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THE VEDIC *NAKṢATRAS* – A REAPPRAISAL

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In the calendar of *Vedāṅga Jyotiṣa* the position of the sun and the moon is identified by a lunar mansion (or a sector of the ecliptic) and the distance from the leading edge of this sector (*bhāṃśa*). It has been generally accepted that the position and the extent of these lunar mansions are defined by the *nakṣatras* (background stars and asterisms). In this paper it is shown that the *jāvādi* arrangement of *nakṣatras*, given in *Vedāṅga Jyotiṣa*, defines an invariant frame of reference that is anchored to the ecliptic and not to the background stars. Fixed and absolute coordinates of the lunar mansions or *nakṣatra*-sectors can be determined within this frame of reference. Unlike all previous determinations of coordinates of *nakṣatra*-sectors, these coordinates are independent of the stellar coordinates found in the post-Vedic texts like *Paitāmahasiddhānta*. In the coordinate system defined by the *jāvādi* arrangement of *nakṣatras*, the position of the sun and the moon is also independent of the coordinates of the background stars. This analysis suggest that between 2000 BC and 1500 BC the Vedic New Year started in spring.

Key words: *Jāvādi* arrangement, *Nakṣatras*, *Vedāṅga Jyotiṣa*, Vedic New Year.

1. INTRODUCTION

In the Vedic texts the word *nakṣatra* indicates both a star (and an asterism) and a lunar mansion. The moon is supposed to conjoin each night with the twenty-seven (sometimes twenty-eight) *nakṣatras* (stars or asterisms) or reside in the twenty-seven lunar mansions. It is very likely that the mansions were identified by nearby stars. It is impossible to identify the origins of *nakṣatras* or their identification by stars but some names, which appear in the lists of *nakṣatras* given in the later

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Saṃhitās and the *Brāhmaṇas*, can be traced back to the earliest Vedic text – *Ṛgveda Saṃhitā* (*RV*). In addition, statements like "*soma* is stationed in the vicinity of *nakṣatra*" (*RV*.X.85.2) suggests that even in this early text the position of the moon in the sky may have been defined by reference to the stars. Pioneering work on Vedic *nakṣatras* was done in the nineteenth century [1,2,3,4] but most of this work is based on interpretation of *nakṣatras* as stars or asterism. This discussion has been one-sided possibly because the stars were seen to provide the only possible fixed (and absolute) frame of reference against which the motion of the moon could be observed and calibrated. The Vedic texts have aided and abetted this one-sided discussion by not distinguishing between the lunar mansions and their stellar markers. To avoid the confusion caused by the dual use of the word *nakṣatra*, in this paper, the stars and asterisms are referred to as '*nakṣatras*' and the lunar mansions are referred to as '*nakṣatra*-sectors'.

The identification of stars and asterisms of the *nakṣatras* 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 the *nakṣatra*, is given in the *Paitāmaha-siddhānta* of the *Viṣṇudharmottarapurāṇa*. The provenance of this text is disputed[5,6] 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 borne 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 the *Paitāmahasiddhānta* and the *siddhānta* 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.

The lists of *nakṣatras* given in one of the earliest *Saṃhitā* and *Vedāṅga Jyotiṣa* (a text of the late Vedic period) are given in Table 1. These lists are broadly similar but differ in detail; the names and the number of *nakṣatras* differ from list to list but every list in the Vedic texts starts with *kṛttikās*. Twenty-seven *nakṣatras* are common to all lists; the *nakṣatra* left out is *Abhijit*. The stellar counterparts, in modern astronomical catalogues, of *yogatārās* were

Table 1. List of *nakṣatras* in one of the earliest *Saṃhitâs* and a late Vedic text

	MS II.13.20	*VJ RJ*.25-28		*MS* II.13.20	*VJ RJ*.25-28
1	Kṛttikâs	Kṛttikâs	15	Anūrâdhâ	Anurâdhâs
2	Rohiṇī	Rohiṇī	16	Jyeṣṭhâ	Jyeṣṭhâ
3	Invaka	Mṛgaśirṣa	17	Mūla	Mūla
4	Bâhu	Ârdrâ	18	Âṣâdhâs	Pūrvâ Âṣâdhâs
5	Punarvasus	Punarvasus	19	Âṣâdhâs	Uttrâ Âṣâdhâs
6	Tiṣya	Puṣya		Abhijit	
7	Âśreṣâs	Âśreṣâs	20	Śroṇâ	Śroṇâ
8	Maghâs	Maghâs	21	Śraviṣṭhâs	Śraviṣṭhâs
9	Phalgunīs	Phalgunīs	22	Śatabhiṣaj	Śatabhiṣaj
10	Phalgunīs	Phalgunīs	23	Proṣṭhapadas	Pūrva-Proṣṭhapadas
11	Hasta	Hasta	24	Proṣṭhapadas	Uttara-Proṣṭhapadas
12	Citrâ	Citrâ	25	Revatī	Revatī
13	Niṣṭyâ	Svâti	26	Aśvayuj	Aśvayujau
14	Viśâkhâs	Viśâkhâs	27	Bharaṇīs	Bharaṇīs

MS - *Maitrâyaṇīya Saṃhitâ* *VJ* - *Vedâṅga Jyotiṣa* *RJ* - *Ṛgveda* recension

identified in the late nineteenth century and recently these attempts have been reassessed and refined[5,7]. In this paper, an attempt is made to determine the absolute coordinates of the *nakṣatra*-sectors without an appeal to *Paitāmahasiddhānta*. This procedure has the advantage that the conclusions are based only on the Vedic texts and are not affected by the corrupt and inaccurate intrusions in the South Asian astronomy and calendric system from times far removed from the Vedic period. In Section 2 the *jāvādi* arrangement of *nakṣatras* in *Vedāṅga Jyotiṣa* is discussed and derived. In Section 3 the equatorial and ecliptic coordinates of the *nakṣatra*-sectors are derived and the discussion of the results and conclusions are given in Section 4.

