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Stars of Vedic *nakṣatra Śraviṣṭhā*: An Independent Identification

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Abstract: *The sky configuration of the sun (moon) and the stars at the start of a yuga described in Vedāṅga Jyotiṣa is computationally modelled to identify the stars of nakṣatraŚraviṣṭhā. This identification is independent of the coordinates of the yogatārā of this nakṣatra given in the post-Vedic texts. The astronomical conditions specified in Vedāṅga Jyotiṣa are satisfied from 1750 BCE to 1000 BCE by a group of four (and more) stars of the Delphinus constellation.*

Keywords: *Śraviṣṭhā, Vedic nakṣatra, Vedāṅga Jyotiṣa*

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Introduction

The Vedic ritualists identified the position of the moon in the sky with twenty-seven (sometimes twenty-eight) *nakṣatras* (constellations) (*RV*.X.85.2). These are single or groups of two or more stars mostly along the ecliptic, although a number *nakṣatras* are significantly removed from the ecliptic. In the Vedic texts a day is named by the *nakṣatra* in the vicinity of the moon on that day. Similarly a month is named by the *nakṣatra* close to the full moon. Names of some *nakṣatras* can be identified in *Ṛgveda Saṃhitā* and some of these denote stars but others define the attributes of gods. Narahari Achar (2002)[1] has claimed that the reference to the path of the sun and the moon in RV.V.51.15 and the names of fifteen *davatās* (presiding deities) of *nakṣatras* mentioned in *RV*.V.51 suggest that the *nakṣatras* were known during the *Ṛg Vedic* time. However, the complete lists of *nakṣatras* appear only in the post-*Ṛgvedic* texts. Gondhalekar (2013)[2] has collated the lists of *nakṣatras* in a number of Vedic texts (*AV*.XIX.7.2-5; *MS*.II.13.20; *KS*.39.13; *TS*.IV.4.10; *TB*.1.5; *TB*.3.1.4-5; *SGS*.I.26; *VJ.RJ*.25-28); apart from small differences in the names, number and their *davatās* these lists are identical. In these post-*Ṛgvedic* texts the lists of *nakṣatras* appear as a complete list and without a preamble. It is impossible to identify the process or processes that might have led to the creation of these lists. Moreover, the texts include no information that could enable the identification of the stars of the *nakṣatras* with the stars in modern star catalogues. In his translation of *Sūryasiddhānta* (a medieval/siddhāntic text),Burgess (1935)[3] attempted to identify the 'principle' star – the *yogatārā* of *nakṣatras*. This identification was based on comparison of coordinates of the *yogatārā* given in *Sūryasiddhānta* and other medieval astronomy texts with coordinates in the nineteenth century star catalogues. Pingree and Morrissey (1989)[4] have attempted to identify the *yogatārās* from the coordinates given in *Paitāmahsiddhānta* (of the *Viṣṇudharmottara Purāṇa*). They demonstrate that the coordinates in *Paitāmahsiddhānta* are a result of observations in about the fifth century CE. They have asserted that these coordinates are "an adaptation of a Greek star catalogue"; they have not provided evidence for this assertion nor have they identified this particular catalogue. The provenance of the coordinates given in *Paitāmahsiddhānta* is also uncertain; according to Billard (1971)[5] these coordinates have been plagiarized from *Brāhmasphuṭasiddhānta*, a text of the seventh century CE. Saha and Lahiri (1992)[6] have given a list of *yogatārās* and they state that this list is derived from stars in *Sūryasiddhānta*. Abhyankar (1991)[7] has combined the Vedic concept of *nakṣatra* with the post Vedic concept of *rāśi* to re-identify a number of *yogatārās*. These identifications of *yogatārās* is from star coordinates given in the texts of the siddhāntic period, these catalogues of coordinates are over a thousand years removed from the Vedic texts (assuming 500 BCE to be the putative epoch of the end of Vedic era). There is no reason to believe that the stars chosen by the compilers of these catalogues were the same as those selected by the Vedic sky watchers. It is, therefore, essential to determine the stars of the Vedic *nakṣatras* without appeal to the first millennium CE catalogues of star coordinates.

