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

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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*, *Brāhmasphuţasiddhānta*, *Khaņḍakhādyaka*, *Laghu- Mahā-Bhāskarīya*, *Siddhānta Śiromaņi*, *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 Lańkā.

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 (*paksas*), 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 ϕ . The radius of this circle (a small circle) is the radius of the sphere (*R*) multiplied by $cos\phi$. The circumference of this latitudinal circle (C_0) is given by

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

The time taken by the Earth to complete one revolution (360°) is 60 *gha* $t\bar{t}s$, and this corresponds to one full rotation of the latitudinal circle $C_{0.}$

According to the *Tantrasangraha* of Nīlakaņtha 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* \approx 4000 miles, and 1 *yojana* = 160/21 = 7.619 \approx 7.6 miles.

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

Heavenly Bodies	Mean Daily Motion	Deśāntara Correction
	o / "	, ,
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 Gaņakānanda

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 hrtāh 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/ π = 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 $(59' 08''/4800) \times 39 = 0' 28''$. 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 *Sūryā-siddhānta* (Gangooly, 1989; Parameśvara, 1957). But according to Ārybhaţa (Sambasivasastri, 1977; Shukla and Sarma, 1976) it is 23⁷/15 *yojanas*. In our modern reckoning, Skanda-śomesvara 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,

 $R = (360^{\circ} \times 36) / [2 \pi \cos \phi (L - 75^{\circ} 45')] \approx 524$ yojanas, (2)

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

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

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

nr- și yojanam ñilā bhūvyāso' rkendvorghrñā giņa ka merohļ (Shukla and Sarma, 1976, Chapter 1: *śl.* 7).

According to the $\bar{A}ryabhativam$ (Sambasivasastri, 1977; Shukla and Sarma, 1976: Chapter 4, śl. 39, 40) the Earth's diameter is 1050 *yojanas*. Therefore, the circumference is 1050 × π = 3298.6722 ≈ 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

Ganesa Daivajña (CE 1520) in his *Grahalā-ghavam* refers to the *desāntara* in Chapter 1 as:

nijanijapurarekhāntastitadyojanaughād rasalavamitaliptāḥ: svarņamindupareprāk II (Rao and Uma, 2006: madhyamādhikara, śl. 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*). Gaņeśa 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 \approx 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 *Tantrasangraha* (Ramasubramanian and Sriram, 2011) the equatorial circumference is 3300 *yojanas* and hence the equatorial radius is $3300/2\pi = 525.211 \approx 525$ *yojanas*. Since the Earth's known radius is approximately 4000 miles, 525 *yojanas* = 4000 miles. Therefore, 1 *yojana* is 160/21 = 7.619 \approx 7.7 miles.

According to the Vatesvara Siddhānta & Gola (Shukla, 1985–1986: 135) the Earth's equatorial diameter is 1527 yojanas. The Earth's circumference is $(1054 \times 3927)/1250 = 3311.2464$ yojanas \approx 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 Karaņakutūhalam of Bhaskara II

In his *Karaņakutūhalam* 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 (ϕ = 38° 54') as $2\pi r \cos \phi$ = 5059.556 × $\cos(38° 54')$ = 3937.56 *yojanas* (Gangooly, 1989: 43–45, *śl*. 60–61). The *Karaņakutūhalam* 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*:

proktoyojanasańkhyayākuparidhiḥsaptā ṅganandābdhayas tadvyasaḥkubhujaṅgasāyakabhuvothap rocyateyojanam I yamyodakpurayohpalāntarahataṃbhuv eṣṭanaṃbhāmśa h t tadbhaktasyapurantarādhvanaiha j ñeyaṃsamamyojanam II (Arkasomayaji, 1980; Vāsanā, 1929: bhuparidhi, 1).

2.5 The Deśāntara According to the Vākya Karaņa

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 $2\pi r \cos(10.4^\circ) = 2818.396/(2\pi \times 0.98357)$ 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 Ardharatrika of Āryabhata 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 siddhantas that follow it also give the same. From this the latitude circle at or near Uijaini should be given according to them as 5027cos24° = 4600 yojanas. According to the Āryabhaţīya 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).

Yavanantarajya nādyaḥ sapṭāˈvantyāṃ tribhāgasaṃyuktāḥ | Vārāṇasyam trikṛtiḥ' sādhanamanyatra vakṣyāmi || (śl.13).

The time correction for the longitude of Yavanapura (Alexandria) relative to Ujjayinī is 7 *nādikās* (*na*) 20 vinādikās (vin) and to Vārāṇasī is 9 *nādikās*. Note that according to Kuppanna Sastry (Sarma, 1993) these are respectively (75° 50' - 30°)/6 = 7 *na* 38vin and (83° - 30°)/6 = 8*na* 50vin. Therefore the distance between Yavanapura and Ujjayinī is [(7 - 20)/60] × 3300 yojanas = 403120 yojanas, and between Yavanapura and Vārāṇasī is (9 × 3300)/60 = 495 yojanas.

For Pudukottai (longitude 78° 52′ E and latitude 10° 23′ N), $(L - L_0)/360 = 24.4/ccos\phi$ (i.e. $\phi = 10^{\circ} 23'$ 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 = 53¹/₃ 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 = 53¹/₃ 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 $15\cos\phi = 12.9947 \approx 13$ *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 $(1^{\circ}$ 50')/ $360 \times 4800 = 24.26 \text{ yojanas.}$

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 $(2\pi R)\cos\phi$, where *R* is the Earth's radius = 4800 $\cos\phi$ yojanas.

For Bangalore (present-day Bengaluru), $4800\cos 13^\circ = 4676.976 \ yojanas$. Then, (1° 5′/ 360) × $4676.976 \ yojanas = 23.8179 \ yojanas$. Taking the Earth's circumference as 3200yojanas, $23.8179 \times (3200/4800) = 15.8786 \ yojanas$. For Machalipattinam, the circumference of a small circle is $4800\cos(16^{\circ} 11') = 4609.799$ *yojanas*. If we take circumference as 39 *yojanas*, $(360^{\circ} \times 39)/5.3667 = 2626$ *yojanas*. Therefore, the equatorial circumference is 2616/ $cos16^{\circ} 11' = 2749$ *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 = 100115135 *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 *Āryabhatiyam*, Pañcasiddhāntā, Sūryasiddhānta, Khaņḍakhādyaka, Siddhanta Śiromni, Grahalāghavam, Karaņakutūhalam, Tantrasangraha and the Vākya Karana, and we found that the main paksas (Schools) adopted different values for the circumference (paridhi) of the Earth. The Aryapaksa adopted a value of 3300 yojanas, the Brāmhapakṣa 4967 yojanas and the Saurapaksa 4800 yojanas. These values were compared using the modern known values for the equatorial circumference and diameter of the Earth.

The three *pakşas* were founded at about the same time (around the sixth century CE), but tended to flourish in different parts of India: the *Āryapakşa* in Southern India, the *Brāmhapakşa* in western and north-western India, and the *Saurapakşa* in northern and eastern India. The fact that the two more northerly *pakşas* have rather similar values for the circumference of the Earth and that they differ markedly from the value used by the southern *pakşa* 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 *smrti* trad-

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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.

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