2. The *Jāvādi* arrangement of *nakṣatras*

The *Vedāṅga* (arm or limb of the Veda) *Jyotiṣa* (*VJ*) is the earliest South Asian text devoted exclusively to the calendar. The text is a manual for determining the proper times for Vedic ceremonies. This text has survived in two recensions – a *Ṛgveda* recension (*RJ*) called *Ārca- Jyotiṣa* and a *Yajurveda* recension (*YJ*) called *Yājuṣa-Jyotiṣa*. The *Ṛgveda* recension is considered to be the older of the two recensions. The differences between the two recensions are small and of no relevance to this paper. The verses in the text do not follow a thematic or logical order and verses on similar topics are scattered in different parts of the text. This

Table 2. The *jâvâdi* arrangement of *nakṣatra*

	Abbreviations	*nakṣatra*		Abbreviations	*nakṣatra*
1	*jau*	aśvayu**jau**(aśvinī)	14	*mâ*	Arya**mâ** uttraphâlguṇīs
2	*drâ*	âr**drâ**	15	*dhâḥ*	anurâ**dhâḥ**
3	*gaḥ*	bha**gaḥ**(pūrvaphâlgunīs)	16	*ṇaḥ*	śrava**ṇaḥ**
4	*khe*	viśâ**khe**	17	*re*	**re**vatī
5	*śve*	viś**ve**devâḥ uttarâṣâḍhâs	18	*mṛ*	**mṛ**gasirsa
6	*hiḥ*	a**hir**budhnyaḥ (uttra proṣṭapadâs)	19	*ghâḥ*	ma**ghâḥ**
7	*ro*	**ro**hinī	20	*svâ*	**svâ**tī
8	*ṣâ*	âśre**ṣâ**	21	*paḥ*	â**paḥ**(puvâṣâḍhâs)
9	*cit*	**cit**râ	22	*jaḥ*	a**ja**ejapât (pūrva proṣṭapadâs)
10	*mū*	**mū**la	23	*kṛ*	**kṛ**ttikâs
11	*ṣa*	śatabhi**ṣa**j	24	*ṣyaḥ*	pu**ṣyaḥ**
12	*ṇyaḥ*	bhara**ṇyaḥ**	25	*ha*	**ha**sta
13	*sū*	punarva**sū**	26	*jye*	**jye**ṣṭhâ
			27	*ṣṭhâḥ*	śravi**ṣṭhâḥ**

suggests that the present versions of *VJ* are not the original versions. *VJ* came to the attention of early Indologists like Sir William Jones and in the nineteenth and twentieth century various attempts, of varying degree of success, were made to interpret it [8,9,10,11,12]. In 1979 a complete interpretation and translation of *VJ* was produced and this, along with the critical editions of both the *Ṛgvedic* and *Yajurvedic* recensions (from twenty manuscripts) was published in 1984 by the Indian National Science Academy[13]. The discussion in this paper is based on this edition and translation of *VJ*.

The calendar of *VJ* is based on an 'intercalation period' of 1830 days or five tropical years of 366 days each. This intercalation period is called a *yuga*. This period is synchronized with five synodic years by intercalating two synodic months, that is, the intercalated 'synodic *yuga*' is composed of sixty-two synodic months (i.e. 1830.86 days). This intercalation period starts every five years around winter solstice "when the sun and the moon are in the *nakṣatra* Śraviṣṭhās" (*RJ*.5-6 – verses #5-6 in the *Ṛgveda* recension, *YJ*.6-7 – verses #6-7 in the *Yājuṣa* recension) i.e. when the new moon is in *nakṣatra* Śraviṣṭhās around winter solstice. Two lists of *nakṣatras* are given in *VJ*; in *RJ*.25-28 and *YJ*.32-35 a list of *nakṣatras* is identified by their presiding deity. This list is very similar to the lists of *nakṣatras* given in the earlier *Saṃhitās* and the *Brāhmaṇas* and is reproduced in Table 1. In *RJ*.14 and *YJ*.18, *VJ* introduces a different list of *nakṣatras* identified by either an abbreviation of the name of the *nakṣatra* or an abbreviation of the name of the presiding deity of the *nakṣatra*. This arrangement of the *nakṣatras* is called the " *jāvādi* (*jau ādi* beginning with *jau*) arrangement". In *RJ*.18, *YJ*.39, *VJ* states that the sun stays in each *nakṣatra* 13 and $^5/_9$ days. These verses unambiguously state that in *VJ* a *nakṣatra* is not considered to be a star or an asterism but a sector of the ecliptic and this sector is 13.33° wide. There is also an implicit assumption here that all sectors are of equal width.

The *jāvādi* arrangement of *nakṣatras* is given in Table 2; the abbreviation, as given in *VJ*, are given in columns #2 and #5 and the *nakṣatra* or the deity and the *nakṣatra* are given in columns #3 and #6 and the *VJ* abbreviations are highlighted in these names. *VJ* does not give the scheme or the algorithm used to obtain this arrangement. An inspection of the list of *nakṣatras* in Table1 and the list in the *jāvādi* arrangement (Table 2.) suggests that the *nakṣatras* in the arrangement are every fifth *nakṣatra* from Table 1 starting from Śraviṣṭhās (*nakṣatra* number #21). That is, Śraviṣṭhās is assumed to be *nakṣatra* number #0 and the fifth *nakṣatra* is *Aśvayujau* and the fifth after that is *Ārdrā* and so on to choose twenty-seven *nakṣatras*. This of course prompts the question, why choose every fifth *nakṣatra.* A pedestrian answer could be "the Āryan predilection for numbers five"! A rational explanation for the choice of *nakṣatras* of the *jāvādi* arrangement is likely to be as follows. This derivation was presented and discussed by Thibaut[14], it is reproduced here to make more comprehensible the derivation of the absolute coordinates of *nakṣatra*(-sectors) that follows.

