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Equinoctial full moon of the *Brahmāṇḍa Purāṇa* and the *nakṣatra* solar zodiac starting from summer solstice

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Abstract
The first theoretical system of tracking sun in the tropical annual cycle is cryptically mentioned in the *Maitrāyaṇīya Āraṇyaka Upaniṣat* (MAU) of the *Kṛṣṇa Yajurveda*, as the southern sojourn of sun starting at the summer solstice. This is called *maghādyaṁ,* the first point of the *maghā nakṣatra*, identified most likely with the early morning visibility of ε-Leo, near the azimuth of the sunrise point on the horizon as observed at Kurukshetra. Twenty seven equal *nakṣatra* sectors named in the traditional sequential order cover one tropical circuit of sun of 366 days with the winter solstice falling exactly at the middle of the *śraviṣṭhā* sector. Even though MAU mentions each *nakṣatra* to be made up of four quarters, no practical application of this ¼-*nakṣatra* sky part amounting to 3º20′ in longitude is seen in Vedic texts till we come to the *Brahmāṇḍa Purāṇa*, a text closer to the Vedas. This *Purāṇa* states, observed equinoctial full moon positions corresponding to spring equinox at ¼-*kṛttikā* and autumn equinox at ¾-*viśākha* exactly 180º apart as they should be. This statement is analysed in this paper by computer simulation of full moon time series for the years − 2400 to − 800 to show that the *Purāṇa* data would be realistically valid for the period 1980 BCE to 1610 BCE. It is further demonstrated that the *Purāṇa* has followed the *maghādi* system of solar *nakṣatra* system stated in the MAU. The central epoch *circa* 1800 BCE of this *maghādi* equal *nakṣatra* solar zodiac got modified, due to precession effects, to the *śraviṣṭhādi* scheme of Parāśara, Vṛddha Garga and Lagadha dateable to *circa* 1300 BCE.

Keywords *Brahmāṇḍa Purāṇa* · *Maghādi* solar zodiac · Equinoctial full moon · Epoch 1800 BCE · Precession effects

Abbreviations

AE	Autumn Equinox
BP	*Brahmāṇḍa Purāṇa*
FM	Full Moon
MAU	*Maitrāyṇīya Āraṇyaka Upaniṣat*
PT	*Parāśara Tantra*
RV	*Ṛgveda*
SE	Spring Equinox
SS	Summer Solstice
TB	*Taittirīya Brāhmaṇa*
VGJ	*Vṛddhagārgīya Jyotiṣa*
WS	Winter Solstice

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1 Introduction

Solar phenomena of the two solstices have been of deep mystical and cultural importance in India since the Vedic times. The astronomical significance of the days when sun is at the extreme north and south declination, in the annual cycle, would have been directly observed and experienced in terms of the differing length of the day light. The Vedic sacrificial year started with or near the winter solstice day and the *śiśira ṛtu* (winter) with several texts indicating that the tropical year was taken to be 366 *ahorātra* (day-night), counted in terms of sun rises. In this reckoning, the mid-year was close to the summer solstice day that divided the year into two equal parts of six months each. The central day of the yearlong *gavāmayana* sacrifice, when sun rise was observed far north of due East, was called *viṣuvat,* a day of special significance in Vedic rituals. This was also the day when formally the *varṣa ṛtu* (rainy season) started. The meaning of the word *viṣuva* indicates a point in time that divides the year in half. This point is figuratively

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explained in the *Taittirīya Brāhmaṇa* (TB) by comparing the *viṣuva* day to the east–west running central roof beam of a sacrificial hall that divides the hall symmetrically into north–south wings of equal measure.[1] But this was not the only technical meaning of the word *viṣuva,* which in its etymological sense meant equality and symmetry with respect to a middle point. Thus, the *Purāṇas* define *viṣuva* as when the *ahorātra* (day–night) gets divided into day and night of equal length. This is the equinoctial day that occurs twice in a year. The practitioners of yearlong rites such as the *gavāmayana* would have noticed such days, but explicit reference to the two equinoctial days is not found in the available Vedic texts, unlike weather related narratives of the two solstice days.

Another significant feature of sky observation was about the background stars along the ecliptic, called *nakṣatra*. Special professionals known as *nakṣatradarśa* were the ancient Indian sky watchers. *Nakṣatra* (asterisms) were used not only for specifying moon's position in the monthly cycle, but also for sun in the tropical year. A clear reference to solar *nakṣatra* appears in the *Maitrāyāṇīya Āraṇyaka (aka Maitrī Upaniṣat;* MAU), which declares *Time* to have manifested coeval with sun. This text divides the tropical year into two solar transits *(ayana)* starting from the summer solstice to the winter solstice and back. This would be valid for any year, but the text indirectly refers to an epoch, when the southern sojourn of sun (*āgneyaṁ*) was from the beginning of *nakṣatra maghā* (*maghādyaṁ*) to half-of-*śraviṣṭhā* (*śraviṣṭhārdhaṁ*). The *saumya* transit (northern) is indicated to be between the start of *āśleṣā (sārpadyaṁ)* and middle-*śraviṣṭhā* but in reverse order (*utkrameṇa*). When reckoned in the direct order this northern transit was from half-*śraviṣṭha* to end of *āśleṣā*.[2] This scheme is the earliest Vedic solar zodiac that not only divides the year into two equal halves but also mentions names of the starting, ending and half-of-*nakṣatra* divisions, in terms of eponymous stars that should have been visible in the sectors. Further, MAU refers to discrete time starting from the *nimeṣa* (eye wink) and the *twelve* (stellar divisions) each with *navāṁśa* (nine-quarter) parts. This amounts to dividing the year (*vatsara*) into twelve parts, each with nine divisions for sun to move through 2¼ *nakṣatra* in a solar month. In modern terminology, this makes the smallest angular measure indicated by MAU to be 3º20′ which is an indicator of possible error of about three to four days in the observation of the solstice day, and *nakṣatra* sector boundaries.

