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The Dhruvabhrama-Yantra of Padmanābha

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श्रीरामुलराजेश्वरशर्ममहाभागः मध्यभारतस्य नर्मदानदीतीरवासिना पद्मनाभेन पञ्चदशशताब्दस्य प्रथमपादे आविष्कृतस्य ध्रुवभ्रमनामकस्य दिने रात्रौ च काल-राशि-दशमभावादिगणनानुकूलस्य यन्त्रस्य साङ्गोपाङ्गविवरणम् अप्रकाशितमातृकानां साहाय्येन स्पष्टयति। पुण्यपत्तने, जयपुरनगरे पारिसनगरे च पुरावस्तुसङ्ग्रहालयेषु विद्यमानध्रुवभ्रमयन्त्राणां चित्राणि प्रदर्श्य तन्निर्माणप्रकारं वैविध्यञ्च निरूपयति। प्रायः विंशत्यधिकानि ध्रुवभ्रमयन्त्राणि विश्वस्मिन् विविधसङ्ग्रहालयेषु सन्ति इत्यपि प्रकटयति।

1.1 Introduction

Diksāmya, the agreement between the computed and observed positions of the astral bodies, has always been the ideal of the Indian astronomer. Nīlakaṇṭha Somayājin enjoins that only such astronomical treatises should be followed which agree with actual observations.[1] While astronomical texts of different *genres* like the *Siddhāntas, Karaṇas* and *Koṣṭhakas* help the astronomer to mathematically compute the planetary positions, he has to verify them through direct observation with astronomical instruments (*yantras*). Therefore Sanskrit astronomical texts describe the method of construction and use of several astronomical instruments. Brahmagupta devoted the twenty-second chapter of his *Brāhmasphuṭa-siddhānta* (composed in AD 628) to instruments and named it appropriately as *Yantrādhyāya.*[2]

The following abbreviations are used in this paper.
CESS = *Census of the Exact Sciences in Sanskrit* by David Pingree
DBA = *Dhruvabhramādhikāra* by Padmanābha
DBAC = Padmanābha's auto-commentary on *Dhruvabhramādhikāra.*

1. Nīlakaṇṭha Somayājin, *Jyotirmīmāṃsā,* p. 6: *yaḥ siddhāntaḥ darśanāvisaṃvādī bhavati so 'nveṣaṇīyaḥ,* quoted in: Subbarayappa & Sarma, *Indian Astronomy: A Source-Book*, p. 7; for similar statements by other astronomers, see ibid, pp. 5-8.
2. Sarma, "Astronomical Instruments in Brahmagupta's Brāhmasphuṭasiddhānta."

Subsequently several other *Siddhāntas* emulated this practice. There are also texts that deal exclusively with astronomical instruments. These can be divided into two categories, viz. those which describe several instruments, like the *Yantraprakāśa* (AD 1428) by Rāmacandra Vājapeyin of Naimiṣāraṇya [1] or the *Yantraśiromaṇi* (AD 1615) by Viśrāma of Jambūsara,[2] and those which discuss a single instrument, like the *Yantrarāja* or *Yantrarājāgama* (AD 1370) on the astrolabe by the Jaina monk Mahendra Sūri,[3] or the *Turya-yantra-prakāśa* (AD 1572) on the sine quadrant by Bhūdhara of Kampilya.[4]

Among the various astronomical instruments described in these Sanskrit texts, the *Dhruvabhtama-yantra* is an interesting multi-purpose instrument. While it is generally difficult to say which instrument was invented by whom, we know fortunately that this instrument was invented by Padmanābha in the first quarter of the fifteenth century.

1.1 Padmanābha

Padmanābha wrote three small tracts on the construction and use of three different instruments, viz. the *Yantrarājādhikāra* [5] on the southern astrolabe, the *Diksādhana-yantra* on an instrument of the same name and the *Dhruvabhramādhikāra* on the *Dhurvabharma-yantra.*[6] While the southern astrolabe is an