In a *yuga* (the five year Vedic intercalation period) there are

62 lunations/lunar months

67 sidereal months (both these numbers are given in the *VJ*)

Therefore, in 1 lunation there are 67÷62 sidereal months

Or 1 lunation = $1^5/_{62}$ sidereal months

In a sidereal month the moon passes by 27 *nakṣatras*

Therefore in 1 lunation the moon passes by $27 \times 1^5/_{62}$ *nakṣatras*

= $29^{22}/_{124}$ *nakṣatras*

Thus the separation of successive new (or full) moons is $29\,^{22}/_{124}$ *nakṣatras.*

And the separation between a new and full (or full and new) moon (or

a *pakṣa*) is $14\,^{73}/_{124}$ *nakṣatras.*

To obtain the *jāvādi* arrangement of *nakṣatra*-sectors an 'origin' from which the *nakṣatra* of a full or a new moon is counted is required. As discussed above, the *VJ yuga* commences with new moon in Śraviṣṭhās (around winter solstice) and this is the origin for *jāvādi* arrangement. Thus starting from new moon in Śraviṣṭhās, it is possible to obtain the *nakṣatra*-sectors at successive full moons and new moons in a *yuga* by the scheme given above; the *nakṣatras* are from the list of *nakṣatras* in Table 1. For example, the *nakṣatra*-sector of the first full moon after the start of a *yuga* will be the fourteenth *nakṣatra* counted from Śraviṣṭhās. If the *nakṣatra*-sector is divided into 124 parts then the first full moon will be in the 73rd part of the fourteenth *nakṣatra*-sector. Similarly, the first new moon after the start of a *yuga* will be in the 22nd part of the twenty-ninth *nakṣatra*-sector. However, there are only twenty-seven *nakṣatras*-sector therefore this new moon will be in the (29 – 27) or the second *nakṣatra*-sector. The division of the *nakṣatra*-sector into 124 parts is implicit in *VJ* and each part is called a *bhāṃśa*, but an explicit definition of a *bhāṃśa* is not given in *VJ*. The *nakṣatras*-sector of the new moon and full moon (and the location of the moon within a *nakṣatras*-sector in terms of the number of *bhāṃśas*) of the sixty-two lunations of a *yuga* are given in Table 3. These *nakṣatra*-sectors and *bhāṃśas* are obtained by assuming that the 'length' of a synodic month is $29\,^{22}/_{124}$ *nakṣatras* i.e. 29.52502 days (the modern value for the mean length of the synodic month is 29.53059 days). The *nakṣatras*-sectors of the *jāvādi* arrangement are selected from this list of new-moon and full-moon *nakṣatras*-sectors. The *nakṣatras*-sector when the moon is in the first twenty-seven *bhāṃśa* are selected (the sequence of *nakṣatra*-sectors repeats after the twenty-seventh *nakṣatra*-sector) for the arrangement, these *nakṣatra*-sectors are highlighted in Table 3. Equivalently the position of a *nakṣatra*-sector in the *jāvādi* arrangement is given by X where

$$B \equiv X \text{ modulo } (27)$$

where B is the *bhāṃśa* given in Table 3. For example, the first full moon of a *yuga* is in the *nakṣatra*-sector Maghā at *bhāṃśa* #73, then the position of *nakṣatra*-sector Maghā in the *jāvādi* arrangement, by the above equation

Table 3. The *bhâṃśa* and the *nakṣatra* at new moon and full moon of sixty-two synodic months of a *yuga*. The *jâvâdi* arrangement of *nakṣatras* is high-lighted

No:	New moon			Full moon			No:	New moon			Full moon		
	#1	#2	#3	#1	#2	#3		#1	#2	#3	#1	#2	#3
1	0	0	śraviṣṭhâ	14	73	maghâ	32	13	62	âśleṣâ	**1**	**11**	**śatabhiṣaj**
2	**2**	**22**	**p. proṣṭapadâ**	16	95	u. phâlguṇī	33	15	84	p. phâlguṇī	3	33	u. proṣṭapadâ
3	4	44	revatī	18	117	citrâ	34	17	106	hasta	5	55	asvayujau
4	6	66	bharaṇī	**21**	**15**	**anurâdhâ**	35	**20**	**4**	**viśâkhe**	7	77	kṛttikâ
5	8	88	rohinī	23	37	mūla	36	**22**	**26**	**jyeṣṭhâ**	9	99	mṛgasirsa
6	10	110	ârdrâ	25	59	u. âṣâḍhâ	37	24	48	p. âṣâḍhâ	11	121	punarvasū
7	**13**	**8**	**âśleṣâ**	0	81	śraviṣṭhâ	38	26	70	śravaṇa	**14**	**19**	**maghâ**
8	15	30	p. phâlgunī	2	103	p. proṣṭapadâ	39	1	92	śatabhiṣaj	16	41	u. phâlgunī
9	17	52	hasta	**5**	**1**	**asvayujau**	40	3	114	u. proṣṭapadâ	18	63	citrâ
10	19	74	svâti	**7**	**23**	**kṛttikâ**	41	**6**	**12**	**bharaṇī**	20	85	viśâkhe
11	21	96	anurâdhâ	9	45	mṛgasirsa	42	8	34	rohinī	22	107	jyeṣṭhâ
12	23	118	mūla	11	67	punarvasū	43	10	56	ârdrâ	**25**	**5**	**u. âṣâḍhâ**
13	**26**	**16**	**śravaṇa**	13	89	âśleṣâ	44	12	78	puṣya	**0**	**27**	**śraviṣṭhâ**
14	1	38	śatabhiṣaj	15	111	p. phâlguṇī	45	14	100	maghâ	2	49	p. proṣṭapadâ
15	3	60	u. proṣṭapadâ	**18**	**9**	**citrâ**	46	16	122	u. phâlguṇī	4	71	revatī
16	5	82	asvayujau	20	31	viśâkhe	47	**19**	**20**	**svâtī**	6	93	bharaṇī
17	7	104	kṛttikâ	22	53	jyeṣṭhâ	48	21	42	anurâdhâ	8	115	rohinī
18	**10**	**2**	**ârdrâ**	24	75	p. âṣâḍhâ	49	23	64	mūla	**11**	**13**	**punarvasu**
19	**12**	**24**	**puṣya**	26	97	śravaṇa	50	25	86	u. âṣâḍhâ	13	35	âśleṣâ
20	14	46	maghâ	1	119	śatabhiṣaj	51	0	108	śraviṣṭhâ	15	57	p. phâlguṇī
21	16	68	u. phâlguṇī	**4**	**17**	**revatī**	52	**3**	**6**	**u. proṣṭapadâ**	17	79	hasta
22	18	90	citrâ	6	39	bharaṇī	53	5	28	asvayujau	19	101	svâtī
23	20	112	viśâkhe	8	61	rohinī	54	7	50	kṛttikâ	21	123	anurâdhâ
24	**23**	**10**	**mūla**	10	83	ârdrâ	55	9	72	mṛgasirsa	**24**	**21**	**p. âṣâḍhâ**
25	25	32	u. âṣâḍhâ	12	105	puṣya	56	11	94	punarvasū	26	43	śravaṇa
26	0	54	śraviṣṭhâ	**15**	**3**	**p. phâlguṇī**	57	13	116	âśleṣâ	1	65	śatabhiṣak
27	2	76	p. proṣṭapadâ	**17**	**25**	**hasta**	58	**16**	**14**	**u. phâlguṇī**	3	87	u. proṣṭapadâ
28	4	98	revatī	19	47	svâtī	59	18	36	citrâ	5	109	asvayujau
29	6	120	bharaṇi	21	69	anurâdhâ	60	20	58	viśâkhe	**8**	**7**	**rohinī**
30	**9**	**18**	**mṛgasirsa**	23	91	mūla	61	22	80	jyeṣṭhâ	10	29	ârdrâ
31	11	40	punarvasū	25	113	u. âṣâḍhâ	62	24	102	p. âṣâḍhâ	12	51	puṣya