The partition of the sun's path or the ecliptic into twenty-seven equal *nakṣatra* sectors and ordering them in terms of day counts is an interesting practical approach. But use of the same nomenclature for the visible asterisms and also for the *nakṣatra* stretches, can be confusing in identifying the starting point of the first *nakṣatra*. This -*ādi* scheme works well when the beginning of the division is identifiable with a star named and familiarized from the past becomes visible before sun rise. In this model of sun spending 366 days equally distributed over 27 *nakṣatra* divisions, days are counted as integral number of *ahorātra* or day-night (day for convenience) from the summer/winter solstice day. Once the *nakṣatra* part of sun on the solstice day can be estimated or observed, the remaining equal *nakṣatra* divisions can be marked in terms of number of days. Moon plays no role in this scheme as far as the divisions are concerned. But it is known that *pūrṇimā* (full moon), *aṣṭami* (half-moon) and *darśa* (new moon) have had important role in Vedic rites and practices. Although, unambiguous luni-solar observations are not found in the available Vedic texts, it is interesting to come across reference to Full Moon (FM) coordinates in terms of *nakṣatra* parts on equinoctial days, in the *Brahmāṇḍa Purāṇa* (BP) and a few other *Purāṇas* with minor variations.

In this paper, the *Brahmāṇḍa Purāṇa* statements are investigated first to demonstrate that this data is compatible with observations spread over a period of four centuries, the latest being 1700–1600 BCE. This is followed by a discussion of this result to demonstrate the *maghādi* scheme of MAU and BP as the original version of the formal Vedic solar zodiac that changed into the *śraviṣṭhādi* scheme *circa* 1400–1300 BCE due to the precession of the equinoxes. This represents an interesting period of pre-*siddhāntic* Hindu astral sciences that is important for the history of Indian astronomy before Common Era.

2 *Brahmāṇḍa Purāṇa* (BP)

Among the traditionally recognised eighteen *Purāṇas*, the *Brahmāṇḍa*, *Vāyu*, *Matsya*, *Viṣṇu*, *Liṅga Purāṇa* texts carry interesting astronomical and cosmological models inherited from their Vedic past. For example, all the above *Purāṇas* refer to the Vedic legend of *somapāna* by gods as the daily decrease in the brightness of moon in the dark fortnights (Iyengar, 2016). The Meru-Dhruva centric model for the periodic motion of sun, moon and other celestial bodies is also available in the above texts with variant readings, additions and omissions. Even though some of the statements may sound fanciful, there is a discernible layer of observation and effort to explain the same in terms of prevalent physical models. The first part of BP, in chapters 21 to 24 totalling 520

[1] विषूवान् दिवाकीर्त्यम् । यथा शालायै पक्षसी । एवं संवत्सरस्य पक्षसी । यद्येते न गृहेरन् । विषूची संवत्सरस्य पक्षसी व्यवस्रंसेयाताम् । आर्तिमार्छेयुः । यद्येते गृह्यन्ते । यथा शालायै पक्षसी मध्यमं वंशमभिसमायच्छति ।। TB (1.2.3).

[2] सूर्यो योनिर्वै कालस्य तस्य एतद्रूपम् । यन्निमेषादि कालात्संभृतं द्वादशात्मकं वत्सरम्। एतस्याग्नेयमर्धमर्धं वारुणम् । मघाद्यं श्रविष्ठार्धमाग्नेयं क्रमेणोत्क्रमेण सार्पाद्यं श्रविष्ठार्धान्तं सौम्यम् । तत्र एकैकमात्मनो नवांशकसचारकविधम् ॥ MAU (6.14).

verses presents this Purāṇic astronomy that must have been formulated before the Common Era. The intention here is not to critically assess or discuss the ancient Purāṇic cosmography and the geocentric geometric models used to explain the apparent movement of sun and other celestials. Readers interested in the interpretation and limitations of such models are referred to Thompson (2007) and Das (2018). Our primary focus here is to analyze the stated observation of equinoctial full moon in fractional *nakṣatra* sectors and trace them to the *maghādi* epoch as stated in MAU.

The 21st Chapter of BP titled *āditya-vyūha-kīrtanaṁ* in 176 verses gives an account of the southern and northern *ayana* (lateral motion) of sun with description of seasons, in a colourful poetic style. There are a few statements here and there that cannot be easily understood due to lack of context in the currently available publications. Equally well, there are statements that are realistic, valid and hence of interest in understanding the growth of natural sciences in India. Among these are the six seasons with names inherited from past, but curiously enough *viṣuvat* day being in the center of the spring and autumn seasons unlike in the Vedic texts. Reference to *viṣuvat* as equinox event appears twice in this chapter of BP. After mentioning that the day light varies with the *ayana,* the text mentions a day that is of fifteen *muhūrta* duration. On such a day, it is said not only the day and night are equal, but moon acquires its digits equally in day and night.[3] The five-year cycle of sun is stated to be made of 1830 sun rises. The solar year is said to be made of two *ayana*s and six seasons each of 61 days. After a few verses sun is said to attain uniform or medium speed at the middle of spring and autumn. Once again moon is referred, but quite clearly to be associated with *viśākhā* and *kṛttikā* asterisms. The text and translation follows:

शरद्वसन्तयोर्मध्ये मध्यमां गतिमास्थितः ।
अतस्तुल्यमहोरात्रं करोति तिमिरापहः ॥
हरिताश्च हयादिव्याः तस्य युक्ता महारथे ।
अनुलिप्ता इवाभान्ति पद्मरक्तैर्गभस्तिभिः॥
मेषान्ते च तुलान्ते च भास्करोदयतः स्मृताः ।
मुहूर्त्ता दश पञ्चैव अहोरात्रिश्च तावती ॥
कृत्तिकानां यदा सूर्यः प्रथमांशगतो भवेत् ।
विशाखानां तथा ज्ञेयश्चतुर्थांशे निशाकरः॥
विशाखायां यदा सूर्य: चरतेंऽशं तृतीयकम्।
तदा चन्द्रं विजानीयात् कृत्तिकाशिरसि स्थितम् ॥
विषुवं तं विजानीयादेवमाहुर्महर्षयः।
सूर्येण विषुवं विद्यात् कालं सोमेन लक्षयेत् ॥
समा रात्रिरहश्चैव यदा तद्विषुवद्भवेत्।
तदा दानानि देयानि पितृभ्यो विषुवेषुच॥ (Ch. 21 v.143–149).

