Measurement of coordinates of *Nakśatras* in Indian astronomy

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It is well known that ancient Indian calendar dwelled on the 27 nakśatra system for fixing the positions of the sun, moon and the planets. Several attempts to identify these 27 stars in the sky have yielded very precise results for stars bright enough not to be misidentified, which is not so for the fainter ones. The basis for identification is the coordinate system available in the texts. Here, we try to understand the ambiguity and offer a possible solution by using the measured coordinates, which have not been utilized for this purpose so far. This also provides clues on the techniques used for measuring the coordinates.

The coordinate system

The foremost requirement for understanding the methods used in Indian astronomical texts is the coordinate system itself. Coordinates of stars in all texts of Indian astronomy are expressed in *Dhruvaka* and *Vikśepa* as explained in the figure; exact equivalent terms are not found in modern spherical astronomy texts. The great circle passing through the pole and the star, called the hour circle, intersects the ecliptic at a point B. The angle measured from the first point of Aries along the ecliptic to this point B is called the *Dhruvaka*. The angle measured along the great circle passing through the pole of the ecliptic is called the *Vikśepa*.

Polar longitude and latitude are the terms that have been coined by later investigators. Modern text books define longitude and latitude relative the great circle passing through the pole of ecliptic; right ascension and declination are defined for the hour circle with reference to the equator.

All the sets of coordinates are interrelated by trigonometric relations to transform one set of coordinates to the other. Similarly, *Dhruvaka* and *Vikśepa* also can be converted to right ascension and declination. One of the earliest attempts is by Burgess[1]; subsequently others have come up with alternate formulae. A comparison of the different methods discusses the advantages of the *Dhruvaka–Vikśepa* system[2].

The coordinates have been described as verses or phrases in various texts from *Surya Siddhántha* and its commentaries by various authors up to the 20th century – the last in the series by astronomer Chandrashekhar Samantha of Odisha.

Narahari Achar[3] discussed the epochs as calculated using the names of the stars that are mentioned in texts in the context of using *Krittika* for the sacrificial fire; he writes

> '… For, according to Pingree[4], parts of nakSatras, Hasta, VisAkha, and perhaps SravaNa would also be on the equator on this date and this would contradict SB's claim that only kRttikAs "never swerve from the east." Further, he shows that there are about a dozen stars close to the equator. Of these, three are 30 minutes or less away from the equator, and four more are less than a degree away. There are additional four stars at about 1.5 degrees and the last one is about 2 degrees away from it.
>
> Using the scheme of Pingree to identify the stars Hasta, visAkha, and SravaNa correspond to delta-Corvi, iota-Librae, and alpha-Aquilae respectively for 2927 BC, he further shows that none of the faint stars can be identified with the junction stars or the yogatArAs themselves. It is true however, that there are stars which may be considered to be other members of the groups associated with some junction stars, i.e., asterisms. For Hasta, it is beta-Corvi, with a declination 1 degree 5 minutes, and epsilon-Corvi, with a declination of just 41 minutes. For visAkha, it may be sigma-Librae with a declination of mere 23 minutes; and/or delta-Scorpi with a declination of 57 minutes, and perhaps uttara proSThapada (Uttarabhadra), epsilon-Pegasi, with a declination of –1 degree 23 minutes

However, this objection does not really have any efficacy when one examines carefully the context under which that statement is made, namely, choosing the most auspicious nakSatra for performing agnyAdhAna. If the ritual of agnyAdhAna is to be done under kRttikAs because, "they never swerve from the east", then,

