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IDENTIFICATION OF THE STARS OF THE *SAPTARṢI MAṆḌALA* AND ITS VICINITY

B.S. Shylaja
Jawaharlal Nehru Planetarium, High Grounds, Bengaluru 560001, India.
Email: shylaja.jnp@gmail.com

and

Venketeswara R Pai
Indian Institute of Science Education and Research, Pune 411008, India.
Email: venkateswara@iiserpune.ac.in

Abstract: The *Saptarṣi Maṇḍala* is the group of the seven main stars in the constellation Ursa Major. It is familiar to all the observers of the northern hemisphere, and is cited in both astronomical and non-astronomical texts. Here, we study the positions of the seven stars based on their co-ordinates provided in different star catalogues. This also helps in fixing the epochs of the catalogues. We also discuss the relatively unknown constellations *Trivikrama* and *Śiśumāra* (or *Śiṃśumāra*). We also discuss the constellation corresponding to Ursa Minor, as a fish with the Pole Star at its centre.

Keywords: Ursa Major, star names in Indian texts, *Saptarṣi Maṇḍala,* identification of *Śiśumāra, Dhruva, Pole Star,* the constellation *Trivikrama*

1 INTRODUCTION

The seven stars of the constellation Ursa Major are very well known in India by the name *Saptarṣi Maṇḍala.* References to this group can be seen in the literature of almost all languages in India. The names of these seven sages are also equally well known. The mythological stories give different sets of names, while the astronomical texts refer to them as the seven *ṛṣis* or *munis*. In fact, in most of the mathematical and astronomical texts, in the *bhūta-saṅkhyā* system of depicting numbers (where some specific objects denote individual numbers, for example the word 'eyes' refers to the number 2), the number 7 is represented by the word *muni*.

The seven stars can be identified in the sky without any ambiguity. Therefore, we can use them to fix the coordinates of other fainter stars. References to their positions are given in the context of the heliacal rising with the star Regulus (*Maghā*) which has been used by various scholars to fix the epoch of specific texts (e.g. see Abhyankar, 2007; Saha and Lahiri, 1954).

2 THE STAR LIST

The names of the individual stars differ in the texts. We have used *Āṅgirasa, Kratu, Marīci Pulaha, Pulastya, Pulastya Atri* and *Vasiṣṭha*, with their coordinates as defined in the *sācalya samhitā*:

> Vasiṣṭha is 10 degrees west of Marīci. Āṅgirasa is 7 [degreeoridnatess] west of the [star Vasiṣṭha]. Atri is 8 [degrees] west [of Āṅgirasa]. Pulastya is 3 [degrees] west [of Atri]. Pulaha is 10 [degrees west of Pulastya]. [The star] Kratu is 3 [degrees from Pulaha]. At the beginning of the yuga, Kratu was 5 degrees north at the beginning of Visṇu's nakṣatra [that is, 'Sravaṇa]. The [northern distances from the ecliptic] of the [seven] sages are, in order, 55, 51, 50, 56, 57, 60, and 60 [degrees]. Their motion is 8 arc minutes [per year] eastward. [With] their exceedingly small north-south motion [the seven sages] complete a revolution in 2,700 years. (Colebrook, 1809: 360–361).

Sule et. al. (2007) cite *Srīratnagarbha* as the first text stating *Arundhati*, along with *Vasiṣṭha (Mizar* and *Alcor)*. As we see below there seems to be no consensus on the order of names. Generally *Marīci* is always cited as the last. The catalogues used here have followed the order of increasing E-W coordinates, *Dhruvaka.*

We use the list cited above (Colebrook, 1809) because it specifically gives the names of the stars and their relative coordinates. It should be noted that instead of providing the *Dhruvaka* (D) and *Vikṣepa* (V) separately for each star he quotes only the differences. The coordinates D and V used here are different from those used in contemporary European texts, and refer to polar longitudes and latitudes (Saha and Lahiri, 1954). For objects close to the equator or ecliptic the error between these and the ecliptic latitude and *Vikṣepa* is not large (Pai and Shylaja, 2016). However, for these seven stars with latitudes more than 45° from the ecliptic, the differences are large; a small error in measurement can lead to a very large deviation from the position, as will be shown below.