śaradvasantayormadhye madhyamāṁ gatimāsthitaḥ ।
atastulyamahorātraṁ karoti timirāpahaḥ ॥
haritāśca hayādivyāḥ tasya yuktā mahārathe ।
anuliptā ivābhānti padmaraktairgabhastibhiḥ ॥
meṣānte ca tulānte ca bhāskarodayataḥ smṛtāḥ ।
muhūrttā daśa pañcaiva ahorātriśca tāvatī ॥
kṛttikānāṁ yadā sūryaḥ prathamāṁśagato bhavet ।
viśākhānāṁ tathā jñeyaścaturthāṁśe niśākaraḥ ॥
viśākhāyāṁ yadā sūrya carateṁ'śaṁ tṛtīyakam ।
tadā candraṁ vijānīyāt kṛttikāśirasi sthitam ॥
viṣuvaṁ taṁ vijānīyādevamāhurmaharṣayaḥ ।
sūryeṇa viṣuvaṁ vidyāt kālaṁ somena lakṣayet ॥
samā rātrirahaścaiva yadā tadviṣuvadbhavet ।
tadā dānāni deyāni pitṛbhyo viṣuveṣuca ॥

Sun being in normal (medium) speed at the middle of *śarat* (autumn) and *vasanta* (spring) makes the day and night to be equal. The yellowish divine horses of his chariot shine as if painted by lotus-red coloured rays. At the end of *meṣa* and *tulā* (*rāśi*/months) from sunrise, the day is fifteen *muhūrta* long; so is the night. When the sun is in the first *aṁśa* (quarter) of *kṛttikā*, it has to be understood that the moon is in the fourth *aṁśa* of *viśākhā*. When the sun moves in the third *aṁśa* (quarter) of *viśākhā*, then moon has to be known to be at the head (beginning) of *kṛttikā*. This has to be understood as the equinox day; so it has been said by the sages. From the sun one should know the *viṣuva* (day) and the time observed from the moon. When the *viṣuvat* happens, day and night are of the same duration. Then charities are to be offered for (pleasing) the manes.

The *purāṇa* bringing up the equinox definition twice within about twenty verses raises the doubt that the text might have been edited for some purpose. The mention of solar *rāśi* (months) named *meṣa* and *tulā*, that were not popular before Common Era adds to this doubt. While this verse might have been added later, it seems to have been done with a purpose to assert that the day and night should be of fifteen *muhūrta* at the equinoxes. The next verse does not sound modern as it is about sun and moon in *nakṣatra* parts and not in the *rāśi* (sign) of later texts. Since the equinox is asserted to be at the middle of the *vasanta* and the *śarad* seasons, the words *meṣa* and *tulā,* whether they refer to solar months or *rāśi* names (signs) are of no consequence to the present study. The observation of the equinoctial full moon near the two unambiguously recognizable stars and within their eponymous sectors is amenable for archaeo-astronomical analysis.

3 Equinoctial full moon

The BP text quoted above clearly takes equinoctial sun to be at the quarter point of the *kṛttikā* sector when moon would be at the third-quarter of the *viśākha* division. The asterism

[3] शरद्वसन्तयोर्मध्यं विषुवत्परभाव्यते । अहोरात्रे कलाश्चैव समं सोमः समश्नुते ॥ (Ch. 21.124).
Here and elsewhere the *Brahmāṇḍa Purāṇa* (ed. KV Sharma) Krishna Das Academy, Varanasi is followed.

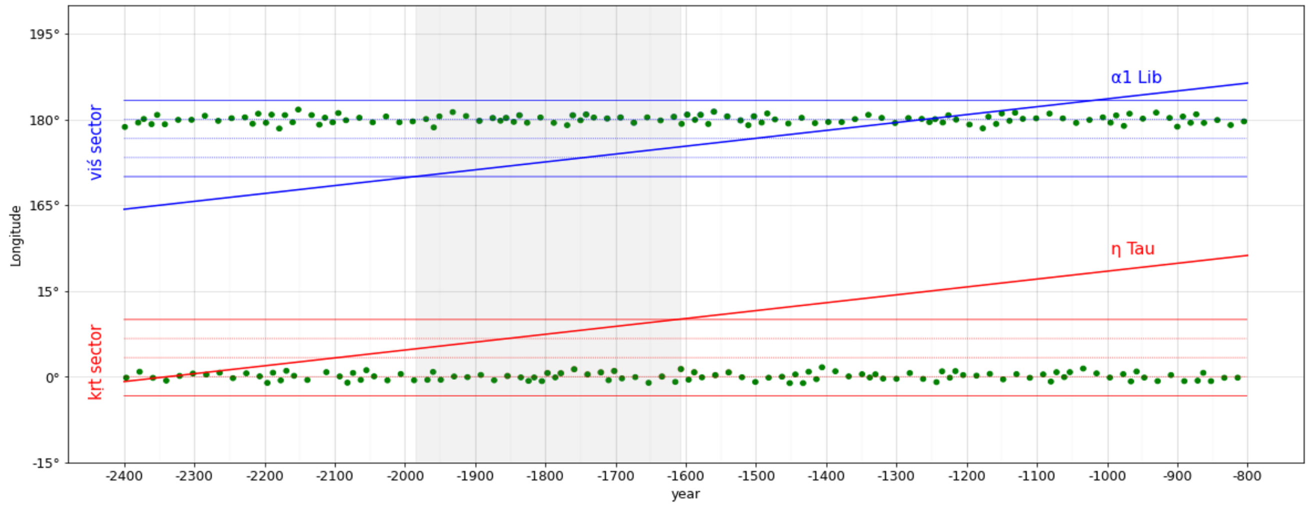

Fig. 1 Full moon points around 180° longitude with sun at 0° longitude (*vasanta*/spring equinox) are marked in the *viśākhā* sector. Full moon points around 0° longitude with sun at 180° longitude (*śarat*/autumn equinox) are marked in the *kṛttikā* sector. Red and blue lines show the variation in longitude of the stars *kṛttikā* (η-Tau) and *viśākhā* (α1-Lib) due to precession of the equinoxes

