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POSSIBLE CHRONOLOGICAL MARKERS IN THE VEDIC TEXTS

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Three independent chronological markers can be identified from the analysis of the calendric passages in the Vedic *Saṃhitā*, *Brāhmaṇas* and *Sūtras*, these are: (i) The circumpolar *Sapta Ṛṣis*/Ursa Major constellation, (ii) The unambiguous identification of the season, *nakṣatra* and the phase of the moon for the three *Cāturmāsya* (seasonal) sacrifices, (iii) The identification of the *nakṣatra* at winter solstice at the start of a *yuga*.

The *Sapta Ṛṣis* or the constellation of Ursa Major can be seen to be circumpolar from around 30º north (mid-latitude in South Asia) only before about 1500 BC. Analysis of the 'dates' for the *Cāturmāsya* (seasonal) sacrifices and start of the *yuga* of the calendar of *Vedāṅga Jyotiṣa* suggests a period between 1550 BC and 1150 BC. The invariant *nakṣatra*-sectors are unique to *Vedāṅga Jyotiṣa* and are of fundamental importance to the calendar described in *Vedāṅga Jyotiṣa*. It is very likely that at the epoch of formulation of this *nakṣatra*-sector coordinate system the sectors of the ecliptic were identified by the *nakṣatras* (stars and asterisms) that were already in use as calendric markers. Cross-correlation of the *nakṣatra*-sectors and the (*yogatārās* of) *nakṣatras* suggests that the final list of *nakṣatras* (stars and asterisms) may have been formulated at 1300±300 BC. This epoch is consistent with those obtained from the three chronological markers identified above. It is possible that this was also the epoch of formulation of *Vedāṅga Jyotiṣa* although the available text may have been redacted at a later date.

Key words: *Cāturmāsya* sacrifices, *Nakṣatra*-sector coordinate system, *Sapta Ṛṣis*/Ursa Major, *Vedāṅga Jyotiṣa*, Vedic chronology, *Yuga*

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Introduction

The chronology of the Vedic Period in the history of South Asia has been a matter of contention since about the beginning of nineteenth century after Western scholars became acquainted with Sanskrit language and in particular with the Vedic texts. Lacking any attested archaeological artefacts the tried and tested methods of dating cannot be brought to bear on this Period. At present, the only data and the only source of data of this Period are the texts of this Period. The Vedic texts are one of the most original and interesting product of human endeavour. These religious texts were composed over many centuries and consist of numerous works dealing with a variety of theological and sacerdotal topics. The texts were composed orally and still are an oral literature. Over centuries, they were transmitted orally with remarkable fidelity. The Vedic texts were known to and were quoted by the Sanskrit grammarian Pāṇini (estimated to have lived between 600 BC and 400 BC), thus these texts probably pre-dates 400 BC. This date is rather weakly corroborated by the Buddhist texts in Pāli, which have knowledge of the Vedic texts. This suggests that the Vedic corpus pre-dates Buddha, who, it is estimated, was born around 400 BC. The earliest Vedic text is *Ṛgveda Saṃhitā* and all other Vedic texts follow *Ṛgveda Saṃhitā*. Smelted iron - *śyāma ayas* (black metal/iron) is not mentioned in *Ṛgveda Saṃhitā* but is mentioned in *Atharvaveda* (*AV*.XI.3.7), a text that post-dates *Ṛgveda Saṃhitā*. Smelted iron has been archaeologically attested at a number of sites, including those in northern parts of South Asia, from about thirteenth century BC onwards. This puts *Atharvaveda Saṃhitā* in the post-1300 BC period and by inference *Ṛgveda Saṃhitā* in the pre-1300 BC period. These two dates (about 400 BC and 1300 BC) are the only two dates of the Vedic Period attested independent of the Vedic texts.

The nineteenth century Sanskrit scholar Max Müller (1823–1900) attempted to estimate the date of composition of *Ṛgveda Saṃhitā* just from the textual sources. Max Müller arrives at a period of 1200–1000 BC for the composition of this text. The lack of rigor in his analysis is obvious from an examination of his work. Müller identified a fictional character in a ghost story (*Kathāsaritsāgara* by Somedeva) written in the twelfth century with a possible historic figure (Kātyāyana) in the fourth century BC. He then assumed that this Kātyāyana was also the author of a number of *sūtras*. Müller thus believed that he had established the epoch of composition of *Sūtras*, a genre of late Vedic texts. Assuming that the *Brāhmaṇas* preceded the *Sūtras* which preceded the

Saṃhitās, Müller arrives at the date of composition of *Ṛgveda Saṃhitā*. Challenges to this date were immediate and robust. It should be said, in fairness to Max Müller, that he was fully aware of the arbitrary nature of his assumptions in dating *Ṛgveda* and he willingly retracted the rather precise chronology he had suggested. However, it became a habit, particularly among Western Indologists, to claim that "Max Müller had proved 1200–1000 BC to be the date of *Ṛgveda Saṃhitā*". For over hundred years, this date has proved remarkably resistant to re-evaluation. Re-examination of the chronology of *Ṛgveda Saṃhitā* has only been undertaken in the last decade of the twentieth century[1]. The current consensus appears to be that this text was composed over a period of five hundred years from about 1700 BC to about 1200 BC. At present, this should be treated as a chronological hypothesis and not a proof.

It has been recognized since the eighteenth century, that astronomical references in the Vedic texts hold promise of establishing a chronology of these texts, independent of the chronology based on philological analysis. In the last decade of the nineteenth century and the first of the twentieth century, the astronomical significance of various passages in the Vedic text and the dates that could be inferred from these passages, were subjects of intense speculation and debate. The arguments presented can be summarized as follows:

- The *nakṣatra Mārgaúîrṣa* is also known as *Âgrahāyana* which means "belonging to the beginning of the year". Tilak[2] contended that during the early Vedic Period the beginning of the year was at autumnal equinox. The J(2000) ecliptic longitude of the *yogatārā* (defined in Section 1, below) of *nakṣatra Mārgaúîrṣa* (λ Ori) is 83.71º and it would have been 180º, the ecliptic longitude of autumnal equinox, at 4894 BC.
- In his analysis of various legends about stars in and around the constellation of Orion, Tilak[3] suggested (following Sâyana, a fourteenth century Sanskrit scholar) that *RV*.I.105.11 refers to heliacal rising, at vernal equinox, of the star Sirius. The J(2000) ecliptic longitude of Sirius is 104.08º and this would have been 0º, the ecliptic longitude of vernal equinox, at 5452 BC.
- The so called "frog hymn", *RV*.VII.103, paints a graphic picture of the intense humid heat before the onset of the monsoon in South Asia. Jacobi[4] held that this hymn suggests that the start of a year was at summer solstice when the sun is in the *nakṣatra Phalgunî*. The stars δ Leo and β Leo have been

identified[5] as the *yogatārās* of *Pūrva-Phalgunî* and *Uttara-Phalgunî* respectively. The J(2000) ecliptic longitudes of these two *yogatârâs* are 161.32º and 171.62º respectively. These stars would have been at summer solstice, that is at ecliptic longitude of 90º, at 3106 BC and 3844 BC respectively.