#1: *nakṣatra* number as counted from śraviṣṭhâ, see Table 1; #2: *bhâṃśa* of the new and full moon; #3. *nakṣatra*

(73 ÷ 27 remainder 19) is at #19 as given in Table 2. The *bhāṃśas* of the new and full moons in Table 3 can similarly be 'reduced' to obtain the position of the *nakṣatra*-sector of the moon in the *jāvādi* arrangement. The *nakṣatra*-sectors of the *jāvādi* arrangement are rearranged in Table 4 to demonstrate that, as stated above, the selected *nakṣatra*-sectors are the *nakṣatra*-sector of the full moon and the new moon in the first twenty-seven *bhāṃśas* following the new moon in Śraviṣṭhās at the start of a *yuga*. It is not entirely clear why the composer(s) of *VJ* chose to arrange the *nakṣatra*-sectors of the *jāvādi* arrangement in the *bhāṃśa* sequence. The *jāvādi* arrangement or the derivation of the *jāvādi* arrangement emphasises the primary usage of the word *nakṣatra* in the calendric system of *VJ* – the *nakṣatras* are wide sectors of the ecliptic and are evenly distributed along the path of the moon or they are *nakṣatra*-sectors and these are anchored to the ecliptic and are independent of the background stars. Since every *yuga* starts around winter solstice when the new moon is in *nakṣatra* Śraviṣṭhās, the *nakṣatra*-sectors (and the *bhāṃśas*) define the fixed (and absolute) position of the full moon and new moon in every *yuga*. In other words, the *jāvādi* arrangement defines a coordinate system along the ecliptic with the origin around winter solstice when the new moon is in *nakṣatra* Śraviṣṭhās.

Table 4. The *jāvādi* arrangement of *nakṣatra* arranged in the *bhāṃśa* sequence

Full Moon			New Moon		
N	B	*nakṣatra*	N	B	*nakṣatra*
9	1	âsvayujau	18	2	ârdrâ
26	3	p. phâlguṇī	35	4	viśâkhâ
43	5	u. âṣâdhâ	52	6	u. proṣṭapada
60	7	rohini	7	8	âśleṣâs
15	9	citrâ	24	10	mūlâ
32	11	śatabhiṣaj	41	12	bharaṇya
49	13	punarvasu	58	14	u. phâlguṇī
4	15	anurâdhâ	13	16	śravaṇa
21	17	revatī	30	18	mṛgasirsa
38	19	maghâ	47	20	svâtī
55	21	p. âṣâdhâ	2	22	p. proṣṭapada
10	23	kṛttikâ	19	24	puṣya
17	25	hasta	36	26	jyeṣṭhâ
44	27	śraviṣṭhâ			

N – Full moon and new moon number from Table 3; B – *bhāṃśa*

3. *NAKṢATRAS* – ABSOLUTE COORDINATES OF LUNAR MANSIONS

The *jāvādi* arrangement (and the procedure to obtain the arrangement) gives the location of the (new and full) moon in a *nakṣatra*-sector and if the (ecliptic or equatorial) coordinates of the moon are determined then the (ecliptic or equatorial) coordinates of a point in the *nakṣatra*-sector are established. The coordinates of the full moons in a *yuga* are determined as follows;

- Determine the date(s) of the new-moon at or around winter solstice.
- Determine the separation in days between the new moon at winter solstice and the following full moons in a *yuga*.
- Convert the separation to coordinates of the full-moon. The reference frame for this conversion is the standard reference frame with the origin at the first point of Aries.
- The *nakṣatra*-sector of this full-moon is given by the scheme for *jāvādi* arrangement and is given in Table 3.

