Observational records of stars in Indian astronomical texts

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In an effort to search observational records of stars in the Indian astronomical texts, we have compiled all bright stars in various texts from Sūryasiddhānta to Siddhāntadarpaṇa by Candraśekhara Sāmanta of the 19th century, totalling to 106 based on the listed coordinates. Using the 27 nakṣatras on the ecliptic, used for fixing the position of the solar system bodies, the coordinates were matched for the epochs of the catalogues. This resolved some ambiguity with respect to the identification of faint stars and provided a means to extend the method to other stars outside the zodiac. We have specifically chosen those lists which are characterized by observations that are highlighted in the discussion. Our study reveals that a scale similar to the magnitude scale of brightness (currently in use) was in vogue. The origins of the names are also described.

Standardizing the coordinate system

Coordinates of stars in all texts of Indian astronomy are expressed in *Dhruvaka* and *Vikṣepa* (see Figure 1); exact equivalent terms are not found in texts on modern spherical astronomy. In Figure 1, 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 point *B* is called *Dhruvaka*. The angle measured along the great circle passing through the pole of the ecliptic is called *Vikṣepa* (Figure 1).

Polar longitude and latitude are the terms that have been coined by later investigators. Modern textbooks define longitude and latitude relative to 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 sets of coordinates are inter-related by trigonometric relations to transform one set of coordinates to the other. Similarly, *Dhruvaka* and *Vikṣepa* 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 by Abhyankar[2] and Chandra Hari[3] discusses the advantages of the *Dhruvaka–Vikṣepa* system. The coordinates have been described in the verses or prose is encoded in the form of phrases in various texts.

The conversions of the coordinates can be done using trigonometric relations. This is essential to compare the coordinates as derived from the current ephemeris. 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.

In an earlier work, we examined (Pai and Shylaja[4], hereafter called paper I) the identification of 27 stars named *Yogatāras* (junction stars) with those that are conventionally known to us now. One of the earliest studies that provides a list is by Colebrook[5] for stars from the *Sūryasiddhānta*. Other texts with the list of stars are by Mahendra Sūri (who translated the manual *Yantra Rāja* using the astrolabe into Sanskrit for the first time in the 13th century[6]), Malayendu[7] (Commentary on *Yantra Rāja*, 15th century), Nityānanda (who wrote *Siddhāntharāja*[8]; 15th century), Padmanābha (author of *Yantrakiraṇāvali*, 16th century[9]), Putumana Somayājī (*Karaṇapaddhati*, between 16th to 18th century[10]) and *Siddhāntadarpaṇa* of Candraśekhara Sāmanta (the last traditional astronomer, 20th century). *Karaṇapaddhati* gives longitudes and latitudes and provides methods to derive one set of coordinates from the other. The methods of comparison are demonstrated for *Asvini* (β Ari; see table 1 in paper I).

The texts by Nityānanda, Padmanābha and Malayendu provide direct measurements; therefore, comparisons are easy and reliable. Malayendu lists another quantity named *Paramonnatāṃśa*, which is a measured parameter. He explains how to get the declination from this reading given that the latitude of the place is 28°39′0″, clearly indicating that it is a measured quantity. As seen in Figure 2,

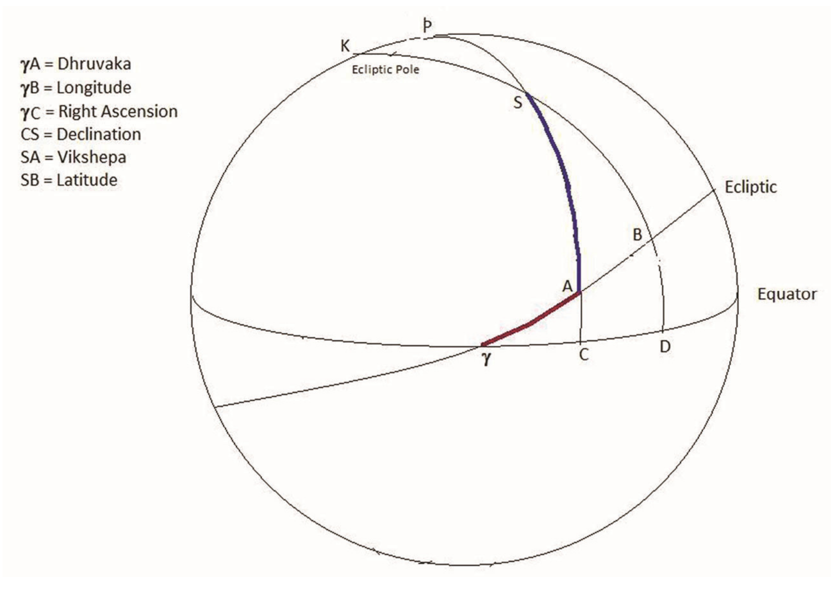
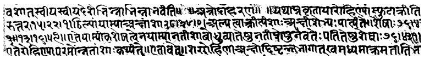


Figure 1. Coordinates *Dhruvaka–Vikṣepa* and right ascension–declination.

it is the maximum altitude, obviously corresponding to the meridian passage (Figure 2).