- A late Vedic text (*SGS*. 1.17.3*)* recommends that a newly wed husband should show his bride the polestar (*dhruva*) and urge her to "Firm be thou thriving with me". Jacobi[6] contended that this passage has preserved a memory of ancient times when there was a star at the celestial pole. By precession of the equinox, only two stars come sufficiently close to the north celestial pole to be considered to be stationary (*dhruva*); these are the present star, Polaris or α Ursa Minor and α Draconis around 2780 BC. Jacobi's contention suggests that the passage, *SGS*. 1.17.3, refers to a period around 2780 BC.
- In *Śatapaṭha Brāhmaṇa* II.1.2.3 an Āryan householder was enjoined to establish the ritual fire for the first time under the *nakṣatra Kṛttikās* because its presiding deity is *agni*, they confer abundance because the *nakṣatra* consists of many stars and they "do not move away from the eastern quarter"[7]. The significance of this passage to establish the chronology of the Vedic texts was first recognised by Dîkṣita[8] and since the late nineteenth century, much ink (and keystrokes) has been expended on discussions of this passage. Dīkṣita interprets this passage to means that the *Kṛttikās* or the *yogatārā* of *Kṛttikās* (star η Tau) was exactly on the celestial equator or the declination of this star was 0º at the epoch of the passage from *ŚB*. This gave him a date of about 2900 BC. This passage and the implied chronology have recently been re-examined[9,10].

These dates of the Vedic Period were vigorously challenged, mostly by Western scholars, and continue to be challenged to this day. The core of this challenge appears to be that these dates are based on simple-minded interpretation of passages in the Vedic texts and more importantly, these interpretations suggest astronomical observations that the Indians/South Asians were unable and incapable of making.

It is not the aim of this paper to re-examine these data from the perspective of the proponents or the opponents of these dates. In this paper, new data are presented which enable dates within the Vedic Period to be determined. The data are presented in Section 1 and Section 2 and the conclusions are presented in Section 3.

1. Stars and Asterisms

In the bulk of the Vedic texts, that is in the *Saṃhitās, Brāhmaṇas* and the *Sûtras*, the *nakṣatras* mean stars or asterisms. In these texts, the *nakṣatras* are always a list of twenty-seven (sometimes twenty-eight) stars or asterisms and the first *nakṣatra* is always the *Kṛttikās*. The *nakṣatras* are along the ecliptic but are not evenly distributed along the ecliptic and some stars and asterisms are far from the ecliptic. The number of *nakṣatras*, their location and their use in the Vedic texts suggests that their primary purpose was to identify the days of the (synodic) month and (at a later date) to identify the synodic months. The Sanskrit grammarian Pâṇini (about 600 BC to 400 BC) has given rules for obtaining the name of the month from the name of the appropriate *nakṣatra* (*Aṣṭādhyāyī* iv.2.21). The identification of *nakṣatras* with stars and asterisms of modern star catalogues is fraught with difficulties and uncertainties. The Vedic texts provide little or no information to identify the stellar markers; neither relative position nor the shape of an asterism are given. The number of stars in each *nakṣatra* is of some help, that is, *nakṣatras* whose names are dual probably have two stars and plural names suggest a group of stars. In South Asia, coordinates of stars are only given in astronomical texts produced after fifth century AD. The oldest catalogue of coordinates of one (prominent) star, the *yogatārā* of a *nakṣatra*, is that of *Paitā-mahasiddhānta* of *Viṣṇudharmottarapurāṇa*. The provenance of this text is disputed[11,12], but that is of no concern here. Suffice it to say that there is a gap of over a thousand years between the Vedic texts and this catalogue of coordinates. This gap should be born in mind in arriving at conclusions based on the coordinates of the *yogatārās*. All attempts till date to identify the *nakṣatras* and their *yogatārās* are based either explicitly or implicitly on the coordinates given in *Paitā-mahasiddhānta* and the *siddhânta* is silent on the procedure by which these coordinates were obtained. Moreover, these coordinates – polar longitude and latitude – are very inaccurate; they are mostly expressed as integer degrees. It is discussed in this paper but with the caveat mentioned above. Recently the coordinates of the *yogatārās* of the *nakṣatras* have been re-examined[13,14] and these data are used in the Fig. 1.

1.1 *Sapta Ṛṣis* (Ursa Major)

In *Ṛgveda Saṃhitā*, a group of stars is referred to as '*ṛkṣa*' (*RV*.I.24.10); this asterism cannot be identified from *Ṛgveda* but the verse puts it at a high place (*uccā naktaṃ*) which suggests that this is a northern asterisms. In *ŚB*.II.1.2.4[15]

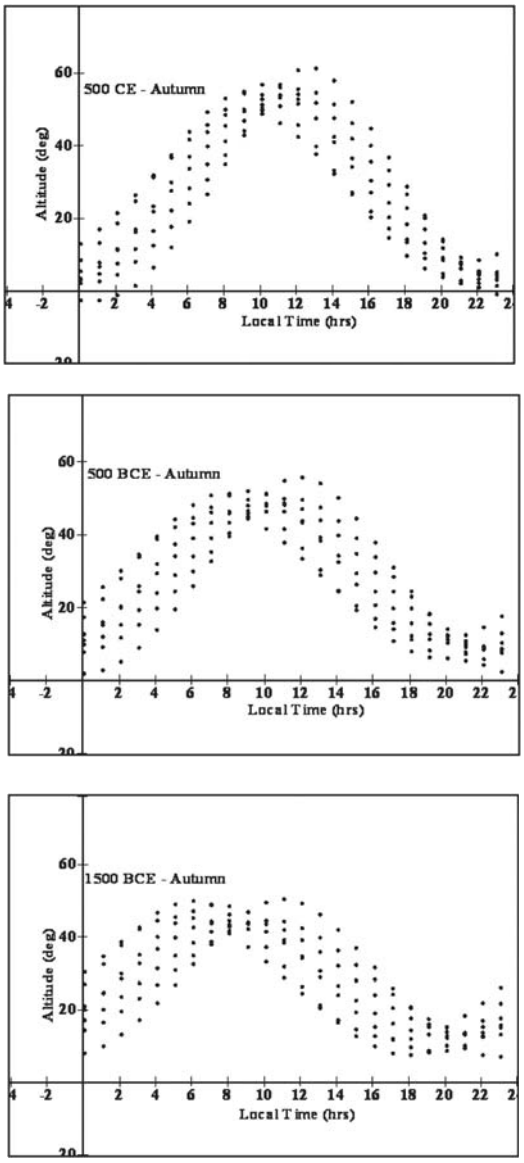

Fig. 1. The altitude of the seven brightest stars of the constellation Ursa Major (*Sapta Ṛsis*). The data are shown for autumn because in this season all stars are visible from sunset to sunrise. At 500 AD some stars of the constellation set (altitude less than 0º) at some time during the night. At 500 BC some stars are just at the horizon but none of the stars set at any time. At 1500 BC all stars are well above the horizon at all times.