The other source of star lists for this study is the star dials of astrolabes. A large variety of these instruments from India has been catalogued (Sarma, 2017), and many of them provide lists of stars although these are generally restricted to a small number of bright stars. It is interesting that most of the stars in *Saptarṣi Maṇḍala* do not appear in the star lists on the

majority of astrolabes. Many astrolabes only cite *Marīci*, a few also cite *Vasiṣṭha*, while a few more cite three of the seven stars. Only one of them (D001, the large astrolabe at Jaipur) lists all seven stars, but only the names are written on the rete and the coordinates are not included. Consequently, we could not use this astrolabe for our research.

Mahendra Sūri referred to the astrolabe as *Yantrarāja*, and in CE 1370 he prepared a manual, written in Sanskrit, for its use. The procedural details, including a list of stars, were translated from the original Persian text, and included the epoch of the coordinates. Subsequently Malayendu, a pupil of Mahendra Sūri, wrote a commentary on this text in CE 1377–1382 (Ôhashi, 1997). The star list in this manual provides various observed parameters like the readings on the instruments, the corrected readings for the epoch and also measured values of the maximum altitude. The *Pārasika* name (the original Persian name written in Sanskrit script) is helpful in identifying very faint stars, though they are very distorted. This text does not contain the names of the seven stars being researched here, but it does provide a very good resource for the cross-verification of the coordinates of stars.

Nityānanda wrote another text titled *Siddhāntarāja* (which has still not been published), which lists the coordinates of about 84 stars; and it is possible to identify almost all of them (Shylaja and Pai, 2018b). This source gives additional information on the brightness scale (magnitude) such as *ekamāna, dvimāna* and so on. Thus, it is a very reliable source for fixing the names and positions of stars.

The book *Yantra-Kiraṇāvali*, authored by Padmanābha in the fifteenth century also provides a list of stars. As always, the 27 stars of the zodiac help in fixing the positions.

We have calculated the coordinates of the *Saptarṣi Maṇḍala* stars using the star-lists provided by Nityānanda and Padmanābha, and these given in Table 1. Nityānanda's list also gives coordinates for three pairs of stars, designated *Yugmaka*, *Yugma* and *Yugmaka*, which are situated within the boundary of the constellation of Ursa Major, and they helped us in fixing the correction for the epoch. The entries in Table 1 drawn from Padmanābha's list are indicated by a P, while those taken from Nityānanda's list are marked with an N.

The astrolabe or any other instrument can provide the maximum altitude based on which *Vikṣepa* (V) has been assigned. As mentioned earlier, the error in *Dhruvaka* (D) is greater for higher latitudes. Nityānanda's list is presented in order of increasing longitude, with all stars from 0° to 3° listed under Aries (*Meṣa*), those between 30° and 60° grouped under Taurus (*Vṛṣabha*), and so on. Perhaps this was achieved using another table-top device like an armillary sphere. The values of *Dhruvaka* are given within that *rā'si* in degrees (bhāga/vibhāga) and its fraction. Therefore, to get the longitude we need to add 30 or a multiple of 30 as the case may be. Furthermore, the precession correction also has to be added. The result is that for some stars in UMa, we may have to add n × 30 and for some we may have to add (n + 1) × 30.

We converted all the D and V values to Right Ascensions and Declinations so as to facilitate the comparison with conventional star catalogues and software like Stellarium, Celestia or Night Shades (the methods are described by Abhyankar, 2007; Chandra Hari, 2007; and Saha and Lahiri, 1954).