The list of *nakṣatras* created by the Vedic sky-watchers had no astronomical purpose; the list was created only to determine the time of rituals. Thus each *nakṣatra* has a ritual context. The word *yogatārā* is not in Vedic texts. The Vedic ritualists considered each *nakṣatra* as an asterism although the Vedic name of *nakṣatras* suggests that some *nakṣatras* were single stars. The *yogatārās* in siddhāntic texts were identified by comparing the star coordinates in these texts with the coordinates given in modern star catalogues. No attention was paid to the ritual context in which the Vedic people might not have observed these stars nor was any attention paid to check if the Vedic astronomers would have been able to observe these stars at times that were significant to the ritualists. The Vedic astronomers did not have access to the coordinates of stars; they would have relied only on naked-eye observations. No measurements were made as the technology did not exist and even the concept of making astronomical measurements may not have been known. The sky watchers recorded (or remembered) the objects they saw in the sky and the sky configuration and the ritual context at the time of observation. Over the last two hundred years almost all discussion of astronomical passages from Vedic texts has been in terms of abstract concepts like right ascension and declination (or equatorial coordinate system). These discussions are not particularly enlightening as they tell us nothing about what and when the composers of these passages might have seen in the sky. In order to interpret and understand astronomical and calendric passages in the Vedic texts it is essential to look at the sky with the Vedic observers (Gondhalekar 2017)[8]. The only coordinate system known to the Vedic observers and which has been identified in the Vedic texts (in *ṚgvedaSaṃhitā*), is the horizon coordinate system (Gondhalekar 2013)[9]. In this coordinate system a Vedic sky watcher would have identified an astronomical object by its height above the horizon and its distance along the horizon with descriptive terms like 'here' and 'there'. In modern terminology the descriptive terms would be the altitude and the azimuth and in this article the position of celestial objects is defined only in terms of these two observable coordinates. The rationale for grouping stars into *nakṣatras* is not known but the Vedic people would have grouped only those stars they were able to see into *nakṣatras*. Pingree & Morrissey (1989)[10] state that "The identification of the constellations (*nakṣatras*) referred to in these Vedic lists of the first millennium B.C. with stars in modern catalogues is almost impossible". However, some Vedic texts describe the configuration of the sun, moon and the stars required to perform their rituals. By numerically modelling the sky configuration described in these texts it may be possible to identify stars of *nakṣatras* that the Vedic people might have observed. As an example, the sky configuration of the sun, moon and stars described in two verses of *Vedāṅga Jyotiṣa* is modelled to identify the stars of *nakṣatra Śraviṣṭhā*

Asterism of Śraviṣṭhā

Vedāṅga Jyotiṣa – The astronomical 'arm' or auxiliary of the Vedas is the oldest known mathematically codified calendric text of South Asia. This text is the culmination of the developments in the Vedic calendric science (see, for example, Iyengar (2009)[11] but this history is not relevant to current analysis. *Vedāṅga Jyotiṣa* has survived in two recensions – the *Ṛgvedic* recension (*RJ*) and the *Yajurvedic* recension (*YJ*). The *Ṛgvedic* recension is considered the older of the two. There are minor differences between the two but these are not pertinent to this analysis. The terse (and at times coded) verses of the text describe algorithms to determine the time and position of the sun and the moon required to perform the Vedic rituals and ceremonies that are described and discussed in the *Saṃhitās* and *Brāhmaṇas*. A number of these algorithms have been analysed and discussed in terms of contemporary mathematics and astronomy by Gondhalekar(2013)[12]. This text also has a list of twenty-seven *nakṣatras* (*RJ*.25-28 and *YJ*.32-35) and this list is similar to the lists of *nakṣatras* in the *Saṃhitās* and the *Brāhmaṇas*. However, in *Vedāṅga Jyotiṣa* the term *nakṣatra* does not mean star(s) but a sector of the path of the moon.

The fundamental calendric unit of *Vedāṅga Jyotiṣa* is a *yuga* (*RJ*.1,3; *YJ*.1-2) – a period of 62 lunations and the Vedic lunation is approximated to 29.5 days (the modern mean value is 29.53 days); thus a *yuga* is 1830 days. The start of a *yuga* is given in *RJ*.5-6 and *YJ*.6-7; these verses have been interpreted and translated by Kuppanna Sastry (1984)[13] as follows:

svar ākramete somārkau yadā sākaṃ savāsavau/
syāt tadādi yugam māghaḥ tapaḥ śuklo 'yanam hy udak//
prapadyete śraviṣṭhādau sūrācandramasāv udak/
sārpārdhe dakṣiṇārkas tu māghaśrāvaṇayoḥ sadā//

When the Sun and the Moon occupy the same region of the zodiac together with the asterism of *Śraviṣṭhā*, at that time begins the *yuga*, and the (synodic) month of *Māgha*, the (solar seasonal) month called *Tapas*, the bright fortnight (of the synodic month, here *Māgha*), and their northward course (*uttaram ayanam*). When situated at the beginning of the *Śraviṣṭhā* segment, the Sun and the Moon begin to move north. When they reach the midpoint of the *Aśleṣā* segment, they begin to move south. In the case of the Sun, this happens always in the month of *Māgha* and *Srāvaṇa*, respectively.

