānta* attributed to him) is still controversial. David Pingree (1933–2005) thinks that it is between c.950 and 1100 (Pingree, 1970–94, vol. 1, p. 53), while Roger Billard (1922–2000) thinks that it is the sixteenth century (Billard, 1971, p. 161).

6.2.2. Varāhamihira

Varāhamihira was an astronomer and astrologer of the sixth century AD. He resided in Avanti, i.e. Ujjain in modern Madhya Pradesh.

He composed an astronomical work *Pañca-siddhāntikā* [for its text and English translation, see Thibaut and Dvivedī (1889), Neugebauer and Pingree (1970–71), and Sastry (1993)], and several astrological works. Among his astrological works, the *Bṛhaj-jātaka* (on the *horā* branch) [for its text and English translation, see Vijnanananda (1912)] and the *Bṛhat-saṁhitā* (on the *saṁhitā* branch) [for its text and English translation, see Bhat (1981–82)] are famous and important. Especially, the *Bṛhat-saṁhitā* is an encyclopaedic work, and is an important source material of Indian science, technology, and culture at his time.

The *Pañca-siddhāntikā* is a compilation of five earlier astronomical works, namely, the *Paitāmaha-siddhānta*, the *Vāsiṣṭha-siddhānta*, the *Pauliśa-siddhānta*, the *Romaka-siddhānta* and the *Saura-siddhānta*. The *Paitāmaha-siddhānta* is a text of the *Vedāṅga* astronomy. The *Vāsiṣṭha-siddhānta* is, according to my study, the remnant of *Vedāṅga* astronomy after the introduction of Greek horoscopy. Its mathematical astronomy, such as the annual variation of the length of gnomon shadow and the annual variation of the length of daytime, is that of the stage of the *Vedāṅga* astronomy, but the zodiacal signs, which were introduced with Greek horoscopy, are used there. It also tells a method to calculate *lagna* (rising point of the ecliptic), and the *lagna* itself is an element of Greek horoscopy, but its method of calculation is similar to the method of the *Vedāṅga* astronomy (Ôhashi 2002b). The *Pauliśa-*, *Romaka-* and *Saura-siddhānta* are the texts after the introduction of Greek astronomy, and the *Saura-siddhānta* (also called *Sūrya-siddhānta*) is, according to Varāhamihira's own words, more accurate than other works. (This *Sūrya-siddhānta* should not be confused with the famous modern *Sūrya-siddhānta*, which was composed in c.tenth–eleventh century AD.) This *Pañca-siddhāntikā* of Varāhamihira gives very important information on the early history of Hindu astronomy.

6.2.3. Bhāskara I

Bhāskara I was an astronomer of the seventh century AD. The number "I" is added by modern historians only for the sake of convenience in order to differentiate from his namesake (Bhāskara II) of the twelfth century. Bhāskara I probably belonged to the Aśmaka country but lived at Valabhī in Kathiawar on the western shore of the gulf of Khambhat (now in Gujarat). Bhāskara I was a follower of

Āryabhaṭa (b. AD 476), the earliest astronomer of the Hindu Classical Astronomy.

Bhāskara I composed three works, namely, the *Mahā-bhāskarīya* (large work of Bhāskāra) [for its text and English translation, see Shukla, 1960)] the *Āryabhaṭīya-bhāṣya* (AD 629) (commentary on the *Āryabhaṭīya* (AD 499) of Āryabhaṭa) [for its text, see Shukla (1976), also see Keller (2006)] and the *Laghu-bhāskarīya* (small work of Bhāskara) [for its text and English translation, see Shukla (1963)]. Bhāskara I was contemporary with another famous Indian astronomer Brahmagupta, but it is not known whether they knew each other.

The *Mahā-bhāskarīya* is a detailed work of mathematical astronomy. The planetary motion is explained by means of both epicyclic and eccentric models for both *manda*-correction (equation of centre) and *śīghra*-correction (annual parallax in the case of outer planets, and planets' own revolution in the case of inner planets) in detail.

Let us see the history of the study of two different Bhāskaras briefly.

The famous astronomer Bhāskara II has been well known since his time, and the mathematical portion of his work was already translated into English by Henry Thomas Colebrooke (1765–1837), a pioneer of the study of Indian mathematics in the early nineteenth century (see the following section of Bhāskara II). Colebrooke was aware of the existence of Bhāskara I cited by Pṛthūdakasvāmin, an Indian astronomer of the ninth century, but Colebrooke could not find any work written by Bhaskara I (Colebrooke 1817, note H).

Bibhtibhusan Datta (1888–1958) secured the works of Bhāskara I and wrote a paper on two Bhāskaras (Datta, 1930). However, Datta misunderstood that Bhāskara I was a direct disciple of Āryabhaṭa, and that Bhāskara I lived in the first half of the sixth century AD.

T.S. Kuppanna Sastri (1900–1982) pointed out in the introduction of his edition of the *Mahā-bhāskarīya* (Sastri, 1957, Introduction, pp. xiii–xvii) that Bhāskara I was not a direct disciple of Aryabhaṭa, but he could not ascertain Bhāskara I's date exactly.

K.S. Shukla (c. 1918–2007) has shown that Bhāskara I actually lived in the seventh century AD, because Bhāskara I wrote his commentary on the *Āryabhaṭīya* in AD 629, and is accordingly not a direct disciple of Āryabhaṭa (see Shukla, 1976, Introduction, pp. xix–xxv). K.S. Shukla edited all works of Bhāskara I and translated two of them into English (Shukla 1960, 1963, 1976).

6.2.4. Brahmagupta

Brahmagupta was an astronomer who was born in AD 598. He probably lived in Bhillamāla (modern Bhinmāl in the southwest of Rajasthan). Brahmagupta's father was Jiṣṇu, and Brahmagupta was sometimes called Jiṣṇu-suta (son of Jiṣṇu). Brahmagupta was a follower (or possibly founder) of the Brāhma school of Hindu Classical Astronomy, which was followed by Bhāskara II (b. AD 1115), etc.

Brahmagupta composed two works, namely, the *Brāhma-sphuṭa-siddhānta* (AD 628) (Precise treatise of the Brāhma school) [for its text, see Dvivedī (1902), for its ch. 21, see Ikeyama (2003)] and the *Khaṇḍa-khādyaka* (AD 665) ("Candied sugar") [for its text and English translation, see Sengupta (1934–41) and Chatterjee (1970)].

Brahmagupta composed the *Brāhma-sphuṭa-siddhānta* when he was 30 years old. Brahmagupta himself states that his work is an improved version based on the astronomical system told by Brahman. If this is true, the Brāhma school, whose name "Brāhma" is a derivative of Brahman, might have existed before Brahmagupta. There are some extant works whose title is *Brahma-siddhānta* or its synonym (such as *Paitāmaha-siddhānta*), but their relationship with the work of Brahmagupta is yet to be investigated. What we can say at present is that the *Brāhma-sphuṭa-siddhānta* is the earlist extant work of the Brāhma school whose author and date are definitely known.

Brahmagupta criticized Āryabhaṭa (b. AD 476), the founder of the Ārya school, in his *Brāhma-sphuṭa-siddhānta,* and Brahmagupta himself was criticized by Vaṭeśvara (b. AD 880), who followed the Ārya school. Brahmagupta later accepted the system of Ārdharātrika school, another school founded by Āryabhaṭa, in his *Khaṇḍa-khādyaka.* Brahmagupta was contemporary with another Indian astronomer Bhāskara I, but it is not known whether they knew each other.

The method of the calculation of planetary position in the *Brāhma-sphuṭa-siddhānta* is very interesting, which we shall discuss in the section 6.3.1 below.

6.2.5. Lalla

Lalla was an astronomer of the eighth or ninth century AD or so. Bina Chatterjee wrote that the date of Lalla is sometime between the eighth and eleventh century (Chatterjee, 1981, part II, p. xiv). Kripa Shankar Shukla says that Lalla's date is sometime between AD 665 (*Khaṇḍakhādyaka*'s date) and AD 904 (*Vaṭeśvara-siddhānta*'s date)

(Shukla and Sarma, 1976, p. lx). Lalla seems to have belonged to Lāṭadeśa which is the present south Gujarat.

Lalla composed an astronomical text *Śiṣyadhī-vṛddhida-tantra* (for its text and English translation, see Chatterjee 1981), and an astrological work *Jyotiṣa-ratnakośa* (unpublished), which are extant. Lalla seems to have composed some other works which are not extant.

In the *Śiṣyadhī-vṛddhida-tantra,* Lalla basically followed the *Āryabhaṭīya* of Āryabhaṭa. And also, Lalla described several astronomical instruments, some of which are quite different from earlier instruments, and Lalla's description is very interesting (see Ôhashi, 1994).

The *Jyotiṣa-ratnakośa* is still in manuscript form only, and its edition and study are needed.

6.2.6. Vaṭeśvara

Vaṭeśvara was an astronomer who was born in AD 880. He belonged to Ānandapura which is identified with Vaḍnagar in northern Gujarat.

Vaṭeśvara composed the *Vaṭeśvara-siddhānta* in AD 904. [For its text and English translation, see Shukla (1985–86).] It is the largest astronomical *siddhānta.* Vaṭeśvara criticized Brahmagupta, who criticized Āryabhaṭa, and Vaṭeśvara defended Āryabhaṭa.

It is known that al-Bīrūnī quoted in his *India* from the *Karaṇa-sāra* of Vaṭeśvara. However, its original text has not been found so far. The original idea of the second correction of the moon, which is stated in the *Laghu-mānasa* of Mañjula (see below), is attributed to Vaṭeśvara by Yallaya (AD 1482), but it is not found in the extant *Vaṭeśvara-siddhānta.* K.S. Shukla suggested that it must have been mentioned in the *Karaṇa-sāra* or some other work of Vaṭeśvara (Shukla 1985–86, Part II, Introduction, p. LIII). The *New Catalogus Catalogorum* [Raghavan (1967 of 1949 f.), vol. 3, p. 176] of Madras University records a manuscript of the '*Karaṇasāra of Vitteśvara*' in the "State Library", Kota, Rajasthan, but its existence has not been ascertained. I was suggested this fact by Professor Shukla, and visited Kota once, but could not find the manuscript during my short stay. It will be necessary to search the manuscript further.

6.2.7. Mañjula

Mañjula was an astronomer of the tenth century AD. His name is sometimes spelled Muñjāla, but Kripa Shankar Shukla pointed out that Mañjula is his real name (Shukla, 1990, p. 1).

Mañjula composed the *Laghu-mānasa* (AD 932). (For its edition and English translation, see Shukla, 1990.) This is a *karaṇa* work (handy practical work of astronomy) of mathematical astronomy. It is a small but very important work. It contains the second correction of the moon, which is a combination of the deficit of the equation of centre and the evection.

6.2.8. Śrīpati

Śrīpati was an astronomer of the eleventh century AD. He probably lived in Rohiṇīkhaṇḍa [probably present Rohiṇakheḍa in Malkapur of Buldana district in Maharashtra (see Panse, 1957)].

Śrīpati composed three astronomical works, namely, the *Siddhānta-śekhara* [for its text, see Miśra (1932–47)], the *Dhīkoṭida-karaṇa* (AD 1039) [for its text and English translation, see Shukla (1969)] and the *Dhruvamānasa* (AD 1056) (I have not seen this text), a mathematical work *Gaṇita-tilaka*, and astrological works *Jātaka-paddhati* and *Jyotiṣa-ratnamālā* (for the *Jyotiṣa-ratnamālā*, see Panse, 1957).

Among the astronomers who composed classical *siddhāntas* or similar works, only Varāhamihira, Lalla and Śrīpati wrote on both astronomy and astrology. As Lalla's work on *horā* is not extant, Śrīpati is the second person after Varāhamihira whose works on all of three branches of *Jyotiḥ-śāstra* are extant. All other authors of *siddhāntas* in this Classical Siddhānta period wrote exclusively on mathematical astronomy as far as extant texts are concerned.

As regards the mathematical astronomy, Śrīpati's *Siddhānta-śekhara* basically followed the Brāhma school of Brahmagupta, but Śrīpati was also much influenced by the *Śiṣyadhī-vṛddhida-tantra* of Lalla who followed the Ārya school of Āryabhaṭa. [For the description of the astronomical instruments of Śrīpati, which are similar to those of Lalla, see Ôhashi (1994).] The *Dhīkoṭida-karaṇa* is a small work which gives the method of calculation of lunar and solar eclipses. The *Jātaka-paddhati* belongs to the *horā* branch. As regards the "*muhūrta*" (astrology of auspicious time or otherwise) which belongs to the *saṁhitā* branch, Śrīpati's *Jyotiṣa-ratnamālā* followed the *Jyotiṣa-ratnakośa* of Lalla.

6.2.9. Bhāskara II

Bhāskara II was an astronomer who was born in AD 1114. The number 'II' is added by modern historians only for the sake of convenience in order to differentiate from his namesake (Bhāskara I) of the seventh century (see above). Bhāskara II is frequently called Bhāskara-ācārya (= Bhāskarācārya) (Master Bhāskara). Bhāskara II probably lived in Vijjaḍaviḍa (possibly present Bijapur in the north of Karnataka). His father was Maheśvara, who was also an astronomer.

Bhāskara II composed the *Siddhānta-śiromaṇi* (AD 1150) with his auto-commentary, the *Karaṇa-kutūhala* (AD 1183) (for its text and English translation, see Rao and Uma, 2007–2008), and the *Śiṣyadhī-vṛddhida-vivaraṇa* [commentary on the *Śiṣyadhī-vṛddhida-tantra* of Lalla (c.eighth or ninth century AD)]. There is also a work attributed to Bhāskara II, the *Bīja-upanaya* (= *Bījopanaya*), whose authorship is controversial [see Ghosh, 1926 and Sastry (1958–59)].

The *Siddhānta-śiromaṇi* (AD 1150), which he wrote at the age of 36 with his own commentary, is a comprehensive treatise of mathematics and astronomy. It consists of four parts as follows.

(1) *Līlāvatī* on arithmetical operations (for its English translation, see Colebrooke, 1817),
(2) *Bījagaṇita* on algebraic operations (for its English translation, see Colebrooke, 1817),
(3) *Graha-gaṇita-adhyāya* (=*Grahagaṇitādhyāya*) on the calculation of the position of planets (for its English translation, see Arkasomayaji, 1980/2000), and
(4) *Gola-adhyāya* (=*Golādhyāya*) on spherics (for its English translation, see Sastri and Wilkinson, 1861).

The first two parts on mathematics are sometimes treated as independent works. In the last two parts, the word "adhyāya" stands for "chapter". [There are several publications of their Sanskrit text.]

In most cases of Indian astronomers of the pre-modern period, only their own works are the sources about them, and very little about their life and family is known. Bhāskara II is a happy exception, whose grandson left an inscription about his ancestors.

A stone inscription was discovered by Bhâu Dâjî in the nineteenth century in a temple at a village called Pāṭṇā about 10 miles south-west of Chalisgaon in the north of Maharashtra (Kielhorn 1892). The inscription tells the following lineage: (1) the poet Trivikrama; (2) his son Bhāskara-bhaṭṭa, who from king Bhoja (known to have ruled in AD 1021) received the title of Vidyāpati (Lord of learning); (3) his son Govinda; (4) his son Prabhākara; (5) his son Manoratha; (6) his son, the poet Maheśvara-ācārya; (7) his son

Bhāskara (the astronomer Bhāskara II); (8) his son Lakṣmīdhara, who was appointed as the chief Pandit (Savant) by the king Jaitrapāla (ruled from AD 1191 to 1209); (9) his son Caṅgadeva, chief astrologer of the king Siṁghaṇa (throned in AD 1209/10). Caṅgadeva founded a college for the study of the *Siddhānta-śiromaṇi* and other works of Bhāskara II, and other works of his relatives, and the college was endowed with land, etc., by the king's feudatory Soïdeva (in c. AD 1207) and his younger brother and successor Hemāḍideva.

There is another inscription (AD 1222/23) found in a temple at a village called Bahāḷ in Chalisgaon in the north of Maharashtra (Kielhorn 1894–95). This inscription tells the following lineage: (i) Manoratha; (ii) his son Maheśvara (the father of Bhāskara II), who composed works on astronomy and astrology; (iii) his son Śrīpati (who must be Bhāskara II's brother); (iv) his son Gaṇapati; (v) his son Anantadeva, the chief astrologer of the king Siṁghana.

The above information tells us that Bhaskara II's lineage produced several astronomers and astrologers, and they promoted their learning. Bhāskara II's *Siddhānta-śiromaṇi* is a well-written treatise, and must have become very popular under the promotion of his grandson, etc.