Here we encountered another problem. Although the times of composition of the two texts are the fourteenth and fifteenth centuries, the copies available to us are more recent. The tabulated values in Nityānanda's work do not correspond to his epoch. As was pointed out by Pingree (1996), they have been borrowed from the original text. The manuscript used by us was procured from the Bhandarkar Oriental Research Institute in Pune, and was composed in *Vikrama-saṃvat* 1696 which corresponds to CE 1638. Padmanābha's tables again do not correspond to the epoch of his time. He mentions that 15° needs to be added to the *Dhruvaka* values. Ôhashi (1997) has studied two manuscripts, and the second one included the list of the stars under study here. They have been called 'minor stars' and appear in only one manuscript (Lucknow, 45888); there is a colophon that follows this tabulation giving the date as *samvat* 1634, *marga'sira masa, śukla pakṣa, ṣaṣṭi, bṛghuvāra* corresponding to CE 26 December 1576. For ease of comparison, we converted the D and V values to Right Ascension and Declination (as explained in Pai and Shylaja, 2016) corresponding to CE 1634.

The results are displayed in the Table1 and are also represented in the star map in Figure 1; the letters N and P are used to indicate the positions provided by the two sources.

3 THE CATALOGUES

We found no ambiguity in the identification of the stars, but the large errors in the declination values need to be understood. As mentioned earlier, an error in *Dhruvaka* leads to an error in longitude and this carries forward to the value of the declination.

Now, we shall discuss the coordinates of the individual stars as per the *Siddhāntarāja* of Nityānanda and the *Yantrakiraṇāvali* of Padmanābha.

3.1 Coordinates as Given by Nityānanda in the *Siddhāntarāja*

Here we provide a detailed description, the Sanskrit version, the translation and the coordinates of the *saptarṣis* as given by Nityānanda.

Nityānanda lists the names without providing the formal names—the first one is called *Munīndra* (The Great Sage), then follows *anyomuni* (the other sage), *purato-muni* (next muni), *tatpurato-muni* (further next), and so on. There is confusion with the 5th and 6th, since the 5th has been called *Vasiṣṭha*. Traditionally the 6th is called by that name; it has a visible companion and that has been designated *Arundhati*, (wife of *Vasiṣṭha*) in non-astronomical texts. The 6th is called *muni* and the 7th is *Marīci.*

Nityānanda's list gives the coordinates of the stars in the *bhūta-saṅkhyā* system. The values correspond to the coordinate *dhruvaka* (polar longitude) of stars ranging from 0 to 30°. That means, in the case of *dhruvaka*, that the actual coordinate has to be determined by adding 30 × *i* to the coordinate given in the text. Here, the '*i'* ranges from 0 to 11 depending upon the *ra'si* (zodiac constellation) into which the star is grouped. For example, suppose a star is situated in *karka-ra'si* (Cancer) and the coordinate given in the text is '*y'* degrees. In this case *i* is 3 and the actual coordinate of the star is (30 × 3) + *y* = 90 + *y*. However, the second coordinate *vikṣepa* is to be used without any modification.

The first star in the *saptarṣi* constellation is *munīndra.* The star *munīndra* comes after the star named *dhruvākṣa* and is situated in the *karka-rā'si* (the zodiac named Cancer):

सत्र्यंशसूर्यैः १२ | २० त्रिमितं सदोदग् गोलोचनैः २९ युग्मकमस्य संज्ञं |

One-third of a degree added to (*satryaṃ'sa*) 12 (*sūrya*) degrees [is one of the coordinates of the star which] shines with the third degree of brightness (*trimitam*) and directed towards the north always (*sadodag*). [The second coordinate] is 29 (*go* (9), *locana* (2)) and this [star] is known by the name *yugmaka.*

पश्चात्मुनीन्द्रो द्विमितिस्तुसिद्धैः २४ उदग्रवाब्धिप्रमितैर्जिनैश्च ४९ | २४ |

After that, [the star named] *munīndra* which has a scale of brightness of 2 (*dvimiti*), along the northern (*udag*) direction [having the coordinate] 24 (*siddha*.[1] [The second coordinate is] 49 (*nava* (9), *abdhi* (4)) [degrees] and 24 (*jina*) minutes.