kṛttikā is made of six stars that are compactly clustered and hence can be represented for practical purposes by η-Tauri. Similarly, *viśākha* with two close stars can be treated as α1-Librae. These two prominent visible stars are separated in longitude by 165º. However, in the equal *nakṣatra* model, when the ecliptic is divided into twenty-seven equal parts with names ascribed as per the standard sequential order of the twenty-seven asterisms, the ¼-*kṛttikā* and ¾-*viśākha* points are always exactly 180º apart. Since BP text mentions moon to be at ¾-*viśākha* when sun is at ¼-*kṛttikā*, this event can be surmised to be the observation of the spring equinox FM rising or setting closer to sun set or sun rise, respectively. Subsequently, after about six months when sun is in the third part of *viśākha*, moon is said to be at the head or the first part of *kṛttikā*. This is not as sharp a statement as the first one but is realistic enough to be a naked eye observation of an autumnal FM observed near the visible star *kṛttikā*. It may be noted that *kārtika-pūrṇimā* and *vaiśākha-pūrṇimā* are important even now in the Hindu religious and socio-cultural calendar but have no special relation to the equinoxes. This fact underscores the chronological importance of the BP observations, when the solar equal *nakṣatra* zodiac was invoked to mention the position of full moons, visibly associated with the two important stars.

The possibility of the equinoctial FM in the indicated *nakṣatra* sectors can be found out by computer simulation of a time series of full moons. This exercise has been carried out for the years − 2400 to − 800 using the Astropy library algorithms.[4] The FM data thus obtained is sieved to select only those that are on the equinoctial days when sun is at 0º or 180º longitude with an error of two degrees on either side. Since the accuracy of the BP text is of the order of ¼-*nakṣatra*, the above error limit is found necessary to pick up equinoctial FM with observational error of about three days. This results in about 220 such FM, hovering around 0º and 180º longitude. In Fig. 1, these simulated results are shown for further discussion. The BP text is clear that the spring equinox should correspond to ¼-*kṛttikā* and on the other side it should be ¾-*viśākhā*. This partition helps us to mark the particular epochal *nakṣatra* sector of *kṛttikā* as (− 3º20', 10º) and of *viśākha* as (170º, 183º20′) in longitude.

Observation of FM near the stars *kṛttikā* or *viśākha* in a year is not at all rare. But FM on or close to the equinoctial day is not that frequent. The simulated results show that there will be about fifteen such events per century. Thus, the rationale behind the BP text can be taken as observation of a few equinoctial FM near the two visible stars in their designated sectors. In Fig. 1, the locus of these stars *kṛttikā* (η-Tau) and *viśākha* (α1-Lib) is indicated by red and blue lines, incorporating the effect of precession of the equinoxes. The *nakṣatra* sector concept was an ancient Indian artifice for keeping track of the passage of time when the named star was visible to naked eye and could be associated for a few days with a solar or lunar event of interest. In Fig. 1, it is seen that star *viṣākha* enters its assigned sector by 1980 BCE whereas star *kṛttikā* leaves its eponymous *nakṣatra* sector by 1610 BCE. Hence, the BP statement could have been possible anywhere in this wide window of nearly four hundred years, shown shaded in the above figure. However as pointed out before, the spring equinox statement is more specific than the other one. Thus, one may argue that FM observations nearer to star *viśākha* should be treated as more reliable. With this rider, 1700–1600 BCE will be a

[4] Astropy Collaboration et al. (2022), Astropy Paper III (v5.0), A&A, 658, A5 https://arxiv.org/abs/2206.14220.