1. Sarma, "On the Life and Works of Rāmacandra Vājapeyin."
2. See the note below.
3. Mahendra Sūri, *Yantrarāja,* with the commentary of Malayendu Sūri, together with the *Yantra-śiromaṇi* of Viśrāma, ed. Kṛṣṇaśaṃkara Keśavarāma Raikva, NSP, Bombay 1936.
4. Available in just two manuscripts, viz. 35097 of the Varanasi Sanskrit University and 12828 of the Oriental Institute of Vadodara. The latter is incomplete.
5. For an excellent critical edition, English translation and mathematical commentary of this work, see Ohashi, "The Early History of the Astrolabe in India."
6. About the mutual relationship of these tracts, the manuscript tradition is rather confusing. It is not clear whether these are independent works or chapters of one or more treatises. While the *Yantrarājādhikāra* is described in the colophons as the second chapter of the *Yantrakiraṇāvalī,* the *Dhruvabhramādhikāra,* (also

unusual variety of astrolabe and the *Diksādhana-yantra* is a simple instrument to determine the cardinal directions, the *Dhruvabhrama-yantra* is a multi-purpose instrument that can be used both in the day and at night to measure various parameters. Padmanābha wrote commentaries on his *Yantrarājādhikāra* and *Dhruvabhramādhikāra,* and also on the *Karaṇakutūhala* (AD 1183) of Bhāskara II.

We know very little about Padmanābha's personal life save that his father was born by the grace of the river goddess Narmadā and was therefore named Nārmada.[1] This Nārmada was himself an astronomer and composed the *Nabhogasiddhi* following the Brāhmapakṣa.[2] Padmanābha acknowledges him as his teacher. Padmanābha's son Dāmodara too was an astronomer. He is known by three works: a *Karaṇa* work called *Bhaṭatulya* based on the *Āryabhaṭīya* of Āryabhaṭa, another *Karaṇa* by name *Sūryatulya* based on the *Sūryasiddhānta,* and a commentary on the *Karaṇaprakāśa* of Brahmadeva.[3]

In his *Dhruvabhramādhikāra* (verses 21-26), Padmanābha gives the meridian altitudes (*madhyonnatāṃśas*) of the lunar mansions (*nakṣatras*) for the terrestrial latitude of 24 degrees. He must, therefore, belong to some place in Central India, close to the river Narmadā. Again, in his *Yantrarājādhikāra,* he gives the precession (*ayanāṃśa*) for the Śaka year 1345 (= AD 1423), which may be the

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known as *Dhruvabhramaṇādhikāra*), is styled the second chapter of the *Yantraratnāvalī.* It is not clear if these *Yantrakiraṇāvalī* and *Yantraratnāvalī* are one and the same book or two different works. Nor do we know whether the third work *Diksādhana-yantra* is an independent work or a chapter of the *Yantrakiraṇāvalī* or of the *Yantraratnāvalī.* If these are two different texts, the *Yantrakiraṇāvalī* must surely have other chapters besides the first *Yantrarājādhikāra,* and the *Yantraratnāvalī* should contain at least a first chapter besides the second *Dhruvabhramādhikāra*; cf. Ohashi, "The Early History of the Astrolabe in India," p. 217.

1. DBA 1: *śrīnarmadānugrahalabdhajanmanaḥ padāravindaṃ janakasya sadguroḥ |*
   natvā triyāmāsamayādibodhakaṃ dhruvabhramaṃ yantravaraṃ bravīmy atha ||
2. CESS, A-3, 171b; A-5, 183a.
3. CESS, A-3, 100b-101a; A-4, 108a; A-5, 137a.

year of composition of this work.[1] Padmanābha's son Dāmodara composed his *Sūryatulya* in Śaka 1339 (= AD 1417). Thus both Padmanābha and his son must have flourished in the first quarter of the fifteenth century somewhere in Central India.

1.3 The Dhruvabhramādhikāra

The *Dhruvabhramādhikāra* is a small tract of 31 verses in different metres, accompanied by an auto-commentary. Because this text has not been published so far and is available only in manuscript form[2] and because the instrument is rather unknown but important for the history of astronomical instrumentation,[3] we introduce the instrument and its function in the following pages largely through select extracts from the *Dhruvabhramādhikāra* and its commentary. Since this is a technical subject, whenever a technical term is used for the first time, its Sanskrit equivalent will be given in parenthesis.