The currently used zero point (the first point of Aries) is used to obtain the coordinates of the full moon because the origin that may have been used by the Āryas is not known. However, as will be shown below, the Āryas may have (unwittingly) used the vernal equinox as the origin. Two procedures have been followed to determine the coordinates of the full moons in a *yuga*. In the first method, the dates of the new moon at or within one day of the winter solstice between 1900 AD and 2000 AD were obtained from the available calendars. The dates of the sixty-two full moons following each of these new-moons were also obtained from these calendars. In the second method, the dates of the new moon at or within one day of the winter solstice between 1500 BC and 500 BC were obtained by first calculating the dates of the winter solstice, that is, dates of minimum declination of the sun each year. The separation between the sun and the moon was calculated for each date and the dates when the separation was within five degree (i.e. the sun and the moon were in conjunction) were retained. These dates were considered to be the dates of the new moon at winter solstice. For each new moon date the following sixty-two dates when the sun and the moon were in opposition (i.e. about 180° apart or full moon) were determined, these were considered to be the dates of the full moons of a *yuga*. For both methods, the dates determined were in Julian days and for the second method the currently available orbital parameters of the earth and moon were used. The separation between the new moon at winter solstice and the following full moons was converted to equatorial and ecliptic coordinates. For the two periods considered, the coordinates for each full moon in a *yuga* were averaged to obtain the spread (root mean square deviation) in the mean value. The full moon number, the corresponding *nakṣatra*-sector, *bhāṃśa* and the ecliptic and the equatorial coordinates of the moon determined for the 1500 BC to 500 BC period, are given in Table 5. The computed *nakṣatra*-sector and the *bhāṃśa* at each full moon can be compared with the corresponding parameters given in Table 3, the match between the *nakṣatra*-sectors is prefect but the *bhāṃśas* differ. This is because in computing the *nakṣatra*-sectors and the *bhāṃśas* of Table 3 a fixed value (the mean length) of the synodic month was used but in the computations for the period of 1500 BC to 500 BC the length of the synodic month varies (slightly) because of the changes in the speed of the moon in its orbit. The mean ecliptic coordinates of the first twelve full moons in a *yuga* determined for both the 1500 BC to 500 BC period and for the 1900 AD to 2000 AD period are plotted in Fig. 1. It is important to emphasise that the coordinates determined and given in Table 5 are the coordinates of the (full) moon; the *nakṣatra*-sector of the moon is obtained from the procedure followed to obtain the *jāvādi* arrangement

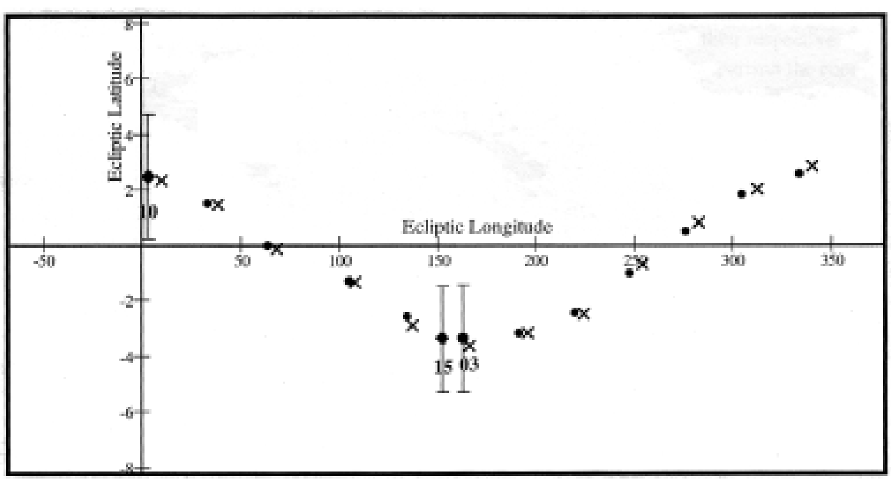

Fig. 1. The ecliptic longitude and latitude of first twelve full-moons of a *yuga*. The 'lay-out' of the positions of all subsequent full moons of the *yuga* will be similar but slightly shifted to the left. The data obtained for the 1500 BC to 500BC period are shown by crosses and the data for 1900 AD to 2000 AD period are shown by dots. To avoid crowding only representative error bars are shown. The *nakṣatra* of full moon #10 is Kṛttikās. The *nakṣatra* of full-moon #3 and #15 is *Citrā*.

Table 5. Ecliptic and equatorial coordinates of the first twenty-seven full moons of a *yuga* and their respective *nakṣatras* or lunar mansions. The equatorial coordinates of the centre of the *nakṣatra*-sectors are given and for comparison the coordinates of the *yogatârâs* determined by Pingree and Morrissey (1989) and Abhyankar (1991) are included

				Full-moon coordinates		C n-s	P & M (1989)		A (1991)	
	nakṣatra	FM	*bhāṃśa*	L B	α δ	α δ	α δ J(2000)	mag	α δ J(2000)	mag
1	Kṛttikâ	10	3	3.22±0.72 2.45±2.24	1.96±1.26 3.54±1.99	00 35 48+ 04 45 04	03 47 29 +24 06 18	2.87	03 47 29 +24 06 18	2.87
2	Rohiṇī	23	55	22.20±0.61 1.21±3.16	20.01±1.53 9.90±2.85	01 28 09+ 07 37 34	04 35 55+ 16 30 33	0.85	04 35 55+ 16 30 33	0.85
3	Mṛgaśirṣa	11	37	33.28±0.87 1.50±3.03	30.44±1.66 14.20±2.71	02 17 16 +12 55 11	05 35 08 +09 56 03	3.66	05 35 08 +09 56 03	3.66
4	Ârdrâ	24	90	52.37±0.61 -0.43±3.41	49.98±1.33 18.23±3.23	03 13 42 +14 56 33	05 55 10 +07 24 25	0.50	06 37 42 +16 23 57	1.93
5	Punarvasu	12	72	63.61±0.70 -0.01±3.40	61.51±1.31 21.19±3.26	04 6 13 +18 14 24	07 45 19 +28 01 34	1.15	07 45 19 +28 01 34	1.15
6	Puṣya	25	1	82.58±0.75 -2.01±2.90	82.02±0.91 21.60±2.89	05 02 58 +19 18 55	08 44 41 +18 09 15	3.94	08 44 41 +18 09 15	3.94
7	Âśleṣâ	13	104	93.65±0.82 -1.67±3.12	93.93±0.82 22.10±3.15	05 59 23 +19 58 45	08 46 47 +06 25 08	3.38	08 55 23 +05 56 44	3.11
8	Mâgha	1	81	104.72±0.75 -1.31±3.26	105.87±0.63 21.69±3.30	06 53 46 +19 33 36	10 08 23 +11 58 02	1.35	10 08 23 +11 58 02	1.35
9	Purva Phâlgunī	14	7	123.42±0.90 -2.93±2.32	125.08±0.82 16.84±2.37	07 50 35 +17 37 18	11 14 06 +20 31 25	2.56	11 14 06 +20 31 25	2.56
10	Uttra Phâlgunī	2	104	134.14±0.82 -2.62±2.57	135.91±0.72 14.33±2.62	08 43 07 +14 36 46	11 49 04 +14 34 19	2.14	11 49 04 +14 34 19	2.14
11	Hasta	27	55	141.92±0.97 -3.45±1.96	143.22±1.23 11.16±1.82	09 35 31 +10 41 36	12 29 52 -16 30 56	2.95	12 15 48 -17 32 31	2.59
12	Citrâ	3	1	163.16±0.93 -3.38±1.91	163.22±1.09 3.59±1.83	10 27 55 +07 00 40	13 25 12 -11 10 57	0.98	13 25 12 -11 10 57	0.98
13	Svâti	28	73	170.71±1.05 -2.90±2.62	170.34±1.74 1.07±2.22	11 16 57 +01 28 40	14 15 40 +19 12 37	-0.04	14 15 40 +19 12 37	-0.04
14	Viśâkhe	16	45	181.30±0.94 -3.15±2.44	179.92±1.53 -3.41±2.12	12 09 09 - 01 58 19	15 12 13 -19 47 30	4.54	14 50 41 -15 59 50	5.15
15	Anūrâdhâ	4	12	191.56±1.02 -3.20±2.24	189.32±1.45 -7.58±1.99	12 57 14 - 08 00 46	16 00 20 -22 37 17	2.32	16 00 20 -22 37 17	2.32