6.2.10. Appendix—The anonymous author of the *Sūrya-siddhānta* and Commentators

Although the *Sūrya-siddhānta* is the most popular work of astronomy written in Sanskrit, its author is not known.

There are two different *Sūrya-siddhāntas* come down to us. One is the lost *Sūrya-siddhānta,* which is a text of the Ārdharātrika school of Hindu Classical Astronomy, which has been summarized in the *Pañca-siddhāntikā* of Varāhamihira (sixth century AD). This old *Sūrya-siddhānta* is connected with the lost work *Āryabhaṭa-siddhānta* of Āryabhaṭa (b. AD 476). The other is the "modern *Sūrya-siddhānta*" (usually simply called *Sūrya-siddhānta*), which is the fundamental text of the Saura school of Hindu Classical Astronomy. The text which we are going to discuss in this section is the latter.

The date of the (modern) *Sūrya-siddhānta* is controversial. Let us consider external and internal evidences of its date. (i) External evidences: Bhaṭṭotpala (=Bhaṭṭa Utpala) (later half of the tenth century) is said to have written a lost commentary on the *Sūrya-siddhānta,* and its one portion, which corresponds to the modern *Sūrya-siddhānta*, is quoted in a later work. However, the quotations of the *Sūrya-siddhānta* in Bhaṭṭotpala's commentary on the *Bṛhat-saṁhita* of Varāhamihira (sixth century AD) are not found in the modern *Sūrya-siddhānta*. It is difficult to say whether the modern *Sūrya-siddhānta* existed as a whole at that time or not. It may be that it was the time of transition from the old *Sūrya-siddhānta* to the modern one. On the other hand, Mallikārjuna Sūri's commentary (AD 1178) on the (modern) *Sūrya-siddhānta* is extant, and it is definite that the (modern) *Sūrya-siddhānta* existed at that time. (ii) Internal evidence: As John Bentley already pointed out in 1799, the position of the planets calculated by the (modern) *Sūrya-siddhānta* is most close to the actual planets around the eleventh century AD (Bentley, 1799). This estimation is reasonable, although Bentley made several other mistakes. From the above considerations, I think that the *Sūrya-siddhānta* was composed around the tenth–eleventh century AD.

There are several commentaries on the *Sūrya-siddhānta*. As far as I actually have seen, the authors who wrote earlier than Raṅganātha (see below) are Mallikārjuna Sūri (AD 1178), Caṇḍeśvara (AD 1185), Madanapāla (end of the fourteenth century), Parameśvara (AD 1432), Yallaya (AD 1472), Rāmakṛṣṇa Ārādhya (AD 1472), Bhūdhara (AD 1572) and Tamma Yajvan (AD 1599). Among them, the commentary of Parameśvara has been published (Shukla, 1957).

The most popular version of the *Sūrya-siddhānta* is the text with Raṅganātha's commentary (AD 1603).

There are several differences of the readings of the text between the early commentators' versions and Raṅganātha's version. So, a detailed comparative study of the different versions of the text is needed. I shall give one example here. In Raṅganātha's version of the *Sūrya-siddhānta* (XIII.21), the sand clock is mentioned, where the word "reṇu-garbha" (sand-receptacle) is used. However, in all other earlier versions which I listed above except for that of Mallikārjuna Sūri whose relevant portion has not been available to me, the word "veṇu-garbha" (bamboo-receptacle) is used there, and it is only a description of a kind of water clock. Apart from the *Sūrya-siddhānta*, the earliest Sanskrit work which mentions the sand clock is the *Yantra-prakāśa* (AD 1428) of Rāmacandra, and the second is the *Sundara-siddhānta* (AD 1503) of Jñānarāja. As Raṅganātha is later than both of them, it is not surprising if he was familiar with the sand clock.

However, the sand clock was not mentioned in the earlier versions of the *Sūrya-siddhānta*. So, we can say that the Raṅganātha's version has certain originality (see Ôhashi, 1994, pp. 285–286).

At present, several editions of the *Sūrya-siddhānta* are available in India, and most of them are based on Raṅganātha's version. And also, two English translations (Sastri and Wilkinson 1861, Burgess 1860/1935) of the *Sūrya-siddhānta* are also based on Raṅganātha's version, one of which (Burgess 1860/1935) is very popular. Therefore, Raṅganātha's influence on our understanding of Hindu astronomy is immeasurable.

Let us briefly review the history of the study of this most popular Sanskrit astronomical work entitled *Sūrya-siddhānta*.

Already in the eighteenth century, Samuel Davis studied the *Sūrya-siddhānta*, and published his paper (written in 1789) in the next year (Davis 1790).

In 1799, John Bentley published a paper (Bentley, 1799). In this paper, Bentley criticized the views of Jean Sylvain Bailly (1736–1793) and John Playfair, who estimated the age of Hindu astronomy too old, and pointed out that the position of the planets according to the *Sūrya-siddhānta* is most close to the actual position in around the eleventh century AD. However, Bentley mistook the author of *Sūrya-siddhānta* to be Varāhamihira. Bentley misunderstood that Varāhamihira belonged to the eleventh century. However, Varāhamihira actually belonged to the sixth century. Bentley wrote a more detailed book (Bentley, 1825).

In 1859, the text of the *Sūrya-siddhānta* with Raṅganātha's commentary edited by Hall and Śāstrī was published (Hall and Sastri, 1859), and in 1861, a translation of its text (and the *Gola-adhyāya* of the *Siddhānta-śiromaṇi* (AD 1150) of Bhāskara II) was published (Sastri and Wilkinson, 1861).

In 1860, a popular translation of the *Sūrya-siddhānta* translated by Rev. Ebenezer Burgess (1805–1870) with the help of the Committee of Publication (particularly W.D. Whitney) was published (Burgess, 1860/1935). This translation is also based on Raṅganātha's version. Burgess consulted a manuscript of Raṅganātha's commentary as well as Hall and Śāstrī's edition. This Burgess's translation was reprinted in India several times, and is still popular.

The *Sūrya-siddhānta* with the commentary (AD 1432) of Parameśvara was published by Kripa Shankar Shukla (1918–2007)

(Shukla, 1957). In this edition, the readings in the versions of Mallikārjuna Sūri, Yallaya, Rāmakṛṣṇa Ārādhya and Raṅganātha are also given in its foot notes. Its English introduction is also useful to understand the *Sūrya-siddhānta*. This is the first published text of the early version of the *Sūrya-siddhānta*, earlier than Raṅganātha.

A recent work of A.K. Chakravarty is a summary of the contents of the *Sūrya-siddhānta*, and can be said to be a convenient introduction for modern readers (Chakravarty, 2001).

6.3. Some Features of the Classical Siddhāntas

6.3.1. Significance of the planetary models in the Siddhāntas

In the Hindu Classical Astronomy, geocentric epicyclic and eccentric systems are used. Firstly, mean (*madhya*) planet, which is supposed to rotate constantly around the Earth, is calculated, and then, corrections are applied to the mean planet in order to obtain the true (*sphuṭa*) planet. One correction is the *manda*-correction, which corresponds to our equation of centre. The other is the *śīghra*-correction, which corresponds to the annual parallax in the case of outer planets, and the planet's own revolution in the case of inner planets. Firstly, the *manda*-correction is applied to the "mean planet", which corresponds to the planet's own mean revolution in the case of outer planets, and the Sun's mean revolution in the case of inner planets. The result is called "*manda-sphuṭa* planet", which is the mean planet corrected by the equation of centre only. Then, the *śīghra*-correction is applied to the "*manda-sphuṭa* planet", and the "true planet" is obtained. In the actual calculation, some special methods are used in the classical texts.

It may be mentioned here that the *manda*-correction is not based on a simple geometrical model, but a special modification is applied (see the *Mahā-bhāskarīya* (IV) etc.). Its result is that the equation of centre in this method becomes a simple sine function of anomaly. Its accuracy is slightly less than the simple eccentric model, but their errors (in the opposite directions) are not so different.

The method of the application of the *manda*-correction and *śīghra*-correction in the *Brāhma-sphuṭa-siddhānta* is very interesting. Its process, except for the Mars, is as follows. Firstly, the amount of the *manda*-correction is calculated from the mean planet, and is applied to the mean planet. The result is the *manda-sphuṭa* planet. Secondly, the amount of the *śīghra*-correction is calculated from the *manda-sphuṭa* planet, and is applied to the *manda-sphuṭa* planet. The result is the true planet after the first approximation. From the result, the amount of the *manda*-correction is calculated, and applied to the original mean planet. From this result, the amount of the *śīghra*-correction is calculated and applied. The result is the true planet after the second approximation. This process is repeated until a constant value is obtained. In the case of the Mars, the above-mentioned process is not used. The method for the Mars is as follows. Firstly, a half of the amount of the *manda*-correction and a half of the *śīghra*-correction are applied, and the once corrected Mars is obtained. From the result, the amount of the *manda*-correction is calculated, and its whole amount is applied to the original mean Mars. From this result, the amount of the *śīghra*-correction is calculated, and its whole amount is applied. The result is the true Mars. This method is the ordinary method used by other Indian astronomers in those days.

The above-mentioned process of the *Brāhma-sphuṭa-siddhānta*, except for the case of the Mars, means that the amount of the equation of centre is a function of the true anomaly of the planet, and not of the mean anomaly. This fact shows that the Indian model of planetary motion is not a simple imitation of the Greek geometrical model, and further investigation of the Indian model is needed. At present, I suspect that Indian astronomers in those days considered that the inequality of the *manda*-correction is produced by a kind of physical force originated to the apogee, and this force is equilibrated with the displacement of the planetary position due to the inequality. If so, the amount of the inequality should be a function of the actual position of the true planet.

It may be mentioned here that Brahmagupta did not use the above-mentioned successive approximation for the calculation of true planets in his *Khaṇḍa-khādyaka*, but used the ordinary method like the case of Mars in his earlier work.

6.3.2. The precession of the equinoxes

The earliest Indian astronomer who mentioned the movement of the solstices is Varāhamihira (sixth century AD). He mentioned it in his *Pañca-siddhāntikā* (III.21) (Thibaut and Dvivedī, 1889; Neugebauer and Pingree, 1970–71; Sastri, 1993) and *Bṛhat-saṁhitā* (III.1–3) (Bhat, 1981–82), but did not write its rate. Brahmagupta denied the motion of the solstices in his *Brāhma-sphuṭa-siddhānta* (XI.54) (AD 628), and this fact shows that the motion of the solstices was discussed by some astronomers in his time. Probably the earliest extant Sanskrit work which mentions the rate of the motion of the solstices or equinoxes is the *Karaṇa-ratna* (I. 36) (AD 689) of Devācārya (Shukla 1979), where the solstices are considered to have an oscillatory motion of amplitude 24° at the rate of 47″ per year. According to H.T. Colebrooke, Pṛthūdakasvāmin (ninth century AD) mentions the name Viṣṇucandra, who considered that the equinoxes and solstices continuously revolve (Colebrooke, 1816).

Bhāskara II wrote in his *Gola-adhyāya* (VI. 17–18) (Sastri and Wilkinson, 1861) that the retrograde revolutions of the equinoxes in a *kalpa* (4,320,000,000 years) are 30,000 according to the *Sūrya-siddhānta,* and are 199,699 according to Muñjāla (=Mañjula). This statement is not harmonious with the extant *Sūrya-siddhānta* (III. 9–10) (c.tenth–eleventh century AD) (Sastri and Wilkinson, 1861 or Burgess, 1860/1935), where the equinoxes are considered to oscillate 600 times in a *yuga* (4,320,000 years) at the amplitude of 27°, that is 54″ per year. Bhāskara II's reference to Mañjula is important, because it implies that the equinoxes revolve continuously at the rate of 59″.9 per year. This theory is not found in Mañjula's extant work *Laghu-mānasa* (AD 932) (Shukla, 1990), where the equinoxes are said to move at the rate of 1′ per year, without mentioning whether the equinoxes are revolving or oscillating. It may be that Bhāskara II's reference is from a lost work of Mañjula.

Traditional Hindu calendars usually use sidereal year instead of tropical year, and the equinoxes are fixed to their position in the sixth century AD or so. Therefore, the amount of the precession of the equinoxes is very important in Hindu astronomy, and has been mentioned in Hindu traditional calendars. [See section 8 below.]

6.3.3. Astronomical instruments in classical Siddhāntas

In the *Vedāṅga* astronomy period, only two astronomical instruments, namely the gnomon and the water clock (outflow type), were used.

Some of the classical Siddhāntas have the section of astronomical instruments, and several astronomical instruments are described there. [For the detail of the astronomical instruments in this period, see Ôhashi (1994) and (2000b).] The following texts have the section (or chapter) of astronomical instruments, entitled *Yantra-adhyāya*, etc.: the *Āryabhaṭa-siddhānta*, the *Pañca-siddhāntikā*, the *Brāhma-sphuṭa-siddhānta*, the *Śiṣyadhī-vṛddhida-tantra*, the *Sūrya-siddhānta*, the *Siddhānta-śekhara* and the *Siddhānta-śiromaṇi*. (See Fig. 3 and Fig. 4)

The gnomon (*śaṅku*) was continually used in this Classical Siddhānta period. The theory of the gnomon, such as the relationship between the length of gnomon shadow, the latitude of the observer, and time, was developed in this period, and a special chapter entitled *Tripraśna-adhyāya* in the Siddhāntas was devoted to this subject. Trigonometry, invented in India, was fully utilized for this purpose.

The staff (*yaṣṭi-yantra*) is a simple stick, used to sight an object. There are some variations of the staff, such as the V-shaped staffs for determining an angular distance with the help of a graduated level circle.

The circle-instrument (*cakra-yantra*) is a graduated circular hoop or board suspended vertically. The Sun's altitude or zenith distance is determined by this instrument, and the time is roughly calculated from it. Variations of the circle-instrument are the semi-circle instrument (*dhanur-yantra*) and the quadrant (*turya-golaka*).

The circular board kept horizontally with a central rod is the chair-instrument (*pīṭha-yantra*), and a similar semi-circular board is the "bowl-instrument" (*kapāla-yantra*). The Sun's azimuth is determined by them, and time is roughly calculated from them.

A circular board kept in the equatorial plane is the equator-instrument (*nāḍīvalaya-yantra*). It is a kind of equatorial sundial. The combination of two semi-circular boards, one of which is in the equatorial plane, is the scissors-instrument (*kartarī-yantra*). Its simplified version is the semi-circular board in an equatorial plane with a central rod.

The armillary sphere (*gola-yantra*) in India was based on equatorial coordinates, and was different from the Greek armillary sphere, which was based on ecliptical coordinates. Probably, the celestial coordinates of the junction stars of the lunar mansions were determined by the armillary sphere since the seventh century or so (Fig. 5 and Fig. 6). There was also the celestial globe rotated by flowing water (Fig. 5).

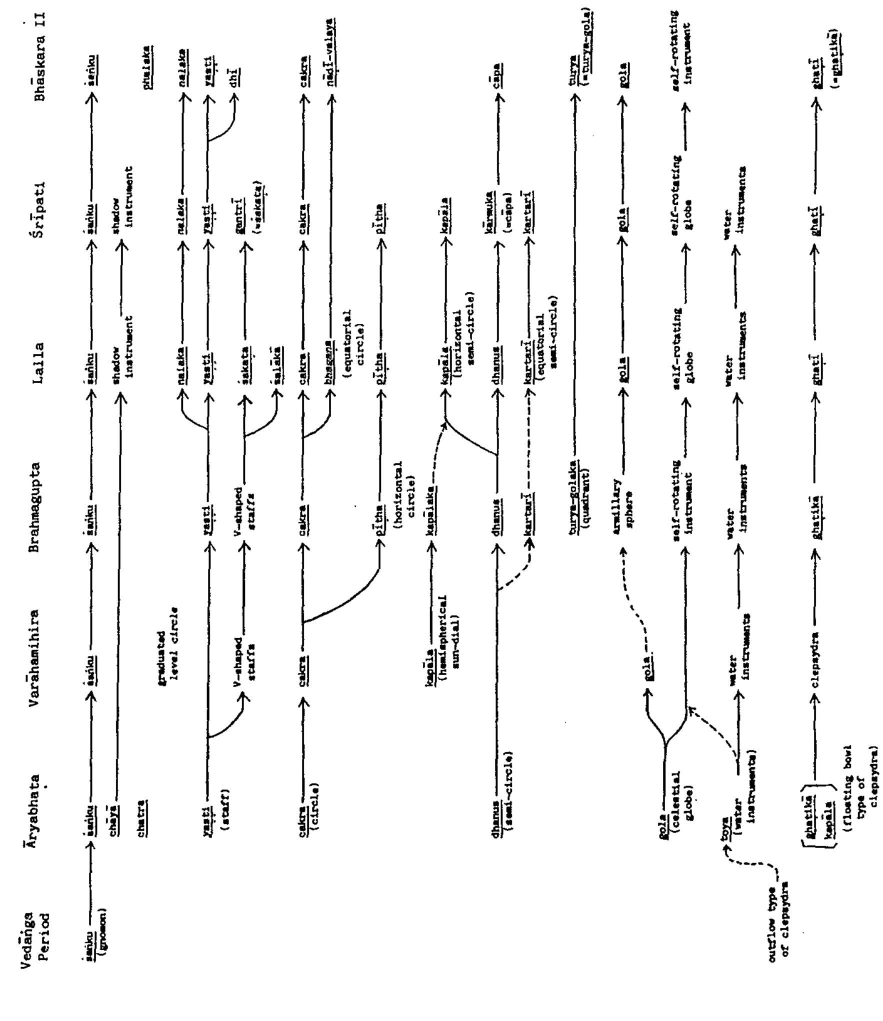


Fig. 3: Genealogy of astronomical instruments in Classical Siddhānta period.