2.0 The Dhruvabhrama-Yantra

The *Dhurvabhrama-yantra* is an oblong (*āyata-caturasra*) metal plate one side of which is designed as the *Dhurvabhrama-yantra* and the reverse side as a sine quadrant (*Turya-* or *Turīya-yanta*). The *Dhurvabhrama-yantra* proper is a kind of nocturnal, i.e. an instrument to be employed at night. Its construction is based on the apparent diurnal rotation of the stellar sphere around the celestial poles. In his commentary, Padmanābha explains the diurnal rotation thus:

> "At the beginning of the creation, the resplendent Brahmā arranged two stars as the celestial poles at

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1. Ohashi, "The Early History of the Astrolabe in India," p. 217, 249.
2. David Pingree's *Census of the Exact Sciences in Sanskrit* lists some seventy manuscripts; cf. CESS, A-4, 170a-172a; A-5, 205b. I have prepared a working edition of the *Dhruvabhramādhikāra* together with Padmanābha's own commentary on the basis of eight manuscripts. The citations in this paper are from this edition.
3. For a description of the instrument, see Garrett & Guleri, *The Jaipur Observatory and its Builder*, pp. 62-64, pl. X; Ohashi, "History of Astronomical Instruments of Delhi Sultanate and Mughal India," p. 167; Sarma, "Indian Astronomical and Time-Measuring Instruments : A Catalogue in Preparation," pp. 517-518.

> the end of the southern and northern directions so that the stellar sphere (*bhacakra*) can properly revolve in the sky towards the west, without any support but impelled by the *Pravaha* wind. These two stars were designated as the celestial poles. That which is the southern [Pole] Star is situated below the horizon at the degrees of the local latitude (*palāṃśa*). The northern Pole Star lies above the horizon at the degrees of the local latitude. Around the latter is seen a fish-shaped constellation consisting of twelve stars. This is designated as the Polar Fish (*dhruva-matsya*). Two bright stars are visible at its mouth and tail. Of these, the one at the mouth lies at an interval of three degrees (*bhāga*) from the [actual] Pole Star and the one at the tail lies at thirteen degrees. The two are separated from one another by sixteen degrees."[1]

The star at the mouth of the fish is Polaris (α Ursae Minoris) and the one at the tail end is called *Markaṭī* in Sanskrit (β Ursae Minoris or Kochab). If these two were joined by a straight line, this line would rotate like the hand of a clock and make a full circle in a sidereal day of 23 hours and 56 minutes.

The rotation of the *Dhruva-matsya* is known to earlier astronomers as well. Brahmagupta makes a brief reference to it

1. DBAC 11: *pūrvaṃ sṛṣṭyādau śrībrahmaṇākāśa ādhārarahitasya pravahānilākṣiptasya bhacakrasya samīcīnapaścimābhimukha-paribhramaṇāya dakṣiṇottarayoḥ prāntasthite dve tārake dhruvatve niyukte | tayor ubhayor dhruva-saṃjñā kṛtā | yā dakṣiṇā tārā sā tu palāṃśaiḥ kṣitijād adhasthād vartate | yā tūttarā tārā sā palāṃśaiḥ kṣitijād uparito varīvarti | tatparito dvādaśatārakābhir matsyākāramaṇḍalam upalakṣyate | tasya dhruvamatsya-saṃjñā vihitā | tanmukhe pucche sthūle tārake dve dṛśyete | tayor madhye yā mukhasthā sā dhruvatārāyās tribhir aṃśair antaritā | yā pucchasthā sā tu trayodaśabhir aṃśair antaritā vartate | ubhe parasparaṃ ṣodaśabhāgāntarite staḥ |*

in his *Brāhmasphuṭa-siddhānta.*[1] Bhāskara II, in his *Vāsanābhāṣya* commentary on his *Siddhāntaśiromaṇi,* speaks of the daily rotation of the *Dhruva-matsya* in somewhat greater detail:

> "When the Sun is situated in the lunar mansion Bharaṇī, then at the time of his setting, the Polar Fish becomes horizontal. The star at its mouth will be in the west and the star at the tail in the east. It means that the Sun would be in line with the star at the mouth. At the end of the night, the star at the mouth reverses its position and comes to the east and the star in the tail goes to the west. Then will be seen the rise of the Sun who is again in line with the star at the mouth.[2]