it is noted that the (constellation of) *Sapta Ṛṣis* was earlier known as '*ṛkṣaḥ*' and this suggests that the asterism referred to in the *Ṛgveda* is also that of *Sapta Ṛṣis* which is indeed a northern asterism. In *Ṛgveda* there are further oblique references to the constellation of *Sapta Ṛṣis*, for example, there are references (*RV*.V.85.3) to a cask or a barrel (*kavandha* or *kabandha, kośa* and *avata*) that is turned over by various gods to pour riches on the earth. In these verses, the words for the cask or the barrel can be interpreted as clouds that pour rainwater on earth. However, *AV*.X.8.9 identifies the cask as the constellation of *Sapta Ṛṣis*[16]. In the night sky this constellation does indeed look like a spoon or a pot with a handle and during the night (and the year) it 'turns over to empty its contents'. If this interpretation is correct then all stars of *Sapta Ṛṣis* must have been circumpolar when these passages were composed, otherwise the constellation will not appear like a pot or a cask at all times in a year. In Figure 1 is shown the altitude of the seven stars of *Sapta Ṛṣis* over a period of twenty-four hours in autumn, as viewed from *Madhyadeśa* (Delhi 77°12'E; 28°35'N). The data are shown only for autumn because in autumn this constellation approaches the horizon (altitude 0°) at sunset and is visible through the night. After 500 AD not all stars of *Sapta Ṛṣis* are circumpolar from *Madhyadeśa*, some stars set in the evening. Due to precession of equinox, all stars of this constellation will be just circumpolar around 500 BC but some stars will be on the northern horizon for part of the night. All stars of the constellation will precess "far to the north (*uccā nakaṃ*)" around 1500 BC and will, of course, be well above the horizon at epochs earlier then 1500 BC. There is here circumstantial evidence that the *RV* and *AV* passages noted above may have been composed around or before 1500 BC.

1.2. *Cāturmāsya* (or seasonal) sacrifices

The Vedic texts emphasise the importance of performing the three (sometimes four) *Cāturmāsya* (or seasonal) sacrifices. In these texts the 'dates' of the performance of these sacrifices are specified by the coincidence of the seasonal full moon with three prescribed *nakṣatras*. The spring sacrifice, *Vaiśvadeva* was performed when the full moon was in the *nakṣatra* (*Uttara*-) *Phalgunīs* (*KŚS*.5.1.1[17]), the summer sacrifice, *Varuṇapraghāsas* was performed when the full moon was in (*Uttara*-) *Āṣāḍhās* (*KŚS*.5.3.1) and the autumn sacrifice, *Sākamedha* was performed when the full moon was in *Kṛttikās* (*KŚS*.5.6.1). Sometimes a fourth sacrifice, *Śunāsīrīya* was performed. The Vedic texts (e.g. *AB*. iv.26(xix.4)[18]) prescribe that the ritual year (or the *sattra* of *Gavâm ayana*)

should commence in the cool season (*śiśira*) in the months of (*Māgha* or *Phālguna*). The *Cāturmāsya* sacrifices must have been a feature of the Vedic ritual year. For a start of the ritual year at new moon of the month of *Māgha*, the specified coincidence of the full moon and the *nakṣatras* suggests that the *Cāturmāsya* sacrifices were performed as follows;

- *Vaiśvadeva* in later half of *śiśira* or first half of *vasanta* (approximately latter half of January and first half of February).
- *Varuṇapraghâsas* in the later half of *grîṣma* (approximately latter half of May).
- *Sâkamedha* in the later half of *śarad* or first half of *hemanta* (approximately latter half of September and the first half of October).
- *Śunāsîrîya*, if performed on the fifth full moon after *Sâkamedha*, would coincide with the performance of *Vaiśvadeva* of the following year. It was therefore performed on the day before the full moon (*ŚB* II.6.3.13). However, this sacrifice could also be performed on any day after the *Sâkamedha* sacrifice (*KŚS* 5.11.2).

The 'dates' indicate that the sacrifices were performed at an interval of four synodic months in agreement with the name (*Cāturmāsya*) of the sacrifices. The ecliptic longitude and latitude of the full moon of these three seasons were calculated with the currently available orbital parameters of the earth and the moon and with origin at the first point of Aries (or vernal equinox). The position of the full moon for these three seasons in a period of five years (a *yuga*), starting with the new moon of the month of *Māgha* in the season of *śiśira*, are shown in Fig. 2.

As noted above an unambiguous identification of stars or asterisms of the *nakṣatras* of the Vedic texts has not been possible. However, the position of the *Kṛttikās* in the lists of *nakṣatras*, the number of stars in this *nakṣatra* (mentioned in the Vedic texts), the mythologies associated with this *nakṣatra* and the similarities with other cultures suggests identification of *Kṛttikās* with the Pleiades. The autumn sacrifice or *Sâkamedha* was performed when the seasonal full moon was in *Kṛttikās* (*KŚS* 5.6.1). For *nakṣatra Kṛttikās*/Pleiades to conjoin the full moon of the first autumn of a *yuga* it is necessary to precess the stars of this asterism to about 1400 BC. The position of *yogatārā* (η Tau) of *nakṣatra Kṛttikās* precessed to 1400 BC is shown in Fig. 2.