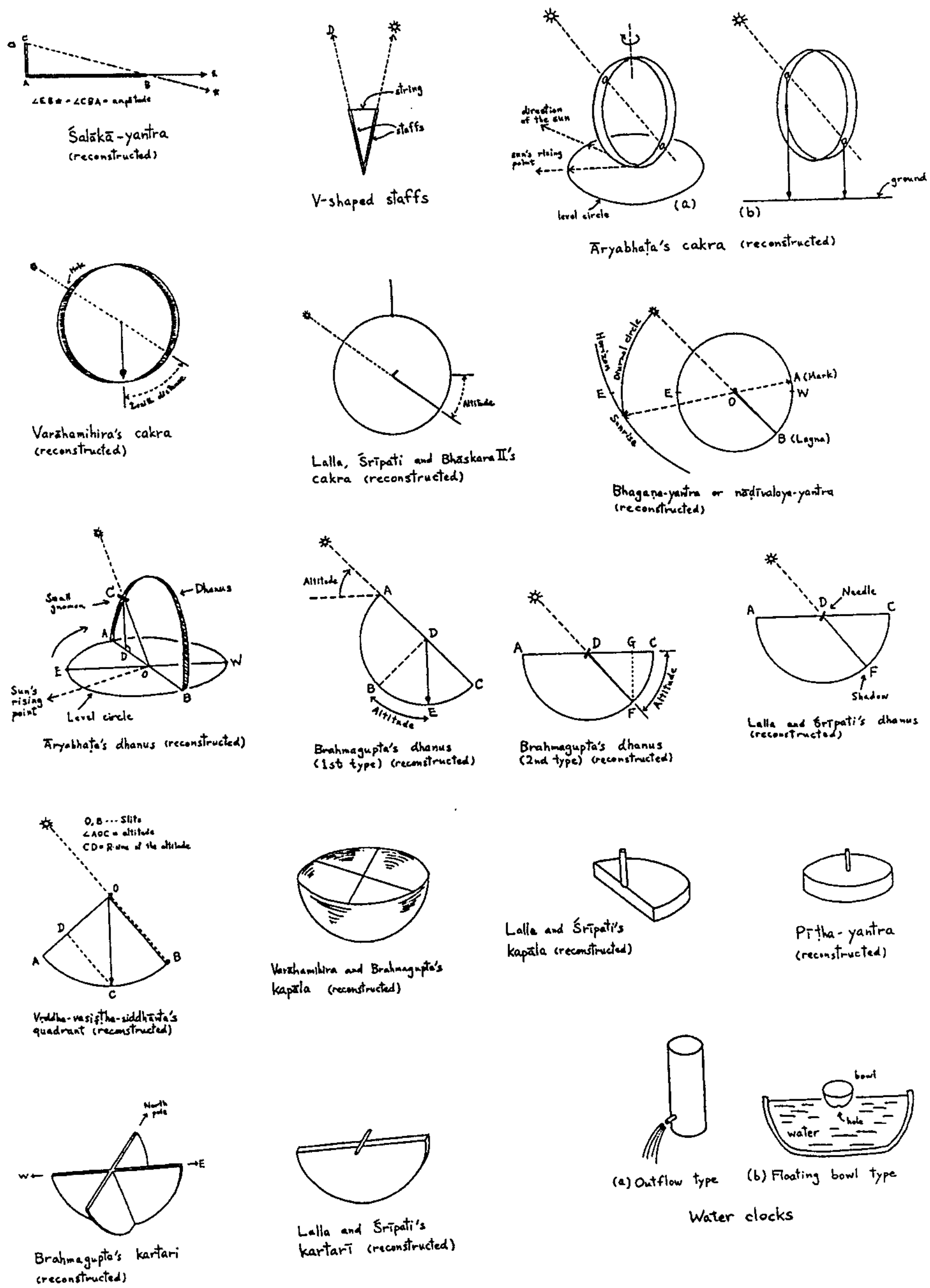


Fig. 4: Astronomical instruments in Classical Siddhāntas.

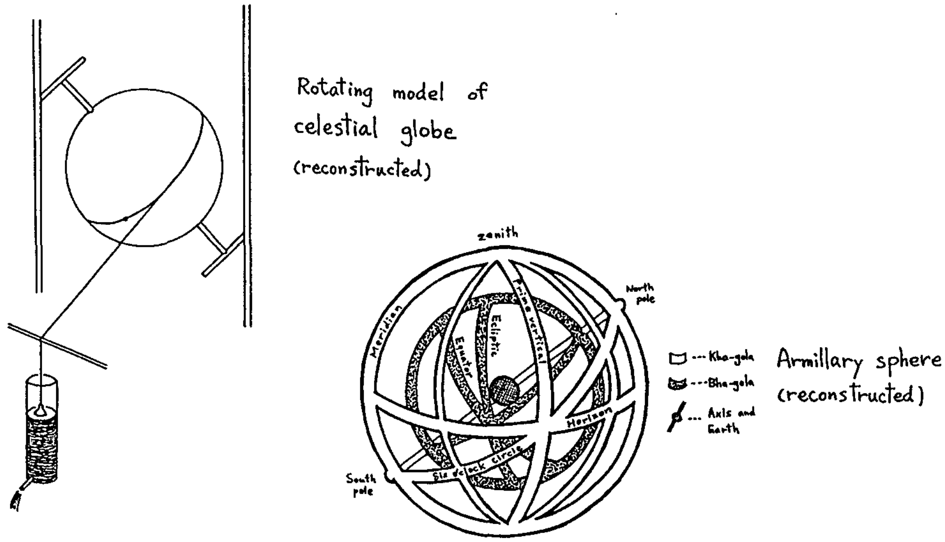


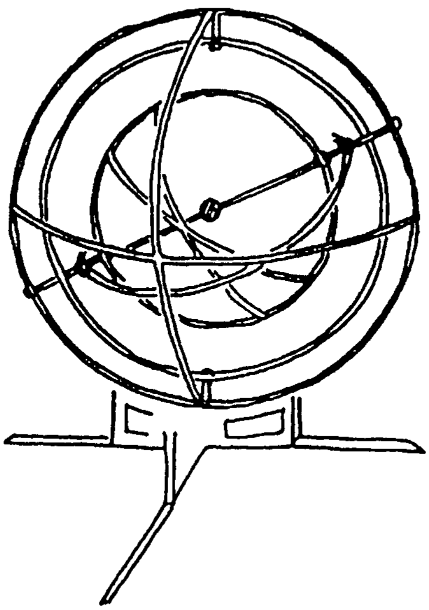
Fig. 5: The rotating model of celestial globe and the armillary sphere.

The water clock (*ghaṭī-yantra*) was widely used until recent times. Unlike the water clock of the *Vedāṅga* period, which was outflow type, the water clock of this Classical *Siddhānta* period was a bowl with a hole at its bottom floating on water. Water flows into the bowl, and it sinks after a certain time interval. The actual use of the water clock of this type was recorded by a Chinese Buddhist traveller Yijing (AD 635–713). The clepsydra actually used can be seen in a museum in Kota (Rajasthan) (Fig. 7). Several astronomers also described water-driven instruments such as the model of fighting sheep.

The *phalaka-yantra* (board-instrument) invented by Bhāskara II is a rectangular board with a pin and an index arm, used to determine time graphically from the Sun's altitude. This is an ingenious instrument based on the Hindu theory of gnomon (Fig. 8).

6.4. Hindu Astronomy in Different Regions in India

Although Sanskrit was the common academic language in ancient India, there were several regional traditions of astronomy, and texts written in regional languages were produced besides Sanskrit texts. There are also special features in Sanskrit texts produced in several regions in India.



Goverment Museum, Jaipur

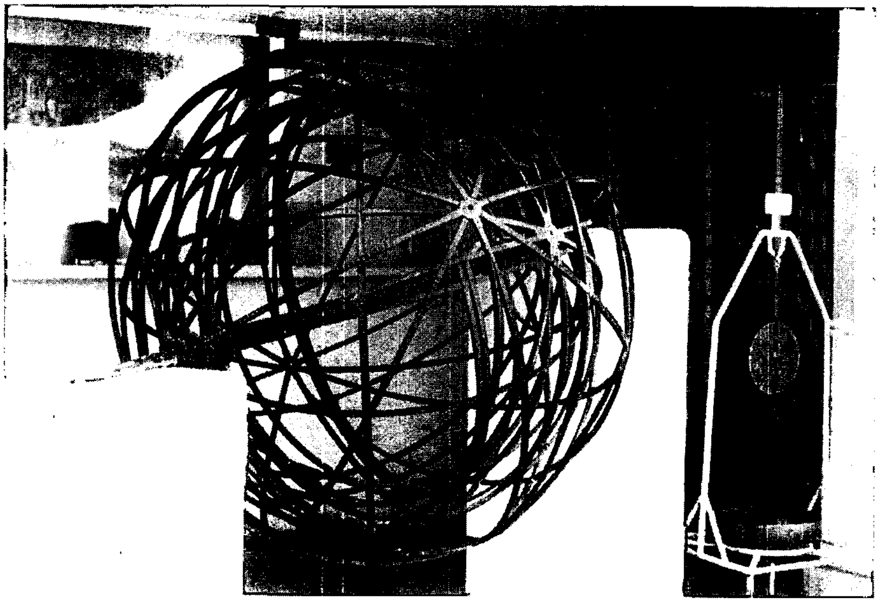


Fig. 6: The armillary sphere in the Government Museum, Jaipur and in Rao Madho Singh Museum, Kota (both in Rajasthan).

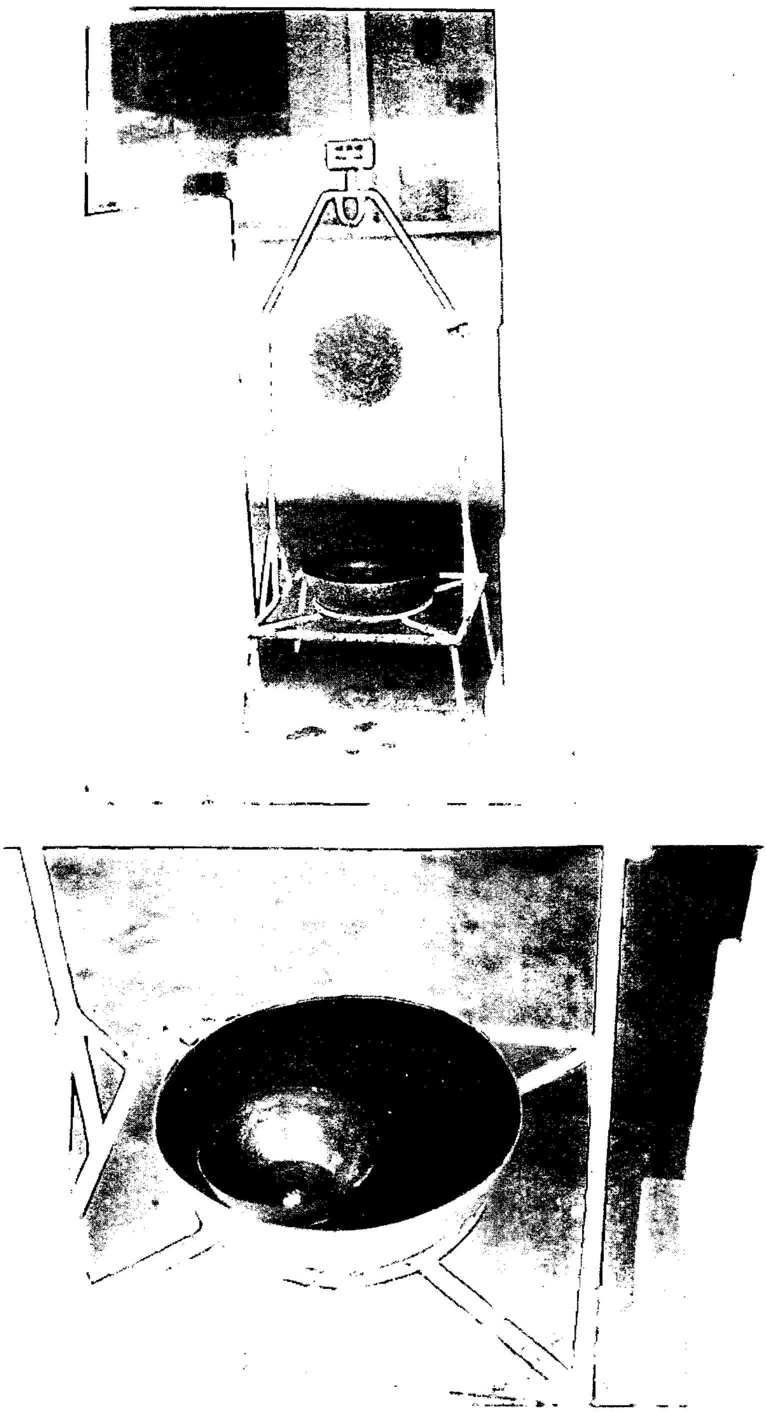


Fig. 7: The clepsydra preserved in Rao Madho Singh Museum, Kota (Rajasthan).

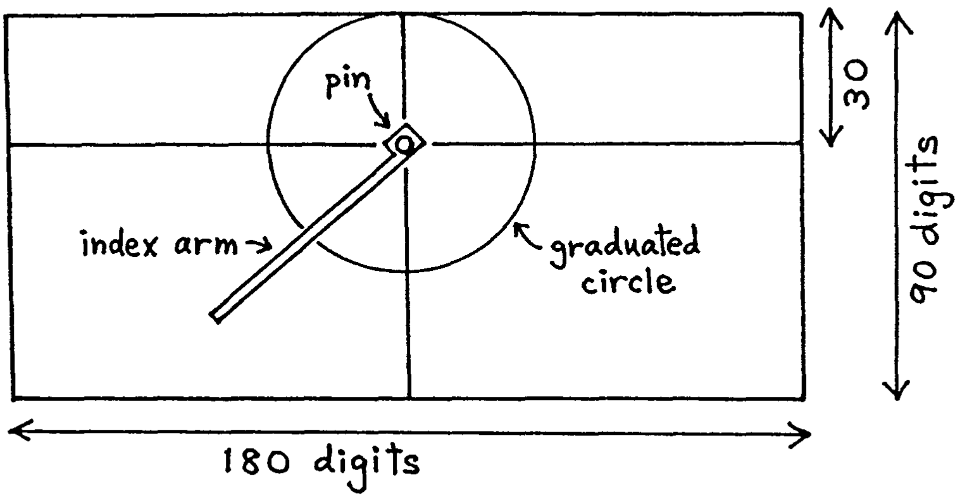


Fig. 8: The *phalaka-yantra* of Bhāskara II.

Already in 1825, John Warren pointed out in his *Kala Sankalita* that the solar calendar of Tamil region is based on the *Ārya-siddhānta* (=*Āryabhaṭīya*), and the luni-solar calendar of Telingana region (present Andhra Pradesh) is based on the *Sūrya-siddhānta*, while Muslims are using lunar calendar (Warren, 1825). Warren mentioned three Telugu astronomers in his book, namely, Bālādityakalu (who wrote in the 4558th year of the *Kali-yuga*, i.e. AD 1456), Mallikārjunuḍu (who is supposed to have flourished in the 4279th year of the *Kali-yuga*, i.e. AD 1177) and Vāvilāla Koccanna (who is supposed to have flourished in the 4399th year of the *Kali-yuga*, i.e. AD 1297). (The name of these astronomers was spelled as "Báladityacalu", "Malli Cárjanadu" and "Vavilala Cuchinna" respectively in Warren's original book.) This Warren's book gives detailed information of astronomical calculation in Andhra Pradesh, and is a mine for future study.