Dikshit (1969)[14] has interpreted these verses as follows:

When the sun and the moon while moving in the sky, come to *Vāsava* (*Dhaniṣṭhā*, β-Delphini) star together, then the *yuga*, the *Māgha* (month), the *Tapas* (season), the light half of the month, and the winter solstice, all commence together.

> The sun and the moon turn towards North in the beginning of *Dhaniṣṭhās*[1] and towards the South in the middle of *Āśleṣā*. The sun always does this respectively in the months of *Māgha* and *Śrāvaṇa*.

There is, however, more to these two verses than just the time of the start of a *yuga*. The algorithms of *Vedāṅga Jyotiṣa* are based on a quasi-ecliptic coordinate system. The coordinate system is introduced in *RJ*.14 and *YJ*.18; these verses have been decoded by Thibaut (1877)[15]. The arrangement of *nakṣatras* in *RJ*.14 and *YJ*.18 is called *jāvādi* (*jau ādi* – beginning with *jau*, abbreviation for the *nakṣatraAśvayu**jau***or *Aśvins*) arrangement. The coordinate system is formulated by identifying the *nakṣatra* of the new and full moon during a *yuga* (Gondhalekar 2009[16] and Gondhalekar 2013[17].) The coordinate system is twenty-seven *nakṣatra*-sectors along the path of the moon; each sector, of equal width, is $13^5/_9$ days wide (*RJ*.18; *YJ*.39). Each *nakṣatra*-sector can be identified by a *nakṣatra* and each *nakṣatra*-sector is divided into 124 parts called *bhāṃśa*. The celestial position of the sun or the moon in a sector is given in terms of a *nakṣatra* (i.e. the name of a sector) and the *bhāṃśa* within that *nakṣatra*-sector – this is equivalent to the ecliptic longitude in degrees and minutes. This is a partial coordinate system; partial in the sense that only the longitude of the celestial objects is defined (and this longitude is along the path of the moon) and not the latitude[2]. This is because *Vedāṅga Jyotiṣa* is only concerned with the position of the sun (which defines the ecliptic) and the moon (that deviates from the ecliptic by about ±5°). The origin of the coordinate system is at *bhāṃśa* zero of *Śraviṣṭhānakṣatra*-sector; this is implicit in *RJ*.14 and *YJ*.18 and is stated in *RJ*.5-6 and *YJ*.6-7. Although each *nakṣatra*-sector is identified by a *nakṣatra*, the asterism (stars) identifying the *nakṣatra* is neither at the beginning of a sector nor at a predefined position within the *nakṣatra*-sector. The exception, of course, is the asterism of *Śraviṣṭhā*, this asterism is at the beginning of the *Śraviṣṭhā*-sector (*RJ*.5-6 and *YJ*.6-7) at the start of a *yuga*. The identification of the asterism of *Śraviṣṭhā* is thus of crucial importance. The identification will not only establish the asterismat the beginning of a *yuga* but also establish the asterismat the origin of the *jāvādi* coordinate system that is central to the algorithms of *Vedāṅga Jyotiṣa*.

The two verses (*RJ*.5-6 and *YJ*.6-7) are unusual in Vedic texts; there is here a detailed description of the configuration in the sky of the sun (and the moon) and the stars at a specific time, namely the winter solstice. It is impossible to tell what the Vedic sky watchers could have meant by 'in the same region of the sky'. It is not possible to determine when the sun is in the vicinity of a *nakṣatra* because when the sun is visible (i.e. during the day) stars will not be visible in the glare of the sun and the sun is below the horizon when the stars are visible at night. However, there are two periods in a day when bright stars are visible in the sky and the presence of the sun can be discerned; this is at heliacal rising and setting of a star. Only at these two times it is plausible to claim (observationally) that the stars near the horizon are 'in the vicinity of the sun'. Ancient cultures were familiar with heliacal rising and setting of stars (Frazer 1933[18]; Aveni 2001[19]) and in particular with the heliacal rising and setting of the Pleiades/*Kṛttikās*. The Vedic sky-watchers were also familiar with heliacal raising and setting of stars (*TB*.1.5.2.1, Subbarayappa & Sarma 1985[20]). In this analysis it is assumed that the alignment of the sun (and the moon) and the stars of the *nakṣatra*, described in these verses (*RJ*.5-6 and *YJ*.6-7) was seen by the Vedic people. They would have regarded the sun and a group of stars to be 'in the same region of the sky' if they had *observed* the group of stars when the presence of the sun was evident. At astronomical twilight bright stars will be visible near the horizon and the presence of the sun can be discerned from the faint glow on the horizon at the position of sunrise or sunset. The dawn astronomical twilight is when the sun rises from 18° below the horizon to 12° below the horizon. The dusk astronomical twilight is when the sun sets from 12° below the horizon to 18° below the horizon. In this analysis it is assumed that Vedic sky-watchers would have regarded the asterism of *Śraviṣṭhā* to occupy the same region of the sky as the sun if the stars of this *nakṣatra* were visible close to the horizon at the dawn astronomical twilight and also at the dusk astronomical twilight. It could then be claimed that the stars are in the same region of the sky as the sun at all times. The problem of identifying the asterism of *Śraviṣṭhā* (independent of the coordinates of a *yogatārā* in the post-Vedic texts) can then be stated thus – *which bright stars would have been seen close to the horizon by the Vedic sky watchers at dawn and also dusk astronomical twilight on* (*or around*) *winter solstice*?