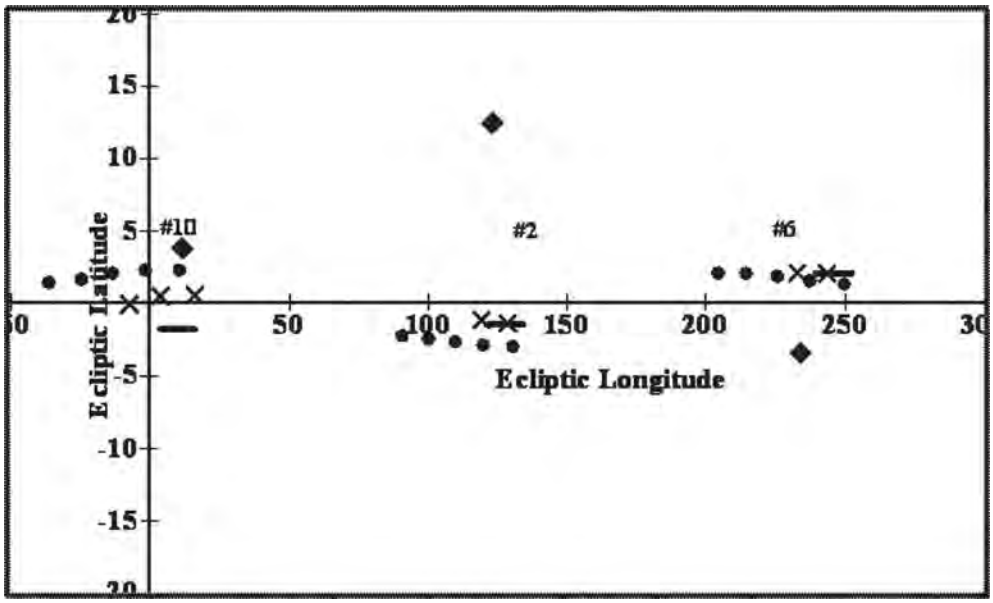

Fig. 2. The ecliptic longitude and latitude of *Cāturmāsya nakṣatras* (dimonds), and the second (spring) sixth (summer) and tenth (autumn) full moons (dots and crosses) in a *yuga*. The three sacrifices are; *Vaiśvadeva* at #2, *Varuṇapraghāsas* at #6 and *Sâkamedha* at #10. The dots denote the positions of the seasonal full moons with no correction for intercalation. The crosses denote the positions of the seasonal full moons when the correction for intercalation is included. Only the corrected positions of the full moons are shown, that is, the positions in the fourth and fifth year of full moon #2 and #6 and the positions in the third, fourth and fifth year of full moon #10. The short black line is the extend of the respective *nakṣatra*-sectors (see Section 2).

Consistency requires that the *yogatārās* of seasonal *nakṣatras Uttara-Phalgunîs* and *Uttara-Āṣâḍhâs* should also be precessed to this epoch and these are also shown in Fig. 2. The coincidence between the full moon of the first autumn of a *yuga* and *nakṣatra Kṛttikās* (or the *yogatārā* of this *nakṣatra*) is good as expected but that between the full moon of the first spring and summer of a *yuga* and the respective *nakṣatras* (or the *yogatārās* of their *nakṣatras*) prescribed for these seasons is poor. However, the lack of coincidence between the *yogatārās* and the full moon for these two seasons is equivalent to an error of one day in the day of the full moon. In this analysis there is thus an implicit assumption that the coincidence between the seasonal full moon and the *yogatārās* must have been determined from observations over an extended period

and an error of a day (or two) in the full moon day would have been corrected. As the identity of *nakṣatra Kṛttikās* is secure, the epoch of 1400 BC is retained. The position of these seasonal full moons in the years following the first year of a *yuga* are also shown in Figure 2 (black dots). The full moon 'drifts' to the left or to lower ecliptic longitude each year because the synodic year is shorter then the sidereal and tropical/seasonal years. If this is not corrected after first couple of years of a *yuga* then the *Cāturmāsya* sacrifices will be performed when the seasonal full moon is in *nakṣatras* different from those prescribed in the Vedic texts. The correction required is the synchronization of the seasonal/tropical year (that fixes the position of the seasons) and the synodic year (that determines the position of the full moon). The 'synodic *yuga*' was brought into harmony with the seasons by intercalating a synodic month after thirty synodic months of a *yuga* and an additional synodic month was intercalated after sixty-one synodic months of a *yuga*. This intercalation scheme is similar to that proposed in *MS*.I.10.8 and in *Vedāṅga Jyotiṣa*[19].

The positions of the spring (full moon #2) and summer (full moon #6) full moons are not affected in the first three years of a *yuga* because the first intercalation is after the first thirty synodic months of a *yuga*. The position of full moons of these two seasons in the fourth and the fifth years of a *yuga* are affected and these are shown in Fig. 2 (crosses). Similarly, the position of the autumn (full moon #10) full moon is not affected in the first two years of a *yuga* but the position in the last three years of a *yuga* is affected and this is also shown in Fig. 2 (crosses). After intercalation, all five seasonal full moons of a *yuga* cluster close to their prescribed *nakṣatras*; thus the *Cāturmāsya* sacrifices would have been performed at their proper times every year of a *yuga*. This cycle repeats in the following *yugas*.

The three *Cāturmāsya-nakṣatras* considered here continuously precess away from their respective seasons. It is difficult to determine the period after which the three seasonal-*nakṣatras* prescribed in the Vedic texts would have been considered not to conjoin the seasonal full moons. This is because the accuracy with which observations may have been made during the Vedic period is not known nor is it possible to guess the separation between a seasonal full moon and a seasonal-*nakṣatra* that the Āryas would have accepted as coincidence. For lack of more data, it is assumed that the spread, after intercalation, in the ecliptic longitude of the five seasonal full moons of a *yuga* is the maximum

separation between a full moon and a *nakṣatra* that would have been considered as coincidence. This suggests that a recalibration of the *nakṣatras* and the seasons would have been necessary after about 500 years. Thus, the prescribed *nakṣatras* of the *Cāturmāsya* sacrifices suggest an epoch of 1400±500 BC.

1.3. New *yuga* Day of *Vedāṅga Jyotiṣa*

Vedāṅga Jyotiṣa – the astronomical 'arm' or auxiliary of the Veda is the earliest mathematically codified calendric text of South Asia. The text is a manual for determining the proper times for Vedic ceremonies and rituals. The Vedic period has left us a rich store of religious texts but nothing on secular matters. *Vedāṅga Jyotiṣa* and *Śulva Sûtra* are the only two known texts of this period that do not discuss theological, liturgical or ritual matters and are the only two known text of this period that can be considered to be 'scientific and mathematical' texts. *Vedāṅga Jyotiṣa* has survived in two recensions – a *Ṛgveda* recension called *Ârca-Jyotiṣa* and a *Yajurvada* recension called *Yājuṣa-Jyotiṣa*. There are minor differences between the two recensions. These differences will not affect the discussion presented here. The *Ṛgveda* recension is considered to be the older of the two recensions. The contents of the available recensions are not in a thematic or a logical order and topics on the same subject are distributed in different places suggesting that the original text has not come down to us. *Vedāṅga Jyotiṣa* is not for the faint hearted and for over hundred years, it has taxed the ingenuity and scholarship of the most eminent Sanskritists. In 1979 a translation and interpretation of *Vedāṅga Jyotiṣa* was produced and this, along with critical editions of both the *Ṛgvedic* and *Yajurvedic* recensions (from twenty manuscripts) were published in 1984 by the Indian National Science Academy[20]. The following discussion is based on this translation of *Vedāṅga Jyotiṣa*.

