Indian astronomical tables – a study with special reference to *Makarandasārinī*

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Among the astronomical tables belonging to different schools of astronomy (*pakṣas*), *Makarandasāriṇī* (*MKS*) is the prominent and most popular text. This article highlights the important aspects of *MKS* like making of almanacs (*Pañcāṅga*), finding the equation of centre, equation of conjunction, moments of solar ingress into zodiacal signs and 27 lunar mansions (*nakṣatra*), and so on. A detailed study of the work done on *MKS* and further scope of research are also discussed.

Keywords: Almanac, astronomical tables, lunar mansions, *Makarandasāriṇī*, solar ingress.

THERE are various astronomical tables recorded in different forms in Sanskrit in a variety of ways for more than 2000 years, in the form of ancient hymns, mathematical functions, numeric array tables used to generate calendars and ephemeris[1].

The annual Indian calendrical-cum-astronomical almanacs are compiled with the help of traditional astronomical tables. These tables are differently called as *Sāriṇī*, *Padakam*, *Koṣṭhaka* and *Vākya*. There are a large number of tables belonging to different schools (*pakṣa*) like Saura, Ārya, Brāhma and Gaṇeśa. These schools of astronomy are conformed to the parameters and procedures of *Sūryasiddhānta* of Āryabhata I (476 CE), *Brahmasphuṭa siddhānta* of Brahmagupta (628 CE) and *Grahalāghava* of Gaṇeśa Daivajña (1520 CE).

The major tables of the *saurapakṣa* are (i) *Makarandasāriṇī* by Makaranda (1478 CE), (ii) *Gaṇakānanda* by Sūryacārya, son of Bālāditya (16 March 1447), (iii) *Rāmavinoda* by Rāmacandra (1590 CE), (iv) *Ravisiddhāntamañjarī* by Mathurānātha Śukla (1609 CE), (v) *Pratibhāgī* and (vi) *Tyāgarti* manuscripts. The *Gaṇakānanda* of Sūrya is a *karaṇa* text (handbook) popular mainly in Andhra Pradesh and Karnataka. *Pratibhāgī* and *Tyāgarti* tables are used by the *saurapakṣa* followers in Karnataka[2].

The important tables belonging to *Brāhmpakṣa* are *Brahmatulyasārinī* (epoch 1183 CE), *Mahādevī* by Mahādeva (1316 CE), *Jagadbhūṣaṇa* by Haridatta (1638 CE) and *Khecaradīpikā* by Kalyāṇa (1649 CE).

Tithichintāmaṇi (1525 CE) and *Grahalāghavasārinī* (epoch, 18 March 1520 CE) are the tables based on *Grahalāghava* of Gaṇeśa Daivajña. Among the practitioners of the Gaṇeśa *pakṣa* based on Gaṇeśa Daivajña's *Grahalāghava* (GL), the astronomical table called *Tithichintāmaṇi* is most popular. It involves different tables for the calculation of the ending moments of lunar day (*tithi*), lunar mansion (*nakṣatra*), etc. Once an almanac maker obtains the required annual constants for *tithi*, *nakṣatra*, etc. for the beginning of a solar year, the rest of the work is simple and rather mechanical. One needs to add or subtract the related elements, using the tables in the text, for successive days[2].

There are tables belonging to other schools as well. In fact, the *vākya* tables used mainly in Kerala and Tamil Nadu composed by the legendary Vararuci comprise Sanskrit sentences which are numerical chronograms based on the *kaṭapayādi* system. Unlike the other Indian astronomical tables, the *vākya* system comprises simple Sanskrit sentences in which each letter represents a number following the *katapayādi* system. The significant achievement of the *vākya* system is that true position of each planet is given in simple sentences. The *vākya* system prevents the elaborated procedures of repeatedly determining and applying the equation of centre and equation of conjunction to obtain the true position. Interestingly, this system of astronomical tables scores over other types of Indian astronomical tables. The number represented by these sentences (*vākyas*) gives directly the true positions of the heavenly bodies. The *vākya* system is based on *Āryapakṣa* by Āryabhaṭa I.

Indian astronomical tables may also be classified into three types based on their arrangement as (i) mean linear, (ii) true linear and (iii) cyclic. In the mean linear arrangement, mean motion tables are accompanied by the tables of equations. *Grahalāghavasārinī*, *Ravisiddhāntamañjarī*, *Makarandasāriṇī* and *Brahmatulyasārinī* are mean linear-type tables. In true linear mean motion tables are accompanied by the true longitude tables, whereas in the cyclic arrangement true longitudes are given for several years of the goal-year periods. *Mahādevī*, *Rāmavinoda* and *Khecaradīpikā* are examples of true linear tables. *Jagadbhūṣaṇa* by Haridatta is a cyclic table[2].