He gives a practical example (उदाहरणं/ *udāharaṇam*) of this for the star *Rohiṇī* (Aldeberan) as follows:



अत्रोदाहरणम् । यथात्र कृताया रोहिण्या स्फुटक्रान्तिरुत्तर १५ । २२। १ । ...... याम्या अक्षांशा २८ । ३९ । ० । ...... अल्पत्वाद् क्रान्त्यंशाः अक्षांशेभ्यः पात्यंते । शेषाः १३। १६ । ५९। ..... नवतेः पतितेषु शेषाः ७६ । ४३ । १।

The content of the above Sanskrit passage is as follows:

The true-declination (*sphuṭakrānti*) of the *Rohiṇī* is 15°22′1″ north and the latitude of the place is 28°39′0″. Subtract the declination from the latitude since the magnitude [of the declination] is lesser [than that of the latitude]. The difference between these two is 13°16′59″. Subtract this from 90°. The result is the angle at the meridian transit which is called as '*Paramonnatāṃśa*'. This is clearly mentioned in the above passage:

'एते रोहिण्या: परमोन्नतांशाः कथ्यते। These are the *Paramonnatāṃśas* of the *Rohiṇī*'.

It means that the observed maximum altitude (*Paramonnatāṃśa*) for *Rohiṇī* is 76°43′1″.

Malayendu provides both the declination and maximum altitude; the former is given accurate to degrees, minutes and seconds. There is a small difference in the values of declination derived directly from maximum altitude. It can be either treated as instrumental error or a correction deliberately applied (may be for refraction). Noticing that all the values of *Dhruvakas* (for 32 stars) end with 33′52″, we can infer that they are calculated and/or corrected. Thus, the measured quantities are only *Vikṣepa* and *Paramonnatāṃśa* (given values terminate with degrees and minutes).

Karaṇapaddhati and many other texts provide formulae for calculating declination from the longitude and latitude measures. The word '*Vikṣepa*', in many *karaṇa* texts, refers to latitude itself. This can be understood in the context of deriving the planetary positions which are generally close to the ecliptic, and the error is small.

We have converted the given coordinates of all stars to Right Ascension and declination, so that comparison becomes easy. This has been explained in detail earlier (Paper I).

Nityānanda lists the values of *Dhruvaka* which are corrected for precession. In case of three stars specifically mentions *āyanakarmayukta*. The text reads

...एतानि पञ्चैव हि यन्त्रदृष्ट्याधीतानि कुम्भे ...

'....These five are the ones which have been studied by the observation made using the instrument[s] and are pertaining *Kumbha* ...' The reason for the specific mention of these five is yet to be understood.

Brightness scale

Nityānanda provides the brightness as a scale called *pramāṇa*, which is equivalent of the magnitude scale used today. The first (termed *prathamapramāṇa* or *ādyamāna*) is the brightest; the second brightest is termed *dvimiti*, the third as *trimiti*; it mentions even a fourth one as *caturtha-pramāṇa*. These scales are specifically described at the middle of the text after the description of stars of Leo. It states that there are thousands of stars fainter than magnitude 4. 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 intended one can be identified.

The verse (numbered 30) which describes this is as follows:

यदाद्यमानं महदेव तत्स्यात् मध्यं
त्रिमानं किल षष्टमानम् भं
सूक्ष्मभाभमनेकतारम् ||

It translates as:

The [term] *ādyamaana* is [referring to the] stars of biggest/brightest (*mahat*) [magnitude]. The [word] *trimāna* refers [to the stars] of medium (*madhya*) [magnitude]. [Similarly,] there are many stars that are tiny/fainter [magnitudes] which are referred to as *ṣasṭhamāna*, shining in the sky.

We were particularly puzzled by the use of the word '*agnimānam*' for Pleiades. Although the *bhūtasaṅkhyā* system of numbers puts this as 3, we tend to believe that this may represent a nebulous source. We find that for stars of magnitude 3, other words like *Rāma* and *Guṇa* are used. The word *Agni* is used again for *Pushya* corresponding to δ Cnc; however, the coordinates match with the cluster Preasepe, which also appears like a nebula (diffuse object) to the naked eye. The third instance of the use of *agnimāna* is in Leo; the coordinates agree with i Leo, a double star.

The star list based on the coordinates points to a small region in the sky. Within the observational errors and errors in fixing the epoch, these magnitude values offer the best possible identifications.