The calendar of *Vedāṅga Jyotiṣa* is a luni-solar calendar in which the synodic year is harmonized with the seasons over a period of sixty-two lunations (approximately five tropical years). This period is called a *yuga*. Each *yuga* starts "when the sun and the moon occupy the same region of the sky with the *nakṣatra Śraviṣṭhās*" (*RJ*.5-6, verses #5-6 of *Ṛgvedic* recension; *YJ*.6-7, verses #6-7 of *Yajurvedic* recension), at this time also begins "the (synodic) month of *Māgha*, the (seasonal) month of *tapas*.....the sun and the moon begin to move north.....". To put it differently, each *yuga* starts when the new moon conjoins *nakṣatra Śraviṣṭhās* at winter solstice. This clearly is impossible at the start of every *yuga*, as there cannot be a new moon at winter solstice every five years. A more realistic

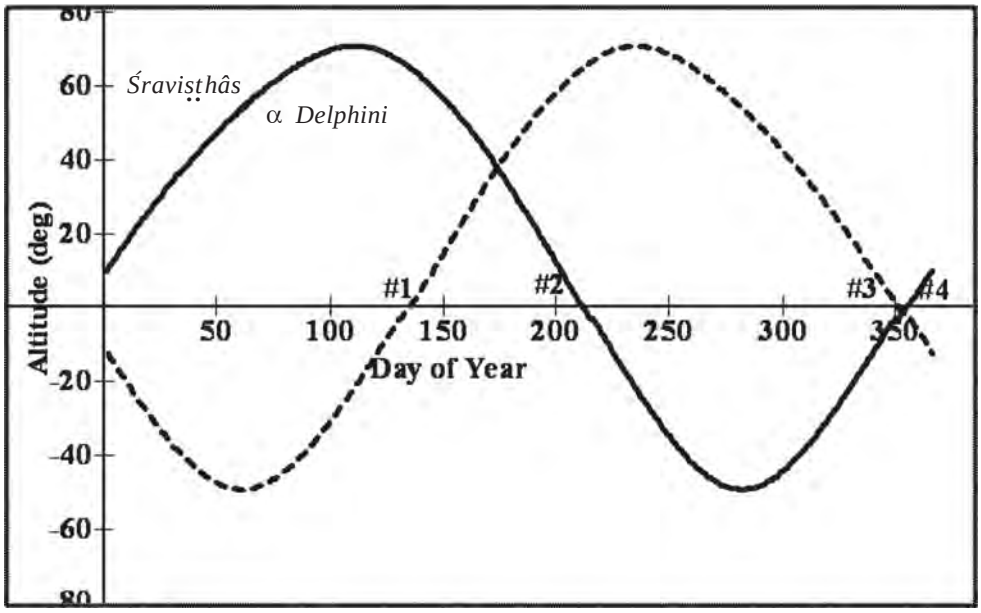

Fig. 3. The annual apparent path of *nakṣatra Śraviṣṭhâs*. The data plotted are the altitude of the star α *Delphini* (*yogatârâ* of *Śraviṣṭhâs*) at astronomical twilight and the epoch of the data is 1500 BC. The annual path of the star is close to the horizon on four days. At #1 the *Śraviṣṭhâs* will be just above the eastern horizon at sunset and will be visible during the night. At #2 the *Śraviṣṭhâs* are on the western horizon just before sunrise and will set soon afterwards. At #3 the *Śraviṣṭhâs* are on the western horizon and will be visible after the sun sets and the stars will set soon afterwards (stars set heliacally). At #4 the *Śraviṣṭhâs* are on the eastern horizon just before sunrise (stars rise heliacally) and will be lost in the glare of the sun as it rises.

interpretation of these verses would be that a *yuga* starts when the new moon conjoins *nakṣatra Śraviṣṭhās* around winter solstice. This would also bring the sun at winter solstice close to *nakṣatra Śraviṣṭhās*.

To interpret *RJ*.5-6 and *YJ*.6-7 it is necessary to examine the annual visibility of *nakṣatra Śraviṣṭhās*. One of the proposed *yogatārās* of *nakṣatra Śraviṣṭhās* (also called *Dhaniṣṭhās*) is α *Delphini*. In Fig. 3 is shown the altitude of α *Delphini*, at astronomical twilight (i.e. when the sun is 18º below the horizon), from the beginning of January to the end of December. These data are for 1500 BC and for a location in *Madhyadeśa* (Delhi 77°12'E; 28°35'N). The *nakṣatra Śraviṣṭhās*/α *Delphini* is close to the horizon (altitude close to 0°) on

four days of a year. At #1 the *Śraviṣṭhās* will be just above the eastern horizon at sunset and will be visible during the night. At #2 the *Śraviṣṭhās* are on the western horizon just before sunrise and will set soon afterwards. At #3 the *Śraviṣṭhās* are on the western horizon and will be visible after the sun sets and the stars will set soon afterwards (stars set heliacally). At #4 the *Śraviṣṭhāss* are on the eastern horizon just before sunrise (stars rise heliacally) and will be lost in the glare of the sun as it rises. It is these last two days that are of interest in interpreting verses *RJ*.5-6 and *YJ*.6-7. *Vedāṅga Jyotiṣa* does not describe how "when the sun (and the moon) occupy the same region of the sky with the *nakṣatra Śraviṣṭhās*" (*RJ*.5-6; *YJ*.6-7) was determined. If it is assumed that these verses mean that the sun is visually close to the *nakṣatra Śraviṣṭhās* then this is only possible at the heliacal rising and setting of this *nakṣatra* and this occurs on days #3 and #4 (Fig. 3). Because of the precession of the equinox, the days when *nakṣatra Śraviṣṭhās*/α *Delphini* rises and sets heliacally will change with epoch. In Figure 4 are plotted the days (in a Gregorian year) when *nakṣatra Śraviṣṭhās*/α *Delphini* rises and sets heliacally from 2000 BC to 500 BC. At

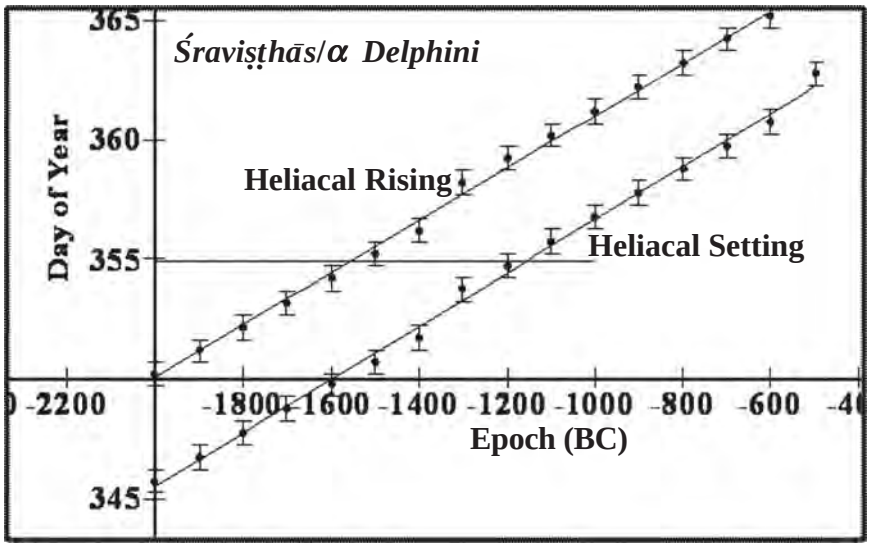

Fig. 4. The day of heliacal rising and setting of *Śraviṣṭhās*/ α *Delphini* from 2000 BC to 500 BC. There is a computational error of one day in this Day of the Year and this is represented by the error bars in the data. The lines through the data are straight line fits to the data. The winter solstice is at day 355 (or 356) of the (Gregorian) year. The line at day #355 intersects the heliacal rising line at about 1550 BC and intersects the heliacal setting line at about 1150 BC.