Makarandasāriṇī

Makarandasāriṇī (*MKS*) is the most popular Sanskrit text containing a large number of astronomical tables. The major tables in *MKS* are for (i) the ending moments of lunar

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month (*tithi*), lunar mansion (*nakṣatra*), etc.; (ii) mean longitudes of the Sun, Moon and the five star planets (*tārāgrahas*), namely Mars, Mercury, Jupiter, Venus and Saturn; (iii) equation of the centre (*mandapala*) of each of the heavenly bodies; (iv) equation of conjunction of the five star planets; (v) moments of solar ingress (*sankrānti*) into zodiacal signs and 27 *nakṣatra*; (vi) the Sun's declination, (vii) latitude of the Moon, and (viii) angular diameters of the Sun, Moon and the Earth's shadow cone for computing lunar and solar eclipses[3–5].

David Pingree has provided a detailed description of *MKS* with his learned critical comments, in his remarkably useful and intense catalogues. In order to elucidate the procedures of *MKS*, the famous commentator Viśvanātha Daivajña composed the useful commentary with a large number of examples in śālivahana śaka 1540 (AD 1618). Prior to that, Divākara had composed the explanatory commentary. In śaka 1688 (AD 1766) Gokulanātha Daivajña wrote the upapatti (derivations and rationales) for *MKS*. For further elucidation of the text, Daivajña Nārayana Śarmā published his *Makaranda Prakāśa* in śaka 1831 (AD 1909). Achārya Ramajanma Mishra and Gangādhara Tandan have written commentaries on *MKS* in Hindi[6–8]. According to Pingree, there are commentaries and derivative texts by Harikarṇa of Hisāranagara (AD 1610), Puruṣottama (AD 1613), Kṛpārāma Miśra (AD 1809) of Ahmadabad, Jīvanātha of Patna (AD 1823) and Nīlāmbara Jhā of Koilakh, Mithilā (19th century). They were also published many times in the 19th century. This shows how popular *MKS* is among the almanac makers, especially the followers of the *saurapakṣa*[9,10].

Special features of *MKS*

Compared to other Indian astronomical tables, *MKS* has some unique and special features. Makaranda has made quite a few innovations in the procedures for planetary positions and eclipses.

The equation of centre (Mandaphala) and equation of conjunction (śīghraphala)

In Indian classical procedures for the true positions of heavenly bodies, two important equations are applied to the mean positions. These are: (i) equation of centre and (ii) equation of conjunction. The equation of centre is applied as the orbit of a heavenly body is eccentric and its motion is not uniform. The equation of conjunction corresponds to transforming the heliocentric true position to the geocentric true position of the five star planets. However, in the case of the Sun and the Moon only one correction, i.e. equation of centre is applied. In *MKS* a detailed procedure to calculate the equation of centre for the Sun, Moon and the five star planets is explained. For obtaining the true position of the star planets (*tāragrahas*), in the other systems the *manda* and *śīghra* equations are generally applied in four stages. However, this procedure is reduced to only three significant stages, namely (i) half *śīghra*, (ii) *manda* and (iii) full *śīghra*. In this case the usual half *manda* and full *manda* corrections are combined in a mathematically justified manner[11].

Solar ingress

Solar ingress or *sankrānti* is the instant when the Sun enters a sidereal zodiac sign (*rāśi*), viz. Aries (*Meṣa*), Tauras (*Vṛṣabha*), etc. In Indian society, solar ingress plays an important socio-religious role. Also in the Hindu calendar, religious festivals are celebrated according to the solar calendar (*sauramāna*) or lunar calendar (*cāndramāna*). The solar months are generally named after the Sun's entry into the sidereal zodiac signs such as Aries, Taurus, etc. More generally, the names of the solar months are same as the lunar months, i.e. *Caitra*, *Vaiśākha*, etc. These names are prefixed as *saura* to distinguish them from lunar. The solar year commences with *saura Caitra* around 14 April and ends with *saura Vaiśākha*. The names of the solar months are ambiguous, followed differently in different regions of India. Therefore, it is better to name them after zodiac signs occupied by the Sun[4]. The durations of the Sun's occupation of the 27 asterisms are called *Mahānakṣatras* or *Malenakṣatras* (in Kannada). Farmers in India determine the seasons by these *Mahānakṣatras*. For example, the rainy season in Karnataka, due to the southwest monsoon, ranges over about ten *Mahānakṣatras*, namely *Rohiṇī* to *Hasta*. *MKS* includes the tables for determining the solar ingress and the procedure for determining the durations of the successive solar months[12].