Hence, the coordinates of the star *munīndra* are 114° and +49° 24′.

सपादपिण्डैः २८ | १५[2] त्रिमितिस्ततः प्राग् अन्योमुनिः पञ्चयुगैः ४५ उदक्यः

The coordinates of the star *anyomuni* (meaning of which is 'the other sage') are 28 (*piṇḍa*) and a quarter (*sapāda*) degrees and 45 (*pañca* (5) *yuga* (4)) degrees. [The star] whose scale of brightness is 3 (*trimiti*) is situated in the northern direction.

Hence, the coordinates of the star *anyomuni* are 118° 15′ and +45°.

त्रिमानमन्त्यांशचतुर्थपादे २९ | ४५ सौम्यं नवाश्वि २९ | ० प्रमितैस्तु युग्मम् |

[The star] *yugma* shines with the brightness scale three (*trimāna*) with the first coordinate being in the fourth quadrant of 30 (*antyāṃśa-caturthapāda*) degrees and the second coordinate is 29 (*nava* (9), *aśvi* (2)). [The direction] is towards north (*saumya*).

Hence, the coordinates of the star *yugma* are 119° 45′ and +29°.

खेटैर्नगैः ९ | ७ उत्तरदिक् त्र्यमानः सभा[3]विभागैः ४७ पुरतोमुनीन्द्रः

The star of brightness scale 3 having the [first coordinate] 9 (*kheṭa*) degrees, 7 (*naga*) minutes is directed towards the north (*uttaradik*). This [star] is called as *puratomunīndra* (the one which is next to the *munīndra*) [whose second] coordinate is 47 degrees (*vibhāga*).

Hence, the coordinates of the star *puratomunīndra* are 129° 07′ and +47°.

दिङ्ग्भिः १०[4] त्रिमानः सदलैकबाणैः ५१ | ३० रुदक्व्यतः तत्पुरतोमुनीन्द्रः

[The coordinates of the star named] *tatpurato-munīndra* (second next to the star *munīndra*) are 10 (*dig*) degrees and 51 (*eka-bāṇa*) degrees along with a half (*sadala*) degree. [The magnitude of the brightness] is three (*trimāna*) and the direction is towards north.

Hence, the coordinates of the star *tatpurato-munīndra* are 130° and +51° 30′.

मेघै १७ | ० लवैस्त्रिप्रमितं सदोदग् तत्वांशकैः २५ | ० युग्मकमन्यदेव इतीह युग्मत्रयमेवलोक्य त्रिविक्रमस्य प्रवदन्ति पादान्

Another [star named] *yugmaka*,[5] which is entirely (*anyadeva*) different [from the star named yugma which is mentioned earlier], has the coordinates 17 (*megha*) degrees (*lava*) and 25 (*tatva*) degrees. It has third order brightness and is directed towards the north. Therefore, having seen three (*traya*) such pairs (*yugmaka*), it is being told that they are the three pairs of legs (*pādān*) of the *Trivikrama.*

Hence, the coordinates of the star *yugmaka* are 137° and +25°.

We see here the name of a hitherto unknown constellation named *Trivikrama*: "It is said that these are the three footprints of *Trivikrama.*" Their positions are shown in Figure 1, and their resemblance to foot-prints is striking.

षष्टांशयुक्ताब्द १७ | १० लवैर्द्विमानो मुनिर्वसिष्ठो विद्शरैः ५४ | ० उदक्यः

The coordinate of the star *vasiṣṭha* who is a sage (*muni*) is one-sixth (*ṣaṣṭāṃ'sa*) of a degree added to 17 (*abda*) degrees (*lava*). The brightness scale is 2, the second coordinate is 54 degrees and the direction is towards the north.

Hence, the coordinates of the star *vasiṣṭha* are 137° 10′ and +54°.