It is known that Mallikārjuna Sūri (=Mallikārjunuḍu in Warren's book), the author of the earliest extant commentary of the *Sūrya-siddhānta*, wrote his commentary both in Sanskrit and Telugu. Therefore, the tradition of the *Sūrya-siddhānta* in Andhra Pradesh is very important. More study of astronomical texts written in Telugu, etc. is needed.

Astronomical texts in Kerala are relatively well studied. [See Raja (1963) and Sarma (1972). For the texts of science in general in Kerala and Tamil Nadu, see Sarma (2002).] There were two major systems of Kerala astronomy. One is the *Parahita* system, which is based on the *Āryabhaṭīya* of Āryabhaṭa, and was started by Haridatta (c.AD 650–700), who composed the *Graha-cāra-nibandhana.* It is said that this *Parahita* system was started in AD 683. The other system is the *Dṛk* system started by Parameśvara (c.AD 1360–1455) who composed the *Dṛg-gaṇita* (AD 1431) (see Sarma, 1963), etc. Parameśvara's teacher Mādhava (c.AD 1340–1425) was a great mathematician and astronomer. Parameśvara's son's disciples Nīlakaṇṭha Somayājī (AD 1444–c.1543), who is the author of a comprehensive treatise of astronomy entitled *Tantra-saṁgraha* (AD 1500) (see Sarma, 1977 and Sriram et al., 2002), and Jyeṣṭhadeva (c.AD 1500–1610) (see Sarma, 2004–2008) and Jyeṣṭhadeva's disciple Acyuta Piṣāraṭi (c.AD 1550–1621) (see Sarma, 1974) were also great astronomers. The *Karaṇa-paddhati* (AD 1732) of Putumana Somayājin (c.AD 1700–1760) and the *Sadratnamālā* (AD 1823) of Śaṁkaravarman (AD 1800–38) are also comprehensive treatises on astronomy.

Another astronomer who probably belonged to Kerala is Devācārya who composed the *Karaṇa-ratna* (AD 689) (Shukla, 1979). This is probably the earliest extant Sanskrit work which mentions the rate of the motion of the solstices or equinoxes.

Astronomy in Tamil Nadu is also closely connected with the astronomy of Kerala. Before the introduction of modern Astronomy, Tamil calendars were solely based on the *Vākya-karaṇa* (c.AD 1300) and its auxiliary tables (Sastri and Sarma, 1962). This is practical work for calendar making, and is basically based on the *Mahā-bhāskarīya* of Bhāskara I and the *Parahita* system of Haridatta.

It may be mentioned here that the *Vākya* method of Tamil astronomy was already recorded by le Gentil, a French astronomer, who visited India in order to observe the transit of Venus of 1769. The observation itself was not successful due to the clouds, but he collected interesting information of Tamil astronomy (Gentil 1772, Bailly 1787).

7. COEXISTENT PERIOD OF HINDU ASTRONOMY AND ISLAMIC ASTRONOMY

7.1. Introduction

After the establishment of Islamic dynasties in north India, the coexistent period of Hindu astronomy and Islamic astronomy (the thirteenth/fourteenth century to the eighteenth/nineteenth century AD) began. Actually, the earliest Sanskrit work which mentions a kind of information of Islamic calendar is the *Kālacakra-tantra* (an esoteric Buddhist work, probably written in the eleventh century AD), where the year of Hijra is mentioned with 2 years' error (see the following (9.2) section of Tibetan astronomy). However, the first Sanskrit work where Islamic astronomy is explained in detail is the *Yantra-rāja* (AD 1370) of Mahendra Sūri, which is the first Sanskrit work on the astrolabe. At this time, some Sanskrit works on Hindu astronomical sciences were also translated into Persian by the order of Fīrūz Shāh (reign AD 1351–1388), a Sulṭān of the Tughluq dynasty. These events mark the real beginning of the coexistent period of Hindu and Islamic astronomy. For the sake of convenience, let us divide this period into two parts, namely the Delhi Sultanate period and the Mughal Empire period. [For more detail, see Ôhashi 2008 b).]

(A) Delhi Sultanate period (AD 1206–1526)
During the Delhi Sultanate period, only one *siddhānta* (fundamental treatise of astronomy) was produced. It is the *Sundara-siddhānta* (also called *Siddhānta-sundara*) (AD 1503) of Jñānarāja.

Some interesting *karaṇas* (handy practical works of astronomy) were produced in this period. One is the *Karaṇa-kautuka* (AD 1496) of Keśava. Keśava compared the position and velocity of planets according to three schools of Hindu Classical Astronomy, namely, the Brāhma school, Ārya school and Saura school, and tried to determine the best astronomical constants which agree with the actual observation. This was a great progress of that time, when the tradition of the schools was considered to be very important. Keśava's son Gaṇeśa (b. AD 1507) was also a great astronomer, and his *Graha-lāghava* (AD 1520) is a quite popular *karaṇa*. [For its Sanskrit text, see, for example, Jośī (1983). There are several other publications. For its text and English translation, see Rao and Uma (2006).]

There is also a popular Sanskrit astronomical table *Makaranda-sāraṇī* (AD 1478) of Makaranda, which is based on the *Sūrya-siddhānta.*

(B) Mughal Empire period (AD 1526–1858)
Some new *siddhāntas* were composed during the Mughal Empire period. Nityānanda wrote the *Siddhānta-sindhu* (AD 1628) (I have not seen this text), and the *Siddhānta-rāja* (AD 1639) under the reign of

Emperor Shāh Jahān (reign 1628–1658). At the same time, Farīd ad-Dīn Mas'ūd ibn Ibrāhīm Dihlawī, a court astronomer of Shāh Jahān, composed the *Zīj-i Shāh Jahānī* (Astronomical table dedicated to Emperor Shāh Jahān) (AD 1629) in Persian.

Munīśvara (b. AD 1603) wrote the *Siddhānta-sārva-bhauma* in AD 1646 [for its first part, see Munīśvara (1932–78)]. This work basically follows the *Sūrya-siddhānta.*

Kamalākara wrote the *Siddhānta-tattva-viveka* in AD 1658 (Kamalâkara 1880–85/1924–35). This work basically follows the *Sūrya-siddhānta.*

In the first half of the eighteenth century, five traditional astronomical observatories, among which four still exist, were built by Sawai Jai Singh (or Savāī Jaya Siṁha in literal transcription of Nāgarī script) (reign AD 1699–1743), Mahārāja of Jaipur. [For the observatories of Jai Singh, see Garrett and Guleri (1902), Bhāvana (1911), Kaye (1918, 1920), Sharma (1982 b), Sharma (1995) and Volwahsen (2001).] At his court, some astronomical works in Sanskrit and Persian were composed, for example, the *Zīj-i jadīd-i Muḥammad Shāhī* (new astronomical table dedicated to Emperor Muḥammad Shāh) (AD 1728) in Persian (see Hunter, 1797) and the *Siddhānta-kaustubha* of Jagannātha in Sanskrit (see Pingree, 2004). And also, at his court, Jagannātha translated aṭ-Ṭūsī's Arabic version of Ptolemy's *Almagest* into Sanskrit as the *Samrāṭ-siddhānta* (Sharma, 1967), and aṭ-Ṭūsī's Arabic version of Euclid's *Elements* into Sanskrit as the *Rekhā-gaṇita.* And also, Nayanasukha-upādhyāya translated some Arabic astronomical works into Sanskrit (see Kusuba and Pingree, 2002).

Jai Singh's observatory is extant in Jaipur, Delhi, Banaras and Ujjain. His observatory in Mathura is not extant. Among them, the Jaipur observatory is the largest (See Figures 9–13).

Among the several instruments in Jai Singh's observatories, the most famous instrument is probably the *Samrāṭ-yantra* ("emperor instrument"). It is a kind of equatorial sundial (see Figure 10). In the figure, φ is the latitude of the observer, δ is the Sun's declination and h is the Sun's hour angle. In the afternoon, the shadow of the gnomon (AB) is cast on the quadrant (EFGH), and its position (Y) indicates time. In the forenoon, the shadow of the gnomon (CD) is cast on the quadrant (JKLM). The position (X) indicates the Sun's declination (also see Figure 11).

Fig. 9: Jai Singh's observatory at Jaipur, viewed from its larger *Samrāṭ-yantra*.

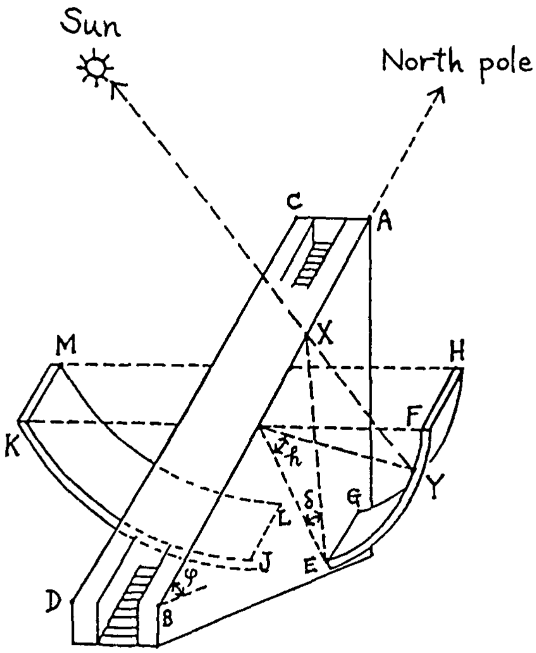


Fig. 10: Principle of the *Samrāṭ-yantra.*

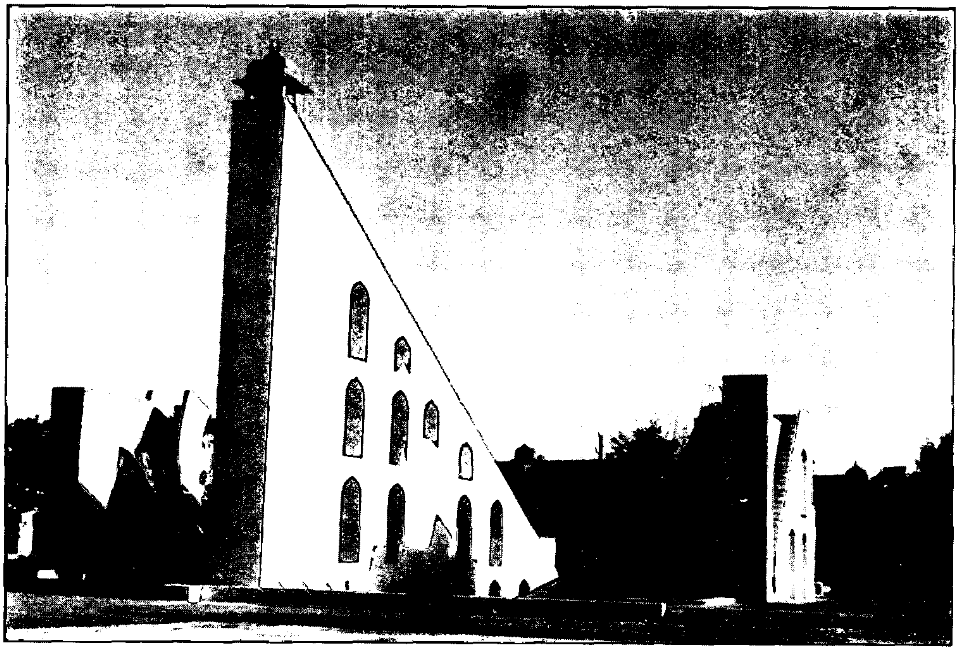


Fig. 11: Larger *Samrāṭ-yantra* in the Jaipur observatory.

Under each quadrant of the larger *Samrāṭ-yantra* in the Jaipur observatory is constructed a chamber in which the *Ṣaṣṭhāṁśa-yantra* ("sextant instrument") is kept (see Figure 12). The image of the Sun (D and D′) through a pair of pinholes (A and A′) at its ceiling is cast on a pair of mural sextants (BC and B′C′) at midday (also see Figure 13). The Sun's declination and zenith distance are obtained by this

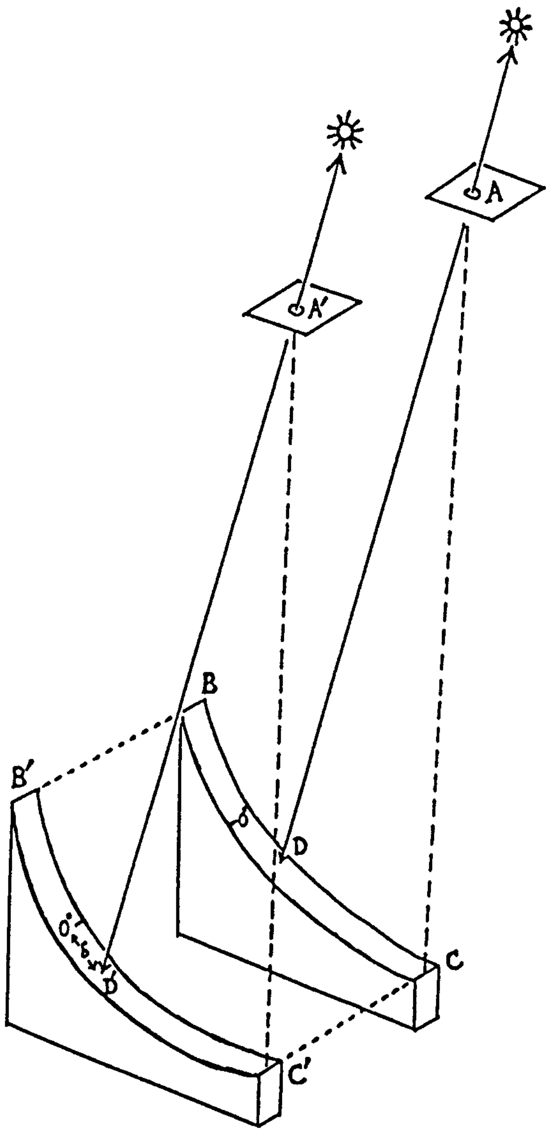


Fig. 12: Principle of the *Ṣaṣṭhāṁśa-yantra.*

instrument. This is probably the most precise instrument in Jai Singh's observatories. There was also a *Ṣaṣṭhāṁśa-yantra* in the Delhi observatory, but it is a ruin now.

The *Miśra-yantra* (Figure 14) is a unique instrument in the Delhi observatory, which is a combination of some instruments. Its front side is used to observe a heavenly body's declination four times a day. It may not be so useful astronomically, but is certainly a beautiful art

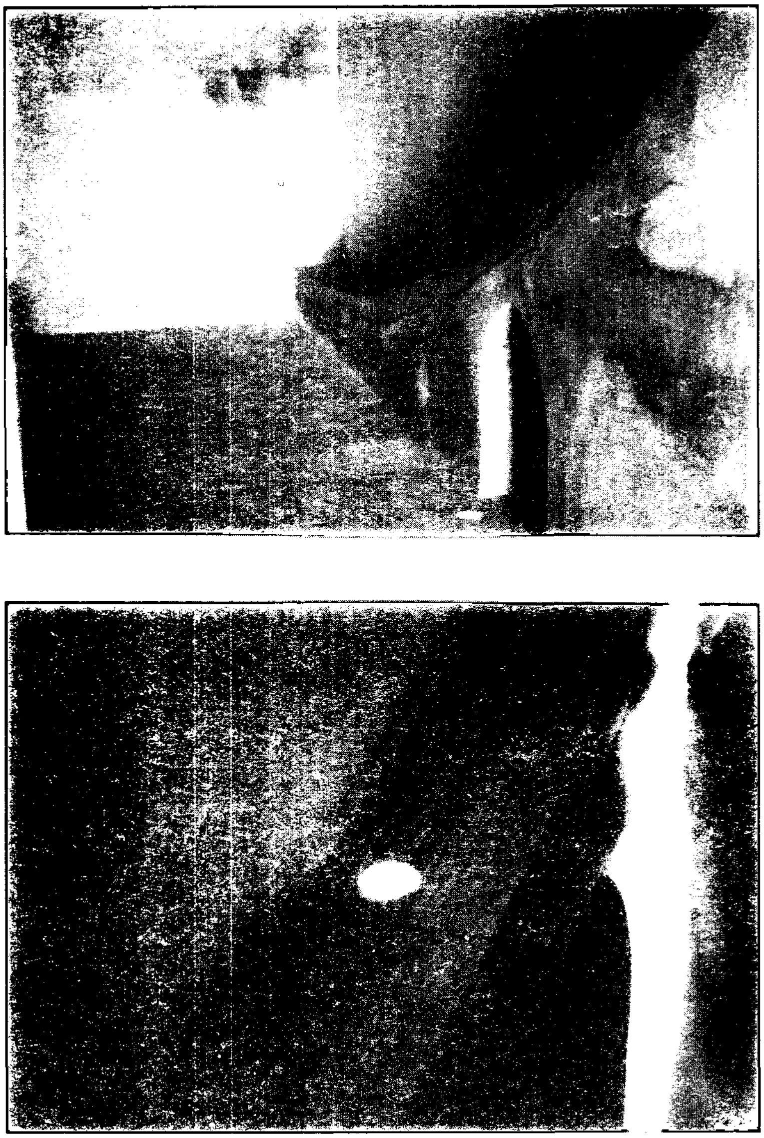


Fig. 13: Image of the sun projected on the *Ṣaṣṭhāṁśa-yantra* in the Jaipur observatory.