Ahargaṇa

Ahargaṇa is the number of civil days elapsed since a chosen epoch, literally meaning 'heap of days'. It is the basic parameter used for calculating mean positions of planets and other elements. The intercalary months play an important role in calculating *ahargaṇa*. According to *Siddhāntas*, it is the number of mean civil days elapsed at midnight or mean sunrise for the Ujjain meridian. This meridian passes through a point on the equator with the same longitude as Ujjain, called Laṇkā. In *MKS*, the procedures for determining *ahargaṇa* are explained. It is also shown how easy it is to convert a given traditional lunar calendar date to *kali* days using vallī components of *MKS*, compared with other astronomical texts belonging to *Saurapakṣa*.

The author of *MKS* has incorporated many changes to yield better results during his time. For example: (i) to find the mean motion of the Sun and (ii) to work out the revolutions of other bodies also based on their mean daily motions[13].

The ending moments of a lunar day (tithi), lunar mansion (nakṣatra) etc

In traditional Indian custom, the annual almanac is vitally important. A Hindu uses the almanac for all religious practices and also for recognizing the dates of important festivals as well as special days like no-moon day (*Amāvāsya*) and full-moon day (*Pūrnima*). The almanac consisits of five parts, namely *tithi*, *nakṣtra*, *vārā*, *yoga* and *karaṇa*. It also contains information regarding daily motion of planets, planetary positions, sunrise and sunset timings. Also, in the Indian calendar there are essentially two systems followed, namely luni-solar calendar and purely solar calendar. In the luni-solar calendar, the lunar month starts with one full moon and ends with the next full moon. In most of the North Indian states the luni-solar system is followed. The solar year is the time taken by the Sun to go round the elliptic once with reference to the fixed stars. The lunar month is divided into 30 parts called *tithis*, i.e. the ending moments of phases of the Moon. The *nakṣatra* at a given time, on a given day, is one of the 27 divisions of the zodiac, from *Aśvinī* to *Revatī*, occupied by the sidereal Moon.The sum of the *nirayaṇa* longitudes of the Sun and the Moon is divided into 27 equal divisions called *yogas*[3,5].

The mean *tithis* are tabulated for 16 cumulated years in table 1 and the difference years 1–16 in table 2. The weekday and the starting moment of that weekday are calculated using tables 1 and 2, i.e. *tithi kanda* for *śaka* years (16 years intervals) and *śakāvaśeṣa tithi kanda* (the difference years). Further using table 3, i.e. *tithi guccha*, the beginning moments of the weekday for each fortnight and also each day of each fortnight can be calculated. Table 4, i.e. *tithi saurabha* gives the correction to obtain the corrected moments of *tithi* ending from the mean values. The constant values in tables are expressed in terms of *vāra* (weekday number), *vallī*, *ghaṭī* and *pala*. Here 1 *ghaṭī* = 1 *nāḍī* = 1 *daṇḍa* = 60 *palas* = 24 min and 1 *pala* = 1 *vighaṭī* = 24 sec (refs 9, 10). Similarly, *MKS* gives tables for calculating the ending moments of 27 asterisms and *yoga* for each fortnight and each day of every fortnight, which are the source for socio-religious practices. Once the almanac-maker obtains the required annual constants for calendrical elements for the beginning of the solar year, the rest of the work is simple and rather mechanical by adding or subtracting the related elements using the tables given in the text *MKS*. These can be obtained easily[5,14].

Angular diameter

In the computations of lunar and solar eclipses, the angular diameters of the Sun, Moon and the Earth's shadow are obtained from the Moon's duration of asterisms (*nakṣatramāna*) and solar ingress. The speciality of *MKS* lies in giving the procedure for obtaining the angular diameters of the Sun, Moon and the Earth's shadow-cone using the total duration of the running asterism and the solar ingress, which are readily available in a traditional almanac[14–16].

Scope for further research

The main scope for the research work is to analyse mathematically the large number of tables given in the texts, formulate their algorithms and finally to write computer programs for obtaining results with a better accuracy to enable comparison of *MKS* results with those of other tables. We also need to present an expository work on *MKS* in English with a good number of illustrations and examples, suggesting the improvement in the procedures and making the table relevant to modern time by updating the parameters.

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