विंत्र्यंशतत्वैः २४ | ४० द्विमितिः सदोदग् मुनिः पुरस्थः सपदाङ्गबाणैः ५६ | १५[6]

The [coordinate of the star] *Muni* which is situated at the front (*purastha*) is one-third of a degree subtracted (*vitryaṃ'sa*) from 25 (*tatva*). It shines with the second order brightness in the northern direction. The other coordinate is 56 (*aṅgabāṇa*) degrees along with a quarter of a degree (*sapāda*).

Hence, the coordinates of the star *Muni* which is at the front are 144° 40′ and +56° 15′.

पादोनषड्भिः ५ | ४५ द्विमितिः सदोदक् वेदेषु ५४ | ० भागैः भगवान् मरीचिः |

The star *Marīci* has the coordinates quarter of a degree subtracted (*pādona*) from 6 (*ṣaṭ*) degrees and 54 (*veda* and *iṣu*)[7] degrees. The brightness scale is 2 and the star is towards the north always (*sadā-udak*).

Hence, the coordinates of the star *Marīci* are 155° 45′ and +54°.

3.2 Coordinates as Given by Padmanābha in the *Yantra Kiranāvali*

The first two stars are called *Ūrdhva-Pa'scimaga* and *Adhaḥ-Pa'scimaga*; the last one is called *Prāgmuni*. It was possible to deduce the identification of these four (including *Vasiṣṭha*) based on the coordinates provided by Ôhashi (1997). The *Dhruvaka* of the first two are the sameas given by *saśīndraḥ* (141). The *Vikṣepa* of one is given as *khākṣa* (50) and the other is *śareṣavaḥ* (55). Here, Ôhashi mentions that the word *kha* is inferred as it is not clearly legible in the manuscript. Thus, there is no ambiguity in the identification for the four stars. These are also included in the Table 1. Their positions (marked by Ps) are shown in Figure 1.

4 DISCUSSION

Thus we have found that all ten stars in the constellation of Ursa Major mentioned in these two texts can been identified. Table1 and Figure 1 indicate that although the identifications match, there seems to be a systematic error in the declinations. The large deviation in Nityānanda's declination values still needs to be investigated in terms of instrumental and/or calibration errors. As mentioned earlier, if measurements were used to read out the coordinates from a table-top instrument, then the errors would have been larger at higher latitudes because of the spherical nature of the surface.

As also mentioned earlier, the seven main stars in the *Saptarṣi Maṇḍala* have been known and cited in all forms of literature. The seven constitute a group—but not the equivalent of the constellation of Ursa Major as we know it today, whose boundary as defined by the IAU extends beyond these seven stars. Therefore, the pairs of stars *Yugma* and *Yugamka* were not associated with *Saptarṣi*. The three pairs discussed above that constituted the constellation *Trivikrama* are mentioned on only one astrolabe, on p.3202 of Sarma's *Descriptive Catalogue of Indian Astronomical Instruments* (2017). However, the names engraved there appear to be distortions of the Arabic names: *Phikarai – ullā a.ca*

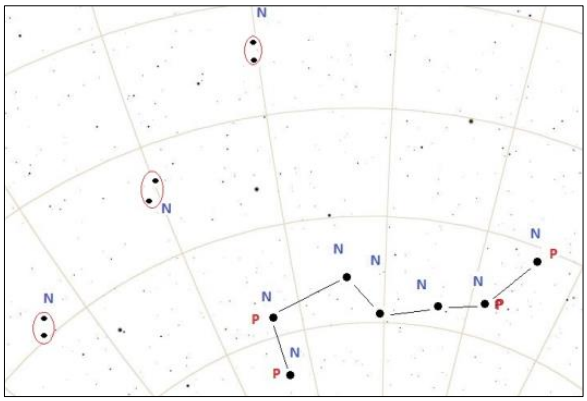

Figure 1: A star chart of Ursa Major. Positions of the stars in the two catalogs are indicated by P (Padmanābha) and N (Nityānanda). The three pairs identified with three foot prints of Trivikrama are circled (star chart: B.S. Shylaja and V.R. Pai).

