*Journal of Astronomical History and Heritage*, 22(3), 401–406 (2019).

# THE CONCEPTS OF *DEŚĀNTARA* AND *YOJANA* IN INDIAN ASTRONOMY

**Padmaja Venugopal**
*Department of Mathematics, SJB Institute of Technology, Kengeri, Bangalore-560 060, India.*
Email: venugopalpadmaja@gmail.com

**K. Rupa**
*Global Academy of Technology, Rajarajeshwari Nagar, Bangalore-560098, India.*
Email: shr_rupak@yahoo.co.in

**S.K. Uma**
*Department of Mathematics, Sir MVIT, Bangalore-560 157, India.*
Email: uma.sreenath@yahoo.com

**and**

**S. Balachandra Rao**
*Gandhi Centre of Science and Human Values, BharatiyaVidyaBhavan, #43/1, Race Course Road, Bangalore-560 001, India.*
Email: balachandra1944@gmail.com

**Abstract:** In this paper we discuss in detail the concepts of (i) the *deśāntara* correction to the mean longitude of a heavenly body, and (ii) the linear distance, called *yojana*. We consider the definitions and procedures given in classical Indian astronomical texts like the *Ārybhaṭīyam*, *Brāmasphuṭasiddhānta*, *Khaṇḍakhādyaka*, *Laghu- Mahā-Bhāskarīya*, *Siddhānta Śiromaṇi*, *Grahalāghavam* and *Tantrasaṅgraha*. From our findings we notice that there were apparently two distinct schools (*paksas*), which were led by Ārybhaṭa (b. CE 476) and Brahmagupta (ca. 628), who used 1050 and 1581 *yojana*, respectively, for the diameter of the Earth.

**Keywords:** Indian astronomy, deśāntara, *yojana*

## 1 INTRODUCTION

Since the Earth rotates about its own axis from west to east sunrise takes place earlier for places with eastern longitudes and later for those with western longitudes. In classical Indian astronomical texts, the time during a day was reckoned from the instant of local sunrise. But the procedures for the computation of the mean positions of the heavenly bodies were given in the texts with reference to the mean sunrise for the prime meridian of Ujjayinī (in present-day Madhya Pradesh). The meridian through Ujjayinī was assumed to pass through a few more important places, like Kurukṣetra, and intersect the terrestrial equator at Laṅkā.

Therefore while computing the mean positions of the heavenly bodies for a given local time at a given place a correction, called the *deśāntara saṃskāra*, had to be applied to account for the longitudinal difference between that place and Ujjayinī. The computation of the *deśāntara* correction needed the longitudinal difference between the given place and the prime meridian through Ujjayinī. In the classical texts this distance was expressed in terms of the linear difference between the two places. For this purpose, the Earth's circumference in *yojanas* was required. At that time, there were two main schools (*pakṣas*), and they took the Earth's circumference to be about 3300 *yojanas* and 4800 *yojanas* respectively

## 2 THE *DEŚĀNTARA* ACCORDING TO DIFFERENT TEXTS

In Indian astronomy linear distances were measured in *yojanas*. In Figure 1 *PQAC* is the prime meridian through Ujjayinī. *PDBQ* is the meridian

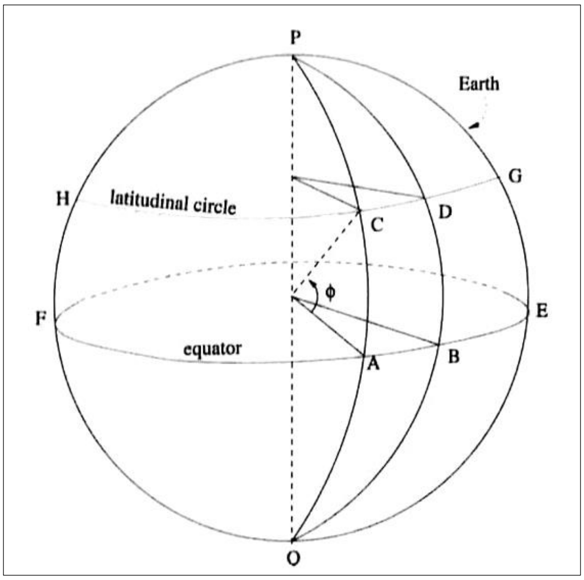



Figure 1: The longitude and latitude lines of a given place (diagram: Padmaja Venugopal).