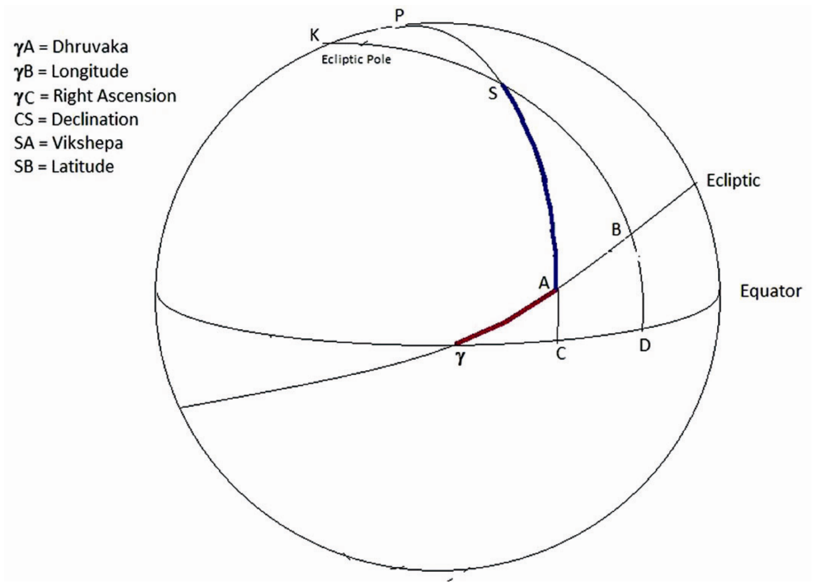

Figure 1. Coordinates *Dhruvaka–Vikśepa* and Right Ascension – Declination.

> Pingree's point would be equivalent to stating that the same ritual could be performed equally well under Hasta, visAkha, and even uttara proSThapada. There may be other reasons why kRttikAs are preferred, such as the presiding deity being Agni. Thus the phrase "never swerve from east" cannot mean anything other than "rising heliacally exactly at the East Point", for, SB (Shathapatha Brahmana) itself declares: "udyanti pura etA[H]" "they rise in the east." On this point, sAyaNa also says in his exegesis "suddhaprAcyam evodyanti" "they rise in the true east."…'

The ambiguity in the identification of stars arises because the east west coordinates are influenced by the shift of the reference point, the *First Point of Aries*, owing to precession. The formulae for driving the north–south coordinate like declination involve this measurement and hence likely to carry forward the associated error. Zero point determination in Indian astronomical texts has been long debated. Saha and Lahiri[5] reported in the Indian Calendar Reform Committee that the longitudes are available mainly for three epochs AD 340, 500 and 560 – Autumnal Equinox on α Vir and Vernal Equinox on ζ Psc. The inability to match the longitude values in subsequent texts was attributed to poor observational capabilities[4].

We examine the identification of the stars named *Yogatáras* (junction stars) with the ones that are conventionally known to us now. One of the earliest lists is by Colebrook[6] for the stars from the *Surya Siddhánta*. Subsequently various versions and commentaries have been made available.

Here is a comparison for the star *Asvini* from different texts – *Surya Siddhánata*, Mahendra Suri (who is believed to have translated the manual *Yantra Rája* of using the astrolabe into Sanskrit for the first time in 13th century, Pingree[7]), Malayendu[8] (commentary on *Yantra Rája* in 15th century), Nityananda (who wrote *Siddhántha Rája*[9] in 15th century), Padmanabha (author of *Yantra Kiraṇávali* in 16th century, Ohashi[10]), Putumana Somayaji (*Karaṇapaddhati;* between 16 and 18 century, Pai *et al.*[11]) and *Siddhántha Darpaṇa* of Chandrashekhara Samanta. The choice of the texts is dictated by the fact they were all associated with observational techniques. There are two dates mentioned in Samantha's text – corresponding to 1869 and 1892 AD as the year of completion of the book.

Karaṇapaddhati gives longitudes and latitudes and are not included in Table 1. It provides methods to derive one set of coordinates from the other.

Table 1 gives a comparison of the values for different epochs; it may be recalled that the values given by Mahendra Suri are the same values provided by Ptolemy and corrected for precession (Ohashi[10]). The values from Nityananda, Padmanabha and Malayendu are tabulated in the context of the use of astrolabe, a measuring device borrowed from Arabs. As they are direct measurements, comparison becomes reliable. Malayendu lists another quantity named *Paramónnatámśa* which is a measured parameter and explains how to get the declination from this reading given that the latitude of the place is 28°38′. It is the maximum altitude, obviously corresponding to the meridian passage. Nityananda has not specified the latitude. Padmanabha mentions the year 1345 śaka, which corresponds to 1423 AD. There is also a mention of a correction of 15° for *Dhruvaka*.

Other texts like *Grahalághava* also list the coordinates which tally with the *Surya Siddhánta* values.

It is interesting to note that Malayendu provides both the declination and maximum altitude; the declination is given accurate to degrees minutes and seconds. There is a small difference in the values of declination derived directly from maximum altitude; we have provided this as correction $\Delta\delta$ (for the measured value) in Table 2. It can be either treated as instrumental error or a correction deliberately applied (maybe for refraction). Noticing that all the values of *Dhruvakas* (for 28 stars) end with 33′52″ we can infer that they are calculated and/or corrected. Thus the measured quantities are only *vikśepa* and *Paramónnatámśa* (values terminate with degrees and minutes). There is a foot note for the table for Malayendu indicating that the *Dhruvakas* are for the period ranging from 1437 to 1637 AD. It is probably added in 1637 AD by a person who copied the text.