The visibility of a star during twilight depends on the topography of the location of the observer, the brightness of the star, the separation in azimuth between the star and the sun, the transparency of the atmosphere, the weather at the time of observation, the phase of the moon, the sky-glow (due to zodiacal light and galactic star-light) and the ability of an observer to detect a point source of light against background light. In this analysis ideal conditions of observations have been assumed, that is, a clear dry night, a clear view of the horizon, no sky-glow and no moon-light or observations made at new moon (consistent with *RJ*.5-6 and *YJ*.6-7). The Babylonian text MULAPIN has lists of heliacally rising and setting stars (List II, III in Hunger and Pingree 1989[21]). The faintest star in this list is (ANUNITU) ζ Piscium, a 5.21^m star. The sky condition or the altitude of the sun for this observation is not known. In the present analysis the sun is assumed to be 14° below the horizon. At this altitude of the sun there is enough light at the site of sunrise and sunset to confirm the presence of the sun. However, the sky will not be as dark as at the beginning (dawn) or end (dusk) of astronomical twilight (sun at −18°) and therefore only stars brighter than 4^{th} magnitude are included in this article.

Schaefer (1985)[22] has investigated the visibility of stars at twilight and the current investigation is based on the model of atmospheric extinction and the physiological response of the eye to a point source viewed against the twilight sky given in his algorithm. The minimum altitude when a star of given magnitude would be visible at astronomical twilight (parametrized by the altitude of the sun) is given in **Table- I.** In the morning as the sun rises to −14° a faint glow would be visible on the horizon (at the point of sunrise) and stars of 4^{th} magnitude and brighter would be visible if they are more then 6° above the horizon. As the sun rises further the dawn twilight will overwhelm stars of 4^{th} magnitude and even the brighter stars will be lost in the glare of the scattered sunlight and at the end of the astronomical twilight (sun at −12°) only stars brighter than 2^{nd} magnitude will be visible if they are 3° or more above the horizon. In the evening as the sun sets to −12° stars brighter than 2^{nd} magnitude will be visible if they are at an altitude of 3° or more. As the sun sets further fainter stars will be visible if they are at or higher than the altitude given in Table I. As the sun sets to −14° there will be a faint glow at the point on the horizon where the sun sets and stars of 4^{th} magnitude and brighter will be visible if they are more than 6° above the horizon. As the sun sets further the glow on the horizon due to the sun will fade and there will be no observable evidence of the sun.

Table I: Minimum altitude of a star visible at astronomical twilight

mag	*Alt(Sun)*	*Alt(Star)*
2	-12	3
3	-14	5
4	-14	6
Alt: Altitude in degrees		

This article is based on the assumption that *RJ*.5-6 and *YJ*.6-7 describe naked-eye observations of stars at twilight around winter solstice. The Vedic sky watchers have not left an account of how they determined the solstices. It is possible that the solstice was determined by observations of the apparent motion of the sun to determine the day the sun (appeared) to stand still (*KB*.xix.3, Keith 1920[23]). These observations would have been at the mercy of all the uncertainties that plague observational astronomy. The two issues that would have concerned the Vedic sky-watchers most are – the visibility of stars close to the horizon (that is, at the altitudes given in Table I) and the separation between winter solstice and the day of visibility of stars. In this article these observational problems have been addressed by including only data on stars at altitude lower than 10° but greater than the minimum altitude of visibility given in Table I and by limiting data to stars visible within ±10 days of winter solstice. The article is bias-free, that is, *all* stars that satisfy the alignment of stars and the sun in the sky at winter solstice given in *RJ*.5-6 and *YJ*.6-7 are included in the results.