Discussion

We have a list of 84 stars from Nityānanda, including the 27 stars of the zodiac. We have 22 more from Malayendu, eight

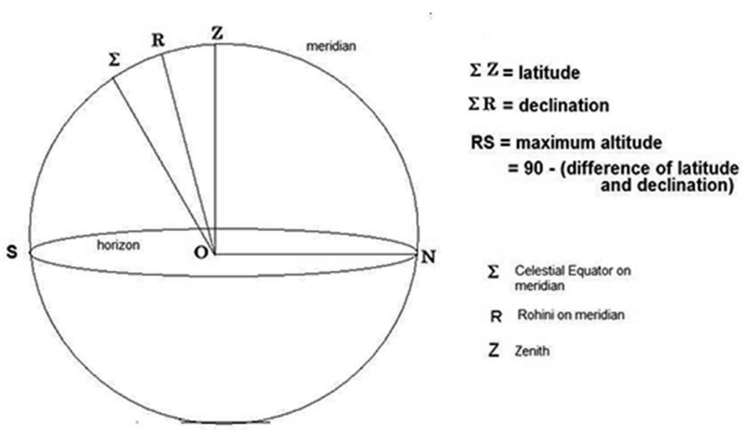


Figure 2. Explanation of the relation between maximum altitude and declination.

Table 1. Identification of stars from the catalogue of Nityānanda and comparison with others

Star	Dhruvaka ° ′ ″	Vikśepa ° ′ ″	Magnitude	Max. altitude	Identification/remarks
Nadyantaka	5 16′	53/45 S	1		γ Phe is the best choice for Nityānanda's values ν Eri masaf-al-nahar meaning valley of the river
	0/19/43/52	53/30 S		20/19	Malayendu; parsi name matches with ν Eri
Aśvanābha	0/6/43/52	27 01		88/23	α And Malayendu: name matches with Surrat al faras
Matsyodara	9 50′	+25 30′	3		β And: Nityānanda
	11 43 51	26 20		86 /18	Malayendu: Parsi name matches with Batn-al-Hut
Aśvinī	14°6′	7°50′	3		β Ari Nityānanda
	8	10			identified by S&L values from *Sūryasiddhānta* (SS)
	8 23	10 55			β Ari Padmanābha's values AD 1428
	25 27	7.2			Pingree identifies γ Ari from Mahendra Suri's values
	25/21/52	7/20		78/2	Malayendu; name matches with Sheratan
Kartitakara	0/26/43/52	51/20		63/7	β Cas Malayendu; name matches with Kaff al Khadib
Āptapāṇi	14/33	50/50	3		α Cas is the best match :Nityānanda
Yama	22	66S	8″		α Eri; Sāmanta Candraśekhara (1875 AD), magnitude is given in *vikalas*
Pīṭhamūla	16/0	45/45	3		γ Cas is the best match: Nityānanda
Bharaṇī	23°31	5°45	2		ε Eri: Nityānanda
	20°	12			41 Ari (Abhyankar) based on SS coordinates
	21 7	12 16			41 Ari Padmanābha's values
Supīṭha	26 55	50/50	3		δ Cas based on differences in RA: Nityānanda
Kṛttikā	38 24	3°45	?		η Tau Nityānanda; magnitude not specified;
	37 30	5 0			sharognimanam – looks like arrow of fire
	37 46	4 35			No ambiguity with SS or *Yantrakiraṇāvali: Padmanābha*
Mānuṣaśīrṣa	35/37	22/0			β Per – name matches with Alogol
Malayendu	48/33/52	23 10		80/1	Malayendu – names as *Pretaśira*
Rohiṇī	49 10	5°15′S	1		α Tau no ambiguity
	61/43/52	5 10S		76/53	Malayendu – Parsi name matches
	49 30	5S			SS – no ambiguity
	49	40°36′S			Padmanābha
Nṛpārśva	42 45	29 20	2		α Per no ambiguity
	53/43/52	30 0		71/53	Malayendu: names as *Manuṣyapārśva*
Hutabhuk	52	8			*Sūryasiddhānta* and all texts
	58	15	6″		β Tau Sāmanta Candraśekhara

from Padmanābha and 10 from Candraśekhara Sāmanta. Thus, at a first glance, it appears that this is a fairly long list. However, upon careful analysis of the positions we find that there is considerable overlap; the same stars are listed with different names. There are two entries called *dhruvākṣa* and *pūrva-dhruvākṣa*. While the first reference is for the pole which is also cited as *Dhruva-tāraka*, the latter matches with the position of the pole of an earlier epoch.

We observe that the names provided in the list are not all necessarily of Indian origin. *Matsyodara* (belly of a fish) appears to be an original Indian name. The fish that is imagined here for which this star should be the belly has got to be huge. Although there are frequent references to a fish in the sky, its dimensions are not defined (S. R. Sarma, 2016, pers. commun.).