16	Jyeṣṭhâ	17	55	209.38±0.95	206.49±1.86	13 50 21	16 29 24	0.96	16 29 24	0.96
				-2.05±3.14	-13.34±2.73	-10 40 44	-26 25 53		-26 25 53	
17	Mūla	5	27	219.75±0.96	216.44±1.62	14 41 41	17 27 21	4.29	17 33 36	1.63
				-2.44±2.91	-17.27±2.66	-15 28 51	-29 52 01		-37 06 14	
18	Pūrvâṣâdhâ	18	66	237.36±0.95	234.83±1.64	15 37 55	18 20 59	2.70	18 20 59	2.70
				-0.64±3.37	-20.50±3.16	-20 05 40	-29 49 40		-29 49 40	
19	Uttrâṣâdhâ	6	41	247.88±0.74	245.85±1.17	16 33 10	18 55 16	2.02	18 55 16	2.02
				-1.03±3.37	-22.98±3.29	-20 16 54	-26 17 46		-26 17 46	
20	Śravaṇâ	19	81	265.52±0.68	265.13±0.80	17 29 34	19 50 47	0.77	20 37 33	3.63
				0.92±3.07	-22.81±3.07	-20 38 29	+08 52 06		+14 35 43	
21	Śraviṣṭhâ	7	53	276.00±0.78	276.53±0.76	18 28 00	20 39 38	3.77	19 55 18	3.71
				0.48±3.23	-23.19±3.26	-20 49 49	+15 54 43		+06 24 24	
22	Śatabhiṣaj	20	96	293.96±0.72	295.52±0.71	19 24 10	22 52 37	3.74	22 57 39	1.16
				2.09±2.31	-19.59±2.33	-19 32 05	-07 34 47		-29 37 20	
23	Purva	8	74	304.52±0.57	306.49±0.78	20 19 52	23 04 45	2.49	23 04 45	2.49
	Proṣṭhapada			1.81±2.55	-17.67±2.52	-16 52 09	+15 12 19		+15 12 19	
24	Uttra	33	16	312.05±0.82	313.84±1.01	21 13 33	00 08 23	2.06	00 13 14	2.83
	Proṣṭhapada			2.60±1.97	-14.94±1.89	-14 21 16	+29 05 26		+15 11 01	
25	Revatī	21	117	322.73±0.74	324.28±0.97	22 6 54	01 13 44	5.24	00 08 23	2.06
				2.61±1.90	-11.68±1.81	- 09 39 08	+07 34 31		+29 05 26	
26	Asvayujau	9	97	333.61±0.72	334.65±0.84	22 58 45	01 53 32	4.75	01 53 32	4.75
				2.55±1.93	-7.96±1.89	- 06 27 21	+19 17 37		+19 17 37	
27	Bharaṇī	22	21	352.26±0.61	352.00±1.21	23 44 07	02 43 27	4.66	02 49 59	3.63
				2.30±2.44	-1.01±2.20	+ 00 47 09	+27 42 26		+27 15 38	

P & M (1989) : Pingree and Morrissey (1989) A (1991) : Abhyankar (1991) C n-s: Centre of the *nakṣatra*-sectors
α, δ : right ascension and declination L, B : ecliptic longitude and latitude
J(2000) : reference epoch and equinox FM: The full-moon number

Table 6. The width of the *nakṣatra*-sectors (in degrees)