Karaṇapaddhathi and many other texts provide formulae for calculating declination from the longitude and latitude measures. The word *Vikśepa*, in these texts, refers to latitude itself.

The mode of observation for deriving the coordinates has been discussed by Saha and Lahiri[5] by an armillary sphere with an ecliptic circle passing through stars like *Pushya* (δ Cnc). The meridian transit was used for measuring the *Dhruvaka* and *Vikśepa*. As most of the records provided are integers, the accuracy is about 0.5 deg. Chandra Hari[12] demonstrates the effectiveness of the procedure.

The bright stars which have been identified without any ambiguity can be used to verify the observations. The errors can be considered instrumental (Table 2).

It is interesting to note that the difference $\Delta\delta$ is a function of the declination. In other words, it is directly proportional to a, the altitude, clearly hinting at the error due to refraction; it is known that the correction is proportional to

$$\cos a = -\tan \phi \tan \delta$$

where a is the maximum altitude (*paramónnatámśa).* The graph of cos a versus $\Delta\delta$ demonstrates this very clearly, as it is now known that the refraction correction varies as cos a (Figure 2). Thus it clearly establishes the value as an observational record.

The 27 stars – a brightness scale

Now we proceed with the identification for the ambiguous cases. Nityananda provides the brightness as a scale called *pramáṇa*, which is equivalent of the magnitude scale used today. The first (termed *prathama pramáṇa or ádyamána*) is the brightest; the second brightest is termed *dwimithi*, the third as *trimithi*; it mentions even a fourth one as *chaturtha pramána*. These scales are specifically described in the middle of the text after the description of stars of Leo. It states that brightest ones are first magnitude; intermediate ones are third and there are thousands of stars fainter than the 6th. This value of the magnitude helps us in the identification. For example, if there are two stars very close to each other, based on the brightness scale, the correct one can be identified.

There are a few cases where brightness is not specified. For example for *Krittika*, it is described as looking like an arrow and like a fire. We find the notation *agnimána* – fire like for two more cases of nebulosities. One is the faint group in

Table 1. Comparison of coordinates of Aśvini (β Ari) in different texts

	Surya Siddhántha (~500 AD)	Nityananda (1639 AD) Epoch for stars (600 AD)	Mahendra Suri *Siddhánta Rája* (1400 AD)	Malayendu Commentary on *Siddhánta Rája* (1428 AD)#	Padmanabha *Yantra Kiraṇávali* (1423 AD) mentions a correction of 15° for *Dhruvaka*	Padmanabha's values after correction for precession to 1550 AD	Samanta Chandrashekhara *Siddhánta Darpaṇa* (~1880 AD)
Dhruvaka	8°0′	14°6′	25°27′	25°21′52″	+8°23		10°07′
Vikśepa	+10°0′	+7°50′	+7°20′	+7°20′	+10°55′		+8°29′
Right ascension*	7°46′	12°52′	23°35′	23°32′	6°57′	21°48′	9°11′
Declination*	12°54′	13°31′	17°14′	17°32′	14°25′	18°46′	8°27′
Right ascension**	8°30′	9°54′	20°45′	20°45′		22°30′	26°49′
Declination**	12°59′	13°32′	17°48′	17°57′		18°34′	20°12′

*Calculated from *Dhruvaka* and *Vikśepa.*

**From *Stellarium* for the epoch.

#The foot note to the table indicates another year 1637 AD; extended from 1437 AD.

Table 2. The error $\Delta\delta$ as derived from two measurements provided by Malayendu – the declination derived from maximum altitude and from *Dhruvaka* and *Vikśepa* measures

Star	*Paramónnatámśa* and derived declination	Declination (*kranti*) derived from *Dhruvaka*	$\Delta\delta$ diff derived from columns 2 & 3	Declination (1428 AD) from stellarium
Asvini/β Ari (used for fixing latitude)	78°02′/16°40′	16°40′37″	0°0′37″	17°56′
Rohini/Aldeberan/α Tau	76°53′/15°25′	15°22′7″	0°2′53″	15°11′
Chitra/Spica/α Vir	53°21′/–8°07′	–6°55′38″	1°12′22″	-8°08′
Magha/Regulus/α Leo	75°10′/13°42′	13°39′19″	0°3′44″	14°39′
Svati/Arcturus/α Boo	84°1′/22°33′	22°40′15″	0°7′15″	22°15′
Jyestha/Antares/α Sco	35°3′/–26°25′	–24°30′35″	1°54′25″	–25°20′
Abhijit/Vega/α Lyr	80°4′/38°28′	38°34′35″	0°6′35″	38°18′
Lubdhakabandhu/Procyon/α CMi	66°36′/–5 8′	–6°14′36″	1°6′36″	–6°32′