The stars of the constellation Cassiopeia are referred to as *Supīṭha*, *Pīṭhamūla* and so on. This interpretation also seems to be originally Indian. Perhaps the constellation was imagined as a chair. We also find some names hitherto unknown.

Some of the names are derived from the Arabic origin. Malayendu's list gives the original names as '*pāraśī-nāma*' indicating the name from Persia. The names are literal translations in many cases. For example, the star in the constellation of Pegasus (the flying horse) is given in one list as *Turagāṃśa* and in the other as *Hayāṃśa*. (*Turaga* and *Haya* both mean horse).

Almost all the texts provide coordinates for *Lubdhaka* (Sirius) and *Agastya* (Canopus); it is puzzling that the values of *Vikṣepa* are more or less same in all cases irrespective of the epoch, while the case of *Dhruvaka* there is a variation. The *Sūryasiddhānta* list has five more stars – *Brahma-Hṛdaya*, *Hutabhuk*, *Apa*, *Apavatsa* and *Agni*. *Brahma-Hṛdaya* is usually identified with Capella. Candraśekhara Sāmanta identifies it with β Aur, although the coordinates do lead to Capella. All texts based on *Sūryasiddhānta* (copies or commentaries) give the same coordinates, irrespective of the epoch. Therefore, we may infer that they were copied from the original of a particular epoch and may not represent observed coordinates. Nityānanda clearly mentions that he is citing the coordinates of *Agastya* (he states – knowledgeable people say so); perhaps the star was not visible to him to make actual measurements from his place Indrapuri (this name is mentioned by him at the end of the text). We encounter similar problems with other stars.

The list provided by Candraśekhara Sāmanta is complete only for 27 stars. The other stars are listed separately. The confusion on the name *Prajāpati* is apparent here. He declares that *Mṛgavyādha* is sometimes called *Prajāpati*. His coordinates actually match with Procyon, α CMi. He lists *Lubdhaka* (α CMa) separately. He also lists lesser known stars like *Ilvala*.

The seven stars of the *Saptarṣi* are popular all over India. However, there has always been confusion on the names of the individual stars. The catalogues used in this work do away with this confusion by stating the first *Muni*, the second *Muni*, and so on. The doublet is identified as *Vasiṣṭha* and the last one as *Marīci*. However, there is no mention of the companion of *Vasiṣṭha*, which is known to all Indians as *Arundhati*.

The catalogue

Siddhāntarāja by Nityānanda provides coordinates of stars based on observation. Ohashi[9] has studied *Yantrakiraṇāvali* by Padmanābha and provides the *Dhruvaka* and *Vikṣepa* of stars, also based on observations. The stars have been arranged in groups according to the zodiacal constellations by Nityānanda. The groupings of stars are done according to the zodiac constellations. For example, all the stars within the interval of *Dhruvaka* 0° to 30° are included in the group called Aries irrespective of the value of declination. The stars under the group of Aries and Taurus are listed in Table 1 and are arranged in the order of increasing Right Ascension. The table includes stars of paper I. It is also planned to prepare a chart of these stars indicating the errors from different catalogues in fixing the position.

The names of the stars in Table 1 can be used to understand the influence of the Arabic/Persian astronomy. The names *Nadyantaka*, *Aśvanābha*, *Nṛpārśva/Manuṣyapārśva*, *Mānuṣaśīrṣa* are literal translations of Arabic names. *Matsyodara*, *Yama*, *Āptapāṇi*, *Supīṭha*, *Pīṭhamūla* and *Hutabhuk* are original Sanskrit names. We are not able to decode the meaning of *Kartitakara*.

It remains a question as to why the tables continued with the values of *Sūryasiddhānta* epoch. One possible reason may be inferred by a silver instrument in Kota has been described by Middleton[12]. Such inherited instruments had these numbers (*Dhruvakas – Vikṣepas* and/or longitudes – latitudes) engraved. Conversion of these readings to the current date was perhaps common knowledge and not explicitly mentioned in the texts.

Karaṇapaddhati lists the longitudes as double the actual values[10]. One of the reasons may be because the angles were measured from a device which has to be viewed as a reflection from the water surface. Such a technique has been described in *Siddhānta-śekhara* by Śrīpati in the 11th century (Bhat, pers. commun., 2015) and in *Grahalāghava* by Ganesha Daivajña in the 14th century[13].

It is planned to prepare a complete catalogue of all the coordinates, conversions for the epoch, and the corresponding charts for the area which justifies our choice of the star. The *Bhūtasaṅkhyā* system used in the text by Nityānanda is interesting and the technique used for representing fractions of a degree is also quite indigenous. We are preparing a separate note on this aspect.

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