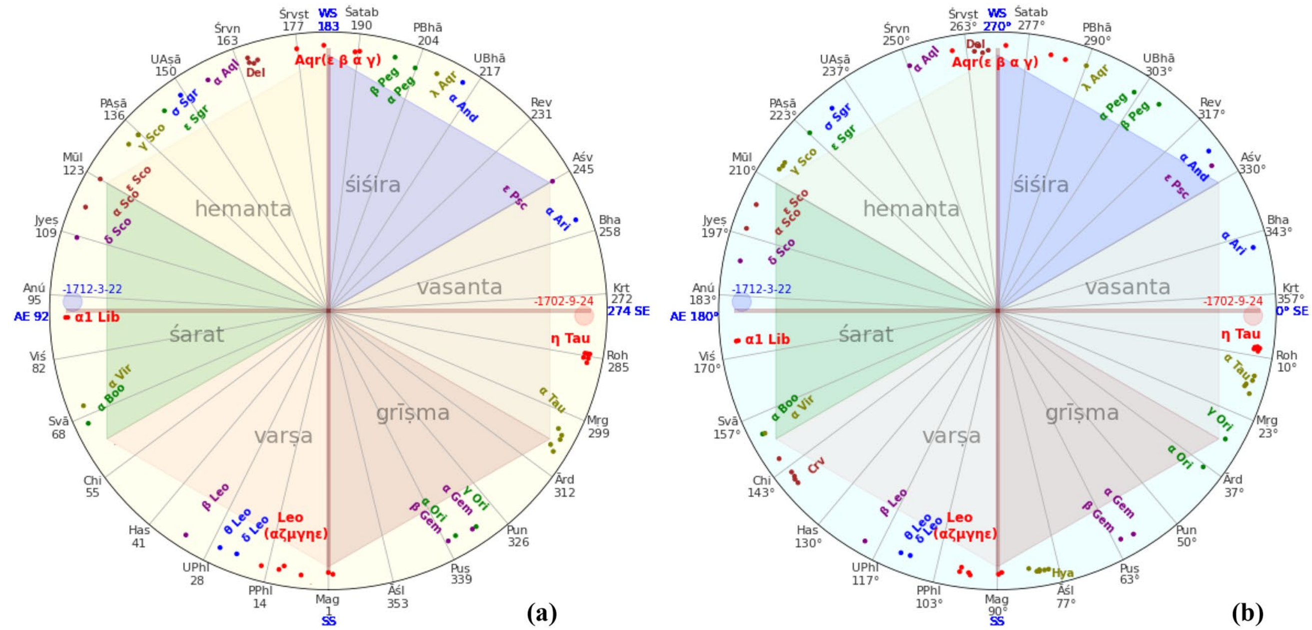

Fig. 2 **a**, **b** Dial plot of the 27 *nakṣatra* sectors, each 13(5/9) days long, super posed on the invariant N-S axis defining the beginning of the *śiśira ṛtu* (WS) and the *varṣa ṛtu* (SS) as in the Vedic MAU. The E-W axis bisects the centre of the *vasanta* (SE) and *śarat ṛtu* (AE) domains as in the *Brahmāṇḍa Purāṇa*. **a** The number of days counted from the summer solstice day to the beginning of each *nakṣatra* sector is marked clockwise in the left figure. As an example, sector visibility of select stars is shown for the year -1700. **b** The ecliptic is divided into 27 equal parts named as per the *nakṣatra* sequence, in terms of longitudes from the spring equinox point to show the spread of some stars along the ecliptic. Two sample equinoctial FM are shown with their dates as in the civil calendar. The dates JD: 1095845.56 (-1712-3-22) and JD:1099683.53 (-1702-9-24) correspond with (-1712-4-6) and (-1702-10-9) respectively in the stellarium software

conservative estimate for the chronological footprint in BP of a bygone era of astronomical observations. The *Purāṇa* text is silent about other *nakṣatra* sectors and the solstices while mentioning about the FM. But it can be demonstrated that *kṛttikā*-¼ being the equinoctial day is same as the winter solstice being at *śraviṣṭhā*-½ as in the Vedic MAU.

4 *Maghādi* scheme

The BP text from a critical study of its content can be understood to have acquired its present scriptural form in the early centuries of CE. But as pointed out above (Sect. 2) the *Purāṇa* describes ancient astronomical models and observations. The above description of equinoxes, FM and *nakṣatra* sectors demonstrate cultivation of astronomy in India prior to the astronomical works of Parāśara, Vṛddhagarga and the calendar formulae of Lagadha. Quite consistently, the *Purāṇa* statement fits in with the Vedic *maghādi* scheme stated cryptically in MAU. This becomes clear in the dial plot of Fig. 2, which shows both the *Purāṇa* equinox line (SE–AE) and the Vedic solstice line (WS–SS) together. The corresponding invariant domains of the six seasons are also shown in the background. In this system the equinox line bisects the *vasanta* and *śarat* seasons as defined in BP. These two axes are superposed on the twenty-seven equal *nakṣatra* sectors marked clockwise starting from the *grīṣma-varṣa* vertex taken to be the first point of the *maghā* sector. It is easily seen that the *kṛttikā*-¼ and *viśākhā*-¾ equinoctial days of the BP are separated by exactly 6¾ *nakṣatra* sectors from *maghādi*, the first point of the *maghā* sector, as required for the compatibility between the astronomical statements in the two texts. In Fig. 2a the leading edges of the *nakṣatra* sectors are marked in number of days counted to the nearest integer from the origin. The 183rd day from *maghādi* gets marked at the middle of the *śraviṣṭhā* sector as the winter solstice day and the formal beginning of *śiśira ṛtu*. Figure 2b has the same information as Fig. 2a, except the origin is at 0º longitude starting from the spring equinox point and the summer solstice corresponds to 90º longitude. The two figures depicting the equinoxes and solstices of BP and MAU, in terms of *nakṣatra* sectors and as longitudes are fully consistent. Thus one can surmise that the *maghādi* system, beyond reasonable doubt, must have been in vogue by 1800 BCE and followed further for a century or two.

The hitherto unsuspected temporal overlap between the two independent Sanskrit texts MAU and BP, brought out here for the first time, is a pointer to the existence of an ancient convention to follow the position of sun, in terms of *nakṣatra* sectors, starting from a fixed summer solstice point on the horizon. This inference brings up in its wake the question of the cultural influence of *maghā nakṣatra* on the Vedic society and how the naked eye visibility of the stars of this asterism might have been taken to indicate the beginning of *varṣa ṛtu*.

5 Stars of *Maghā Nakṣatra*

Summer solstice or the rise of sun at the same north eastern point of the horizon for a few days in the yearly cycle would have been naturally observed and felt as a weather condition in terms of the daylight hours getting longer and longer and the intense heat giving way to rains. The fixed point of sun rise could have been remembered as a mountain peak or marked as a physical object pointing towards a star visible before sunrise, intuitively considered close to sun. Search for this in the ancient Vedic literature leads to the asterism *maghā* as the most probable candidate. MAU clearly refers to the start of the southern sojourn of sun as *maghādyaṁ* which means the beginning of the *maghā* sector understood in terms of a star of the group. In the *nakṣatra-sūkta* of the *Atharva Veda*, *ayanaṁ,* the lateral motion of sun is associated with the asterism *maghā*.[5] In the ancient *nakṣatra* rites of the *Yajurveda*, offerings to this constellation are enjoined on six bowls[6] harmonising with the number of recognized stars.

