Sidereal Ecliptic Coordinate System of *Sūryasiddhānta*

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(Received 15 June 2018; revised 17 August 2019)

Abstract

Indian astronomical texts give the coordinates of the *yogatārās* or junction stars of *nakṣatras*. These coordinates have been interpreted as polar coordinates, which depend on the position of the north celestial pole. Polar coordinates of a star should change with time due to precession. However, different astronomical texts written over many centuries give same coordinates for most *yogatārās*. This has resulted in Indian astronomers being called incompetent, who did not observe the positions of the stars with accuracy. In this paper it is proposed that Indian astronomers were using sidereal ecliptic coordinates, which does not change with time to a significant extent. Even though sidereal ecliptic coordinates do not change, order of *nakṣatras* was periodically changed to take into account the movement of vernal equinox due to precession. Ecliptic longitudes were updated by simple addition corresponding to the shift in origin of the *nakṣatra* system. It is proposed that a mix up of longitudes from different systems has resulted in a list that obfuscates the true understanding of Indian astronomy. To gain a better understanding of coordinates given in *Sūryasiddhānta*, precise boundaries of *nakṣatras* have been determined based on the *yogatārās* of *Rohiṇī* and *Kṛttikā nakṣatras*. Using the coordinates of the boundaries, the identifications of *yogatārās* of *nakṣatras* have been reassessed. Among the 28 *yogatārās*, alternative identifications of six *yogatārās* have been suggested.

Key words: Ecliptic coordinates, *Nakṣatra*, Polar latitude, Polar longitude, *Sūryasiddhānta*, *Yogatārā*.

1 Introduction

Vedic texts divide the ecliptic in 28 or 27 divisions called *nakṣatras*. Later astronomical texts such as *Sūryasiddhānta* adopted the system of 27 equal divisions. In this system, each *nakṣatra* has a span of 13° 20′. In addition to the *nakṣatra* being a geometrical division of ecliptic spanning over a certain segment of ecliptic, each *nakṣatra* is also characterized by a star or group of stars. Each *nakṣatra* is also assigned a *yogatārā* or junction star out of the group of stars belonging to the particular *nakṣatra*. If a *nakṣatra* has only one star in its group, then that star is the *yogatārā* of that *nakṣatra*. Astronomical text *Sūryasiddhānta* gives the coordinates of each *yogatārā*.

Burgess (1860) interpreted the coordinates given in *Sūryasiddhānta* as polar coordinates, which is universally accepted. These coordinates depend on the position of the North Celestial Pole, which changes over time due to precession. However, the coordinates given in different astronomical texts are nearly same, even though the texts were written many centuries apart. The change in coordinates

DOI: 10.16943/ijhs/2019/v54i3/49740

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would have been obvious to the astronomers, if they had the skill to measure the coordinates of the stars. This has resulted in the opinion that Indian astronomers were borrowers from the west and incapable of making accurate astronomical observations. Pingree and Morrissey (1989) write the following about the Indian astronomers:

> ...that the catalogue of stars found in *Paitāmahasiddhānta*, which is almost exclusively the basis of the rest of the Indian tradition, since it is at the beginning of the Indian attempts to provide coordinates and uses a coordinate system derived from Greek astronomy, is more likely to be an Indian adaptation of a Greek star catalogue than to be based on observations that were made in India; and that the ineptitude with which Indians historically tried to 'correct' these coordinates militates against any theory that is founded upon the idea that the Indians of medieval period were experts in astronomical observation. ... Our apparent success in finding "identifications" for Lalla's star catalogue, wherein the coordinates are so clearly a mixture of ecliptic and polar values, shows the futility of attaching any credence to them. ...Whichever stars the author of *Sūryasiddhānta* intended to indicate, he was incapable of determining their coordinates accurately, ...It is most astonishing to see an astronomer convert λ^* into λ and call the latter λ^*; even more astonishing is to see him take λ to be λ^*, convert it on that assumption into another λ, and to assert that this wrongly derived λ is λ^* ! There is no excuse for Āryabhaṭa's coordinates... The impression of incompetence does not disappear when we examine our last star catalogue, which Gaṇeṣa incorporated into his *Grahalāghava* (XI 1–5) in 1520. ...Therefore, either Gaṇeṣa was also incompetent, or he intended to give the coordinates of a different set of stars. ... We must conclude from this survey that the Indians did not observe the positions of the stars with accuracy; by implication, they also did not observe those of the planets with accuracy.

It is obvious that the interpretation of coordinates given in Indian astronomical texts as polar coordinates has resulted in Indian astronomers being called incompetent. In this paper it is proposed that the coordinates of *yogatārās* given in the Indian astronomical texts are ecliptic coordinates and since these coordinates don't change appreciably over time in a sidereal ecliptic coordinate system, Indian astronomers relied on the coordinates received from earlier astronomers. To account for precession, Indian astronomers changed the origin of the *nakṣatra* system periodically. The coordinates were updated to reflect the new origin of the *nakṣatra* system by adding the appropriate amount to ecliptic longitudes. With this insight, the coordinates of *yogatārās* given in *Sūryasiddhānta* have been compared to the coordinates of *yogatārās* identified by Burgess (1860) and new identifications of some *yogatārās* have been proposed. In addition, the exact boundary of each *nakṣatra* has been determined.

2 Textual information

The coordinates of *yogatārās* given in *Sūryasiddhānta* are shown in Table 1. Three different translations of *Sūryasiddhānta* were consulted, Burgess (1860) in English, Śrīvāstava (1982) in Hindi and Siṃha (1986) in Hindi. All translations provide identical information regarding the raw data given in *Sūryasiddhānta* and how the data is to be interpreted. The longitude data is given indirectly using a term "*svabhoga*". Instead of giving *svabhoga* values, one tenth of these values are given as shown in the column "Data" in Table 1. After multiplying by ten, these values yield *svabhoga* in arcminutes, which is then converted to degree and arcminutes as shown under the column "*svabhoga*" in Table 1. *Svabhoga* represents the relative longitude and is to be added to the longitude of the beginning of the respective *nakṣatra* to obtain the longitude of the given *yogatārā*.

The list of *nakṣatras* begins with *Aśvinī* and ends with *Revatī*. Since *Sūryasiddhānta* follows the system of 27 equal divisions of the ecliptic, each *nakṣatra* has a span of 13°20′. The beginning and end points of each *nakṣatra* can then be calculated as shown under the column "Span". Adding relative longitude to the longitude of the beginning point of respective *nakṣatra* yields the longitude of the *yogatārā* and is called *dhruvaka* in *Sūryasiddhānta*. The calculated values of *dhruvaka* are shown in the column "*Dhruvaka*" in Table 1.

Sūryasiddhānta calls the latitude *vikṣepa* and gives the value and direction relative to ecliptic directly as shown in

Table 1 The coordinate of *yogatārās* according to *Sūryasiddhānta* 8.1–9 Burges (1860), Śrīvāstava (1982), Siṃha (1986).

No.	*Nakṣatra yogatārā*	*Svabhoga* (relative longitude)			Span	*Dhruvaka* (longitude)	*Vikṣepa* (latitude)
		Data	Arc min.	Deg.-min.	Deg.-min.	Deg.-min.	Deg.-min.
1	*Aśvinī*	48	480	8°0′	0°0′ – 13°20′	8°0′	10°0′ N
2	*Bharaṇī*	40	400	6°40′	13°20′ – 26°40′	20°0′	12°0′ N
3	*Kṛttikā*	65	650	10°50′	26°40′ – 40°0′	37°30′	5°0′ N
4	*Rohiṇī*	57	570	9°30′	40°0′ – 53°20′	49°30′	5°0′ S
5	*Mṛgaśirā*	58	580	9°40′	53°20′ – 66°40′	63°0′	10°0′ S
6	*Ārdrā*	4	40	0°40′	66°40′ – 80°0′	67°20′	0°0′ S
7	*Punarvasu*	78	780	13°0′	80°0′ – 93°20′	93°0′	6°0′ N
8	*Puṣya*	76	760	12°40′	93°20′ – 106°40′	106°0′	0°0′
9	*Āśleṣā*	14	140	2°20′	106°40′ – 120°0′	109°0′	7°0′ S
10	*Maghā*	54	540	9°0′	120°0′ – 133°20′	129°0′	0°0′
11	*Pūrva-phālgunī*	64	640	10°40′	133°20′ – 146°40′	144°0′	12°0′ N
12	*Uttara-phālgunī*	50	500	8°20′	146°40′ – 160°0′	155°0′	13°0′ N
13	*Hasta*	60	600	10°0′	160°0′ – 173°20′	170°0′	11°0′ S
14	*Citrā*	40	400	6°40′	173°20′ – 186°40′	180°0′	2°0′ S
15	*Swāti*	74	740	12°20′	186°40′ – 200°0′	199°0′	37°0′ N
16	*Viśākhā*	78	780	13°0′	200°0′ – 213°20′	213°0′	1°30′ S
17	*Anurādhā*	64	640	10°40′	213°20′ – 226°40′	224°0′	3°0′ S
18	*Jyeṣṭhā*	14	140	2°20′	226°40′ – 240°0′	229°0′	4°0′ S
19	*Mūla*	6	60	1°0′	240°0′ – 253°20′	241°0′	9°0′ S
20	*Pūrvāṣāḍhā*	4	40	0°40′	253°20′ – 266°40′	254°0′	5°30′ S
21	*Uttarāṣāḍhā*	at the middle of *Pūrvāṣāḍhā*			266°40′ – 280°0′	260°0′	5°30′ S
22	*Abhijīt*	at the end of *Pūrvāṣāḍhā*			None	266°40′	60°0′ N
23	*Śravaṇa*	at the end of *Uttarāṣāḍhā*			280°0′ – 293°20′	280°0′	30°0′ N
24	*Dhaniṣṭhā*	At the junction of 3rd and 4th quarter of *Śravaṇa*			293°20′ – 306°40′	290°0′	36°0′ N
25	*Śatabhiṣaja*	80	800	13°20′	306°40′ – 320°0′	320°0′	0°30′ S
26	*Pūrva-bhādrapadā*	36	360	6°0′	320°0′ – 333°20′	326°0′	24°0′ N
27	*Uttara-bhādrapadā*	22	220	3°40′	333°20′ – 346°40′	337°0′	26°0′ N
28	*Revatī*	79	790	13°10′	346°40′ – 360°0′	359°50′	0°0′