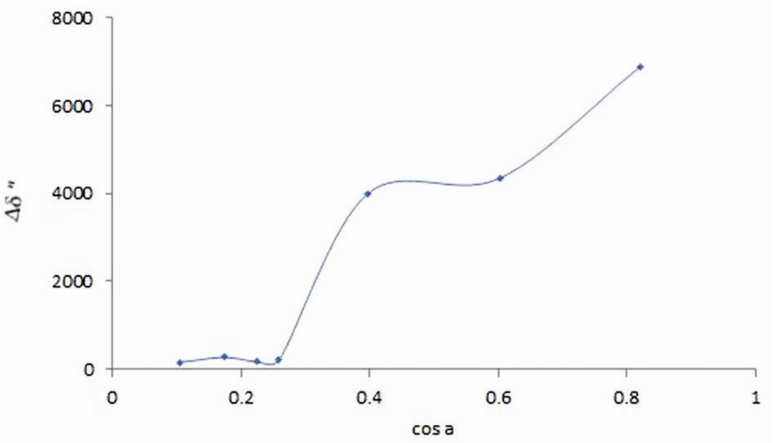

Figure 2. Variation of the difference in (″) between the values of the declination from the tables of Malayandu (see Table 2).

Cancer, including M 44 an open cluster. The other is the region near Milky Way.

Karaṇapaddhathi, *Graha Lághava* and other texts give the same values as provided in *Surya Siddhántha*. Although Padmanabha lists the same values, he adds that a correction of 15° should be made and that brings the date to about 15th century (Ohashi[10]).

Table 3 lists the coordinates of all stars mainly from Nityananda; a comparison is provided from the sources cited above along with the relevant coordinates derived from *Stellarium.*

Bharani has been identified as 41 Ari; however based on the values declination we can find that it was γ^1 Ari. The identifications by Malayendu and Nityananda are two different stars; hence there is bound to be confusion if one uses only the longitude for fixing the star.

The last column of the Table 3 gives our identification in bold along with the justifications; the deviations with other works, if any, are also provided. We note that in case of faint stars the identification is different by different observers.

Revathi is identified as ζ Psc; however the coordinates agree with ε Psc. It is quite possible that the two as a group was called *Revathi*. The former is now known to have a high proper motion based on Hipparcos data, implying that

Table 3. identification of stars (indicated in bold) from the catalogue of Nityananda and comparison with other catalogues