Starting from the *Ṛgveda* (RV) the asterism *maghā* (*aghā*) is always cited in plural, hinting that to be a sky part, made up of more than one star. In this connection the laudation of Indra as *Maghavān* stands out conspicuously in RV. In its ritualistic context the word *maghā* is usually interpreted as wealth/riches, but in the context of Indra's actions in the sky, *maghā* in all probability refers to an asterism of that name. Even though the Vedas are popularly said to be for and about performing sacrifices, the natural meaning behind the mystical hymns indicate Indra to be essentially an abstract entity or force having close affinity with sun, seasons, rhythms and time. The Vedic ritual, philosophical and other exegetical traditions in India were always aware of this. For example, Yāska (*c* 1000 BCE?) points out the act of Indra drinking thirty lakes of Soma juice as in RV (8.77.4) to be an allegorical reference to moon's digits being absorbed for fifteen days and fifteen nights in the dark fortnight. Sāyaṇācārya (14th cent CE) in his commentary, besides explaining the ritualistic practices associated with this hymn paraphrases Yāska; *as per the authority of Nirukta Indra represents time*.[7]

Consistent with this interpretation, following the Nirukta of Yāska, killing of Vṛtra by Indra is understood by many primarily, as an allegory for releasing the waters from the dark clouds. One of the most important attribute of Indra Maghavān is his power to induce rains at the right time by reducing heat, near about the summer solstice day. In RV extolling the extreme northern position of sun as Indra's highest station and Indra said to be causing sun to climb up the peak for longer visibility indicate events connected with the summer solstice.[8], [9] Even though the appellation 'Maghavān' for Indra appearing in more than two hundred places in RV need not mean *maghā* to be an asterism in every context, there is clear reference in the tenth *maṇḍala* about Maghavān hitting Vṛtra by the *maghā*s.[10] This can be interpreted as an indicator of the onset of rains when sun was in the *maghā* asterism. Sengupta (1947) pointed this out correctly but argued that this must be taken as the heliacal rise of α-Leonis in Kurukṣetra (30°N) around 4000 BCE. This does not stand to reason, since α-Leonis (Regulus) the brightest among the six stars of this asterism, was conjunct with sun as the summer solstice star around 2350 BCE. Without going into the intricacies of Vedic chronology, it is still reasonable to note that the broad picture of stationary sun rise at the summer solstice; the diffuse felt-weather border between the *grīṣma* and *varṣa* seasons with links to the *maghā* asterism has existed from the period of the *Ṛgveda*. This tradition of cultural astronomy may be inferred to have provided inspiration for the theoreticians among the star gazers (*nakṣatradarśa)* around 1800 BCE, to formalize a scheme for sun's yearly transit among the visible *nakṣatra* sectors. Further delineating the evolution of this through the *gavāmayana,* and different *atirātra*- and *ahargaṇa-yāga* rites as preserved in the voluminous *Brāhmaṇa* and *Śrauta* texts is beyond the scope of the present work. For our purpose it is sufficient to note that the *Nidānasūtra*, an ancillary *Brāhmaṇa* text (*anubrāhmaṇaṁ*) of the *Sāmaveda*, explains an already existing definition of a year of 366 days as sun dwelling for 13(5/9) days in each of the *nakṣatra*s.[11]

Asterism *maghā* is well described and remembered by the Vedic, Jaina and other traditions as a group of six or seven stars anchored to the bright ecliptic star α-Leo (Regulus); the remaining five or six being above this star, together looking like the sketch of an enclosure (*koṣṭhāgāra*).[12] Visible

[5] पुनर्वसू सूनृता चारुपुष्यो भानुराश्लेषा अयनं मघा मे॥ (*Atharva Veda Saṁhitā*; 19.7.2b).

[6] मघाभ्यः पुरोडाशं षट्कपालम् || Tai. Br. (3.1.4).

[7] नैरुक्तप्रसिद्ध्या तु कालाभिमानी इन्द्रः ||(*Sāyaṇa Bhāṣya* RV 8.77.4).

[8] इन्द्रो दीर्घाय चक्षस आ सूर्यं रोहयद्दिवि | वि गोभिः अद्रिमैरयत् || (RV 1.7.3).

[9] The chanters hymn thee, they who say the word of praise magnify thee. The priests have raised thee up on high, O Satakratu, like a pole. As up he climbed from ridge to ridge and looked upon the toilsome task, Indra observes this wish of his, and the Rain hastens with his troop. (RV 1. 10. 1–2. Translation by R.V. Griffith).

[10] इन्द्रो मघैः मघवान् वृत्रहा अभुवत् || (RV 10.23.2).

[11] स एष आदित्यसंवत्सरो नाक्षत्रः। आदित्यः खलु शश्वदेतावद्भिरहोभिर्नक्षत्राणि समवैति। त्रयोदशाहं त्रयोदशाहमेकैकं नक्षत्रमुपतिष्ठति। अहस्तृतीयं च नवधा कृतयोरहोरात्रयोर्द्वे द्वे कले चेति संवत्सराः। ताश्चत्वारिंशच्चतुःपञ्चाशतं कलाः। ते षण्णववर्गाःसषड्विष्टित्रिशतः।। (*Nidānasūtra* 5.12).

[12] The *Sūrya-candraprajñapti* of the Jaina tradition counts seven stars in *maghā* asterism looking like *prākāra.*

nakṣatra maghā made up of six stars can be identified as the group (α, ε, ζ, η, γ, μ Leo).

6 *Maghādi* epoch

The *Vṛddhagārgīya Jyotiṣa* (VGJ) includes a section called *Mahāsalilaṁ*, in archaic prose, in the form of a set of questions followed by answers. One of the questions is about which star, day, month, season should be considered as the first one for counting. This must have been an important doubt, as it is even now, since any point can be considered as the origin on a circle and hence for practical purposes a convention has to be agreed upon. This is answered in a string of statements covering both the short and the long cyclic measures. For our limited purpose here, it is noted that *kṛttikā* is said to be the first one for work (rites and rituals); *śraviṣṭhā* (is the first) for keeping count of the eastern rise point (*lagna*); and *maghā* (is the first) among solar asterisms.[13]