and through the observer. *ABEF* is the terrestrial equator with circumference given as 3300 *yojanas* in the Ārya *pakṣa*. *CDGH* is a latitudinal circle corresponding to the latitude $\varnothing$. The radius of this circle (a small circle) is the radius of the sphere (*R*) multiplied by $cos\varnothing$. The circumference of this latitudinal circle ($C_0$) is given by

$$C_0 = (3300 \times R\cos\varnothing)/R = 3300\cos\varnothing. \quad (1)$$

The time taken by the Earth to complete one revolution (360°) is 60 *ghaṭīs*, and this corresponds to one full rotation of the latitudinal circle $C_0$.

According to the *Tantrasaṅgraha* of Nīlakaṇṭha Somayājī (Ramasubramanian and Sriram, 2011) the equatorial circumference is about 3300 *yojanas*, and so the equatorial radius is $3300/2\pi = 525.211 \approx 525$ *yojanas*. The Earth's known radius is approximately 4000 miles. Therefore, 525 *yojanas* ≈ 4000 miles, and 1 *yojana* = 160/21 = 7.619 ≈ 7.6 miles.

Table 1: *Deśāntara* corrections for heavenly bodies (after Sastri, 2006).

| Heavenly Bodies | Mean Daily Motion | | | *Deśāntara* Correction | |
|---|---|---|---|---|---|
| | ° | ′ | ″ | ′ | ″ |
| *Ravi* | 00 | 59 | 08 | 00 | 28 |
| *Candra* | 13 | 10 | 35 | 06 | 25 |
| *Kuja* | 00 | 59 | 08 | 00 | 15 |
| *Budha* | 04 | 05 | 32 | 01 | 59 |
| *Guru* | 00 | 04 | 59 | 00 | 02 |
| *Śukra* | 01 | 36 | 08 | 00 | 47 |
| *Śani* | 00 | 02 | 00 | 00 | 01 |
| *Candrocca* | 00 | 06 | 41 | 00 | 03 |
| *Rāhu* | 00 | 03 | 11 | 00 | 03 |

## 2.1 The *Deśāntara* According to the *Gaṇakānanda*

The *Gaṇakānanda was* authored by Sūryācārya, the son of Bālāditya, who came from the Andhra region. The text was based on the *Sūryāsiddhānta*, and it belongs to the *Saurapaksa.* The epochal date of the text is CE 16 March 1447. The currently available text is a single Sanskrit text in the Telugu script, edited and published by Chella Lakshmi Narasimha Sastri from Machalipatnam in the Andhra region and reprinted in the year 2006:

> *lakāvantīpurīmadhyarekhāpūrvāparast hitai I*
> *yojanairgatayonighnaḥkhakhāṣṭanigam ai r hṛtāh II* (Sastri, 2006).

The *deśāntara* is obtained in arc seconds by multiplying the *yojanas* of a given place from the north-south line (*rekhā*) passing through Laṅkā and Avantī Ujjayinī by the mean daily motion and dividing by 4800. Taking the Earth's circumference as 4800 *yojanas* we get the Earth's radius as $4800/\pi = 763.94$. Assuming the Earth's radius as 800 *yojanas*, its circumference is $2\pi \times 800 = 4800$ *yojanas*. According to Sastri (2006), the *yojanas* of Machilipatanam is 39. So the *deśāntara* correction for *Ravi* is (59′ 08″/4800) × 39 = 0′ 28″. Similarly, *deśāntara* corrections for other bodies were computed, and are listed in Table 1.