The *Dhruva-matsya* is a constellation of twelve stars. Of these the stars at the mouth and tail of the fish figure are α and β in the constellation Ursa Minor. The remaining ten stars should include some of the stars in Ursa Minor. But no Sanskrit text seems to have described this constellation in detail.[3]

To come back to the *Dhruvabhrama-yantra,* Padmanābha lays strong emphasis, at the beginning and at the end of his work, on the fact that, while other instruments make use of the Sun or of

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1. *Brāhmasphuṭa-siddhānta* 11.3:
bhāni catuṣpañcāśad dvau dvāv arkaindavo jinoktaṃ yat |
dhruvamatsyasyāvarto bhavati yato 'hnā tatas tad asat ||
2. Bhāskara, *Siddhāntaśiromaṇi, Golādhyāya, Bhuvanakośa* 10, *Vāsanābhāṣya : yadā bharaṇīstho ravir bhavati tadā tasyāstamayakāle dhruvamatsyas tiryakstho bhavati | tasya mukhatārā paścimataḥ | pucchatārā pūrvataḥ | tadā mukhatārāsūtre ravir ity arthaḥ | atha niśāvasāne mukhatārā parivartya pūrvato yāti | pucchatārā paścimato yāti | tato mukhatārāsūtra-gatasyaivārkasyodayo dṛśyate |*
3. The Purāṇas mention a constellation called *Śiśumāra* or *Śiṃśumāra* which is said to be a representation of Viṣṇu. Thus *Medinīkośa* (p. 144, verse 199): *śiśumāro 'mbusambhūtajantau tārātmakācyute.* The star *Dhruva* is said to be at the tail of this constellation, whereas in the *Dhruvamatsya,* it is close to the mouth of the fish figure; cf. *Viṣṇupurāṇa* 2.9.5:
uttānapādaputras tu tam ārādhya jagatpatim |
sa tārāśiśumārasya dhruvaḥ pucche vyavasthitaḥ ||

other fixed stars, this is the only instrument which makes use of the Pole Star and that it is a multi-purpose instrument. Thus he states at the beginning of the work:

> "All the instruments measure time etc. according to the Sun or according to the fixed stars. This one, however, shows time according to the celestial Pole. Therefore it is called the best of the instruments. ... Apart from the time of the night, it also indicates the ascendant (*lagna*), other astrological houses (*bhāva*), and the results in time (*kālaphala*) (oblique ascensions) related to these. The time of the night etc. are found by observing the Polar Fish (*dhruva-matsya*). Therefore the name *Dhruvabhrama* is appropriate."[1]

Again at the end of the work, he repeats that such an instrument based on the Pole has never been mentioned previously by any astronomer:

> "[Others] taught previously how to measure time from the stars, but none [has taught how to find time] from the Pole star. Therefore, out of intellectual curiosity (*kautuka*), this has been done [by me]."[2]

This implies that this instrument was invented by Padmanābha himself. This is very unusual because Sanskrit *śāstra-kāras* do not usually claim originality. They never say that certain inventions or discoveries are made by them; they would rather say that these are derived from the writings of the past masters (*pūrvācāryas*), if not from divine sages (*ṛṣis*). Even the great Bhāskara does not claim originality for the *Phalaka-yantra*

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1. DBAC 1: *sarvāṇi yantrāṇi sūryavaśān nakṣatravaśād eva kālādy-avayava-bodhakāni / idam pṛthag dhruvavaśāt kālāvabodhakam / tasmād yantravaram ity uktam | ... triyāmāsamayādibodhakam .... ādiśabdāl lagnādibhāvās tatsambandhīni kālaphalāny api bodhayati | anena yantreṇa rātreḥ samayādijñānaṃ dhruvamatsyālokanād evotpadyata ity ato dhruvabhramaṃ nāma suyuktam |*
2. The final verse, i.e. DBA 31:
nakṣatrāt samayajñānaṃ tamisrāyāḥ puroditam /
dhruvāt kenāpi na proktam tad etat kautukāt kṛtam //

which he was the first to describe,[1] nor does Gaṇeśa Daivajña for the *Sudhīrañjana-yantra* which had not been mentioned before him.