Apart from the previous analysis of the *Purāṇa* and Vedic texts, the statement *maghā sauryāṇāṁ*, in VGJ is evidence for the formal *maghādi* system of solar *nakṣatra* zodiac to have been in vogue around 1800 BCE with the four cardinal sectors having visible stars of the same name. The remaining sectors might have contained known stars or they might have remained namesake *nakṣatra* with corresponding stars rising/setting in the adjacent sectors. For purposes of illustration, year − 1700 is chosen to show the visibility of a few asterisms, identified in terms of their modern names. In Fig. 2a the earliest visibility of the selected stars in the morning or evening twilight, keeping sun 8º or 6º below the horizon, is marked using the stellarium software. The results shown are in terms of approximate number of days from the first point of the *maghā* sector. The well recognized stars α1-Lib and η-Tau (Pleiades) are seen to be confined to their eponymous sectors for the corresponding equinoctial FM to be known after these visible stars as *vaiśākhī* and *kārtikī.*

In Fig. 2b the year − 1700 is divided into twenty-seven parts in terms of longitudes but marked with the same *nakṣatra* names. This is shown to bring out the differences in characterizing solar *nakṣatras* in terms of their sector visibility days as against their longitudes. The longitudes of the six stars (α, ε, ζ, η, γ, μ Leo) stay in the interval (90º–103º20') not only in the above year but till about 1400 BCE. The specific star reckoned as *maghādi,* the visibility of which seems to have indicated the first day is estimated to be ε-Leo. The stellarium software, for the year − 1700 (1701 BCE) shows this star to be visible early in the morning at Kurukshetra, a few days after the actual summer solstice on 9th July. All the six stars of *maghā*, the last one being Regulus, would have been progressively visible by 27th July early in the morning, near about the same azimuth as the point of sun rise. During this period of nearly twenty days, the azimuth of the point of sun rise is almost stationary at 62º ± 0.5º. However, a few days before 9th July the bright stars γ, α and even ε-Leo would have been visible in the west, just after sun set, giving an opportunity for the *nakṣatradarśa* astronomers to bracket the onset of sun's southern sojourn (*dakṣiṇāyana*) and the start of the rainy season (*maghādi varṣa ṛtu)* with an error of about three days. It may be noted here that if year − 1800 were to be selected as an example the fit in the cardinal sectors for the named stars would be better.

That the rainy season should have been taken as the start of the civil calendar year in the remote past when sun was in *maghā nakṣatra* need not be surprising. The subcontinent has remained always heavily dependent on seasonal rainfall. Two of the Sanskrit words *varṣaḥ* (rainfall) and *abdaḥ* (water giver) used popularly to mean *Year* in Indian languages even now, primarily referred to the start of the rainy season in ancient times.

7 *Śraviṣṭhā Nakṣatra*

It has been pointed out that the *maghā* asterism with its connection to summer solstice has had a long memory before the formulation of the *maghādi* scheme. On similar lines, the ancients would have recognized the cold weather and the short days nearly six months later, when sun rise happened at nearly the same point towards the south eastern corner of the horizon. The statement about sun being in a particular *nakṣatra* sector at the solstices is due to the observation of sun rise at the same azimuth but with new stars appearing close to the point of sun rise. Thus, it is reasonable to expect *śraviṣṭhā* to be configured with several stars, visible sequentially over a period of ten days or more, in the proximity of sun. stars of the Aquarius constellation answer to this picture. In Fig. 2a the *śraviṣṭhā* sector in the year − 1700 starts on the 176th day, when star ε-Aqr would have risen clearly. Four stars of the Aquarius constellation get assigned to this sector, the bright star β-Aqr being visible in the evening nearer the 183rd day. Yajurveda texts refer to this asterism in plural as *śraviṣṭhāḥ*. The Atharvaveda in the famous *rātrisūkta* (Night hymn) poetically describes the rising of *śraviṣṭhāḥ* in the night[14] which seems to be an observation in the evenings around the summer solstice when the stars

[13] तेषां च सर्वेषां नक्षत्राणां कर्मसु कृत्तिकाः प्रथमम् आचक्षते। श्रविष्ठा तु संख्यया पूर्वलग्नानाम्। अनुराधं पश्चिमनिघ्नानां। रोहिणी सर्वनक्षत्राणां। **मघा सौर्याणां।** भोग्यानां चार्यमा सर्वासां च षड्राशीतानाम् आदिः श्रविष्ठा ॥ (*Mahāsalilādhyāya*, VGJ).

[14] अतिविश्वान्यरुहत् गंभीरो वर्षिष्ठमरुहन्त श्रविष्ठाः ॥ (AV 19.49.2a).

of the *maghā nakṣatra* were setting. *Śraviṣṭhā* asterism is invoked in TB as composed of four goddesses belonging to the *Year* and arriving from south.[15] This can be taken as an indication of *śraviṣṭhā nakṣatra* being linked with the winter solstice.

In the *maghādi* epoch the well attested asterisms, *kṛttikā, maghā* and *viśākhā* identifiable with their modern nomenclatures get placed in their respective cardinal sectors both in terms of visibility days and longitudes. The stars of the Aquarius constellation fit in with the *śraviṣṭhā* sector for visibility, but in longitudes they start spilling over to the next sector. The stars of constellation Delphinius, that were visible already by the 164th day in the *śravaṇa* sector (Fig. 2 a) fall into the *śraviṣṭhā* sector (Fig. 2 b) in terms of longitudes.

8 Discussion

The year − 1700 chosen here is only an example to show primarily the positions of the visible cardinal stars vis-à-vis their sectors. It is obvious that these positions would have changed slowly due to precession. If we go forward towards the year − 1300, proximate visibility of *maghā* early in the morning, near the farthest northern point of sun rise on the horizon becomes vague if not totally lost. Perhaps due to this and other cultural reasons, the *Parāśara Tantra* (PT), the *Vṛddhagārgīya Jyotiṣa* (VGJ) and Lagadha's *Ārca-Yājuṣa Jyotiṣa* have taken the stationary sunrise at the extreme southern azimuth as the year marker. These texts use the equal *nakṣatra* scheme when the first point of the *śraviṣṭhā* sector coincided with the winter solstice day, same as the beginning of *śiśira ṛtu.* The relation of this *śraviṣṭhādi* scheme with its predecessor can be understood in Fig. 2, by keeping the cardinal points and season boundaries invariant but rotating the outer dial of sector names clockwise such that the start of *śraviṣṭhā* sector coincides with the *hemanta-śiśira* vertex. This makes, the spring and the autumn equinoxes to correspond with ¾-*bharaṇi* and ¼-*viśākha* respectively. In this system summer solstice will correspond to ½-*āśleṣā*, whether or not the named star rises near the sunrise point around the summer solstice day. The precession of the equinoxes by 6º40′ indicates passage of 480 years between the *maghādi* and the *śraviṣṭhādi* zodiac schemes. This will alter the visibility conditions and the longitudes of the concerned stars supposed to be related to the corresponding older sectors.