the column "*Vikṣepa*" in Table 1. *Dhruvaka* and *vikṣepa* are universally translated as polar longitude and polar latitude respectively. Since this interpretation is contested in this paper, *dhruvaka* and *vikṣepa* are translated simply as longitude and latitude respectively in Table 1. After *Uttarāṣāḍhā nakṣatra* (at number 21 in the list), *Abhijīt nakṣatra* is listed, but no span is given to this *nakṣatra*. *Abhijīt nakṣatra* was part of 28 *nakṣatra* system, but was dropped from the list in 27 *nakṣatra* system, and hence has no span in this system. The longitudes of the *yogatārās* of *Uttarāṣāḍhā, Abhijīt, Śravaṇa*, and *Dhaniṣṭhā nakṣatras* are given differently in terms of their positions relative to other *nakṣatras* as shown in Table 1. The *yogatārās* of *Uttarāṣāḍhā* and *Dhaniṣṭhā* fall outside the span of their respective *nakṣatras*.

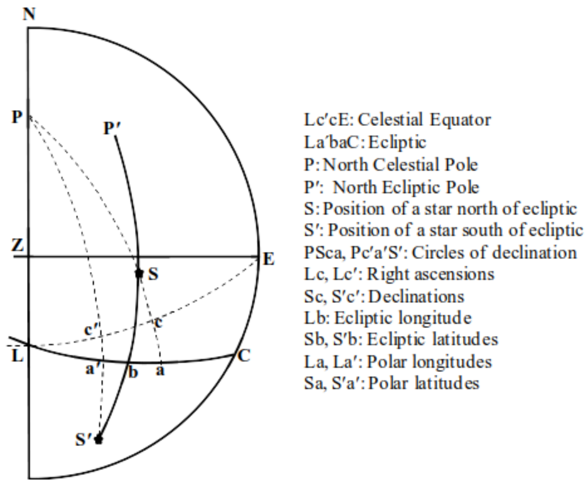


Figure 1 Illustration of polar longitude and latitude of stars by Burgess (1860).

3 Polar longitude and latitude

It is currently accepted that the coordinates of *yogatārās* given in *Sūryasiddhānta* are in terms of polar longitudes and latitudes. The terms polar longitude and polar latitude were coined by Burgess (1860) in his translation of *Sūryasiddhānta*, which uses the term *dhruvaka* for longitude and *vikṣepa* for latitude. Burgess has identified *dhruvaka* and *vikṣepa* as polar longitude and polar latitude respectively. The concept of polar coordinates of stars as illustrated by Burgess (1860) is shown in Figure 1. To determine the polar longitude and latitude of a star (S or S'), a segment of circle of declination (PSca or $Pc'a'S$) is drawn from North Celestial Pole (P) passing through the star up to the ecliptic. Polar latitude is the angular distance of the star (Sa or $S'a'$) from the ecliptic along the circle of declination. Polar longitude is the angular distance (La or L a') from reference point (L) on the ecliptic and the point of intersection of the ecliptic with the circle of declination passing through the star (a or a'). Burgess (1860) has shown ecliptic below the celestial equator in the illustration, which is wrong. For point L to denote vernal equinox, ecliptic should be shown above the celestial equator in Figure 1.

It should be noted that this whole geometrical construction for determining polar longitude and latitude is very artificial. In ecliptic coordinate system, ecliptic latitudes are determined by measuring angular distances from ecliptic along the great circle passing through the North Ecliptic Pole. In celestial coordinate system, declinations are determined by measuring angular distances from celestial equator along the great circle passing through the North Celestial Pole.

In every coordinate system, the latitude is measured respective to the corresponding pole. In the artificial construct of polar latitude, the angular distance is measured from the ecliptic along the great circle that does not pass through the pole of ecliptic (North Ecliptic Pole), but passes through North Celestial Pole instead. Burgess has justified this artificial construction by taking the meaning of *Dhruvaka* as pertaining to *Dhruva* or pole star, and therefore he has drawn great circle passing through North Celestial Pole. In accordance with *Dhruvaka*, Burgess has postulated that *vikṣepa* means polar latitude. There is absolutely nothing in any astronomical text that describes this method of measuring longitude and latitude. The term *vikṣepa* has been used many times in *Sūryasiddhānta* such as in 2.6, 2.63 and 7.7, and in all these places *vikṣepa* has not been interpreted as polar latitude even by Burgess (1960). It will be odd for the same text (*Sūryasiddhānta*) to use two different coordinate systems (ecliptic and polar) without providing any explanation. Moreover, *Dhruva* also means fixed or not moving and thus *Dhruvaka* simply means fixed longitude. Many Indian astronomers such as Bhāskara in *Mahābhāskarīya* (III. 62–71) refer to the coordinates of *yogatārās* as ecliptic longitude and latitude as described by Pingree and Morrissey (1989):

> What is remarkable about Bhāskara's ecliptic coordinates is that, in most cases, they are within 1° of the Paitāmaha's polar coordinates; this is the case for the longitudes of nos. 1, 4, 5, 8, 10, 12, 16, 18, 19, and 28, and for the latitudes of nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18, 19, 23, 24, 25, 26, 27, and 28— that is, for 33 out of 54 possibilities. This fact denies to Bhāskara the possibility of his having himself made independent observations, or of his having used a source based on independent observations. This lack of observational input is emphasized by the fact that his changes of the Paitāmaha's coordinates lead either to worse results or to dimmer stars or to both.

It is surprising that despite the emphatic declaration by Indian astronomers that they were using ecliptic coordinates, no one has challenged the prevailing view that Indian astronomers were using polar coordinates. First, the information provided by Indian astronomers has been incorrectly interpreted and then that false interpretation has been used to claim that Indian astronomers were inept and did not know how to measure the positions of stars and planets. If that is the case, then correct framework needs to be developed in which the coordinates given by Indian astronomers make better sense and currently accepted identifications of *yogatārās* need to be reassessed to check if other stars fit the given coordinates better.

4 Currently accepted identifications of yogatārās

Based on his assumption that coordinates given in *Sūryasiddhānta* are polar longitudes and latitudes, Burgess (1860) identified the *yogatārās* as shown in Table 2. These identifications are currently accepted by most scholars. For comparative purpose, ecliptic coordinates (J2000.0) of these *yogatārās* are also given in Table 2 along with the coordinates (*dhruvaka* and *vikṣepa*) given in *Sūryasiddhānta* (8.1–9). The data for ecliptic coordinates (J2000.0) were obtained using Stellarium software by setting the date to January 1, 2000 at 12:00 noon and noting the ecliptic longitudes and latitudes by selecting the specific stars. With the tabulation of currently accepted identifications of *yogatārās* and their ecliptic coordinates, these identifications can be reassessed to check if other stars fit the description in the astronomical texts better. For this purpose, a precise determination of the boundaries of *nakṣatras* is required.