nakṣatra	FM	*bhāṃśa*	L	FM	*bhāṃśa*	L	WNS
Kṛttikâ	10	23	10.17	35	77	15.98	13.34
Rohiṇī	23	61	27.49	48	115	33.45	13.69
Rohiṇī	48	115	33.45	60	7	21.23	14.03
Mṛgaśirṣa	11	45	38.32	36	99	44.53	14.26
Ârdrâ	24	83	55.91	61	29	50.48	12.47
Punarvasū	12	67	67.90	37	121	73.74	13.41
Punarvasū	37	121	73.74	49	13	61.69	13.84
Puṣya	25	105	85.34	62	51	79.22	14.05
Âśleså	13	89	96.13	50	35	91.45	10.75
Mâgha	1	73	107.91	38	19	102.49	12.45
Purva Phâlguṇī	14	111	125.68	26	3	113.58	13.89
Purva Phâlguṇī	26	3	113.58	51	57	119.71	14.08
Uttra Phâlguṇī	2	95	137.33	39	41	131.45	13.50
Hasta	27	25	143.26	52	79	149.37	14.03
Citrâ	3	117	166.12	15	9	154.32	13.55
Citrâ	15	9	154.32	40	63	160.53	14.26
Svâti	28	47	171.62	53	101	177.76	14.10
Viśâkhe	16	31	183.87	41	85	189.36	12.61
Anurâdhâ	4	15	195.82	29	69	201.47	12.97
Anurâdhâ	29	69	201.47	54	123	207.27	13.32
Jyeṣṭhâ	17	53	212.80	42	107	218.70	13.55
Mūla	5	37	224.49	30	91	229.90	12.42
Purvâṣâḍhâ	18	75	242.20	55	21	235.78	14.74
Uttrâṣâḍhâ	6	59	254.28	31	113	259.81	12.70
Uttrâṣâḍhâ	31	113	259.81	43	5	247.40	14.25
Śravaṇâ	19	97	271.29	56	43	265.19	14.01
Śraviṣṭhâ	7	81	282.63	44	27	277.04	12.84
Śraviṣṭhâj	20	119	300.29	32	11	288.25	13.82
Śatabhiṣaj	32	11	288.25	57	65	294.02	13.25
Purva Proṣṭapada	8	103	312.37	45	49	305.56	15.64
Uttra Proṣṭapada	33	33	317.99	58	87	323.20	11.96
Revatī	21	17	329.53	46	71	335.34	13.34
Asvayujau	9	1	340.56	34	55	346.52	13.69
Asvayujau	34	55	346.52	59	109	352.28	13.23
Bharaṇī	22	39	358.21	47	93	3.71	12.62
Mean Width of the *Nakṣatra* Sector			12.65±3.28				

L: Ecliptic Longitude; WNS: Width of the *Nakṣatra* Sector in degrees of *nakṣatras*. The coordinates of the full moon and the *nakṣatra*-sector of this moon are obtained by independent methods. These lunar positions do not change with epoch because they are not affected by precession of the equinox (this is demonstrated by the agreement between the values obtained for the two periods). If background stars are used to identify the *nakṣatra*-sectors in which the moon is full (or new) each *yuga*, then the positions of the stellar markers will be epoch-dependent, because of the precession of the equinox; the same set of stars will not identify the same *nakṣatra*-sector at different epochs.

It can be seen from Table 3 that the full moon (and new moon) can occur in the same *nakṣatra*-sector at different times in a *yuga* i.e. in a *yuga* different full moons (identified by full moon numbers in Table 3) can occur in the same *nakṣatra*-sector, but they occur at different *bhāṃśas*. For example, full moon three, fifteen and forty occur in the *nakṣatra*-sector Citrā (positions of full moon #3 and #15 are shown in Fig. 1) but at *bhāṃśa* 117, 9 and 63 respectively. In Table 6 are collated all *nakṣatra*-sectors in which there are multiple occurrences of the full moon during a *yuga* and the full moon number, the *bhāṃśa* and the ecliptic longitude (obtained by the first method described above) of the full moon are given. The size of the *nakṣatra*-sector calculated from ecliptic longitudes of pairs of full-moons in the same *nakṣatra*-sector is also given in this table. The mean width of the *nakṣatra*-sector is 12.65±3.28 degrees. The mean width obtained from the ecliptic longitude of the full moon determined by the second method above is 11.38±5.07 degrees. These values are consistent with the width of the *nakṣatra*-sector given in *VJ* (*RJ*.18, *YJ*.39) and discussed above. The spread in the mean values also demonstrates that the *nakṣatra*-sectors are of equal width. The (equatorial) coordinates of the centre of each *nakṣatra*-sector are given in Table 5. For comparison the coordinates of the *yogatārās* of the *nakṣatras*[15,16] are also given in this table. *VJ* emphasises the importance of the *bhāṃśas* and gives algorithms for calculating the *bhāṃśas* of the sun and the moon but the method to empirically determine the *bhāṃśa* (of the sun or the moon) at any particularly time is not given. Since *VJ* describes the use of a clepsydra (water-clock) it is very likely that the Āryas determined the *bhāṃśa* by timing the passage of the moon across a *nakṣatra*-sector.

5. Discussion and Conclusions

The *jāvādi* arrangement of *nakṣatras* in *Vedāṅga Jyotiṣa* enables the invariant positions of the *nakṣatra*-sectors to be determined. This arrangement is unique to *VJ* and no trace of it is found in any of the earlier Vedic texts. However, this arrangement casts light on some of the aspects of calendar of these earlier Vedic texts. The tenth full moon, which is in the *nakṣatra*-sector Kṛttikās (Table 4 and 5.), will be in autumn (*śarad*) (this is determined by counting the number of lunations from the first full moon after the new moon at winter solstice). The sun will occupy this position six months later that is the sun will be in the *nakṣatra*-sector Kṛttikās in spring (*vasanta*). In the northern hemisphere the vernal equinox is in spring, the *jāvādi* arrangement thus states that (around) vernal equinox the sun is in the *nakṣatra*-sector Kṛttikās. In the early Vedic texts, spring (*vasanta*) is described as "the mouth of the seasons" or the seasonal cycle starts with spring. It would appear that at the time of these early Vadic texts the (Vedic) seasonal year commenced in spring (around vernal equinox) when the sun was in the *nakṣatra*-sector Kṛttikās. This hypothesis is confirmed by the absolute position of the *nakṣatra*-sector Kṛttikās. The ecliptic longitude of the tenth full moon which is in the *nakṣatra*-sector Kṛttikās is almost 0° (Table 5.) that is, this *nakṣatra*-sector is close to vernal equinox. The start of the seasonal cycle in spring with the sun in Kṛttikās is consistent with the myth of Skanda (the year) with its six heads (seasons) who was born when *agni*/sun was in Kṛttikās[17]. In this respect the Āryas would appear to be similar to a number of early cultures in which the food gathering and agricultural season started when the sun was 'close' to the Pleiades (Kṛttikās) or around vernal equinox in the northern hemisphere and around autumnal equinox in the southern hemisphere[18].