about 1550 BC the *nakṣatra Śraviṣṭhās*/*α Delphini* rises heliacally on winter solstice and five days earlier the *nakṣatra* would have set heliacally. At about 1150 BC the *nakṣatra Śraviṣṭhās*/*α Delphini* sets heliacally on winter solstice and five days later the *nakṣatra* rises heliacally. Between these two epochs the *nakṣatra Śraviṣṭhās*/*α Delphini* both rises and sets heliacally within five days of winter solstice or the sun and the *nakṣatra* are in the same region of the sky i.e. on the horizon, although they will be separated by about 30º in azimuth. Outside this (epoch-)window the *nakṣatra Śraviṣṭhās*/*á Delphini* will rise and set heliacally but not at or around winter solstice. Thus, the verses *RJ*.5-6 and *YJ*.6-7 of *Vedāṅga Jyotiṣa* could have been composed between 1550 BC and 1150 BC.

This conclusion should be treated with a degree of caution as it depends on the choice of the *yogatārā* of *nakṣatra Śraviṣṭhās*. The star *β Aquarii* has also been identified as a possible *yogatārā* of *nakṣatra Śraviṣṭhās*[21]. The separation between the heliacal rising and setting of *α Delphini* is just over five days (Fig. 4). The separation between the heliacal rising and setting of *β Aquarius* is thirty days or a month. It seems unlike that a star that rises and sets heliacally, thirty days apart, would have been considered to "occupy the same region of the sky" as the sun.

2. *Nakṣatra*-sectors

A list of *nakṣatras* (*RJ*.25-28, verses #25-28 in the *Ṛgveda* recension of *Vedāṅga Jyotiṣa* and *YJ*.32-35, verses #32-35 in the *Yājuṣa* recension of *Vedāṅga Jyotiṣa*) that is almost identical to the lists given in the *Saṃhitās, Brāhmaṇas* and *Sūtras* is given in *Vedāṅga Jyotiṣa*, an astronomical text of the late Vedic period and the only text on mathematical astronomy from this period. Like the list of *nakṣatras* in the *Saṃhitās, Brāhmaṇas* and *Sūtras*, this list also begins with the *nakṣatra Kṛttikās*. In addition, in *Vedāṅga Jyotiṣa* there is a list (*RJ*.14 and *YJ*.18) of '*nakṣatras*' that begins with *Aśvayujau* (or *Aśvina*). This list is referred to as the "*jâvâdi* (*jau âdi* – beginning with *jau*, an abbreviation for *Aśvayujau*) arrangement". The *jâvâdi* arrangement of *nakṣatras* defines an ecliptic coordinate system[22]. This coordinate system consists of twenty-seven evenly spaced sectors along the ecliptic, each sector is identified by the name of a *nakṣatras* given in *RJ*.25-28 and *YJ*.32-35. The origin of this coordinate system is at new moon around winter solstice at the beginning of the *nakṣatra*-sector *Śraviṣṭhās*. Each *nakṣatra*-sector is divided into 124 parts and each part is

called a *bhāṃśa*. The position of the *nakṣatra*-sectors on the ecliptic is defined by the position of the new and the full moon during a *yuga* and is independent of the *nakṣatras* or stars and asterisms. This coordinate system is anchored to the ecliptic and is thus free of precession of the equinox. In this coordinate system the position of the sun and the moon on the ecliptic is given by (the name of) the *nakṣatra*-sector and the number of *bhāṃśas* from the origin of that *nakṣatra*-sector. The *jāvādi* arrangement of *nakṣatras* is unique to *Vedāṅga Jyotiṣa* and no trace of it is found in any of the earlier Vedic texts. In *Vedāṅga Jyotiṣa* '*nakṣatra*' always means a *nakṣatra*-sector, stars and asterisms play no part in the calendar described in this text. The algorithms to determine the position of the sun and the moon on the ecliptic given in *Vedāṅga Jyotiṣa* can be interpreted unambiguously in the context of this coordinate system. Without this coordinate system, these algorithms would be meaningless. The Vedic texts including *Vedāṅga Jyotiṣa* do not differentiate between the stars and asterisms and the sectors of the ecliptic; to avoid confusion that this has caused, in this paper, stars and asterisms are called *nakṣatras* and sectors of the ecliptic are called *nakṣatra*-sectors.

2.1. *Nakṣatra*-sector – *Yogatârâ* Correlation

The annual appearance of bright stars constitutes chronological markers in nature's calendar. This was noted by a number of ancient cultures in order to fix important civil, religious and agricultural (or food gathering) dates in the year. This may also have been true of the Āryas in South Asia. Different stars and asterisms were probably added to the list of chronological markers as the civil and ecclesiastic ceremonies of the Āryas grew in number and complexity. These chronological markers eventually became the twenty seven (or twenty eight) *nakṣatras*. It is impossible to establish the epoch(s) when the stars or asterisms were added to the list of *nakṣatras*. However, when the *nakṣatra*-sectors were formulated as (invariant) sectors of the path of the moon (or the ecliptic) the formulators would have required (insisted) on a correspondence between the *nakṣatra*-sectors and the *nakṣatras* that were already in use as chronological markers. This is because although it is possible to identify a *nakṣatra*-sector by counting the number of new or full moons from the start of a *yuga*, this is prone to errors. It is more accurate to have a representative *nakṣatra* to identify a *nakṣatra*-sector. To address the question: when was the list of *nakṣatras* to