In his commentary, Yallaya, the well-known fifteenth century Andhra astronomer, gives the distance of Skandaśomesvara from the Ujjayinī meridian as 36 *yojanas* according to the *Sūryāsiddhānta* (Gangooly, 1989; Parameśvara, 1957). But according to Ārybhaṭa (Sambasivasastri, 1977; Shukla and Sarma, 1976) it is 23 7/15 *yojanas.* In our modern reckoning, Skandaśomesvara has a longitude of 79° 50′ E and a latitude of 15° 30′ N. The longitudinal distance of this place is 04° 05′ to the east of Ujjayinī (which has a longitude of 75° 45′ E). Therefore,

$$R = (360° \times 36)/[2\pi\cos\varnothing(L - 75°\ 45')] \approx 524 \text{ yojanas}, \quad (2)$$

and according to Yallaya the Earth's circumference is 3292 ≈ 3300 *yojanas* (Gangooly, 1989; Parameśvara, 1957).

## 2.2 The Earth's Diameter and Circumference According to the *Khaṇḍakhādyaka*

The *Khaṇḍakhādyaka* of Brahmagupta (CE 665) follows Ārybhaţa's *Ārdharātrika* system (see Chatterjee, 1970; Sengupta, 1934). In the *Gītika pāda* of the *Āryabhaṭīyam* the description of the *deśāntara correction* is given in *Śloka* 7, which is quoted below:

> nṛ- ṣi yojanaṃ ñilā bhūvyāso'
> rkendvorghrñā giṇa ka meroḥ| (Shukla and Sarma, 1976, Chapter 1: *śl.* 7).

According to the *Āryabhaṭīyam* (Sambasivasastri, 1977; Shukla and Sarma, 1976: Chapter 4, śl. 39, 40) the Earth's diameter is 1050 *yojanas*. Therefore, the circumference is $1050 \times \pi = 3298.6722 \approx 3300$ *yojanas* (the modern value is 3956.55 miles), and 1 *yojana* = 7.53628 ≈ 7.5 miles. Note (i) If we take the circumference as 3200 *yojanas*, then the radius is 509.2958 *yojanas* = 7.76866 miles; and (ii) Sometimes for the purposes of easy calculation, the Earth's circumference is taken as 3200 *yojanas*.

## 2.3 The *Deśāntara* According to the *Grahalāghavam*

Gaṇeśa Daivajña (CE 1520) in his *Grahalāghavam* refers to the *deśāntara* in Chapter 1 as:

> *nijanijapurarekhāntastitadyojanaughād rasalavamitaliptāḥ:*
> *svarṇamindupareprāk* II (Rao and Uma, 2006: *madhyamādhikara*, *ś*l. 9).

To find the *deśāntara* correction for the Moon, the distance of the given place from the Ujjayinī meridian in *yojanas* is divided by 6 to get it in *liptās* (*kalās*). Gaṇeśa takes, for easy calculation the Moon's daily motion as 800′ and the Earth's circumference as 4800 *yojanas* (see Pandey, 1994; Rao, and Uma, 2006). Therefore the *deśāntara* correction is (*yojanas* × daily motion)/4800 = *yojanas*/6 *kalās*. We know that the equatorial radius and polar radius are respectively 3963.2 and 3949.91 miles. The average of the two values is 3956.55 miles. Bhāskara II's value for the circumference of the Earth is 4967 *yojanas* (Mishra, 1991). Therefore, the radius is 790.5 *yojanas* = 3956.55 miles. Therefore, 1 *yojana* = 5.00512334 miles ≈ 5 miles. Along the small circle through *Kāśī* the arc length is 90° 37′ 50″.

Note that (i) in his Hindi commentary on the *Grahalāghavam* Joshi (1981: 30) takes the distance of *Kāśī* as 64 *yojanas* quoting the *prācīna āchāryas*); and (ii) Pandey (1994: 17) takes 1 *yojana* as 8 miles. This is not correct. According to the *Grahalāghavam*, it works out at about 5 miles.

According to the *Tantrasaṅgraha* (Ramasubramanian and Sriram, 2011) the equatorial circumference is 3300 *yojanas* and hence the equatorial radius is $3300/2\pi$ = 525.211 ≈ 525 *yojanas*. Since the Earth's known radius is approximately 4000 miles, 525 *yojanas* = 4000 miles. Therefore, 1 *yojana* is 160/21 = 7.619 ≈ 7.7 miles.