To identify the stars close to the horizon at twilight on winter solstice a Master List of all stars brighter than 4th magnitude was created from the SIMBAD[3] database. The list used has 513 stars. The computational scheme to obtain the visibility altitude of a star during astronomical twilight is as follows:

1. For a given epoch obtain the times when the sun is at −14° (astronomical twilight) at dawn and at dusk, on winter solstice[4].
2. Precess the J(2000) coordinates of all stars in the Master List to this epoch.
3. Dawn – obtain the minimum altitude of visibility (Table I) of all stars at the time when the sun is at –14°.

   Retain only data in the eastern hemisphere (azimuth between 0° and 180°).

   Retain only data for stars with altitude less than 10° but greater than the minimum altitude and within ±10 days of winter solstice.
4. Dusk – repeat the above procedure at the time when the sun is at –14° in the evening but retain only data in the western hemisphere (azimuth between 181° and 360°).
5. Compare the dawn and dusk data and retain only data for stars that will be visible in *both* the dawn and dusk twilight.
6. Repeat for the next epoch.

The results from 2000 BCE (selected arbitrarily) to 500 BCE (the putative epoch of the end of the Vedic era) are given in Table II. These computations are for a location in *Madhyadeśa* – Delhi (77º12´E; 28º35´N; altitude 229m); there would be no significant change in these results if the location was assumed to be to the west and north (73°02′E; 33°43′N; altitude 579m, Islamabad), the earlier location of the Vedic people and in the heartland of the Indus Valley Civilization. There would be a significant difference if a location 10º-15º north or south of Delhi was assumed in these computations. However, it seems unlikely that the Vedic sky watchers would have been in southern India or in the Himalayas. For convenience and familiarity, stars are referred to by the current names of the constellations in which they would have been observed. The Vaidīkas would have had their own nomenclature for the stars in a *nakṣatra*. The data in Table II suggest that stars of Aquila, Sagitta, Delphinus and Cygnus constellations satisfied the conditions specified in *RJ*.5-6 and *YJ*.6-7. Only two stars of the constellation of Aquila would have been observed within ±10 days of winter solstice. The bright star α Aql is within this limit from about 1000 BCE to 500 BCE. The two stars of Sagitta constellation would have been visible within ±10 days of winter solstice from about 1250 BCE to 500 BCE and the brighter of the two would have been visible from about 1500 BCE. Similarly the three stars of the Cygnus constellations would have been visible from about 2000 BCE to 750 BCE except the brightest of these three. From about 1750 BCE the four stars of the Delphinus constellation would have been visible within ±10 days of winter solstice and they would have been visible up to about 1000 BCE. Depending on the epoch of observation the Vedic people would have considered the stars of Aquila, Sagitta, Delphinus and Cygnus constellation to be the stars of *nakṣatraŚraviṣṭhā*. However, the name of the *nakṣatra* (*Śraviṣṭhā*) is plural and suggests at least three stars in this asterism (Dikshit 1969)[24]. Therefore the two stars of constellations Aquila and Sagitta respectively were unlikely to have been candidate stars of *nakṣatraŚraviṣṭhā*. The stars of a *nakṣatras* with more than one star are likely to be a compact group of stars (e.g. *Kṛttikās*). The stars of Cygnus constellation are spread over a wide region of the sky whereas the four stars of the Delphinus do form a compact group. The verses *RJ*.5-6 and *YJ*.6-7 describe the asterism of *Śraviṣṭhā* to be in the same region of the sky as the sun which suggests that the difference in azimuth of the sun and that of the asterism would not be very large. At winter solstice the azimuth of the sun at astronomical twilight (sun altitude of –14°) is about 110° at dawn and about 240° at dusk. The azimuth of Delphinus group of stars is about 78° at dawn and about 278° at dusk. The mean azimuth of the four Cygnus stars in Table II is about 63° at dawn and the mean azimuth at dusk is 294°. The stars of the Delphinus constellation would have appeared closer to the point (on the horizon) of sunrise and sunset than the stars of the Cygnus constellation. It is possible that the Vedic sky-watchers would have considered the compact group of stars of the Delphinus constellation to be in the same region of the sky as the sun at winter solstice and only in the period from 1750 BCE to 1000 BCE.