Name	*Dhruvaka* ° ′ ″	*Vikśepa* ° ′ ″	Magni-tude	RA (calc)	Dec ° ′ ″	RA (600)	Dec (600) ° ′	Max altitude	Driksh-uddha corrected values	Decli-nation from max a ° ′	Identification/remarks
Asvini	14°6′	7°50′	3	0h 52m	13 31	00h 40m	13°26′				β **Ari**
	8	10		0h 30m	13 11						Surya Siddhantha (SS) from S&L
	8 23	10 55		01h 28m	20 16	01h 27m	18 20				β **Ari** Padmanabha's values AD 1428
	25 27	7.2				01h 27m	16 56				Pingree identifies γ Ari – Mahendra Suri's values
Malayendu's	25/21/52	7/20			16/40/37			78/2	0/22/22/18	16/41	Name Suratyena matches with Sheratan
Bharani	23°31	5°45	2	01h 26m	15 55	01h 30m	15 00				ε **Eri**
	20°	12		01h 13m	20	01h 30m	20 46				**41 Ari** (Abhyankar) based on SS coordinates
	21 7	12 16		02h 14m	26 15	02h 21m	25 08				41 Ari Padmanabha's values (AD 1428)
Krittika	38 24	3°45	?	02h 23m	18 08	02h 26m	18 48				η **Tau** magnitude not specified; Sharognimanam – looks like arrow of fire no ambiguity
Rohini	49 10	5°15′S	1	03h 22m	15 2	03h 56m	15 2				α **Tau** no ambiguity
	31/43/52	5 10S					15/22/7	76/53	2/2/23/23	15/25	Malayendu-corrected Dhruvaka 62/23/23
											Davara name matches with Al deberan
Mrigasira	68 7′30″	13 30S	1	04h 20m	8 10	04h 18m	7 49				λ **Ori** with dec difference
	63	10S		04h 03m	11 25						SS values
	62 2	10 9S		05h 03m	12 26	05h 08m	9 28				λ **Ori** Padmanabha's values AD 1428
Ardra	78 07	–7 12	1	05h 08m	15 51	05h 16m	16 20				γ **Gem**
	96 33	–39 10									Pingree – α CMi based on Mahendra Suri's value
	67 20	–9		04h 21m	13 13						SS values
	65 55	–11 6		06h 09m	16 35	06h 09m	16 41				Padmanabha's values AD 1428
Punarvasu	92 30	6	2	06h 11m	30	06h 18m	30 10'				β **Gem** no ambiguity
											Malayendu gives α Gem
Pusya	106 30	1	?	07h12m	23 55	07h 23m	22 14				δ Cnc
						07h 17m	23 49				**M44** Praesepe – a better choice since mag is not defined; dec is given as apratima (maximum 23.5)
	106	0		08h 13m	20 34	08h 16m	19 51				δ Cnc Padmanabha's values
	106	0		07h 10m	23 13						SS Values S&L identify δ Cnc
Aslesha	112 30	–6 55	3	07h 36m	14 46	07h 40m	16 18				α Cnc identified but error in dec
						07h 31m	10 34				ε Hya as suggested by S&L also does not match
	107 14	–6 53		08h 19m	13 25	08h 31m	13 40				α **Cnc** Padmanabha AD 1428
Magha	128 50	0 10	1	08h 46m	13 17	08h 51m	18 06				α **Leo** – error of 5°
	107 14	0		09h 46m	13 57	09h 41m	14 18				α Leo Padmanabha's values (AD 1428)
Malayendu's	141/23/52	0 10					13/39/19	75/1	4/25/11/28	13 42	Dhruvaka 145/11/28; in brackets 141/11/28
									4/21/11/28		Name Kalupubhatrasada matches with Qalb al Asad
Pu Phalguni	142 15	9 30	3	09h 39m	23 49	09h 39m	22 41				θ **Leo**
	147 58	12		10h 01m	24 33						θ Leo Padmanabha's values (AD 1428)
Ut Phalguni	150 24	12	1	10h 10m	24	10h 35m	22 12				β Leo
	155 30	12 47		10h 37m	22 47						β Leo Padmanabha's values (AD 1428)
Malayendu's	163/23/52	11 50		10h 59m	18 23		16/15/37	78/6	5/17/31/50	16 45	Malayendu's values

(*Contd*)

Table 3. (*Contd*)