5 Determination of *nakṣatra* boundaries

Figure 2 illustrates the principle of the division of celestial sphere in *nakṣatra* zones. K and K' represent north ecliptic pole and south ecliptic pole respectively. A, B, C, and D are the boundaries of *nakṣatras* on the ecliptic. In a 27 *nakṣatra* system, there will be 27 such points on the ecliptic through which the boundaries of *nakṣatras* will pass. As the *nakṣatras* have equal span in the 27 *nakṣatra* system according to *Sūryasiddhānta* 2.64, each *nakṣatra* has a span of 13°20′ on the ecliptic. Each *nakṣatra* zone comprises of the area bound by two great semi-circles passing through K and K' and through its boundaries on the ecliptic such as $KAK'BK$, $KBK'CK$, $KCK'DK$, and so on. It is expected that the *yogatārā* and stars belonging to a *nakṣatra* will fall in its *nakṣatra* zone. It should be noted that in the ancient Indian system it was not necessary for the *yogatārā* and stars belonging to a *nakṣatra* to fall within the zodiac, which is a region spanning 8° on both side of the ecliptic.

Though later astronomical texts divide the celestial sphere in 27 *nakṣatras*, earlier texts also describe a system consisting of 28 *nakṣatra*. It takes the moon 27.32 days to return to the same position among the stars. Based on the observation that the sidereal month is more than 27 days but less than 28 days, the path of moon in the background of the stars was divided in 28 or 27 divisions. *Atharvaveda Saṃhitā* (19.7.1–5) lists 28 *nakṣatras* beginning with *Kṛttikā* and ending in *Bharaṇī*. *Taittirīya Saṃhitā* (iv.4.10) and *Taittirīya Brāhmaṇa* (1.5.2.7) list 27 *nakṣatra* beginning with *Kṛttikā* and ending in *Bharaṇī*. *Nakṣatra Abhijīt* is part of the list of 28 *nakṣatras*, but is dropped from the list in the system of 27 *nakṣatras*. There is a dialogue between gods Indra and Skanda regarding the dropping of *nakṣatra Abhijīt* in *Mahābhārata* (*Vana Parva*, Chapter 230, verses 8–10). In this dialogue, Indra says to Skanda that because of jealousy with *Rohiṇī*, her younger sister Abhijīt has gone to forest to do penance. Indra further says that Brahmā had fixed the counting of time from the beginning of *Dhaniṣṭhā* and earlier *Rohiṇī* was first. This story tells

Table 2 Identification of *yogatārās* by Burgess (1860).

No.	*Nakṣatra*	Junction-star (*yogatārā*)[a]	Ecliptic longitude[b]	*Dhruvaka* (longitude)	Ecliptic latitude[b]	*vikṣepa* (latitude)
1	*Aśvinī*	β Ari	33°58′	8°0′	8°29′ N	10°0′ N
2	*Bharaṇī*	35 Ari	46°56′	20°0′	11°19′ N	12°0′ N
3	*Kṛttikā*	η Tau	60°00′	37°30′	4°03′ N	5°0′ N
4	*Rohiṇī*	α Tau	69°47′	49°30′	5°28′ S	5°0′ S
5	*Mṛgaśirā*	λ Ori	83°42′	63°0′	13°22′ S	10°0′ S
6	*Ārdrā*	α Ori	88°45′	67°20′	16°02′ S	9°0′ S
7	*Punarvasu*	β Gem	113°13′	93°0′	6°41′ N	6°0′ N
8	*Puṣya*	δ Cnc	128°43′	106°0′	0°05′ N	0°0′
9	*Āśleṣāu*	ϵ Hya	132°21′	109°0′	11°06′ S	7°0′ S
10	*Maghā*	α Leo	149°50′	129°0′	0°28′ N	0°0′
11	*Pūrva-phālgunī*	δ Leo	161°19′	144°0′	14°20′ N	12°0′ N
12	*Uttara-phālgunī*	β Leo	171°37′	155°0′	12°16′ N	13°0′ N
13	*Hasta*	δ Crv	193°27′	170°0′	12°12′ S	11°0′ S
14	*Citrā*	α Vir	203°50′	180°0′	2°03′ S	2°0′ S
15	*Swāti*	α Boo	204°14′	199°0′	30°44′ N	37°0′ N
16	*Viśākhā*	ι Lib	231°00′	213°0′	1°51′ S	1°30′ S
17	*Anurādhā*	δ Sco	242°34′	224°0′	1°59′ S	3°0′ S
18	*Jyeṣṭhā*	δ Sco	249°46′	229°0′	4°34′ S	4°0′ S
19	*Mūla*	λ Sco	264°35′	241°0′	13°47′ S	9°0′ S
20	*Pūrvāṣāḍhā*	δ Sgr	274°35′	254°0′	6°28′ S	5°30′ S
21	*Uttarāṣāḍhā*	σ Sgr	282°23′	260°0′	3°27′ S	5°0′ S
22	*Abhijīt*	α Lyr	285°19′	266°40′	61°44′ N	60°0′ N
23	*Śravaṇa*	α Aql	301°47′	280°0′	29°18′ N	30°0′ N
24	*Dhaniṣṭhā*	β Del	316°20′	290°0′	31°55′ N	36°0′ N
25	*Śatabhiṣaja*	λ Aqr	341°35′	320°0′	0°23′ S	0°30′ S
26	*Pūrva-bhādrapadā*	α Peg	353°29′	326°0′	19°24′ N	24°0′ N
27a	*Uttara-bhādrapadā*[c]	α And	14°19′	337°0′	25°41′ N	26°0′ N
27b	*Uttara-bhādrapadā*[c]	γ Peg	9°09′	337°0′	12°36′ N	26°0′ N
28	*Revatī*	ζ Psc	19°53′	359°50′	0°13′ S	0°0′

[a] As identified by Burgess (1860)

[b] J2000.0 ecliptic cooridnates based on Stellarium software..

[c] For *Uttara-bhādrapadā*, longitude matches γ Pegasi, while latitude matches α Andromeda.

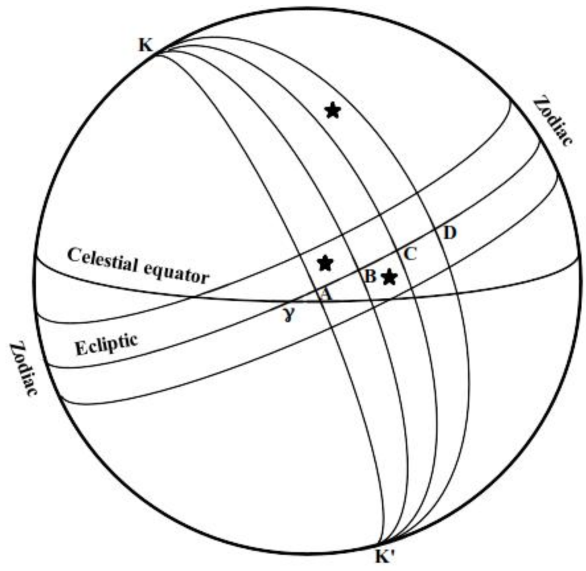
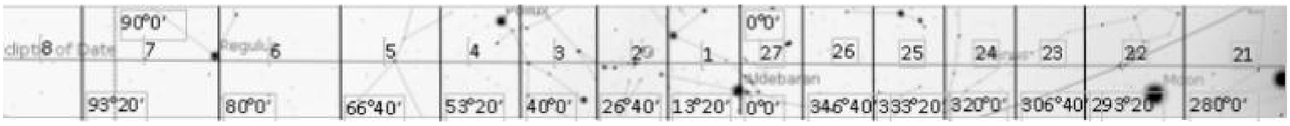


Figure 2 The division of celestial sphere in *nakṣatra* zones

that during the time when *Mahābhārata* was written, it was still remembered that once upon a time *Rohiṇī* was the first *nakṣatra*. As shown in Table 1, the list of *nakṣatra* in *Sūryasiddhānta* begins with *Aśvinī*. A Jain astronomical text *Sūryaprajňapti* (10.1.32) gives five other systems besides the one followed by Jains, which started from *Abhijīt* and ended at *Uttarāṣāḍhā*. These five systems were: 1. *Kṛttikā* to *Bharaṇī*; 2. *Maghā* to *Āśleṣā*; 3. *Dhaniṣṭhā* to *Śravaṇa*; 4. *Aśvinī* to *Revatī*; and 5. *Bharaṇī* to *Aśvinī*.