2.1 Construction of the Dhruvabhrama-yantra

The *Dhruvabhrama-yantra* consists of an oblong (*āyata-caturasra*)[2] plate with a narrow horizontal slit close to and parallel to one of the shorter sides, say at the top. Below the slit are drawn eight concentric circles, producing seven annuli or rings (*koṣṭhakas*). These annuli contain different scales and the legends pertaining thereto (see Figure 1). Padmanābha numbers these annuli serially, counting them from the outside.

Figure 1: *Dhruvabhrama-yantra,* made for Yado Joshi, resident of Ukala-grama (Akola), latitude 20 degrees. Front view. Raja Dinkar Kelkar Museum, Pune.

1. *Siddhāntaśiromaṇi, Golādhyāya, Yantrādhyāya,* verses 16-22. See also Subbarayappa & Sarma, *Indian Astronomy: A Source-Book,* pp. 97-98.
2. Padmanābha takes this occasion to give a learned discourse on the classification of the quadrilaterals (*caturasra*) in his commentary. This passage, which is of interest for the history of geometry, will be reproduced with a translation in the Appendix. Commentaries on Sanskrit astronomical and mathematical texts often contain such valuable digressions.

The outermost or the first annulus (*prathama-koṣṭhaka*) contains a scale of *ghaṭīs* which are the standard units of time (= 24 minutes) in traditional India. The scale is divided into 60 equal parts to represent 60 *ghaṭīs* in a day and night (*ahorātra*). These *ghaṭīs* are numbered in the following manner. At the topmost point of the circle, i.e. where it is closest to the horizontal slit, is marked the commencement of the 22nd *ghaṭī*.[1] For the sake of reference, if we divide the circle into 360 degrees from the topmost point where the 22nd *ghaṭī* commences, and number the degrees serially clockwise, then the *ghaṭī* scale and all other scales would commence from 234 degrees. The remaining six annuli are calibrated as follows:

2. The names of the 27 *nakṣatras* (as related to the signs in the next annulus) and their meridian altitudes which are provided in verses 21-26, after correcting these for precession (*āyana-d kkarman*).
3. Zodiac signs (*rāśi*) at the equator, i.e., 12 divisions in accordance with the rising times of the signs on the equator, i.e. their right ascensions (*svasvaghaṭī-pramāṇena nirakṣodayena*); each division is sub-divided into 30 degrees and numbered accordingly.
4. The names of these signs.
5. The names of the 27 *nakṣatras* (as related to the signs in the next annulus) and their true longitudes (*sphuṭa*), after correcting them for the observer's latitude (*ākṣa-dṛkkarman*).
6. Signs at the observer's latitude, i.e., 12 divisions in accordance with the rising times of the signs at the observer's terrestrial

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1. DBA 4: *randhrasthabāhvardhagavṛttanemyāṃ*
cihnaṃ tataś cākṛtināḍikātaḥ |
aṅkyāḥ samāḥ ṣaṣṭir athādito 'dho
vṛttāntarāle prathame ca koṣṭhe ||

"Make a mark on the circumference of the [first] circle where it touches the middle of the side of the slit. In the first annulus (*koṣṭha*) between the [first and the second] circles, make sixty equal [divisions] and number them from the [above-mentioned] mark, starting with *ghaṭī* twenty-two, and [going up to sixty, and thereafter] from one [to twenty-one]."

latitude, i.e. oblique ascensions (*svadeśīyāḥ [rāśayaḥ] svasvaghaṭībhir aṅkyāḥ*); each division is sub-divided into 30 degrees and numbered accordingly.

7. The names of these signs.

2.2 The Index

Loosely pivoted at the centre of these concentric circular scales is a metal index with four beaks (*cañcu*) or pointers which project into the four cardinal directions. These pointers should be at right angles to one another and of unequal length. The eastern pointer, which is the shortest, should reach up to the sixth annulus to point the degree of the zodiac sign rising at the observer's latitude (*yathā prāk-cañcukāgraṃ nijabhodaya-nijarāśiṣu prāptaṃ bhavati*). The northern pointer is of middle length and reaches the third annulus to point the signs rising at the equator (*madhya-cañcukāgraṃ nirakṣe prāpnoti*). The western pointer is the longest to reach the outermost annulus containing the *ghaṭī* divisions (*paścima-cañcukāgraṃ ghaṭīvṛtte prāpnoti*). The southern-most projection is actually not a pointer but the plumb. Either a plumb should be suspended from this projection, or it should be made considerably heavier than the others, so that it always points downwards and gives a vertical reference.[1]