(Arabic name *Quafzah-al-úláh*), *Phikarausā-niye-chi.ca* (Arabic name *Quafzah-al-Thāní*) and Phikarais*ā* lisai tri.dha (*Quafzah-al-Thālith*). This raises some doubt about the usage of the word *Trivikrama.*

In this context it is interesting to note the other stars in the region, especially the Pole Star. The reference in *Vateśvara*'s commentary cites the *Dhruva-Tāra* as the faint central star of a fish or whale (*Timyākriti tārānām tanu tārā Dhruva tārā madhye*) (Shukla, 1986). Therefore, it is not practical to complete the imaginary figure of a fish without reference to the other stars. Here a discussion about the constellation *Śiśumāra* or *'Siṃ'sumāra* is relevant, as it was used to refer to an aquatic creature (a dolphin, porpoise or the likes of).

The *Si'sumāra Maṇḍala* is considered to be a constellation comprising Ursa Minor (Mukherjee, 1905). It is also called *Dhruva-matsya*, and consists of seven stars. *Dharmatāra* (1) lies at the head of the constellation and *Dhruvatāra* (2) lies at the tail of the *Siśumāra Maṇḍala*. The third

Table 1: Identification of stars from the catalogues of Nityānanda (N) and Padmanābha (P).*

Name	Dhruvaka ° ′	Vikṣepa ° ′	Magnitude	Right Ascension h m	Declination ° ′	Δ α m	Δ δ °
α UMa *Munīndra* (N)	114	49 24	2 (1.8)	10 43	57 36	−03	−06
Adhaḥ-Paścimaga (P)	141	55		10 32	64 20	08	−01
Yugmaka (N) ι UMa, κ UMa	102 20	29	2	08 07	49 19		
β UMa *Anyomuni* (N)	118 15	45	3 (2.37)	10 48	52 21	−01	−06
Ūrdhva-Paścimaga (P)	141	50		10 32	59 19	07	−01
Yugma (N) λ UMa, μ UMa	119 45	29	2	09 18	44 50		
Purato-Munīndra (N) γ UMa	129 07	47	3 (2.4)	10 43	55 12	13	−07
Tatpurato Munīndra (N) δ UMa	130	51 30	3 (3.3)	10 46	56 08	18	−06
Yugmaka (N) ν Uma, ξ UMa	137	25	3	10 25	35		
Muni (N) ε UMa	137 10	54 00	2 (1.76)	11 13	59 08	−22	−03
ζ UMa (N)	144 40	56 15	2 (3.99)	11 40	58 21	−25	−06
Vasiṣṭha (P)	183	66				13	03
η UMa Marīci (N)	155 45	54	2 (1.85)	12 21	51 48	17	−05
Prāgmuni (P)	193	63		12 47	57 42	10	01

* The following colour-coding is used: Blue: stars for which N *and* P values are available. Orange: stars for which N values only are available. Green: the three pairs of stars for which N values only are available. In column 4, the current magnitudes values are provided in parentheses. The systematic shift in declination towards the south, evident in the extreme right hand column, was probably caused by a systematic error in Dhruvaka (which was used to calculate the declination values).

brightest (3) is called *Indratāra*. *Dharmatāra* is 8 units south of *Dhruvatāra*. *Indratāra* is 2 units away from *Dhruvatāra* and is at the mouth of the fish, as per the reference given above.

Al Biruni records that Hindus imagined a fish around the Pole Star (Sachau, 1910). In the long list of astrolabes (Sarma, 2017) only one shows the image of a fish, but it is on the outer rim not on the rete (Sarma, personal communication). Letters *pu* and *pa* (corresponding to *Pūrva*, east and *Pa'scima*, west) are indicated. This does not provide any clue as to the imaginary fish.

The constellation *Śiśumāra or Śiṃśumāra* has been discussed extensively by Iyengar (2016: 145–163). He has identified it as the constellation Draco, but this remains debatable until the co-ordinates are found in some form or other. Iyengar shows that the description agrees with Thuban, the Pole Star, in about 3000 BCE. However, whether it was an aquatic animal is debatable, since it was described as having fairly long legs.