Fig. 14: *Miśra-yantra* in Jai Singh's observatory at Delhi.

object. There are several other interesting instruments in Jai Singh's observatories.

Some works on astronomy written in classical languages were still composed in the nineteenth century. Mention may be made of the *Jāmi'-i Bahādur Khānī* (AD 1833, published in AD 1835) of Ghulām Ḥusain, which is probably the last comprehensive Persian astronomical work written in traditional style in Mughal India. Certain knowledge of modern astronomy is also explained there [Jaunpūrī (1835); and also see Ansari (1995/96), Ansari and Sarma (1999/2000)].

In the British period, the *Siddhānta-darpaṇa* (AD 1893, published in AD 1897) of Candraśekhara Siṁha Sāmanta was composed (Siṁha 1897/1996). This is one of the last Sanskrit astronomical *siddhāntas*.

7.2. Astronomical Instruments in this Period

7.2.1. Introduction

There are several Sanskrit works on astronomical instruments in India. Some of them were published, but many of them are preserved in several libraries in India and abroad in the form of manuscripts. I have been doing research on the Sanskrit manuscripts on astronomical instruments for about 25 years, and published some of them. (For a popular introductlion, see Ôhashi, 2004a.)

The texts of astronomical instruments in this period are, as far as I have seen, as follows. [For their bibliographical information, tentatively see Ôhashi (1986–87).]

(I) Works exclusively devoted to astronomical instruments:

(I.i) Works on a single instrument:

(I.i.a) Works on the astrolabe:

(1) *Yantra-rāja* (AD 1370) of Mahendra Sūri (published in Raikva, 1936. There is another publication also.)

(2) *Yantra-rāja-adhikāra* (Chapter I of the *Yantra-kiraṇāvalī*) (AD 1423) of Padmanābha (published in Ôhashi, 1997).

(3) *Yantra-rāja-vicāra-viṁśādhyāyī* of Nayanasukha-upādhyāya (fl. AD 1730) (published as Bhaṭṭācārya, 1979).

(4) *Yantra-rāja-racanā* of Savāī Jaya Siṁha (AD 1688–1743) (published in Kedāranātha, 1953).

(5) *Yantra-prabhā* of Śrīnātha (published in Kedāranātha, 1953).

(6) *Yantra-rāja-kalpa* (AD 1782) of Mathurānātha Śukla.

(7) *Yantra-bhūṣaṇa* (anonymous).

[Note: According to Sarma (2008) (pp. 246–247) etc., there are also the *Usturalāva-yantra* of Muni Megharatna etc. on the astrolabe.]

(I.i.b) Works on the quadrant:

(8) *Yantra-cintāmaṇi* (sometime between AD 1150 and 1621) of Cakradhara. (Published as Jhā (2007); and also its main verses are quoted in Durgā-prasāda-dvivedin, 1936. There is another publication also.)

(9) *Turya-yantra-prakāśa* of Bhūdhara (fl. AD 1572).

(10) *Turīya-yantra* of Sevārāma.

(I.i.c) Works on the cylindrical sun-dial:

(11) *Kaśā-yantra* of Hema (the late fifteenth century AD) (published in Ôhashi, 1998).
(12) *Pratoda-yantra* of Gaṇeśa Daivajña (b. AD 1507) (published in Ôhashi, 1998).

(I.i.d) Works on other instruments:

(13) *Dhruva-bhramaṇa-yantra-adhikāra* (Chapter II of the *Yantra-ratnāvalī*) of Padmanābha (fl. AD 1423).
(14) *Diksādhana-yantra* of Padmanābha (fl. AD 1423).
(15) *Gola-ānanda* (AD 1791) of Cintāmaṇi Dīkṣita.
(16) *Gola-yantra-nirṇaya* of Yallambhaṭṭa.
(17) *Koneri-yantra* of Koneri (published in Sinha and Hayashi, 1983).
(18) *Valaya-yantra* (anonymous).

[Note: According to Sarma (2008) (pp. 147–175), there is also the *Ghaṭikā-yantra-ghaṭanāvidhi* on the water clock.]

(I.ii) Works on several instruments:

(19) *Yantra-prakāśa* (AD 1428) of Rāmacandra.
(20) *Yantra-śiromaṇi* (AD 1615) of Viśrāma (published in Raikva, 1936).
(21) *Yantra-prakāra* (sometime between AD 1716 and 1724) of Savāī Jaya Siṁha (AD 1688–1743) (published in Sarma, 1986–87).
(22) *Yantra-sāra* (AD 1772) of Nandarāma Miśra.

(II) Later astronomical *siddhāntas* which have chapter of instruments:

(23) *Sundara-siddhānta* (AD 1503) of Jñānarāja.
(24) *Siddhānta-rāja* (AD 1639) of Nityānanda.
(25) *Siddhānta-sārvabhauma* (AD 1646) of Munīśvara (b. AD 1603).
(26) *Siddhānta-samrāṭ* (in or after AD 1732) of Jagannātha (published as Muralīdhara-caturveda (1976), and also in Sharma (1967) vol. 2).

[Note: This Muralīdhara-caturveda's text includes the *Sarvadeśīya-jarakālī-yantra*. Also see Sarma (2008) pp. 223–239.]

And also, the *Siddhānta-tattva-viveka* (AD 1658) of Kamalākara (Kamalâkara 1880–85/1924–35) has a description of the quadrant.

Besides the texts on astronomical instruments, there are several extant specimens of astronomical instruments in museums and libraries in India and abroad (see, for example, Sarma, 2003 and 2008).

In this section, I would like to explain some of the texts of astronomical instruments which I studied.

7.2.2. Introduction of the astrolabe in India

During the reign of Fīrūz Sh̲āh Tug̲hluq (reign AD 1351–88), the third Sultan of the Tug̲hluq dynasty of India, the astrolabe was introduced into India from the Islamic world. This fact is recorded in an anonymous Persian work entitled *Sītat-i Fīrūz Sh̲āhī* (AD 1370), whose manuscript is preserved in the Khuda Bakhsh Oriental Library, Patna, India.

In AD 1370, a Sanskrit work entitled *Yantra-rāja* was composed by Mahendra Sūri. It is a detailed monograph of the newly introduced astrolabe [for its text, see Raikva (1936); for related topics, also see Plofker (2000) and Ôhashi (2008f)].

7.2.3. The *Yantra-rāja-adhikāra* of Padmanābha

Padmanābha was an Indian astronomer who wrote some works on astronomical instruments in Sanskrit. Padmanābha was a son of Nārmada, who was also an astronomer, and Padmanābha was the father of Dāmodara, who composed two handy astronomical works, the *Bhaṭa-tulya* and the *Sūrya-tulya* both in AD 1417).

Padmanābha is known to have composed the *Dhruva-bhramaṇa-yantra-adhikāra* (chapter 2 of his *Yantra-ratnavalī*). This is a description of a kind of nocturnal, where time can be obtained from the direction of α and β Ursae Minoris (see Fig. 15). The existence of this text is relatively well known, and there are several manuscripts of this text. However, this text has not been published. I am trying to edit and translate this text. I hope I will be able to publish it sometime in the future.

Padmanābha is also known to have composed a small work *Dik-sādhana-yantra,* whose single manuscript is preserved in Baroda.

What I am going to explain here is another work of Padmanābha, the *Yantra-rāja-adhikāra* (chapter 1 of his *Yantra-kiraṇāvalī*). The relationship between the *Yantra-ratnāvalī* and the *Yantra-kiraṇāvalī* is yet to be investigated. Only one chapter of each work is known to be

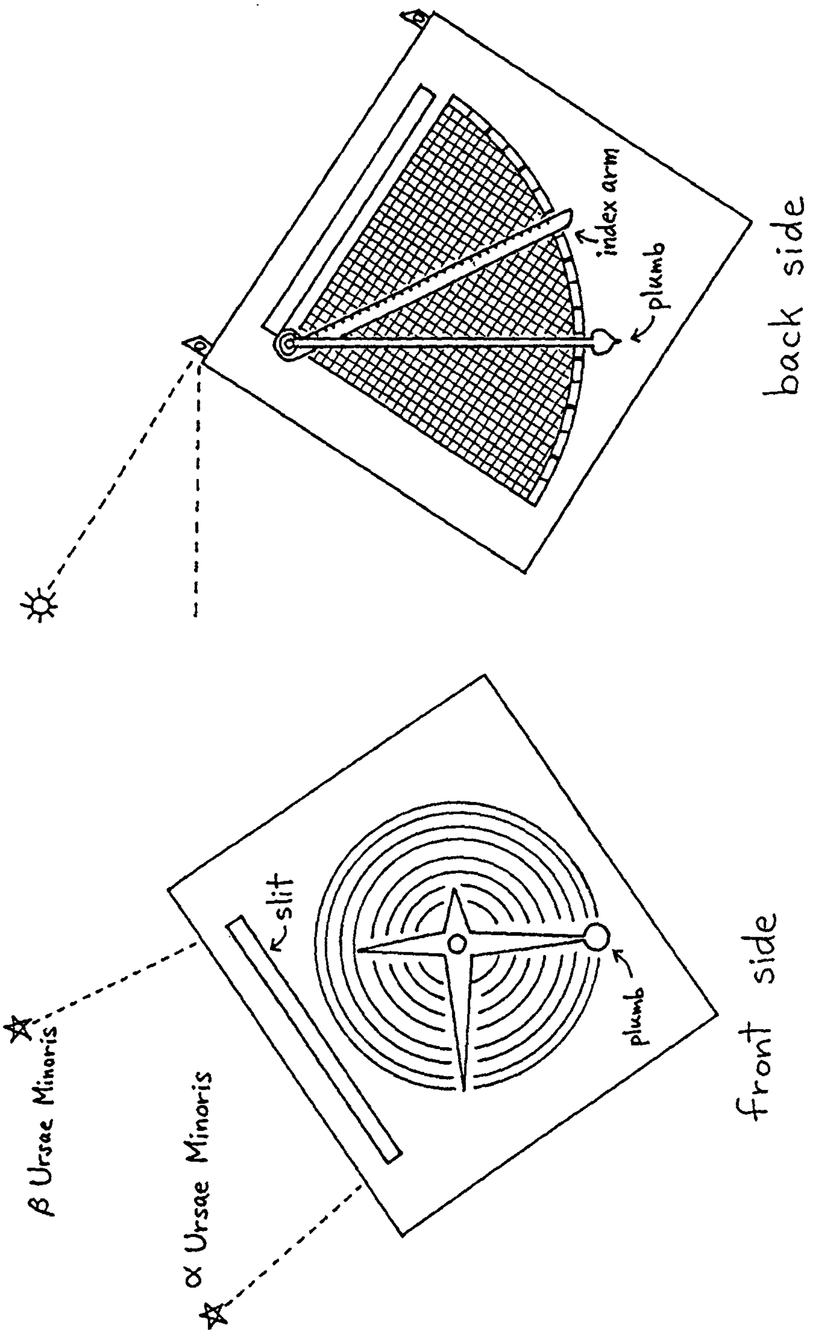


Fig. 15: The *Dhruva-bhramaṇa-yantra* of Padmanābha.

extant. As far as I know, the *Yantra-rāja-adhikāra* had not been studied by modern historians of astronomy when I started my research on the history of astronomical instruments as a research scholar of Lucknow University (Lucknow, India) under the guidance of Professor Kripa Shankar Shukla in 1983. I found that two manuscripts of the *Yantra-rāja-adhikāra* were preserved in Lucknow University, one is in Tagore Library (central library of the university), and one is in the Department of Mathematics and Astronomy. Then I started studying this text and incorporated its partial study in my Ph.D. thesis submitted to Lucknow University. I published its complete text and English translation in 1997 (see Ôhashi, 1997).

The *Yantra-rāja-adhikāra* is the second extant Sanskrit work on the astrolabe since the *Yantra-rāja* of Mahendra Sūri. The Sanskrit word "yantra-rāja" stands for astrolabe (see Fig. 16). Padmanābha mentions the year "1345 Śaka" (=AD 1423) in this work. So, this work must have been composed around this year. This year is after the year when his son Damodara composed his two works.

The astrolabe mentioned in this text is just opposite to the ordinary astrolabe, the centre of which is the North Pole. The centre of Padmanābha's astrolabe is the South Pole. So, it is convenient in the southern hemisphere, but is inconvenient in the northern hemisphere including India. It may be that the astrolabe consulted by Padmanābha was the southern type of astrolabe, which was one type among the several astrolabes introduced into India in the Tughluq dynasty.

Significance of Padmanābha's *Yantra-rāja-adhikāra* is that he explained the principle of the astrolabe using Hindu traditional mathematics. This fact shows that the astrolabe was well understood by Hindu astronomers soon after its introduction.

7.2.4. Cylindrical sundial in India

There are some works on cylindrical sundial written in Sanskrit. The earliest extant monograph of the cylindrical sundial in Sanskrit is the *Kaśā-yantra* of Hema (c. later half of the fifteenth century AD). Actually, an instrument called "*kaśā-yantra*" is mentioned in an earlier work *Yantra-prakāśa* (AD 1428) of Rāmacandra, but its description is too brief, and its construction is not clear. Therefore, the *Kaśā-yantra* of Hema can be said to be the first detailed work on the cylindrical sundial in Sanskrit.

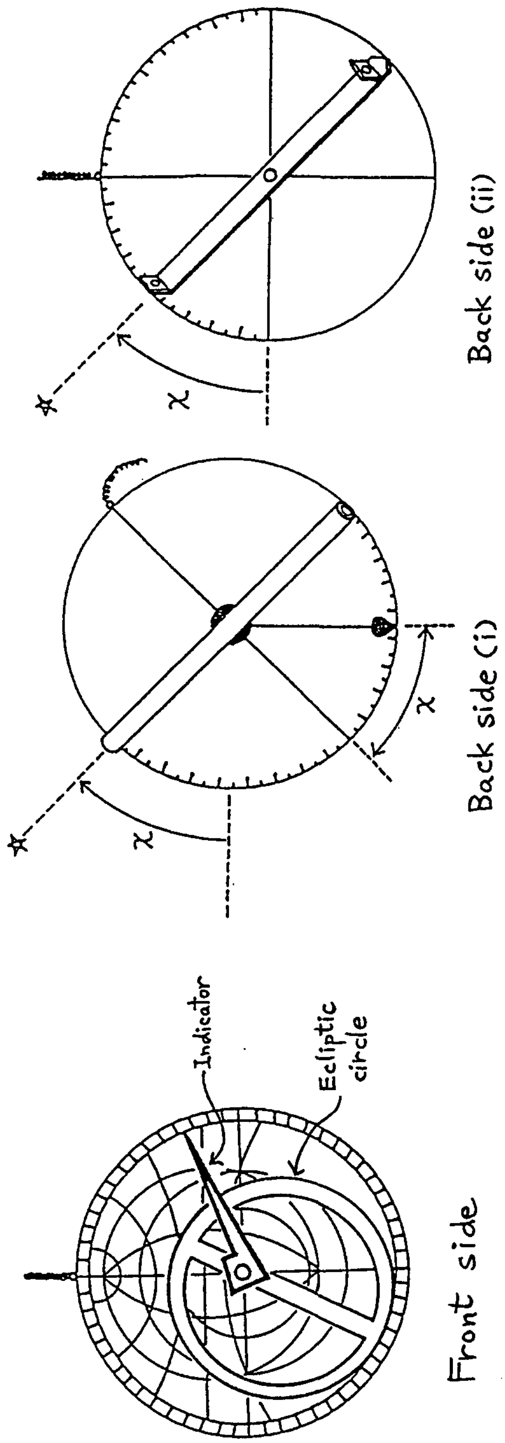


Fig. 16: The astrolabe of Padmanābha.