According to the *Vaṭeśvara Siddhānta* & *Gola* (Shukla, 1985–1986: 135) the Earth's equatorial diameter is 1527 *yojanas.* The Earth's circumference is (1054 × 3927)/1250 = 3311.2464 *yojanas* ≈ 3311 *yojanas.*

In his *Khaṇḍakhādyaka* Brahmagupta gives the Earth's circumference as 4800 *yojanas* (Chatterjee, 1970(1): 50). But in the *Uttara Khaṇḍakhādyaka* he gives the correct method to obtain the circumference of a small circle through the place. Here he gives the circumference of the small circle as 5000 $\cos\phi$ *yojanas*. Therefore, the Earth's radius is $5000/2\pi$ = 795.77 *yojanas* = $5000/2\sqrt{10}$ = 790.569 *yojanas.*

## 2.4 *The Karaṇakutūhalam* of Bhaskara II

In his *Karaṇakutūhalam* Bhaskara II considers the circumference of the Earth as 4800 *yojanas* (Mishra, 1991). To cover 4800 *yojanas* the Earth takes 60 *ghatīs.* For 1 *yojana* the time taken is therefore 60/4800 = 1/80 *ghatīs*. Therefore in his translation of the *Sūryasiddhānta,* Burgess gives the Earth's circumference for the circumference of a small circle through Washington ($\phi$ = 38° 54′) as $2\pi r\cos\phi$ = 5059.556 × $\cos(38° 54')$ = 3937.56 *yojanas* (Gangooly, 1989: 43–45, *śl.* 60–61). The *Karaṇakutūhalam* defines the *deśāntara* correction (Mishra, 1991: Chapter 1, *śl.* 15) as (yojanas/90) × daily motion.

Values for the circumference of the Earth in *yojanas* vary according to the sources consulted. For example, in his *Siddhānta Śiromani* Bhaskara II gives the Earth's circumference as 4967 *yojanas* and its diameter as 1581 *yojanas*:

> *proktoyojanasaṅkhyayākuparidhiḥsaptā ṅganandābḍhayas*
> *tadvyasaḥkubhujaṅgasāyakabhuvo̕thap rocyateyojanam* I
> *yamyodakpurayohpalāntarahataṃbhuv eṣṭanaṃbhāmśa h t*
> *tadbhaktasyapurantarādhvanaiha j ñeyaṃsamamyojanam* II
> (Arkasomayaji, 1980; Vāsanā, 1929: bhuparidhi, 1).

## 2.5 The *Deśāntara* According to the *Vākya Karaṇa*

According to the *Vākya Pañcādhyāyi* (Kuppanna Sastry and Sarma, 1962: 255, *śl.* 16)

> *deśāntarād yojanāḥ syurnāḍya maṇihṛtaṃ phalam* |
> *tādhanaṃ samarekhāyāḥ*
> *pañcaccedanyathā kṣayaḥ*

the Earth's circumference is 3300 *yojanas,* which converting to *nādyas* is 60/3300 = 1/55. *The Pañcāsiddhāntikā* gives the *deśāntara* of Pudukottai (latitude: 10° 23′ N; longitude: 78° 52′ E) as an example (Sarma, 1993). It is 24.4 (E) *yojanas* from Ujjayini. Then

$[(L_1 - L_u)/360] \times c = [(78° 52' - 75° 45')/360] \times c = 24.4 \Rightarrow c = 2818.396$ *yojanas.* Now suppose that $2\pi r\cos\phi = 2818.396$ *yojanas.* Then $2\pi r\cos(10.4°) = 2818.396/(2\pi \times 0.98357)$ and $r = 456.0546326$.