Name	*Dhruvaka* ° ′ ″	*Vikśepa* ° ′ ″	Magni-tude	RA (calc)	Dec ° ′ ″	RA (600)	Dec (600) ° ′	Max altitude	Driksh-uddha corrected values	Decli-nation from max a ° ′	Identification/remarks
Hasta	155 45	22S	3	10h 31m	–9 43	11h 18m	8 49S				δ **Crv** error – dhruvaka is not explicitely mentioned
	170 3	11S		11h 24m	–8 38	11h 04m	9 50S				Padmanabha’s values agree better with γ CrV
Citra	180	0									α **Vir** no ambiguity
Malayendu's	195/33/52	2 0		12h 35m	2		6 55 38S	53 /21	6/14/23/41	8 07S	simak azal matches with Arabic name
Svati	182 9	31 19	1	12h 8m	30 22	13h 11m					α **Boo no ambiguity** error in dec assumption-dhruvaka to be same as that of Citra
Malayendu's	195/53/52	31 30		12h 58m	24 01		22/40/15	84 01	6/29/22/41	22 33	Simak am rame
Tulaikasikha	204 28	0 45S	3	13h 30m	10 17S						α **Lib**
											May be same as Visakha
Visakha	208 52	–1 45	4	13h 47m	10 48	13h 35m	–9 32				α **Lib** if Vikshepa is positive
	213 33	44 30									Pingree identifies with α CrB with dec +32
	212 11	–2 52		15h	–14 30	14h 23m	–13 54				α Lib Padmanabha's values - errors in RA & dec
Tulanyasikha	208 33	9 45	3	13h 45m	1 45S						β **Lib**
Anuradha	251 33	–23	3	14h 36m	–17 26	14h 39m	–17 37				δ **Sco** no ambiguity
Jyeshta	228/52/30	–4 40	2	15h 04m	–22 11	15h 05m	–24 30 35	35 03		–26 25	α **Sco** no ambiguity
Mula	243 7	13 33S	?	16h 02m	–34 27	16h 00m	–34 39				λ **Sco** no ambiguity magnitude given as agnimita
P Ashadha	251 33	6 45S	4	16h 39m	–29 03	16h 51m	–29				δ **Sgr** possibe
Jaladaivatha						16h 35m	–29 02				ν **Sgr** also agreeable
	254 33	5 22S		17h 25m	–29 34	17h 49m	–29 53				δ Sgr Padmanabha’s values AD 1428
U Ashadha	260	5S	3	17h 12m	–27 7	17h 28m	–26 40				σ **Sgr** no ambiguity
Vaishvadeva	260 10	5S		18h 21m	29S	18h 36m	–28 15				τ **Sgr** agrees well – Padmanabha’s values AD 1506
Abhijit	264 55	6 20	1	17h 38m	38 30	17h 49m	38 12				α **Lyr** no ambiguity
Dhanishta	290	36S	3	19h 27m	14	19h 34m	11 49				α **Del** – if vishepa is taken as +36
						19h 31m	10 36				β **Del** also differs in declination
	280	30		18h 44m	6 11						β Del as suggested by S&L based on SS values
	287 30	25 19		20h 20m	5 5	19h 31m	5 16				β **Aql** Padmanabha's values AD 1428
Satabhisa	315	0 30S	3	21h 11m	–16 55	21h 38m	–14 32				λ **Aqr**
						21h 30m	–20 41				τ Aqr also possible
	325 20	0 20S		22h 47m	–8 32	22h 40m	–10 09				λ **Aqr** Padmanabha's values AD 1428
Puravbhadra	326	24	3	21h 54m	11 4	21h 55m	8 4				α Peg
Ajapa	325 20	23 45		21h 48m	15 42	22h 40m	12 35				Padmanabha’s values AD 1428
U Bhadra	338	26	3	22h 40m	17 36	22h 58m	21 28				β **Peg**
Ahirbudhnuya	336 50	25 54		22h 35m	23 28	22h 40m	25 26				β **Peg** Padmanabha's values AD 1428
Turangaasa	338 25	31	2	22h 44m	22 15						
Hayaamsha	351	31									Mahendra Suri's values
Revati	355	29′	?	23h 43m	27	0h 01m	–2				ζ **Psc** magnitude is sukhsmataram – very faint
Pourshna						23h 50m	0 11				ε **Psc** – brighte naked eye visible also is possible
	0	0									Padmanabha’s values

the angular separation has changed over these centuries.

The technique of measurement

All the texts available for study describe instruments used for measurement; however none describes the actual procedure. This has been criticized heavily by all scholars. With the simple techniques available for naked eye measurements, Saha and Lahiri[5], Chandra Hari[12], Abhyankar[2] have deduced the probable procedure, which basically employs the noon shadow measurement. The instruments they had were very simple table top devices for example a 12″ gnomon, which can lead to error of 1° for the noon transit measures of the sun. In the case of stars, an armillary sphere with a sighting tube would yield slightly better results.

The procedure (Chandra Hari[12]) involved in noting the time and shadow length at noon. This fixes the declination of the sun. After dusk the meridian passage of the bright star is noted. This gives the declination of the star. Simultaneously the reading on the great circle joining the ecliptic pole to the equator also is noted. This gives the *Vikśepa*, which will be slightly different from the declination. The interval between the meridian passage of the sun and the star will give *Dhruvaka*.

It is not clear as to how the time interval was measured; it can be shown that it was not essential since the angle corresponding to *Dhruvaka* can be read out from a standard device like the armillary sphere.

Here is an example:

Consider the measurement being done from Bengaluru (latitude 13°) on July 29th. The meridian passage of the sun occurred at 12:28 IST and the altitude was 84°. This gives the declination of the sun as +19°. Using this we can find the longitude λ since

$$\sin \delta = \sin \lambda \sin \varepsilon,$$

which gives longitude λ, of the sun as 128° (ε is the obliquity of the ecliptic).

In the evening we measure the altitude at meridian transit for Antares (*Jyeshta*) occurring at 20:23 IST and the altitude is 50.5°.

Therefore, the declination, δ, of Antares is –26.5°.

The astrolabe has also the ecliptic marked. The angle read out from that scale was –5°, which is the *Vikśepa*, β^*.

Vikśepa and declination are related by

$$\delta = \beta^* - \sin^{-1} \{\sin \lambda^* \sin \varepsilon\},$$

which gives the *Dhruvaka*, λ^*, as – 63° or 243° or 357°; 243° suits here.