A unique manuscript of the *Kaśā-yantra* of Hema is preserved in the Oriental Institute, M.S. University, Baroda.

As far as I know, the *Kaśā-yantra* of Hema had not been studied by modern historians of astronomy before I started studying it. It is the most detailed work among the extant Sanskrit works on the cylindrical sundial. It is interesting to note that Hema quoted from two works in his *Kaśā-yantra*, namely the *Yantra-rāja-adhikāra* of Padmanābha and the *Sūrya-tulya* of Damodara, son of Padmanābha, both of which I mentioned in the previous section. This fact shows that these astronomical works were well circulated among astronomers.

The *Pratoda-yantra* of Gaṇeśa (born AD 1507) is another work on the cylindrical sundial. It is a small work which consists of 13 verses. It is relatively well known, but had not been published before I published it.

I incorporated their study in my Ph.D. thesis, and published the complete text and English translation of the *Kaśā-yantra* of Hema and the *Pratoda-yanra* of Gaṇeśa in 1998 (see Ôhashi, 1998), (see Fig. 17).

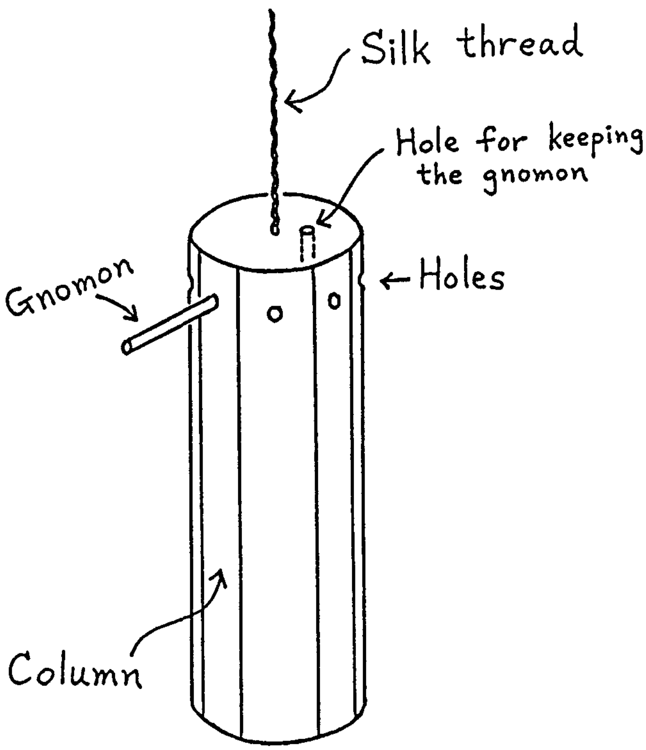


Fig. 17: The cylindrical sundial.

The cylindrical sundial was also described by Munīśvara in his *Siddhānta-sārvabhauma* (AD 1646), and Munīśvara's version was published by Shakti Dhara Sharma (Sharma, 1982a).

8. TRADITIONAL ASTRONOMY IN MODERN INDIA

In modern India, modern astronomy is of course highly developed, and modern Indian astronomers are quite active. Besides, traditional astronomies are also widely used in order to make regional calendars, etc. Besides the Gregorian calendar, which is the commonly used solar calendar, Hindu calendar and Islamic calendar are also used to determine the date of traditional festivals, etc. There are several variations of Hindu calendar according to linguistic regions and schools, whose basis is a theoretical luni-solar calendar. Islamic calendar is an observational lunar calendar, and the beginning of its lunar month is determined by the actual observation of the visibility of the new moon at mosques. [For Indian calendars, Sewell and Dikshit (1896) should still be consulted. For Indian eras, see Cunningham (1883).]

As there are several different Hindu calendars in India, the Calendar Reform Committee was created in 1952 in order to unite calendars. (See Saha, 1955. This report gives a good overview of Indian calendars.) This committee made a new traditional calendar "Rashtriya Panchang", which is a kind of solar calendar, and is published annually.

Among the several regional calendars, some calendars are using Hindu solar calendar, which is based on the solar position in zodiacal signs, for daily use, besides the luni-solar calendar for religious ceremonies, etc. This kind of Hindu solar calendar is used in the Punjabi, Oriya, Bengali and Tamil calendars (which begin from "Meṣa" month), and the Malayalam calendar (which begins from "Siṁha" month). The luni-solar calendar is solely used in the Hindi, Gujarati, Marathi, Telugu and Kannada calendars. The Hindu luni-solar calendars are divided into two types of lunar month, namely *pūrṇimānta* (whose month ends with full moon), and *amānta* (whose month ends with new moon), but a calendrical year of the both ends with new moon.

The beginning of a calendrical year and the type of lunar month (*pūrṇimānta* or *amānta*) are tabulated as Table 1. There must be

Table 1: Hindu regional calendars

	Beginning of a year	Type of lunar month
Hindi	Caitra, śukla-pakṣa	*pūrṇimānta*
Gujarati	Kārttika, śukla-pakṣa	*amānta*
Marathi	Caitra, śukla-pakṣa	*amānta*
Telugu	Caitra, śukla-pakṣa	*amānta*
Kannada	Caitra, śukla-pakṣa	*amānta*
Panjabi	Solar Meṣa	*pūrṇimānta*
Oriya	Solar Meṣa	*pūrṇimanta*
Bengali	Solar Meṣa	*amānta*
Tamil	Solar Meṣa	*amānta*
Malayalam	Solar Siṁha	*amānta*

several other calendars in India, but this table is limited to the calendars which I have actually seen.

I shall explain the system of Hindu luni-solar calendar (particularly Hindi calendar) just briefly. Hindu calendars are divided into *nirayana* (where sidereal year is used) and *sāyana* (where tropical year is used). Although the "Rashtriya Panchang" follows the *sāyana* method, the *nirnaya* method is followed by most of all regional calendars, and the zodiacal signs (*rāśis*) are fixed to its position in the sixth century AD or so. The difference between the *nirayana* zodiac and the current zodiac, i.e. the amount of precession since the sixth century AD or so, is called *ayanāṁśa.* The Sun's entering a sign is called *saṁkrānti,* which is the beginning of a Hindu solar month. A Hindu lunar month is divided into two halves, namely, *śukla-pakṣa* (from new moon to full moon) and *kṛṣṇa-pakṣa* (from full moon to new moon). There are two types of Hindu lunar months, namely, *pūrṇimānta* (which ends with full moon, and the name of a *kṛṣṇa-pakṣa* is the same as its following *śukla-pakṣa*) and *amānta* (which ends with new moon, and the name of a *kṛṣṇa-pakṣa* is the same as its preceding *sukla-pakṣa*). The name of a *sukla-pakṣa* is determined by the position of the Sun in zodiacal signs at the time of new moon (beginning of the *sukla-pakṣa*), as Table 2.

When two successive new moons occur in a single sign, the month between the two new moons becomes an intercalary month (*adhika-māsa*). One lunar half-month is divided into 15 *tithis,* and they are numbered serially from 1 to 15, but the last *tithi* of a *kṛṣṇa-pakṣa* is

Table 2: Hindu lunar months

Sign at new moon	Name of lunar month
Meṣa (Aries)	Vaiśākha
Vṛṣa (Taurus)	Jyeṣṭha
Mithuna (Gemini)	Āṣāḍha
Karka (Cancer)	Śrāvaṇa
Siṁha (Leo)	Bhādrapada
Kanyā (Virgo)	Āśvina
Tulā (Libra)	Kārttika
Vṛścika (Scorpio)	Mārgaśīrṣa
Dhanus (Sagittarius)	Pauṣa
Makara (Capricorn)	Māgha
Kumbha (Aquarius)	Phālguna
Mīna (Pisces)	Caitra

numbered 30. One *tithi* is a period during which the longitudinal difference between the Moon and the Sun changes by 12°. Usually, a day in a Hindu calendar begins from sunrise, and the number of the *tithi* at the time of sunrise becomes the number of the calendrical day. Sometimes, a *tithi* does not contain sunrise, and its number disappears from a calendar. This kind of *tithi* is called *kṣaya-tithi.* Sometimes, a *tithi* contains two successive sunrises, and the same number of day appears twice successively in a calendar. This kind of *tithi* is called *adhika-tithi.*

A traditional Hindu calendar is usually called *pañcaṅga* in Hindi, etc., which means "having five elements". The five elements in Hindu calendar are *tithi, vāra* (day of the week), *nakṣatra* (lunar mansion, which indicates lunar position), *karaṇa* (half-*tithi*) and *yoga* (period during which the sum of the longitude of the Sun and Moon changes by 13°20′, which is used for astrological purpose). A traditional Hindu calendar in book form is sometimes also called *jantrī* in Hindi, and is usually called *pañjikā* in Bengali, etc.

At present, there are several traditional Hindu calendars which have been calculated by the classical method, while there are some Hindu calendars which are calculated using the values of modern astronomy. One example is the case of Bengali calendars. The *Gupta Press Pañjikā,* etc., follow the traditional method, but the *Biśuddha Siddhānta Pañjikā* uses the values of modern astronomy. So, the date of a festival sometimes differs between these calendars (see Government of West Bengal 1963, Chakravarty 1975).

9. APPENDIX—INDIAN ASTRONOMY AND ASIA

9.1. Introduction

Indian astronomy was introduced to several places, the Islamic world, towards west, Tibet, towards north, South-East Asia towards east, and East Asia towards north-east. At some places, Indian influence was large, for example, Tibet, and Mainland South-East Asia (except for Vietnam). At some places, Indian influence was relatively small, for example, East Asia. I would like to explain some topics.

9.2. Indian Astronomy and Tibet

9.2.1. Introduction

There are four branches of Tibetan astronomical sciences:

(1) *sKar-rtsis* (star calculation)—mathematical astronomy based on the *Kālacakra* astronomy of India.

(2) *dByaṅs-'char* (appearance of voice)—divination based on Indian divination called *svarodaya.*

(3) *Nag-rtsis* (black calculation)—astrology based on Chinese astrology and natural philosophy.

(4) *rGya-rtsis* (Chinese calculation)—mathematical astronomy based on the *Shixian* calendar of China.

Among the above-mentioned branches, the *sKar-rtsis* is the basis of the traditional calendars used in Tibet, Mongolia and Bhutan [for Tibetan astronomy, see Schuh (1973), Huang and Chen (1987) and Ôhashi (2000a)].

9.2.2. Tibetan astronomy and India

The Tibetan *Tripitaka,* which is a collection of Tibetan translations of Buddhist works, includes some texts which give astronomical information. One of them is a Tibetan translation of the *Śārdūlakarṇa-avadāna,* which is a Buddhist work in which early Indian astronomy and astrology of the *Vedāṅga* period are mentioned. There is also a Tibetan translation of an early Indian astrological text ascribed to Sage Garga. However, the most important texts in this collection, from an astronomical point of view, are the Tibetan translation of the *Kālacakra-tantra* and related texts.

Tha *Kālacakra* astronomy, on which the *sKar-rtsis* is based, is the system of astronomy mentioned in the *Kālacakra-tantra*, an esoteric Buddhist text, and its commentary *Vimalaprabhā*, etc. The *Kālacakra-tantra* was originally written in Sanskrit, and was translated into Tibetan and Mongolian. [For the Sanskrit text of the *Kālacakra-tantra*, see Banerjee (1985). For the Sanskrit, Tibetan and Mongolian texts of the *Kālacakra-tantra*, see Raghu Vira and Lokesh Chandra (1966). For the Sanskrit text of the *Vimalaprabhā*, see Upadhyaya (1986).]

According to the commentary *Vimalaprabhā*, there was the original text or *Mūla-tantra*, where the *Siddhānta* system of astronomy was explained, and the text on which it comments is the abridged text or *Laghu-tantra*, where the *Karaṇa* system of astronomy is explained. The *Mūla-tantra* is not extant, and it is difficult to say whether it actually existed as a whole or not, but some fragments are quoted in the *Vimalaprabhā*. The *Siddhānta* system of astronomy is called *grub-rtsis* in Tibetan, and the *Karaṇa* system is called *byed-rtsis*. In Tibetan astronomy, these two systems are basically the same, and only the lengths of a year and a month are different. In the *Siddhānta* system, one sidereal year = 365.270645 days, and one synodic month = 29.530587 days. In the *Karaṇa* system, a sidereal year = 365.258675 days, while a synodic month = 29.530556 days. In the Tibetan calendar, there are two intercalary months for 65 ordinary months. This is harmonious with the *grub-rtsis* system, but not with the *byed-rtsis* system. The *grub-rtsis* is usually followed now.

The *Kālacakra-tantra* consists of five chapters, and the first chapter entitled "Lokadhātu-paṭala" (chapter of the parts of the world) contains a detailed description of mathematical astronomy. According to my study, this system of astronomy was produced in the eleventh century AD in India, most probably in east India. The traditional story of the origin of the *Kālacakra-tantra* is that it was taught by Buddha in Dhānyakaṭaka (now Amaravati in Andhra Pradesh) and was brought to Śambhala, which is said to be in the north of the Śītā river. So, some people thought that it was actually produced in Central Asia. However, the annual variation of the length of daytime given in the *Kālacakra-tantra* is more or less similar to that of the *Vedāṅga* astronomy, and fits to the actual variation in north India. So, it is difficult to think that it was produced in Central Asia. The system must have been based on the Ārdharātrika school of Hindu astronomy, which was popular in east India at that time, because astronomical constants used in the *Kālacakra* astronomy are similar to those of the Ārdharātrika school. The *Kālacakra* astronomy uses AD 1027 as the epoch, and this year is a kind of the initial year of Tibetan calendars. So, the text must have been composed around this year. The *Kālacakra-tantra* mentions the year of Hijra with 2 years' error. The actual year of Hijra is AD 622, but the year given in the *Kālacakra-tantra* corresponds to AD 624. There were some people who tried to argue that the original epoch of this system was not AD 1027, in order to explain this error. However, its epoch should be AD 1027 from the beginning of its composition because the system gives the correct position of planets only when its epoch is AD 1027. From the above considerations, I suppose that the system of astronomy in the *Kālacakra-tantra* was produced in the first half of the eleventh century AD in east India (for details, see Ôhashi, 2000a).

According to my study, the error of the year of Hijra is due to the difference between the north Indian and south Indian systems of 60-year Jovian cycle (*bṛhaspati-cakra*). These systems differed by 2 years at that time. At the time of the beginning of the eleventh century, the initial year of the north Indian cycle was AD 1025, while that of the south Indian cycle was AD 1027. The Jovian cycle of the *Kālacakra-tantra* itself is based on the south Indian system, and AD 1027 is used as the initial year. However, the information of Hijra based on the north Indian system must have wrongly been incorporated there, which produced 2 year's error (for details, see Ôhashi, 2000a).

9.2.3. Historical development of Tibetan astronomy

From about the twelfth century AD, the *Kālacakra* calendar has been followed in Tibet. In the fourteenth century, a comprehensive treatise of *Kālacakra* astronomy entitled *mKhas-pa-dga'-byed* (AD 1326) was composed by a Tibetan encyclopaedic scholar Bu-ston Rin-chen-grub (AD 1290–1364). Then, lHun-grub-rgya-mtsho wrote the *Pad-dkar-źal-luṅ* (AD 1447), and his system was developed as the Phug school, which is the most popular school of Tibetan calendar. The most famous work of this school is the *Vaiḍūrya dkar-po* (AD 1683) written by Saṅs-rgyas-rgya-mtsho, who was the regent of the fifth Dalai Lama.

Another famous work of this school is the *Ñin-byed-snaṅ-ba* (AD 1714) of Dharmaśrī. There is another school, mTshur-phu, whose fundamental text is the Ñer-mkho-bum-bzan (AD 1732) written by Karma Ṅes-legs-bstan-'dzin (for details, see Ôhashi, 2000a).

9.2.4. The system of Tibetan calendar

I shall explain the system of Tibetan calendar (*skar-rtsis*) just briefly. In this system, the mean motions of the planets are calculated first, and then the equation of centre and the epicyclic correction are applied. The operation of the equation of centre (Sanskrit: *manda-karman*) is called *dal-ba'i-las*, and the operation of the epicyclic correction (Sanskrit: *śīghra-karman*) is called *myur-ba'i-las* in Tibetan.