According to *Yajuṣ Vedāṅga Jyotiṣa* (verse 7), sun was at the first point of the *Dhaniṣṭhā nakṣatra* on the day of winter solstice. This suggests that the system of *Dhaniṣṭhā* as the first *nakṣatra* was in place when sun was observed at the beginning of *Dhaniṣṭhā nakṣatra* on the day of winter solstice. Sun was in *Maghā nakṣatra* on summer solstice around the same time when it was in *Kṛttikā nakṣatra* on vernal equinox. Thus different systems of *nakṣatras* were related to the careful observation of solstices and equinoxes. A story in *Mahābhārata* not only shows the importance of winter solstice but also the desire of the writers of *Mahābhārata* to carry forward this knowledge to future generations. The story is that of the death of one of the most beloved characters of *Mahābhārata*, Bhīṣma, and is told in *Bhīṣma Parva* (120.51–53). According to this story, when Bhīṣma is incapacitated on the battlefield, he refuses to die. He says that he will lie on the bed of arrows till the time of winter solstice. When sun starts his northward journey, only then he will leave this world. He waited for close to two months for winter solstice to take place and then left this world. This story has been passed on from generation to generation, and the dramatic nature of this narrative ensures that the listener will know the definition of winter solstice, which is the day when sun starts its northward journey. To make sure that the message gets passed on to future generations, a very dramatic situation was created in the storyline. From the details of the story, it is clear that the event cannot be historic as no one can control his time of death and lying on a bed of arrows for close to two months is an improbable event. What the story tells us is that winter solstice, and by implication summer solstice and equinoxes, were being carefully observed in India for many millennia. It would have been obvious to Indian astronomers that the position of sun among the stars during solstices and equinoxes was slowly changing due to the effect of precession. When the change in the position of sun became significant, the order of *nakṣatras* in the list was revised to reflect the new position of the sun on vernal equinox. Out of the different systems mentioned above, the *nakṣatra* systems with orders *Rohiṇī* to *Kṛttikā*, *Kṛttikā* to *Bharaṇī, Bharaṇī* to *Aśvinī*, and *Aśvinī* to *Revatī* are important for correct interpretation of coordinates of *yogatārās* given in *Sūryasiddhānta*. From Table 1, it is seen that the order of *nakṣatras* is *Aśvinī*, *Bharaṇī*, *Kṛttikā*, and *Rohiṇī* according to *Sūryasiddhānta*. Thus first *nakṣatra* in the list was sequentially changed from *Rohiṇī* to *Kṛttikā*, then from *Kṛttikā* to *Bharaṇī*, and finally from *Bharaṇī* to *Aśvinī*. As the original list of *nakṣatras* started with *Rohiṇī*, it is reasonable to assume that the *yogatārā* of *Rohiṇī* was at zero longitude of the original *nakṣatra* system. The *Rohiṇī* system with *yogatārā* of *Rohiṇī*, *Aldebaran*, at zero longitude is shown in Figure 3. The part of celestial sphere close to ecliptic is shown, where *nakṣatra* boundaries have been approximated to straight lines for illustrative purpose. Actual construction of *nakṣatra* boundaries should be done according to the principle illustrated in Figure 2.

The ecliptic longitudes of *yogatārās*, as identified by Burgess (1860), in *Rohiṇī* system are shown in Table 3 along with the longitudes (*dhruvaka*) of *yogatārās* given



(a) Rohiṇī system

(b) Rohiṇī system (continued)

Figure 3

in *Sūryasiddhānta* (8.1–9). The numbers in Figure 3 refer to the serial number of *nakṣatras* shown in Table 3. The ecliptic longitudes in *Rohiṇī* system were obtained by setting a date on which the ecliptic longitude of the *yogatārā* of *Rohiṇī*, *Aldebaran*, became 0°0′. This date was found to be June 12,-3044 by trial and error using Stellarium software. From Table 3, it is seen that the longitude of the *yogatārā* of *Rohiṇī* had shifted by approximately 50° according to *Sūryasiddhānta* from its zero point in Rohiṇī system. As shown in Figure 3a, *nakṣatra* boundaries are at 13°20′, 26°40′, 40°0′, 53°20′, and so on. If the ecliptic longitudes were updated by shifting the zero point of longitude to the beginning of *Revatī nakṣatra*, which is fourth *nakṣatra* from *Rohiṇī*, then 53°20′ should have been added to the ecliptic longitude in *Rohiṇī* system instead of 50°. This raises the possibility that another system was also in use, and there was confusion between these two systems resulting in a mix of data derived from two different systems. From Table 3, it is seen that the difference between ecliptic longitudes of the *yogatārās* of *Rohiṇī* and *Kṛttikā* is approximately 10° or three quarters of a *nakṣatra*. A *nakṣatra* system with its origin at the *yogatārā* of *Kṛttikā* will have *nakṣatra* boundaries at one quarter of a *nakṣatra* or 3°20′ from the *nakṣatra* boundaries in the *Rohiṇī* system. While *Sūryasiddhānta* gives 180° as the longitude of *Citrā* (see Table 1), *Paitāmahasiddhānta* gives 183° (Pingree and Morrissey, 1989). This could simply be a result of using coordinate systems having boundaries 3°20′ apart. The *Kṛttikā* system with *yogatārā* of *Kṛttikā*, Alcyone, at zero longitude is shown in Figure 4. The part of celestial sphere close to ecliptic is shown, where *nakṣatra* boundaries have been approximated to straight lines for illustrative purpose. As mentioned earlier, actual construction of *nakṣatra* boundaries should be done according to the principle illustrated in Figure 2.

The ecliptic longitudes of *yogatārās*, as identified by Burgess (1860), in *Kṛttikā* system are shown in Table 4 along with the longitudes (*dhruvaka*) of *yogatārās* given in *Sūryasiddhānta* (8.1–9). The numbers in Figure 4 refer to the serial number of *nakṣatras* shown in Table 4. The ecliptic longitudes in *Kṛttikā* system were obtained by setting a date on which the ecliptic longitude of the *yogatārā* of *Kṛttikā*, *Alcyone*, became 0°0′. This date was found to be April 17, -2336 by trial and error using Stellarium software. From Table 4, it is seen that the longitude of the *yogatārā* of *Kṛttikā* had shifted by 37°30′ according to *Sūryasiddhānta* from its zero point in *Kṛttikā* system.

Some observations can be made regarding the *nakṣatra* boundaries in *Rohiṇī* and *Kṛttikā* systems. According to *Sūryasiddhānta*, *yogatārā* of *Revatī* (ζ Piscium) is near the origin of the coordinate system. However, ζ Piscium is a very dim star with an apparent magnitude of 5.20. Why would such a star be chosen at the origin? Pingree and Morrissey (1989) write:

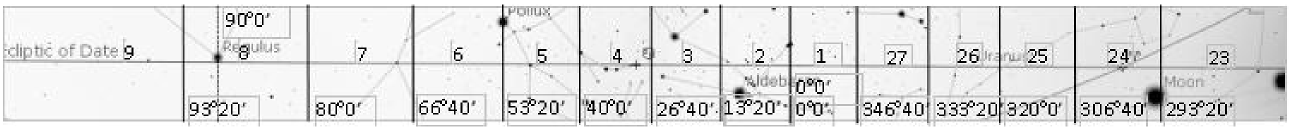
> It is disturbing that ζ Piscium is so dim, and that its α is 0; 7h or nearly 2° too high on the assumption that the original list was drawn up in AD 425, though the situation, of course, improves as one increases that date. But there are no other visible stars in the neighbourhood.

The *yogatārā* of *Revatī* was not at the origin of the coordinate system, when it was designed. The *yogatārā* of *Rohiṇī*, Aldebaran, was at the origin of the coordinate system, which is a bright star with apparent magnitude of

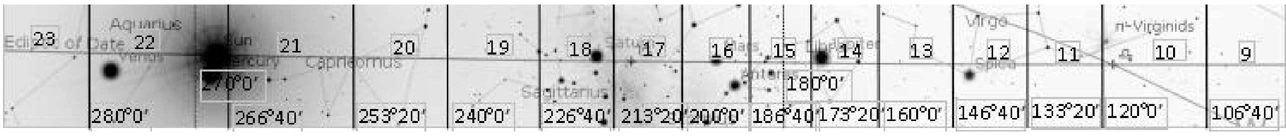
Table 3 Longitudes of *yogatārās* in *Rohiṇī* system.