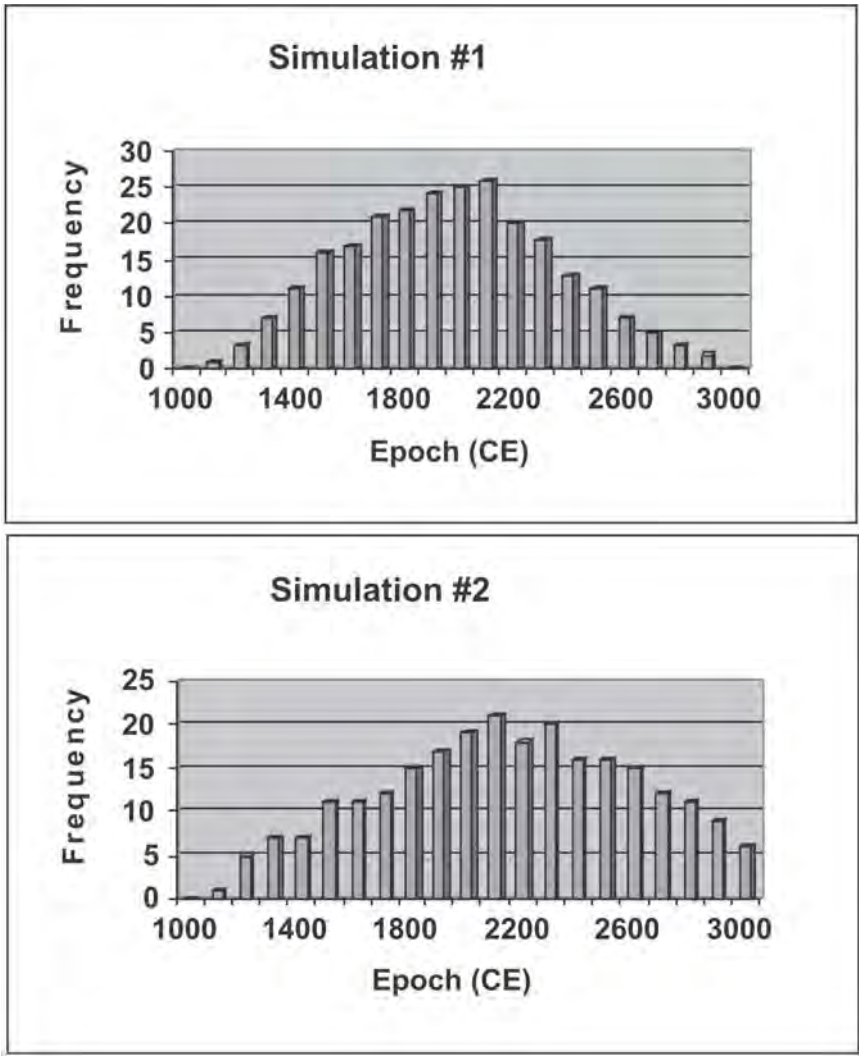

Fig. 5. The cross-correlation of *yogatārās* and *nakṣatra*-sectors. The frequency distribution obtained with the coordinates of *yogatārās* given by Pingree and Morrissey (1989) is shown in the top panel and in the second panel is shown the frequency distribution obtained with the coordinates given by Abhyankar (1991). The results with psudo-*yogatārās* selected at epoch 2000 AD are shown in the bottom two panels. The frequency distribution for psudo-*yogatārās* around the position of the full moon in a *yuga* are shown in Simulation #1. The frequency distribution for psudo-*yogatārās* around the position of the moon for twenty-seven nights of a month, starting from the night after the new moon, is shown in Simulation #2. See text for detail.

identify the *nakṣatra*-sectors formulated (?), it is worth asking, how many *nakṣatras* match their respective *nakṣatra*-sectors at any particular epoch?

The period between 2500 BC and 500 BC was selected for this analysis. The choice of the initial epoch of 2500 BC was entirely arbitrarily. The final epoch of 500 BC was selected as the putative end of the Vedic Period. The period from 2500 BC to 500 BC, was divided into twenty-one epochs each 100 years apart. Unfortunately, the only available identifiers of the *nakṣatras* are *yogatārās* and the *yogatārās* available at present are those identified from *Paitāmahasiddhānta*. Thus, the analysis presented here will have all the uncertainties that go with the data based on this text. Since there is no viable alternative to these data, the currently available *yogatārās*[23,24] were used in this analysis. The J2000 coordinates of *yogatārās* of the *nakṣatras* were precessed to one of the epochs between 2500 BC and 500 BC and the *nakṣatras* whose ecliptic longitudes were within the width of the *nakṣatra*-sector they were meant to represent were identified. This was repeated for all twenty-one epochs in the period between 2500 BC and 500 BC. The results of this cross-correlation are shown in Figure 5; the frequency of coincidences between a *yogatārā* and its *nakṣatra*-sector for the data from Pingree and Morrissey is shown in the top panel of Figure 5 and that for the data from Abhyankar is shown in the second (from top) panel of Figure 5. For both sets of data, 80% of the *yogatārās* fall in their respective *nakṣatra*-sectors at 1300±300 BC. The (surprisingly) large number of coincidences between the *yogatārās* and their respective *nakṣatra*-sectors within this narrow 'window' around 1300 BC suggests that this may well have been the epoch when the list of *nakṣatras* to identify the *nakṣatra*-sectors was created. It is possible that *nakṣatras* to identify the *nakṣatra*-sectors were selected from the list of *nakṣatras* that were already in use as chronological markers. From this list, the *nakṣatras* that corresponded to the *nakṣatra*-sector were (probably) retained and those that did not were discarded and new *nakṣatras* were added for *nakṣatra*-sectors that had no corresponding *nakṣatra*. It is very likely that the *Kṛttikās* is one of these 'old' *nakṣatras*. The discussion above (Section 1.3) on the heliacal rising and setting of *nakṣatra Śraviṣṭhās*/α *Delphini* and its relevance to the start of a *yuga* and the calendar of *Vedāṅga Jyotiṣa*, suggests that *nakṣatra Śraviṣṭhās* may have been one of the 'new' *nakṣatras*. The large number of coincidences also suggests that the *nakṣatras* and their identifying *yogatārās* have been transmitted with considerable fidelity over the gap of more than one thousand years between the Vedic texts and *Paitâmahasiddhânta*.

To verify the results of cross-correlation of the *yogatārās* and the *nakṣatra*-sectors, a list of twenty-seven *nakṣatras* and their *yogatārās* was created for the current epoch i.e. 2000 AD. The criteria the Āryas may have used to select the *nakṣatras* and their *yogatārās* are not known but *nakṣatras* that conjoin the full moon have a central role in the Vedic calendar, e.g. they identify the months and they identify the date of the three seasonal sacrifices (Section 1.2 above). In addition, in the Vedic texts, the *nakṣatras* close to the moon were used to identify the days of a (synodic) month. Two simulations were performed; in the first, the dates of all full moons in a *yuga* starting with the new moon near winter solstice (on 22 December 1995 AD) were identified and the ecliptic coordinates of the full moon were computed with the current orbital parameters for the moon and the earth. The *nakṣatras* of the full moons in spring, summer and autumn are given by the *Cāturmāsya* (or seasonal) sacrifices (see Section 1.2). These three *nakṣatras* establish the 'absolute'*nakṣatra*-grid (at epoch 2000) for the full moons of the *yuga*. That is, the *nakṣatra* of the full moon in spring (in year 2000) was designated as *Uttara-Phalgunīs*, that of full moon in summer (in year 2000) was designated as *Uttarāṣāḍhās* and that of full moon in autumn (in year 2000) was designated as *Kṛttikās*. Since each full moon is separated by $29^{22}/_{124}$ *nakṣatras*[25], the *nakṣatras* of all other full moons in the *yuga* can be established. Thus a list of twenty-seven *nakṣatras* (at epoch 2000) and their associated full moons was created. A *yogatārā* for each *nakṣatra* was selected from SIMBAD Astronomical Database, J2000.0 catalogue of stars.