Three kinds of days are used, namely, *ñin-źag* (Sanskrit: *sāvana-dina*), *tses-źag* (Sanskrit: *tithi*) and *khyim-źag* (Sanskrit: *saura-dina*). A *ñin-źag* is a civil day measured from sunrise to sunrise. A mean *tses-źag* is a 30th part of a synodic month. The equation of centre of the Moon and that of the Sun are applied so as to make a *tses-zag* correspond to the change of 12° of the longitudinal difference between the Sun and Moon. A mean *khyim-zag* is a 360th part of a year.

The ecliptic is divided into 12 *khyim* (Sanskrit: *rāśi*) or zodiacal signs, and also into 27 *rgyu-skar* (Sanskrit: *nakṣatra*) or lunar mansions. Each day as well as *rgyu-skar* is divided into 60 *chu-tsod* (Sanskrit: *nāḍī*). One *chu-tsod* is further divided into 60 *chu-sraṅ* (Sanskrit: *vināḍī*). One *chu-sraṅ* is divided into six *dbugs* (Sanskrit: *prāṇa*).

After the calculation of the mean motion of the Sun, the equation of centre is given for each zodiacal sign. The ecliptic is divided into the first half (*rim-pa*) and the second half (*rim-min*), and each of the two halves is further divided into the first part (*sṅa-rkaṅ*) and the second part (*phyi-rkaṅ*). For the correction of the equation of centre, the variable called *dal-rkaṅ* (slow step) is given for each zodiacal sign. The *dal-rkaṅ* is the difference between the mean motion and the true motion of the Sun during one zodiacal sign's movement of the mean Sun in terms of *chu-tsod*.

One anomalistic month is roughly considered to be 28 *tses-źag*, and a correction is applied to the length of each *tses-źag*. This correction is called *zla-ba'i-myur-rkaṅ* (fast step of the moon). The word *myur* (fast) shows that it was considered to be the epicyclic correction rather than the equation of centre. Since the period of 28 *tses-źag* is a little longer than the actual anomalistic month, a special correction is also applied so as to diminish the period of 28 *tses-źag* at the rate of one *tses-źag* per 3780 *tses-źag*. Then a variable which is added to or subtracted from the length of *tses-źag* is given for each *tses-źag*.

Five planets are divided into *źi-ba'i-gza'* which correspond to the inner planets, and *drag-gza'* which correspond to the outer planets. The inner planets are Mercury (*lhag-pa*) and Venus (*pa-saṅs*). The outer planets are Mars (*mig-dmar*), Jupiter (*phur-bu*) and Saturn (*spen-pa*). A planet's sidereal period is called *dkyil-'khor*.

In the case of the inner planets, the mean motion of the Sun is obtained first, and in the case of the outer planets, the mean daily motion of each planet is obtained first. They are corrected by the *dal-rkaṅ* (slow step) which is given for each zodiacal sign, just like the case of the Sun. Then, the "parameter of step" (*rkaṅ-'dzin*) is used to count steps of epicyclic correction. The period of 60 *chu-tsod*'s change of the "parameter of step" is considered to be one step. Sixty *chu-tsod* correspond to one lunar mansion, and there are 27 lunar mansions, so one cycle of the "parameter of step" consists of 1620 *chu-tsod*. In the case of the inner planets, the daily motion of the "parameter of step" is the daily motion of "parameter of fast step" (*myur-rkaṅ-'dzin*) minus the true daily motion of the Sun. The "parameter of fast step" is, in fact, the daily motion of the planet's revolution. In the case of the outer planets, daily motion of the "parameter of step" is the mean daily motion of the Sun minus the daily motion of the planet which has been corrected by its equation of centre. The variable of the epicyclic correction is given as *myur-rkaṅ* (fast step) for each step (for details, see Ôhashi, 2000a).

9.3. Indian Astronomy and Mainland South-East Asia

9.3.1. Introduction

South-East Asia is divided into two parts, namely, Mainland South-East Asia and Insular South-East Asia (also called Indo-Malay Archipelago). Mainland South-East Asia is further divided into two parts, one is Vietnam, where Chinese influence is larger than Indian influence, and the other includes Burma, Cambodia, Laos and Thailand, where Indian influence is larger. Malay Peninsula is a part of Mainland South-East Asia geographically, but is culturally closer to Insular South-East Asia. [For the calendars in Mainland South-East

Asia (except for Vietnam), see Eade (1989, 1995). For Burmese calendar, see Irwin (1909), de Silva (1914) and Htoon-Chan (1918). For Cambodian calendar, see Faraut (1910). For Lao calendar, see Phetsarath (1940) and Dupertuis (1981). And also, for Tai calendar in Yunnan, China, see Zhang and Chen (1981). For the calendars in Insular South-East Asia, de Casparis (1978) may be consulted.]

9.3.2. Traditional calendars

The traditional calendars of Burma, Cambodia, Laos, Thailand and Tai (or Dai in Chinese system of transliteration) people in Sipsongpanna (or Xishuang-banna in Chinese system of transliteration) in Yunnan province of China are basically based on Indian (Hindu) calendrical system, which is a luni-solar calendar, with certain simplifications. The length of a year used in most of these calendars is 365.25875 days. This is similar to the sidereal year of the Ārdharātrika school of Hindu astronomy. S.B. Dikshit already pointed out that the length of a year used in an astronomical work procured by a French envoy from the Ayutthaya dynasty of Siam (present Thailand) is the same as that of the *Sūrya-siddhānta* quoted in the *Pañca-siddhāntikā* (Dikshit 1981, p. 378). This *Sūrya-siddhānta* belongs to the Ārdharātrika school. There is also Chinese influence, notably the animal names of a 12-year cycle.

The main differences between the Indian (Hindu) traditional astronomy and the calendars in Mainland South-East Asia (except for Vietnam) are as follows. (The traditional calendar of Vietnam is based on Chinese system, which I shall not discuss here. For Vietnamese calendar, see Ôhashi, 2004b, 2005.)

(1) In Hindu traditional calendar, intercalary month is inserted when two successive new moons occur during which the Sun remains in the same zodiacal sign.

In Mainland South-East Asian calendars, a 19-year cycle is usually used for intercalation during which 7 intercalary months which consist of 30 days are inserted after the fixed month of a year. Actually, the 19-year cycle is not harmonious with the sidereal year which is used in Hindu and Mainland South-East Asian calendars, and I suspect that this 19-year cycle might have been introduced from China.

(2) In Hindu traditional calendar, 1 month is divided into 30 *tithi*s, which are the periods during which longitudinal dif-

ference between the Sun and Moon changes by 12°, and the number of the *tithi* at the beginning of a day (usually sunrise) becomes the name of the day. So, the number of days in a month is automatically determined.

In Mainland South-East Asian calendars, 29-day months and 30-day months are usually distributed alternately at the definite months of a year, and 11 intercalary days are distributed in 57 years at the fixed month of a year. Actually this method is slightly inexact.

One thing may be added here. Among Tai (or Thai) people, lunar months are named by serial number, and there are some variations of this method. This method is similar to the Chinese method, but is absent in Hindu traditional calendar. Particularly the method used by Tai people in Sipsong-panna (in China) is quite similar to an ancient variation of the Chinese method.

I suggest the following tentative hypothesis. The 19-year cycle and 57-year cycle of intercalation and the method of month reckoning using serial number were introduced from China (particularly the intercalation of the "Modified *Taichu* calendar" which was unofficially proposed in AD 143 in the Eastern (Later) Han Dynasty (AD 25–220)), and were modified after the introduction of Indian calendar (Ārdharātrika school) (for details, see Ôhashi (2002a), (2005), (2006)).

It may be mentioned here that the calendar used in the inscriptions of Champa, which was a kingdom which existed in present central and south Vietnam until the seventeenth century AD, was also based on Indian calendar.

9.3.3. Controversy regarding the Tai calendar in Yunnan, China

There was a controversy between Dong Yantang and Zhang Yong, both of whom are Chinese scholars, in the first half of the twentieth century regarding the origin of the calendar of Tai people in Yunnan province of China.

In 1938, Dong Yantang published a paper on the origin of the Tai calendar (Dong, 1938). In this paper, Dong Yantang argued that the Tai calendar is based on the Qin calendar of ancient China.

In 1939, Zhang Yong wrote a paper on the Tai calendar (Zhang 1939). Zhang Yong criticized Dong Yantang's paper, and concluded that the Tai calendar is based on Indian calendar. Zhang Yong pointed out some reasons. For example, the Tai calendar uses half months just like Indian calendar, and the Tai calendar divides a year into three seasons just like Indian calendar. These reasons are justified.

Zhang Yong mentioned other reasons also, and tried to show that the Tai calendar is completely based on Indian calendar without Chinese influence.

I think that the Tai calendar is basically based on Indian calendars, but there may be some Chinese influence also, as I mentioned in the previous section.

9.3.4. Historical development in Burma and Sipsongpanna (Yunnan)
Let us see the historical development of South-East Asian calendars briefly. According to Zhang Gongjin and Chen Jiujin (Zhang and Chen, 1981), the texts entitled *Suding* and *Suliya* were followed by the Tai (or Dai) people (in Sipsong-panna in Yunnan province, China) for making calendars before AD 1931, but the text entitled *Xitan* has been followed since AD 1931 or so. Zhang and Chen also say that the *Suding* and *Suliya* do not follow the 19-year cycle of intercalation strictly, but the *Xitan* follows the 19-year cycle of intercalation, and that the calendrical luni-solar year of the *Xitan* practically keeps pace with the tropical year, although the solar new year's day is calculated by the sidereal year as before. I compared their astronomical constants with Indian constants, and found that the *Suding* and *Suliya* follow the Ārdharātrika school, while the *Xitan* follows the Saura school (see Ôhashi 2002a).

According to Irwin (1909), the "*Makaranta*" (there are two methods of epoch: AD 638 and AD 1436), which probably follows the "original *Surya Siddhanta*" (i.e. Ārdharātrika school), was followed in Burma originally, but afterwards the "*Thandeikta*" (epoch: AD 1738), which chiefly follows the "present *Surya Siddhanta*" (i.e. Saura school), was used. Irwin writes that the "*Thandeikta*" is said to have been composed in about AD 1738 or AD 1838, and that the present *Sūrya-siddhānta* is said to have been introduced into Amarapura, Burma, in AD 1786, and translated into Burmese after about 50 years. Irwin also tells that the 19-year cycle of intercalation was followed in the "*Makaranta*", but was not strictly followed in the "*Thandeikta*". We should note that the Burmese "*Makaranta*" is probably different from the well-known Indian Sanskrit astronomical table *Makaranda-sāraṇī* (AD 1478) of Makaranda, which follows the Saura school.

Here, the treatment of the 19-year cycle of intercalation is just the opposite between the Tai calendar (Yunnan, China) and Burmese calendar. More details about the calendar reform in these regions should be investigated further.

9.3.5. Traditional astronomy and modern astronomy in Thailand

In the mid-fourteenth century AD, Lithai (King Ruang) of the Sukhothai dynasty wrote the *Traiphum (Three Worlds)* (Reynolds and Reynolds, 1982). The Thai word *traiphum* corresponds to *trai-bhūmi* in Sanskrit. This is a celebrated text of traditional Thai cosmology, which is based on Buddhist cosmology. Some information about traditional astronomy and calendar, etc., is also found there.

In 1685, King Narai of the Ayutthaya dynasty observed lunar eclipse with a telescope with the Jesuits sent by the French King (see Tachard 1688/1981, pp. 230–246; Choisy; de 1993, p. 215). King Narai requested to send mathematicians from France, and planned to build observatories at "Louvo" (present Lop Buri) and "Siam" (present Ayutthaya). This event may be considered to be the beginning of modern astronomy in Thailand.

In 1687, a French envoy Simon de la Loubère visited the Ayutthaya dynasty and procured an astronomical work entitled "*Souriat*". This work was later analysed by a celebrated astronomer Jean Dominique Cassini (see Loubere 1693/1969, pp. 64–67, 186–199, etc., and Bailly 1787, pp. 3–30). This is the earliest information of India-based astronomy reaching Europe. S.B. Dikshit pointed out that the length of a year used there is the same as that of the *Sūrya-siddhānta* quoted in the *Pañca-siddhāntikā* of Varāhamihira (Dikshit, 1981, p. 378). This is one of the evidences that the Ārdharātrika school of Hindu astronomy was popular in South-East Asia.

In the nineteenth century, King Mongkut (Rama IV) (reign 1851–68) studied European astronomy as well as Thai traditional astronomy. He ordered to construct his own observatory near Phetburi. He predicted the total solar eclipse of 1868. According to the *Dynastic Chronicle*, the King calculated the eclipse "by using the old astrological texts of Siamese and Mon, as well as many old American and English texts". According to Thongchai, the Mon text used by the King is the "*Saram*", one of the two Mon treatises for planetary calculation known in Siam, and the other text more conventionally used by astrologers at that time was "*Suriyayat*" [see Thiphaakorawong, vol. 2 (1966 of 1965–1974), pp. 532–539, Cook (1992) and Thongchai (1994), chapter 2]. This was a symbolic event in the course of the introduction of modern astronomy into Thailand.

It may be mentioned here that there are several inscriptions with calendrical data in Thailand, and are also important sources of Thai astronomy (Eade, 1996).

There was an independent kingdom Lanna in North Thailand from the end of the thirteenth century to the beginning of the twentieth century. The people of Lanna had their own astronomy, which was based on Indian astronomy. [See Soonthornthum (1998). For Northern Thai calendar, see Davis (1976).]

9.3.6. Burmese constellations

Burma has a special system of constellations, and there are three beautiful star maps drawn on the ceilings of corridors of the Kyauktawgyi Pagoda in Amarapura (near Mandalay, Burma). The figures (Figure 18) are the star maps photographed by me in 1984.

The Kyauktawgyi Pagoda was built in 1847 by King Pagan (reign 1846–52) on the model of the Ananda Temple in Pagan (U Lu Pe Win, 1960, p. 5). There is a pioneer study of Burmese constellations by Francis Buchanan (1799) (also see Nishiyama, 1997). Although Burmese constellations include Indian constellations, there are many Burmese unique constellations, and it is very important to investigate Burmese original contribution.

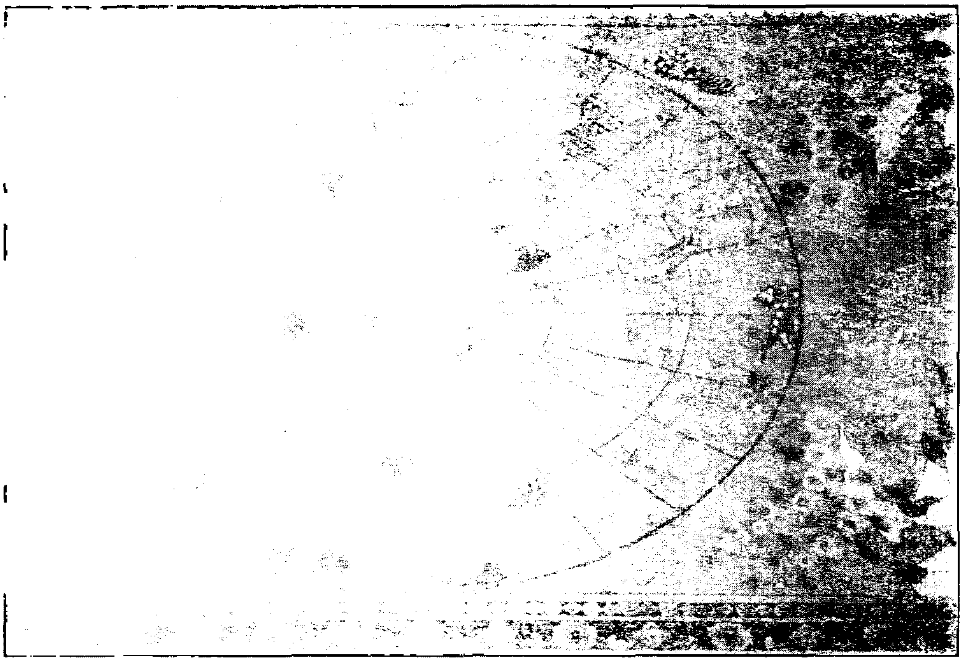
9.4. Indian Astronomy and East Asia

9.4.1. Introduction

Chinese astronomy and Indian astronomy are originally independent. According to my study, the earliest information of the Indian astronomy reached China at the time of the Later Han (Eastern Han) dynasty (AD 25–AD 220).

From the Sanguo (three kingdoms) period (AD 220–AD 265), some Buddhist works, where information of Indian astronomy was included, were translated into Chinese.