Table II: Azimuth (Az) and altitude (Alt) (column 4–17) of stars brighter than 4^m visible in the Morning (M) and in the evening (E) twilight. The data are for ±10 days around winter solstice when the sun is 14° below the horizon. (Location in *Madhyadeśa* – Delhi, 77º12´E; 28º35´N; altitude 229m). The limiting stellar magnitude at zenith is assumed to be 6^m and the visual extension (magnitude loss due to one air-mass) is assumed to be 0.2^m

ID	*α (J2000)* *δ(J2000)*	*mag*	*Az & Alt* *Sep* *500 BCE*		*Az & Alt* *Sep* *750 BCE*		*Az & Alt* *Sep* *1000 BCE*		*Az & Alt* *Sep* *1250 BCE*		*Az & Alt* *Sep* *1500 BCE*		*Az & Alt* *Sep* *1750 BCE*		*Az & Alt* *Sep* *2000 BCE*	
			M	*E*	*M*	*E*	*M*	*E*	*M*	*E*	*M*	*E*	*M*	*E*	*M*	*E*
<Aql	19 50 46.9 +08 52 05	0.76	83 7 3	278 7 0	85 7 6	280 7 2	86 7 9	282 7 5								
© Aql	19 46 15.5 +10 36 47	2.72	82 5 -2	280 5 7	83 5 1	282 5 10										
γ Sge	19 58 45.4 +19 29 31	3.47	73 6 -4	285 6 0	74 6 -2	286 6 2	76 6 1	288 6 4	77 6 3	289 6 7	78 6 6	291 6 10				
™Sge	19 47 23.2 +18 32 03	3.82	74 6 -2	286 6 3	75 6 0	287 6 5	77 6 3	289 6 8	78 6 5	290 6 10						
β Del	20 37 32.9 +14 35 42	3.63					78 7 -10	277 7 1	82 7 -8	281 7 4	81 7 -5	281 7 7	82 7 -3	281 7 9		
α Del	20 39 38.2 +15 54 43	3.80					77 7 -10	278 7 0	80 7 -6	281 7 6	80 7 -6	281 7 6	81 7 -3	282 7 8		
∑Del	20 33 12.7 +11 18 11	4.03					82 7 -10	276 7 5	83 7 -8	277 7 8						
γ Del	20 46 39.2 +16 07 27	3.91							80 7 -7	280 7 5	80 7 -7	280 7 5	80 7 -4	281 7 8		

ID	*α (J2000) δ(J2000)*	*mag*	*Az & Alt Sep 500 BCE*		*Az & Alt Sep 750 BCE*		*Az & Alt Sep 1000 BCE*		*Az & Alt Sep 1250 BCE*		*Az & Alt Sep 1500 BCE*		*Az & Alt Sep 1750 BCE*		*Az & Alt Sep 2000 BCE*	
			M	*E*	*M*	*E*	*M*	*E*	*M*	*E*	*M*	*E*	*M*	*E*	*M*	*E*
41 Cyg	20 29 23.7 +30 22 06	4.01			62 8 -8	289 8 -10	63 8 -5	291 8 -7	66 8 -4	292 8 -6	66 8 -1	293 8 -3	67 8 1	293 8 -1	68 8 4	294 8 1
® Cyg A	19 30 43.2 +27 57 34	3.09	66 6 6	295 6 -3	67 6 8	296 4 -2	68 4 10	298 4 1								
<Cyg	19 56 18.3 +35 05 00	3.88			59 7 2	298 7 -9	60 7 4	299 7 -8	61 7 6	300 7 -5	62 7 8	301 7 -3	62 7 10	301 7 -2		
ζ Cyg	21 12 56.1 +30 13 36	3.21											65 6 -7	286 5 -10	67 6 -5	287 5 -8
			α (J2000) – Right Ascension – hr:min:sec δ(J2000) – Declination – deg:min:sec					**mag** – Stellar Magnitude			Az – Azimuth – deg Alt – Altitude – deg Sep – Separation (days) from winter solstice; -ve, after solstice; -+ve, before solstice						