The late Professor Kuppanna Sastry comments on the *Āryapaksa* and *Saurapaksa* in respect of the Earth's equatorial circumference as follows:

> But it is to be noted that in the *Ārdharātrika* of Āryabhaṭa and in the Khanda Khadyaka, the diameters of the earth is given as 1600 *yojanas* from which the equatorial circumference got is 5027 *yojanas*. Therefore the original *Saura* must have given the same values. The modern Sūrya siddhānta and the *siddhāntas* that follow it also give the same. From this the latitude circle at or near *Ujjaini* should be given according to them as 5027cos24° = 4600 *yojanas*. According to the Āryabhaṭīya which uses a *yojana* measure one and a half times that of *Saura* etc., the equatorial circumference would be 3300 *yojanas.* From this, it is 14° latitude circle that would be 3200 *yojanas* and not the *Ujjaini* latitude circle*.* (see Sarma, 1993: 210).

## 2.6 The *Deśāntara* According to the *Pauliśa Siddhāntha*

> *Yavanantarajya nādyaḥ saptā'vantyāṃ tribhāgasaṃyuktāḥ* |
> *Vārāṇasyam trikṛtiḥ' sādhanamanyatra vakṣyāmi* || (śl.13).

The time correction for the longitude of Yavanapura (Alexandria) relative to Ujjayinī is 7 *nāḍikās* (*na*) 20 *vināḍikās* (*vin*) and to Vārāṇasī is 9 *nāḍikās.* Note that according to Kuppanna Sastry (Sarma, 1993) these are respectively (75° 50′ – 30°)/6 = 7*na* 38*vin* and (83° – 30°)/6 = 8*na* 50*vin*. Therefore the distance between Yavanapura and Ujjayinī is [(7 – 20)/60] × 3300 *yojanas* = 403I20 *yojanas*, and between Yavanapura and Vārāṇasī is (9 × 3300)/60 = 495 *yojanas*.

For Pudukottai (longitude 78° 52′ E and latitude 10° 23′ N), $(L - L_0)/360 = 24.4/c\cos ø$ (i.e. ø = 10° 23′ N); $(L - L_0)/360 = 24.80633/c$, or $c = 24.80633/(L - L0) \times 360 = 2865.6$.

Note that the modern value for Earth's circumference is $2\pi \times 4000 = 8000\,\pi$ miles. In the *Saurasiddhānta* (Sarma, 1993: 209, *śl.* 10) 1 *nādī* = 53⅓ *yojanas*. Therefore, 60 *nādīs* = 60 × 53.333 ≈ 3200 *yojanas.* Taking the circumference as 3200 *yojanas*, we have 60 *nādīs* ≡ 3200 *yojanas.* Therefore, 1 *nādī* = 3200/60 = 160/3 = 53⅓ *yojanas.*

According to the *Pañcasiddhānta* (Sarma, 1993: 52), the longitudes of Kurukshetra and Ujjayinī are 76° 51′ and 75° 45′ respectively. Then (1° 06′/360) × 3300 = 10.8 *yojanas*, and (1° 06′/360) × 4800 = 14.66 *yojanas* ≈ 15 *yojanas*. The number of *yojanas* along the latitude circle is given by $15\cos ø = 12.9947 \approx 13$ *yojanas.*

## 2.7 The Concept of the *Deśāntara* and *Yojana* in Indian Astronomy

The Earth's circumference is 360° which equals 4800 *yojanas.* The longitude of Bangalore is 1° 50′ east of Ujjayinī). For 1° 50′ we have (1° 50′)/360 × 4800 = 24.26 *yojanas.*

For Machalipattanam, $[(L - L_0)/360] \times 4800$ *yojanas* = (5.366/360) × 4800 *yojanas*. Note that along the small circle through Machalipatnam the circumference ≈ 4606.799041 *yojanas*. Therefore, the distance from Machalipatnam to the Ujjayinī meridian is 69.04677. The circumference of the small circle through a specific place is given by $(2\pi R)\cos ø$, where $R$ is the Earth's radius = $4800\cos ø$ *yojanas.*

For Bangalore (present-day Bengaluru), 4800*cos13°* = 4676.976 *yojanas*. Then, (1° 5′/360) × 4676.976 *yojanas* = 23.8179 *yojanas*. Taking the Earth's circumference as 3200 *yojanas*, 23.8179 × (3200/4800) = 15.8786 *yojanas*.