No.	*Nakṣatra*	Junction-star (*yogatārā*)[a]	Ecliptic longitude[b]	*Dhruvaka* (longitude)[c]
1	*Rohiṇī*	α Tau	0°00′	49°30′
2	*Mṛgaśirā*	δ Ori	13°58′	63°0′
3	*Ārdrā*	α Ori	18°58′	67°20′
4	*Punarvasu*	β Gem	44°20′	93°0′
5	*Puṣya*	δ Cnc	58°56′	106°0′
6	*Āśleṣā*	ϵ Hya	63°02′	109°0′
7	*Maghā*	α Leo	80°29′	129°0′
8	*Pūrva-phālgunī*	δ Leo	91°11′	144°0′
9	*Uttara-phālgunī*	β Leo	102°20′	155°0′
10	*Hasta*	δ Crv	124°04′	170°0′
11	*Citrā*	α Vir	134°11′	180°0′
12	*Swāti*	α Boo	134°10′	199°0′
13	*Viśākhā*	ι Lib	161°20′	213°0′
14	*Anurādhā*	δ Sco	172°52′	224°0′
15	*Jyeṣṭhā*	α Sco	180°05′	229°0′
16	*Mūla*	ϵ Sco	194°54′	241°0′
17	*Pūrvāṣāḍhā*	δ Sgr	204°50′	254°0′
18	*Uttarāṣāḍhā*	σ Sgr	212°40′	260°0′
	Abhijīt	α Lyr	215°22′	266°40′
19	*Śravaṇa*	α Aql	231°14′	280°0′
20	*Dhaniṣṭhā*	β Del	246°44′	290°0′
21	*Śatabhiṣaja*	λ Aqr	271°49′	320°0′
22	*Pūrva-bhādrapadā*	α Peg	283°57′	326°0′
23	*Uttara-bhādrapadā*	α And	304°51′	337°0′
24a	*Uttara-bhādrapadā*	γ Peg	299°36′	337°0′
24b	*Revatī*	ζ Psc	310°01′	359°50′
25	*Aśvinī*	β Ari	324°15′	8°0′
26	*Bharaṇī*	35 Ari	337°19′	20°0′
27	*Kṛttikā*	η Tau	350°18′	37°30′

[a] As identified by Burgess (1860).
[b] Ecliptic longitudes on June 12, -3044 based on Stellarium software.
[c] Longitudes as given in *Sūryasiddhānta* 8.1–9.



(a) Kṛttikā system.



(b) Kṛttikā system (continued).

Figure 4

0.85. The *yogatārā* of *Revatī* was not even a boundary star in the original system. It became a boundary star in the *Kṛttikā* system devised later. The *yogatārā* of *Punarvasu*, Pollux, also became a boundary star in the *Kṛttikā* system (see Figure 4a).

The *yogatārā* of *Jyeṣṭhā*, Antares, is at 180° in the *Rohiṇī* system (see Figure 3b and Table 3). When vernal equinox was at the *yogatārā* of *Rohiṇī*, then autumnal equinox was at the *yogatārā* of *Jyeṣṭhā*. The *yogatārā* of *Maghā*, Regulus, is a boundary star in the *Rohiṇī* system (see Figure 3a). Its longitude is close to 80° in the *Rohiṇī* system as shown in Table 3. Its longitude is 90° in the *Kṛttikā* system as shown in Table 4. Thus when vernal equinox fell on the *yogatārā* of *Kṛttikā*, the summer solstice fell on the *yogatārā* of *Maghā*. With the precise determination of *nakṣatra* boundaries, coordinates given in astronomical texts can be better analyzed to check whether some of the *yogatārās* have been misidentified.

6 Reassessing the identifications of yogatārās

It is clear that Indian astronomers did not keep measuring the coordinates because they believed the coordinates to be ecliptic coordinates which do not change when fixed to stars in a sidereal system. The coordinates of the *yogatārā* of *Aśvinī* is given as 8° longitude and 10° latitude in *Sūryasiddhānta*, *Paitāmahasiddhānta*, *Mahābhāskarīya* and *Laghubhāskarīya*, and by Brahmagupta, Vateśvara, Lalla, and Gaṇeśa (Pingree and Morrissey, 1989). It was never changed as would be expected in a sidereal ecliptic coordinate system. The reason the data given in texts do not fit to a single time period is due to a mix up of data during the last update when reference point was changed to account for precession as well as due to misidentification of some *yogatārās*. Based on the analysis of longitude data, following six *yogatārās* have been misidentified.

6.1 The yogatārā of Aśvinī

Since *Aśvinī* is the first *nakṣatra* in the list of *nakṣatras* given in *Sūryasiddhānta* and other texts of classical period, it is of vital importance to correctly identify the *yogatārā* of *Aśvinī*. As mentioned above, every text gives the coordinates of the *yogatārā* of *Aśvinī* as 8° longitude and 10° latitude. Currently accepted *yogatārā* of *Aśvinī* is Sheratan (β Ari) with apparent magnitude of 2.60 and J2000.0 ecliptic longitude and latitude of 33°58′ and 8°29′ respectively. The star Hamal (α Ari) is the brightest star of the Aries constellation. Hamal (α Ari) has apparent magnitude of 2.00 and J2000.0 ecliptic longitude and latitude of 37°40′ and 9°58′ respectively. The ecliptic latitude of 9°58′ of Hamal matches closely with the latitude of 10° given in *Sūryasiddhānta*. This raises the possibility that the *yogatārā* of *Aśvinī* is Hamal instead of Sheratan. This is confirmed from the longitude of 8° given in every text. The ecliptic longitude of Hamal is 327°50′ in *Rohiṇī* system. That is when the ecliptic longitude of *Rohiṇī* was 0°0′ on June 12, -3044, the ecliptic longitude of Hamal was 327°50′ according to Stellarium software. Since *Aśvinī* is three *nakṣatras* away from *Rohiṇī*, the span of *Aśvinī nakṣatra* in *Rohiṇī* system is 320°0′ to 333°20′. This means that Hamal is 7°50′ away from the beginning of *Aśvinī nakṣatra* in *Rohiṇī* system and when *nakṣatra* list was updated to begin with *Aśvinī*, Hamal would have eclip-

Table 4 Longitudes of *yogatārās* in *Kṛttikā* system.

No.	*Nakṣatra*	Junction-star (*yogatārā*)[a]	Ecliptic longitude[b]	*Dhruvaka* (longitude)[c]
1	*Kṛttikā*	η Tau	0°00′	37°30′
2	*Rohiṇī*	α Tau	9°43′	49°30′
3	*Mṛgaśirā*	λ Ori	23°40′	63°0′
4	*Ārdrā*	α Ori	28°41′	67°20′
5	*Punarvasu*	β Gem	53°55′	93°0′
6	*Puṣya*	δ Cnc	68°39′	106°0′
7	*Āśleṣā*	ϵ Hya	72°41′	109°0′
8	*Maghā*	α Leo	90°08′	129°0′
9	*Pūrva-phālgunī*	δ Leo	100°56′	144°0′
10	*Uttara-phālgunī*	β Leo	111°59′	155°0′
11	*Hasta*	δ Crv	133°43′	170°0′
12	*Citrā*	α Vir	143°53′	180°0′
13	*Swāti*	α Boo	143°56′	199°0′
14	*Viśākhā*	ι Lib	171°02′	213°0′
15	*Anurādhā*	δ Sco	182°34′	224°0′
16	*Jyeṣṭhā*	α Sco	189°47′	229°0′
17	*Mūla*	ϵ Sco	204°36′	241°0′
18	*Pūrvāṣāḍhā*	δ Sgr	214°32′	254°0′
19	*Uttarāṣāḍhā*	σ Sgr	222°22′	260°0′
	Abhijīt	α Lyr	225°08′	266°40′
20	*Śravaṇa*	α Aql	241°03′	280°0′
21	*Dhaniṣṭhā*	β Del	256°26′	290°0′
22	*Śatabhiṣaja*	λ Aqr	281°32′	320°0′
23	*Pūrva-bhādrapadā*	α Peg	293°37′	326°0′
24a	*Uttara-bhādrapadā*	α And	314°31′	337°0′
24b	*Uttara-bhādrapadā*	γ Peg	309°17′	337°0′
25	*Revatī*	ζ Psc	319°44′	359°50′
26	*Aśvinī*	β Ari	333°57′	8°0′
27	*Bharaṇī*	35 Ari	347°00′	20°0′

[a] As identified by Burgess (1860)
[b] Ecliptic longitudes on April 17, -2336 based on Stellarium software
[c] Longitudes as given in *Sūryasiddhānta* 8.1–9.

tic longitude of 7°50′ in the new system. This is a close match with 8° longitude of the *yogatārā* of *Aśvinī* given in all astronomical texts. Thus Hamal has excellent match for both latitude and longitude to be the *yogatārā* of *Aśvinī*.

The identification of Hamal as the *yogatārā* of *Aśvinī* with 8° longitude from the beginning of *Aśvinī* provides a zero point from which the longitudes of some of the *yogatārā* have been measured. The date on which the ecliptic longitude of Hamal was 8°0′ is found to be April 13, -130 by trial and error using Stellarium software. Table 5 shows the ecliptic longitude of *yogatārās* when Hamal had an ecliptic longitude of 8°0′. This system has been named *Aśvinī*-beginning *Rohiṇī* system as it measures the longitude from the boundary of *Aśvinī* in *Rohiṇī* system.