The consequence of Thuban being the Pole Star requires that these seven stars be circumpolar at that epoch. This circumstance has been used to identify the antiquity of the tribal story by Halkere et. al. (2018). The seven stars are called the "… old lady's cot and the three thieves." The name of grandmother's cot is prevalent in tribal accounts from Central and Southern India, but the story told by the Gonds of Madhya Pradesh hint that it is circumpolar: the old lady never sleeps because the three thieves are just waiting to carry away the cot.

Quite interestingly, Padmanābha lists a star called *'Si'sumāra* but it is nowhere near the constellation of Draco—it is in the southern sky.

5 CONCLUDING REMARKS

A study of the positions of the seven stars known as the *Saptarṣi Maṇḍala* and recorded in two early catalogues provides us with the epochs of these catalogues. Errors, possibly due to the instruments used, are discussed. We also discuss the little-known constellations of *Trivikrama* and *Śiśumāra*. While the foot-print of *Trivikrama* is identified without any ambiguity, the boundary of *Śiśumāra* is not easily fixed. This may have included Thuban, the Pole Star of yesteryear. The constellation corresponding to Ursa Minor as a fish with the Pole Star at its centre is discussed, but this requires further study once the coordinates for specific stars become available.

6 NOTES

1. The term "*siddha*" is also used to refer to "*jina*", which represents the number 24 in the *bhūta-saṅkhyā* system.
2. The string "*sapādapiṇḍa*" represents the number 28 | 15. But, the numerals in the manuscript are 25 | 15, which are incorrect.
3. Here is an instance where the कटपयादि system of numeration is used. As per the *kaṭapayādi* system the term *"sabhā"* represents the number 47.
4. The manuscript has the number as 17 which is wrong, since the string दिङ्भिः corresponds to the number 10.
5. The author uses the word "*yugmaka*" for the second time to represent the twin star. He

explicitly tells us that this star (*yugmaka*) is entirely different from the "*yugmaka*" that has been described earlier.

6. The manuscript has the number as 51 | 15.
7. The term "*vedeṣu*" combines two words, *veda* and *iṣu* (*bāṇa*), which represent the numbers 4 and 5, respectively, and not the seventh case (*saptamī vibhakti*) of the *prātipadika*, *veda.*

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8 REFERENCES

Abhyankar, K.D., 2007. *Pre-Siddhantic Indian Astronomy.* Hyderabad, Institute of Scientific Research on Vedas.

Colebrook, H.T., 1809. On the *Indian* and *Arabian* divisions of the zodiac. *Asiatic Researches*, 9, 323–376.

Hari, K.C., 2006. Polar longitudes of the Sūryasiddhānta and Hipparchus' commentary. *Indian Journal of History of Science*, 41, 29–52.

Halkere, G., Vahia, M.N., and Orchiston, W., 2018. The astronomy of some Indian tribes. In Orchiston et al., 235–240.

Iyengar, R.N., 2016. Astronomy in Vedic texts. In Ramasubramanian et al., 106–169.

Mukherjee,K., 1905. *Popular Indian Astronomy. Taramandalas and Nakshatras*. Calcutta, S.N. Guna Ray (Google books).

Ôhashi, Y, 1997. Early history of astrolabe in India. *Indian Journal of History of Science*, 32, 199–295.

Orchiston, W., Sule, A., and Vahia, M.N. (eds.), 2018. *Growth and Development of Astronomy and Astrophysics in India and South Asia-Pacific Region. Proceedings of the 9th International Conference on Oriental Astronomy*. Mumbai, Tata Institute of Fundamental Research and Hindustan Book Agency.

Pai, V.R., and Shylaja, B.S., 2016. Measurement of coordinates of *Nakṣatras* in Indian Astronomy. *Current Science*, 111, 1551–1558.