2.3 The Method of Observation

Padmanābha explains how this instrument is to be used at night:

> "When the instrument is held in both hands like a mirror [in a vertical plane] so that these two stars situated at the mouth and the tail of the Polar Fish become visible at the same time through the slit meant for sighting, the disc pivoted at the pin in the centre is pulled downwards by the plumb into [a vertical] position and the tip of its eastern

1. Padmanābha tartly remarks that it is not necessary to specify the lengths of these pointers because the limits up to which circle the pointers should reach have been given: *cañcukāgrāṇām avadher niyamatvāt teṣāṃ pramāṇam anuktam apy uktam eva bhavati,* "Although the lengths of the pointers are not specified, they are implied because the limits of their tips are fixed."

> pointer touches whichever subdivision (*avayava*) of whichever sign in its oblique ascension, that sign together with that subdivision will be the ascendant for that moment (*sāvayavam iṣṭakālalagnam*). It should be known that this ascendant is with precession (*sāyanāṃśam*)."[1]

Thus, when the two stars α Ursae Minoris and β Ursae Minoris are sighted through the slit, the eastern pointer will indicate that point of a zodiac sign which is rising in the east at that moment. This is the ascendant for that moment (*iṣṭalagna*). The point at which the western pointer touches the *ghaṭī* circle is called "point of observation" (*vedha-cihna*). Let us call it A. Now find out the solar longitude for that moment from an almanac (*pañcāṅga*). Place the tip of the eastern pointer at the solar longitude with precession plus six signs (*sa-calana-lava-ṣaḍ-bha*). Note where the western pointer is situated now. [That point will indicate the time of the previous sunset]. Let us call it C. The distance CA equals the number of *ghaṭīs* elapsed (*gata-ghaṭikās*) in the night from the previous sunset up to the time of observation. On the other hand, if the tip of the eastern pointer is placed just at the solar longitude with precession (i.e. without adding 6 signs), then the corresponding western point will indicate the time of the next sunrise. Let it be B. Then the distance AB is tantamount to the number of *ghaṭīs* to come in the night from the time of observation up to the sunrise (*eṣya-ghaṭikās*).[2] Then the time of observation is CA *ghaṭīs* after the previous sunset and AB

1. DBAC 9-10: *te dhruvatimimukhapucchādhisthite tārake vedhasuṣiramadhye yugapad āvrajatas tathā yantre karābhyām ādarśavad dhṛte sati tatkendrakīlasthasya lambākṛṣyamāṇa- cakrasya pūrvacañcukāgraṃ svadeśīyodaye yasmin rāśyavayave lagati tat sāvayavam iṣṭakālalagnam bhavati | ... tat sāyanāṃśam iti jñeyam |*
2. DBAC 11-13: *evam ca sati paścimacañcukāgre nāḍyāṃ cihnaṃ kuryāt | tad vedhasaṃjñaṃ cihnaṃ bhavati | ... svadeśīyodayeṣu sāyanaṣaḍbhārkam upalikhya tatropari prākcañcukāgraṃ nidhāya paścimacañcukāgrasthanāḍikāvayavacihnāt prāksādhitavedhacihnaṃ yāvad rātrer gataghaṭikāḥ syuḥ | ced yadi sāyanārkasyaiva cihnopari prākcañcukāgraṃ kriyate tadāpara-cañcukāgra-sthanāḍīcihnaṃ yāvad vedhacihnād eṣyaghaṭikāḥ syuḥ |*

ghaṭīs before the next sunrise, the total duration of the night being CB *ghaṭīs*.

While the ascendant and the sidereal time of observation are determined thus with the help of the eastern and western pointers, the point at which the middle pointer touches the scale of the risings at the equator (*vy-akṣodaya*), is the culmination (*madhyama lagna*) with precession (*sāyana*). Then from the culmination (*viyad-lagna*) and the ascendant (*udaya-lagna*), other astrological houses (*bhāvas*) can be determined easily.