Table 5 also shows the ecliptic longitude of *yogatārās* when the *yogatārā* of *Revatī* (ζ Piscium) had an ecliptic longitude of 359°50′. This system has been named *Aśvinī*-beginning *Kṛttikā* system as it measures the longitude from the boundary of *Aśvinī nakṣatra* in *Kṛttikā* system. According to Table 4, the ecliptic longitude of the *yogatārā* of *Revatī* (ζ Piscium) is 319°44′ in *Kṛttikā* system, which means the *yogatārā* of *Revatī* is a boundary star in *Kṛttikā* system as the *nakṣatra* boundary between *Revatī* and *Aśvinī* is at 320°. Since the boundary of *Revatī* is 40° from the boundary of *Kṛttikā*, the coordinate of the *yogatārā* of *Revatī* is 359°44′ in *Aśvinī*-beginning *Kṛttikā* system, which is an excellent match with the value of 359°50′ given in *Sūryasiddhānta*. The date on which the ecliptic longitude of *Revatī* star (ζ Piscium) was 359°50′ is found to be December 12, 563 by trial and error using Stellarium software. It should be noted that vernal equinox moves in the opposite direction of the order of *nakṣatras*. Since vernal equinox was at the boundary of *Aśvinī* and *Revatī* in 130 BCE in *Aśvinī*-beginning *Rohiṇī* system, it implies that vernal equinox was in *Aśvinī nakṣatra* for approximately 960 years prior to c. 130 BCE. So the order of *nakṣatra* could have been updated to begin with *Aśvinī* at any time between c. 1090 BCE and c. 130 BCE. Similarly, the coordinates of the *yogatārā* of *Revatī*, ζ Piscium, could have been updated to 359°50′ at any time period between c. 400 BCE and c. 560 CE. Since the longitude of many *yogatārās* given in *Sūryasiddhānta* match the respective longitudes in *Aśvinī*-beginning *Kṛttikā* system, it stands to reason that an attempt was made to update the coordinates between c. 400 BCE and c. 560 CE. The updating of coordinates in two different systems created a confusion resulting in a list that has some coordinates from *Aśvinī*-beginning *Rohiṇī* system, some coordinates from *Aśvinī*-beginning *Kṛttikā* system, and some coordinates resulting from confusion between *Rohiṇī* and *Kṛttikā* systems.

To illustrate this point, another column with title "*Aśvinī*-beginning *Kṛttikā* offset" has been added in Table 5. The values in this column are 3°20′ (one quarter of the span of a *nakṣatra*) lesser than the values in *Aśvinī*-beginning *Kṛttikā* system. It should be noted that the *nakṣatra* boundaries in *Rohiṇī* and *Kṛttikā* systems are separated by one quarter of the span of a *nakṣatra*. Confusion between these two systems would have resulted in subtracting 3°20′ from the values in *Aśvinī*-beginning *Kṛttikā* system. Another reason for error in longitudes would have been an attempt to keep the *yogatārās* within their boundaries. Since the difference in longitude between *Aśvinī*-beginning *Rohiṇī* and *Aśvinī*-beginning *Kṛttikā* systems is 10°, the longitude of Hamal would be 18° in *Aśvinī*-beginning *Kṛttikā* system, but this would put Hamal outside the boundary of *Aśvinī*, as each *nakṣatra* has span of 13°20′. So the longitude of Hamal in *Aśvinī*-beginning *Rohiṇī* system was kept in *Aśvinī*-beginning *Kṛttikā* system.

6.2 The yogatārā of Bharaṇī

Currently accepted *yogatārā* of *Bharaṇī* is Barani II (35 Ari) with apparent magnitude of 4.65 and J2000.0 ecliptic longitude and latitude of 46°56′ and 11°19′ respectively. However, nearby star *Bharaṇī* (41 Ari) is brighter than Barani II and should be the *yogatārā* of *Bharaṇī*. As seen in Table 5, the longitude of Barani II (35 Ari) in *Aśvinī*-beginning *Rohiṇī* system is 17°22′, while the longitude given in *Sūryasiddhānta* is 20°. The longitude of *Bharaṇī* (41 Ari) in *Aśvinī*-beginning *Rohiṇī* system is 18°36′, which is a better match with the longitude given in *Sūryasiddhānta*. *Bharaṇī* (41 Ari) has latitude of 10°27′, which is a reasonable match with 12° latitude given in *Sūryasiddhānta*. *Bharaṇī* (41 Ari) is better suited to be the *yogatārā* of *Bharaṇī* due to it being brighter and matching longitude better.

6.3 The yogatārā of Hasta

The accepted *yogatārā* of *Hasta* is Algorab (δ Crv) with apparent magnitude of 2.90 and J2000.0 ecliptic longi-

Table 5 Ecliptic lognitude of *yogatārās* in *Aśvinī*-beginning *Rohiṇī* and *Aśvinī*-beginning *Kṛttikā* systems.

			***Aśvinī* beginning *Rohiṇī* system (Apr 13, -130)**	***Aśvinī* beginning *Kṛttikā* system (Dec 12, 563)**	***Aśvinī* beginning *Kṛttikā* offset**	***Sūryasiddhānta***
No.	***Nakṣatra***	**Junction-star (*yogatārā*)[a]**	**Relative longitude**	**Relative longitude**	**Relative longitude**	***Dhruvaka* (longitude)**
1	*Aśvinī*	β Ari	4°21′	13°58′	10°38′	8°0′
2	*Bharaṇī*	35 Ari	17°22′	26°58′	23°38′	20°0′
3	*Kṛttikā*	η Tau	30°23′	40°00′	36°40′	37°30′
4	*Rohiṇī*	α Tau	40°09′	49°46′	46°26′	49°30′
5	*Mṛgaśirā*	λ Ori	54°05′	63°42′	60°22′	63°0′
6	*Ārdrā*	α Ori	59°07′	68°45′	65°25′	67°20′
7	*Punarvasu*	β Gem	83°57′	93°27′	90°07′	93°0′
8	*Puṣya*	δ Cnc	99°05′	108°42′	105°22′	106°0′
9	*Āśleṣāu*	ϵ Hya	102°55′	112°28′	109°08′	109°0′
10	*Maghā*	α Leo	120°22′	129°56′	126°36′	129°0′
11	*Pūrva-phālgunī*	δ Leo	131°31′	141°12′	137°52′	144°0′
12	*Uttara-phālgunī*	β Leo	142°11′	151°45′	148°25′	155°0′
13	*Hasta*	δ Crv	163°59′	173°33′	170°13′	170°0′
14	*Citrā*	α Vir	174°15′	183°52′	180°32′	180°0′
15	*Swāti*	α Boo	174°30′	184°09′	180°49′	199°0′
16	*Viśākhā*	ι Lib	201°25′	211°01′	207°41′	213°0′
17	*Anurādhā*	δ Sco	212°58′	222°35′	219°15′	224°0′
18	*Jyeṣṭhā*	δ Sco	220°10′	229°46′	226°26′	229°0′
19	*Mūla*	λ Sco	234°59′	244°35′	241°15′	241°0′
20	*Pūrvāṣāḍhā*	δ Sgr	244°57′	254°34′	251°14′	254°0′
21	*Uttarāṣāḍhā*	σ Sgr	252°46′	262°23′	259°03′	260°0′
22	*Abhijīt*	α Lyr	255°40′	265°18′	261°58′	266°40′
23	*Śravaṇa*	α Aql	271°50′	281°33′	278°13′	280°0′
24	*Dhaniṣṭhā*	β Del	286°47′	296°23′	293°03′	290°0′
25	*Śatabhiṣaja*	λ Aqr	311°57′	321°34′	318°14′	320°0′
26	*Pūrva-bhādrapadā*	α Peg	323°57′	333°32′	330°12′	326°0′
27a	*Uttara-bhādrapadā*	α And	344°48′	354°22′	351°02′	337°0′
27b	*Uttara-bhādrapadā*	γ Peg	339°36′	349°12′	345°52′	337°0′
28	*Revatī*	ζ Psc	350°12′	359°50′	356°30′	359°50′

[a] As identified by Burgess (1860).

tude and latitude of 193°27′ and −12°12′ respectively. As seen in Table 5, the longitude given in *Sūryasiddhānta* is 170°0′, which is 3°33′ lesser than the relative longitude of 173°33′ in *Aśvinī*-beginning *Kṛttikā* system. Nearby star Gienah (γ Crv) has apparent magnitude of 2.55 and J2000.0 ecliptic longitude and latitude of 190°44′ and −14°30 respectively. The relative longitude of Gienah is 170°50′ in *Aśvinī*-beginning *Kṛttikā* system, which is a good match with the relative longitude of 170°0′ given in *Sūryasiddhānta*. Though the latitude of Algorab is a better match for −11°0′ latitude given in *Sūryasiddhānta* compared to Gienah, on account of brightness and better match of longitude, Gienah has a better claim to be the *yogatārā* of *Hasta nakṣatra*.