Pai, V.R., Ramasubramanian, K., Sriram, M.S. and Srinivas, M.D., 2018, *Karaṇapaddhati of Putumana Somayājī, With Translation and Detailed Mathematical Notes.* New Delhi, Hindustan Book Agency and Springer.

Ramasubramanian, K., Sule, A., and Vahia, M. (eds.), 2016. *History of Indian Astronomy: A Handbook*. Mumbai, Indian Institute of Technology and Tata Institute of Fundamental Research.

Raika, K.K., 1936. *Yantrarāja.* With commentary by Malayendu Sūri. Mumbai, Nirnayasagar Press.

Rathnasree, N., Dasgupta, P., and Garg, A., 2018. A quantitative study of accurate positions of star markers on historical astrolabes. In Orchiston et al., 17–33.

Saha, M.N., and Lahiri, N.C., 1954. *Indian Calendar*. New Delhi, CSIR (1992 reprint).

Sarma, S.R., 2017. *A Descriptive Catalogue of Indian Astronomical Instruments.* (Online source: https://srsarma.in/catalogue.php).

Sarvasiddhāntarāja by Nityānanda. Bhandarkar Oriental Research Institute (BORI), Pune. MS. no. 206 of A.1883-84.

Shylaja, B.S., and Pai, V.R., 2018a. Observational records of stars in Indian astronomical texts. *Current Science*, 115, 570–573.

Shylaja, B.S., and Pai, V.R. 2018b. Stars as recorded in Indian texts. In Orchiston et al., 54–58.

Shylaja, B.S., 2016. Navigation and astronomy. In Ramasubramanian et al., 477–499.

Sule A., Vahia, M.N., Joglekar, H., and Bhujle, S., 2007., Saptarshi's visit to different Nakṡatras: subtle effect of Earth's precession. *Indian Journal of History of Science*, 42, 133–147.

Dr B.S. Shylaja completed an MSc in Physics at Bangalore University and joined the Indian Institute of Astrophysics. There she studied binary stars with Wolf-Rayet companions for her PhD thesis (1987) under the guidance of the late Professor M.K.V. Bappu. She also studied comets (including 1P/Halley), metallic line stars and cataclysmic variables. She then joined the Physical Research Laboratory in Ahmedabad and studied the infra-red signatures of winds of massive stars. Since joining the Jawaharlal Nehru Planetarium in Bengaluru in 1994 she has been studying historical aspects of Indian astronomy. She translated the monograph on the 1874 transit of Venus written by Chintamani Ragoonathachari in Kannada, a language of South India, which throws light on the techniques used by the Indian astronomers of that era. She found that stone inscriptions from throughout India and South Asia contain important astronomical information, as outlined in her book *History of the Sky – On Stones* (2016, Bengaluru; co-authored by Geetha Kydala Ganesha). Apart from solar eclipses, she identified documentation about supernova eruptions in these inscriptions. She has studied the temples in India from an astronomical perspective. As an observational astrophysicist she also has studied the stellar observations recorded in various ancient texts and in the traditions of indigenous navigators, with the aim of deducing the observational techniques that were prevalent in India.

Dr Venketeswara R. Pai completed his Post Graduate studies in Physics at the Cochin University of Science and Technology in Kerala, and a PhD in the history of astronomy from the Indian Institute of Technology in Bombay. His broad area of research is the history of science, with a research focus on "The

History and Development of Astronomy and Mathematics in India from 12th to 17th century AD". He is at present an Assistant Professor at the Indian Institute of Science Education and Research in Pune. His particular expertise resides in deciphering the scientific manuscripts documented in Sanskrit and Malayalam. He is currently pursuing his research on the history and development of the *Vākya* School of Astronomy as well as Bhāskara's innovations by studying his auto-commentary known as the *Vāsanā-Bhāṣya* (in collaboration with Professor M.. Sriram from Chennai) which will throw some light on the advancement of astronomy in the twelfth century CE. Dr Pai has won the INSA medal for a "Young Historian of Science", and is a founding member of the Indian National Young Academy of Science.