Abhyanker (1991)[25] has proposed β Aqr as a possible *yogatārā* of *nakṣatraŚraviṣṭhā*. This star is not included in Table II because although at dawn it would have been visible within ±10 day of winter solstice it would not have been visible, within this limit at dusk at any of the epochs considered here. Narahari Achar (2000)[26] has also examined *RJ*.5-6 and *YJ*.6-7; he has interpreted these verses to mean that the right ascension of the asterism of *Śraviṣṭhā* would have been about 18^h at winter solstice; that is, it would have been similar to the right ascension of the sun at winter solstice. He has further asserted, without providing any evidence, that all *nakṣatras* should be within ±10º of the ecliptic. With the aid of the planetarium software Sky Map Pro, he has shown that δ Capricorni (Ra:21 47 02.4; Dec: -16 07 38), a 2.83^m star satisfies these conditions around 1800 BCE. This author has made the same mistake as that made repeatedly by almost all analysts (including Abhyanker) over last almost two hundred years in the interpretation of astronomical references in the Vedic text. These interpretations are based entirely on comparison of coordinates (a concept that would not have been known to the Vedic sky-watchers) without addressing the issue of observations. The Vedic people did not have the advantage of a list of coordinates of stars nor would they have known that the right ascension of the sun is 18^h at winter solstice; they would have relied only on 'naked-eye' observations. Around 1800 BCE the star δ Cap is within 2° of the sun at winter solstice. Within the Vedic Period, this star would not have been visible within ±10º of winter solstice in the dawn twilight and only from about 1000 BCE onwards would it have been visible in the dusk twilight. A critique of attempts to determine the *yogatārās* of *nakṣatras* without addressing the issues of observations has been presented by Gondhalekar (2021)[27].

New Moon at the Start of a *yuga*

Verses *RJ*.5-6 and *YJ*.6-7 of *Vedāṅga Jyotiṣa* specify that a *yuga* starts at winter solstice when the sun and the moon occupy the same region of the sky together with the asterism of *Śraviṣṭhā*. That is, a new *yuga* starts at the new moon on winter solstice. A *yuga* is sixty-two synodic months or about five years and from 2000 BCE to 500 BCE there would be three hundred *yugas*. During this period there is a new moon at winter solstice on sixty-two years, that is, on sixty-two years the sun and the moon occupy the same region of the sky on winter solstice. Clearly not every *yuga* during this period would have started on a new moon. If an error of ±1 day is accepted in the determination of the new moon then between

2000 BCE and 500 BCE there are 111 winter solstices when the sun and the moon could have been considered to occupy the same region of the sky. Thus the specification of *RJ*.5-6 and *YJ*.6-7 that every new *yuga* starts on a new moon day cannot be met. This specification is based on the assumption that the length of the synodic month is fixed; unfortunately nature is not so accommodating[5].

Nakṣatra Āśleṣā

RJ.5-6 and *YJ*.6-7 specify that the sun is at the "midpoint of the *Aśleṣā* segment" at summer solstice. There is a significant difference in what *Vedāṅga Jyotiṣa* has to say about the apparent position in the sky of the sun with respect to stars at winter solstice and that at summer solstice. The two verses state that at (the start of a *yuga* at) winter solstice the sun (and the moon) occupy the same region of the sky as the asterism of *Śraviṣṭhā* and they are at the beginning of the *Śraviṣṭhā* segment. There is here an implication that the sun (and possibly the moon) was *observed* to be in the same region of the sky as the stars of *nakṣatraŚraviṣṭhā*, to start a *yuga*. In contrast, at summer solstice all that is stated is that the sun is at the midpoint of *Aśleṣā* segment, nothing is specified about the stars of *nakṣatraAśleṣā*. It is probable that the position of the sun in the *Aśleṣā* sector was computed rather than observed. The Vaidīkas may have reasoned thus:

- The sun transits each *nakṣatra*-sector in $13^5/_9$ (*sāvana*/civil) days (*RJ*. 18, *YJ*. 39).
- The origin of the *Aśleṣānakṣatra*-sector is separated from the origin of the *Śraviṣṭhā nakṣatra*-sectors (or from the beginning of the *yuga*) by thirteen *nakṣatra*-sectors (this is obtained from the list of *nakṣatras*).
- The thirteen *nakṣatra*-sectors will be traversed in $13\times13^5/_9=176^2/_9$ days.
- A *yuga* is five years of 366 (*sāvana*/civil) days (*YJ*.28) and the sun will traverse from winter solstice to summer solstice in 366÷2=183days.
- The sun at summer solstice is $183-176^2/_9=6^7/_9$ days from the origin of *Aśleṣānakṣatra*-sector.
- This period or 'distance' as a fraction of the width of a *nakṣatra*-sector is $6^7/_9\div13^5/_9={}^1/_2$
- This analysis demonstrates that *RJ*.5-6 and *YJ*.6-7 are internally consistent, that is if the sun is at the start of the *Śraviṣṭhā nakṣatra*-sector at winter solstice then it will be at the mid-point of the *Aśleṣānakṣatra*-sector at summer solstice.