6.4 The yogatārā of Swāti

The currently accepted yogatārā of *Swāti* is Arcturus (α Boo), which is a very bright star with apparent magnitude of 0.15 and J2000.0 ecliptic longitude and latitude of 204°14′ and 30°43′ respectively. As seen in Table 5, the longitude given in *Sūryasiddhānta* is 199°0′, which is 14°51′ more than the relative longitude of 184°9′ in *Aśvinī*-beginning *Kṛttikā* system. The latitude given in *Sūryasiddhānta* is 37°0′, which is 6°17′ greater than the J2000.0 ecliptic latitude of 30° 43′ of Arcturus. The ecliptic longitude of Arcturus is within one degree of the ecliptic longitude of Spica, the *yogatārā* of *nakṣatra Citrā*. According to *Sūryasiddhānta*, the difference in longitudes of the *yogatārās* of *Citrā* and *Swāti* is 19°0′. Thus Arcturus is not a good fit to be the *yogatārā* of *Swāti*. There is another star, Alphecca, which fits the longitude of the *yogatārā* of *Swāti* better. Alphecca (α CrB) has apparent magnitude of 2.20 and J2000.0 ecliptic longitude and latitude of 222°18′ and 44°19′ respectively. In terms of latitude, Alphecca is approximately 7° higher and Arcturus is approximately 7° lower. The relative longitude of Alphecca is 202°5′ in *Aśvinī*-beginning *Kṛttikā* system, which is 3°5′ greater than the longitude of 199°0′ given in *Sūryasiddhānta*. The longitude matches well with *Aśvinī*-beginning *Kṛttikā* offset value of 198°45′. Thus, Alphecca is a much better match in terms of longitude compared to Arcturus.

6.5 The yogatārā of Uttarāṣāḍhā

Currently accepted *yogatārā* of *Uttarāṣāḍhā* is Nunki (σ Sgr) with apparent magnitude of 2.05 and J2000.0 ecliptic longitude and latitude of 282°23 and −3°27′ respectively. As seen in Table 5, the longitude given in *Sūryasiddhānta* is 260°0′, which is 2°23′ lesser than the relative longitude of 262°23′ in *Aśvinī*-beginning *Kṛttikā* system. Latitude given in *Sūryasiddhānta* is −5°0′, which is 1°33′ lesser than the J2000.0 ecliptic latitude of −3°27′ of Nunki (σ Sgr). There is a star in the vicinity that fits the longitude and latitude given in *Sūryasiddhānta* better than Nunki (σ Sgr). The star *Namalsadirah* I (ϕ Sgr) has apparent magnitude of 3.15 and J2000.0 ecliptic longitude and latitude of 280°11′ and −3°57′ respectively. It has relative longitude of 260°10′ in *Aśvinī*-beginning *Kṛttikā* system, which is an excellent match with the 260°0′ longitude given in *Sūryasiddhānta*. Since Namalsadirah I (ϕ Sgr) is a better fit in terms of both longitude and latitude compared to Nunki (σ Sgr), Namalsadirah I (ϕ Sgr) has a better claim to be the *yogatārā* of *Uttarāṣāḍhā*.

6.6 The yogatārā of Dhaniṣṭhā

The accepted *yogatārā* of *Dhaniṣṭhā* is Rotanev (β Del) with apparent magnitude of 4.10 and J2000.0 ecliptic longitude and latitude of 316°20′ and 31°55′ respectively. As seen in Table 5, the longitude given in *Sūryasiddhānta* is 290°0′, which is 6°23′ lesser than the relative longitude of 296°23′ of Rotanev (β Del) in *Aśvinī*-beginning *Kṛttikā* system. Latitude given in *Sūryasiddhānta* is 36°0′, which is 4°5 greater than the J2000.0 ecliptic latitude of 31°55′ of Rotanev (β Del). There is a star in the vicinity that fits the longitude and latitude given in *Sūryasiddhānta* better than Rotanev (β Del). The star Al Salib (γ2 Del) has apparent magnitude of 4.25 and J2000.0 ecliptic longitude and latitude of 319°22′ and 32°42′ respectively. It has relative longitude of 289°57′ in *Aśvinī*-beginning *Rohiṇī* system, which is an excellent match with the 290°0′ longitude given in *Sūryasiddhānta*. Since Al Salib (γ2 Del) is a better fit in terms of both longitude and latitude compared to Rotanev (β Del), Al Salib (γ2 Del) has a better claim of being the *yogatārā* of *Dhaniṣṭhā*.

Based on the reassessment of the identifications of *yogatārās* above, alternative identifications of six *yogatārās* have been proposed. Table 6 shows the J2000.0 ecliptic coordinates of these six *yogatārās* along with the longitudes given in *Sūryasiddhānta*. The ecliptic coordinates of other *yogatārās* along with the longitudes given in *Sūryasiddhānta* have been listed in Table 2. As pointed above, the longitudes given in *Sūryasiddhānta* have some

Table 6 *Yogatārā* identifications different than Burgess (1860).

No.	Nakṣatra	Junction-star (*yogatārā*)	Ecliptic longitude[a]	*Dhruvaka* (longitude)	Ecliptic latitude[a]	*Vikṣepa* (latitude)
1	Aśvinī	*Sheratan* (β Ari)[b]	33°58′	8°0′	8°29′ N	10°0′ N
1	*Aśvinī*	*Hamal* (α *Ari*)[c]	37°40′	8°0′	9°58′	10°0′ N
2	Bharaṇī	Barani II (35 Ari)[b]	46°56′	20°0′	11°19′ N	12°0′ N
2	*Bharaṇī*	*Bharani* (41 *Ari*)[c]	48°12′	20°0′	10°27′ N	12°0′ N
13	Hasta	Algorab (δ Crv)[b]	193°27′	170°0′	12°12′ S	11°0′ S
13	*Hasta*	*Gienah* (γ *Crv*)[c]	190°44′	170°0′	14°30′ S	11°0′ S
15	Swāti	Arcturus (α Boo)[b]	204°14′	199°0′	30°44′ N	37°0′ N
15	*Swāti*	*Alphecca* (α *CrB*)[c]	222°18′	199°0′	44°19′ N	37°0′ N
21	Uttarāṣāḍhā	Nunki (σ Sgr)[b]	282°23′	260°0′	3°27′ S	5°0′ S
21	*Uttarāṣāḍhā*	*Namalsadirah I* (ϕ*Sgr*)[c]	280°11′	260°0′	3°57′ S	5°0′ S
24	Dhaniṣṭhā	Rotanev (β Del)[b]	316°20′	290°0′	31°55′ N	36°0′ N
24	*Dhaniṣṭhā*	*Al Salib* (γ2 *Del*)[c]	319°22′	290°0′	32°44′ N	36°0′ N

[a] J2000.0 ecliptic coordinates based on Stellarium software.
[b] Identifications by Burgrss (1860).
[c] This Study.

coordinates from *Aśvinī*-beginning *Rohiṇī* system, some coordinates from *Aśvinī*-beginning *Kṛttikā* system, and some coordinates resulting from corrections made due to confusion between *Rohiṇī* and *Kṛttikā* systems. A comparison of longitudes of *yogatārās* in these different systems is presented in Table 7 to show the best fit with the longitudes given in *Sūryasiddhānta*.

Some researchers have used the best fit method to date *Sūryasiddhānta*. Burgess (1860) had assumed a base year of 560 CE for identifications of *yogatārās*. He then calculated the average error in longitudes of the *yogatārās* and came to the conclusion that the star coordinates given in *Sūryasiddhānta* were measured around 490 CE. Abhyankar (1991) used a least square method to conclude that the best fit was obtained for 430 CE.

Pingree and Morrissey (1989) compared the star coordinates given in *Sūryasiddhānta* with star coordinates in 400, 425, 450, 475 and 500 CE and concluded that best fit was close to 425 CE. As discussed above, the longitudes given in *Sūryasiddhānta* are inconsistent due to a mix up between different systems and therefore a best fit approach cannot be applied to determine the date of observations. Since some of the *yogatārās* fit the *Aśvinī*-beginning Rohiṇī system, which has zero longitude in 131 BCE, current list of coordinates was updated before c. 130 BCE. Since most of the *yogatārās* fit the *Aśvinī*-beginning *Kṛttikā* system, which has zero longitude in 563 CE, current list of coordinates was updated again before c. 560 CE. Since vernal equinox stays in a *nakṣatra* for approximately 960 years, the updates could have taken place up to 960 years before these dates. As the original system, *Rohiṇī* system, has zero longitude in 3045 BCE, the original list of *nakṣatras* was compiled in fourth millennium BCE.