For Machalipattinam, the circumference of a small circle is 4800*cos(16° 11′)* = 4609.799 *yojanas*. If we take circumference as 39 *yojanas*, (360° × 39)/5.3667 = 2626 *yojanas*. Therefore, the equatorial circumference is 2616/*cos16° 11′* = 2749 *yojanas*.

## 2.8 The *Deśāntara* According to Modern Astronomy:

The longitudes of Kāśī and of Ujjayinī are 83° 01′ and 75° 45′ respectively. The difference in longitudes is 7° 16′, therefore (7° 16′/360°) × 4967 = 100I15I35 *yojanas* along the equator. The equatorial diameter is 12756 km, the circumference is 40090 km, and the radius is 6378/1.6 km = 3986.25 miles.

## 3 CONCLUDING REMARKS

A fairly elaborate analysis of the concept of the *deśāntara*—resulting in the time of local sunrise due to the Earth's rotation—has been presented in this paper. We have discussed the effect of the difference in longitudes of a given place and the then-adopted central meridian (of Ujjayinī) on the local time.

The linear distance between the places was measured in terms of a unit of distance called a *yojana*. This unit is defined in terms of the circumference and the diameter of the Earth. We examined important texts like the *Āryabhaṭiyam*, *Pañcasiddhāntā*, *Sūryasiddhānta*, *Khaṇḍakhādyaka*, *Siddhanta Śiromni*, *Grahalāghavam*, *Karaṇakutūhalam*, *Tantrasaṅgraha* and the *Vākya Karaṇa*, and we found that the main *pakṣas* (Schools) adopted different values for the circumference (*paridhi*) of the Earth. The *Āryapakṣa* adopted a value of 3300 *yojanas*, the *Brāmhapakṣa* 4967 *yojanas* and the *Saurapakṣa* 4800 *yojanas*. These values were compared using the modern known values for the equatorial circumference and diameter of the Earth.

The three *pakṣas* were founded at about the same time (around the sixth century CE), but tended to flourish in different parts of India: the *Āryapakṣa* in Southern India, the *Brāmhapakṣa* in western and north-western India, and the *Saurapakṣa* in northern and eastern India. The fact that the two more northerly *pakṣas* have rather similar values for the circumference of the Earth and that they differ markedly from the value used by the southern *pakṣa* is interesting, but the precise reasons why the adopted values were so different is not known. Plofker (2009: 70) writes:

> The sources of competing parameters and authors' reasons for choosing them are not always clear … a frequently stated motive is the desire to harmonize astronomical calculations as far as possible with *smṛti* trad-

itions about cosmological time, or to bring them into agreement with observed positions.

Yet these reasons can hardly apply in the case of the circumference of the Earth, so further research is required in order to explain these differences.

## 4 ACKNOWLEDGEMENTS

We are grateful to Professor Wayne Orchiston for helping finalise this paper.

## 5 BIBLIOGRAPHY

Arkasomayaji, D. (transl.), 1980. *Siddhānta Śiromani of Bhāskaracharya.* Tirupati, Kendriya Sanskrit Vidyapeetha.

Chatterjee, B. (ed. and transl.), 1970. *The Khaṇḍa-khādyaka* (an Astronomical Treatise) *of Brahmagupta: with the commentary of Bhattotpala. Two Volumes*. New Delhi, Motilal Banarsidass.

Gangooly, P. (ed.), 1989. *The Sūryasiddhānta, translated by the Reverend E. Burgess … and Introduction by P.C. Sengupta*. Delhi, Motilal Banarsidass.

Joshi, K. (comm.), 1981. *The Grahalāghavam of Gaṇeśa Daivajña, with a commentary by Mallāri and Viśvanātha* … Varanasi, Motilal Banarsidass.

Kuppanna Sastry, T.S., and Sarma, K.V. (eds.), 1962. *Vākya Pañcādhyāyi*. Madras. K.S. Research Institute.

Kuppanna Sastry, T.S (transl. and notes), 1993. *Pañcasiddhāntikā of Varāhamihira.* Madras, P.P.S.T. Foundation.

Mishra, A.R. (comm.), 1982. *The Makarandasārinī* … Varanasi, Madālasā Publications.