Both PT (Iyengar 2013) and VGJ state the six seasons of a year in terms of the transit of sun through specified 4½ *nakṣatra* sectors, each of 61 days, starting from *śraviṣṭhādi* or the first point of *śraviṣṭhā* sector. In the above texts visible *nakṣatras* are assembled with multiple stars such that eighty-three or eighty-four visible stars make up the 27 asterisms. PT and VGJ are more matter of fact and have modified past methods to match with their observations of the seasons. It is likely, star ε-Aqr would have served as the fiducial star of the *śraviṣṭhā* sector for some years even after the starting point of the solar year was shifted from the northern standstill sunrise to the southern standstill of sun; same as the winter solstice or the start of the northern travel of sun (*udagayanaṁ/uttarāyaṇaṁ*).

However, there are some issues with the identification of the first (*ādi*) star of the *śraviṣṭhā* sector that is important mainly for the calendar text of Lagadha. These have been discussed with alternate possibilities of taking β-Aqr or β-Del as the first star while analysing the *ādityacāra* chapter on sun's transit in VGJ to demonstrate that the stated observations of the seasonal stars, assigned to their respective sectors, would be valid with minimum error for the epoch of 1300 BCE (Iyengar & Chakravarty, 2021). This is in harmony with the *maghādi* solar *nakṣatra* scheme demonstrated to have been prevalent in India around 1800–1600 BCE. This result is of historical importance as this system predates by four to five centuries the much discussed *śraviṣṭhādi* later known as *dhaniṣṭhādi* scheme of Lagadha (Abhyankar, 1991; Gondhalekar, 2013; Sastry, 1984) usually propagated as the original Vedic calendar.

9 Conclusion

A tendency to describe sky observations allegorically along with a predisposition to associate numbers with visible objects and to count words and syllables is widely recognizable in Vedic texts. The solar standstills and seasons are characterised in poetical language in the *Ṛgveda* and contextually ritualised with the number twenty-one in the ancillary texts. Efforts at making the annual passage of sun, between the two extreme points on the eastern horizon, more structured using the visible stellar background takes one to the very genesis of matter-of-fact Indian astral sciences. The two asterisms *maghā* and *śraviṣṭhā* are addressed in plural, indicating a sequence of stars to be associated with sun at the northern standstill and the southern standstill point for about 15–20 days. It is probably the perceived slowness of sun that has lead later astronomers to the concept of sun dwelling in the above two asterisms made up of multiple stars. This is clearly reflected in the MAU where the solstices are linked to the *maghā* and the *śraviṣṭhā* group of stars, with a further measure assigned to them in terms of four quarters. Start of the *ayana* of sun from the first point of *maghā* to ½-*śraviṣṭhā* and back, implies a year of twenty-seven equal *nakṣatra*

[15] चतस्रो देवीरजराः श्रविष्ठाः[...] संवत्सरीणममृतं स्वस्ति [...] दक्षिणतो अभियन्तु श्रविष्ठाः || (TB III.1.2.6–7).

sectors of 13 (5/9) days each. Each *nakṣatra* is considered to have four parts such that the complete stellar circle is made of 108 parts, foreshadowing the modern ecliptic longitude measure.

Since sun rise is nearly stationary at the solstices naked eye observation of the associated *nakṣatra* is possible early in the morning with a level of confidence, but such will not be the case at the equinoxes where sun moves fast. In this regard, considerable development is seen in chapter twenty-one of the *Brahmāṇḍa Purāṇa*, where equinoxes are defined in terms of day and night being equal to fifteen *muhūrta*s. Some type of instrument like an outflow water clock (*nāḍikā*) might have existed to measure time within a day. The statement about the equinoctial day as ¼-*kṛttikā* and the FM on that day to be exactly opposite at ¾-*viśākha*, shows considerable sophistication in combining observation and theory. Detailed computer simulation of past equinoctial FM (2400–800 BCE) as per modern astronomical theories shows that the period of the *Brahmāṇḍa Purāṇa* statements match with 1980–1610 BCE. That the *Purāṇa* follows the Vedic *maghādi* scheme is a sign of progress in astronomy centuries before the calendar text of Lagadha. Synchronization of the four important solar events in terms of *nakṣatra* and correct alignment of the equinoctial full moon represents a science cultivated in terms of both observation and theory. It may be mentioned in passing that Koch (2014) has analyzed the BP statements by a different method using the precession value known as *Lahiri-ayanāṁśa* in present day Hindu calendar astronomy. As per this method it is found that the equinoctial FM of BP is dateable to 1885–1645 BCE. This result satisfactorily matches with the more detailed simulation undertaken in the present paper. The results presented in Figs. 1 and 2 demonstrate that the late Vedic text MAU and the *Brahmāṇḍa Purāṇa* taken together represent an important central period of Indian astronomy *circa* 1800 ± 100 BCE. The two texts match perfectly in their cardinal sectors pointing towards the origin of their science to the same source, which can be inferred to be the early Vedic astronomical tradition.

The investigation undertaken in this paper broadly shows that, in addition to the untapped wealth of manuscripts (Srinivas, 2019), Vedic texts and some of the *Purāṇas* more ancient than the *Viṣṇudharmottara* should be seriously treated as containing hidden source material for mapping the history of Indian astronomy and mathematics before the advent of *siddhānta* astronomy in the early centuries of the Common Era.

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