Misidentification of the *yogatārās* has also been investigated by Abhyankar (1991) and Venkatachar (2014). Abhyankar (1991) identified the *yogatārās* of *Bharaṇī* as *Bharani* (41 *Ari*) instead of Barani II (35 Ari), *Ārdrā* as Alhena (γ Gem) instead of Betelguese (α Ori), *Āśleṣā* as Minazal V (η Hya) instead of Minazal III (ϵ Hya), *Hasta* as Gienah (γ Crv) instead of Algorab (δ Crv), *Viśākhā* as Zubenelgenubi (α Lib) instead of HIP 74392 (ι Lib), *Ab-*

Table 7 Comparision of longitudes of *yogatārās*.

(a)

	1. *Aśvinī*	2. *Bharaṇī*	3. *Kṛttikā*	4. *Rohiṇī*	5. *Mṛgaśirā*	6. *Ārdrā*	7. *Punarvasu*
	α *Ari*	41 *Ari*	η Tau	α Tau	λ Ori	α Ori	β Gem
Aśvinī beginning *Rohiṇī* system	8° 0′	18° 36′	30° 23′	40° 23′	54° 05′	59° 07′	83° 57′
Aśvinī beginning *Kṛttikā* system	17° 38′	28° 13′	40° 0′	49° 46′	63° 42′	68° 45′	93° 27′
Aśvinī beginning *Kṛttikā* offset	14° 18′	24° 53′	36° 40′	46° 26′	60° 22′	65° 25′	90° 07′
Sūryasiddhānta	8° 0′	20° 0′	37° 30′	49° 30′	63° 0′	67° 20′	93° 0′
Best fit	*Aśvinī* beginning *Rohiṇī* system	*Aśvinī* beginning *Rohiṇī* system	*Aśvinī* beginning *Kṛttikā* offset	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system
Deviation	0° 0′	−1° 24′	−0° 50′	0° 16′	0° 42′	1° 25′	0° 27′

(b)

	8. *Puṣya*	9. *Āśleṣā*	10. *Maghā*	11. *Pūrvaphālgunī*	12. *Uttara-phālgunī*	13. *Hasta*	14. *Citrā*
	δ Cnc	ϵ Hya	α Leo	δ Leo	β Leo	γ *Crv*	α Vir
Aśvinī beginning *Rohiṇī* system	99° 05′	102° 55′	120° 22′	131° 31′	142° 11′	161° 17′	174° 15′
Aśvinī beginning *Kṛttikā* system	108° 42′	112° 28′	129° 56′	141° 12′	151° 45′	170° 50′	180° 32′
Aśvinī beginning *Kṛttikā* offset	105°22′	109°8′	126°36′	137°52′	148°25′	167°30′	180°32′
Sūrya-siddhānta	106° 0′	109° 0′	129° 0′	144° 0′	155° 0′	170° 0′	180° 0′
Best fit	*Aśvinī* beginning *Kṛttikā* offset	*Aśvinī* beginning *Kṛttikā* offset	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* offset
Deviation	−0° 38′	0° 8′	0° 56′	−2° 48′	−3° 15′	0° 50′	0° 32′

(c)

	15. *Swāti*	16. *Viśākhā*	17. *Anurādhā*	18. *Jyeṣṭhā*	19. *Mūla*	20. *Pūrvāṣāḍhā*	21. *Uttarāṣāḍhā*
	α CrB	*ι* Lib	*δ* Sco	*δ* Sco	*λ* Sco	*δ* Sgr	*ϕ Sgr*
Aśvinī beginning *Rohiṇī* system	192° 22′	201° 25′	212° 58′	220° 10′	234° 59′	244° 57′	250° 32′
Aśvinī beginning *Kṛttikā* system	202° 05′	211° 01′	222° 35′	229° 46′	244° 35′	254° 34′	260° 10′
Aśvinī beginning *Kṛttikā* offset	198° 45′	207° 41′	219° 15′	226° 26′	241° 15′	251° 14′	256° 50′
Sūrya-siddhānta	199° 0′	213° 0′	224° 0′	229° 46′	241° 0′	254° 0′	260° 0′
Best fit	*Aśvinī* beginning *Kṛttikā* offset	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* offset	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system
Deviation	−0° 15′	−1° 59′	−1° 25′	0° 46′	0° 15′	0° 34′	0° 10′

(d)

	22. *Abhijita*	23. *Śravaṇa*	24. *Dhaniṣṭhā*	25. *Śatabhiṣaja*	26. *Pūrva-bhādra-padā*	27. *Uttara-bhādra-padā*	28. *Revatī*
	α Lyr	*α* Aql	*γ*2 *Del*	*δ* Aqr	*α* Peg	*γ* Peg	*ζ* Psc
Aśvinī beginning *Rohiṇī* system	255° 40′	271° 50′	289° 57′	311° 57′	323° 57′	339° 36′	350° 12′
Aśvinī beginning *Kṛttikā* system	265° 18′	281° 33′	299° 31′	321° 34′	333° 32′	349° 12′	359° 50′
Aśvinī beginning *Kṛttikā* offset	261° 58′	278° 13′	296° 11′	318° 14′	330° 12′	345° 52′	356° 30′
Sūrya-siddhānta	266° 40′	280° 0′	290° 0′	320° 0′	326° 0′	337° 0′	359° 50′
Best fit	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Rohiṇī* system	*Aśvinī* beginning *Kṛttikā* system	*Aśvinī* beginning *Rohiṇī* system	*Aśvinī* beginning *Rohiṇī* system	*Aśvinī* beginning *Kṛttikā* system
Deviation	−1° 22′	1° 33′	−0° 3′	1° 34′	−2° 3′	2° 36′	0° 0′

hijīt as Altair (α Aql) instead of Vega (α Lyr), *Śravaṇa* as Rotanev (β Del) instead of Altair (α Aql), *Dhaniṣṭhā* as Sadalsuud (β Aqr) instead of Rotanev (β Del), and *Śatabhiṣaja* as Fomalhaut (α PsA) instead of Hydor (λ Aqr). These identifications of alternative stars as the *yogatārās* have been justified based on the accepted *yogatārās* not being within their boundaries or being too far away from ecliptic. Both of these reasons are unjustified. Many *yogatārās* are outside their boundaries in uniform division of ecliptic because the original span of *nakṣatras* was not uniform. This will be discussed in detail in a future paper. There was no constraint on *yogatārās* to be close to ecliptic, which is evident from the latitudes of many *yogatārās* being over 20 degrees. Also, many of these identifications completely disregard the latitudes given in *Sūryasiddhānta*, and hence are unacceptable. Venkatachar (2014) has also proposed alternative identifications of *yogatārās* and justified the identifications based on the accepted *yogatārās* not being within their boundaries. This reasoning, as discussed above, is unjustified. Similar to Abhyankar (1991), many of these identifications completely disregard the latitudes given in *Sūryasiddhānta*, and hence are unacceptable.

7 Conclusions

(i) Contrary to accepted view that Indian astronomers were using polar coordinates, Indian astronomers were using sidereal ecliptic coordinates, which does not change with time to a significant extent. (ii) Indian astronomers had developed precise *nakṣatra* boundaries with zero points at the *yogatārās* of *Rohiṇī* and *Kṛttikā*. (iii) The origin of the *nakṣatra* system can be traced to 4th millennium BCE. (iv) The star positions given in *Sūryasiddhānta* are an extrapolation of the earlier sidereal ecliptic longitudes after applying correction for the change in zero point due to shift of equinox. (v) The star positions based on zero points corresponding to two different epochs seem to have been mixed up. The coordinates given in astronomical texts are a mix of coordinates from *Rohiṇī* and *Kṛttikā* systems. This would imply that an earlier Indian tradition of making observations of star coordinates was lost by the time of *Sūryasiddhānta*. (vi) Some of the *yogatārās* have been misidentified. Most importantly, the *yogatārā* of *Aśvinī* is Hamal (α Ari) instead of Sheratan (β Ari).

Acknowledgement

Financial support received from the Federation of Jain Associations in North America (JAINA) is gratefully acknowledged. Author would also like to thank Dr. Manish Mehta, Dr. Sulekh Jain and Dr. Shugan Jain for their comments and encouragement. Additionally, author would like to thank one of the reviewers for pointing out that *Sūryasiddhānta* uses ecliptic coordinates for its planetary model and it would not make sense for *Sūryasiddhānta* to use polar coordinates for star positions.

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