Following criteria were used to choose these *yogatārās*;

- Only stars brighter then 6th magnitude were selected
- Only stars with ecliptic latitude within ±20° of the ecliptic were selected.
- Only stars with ecliptic longitude within ±5° of the corresponding full moon were selected.
- If there was a multiple choice of stars then the brightest star was selected.

The J2000.0 coordinates of these psudo-*yogatārās* (or J2000-*yogatārās*) were cross-correlated with the coordinates of the *nakṣatra*-sectors i.e. the cross-correlation described above was replicated for these psudo-*yogatārās*. The frequency distribution for this cross-correlation is shown as Simulation #1 in Fig. 5. The profile of this frequency distribution is similar to that of the frequency distribution for the cross-correlation of the *yogatārās* and the

nakṣatra-sectors (the top two frequency distributions in Fig. 5) but the peak of the distribution is around 2000 AD, the epoch of the pseudo-*yogatārās*.

For the second simulation, the *nakṣatras* close to the moon on twenty-seven nights of a month were determined. The *nakṣatra* on the full moon night in autumn was designated as *Kṛttikās* (as prescribed for the *Cāturmāsya* sacrifices, Section 1.2) and the *nakṣatras* of the thirteen nights either side of this night were obtained from the list of *nakṣatras* in the Vedic texts. A *yogatārā* for each *nakṣatra* was selected from SIMBAD Astronomical Database J2000.0 catalogue of stars, using the criteria given above. The J2000.0 coordinates of these psudo-*yogatārās* (or J2000-*yogatārās*) were cross-correlated with the coordinates of the *nakṣatra*-sectors and the frequency distribution for this cross-correlation is shown as Simulation #2 in Figure 5. The peak of this distribution is also around 2000 AD, the epoch of these psudo-*yogatārās*.

The distribution of *yogatārās* at epochs other then those around 1300±300 BC (and 2000 AD, in the simulations shown in Fig. 5) is to be expected because the *nakṣatra*-sectors are wide and will straddle more then one epoch. In addition, misidentification of *yogatārās* is likely and should be expected when data have been transmitted over a considerable period. These uncertainties will also be included in the frequency distribution of the simulated *yogatārās* at the current epoch. Each night the moon does not move through a complete *nakṣatra*-sector and depending on the choice of (psudo-) *yogatārās*, some *nakṣatra*-sector will have two *yogatārās* and this will influence the frequency distribution of the cross-correlation of the 'nightly' psudo-*yogatārās* and the *nakṣatra*-sector (Simulation #2). Not withstanding these deficiencies, these simulations demonstrate that the frequency distribution of the cross-correlation of the *yogatārās* and the *nakṣatra*-sectors peaks around the epoch at which the *nakṣatras* and *yogatārās* are selected to represent the *nakṣatra*-sectors and therefore the *nakṣatras* listed in the Vedic Texts must have been selected at 1300±300 BC.

3. Conclusions

The unambiguous identification in the Vedic texts, of the season, *nakṣatra* and the phase of the moon for the *Cāturmāsya* (or seasonal) sacrifices presents the best means to determine an epoch in the Vedic Period. This epoch can be accepted with confidence as it is based on the identification of *nakṣatra*

Kṛttikās (with the asterism of Pleiades) that is secure. The accuracy with which the Āryas would have observed the proximity of a *nakṣatra* to the full moon or the separation between a *nakṣatra* and the full moon, which would have been accepted as conjunction, are not known. With these caveats, the epoch of *Cāturmāsya* sacrifices appears to be 1400±500 BC.

In the luni-solar calendar of *Vedāṅga Jyotiṣa* the synodic year is harmonized with the seasons over a period of sixty-two lunations by intercalation of two synodic months. This period is a *yuga* and it starts every sixty-two lunations at winter solstice when the new moon (and therefore the sun) are "in the same region of the sky" (*RJ*.5-6; *YJ*.6-7) as *nakṣatra Śraviṣṭhās*. These verses in *Vedāṅga Jyotiṣa* suggest that the Vedic calendar-makers may have observed the sun "in the same region of the sky" as *nakṣatra Śraviṣṭhās*. This is only possible at heliacal rising and setting of the *nakṣatra Śraviṣṭhās*. An analysis of heliacal rising and setting of α *Delphini* the proposed *yogatārā* of *nakṣatra Śraviṣṭhās* indicates that from 1550 BC to 1150 BC this *yogatārā*/*nakṣatra* was close to the horizon at either sunrise or sunset within less than five days of winter solstice. To put it differently, during this interval, *nakṣatra Śraviṣṭhās* and the sun could have been considered to be in the same region of the sky at winter solstice. Outside this interval, the sun, at winter solstice, could not be considered to be in the same region of the sky as the *nakṣatra Śraviṣṭhās*.

The *nakṣatra*-sector coordinate system is unique to *Vedāṅga Jyotiṣa* and cannot be identified in any other Vedic text. It is possible that at its formulation the sectors were identified by the *nakṣatras* (stars and asterisms) that were in use to map the position of the moon on the sky (e.g. for *Cāturmāsya* sacrifices). This suggests a correspondence between a *nakṣatra*-sector and its indicative *nakṣatra* at some epoch. Cross-correlation of the *nakṣatra*-sectors and the *yogatārās* of the *nakṣatras* suggest an epoch of 1300±300 BC for the formulation of the list of *nakṣatras* (stars and asterisms). This result should be treated with caution as it depends on identification of *yogatārās* that ultimately are based on *Paitāmahasiddhānta*.

The epoch of the Vedic texts determined from the date of *Cāturmāsya* sacrifices, the start of a *yuga* of the calendar of *Vedāṅga Jyotiṣa* and the cross-correlation of *nakṣatra*-sectors and the *yogatārās* of the *nakṣatras* are consistent with the epoch of circumpolar *Sapta Ṛṣis* from *Madhyadeśa*. It is possible that *Vedāṅga Jyotiṣa* was formulated around this date although the text available at present may have been redacted at a latter date.

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ABBREVIATIONS

Ṛgveda Saṃhitā – RV
Atharvaveda Saṃhitā – AV
Maitrāyaṇīya Saṃhitā – MS
Aitareya Brāhmaṇa – AB
Śatapatha Brāhmaṇa – SB
Kātyāyana Śrauta Sūtra – KŚS
Sāṅkhyana Gṛhya Sūtra – SGS
Ṛgveda recension of Vedāṅga Jyotiṣa – VJ
Yājuṣa recension of Vedāṅga Jyotiṣa – VJ

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