Conclusion

The verses *RJ*.5-6 and *YJ*.6-7 are central to the calendar of *Vedāṅga Jyotiṣa*; these verses define the start of a *yuga* which is the basis of the calendar of *Vedāṅga Jyotiṣa* and they also define the origin of the *jāvādi* coordinate system that is essential to the algorithms of *Vedāṅga Jyotiṣa*. The chronological marker specified in these verses is the asterism of *Śraviṣṭhā*. The identification of this asterism (without appeal to the coordinates of *yogatārās* given in the medieval/siddhāntic texts) is of crucial importance in the examination of the calendar and astronomy of the Vedic era. In the analysis presented here it is assumed that the alignment of the sun, (moon) and stars at winter solstice (at the start of a *yuga*) described in *Vedāṅga Jyotiṣa* was observed (seen) by the Vedic people. This alignment that the Vedic sky-watchers may have observed presents a unique opportunity to identify the asterism of *Śraviṣṭhā* independent of the coordinates given in the post-Vedic texts. This alignment has been modelled computationally to identify bright stars close to the horizon and therefore close to the apparent position of the sun at dawn and dusk astronomical twilight around winter solstice. This analysis suggests that the most probable stars that the Vedic sky-watchers would have observed as stars of *nakṣatraŚraviṣṭhā* would have been the four (or five) stars of the Delphinus constellation. The celestial coordinates of stars in the texts after fifth century CE identify α/β Delphini as the *yogatārā* of *nakṣatraŚraviṣṭhā*. This is consistent with the current analysis and would suggest that this *nakṣatra* and its asterism have been transmitted with fidelity over a period of almost two thousand years. The result of this article is also in agreement with the statistical study of Gondhalekar (2011[28] and 2013[29]) that demonstrated that about 80% of *nakṣatras* and their asterisms may have been identified around 1300±300BCE. However, the statistical study was based on the coordinates of *yogatārās* in the post-Vedic texts whereas the identification of stars of *nakṣatraŚraviṣṭhā* in this article is independent of these texts and is based only on the sky configuration given in *Vedāṅga Jyotiṣa*.

It is not known how the Vaidīkas selected the stars of *nakṣatras* but they would have only selected stars that they were able to observe/see. The asterism of *Śraviṣṭhā* may have been selected to define or identify the start of a *yuga* because of all stars brighter than 4th magnitude only stars of this constellation can be considered to be 'in the same region of the sky' as the sun at winter solstice. It seems very likely that the start of a *yuga* is based on observations made in the period from 1750 BCE and 1000 BCE. The reconstructed evolution of Sanskrit literature from early Vedic to Classical places the linguistic form of *Vedāṅga Jyotiṣa* in the last half of first millennium BCE. It is possible that the text available now was composed in this period. However, the Vedic texts were frequently reworked and the content of *Vedāṅga Jyotiṣa* may be much older, not unlike Euclid's *Elements of Geometry* or MULAPIN (Hunger and Pingree 1989).

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Abbreviations

Atharvaveda Saṃhitā – *AV*

Kauṣītaki Brāhmaṇa – *KB*

Kāṭhaka Saṃhitā – *KS*

Kātyāyana Śulbasūtra – *KŚ*

Maitrāyaṇī Saṃhitā – *MS*

Pañcaviṃśa Brāhamana – *PB*

Śatapatha Brāhmaṇa – *ŚB*

Sāṅkhāyana Gṛhya Sūtra – *SGS*

Taittirīya Brāhmaṇa – *TB*

Taittirīya Saṃhitā – *TS*

Vedāṅga Jyotiṣa – *VJ*

Vedāṅga Jyotiṣa; *Ṛgvedic* recension – *RJ*

Vedāṅga Jyotiṣa; *Yajurvedic* recension – *YJ*

Ṛgveda Saṃhitā – *RV*

Notes

1. Note: *Śraviṣṭhā*, Vāsava and Dhaniṣṭhā refer to the same group of stars.
2. It should be stressed that this is not an ecliptic coordinate system as the *nakṣatra*-sectors determine the position of the sun and the moon along the path of the moon and *not* on the ecliptic.
3. Operated by Centre de Données astronomiques de Strasbourg, Strasbourg, France.
4. These data were obtained from Jet Propulsion Laboratory, HORIZONS Web-Interface.
5. Moon's orbit around the Earth is not circular but elliptical; therefore, the Moon's angular speed around the Earth is not uniform but varies. A smaller secondary variation in the angular speed is added by Earth's elliptical orbit around the sun. Because of these variations in the angular speed the duration of lunation can range from about 29.18 days to about 29.93 days. The long-term mean is 29.53 days. The *Vedāṅga Jyotiṣa* length of a lunation is 29.52 days.

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