Alternately the time interval between the meridian passages of the sun and Antares can be used for getting the *Dhruvaka*. The measured interval is 7 : 55 which gives the angular separation as 120°. This is to be added to the longitude of the sun, 128°. Therefore *Dhruvaka* of Antares is 248°.

As can be seen there is an error in the calculation using the time difference, because the time difference of meridian passages will correspond to difference in right ascension and not *Dhruvaka*. (*Dhruvaka* is measured along the ecliptic.) This has been pointed out by Plofker[13].

An error of 1° in *Vikśepa* will result in almost 4° for *Dhruvaka.*

The same technique is described by Middleton[13]. He describes a plate resembling an astrolabe which was used for conversions.

The errors in the measurements have been pointed out by earlier authors. The observational record of *paramónnatámśa*, which the maximum altitude (meridian passage) can at best be accurate to 0°.5 and the other values are derived from calculations. On the other hand with an astrolabe like instrument, *Dhruvaka* also can be read out. A clue to this comes from the study of Plofker[14], who pointed out that the observers approximated the *Vikśepa* itself as declination for planets, which are generally close to the plane of ecliptic (therefore the errors are small).

There is no clue on the type of devices that were used prior to the introduction of astrolabe and therefore on how the correction to be applied for precession was incorporated on the dials. *Aśvini* is identified as γ Ari by Pingree[4] and others have identified as β Ari. This confusion arises basically because of the *Dhruvaka* measurements. Samanta Chandrashekhar calls Aśvini as zero (origin for longitude measures, the First Point of Aries) and measures the *Dhruvaka* and *Vikśepa* of the *yogatara* named *Aśvini*. Saha and Lahiri[5] considered the epoch of 1950 and converted all measurements to this epoch. Such an extension is not possible for the values provided by Samantha. It is better to compare the values of declination rather than the right ascension.

Hipparcos has made precise measurements of the proper motion and parallax of all these stars. The approximate epoch of measurements can be read out from the text and the declination may be extrapolated. Here is the example for *Rohini* (Aldeberan). The measurements by Malayendu gives *Dhruvaka* as 2^R (2^R = two zodiacal constellations = 60°) 1°22′52″, which means 61°22′52″. He also provides *Drkshuddha* (corrected from observation) as 2^R 2°36′13″, which means 62°36′13″. Using this value we can calculate the declination as 15°12′. The declination in the table is 15°22′7″. From Hipparcos data this declination applied to 14th century which agrees within the observational errors for the date of the work.

Nityananda lists the values of *Dhruvaka* which are corrected for precession, in case of three stars specifically mentions *ayanakarmayukta*.

Discussion

We have now a list of the 28 stars as obtained from different texts with the coordinates fixed from the declination value.

The procedure for estimating the declination has been described in great detail by Plofker[14]. The approximations to be done for smaller values of *Vikśepa* have been pointed out. However, such approximations are applicable case of planets, as their latitudes are small; but not for stars of higher latitudes. This becomes especially obvious in the case of Sirius.

Although Mahendra Suri was the first to write a book on the astrolabe, the values provided by him for *Dhruvaka* and *Vikśepa* seem to be in great error; they were simply reproduced from original Islamic source which in turn agree with the values provided by Ptolemy (Ohashi[7]). Later, Malayendu Suri provided the commentary and tabulated the coordinates. By comparing these values, we may infer that they were derived from actual measurements.

It appears that not much weightage was given to these tables. Subsequent authors continued to provide the coordinates from *Surya Siddhántha*. This