In horoscopy (*horāśāstra*), the zodiac is divided into twelve houses (*bhāvas*) which are different from the twelve signs (*rāśis*). The twelve houses are divided on the basis of four key points where the ecliptic intersects the local horizon and the local meridian. These are as follows:

1. "Ascendant" (*lagna, udaya-lagna*), i.e. the degree of the ecliptic which is on the eastern horizon;
2. "lower mid-heaven" (*pātāla, caturtha-bhāva*), i.e. the degree of the ecliptic which is on the lower meridian;
3. "Descendant" (*asta-lagna, saptama-bhāva*), i.e. the degree of the ecliptic which is on the western horizon;
4. "Culmination" or "mid-heaven" (*khamadhya, madhyama-lagna, viyad-lagna, daśama-bhāva*), i.e. the degree of the ecliptic which is on the upper meridian.

Of these the ascendant (*lagna*) and the descendant (*saptama-bhāva*) are diametrically opposite, i.e. at 180 degrees from one another; so also the culmination (*daśama-bhāva*) and the lower mid-heaven (*caturtha-bhāva*).

Thus the *Dhruvabhrama-yantra* is a multipurpose instrument with which the sidereal time, ascendant (*lagna*) and the culmination (*daśama-bhāva)* can be found for any moment at night. Furthermore, from the ascendant and the culmination, the other two astrological *bhāvas*, namely the *saptama-bhāva* and the *caturtha-bhāva,* can easily be found out by locating the diametrically opposite points on the corresponding circular scales of the *Dhruvabhrama-yantra.*[1]

3.0 Sine Quadrant on the Reverse Side

The *Dhruvabhrama-yantra* which we have described can be used only at night. Padmanābha desires that it can be used also in the daytime and prescribes that the reverse side of the oblong plate is fashioned as a sine quadrant (*Turīya-yantra*) (see Figure 2). The simple quadrant with a graduated arc was known in India at least from the time of Brahmagupta. The sine quadrant, however, was invented at Baghdad in the ninth century. Later on it was incorporated into the astrolabe. Along with the astrolabe, it must have reached India in the early centuries of the second millennium of the Christian Era. Padmanābha is the first one to describe it in Sanskrit. Later on it was discussed in several Sanskrit texts; there were also exclusive Sanskrit texts like Bhūdhara's *Turya-yantraprakāśa* which has been mentioned at the beginning of this paper.[2]

In the sine quadrant, the radial edges are divided sexagesimally and parallels are drawn from these divisions to produce a grid of sines and cosines of the angles marked on the arc. Angles measured on the arc can be graphically converted into the corresponding sines and cosines on the grid and thus several trigonometric problems can be solved with the sine quadrant.

But Padmanābha uses the sine quadrant just for measuring time. This is the method of construction of the sine quadrant according to Padmanābha:

> "On the reverse side of the instrument, from the corner above Libra draw a quarter circle (*vṛti-turya*) with a radius slightly less [than the side of the square]. From the side containing the aperture, draw thirty sines at equal intervals like dangling strings.

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1. On the astrolabe also these four points can be directly read off from the dial, when once the rete is correctly set for the moment.
2. Cf. Sarma, "Sine Quadrant in India: Sanskrit Texts and Extant Specimens."