In the calculation of the coordinates of the full moons in a *yuga* the origin was assumed to be the first point of Aries or vernal equinox and a *nakṣatra* would be expected to be close to this origin or close to vernal equinox. That this *nakṣatra* should be the Kṛttikās is perhaps not entirely fortuitous; the start of the seasonal year discussed above suggests that the Āryas set-up their scheme of *nakṣatra* with origin at vernal equinox i.e. the *nakṣatra* of the sun at vernal equinox was considered to be the first *nakṣatra* and this was Kṛttikās. This explains why all lists of *nakṣatras* in Vedic texts start with Kṛttikās.

The use of the word *nakṣatras* both as *nakṣatra*-sectors and as asterisms suggests that the Āryas may have identified the *nakṣatra*-sectors by the stars in proximity of these sectors. This method of identification of *nakṣatra*-sectors would be more reproducible then counting the number of full or new moons from the start of every *yuga*. The stellar identifiers of the *nakṣatras* are not given in the Vedic text including *VJ*. An exception may be the Kṛttikās; the mythology, the number of stars, the position in the list of *nakṣatras* and the comparison with other cultures suggests that the identification of the Kṛttikās with the Pleiades is unambiguous. Like other cultures the Āryas could have used the heliacal rising or setting of the Pleiades (Kṛttikās) to herald the seasonal cycle and the New Year.

To identify the epoch when the Vedic New Year was in spring it is necessary to identify the (precessed) coordinates of the Pleiades at this epoch. To determine this epoch it is necessary to consider the *Cāturmāsya* (or seasonal) sacrifices. In the post-*Ṛgvedic* texts the 'dates' of the performance of these three sacrifices are identified by the conjunction of the full moon and three prescribed *nakṣatras*. The autumn sacrifice, *Sākamedha*, was performed when the full moon was in Kṛttikās [19,20]. In Figure 2 are shown the ecliptic longitude and latitude of the tenth full moon of a *yuga*; as discussed above, this full moon is in autumn (*śarad*). Also shown in Figure 2 are the coordinates of seven principle stars of the Pleiades precessed to eleven evenly spaced epochs (250 years apart) between 3000 BC and 500 BC. Between 2000 BC and 1500 BC the

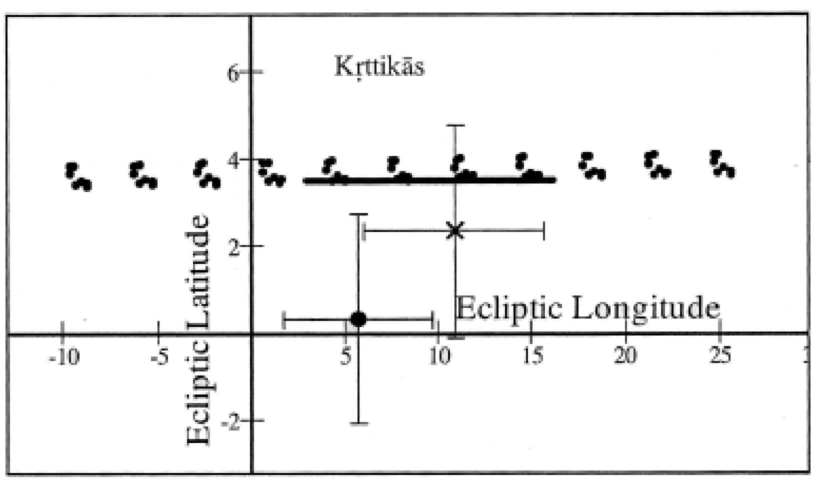

Fig. 2. The coordinates of seven brightest stars of the Pleiades (Kṛttikās) precessed to eleven epochs (250 years apart) between 3000 BC and 500 BC. In this diagram, the ecliptic is the line along latitude 0°. The 'bar' is the width of the *nakṣatra*-sector Kṛttikās. For clarity, the *nakṣatra*-sector is off-set from the ecliptic. The ecliptic longitude and latitude of the 10th full moon in a *yuga* are shown. The mean coordinates obtained for 1900 AD to 2000 AD period are plotted as a large dot and those obtained for 1500 BC to 500 BC period are plotted as a cross. The error bars denote the spread in the coordinates over the period for which the coordinates have been calculated (see text for details).

Kṛttikās conjoin the autumn full moon and during this period the sun will be in Kṛttikās in spring (*vasanta*). During this epoch the *nakṣatra Kṛttikās* are also in the *nakṣatra*-sector Kṛttikās (shown in Fig. 2). At vernal equinox at this epoch the Pleiades will rise after sun-rise but set after sun-set. Few (fifteen to twenty) days later they will rise before sun-rise and set before sun-set. Thus around vernal equinox between 2000 BC and 1500 BC the Kṛttikās/Pleiades would have been observed to rise and set heliacally and this would have been (perhaps) a good omen to start a New Year.

A number of passages in various Vedic texts suggest that during the Vedic period there was also a tradition to start a New Year at winter solstice. As discussed above, in the calendar of *Vedāṅga Jyotiṣa*, the *yuga* starts at winter solstice "when the sun and the moon are in Śraviṣṭhās". The parameters of the calendar of *Vedāṅga Jyotiṣa* depend on this start of the *yuga*. It is possible that the New Year in spring was an earlier tradition (in conformity with most other early cultures) and the New Year at winter solstice was a later development. It is equally possible that these were two parallel traditions. It would have been possible for the composer(s) of *Vedāṅga Jyotiṣa* to rearrange the list of *nakṣatras* to start with *Śraviṣṭhās* but they clearly opted to retain the arrangement of *nakṣatras* given in the earlier texts. The *jāvādi* arrangement of *nakṣatras* appears to have been devised to create an absolute and fixed frame of reference that is anchored to the ecliptic. Background stars could be and most probably were used to identify the sectors of this reference frame. However, because of precession of the equinox, over time these stellar identifiers will have moved out of their original sectors.

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