Mishra, S. (transl.), 1991. *The Kāranakutūhalam of Bhāskara II, with a commentary by Sumatiharsa and Sudhākara Dvivedi* … Varanasi, Oriental Publishers (Krishnadas Academy).

Pandey, R.C. (ed.), 1994. *The Grahalāghavam of Gaṇeśa Daivajña, with a Hindi commentary by Mallāri* … Varanasi, Chowkhamba Sanskrit Series.

Parameśvara (ed.), 1957. *The Sūryasiddhānta* ... Lucknow, K.S. Shukla.

Plofker, K., 2009. *Mathematics in India*. Princeton, Princeton University Press.

Ramasubramanian, K., and Sriram, M.S., 2011. *The Tantrasaṅgraha of Nīlakaṇṭha Somayājī.* New Delhi, Hindistan Book Agency.

Rao, S. Balachanra, 2000. *Ancient Indian Astronomy – Planetary Positions and Eclipses*. Delhi, B.R. Publishing.

Rao, S. Balachandra, 2000. *Indian Astronomy – An Introduction*. Hyderabad, Universities Press.

Rao, S.B., and Uma, S.K. (trans.), 2006. *The Grahalāghavam of Gaṇeśa Daivajña* … New Delhi, Indian National Science Academy.

Rao, S. Balachandra, 2008. *Indian Astronomy – A Primer*. Bengalaru, Bhavan's Gandhi Centre of Science and Human Values.

Rao, S. Balachandra, and Venugopal, P., 2008. *Eclipses in Indian Astronomy*. Bangalore, Bhavan's Gandhi Centre of Science and Human Values.

Rao, S. Balachandra, and Venugopal, P., 2009. *Transits and Occultations in Indian Astronomy.* Bangalore, Bhavan's Gandhi Centre of Science and Human Values.

Rao, S. Balachandra, 2016. *Indian Astronomy – Concepts and Procedures*. Bengaluru, M.P. Birla Institute of Management.

Rupa, K., Venugopal, P., and Rao, S. Balachandra, 2014. Makarandasārinī and allied Saurapaksa tables —a study. *Indian Journal of History of Science*, 49, 186–208.

Sambasivasastri, K. (ed.), 1977. *The Āryabhaṭīyam of Āryabhaṭa, with a commentary by Nīlakaṇṭha Somasutvan* … Trivandrum, K. Sambasivasastri (reprint).

Sarma, K.V. (trans.), 1993. *The Pañcasiddhāntikā of Varāhamihira, English translation and notes by T.S. Kuppana Sastry* … Madras, P.P.S.T. Foundation.

Sastri, C.L.N. (ed.), 2006. *The Gaṇakānanda, Sanskrit text in Telugu script ...* Machalipatnam, Chella Lakshmi Narasimha Sastri (reprint).

Sengupta, P.C. (ed. and transl.), 1934. *The Khaṇḍa-khādyaka of Brahmagupta*. Calcutta, University of Calcutta.

Shukla, K.S. (ed. and transl.), 1985–1986. *The Vaṭeśvara Siddhānta & Gola.* New Delhi, INSA.

Shukla, K.S., and Sarma, K.V. (eds.), 1976. *The Āryabhaṭīyam of Āryabhaṭa*. New Delhi, Indian National Science Academy.

Tandan, V. (comm.), 1945. *The Makarandasārinī* … Bombay, Sri Venkateshwara Press.

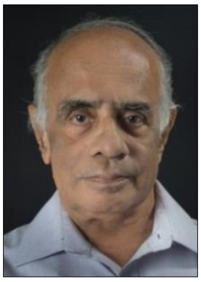
Vāsanā (ed.), 1929. *The Siddhānta Śiromani of Bhāskara II, with Bhāskara's commentary* … Benaras, Sudhakara Dvivedi (Kashi Skt. Series, No.72).