At the time of the Tang dynasty (AD 618–AD 907), some detailed monographs of Indian astronomy and astrology were composed in



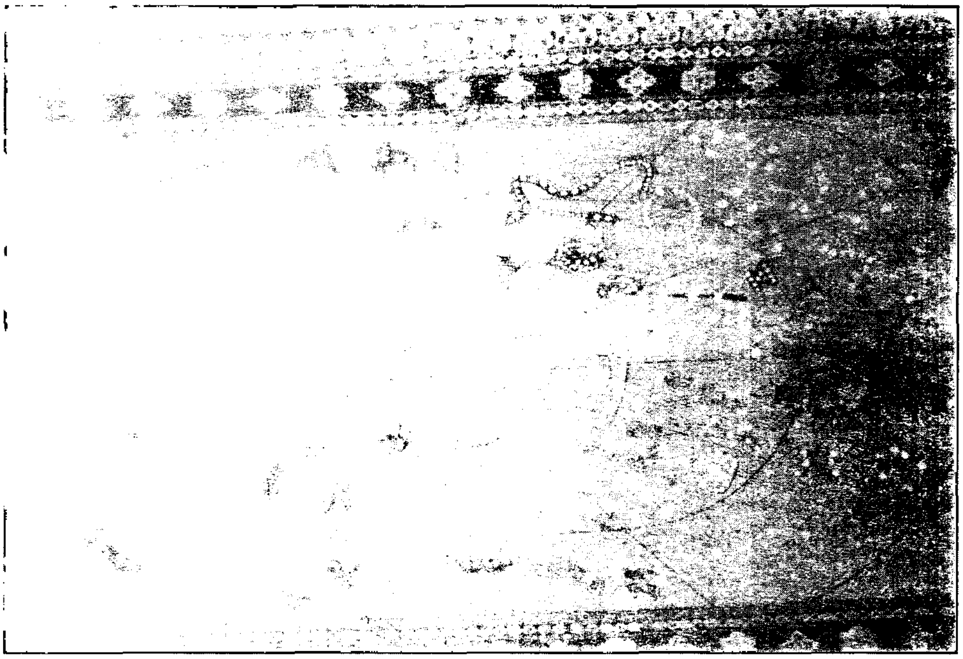


Fig. 18a&b: Star maps in the Kyauktawgyi Pagoda at Amarapura (near Mandalay, Burma).

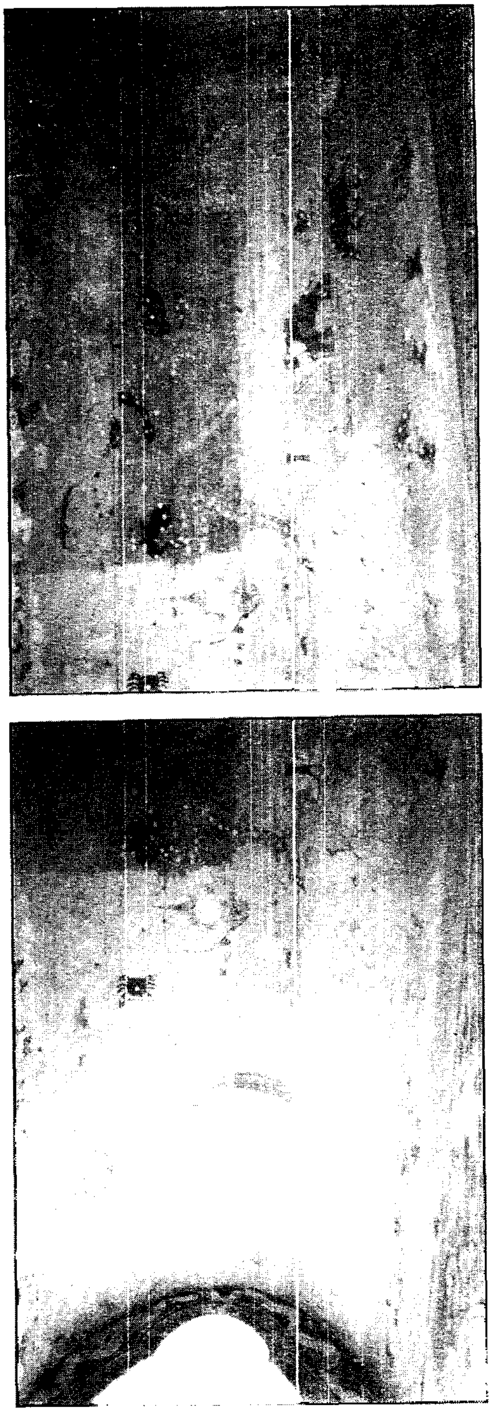


Fig. 18c: Star maps in the Kyauktawgyi Pagoda at Amarapura (near Mandalay, Burma).

China. There were some astronomers who were well versed in both Chinese astronomy and Indian astronomy. Yixing was one of them.

9.4.2. Indian astronomy in Later Han dynasty

At the time of the Former Han (Western Han) dynasty (206 BC–AD 23), there was no apparent foreign influence on Chinese astronomy. As Buddhism was gradually being introduced into China at the beginning of the Later Han dynasty, there was a possibility that certain Indian culture including astronomy was also introduced into China.

According to my study, some fragmental information about Indian calendar reached China at the time of the Later Han dynasty (see Ôhashi, 1999, 2007). There are three reasons for my view.

(a) When the Later Han *Sifen* calendar was compiled in AD 85, its first month was proposed to be large, although it was finally rejected. In the Chinese traditional calendar, the first month should be small, because the first new moon occurs at the initial point of time, and the second new moon is included in the first day of the next month. In contrast, the first month of the Indian traditional calendar is large, because the first new moon occurs at the initial point of time, and the second new moon is included in the last day of the same month. I suspect that the rejected proposal of the Later Han *Sifen* calendar might have been influenced by the Indian method.

(b) The Later Han *Sifen* calendar has special days called "*mori*" and "*mieri*", which did not exist in the Former Han dynasty. If 1 year is divided into 360 parts and 1 day is included within a part, the day is called "*mori*". If the end of a day coincides with a boundary of the parts, the day is called "*mieri*". These days are of no use in Chinese traditional calendars, but are similar to certain concept of Indian traditional calendars, such as the method of intercalation in the *Artha-śāstra* [see the section of Yixing below, and also, for details, see Ôhashi (2001)].

(c) When the date of the half moon and full moon was calculated in the Later Han *Sifen* calendar, daybreak was considered to be the beginning of a day, although midnight was basically considered to be the beginning of a day in China.

In Indian traditional calendars, sunrise is usually the beginning of a day. Therefore, the use of daybreak might have connection with the Indian method.

For these three reasons, I suspect that certain information of Indian calendar reached China. However, the information must have been fragmental, and did not influence Chinese calendar much.

9.4.3. Indian astronomy in Chinese Buddhist texts

9.4.3.1. The Madengqie-jing: At the time of Sanguo (three kingdoms) period (mid-third century AD), a Buddhist text called *Śārdūlakarṇa-avadāna* in Sanskrit was translated into Chinese by Zhu Lüyan and Zhi Qian as the *Madengqie-jing*. This is the first Chinese text where Indian astronomy and astrology are explicitly mentioned. This text explains the lunar mansions and astrology based on them at length, and also mentions some calendrical information. (The Sanskrit text of the *Śārdūlakarṇa-avadāna* is included in Vaidya, 1959.)

The astronomical system of the *Śārdūlakarṇa-avadāna* belongs to the stage of the *Vedāṅga* astronomy. The description of astrology in the *Śārdūlakarṇa-avadāna* is also based on Indian traditional system.

The original Sanskrit version of the *Śārdūlakarṇa-avadāna* has the description of the annual variation of the gnomon shadow, which is similar to that of the *Vedāṅga* astronomy. The Chinese version *Madengqie-jing* also has the description of the annual variation of the gnomon shadow, but it is different from the Sanskrit original. S. Shinjō, a pioneer of the study of the history of Eastern astronomy, pointed out that the description of the *Madengqie-jing* is based on the data around 43°N, and that the data might have been incorporated in Central Asia (Shinjō, 1928, pp. 217–218).

The *Śārdūlakarṇa-avadāna* was also translated into Chinese as the *Shetoujian-taizi ershiba-xiu jing* by Zhu Fahu at the time of Xi-Jin (Western Jin) dynasty (AD 265–316).

9.4.3.2. The Daji-jing: The *Daji-jing* (or *Dafangdeng-dajijing*), is a collection of *Mahāyāna* texts in Chinese. The *Yuecang-fen* (one text in the *Daji-jing*), which was translated by Narendrayaśa in AD 566, is the earliest Chinese text where zodiacal signs are mentioned.

The *Ricang-fen* (another text in the *Daji-jing*), which was translated by Narendrayaśa in AD 586, also mentions the zodiacal signs. It is interesting to note that the annual variation of the length of daytime and that of the gnomon shadow, which are similar to those of the *Vedāṅga* astronomy, are mentioned there, but the position of the Sun corresponding to their data is given with reference to zodiacal signs. This fact means that the system of the *Vedāṅga* astronomy was still in use when Greek horoscopy reached India. According to my study, the *Vedāṅga* astronomy was widely used in India from sometime during the sixth and the fourth centuries BC to sometime during the third and the fifth centuries AD or so, and was mixed with the system of zodiacal signs which was introduced into India along with Greek horoscopy in the second(?) or third century AD or so (see Ôhashi, 2002b).

The *Ricang-fen* of the *Daji-jing* is, therefore, an important source material to study the history of Indian astronomy also. It says that the length of the daytime and night-time is 15 *shi* (which corresponds to *muhūrta* or 1/30 of a day) in the months of Scorpio and Taurus, that of the daytime is 12 *shi* (minimum) and nighttime is 18 *shi* (maximum) in the month of Aquarius, and that of the daytime is 18 *shi* and night-time is 12 *shi* in the month of Leo. The length of daytime and night-time changes linearly. The above-mentioned data look strange at first sight. The relationship between the length of daytime and night-time and the sign of zodiac differs by 1. For example, the above data tell that the vernal equinox occurs in the month of Taurus, and not in the month of Aries. The only possible explanation of this difference is that the data of the length of daytime and night-time are for the beginning of the month, and the sign of the zodiac is for the end of the month. The linear function of the length of daytime and nighttime is the same as that of the *Vedāṅga* astronomy, which is based on the observational data in north India. The *Ricang-fen* also gives the length of the midday gnomon shadow, which is basically the same as that of the *Vedāṅga* astronomy, which is also based on the observational data in north India. Here, we can see that the *Vedāṅga* astronomy was still widely used even after Greek horoscopy was introduced into India (see Ôhashi, 2002b).

9.4.4. Indian astronomy during the Tang dynasty

9.4.4.1. The Jiuzhi-li: One system of the Hindu Classical Astronomy was introduced into China, and was recorded in Chinese as the *Jiuzhi-li* (AD 718) of Qutan Xida, which is included in his *(Da-) Tang Kaiyuan-*

zhanjing. The author Qutan Xida (probably Chinese transliteration of his Indian name Gotama Siddha) belonged to a family of Indian astronomers in China, and was the director of the national observatory. In the title of the *Jiuzhi-li*, "*jiuzhi*" corresponds to the Sanskrit word "*nava-graha*" (nine planets, i.e. Sun, Moon, five planets, "Rahu" (ascending node of the lunar orbit), and "Ketu" (usually considered to be the descending node of the lunar orbit)), and "*li*" means calendar. This work explains the method to calculate the Sun's longitude, the Moon's longitude, solar and lunar eclipses, etc. This text also contains a sine table. The work also tells that Indian numeral is mentioned there, but the actual shape of the figure has not come down to its extant texts.

K. Yabuuti pointed out that some astronomical constants of the *Jiuzhi-li* are similar to the *Sūrya-siddhānta* summarized in the *Pañca-siddhāntikā* (i.e. *Ārdharātrika* school of Classical Hindu Astronomy). [See Yabuuti (1944/1989) and (1979). Also see Yano (1979).]

It is interesting to note that the traditional calendars of mainland South-East Asia (except for Vietnam) and also the classical astronomy of Tibet are also related to the *Ārdharātrika* school. It may be that the *Ārdharātrika* school was quite popular among Buddhists.

It should be noted that the *Jiuzhi-li* has never been used as an official calendar in China, because the tradition of Chinese original astronomy was so strong.

9.4.4.2. Yixing: There was also a famous monk astronomer Yixing (AD 683–727). Yixing had certain knowledge of Indian astronomy. For example, he mentioned Indian zodiac in his *Dayan* calendar. However, he made his *Dayan* calendar in Chinese traditional way. There is only one thing in which I suspect Indian influence in his *Dayan* calendar. It is the change of the meaning of "*mieri*".

Yixing explained the method to calculate the "*mieri*" as follows.

> If the *xiaoyu* (time in terms of 1/3040 day) of the mean new moon is less than *shuoxufen* (=1427), subtract the *xiaoyu* from the *tongfa* (=3040), and multiply the result by 30, and subtract the result from *miefa* (=91200). Divide the result by *shuoxufen.* The result is the number of days. Count the days from the mean new moon day and take the day after the resultant day. It is the *mieri.*

The meaning of this "*mieri*" is as follows. Let a synodic month be divided into 30 parts. Then, sometimes a part is included within a day. This kind of day is the "*mieri*" defined by Yixing.

This "*mieri*" of Yixing is similar to the "omitted *tithi*" (*kṣaya-tithi*) in Indian calendars. In the *Vedāṅga* astronomy, a *tithi* was a 1/30 part of a synodic month, where the equation of centre was not known. In the Hindu Classical Astronomy, a *tithi* is a period of time during which the longitudinal difference of the Sun and Moon changes by 12°. If a *tithi* is included within a day, the *tithi* is called "omitted *tithi*".

The significance of Yixing's definition is that when the sum of the "*mori*" (a day which is included within a segment of 1/360 of a tropical year) and "*mieri*" grows up to 30, one intercalary month is produced. This way of thinking is similar to certain description in Indian classics, such as the *Artha-śāstra.* Similar description is also found in a Chinese version of Buddhist text *Lishi-apitan-lun,* translated by Zhendi at the middle of the sixth century AD.

I suspect that Yixing knew this Indian method, and changed the meaning of the "*mieri*" in order to make it meaningful in Indian calendrical context (see Ôhashi, 2001).

9.4.4.3. Other texts in the Tang dynasty: Besides the above-mentioned texts, the *Suyao-jing* is also famous. In the title, "*su*" means lunar mansions, "*yao*" means planets, and "*jing*" means sutra. It is an astrological work which was compiled by Amoghavajra in the middle of the eighth century AD. It is based on the Indian horoscopic astrology.

There is also an astrological work with planetary ephemeredes entitled *Qiyao-rangzaijue,* compilede by Jin Juzha, who is said to be a Brahmana priest from western India, in the early ninth century or so. In the title, "*qiyao*" means seven planets, and "*rangzaijue*" means formulae to avoid disasters (caused by planets). This work is a kind of mixture of Indian astrology and Chinese astronomy. It includes the ephemeredes of five planets, "Rāhu" (ascending node of the lunar orbit), "Ketu", and the Sun. In Indian astronomy, "Ketu" usually mean the descending node, or comets. However, "Ketu" in the *Qiyao-rangzaijue* is, according to the study of M. Yano, the apogee of the lunar orbit. This is a special feature of this work (see Yano, 1986).

9.4.5. Concluding remarks on the Indian astronomy in China

We have seen some records of Indian astronomy in Chinese sources. We have to keep in mind that Indian influence on Chinese astronomy was very small. The tradition of Chinese original astronomy was very strong, and it seldom accepted foreign influence. However, we can find some exceptional Indian influences in Chinese sources, and these exceptions draw attention to researchers. I request the readers to understand this point. [For the development of Chinese original astronomy, see, for example, Ôhashi (2008a).]

10. CONCLUSION

The tradition of Indian astronomy, which is one of the biggest traditions of astronomy in the world, has produced plenty of source materials, which form a mine of further investigations. Moreover, the Indian traditional astronomy is still living, and its relationship with daily life, etc., can be learned directly.

At present, only a very few people are studying the history of Indian astronomy. However, more research work is needed, and will definitely be fruitful. The research work should, of course, be scientific. It should be based on original sources. So, the deep knowledge of classical astronomy as well as the ability of classical languages, such as Sanskrit, Persian, etc., is needed. As different traditions of astronomy are related to each other, the researchers should study different traditions impartially. And also, researchers belonging to different traditions should collaborate.

I hope some readers of my paper will become future researchers, and they will make my paper outdated by their own research works!

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