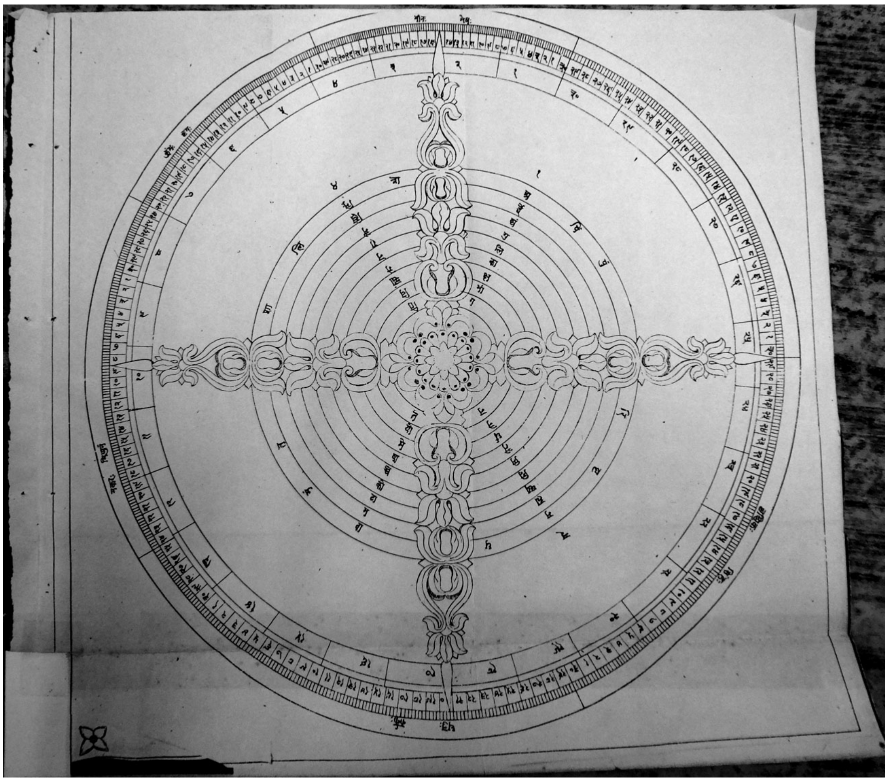

Figure 3. The (silver) instrument used in Kota during the 19th century, described by Middleton, reproduced from the *Journal of the Asiatic Society*.

makes it difficult to fix the epoch or even cross check with the actual values.

Most of the subsequent books concentrated on the movement of planets, prediction of eclipses and phenomenon related to planets. Extension to other stars, though not many, is in progress with a few star tables available for comparison.

As discussed above, the book *Siddhántha Rája* by Nityananda provides coordinates of stars based on observation. Ohashi has studied *Yantra Kiraṇávali* by Padmanabha and provides the *Dhruvaka* and *Vikśepa* of stars, also based on observations.

Almost all the texts provide the coordinates for *Lubdhaka* (Sirius) and *Agastya* (Canopus); it is puzzling that the values of *Vikśepa* are more or less the same in all cases irrespective of the epoch, while in the case of *Dhruvaka* there is a variation. This can be interpreted in two ways: (1) They followed the method of measuring the angles at the meridian passage; the values of *Vikśepa* have observational errors; (2) Alternately they used the time difference method for measuring *Dhruvaka* but did not correct it for precession.

Nityananda clearly mentions that he is *citing* the coordinates of *Agastya* (he states – knowledgeable people state so); perhaps the star was not visible for him to make actual measurements from his place Indrapuri, (as mentioned by him at the end of the text).

Abhyankar pointed out that *Dhruvaka* and *Vikśepa* system is independent of the epoch, giving a clue on the instrument that might have been used for this purpose. An instrument like the *Kránti Vritta* with graduation along the ecliptic reads out the *Dhvarka*. As it was only the difference that mattered for calculations, the epoch being fixed otherwise, the readings taken on the face value seem to be in error.

This resolves the ambiguity in the coordinates which can be used for extrapolated calculations; the residuals are experimental errors, as can be tolerated of a small table top instrument.

It remains a question as to why the tables continued with the values of *Surya Siddhántha* epoch. One possible reason may be inferred by a silver instrument in Kota has been described by Middleton[13] and is reproduced in Figure 3. Such inherited instruments had these numbers (*Dhruvakas–vikśepas* and/or longitudes–latitudes) engraved. Conversion of these readings to the current date was perhaps common knowledge and not explicitly mentioned in the texts.

Karaṇapaddhathi lists the longitudes as the double the actual values. One of the reasons may be because the angles were measured from a device which has to be viewed the reflection from a water surface. Such a technique has been described in *Siddhántha Śèkhara* by Sripathi in the 11th century (Bhat[15]). Incidentally, this text also provides *Dhruvakas* of the 27 stars; the values are the same as these mentioned in *Surya Siddhántha*.

Conclusions

The coordinates of stars as listed in various astronomical texts have been studied with the purpose of understanding the techniques that were devised for measurements. Most of the earlier attempts were based on extrapolating the precession corrections, leading to confusions. This work described the actual observational aspects and possible reasons for retaining old values for tabulation. In the process, it also revealed the finer observational details like estimates of brightness measures even for nebulosities. A comparison with coordinates from *Stellarium* showed the refraction and other instrumental effects contributing to the errors.

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