**Professor Padmaja Venugopal** has a PhD from Bangalore University. Currently she is Professor and Head of the Department of Mathematics at the SJB Institute of Technology in Bangalore. Her recent publications include *Eclipses, Transits, Occultations and Heliacal Rising and Setting of Planets*. She has been working in the field of Indian astronomy for the past two decades, and has presented papers at various conferences and published a few papers in the *Indian Journal of History of Science* and other journals. She worked on the Indian National Science Academy (INSA) research project 'Comparative Study of Planetary Models in Respect of Epicycles in Classical Indian Astronomy vis-à-vis Ptolemaic and Copernican Models'. Currently she is working on another INSA project: 'Gankananda – English Translation, a Critical Analysis & Comparison with other Indian Astronomical Tables'. She is guiding PhD candidates in the field of astronomy. She has authored books on *Eclipses in Indian Astronomy* and *Transits and Occultations in Indian Astronomy*. She presented a stand-alone paper on "Eclipses – inscriptional and literary references, a survey" at the 25th International Congress of History of Science and Technology, in Rio de Janeiro, Brazil, in July 2017.

**Associate Professor K. Rupa** has an MSc from Bangalore University and a PhD from Anna University, Chennai. The title of her doctoral thesis is: *Planetary*

*Models in Classical Indian Astronomy in Comparison with Ptolemaic, Copernican and Keplerian Models – A Mathematical Analysis.* Currently she is an Associate Professor in the Department of Mathematics at the Global Academy of Technology in Bangalore. She has presented papers at various conferences and published a few papers in the *Indian Journal of History of Science* and other journals. Currently she is working on the INSA research project 'Occultation and Transits in Indian Astronomy – A Mathematical Analysis'. She has co-authored the book *Bharathada Suprasidda Ganitajnaru* (*Famous Indian Mathematicians*).

**Professor S.K. Uma** has an MSc from Bangalore University and PhD from Manipal University. Currently she is a Professor in the Department of Mathematics at the Sir Mokshagundam Visvesvaraya Institute of Technology in Bangalore. She has been working in the field of Indian astronomy for the past two decades and has presented papers at various conferences and published a few papers in the *Indian Journal of History of Science* and other journals. Her most recent published paper is on the *Ahargana* according to Makarandasāriṇī, and other Indian astronomical texts. She worked on the Indian National Science Academy research project "MAKARANDASĀRIṆĪ – English Exposition, A Critical Analysis and Comparison with Other Indian Astronomical Tables". She is guiding PhD candidates in the field of astronomy, and has authored three books on Indian Astronomy.



**Professor S. Balachandra Rao** has an MSc (Mathematics) from the University of Mysore and a PhD (Fluid Mechanics) from Bangalore University. He served at the National Colleges at Gauribidanur and Bangalore, teaching mathematics for 35 years, and retired in 2002 as Principal. Currently he is (1) Honorary Director, Gandhi Centre of Science and Human Values, Bharatiya Vidya Bhavan, Bengaluru; (2) a Member of the National Commission for History of Science, INSA, New Delhi; and (3) an Honorary Senior Fellow at the National Institute of Advanced Studies (NIAS) in Bengaluru. Professor Rao has been researching in the field of classical Indian astronomy since 1993 under successive research projects from INSA. He has authored, singly and jointly, quite a few papers in reputed journals and books on Indian mathematics and astronomy. The books published so far are about 30, half in English and the remainder in Kannada. The more popular ones among them are: (1) *Indian Mathematics and Astronomy—Some Landmarks*; (2) *Indian Astronomy—Concepts and Procedures*; (3) *Eclipses in Indian Astronomy*; (4) *Transits and Occultations in Indian Astronomy* [titles (3) and (4) were co-authored by Dr Padmaja Venugopal]; (5) Grahalaghavam *of Ganesha Daivajna*, *English Translation and Notes*; (6) Karanakutuhalam *of Bhaskara II*, *English Translation and Notes* [titles (5) and (6) were co-authored by Dr S.K. Uma]; (7) *Astrology—Believe it or Not?*; (8) *Traditions, Science and Society*, *etc*. While title (7) was translated into the Kannada and Marathi languages, title (8) was rendered into Kannada, Telugu and Malayalam versions. The Kannada versions of books (7) and (8) have won awards as "The Best Works of Rational Literature" from the Kannada Sahitya Parishat (Kannada Literary Authority).