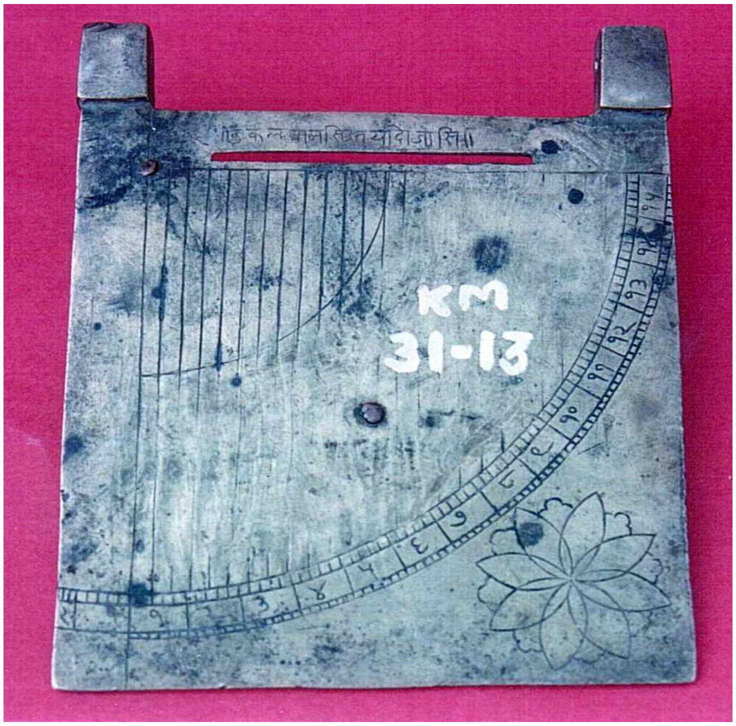

Figure 2: *Dhruvabhrama-yantra,* made for Yado Joshi, resident of Ukala-grāma (Akola), latitude 20 degrees. Reverse side, with the sine quadrant.
Raja Dinkar Kelkar Museum, Pune.

> "Below the centre, starting from the foot of the corner (*koṇa-pāda*), mark ninety equal degrees on the rim of the quadrant and number them. Having attached an index (*paṭṭī*) marked in thirty units, together with a plumb line (*lambasūtra*) at the apex of the quadrant, affix two sighting vanes (*kīla*) with holes at the two ends of the edge [of the instrument] on the side of the slit."[1]

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1. DBA 14-16ab:
kadūnadoṣṇā vaṇigūrdhvakoṇato yantrānyapārśve vṛtituryam ālikhet |
tadrandhrabāhoḥ khaguṇonmitajyakās tulyāntarālāś ca vilambasūtravat ||
kendrād adhaḥ koṇapadāc ca nemyām aṅkyāḥ samāḥ khāṅkalavās tu sāṇkāḥ |

That is, from one of the radial edges thirty lines are drawn parallel to the other radial edge. The arc of the quadrant is graduated into 90 degrees. At the apex of the quadrant, an index is pivoted, which is marked with 30 divisions, and also a plumb line. Furthermore, two sighting vanes with holes are attached to one of the sides of the quadrant.

Holding the sine quadrant in a vertical plane, one observes the Sun or the stars through the two sights by tilting the quadrant appropriately. Where the plumb line touches the graduated arc is the altitude of the object sighted. With the help of the index and the parallel lines drawn on the quadrant, time can be measured in the daytime by sighting the Sun and at night by sighting a star whose meridian altitude is known. For this purpose, Padmanābha gives the meridian altitudes of the 28 lunar mansions which are valid for the latitude of 24 degrees. For those who live at other geographical latitudes, Padmanābha also teaches how to convert the given meridian altitudes for other latitudes (verse 27).

In the case of the *Dhruvabhrama-yantra,* it may be recalled that some of the circular scales are related to the oblique ascensions which pertain to a specific latitude. Therefore, it cannot be used at other latitudes, while the sine quadrant can be used at all latitudes. Padmanābha also teaches how to obtain time at one's own latitude with a *Dhruvabhrama-yantra* made for another latitude (verse 28).

4.0 Popularity of the *Dhruvabhrama-yantra*

When one studies Sanskrit texts on astronomical instruments, a question that arises naturally is whether any of these instruments have actually been constructed and made use of in observation. In Europe, such pre-modern instruments are carefully preserved and studied, because these extant specimens of astronomical instruments are, like the literary documents, important sources for the history of science and technology.

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tatturyakendre viniyojya paṭṭīṃ triṃśatpadāṅkāṃ sahalambasūtrām ||
randhrordhvabāhūpari kīlayugmaṃ sarandhrakaṃ prāntagataṃ vidadhyāt |

Since nobody has so far documented Indian astronomical instruments in this manner, I began to make a systematic study of these instruments some years ago. Like Indian manuscripts, paintings, sculpture and other artifacts, several pre-modern astronomical instruments also were taken to various European museums during the colonial period. Fortunately, in these foreign museums Indian objects are more carefully preserved than they are in India. It is also much easier for scholars to get access to these objects for study than is the case in India, provided of course they can reach these countries. I have so far located and studied about 450 Indian astronomical instruments which are preserved in about 100 museums and private collections in India, Europe and the USA. These will be described with full technical details in my *Descriptive Catalogue of Indian Astronomical and Time Measuring Instruments* which is under preparation.

Of the *Dhruvabhrama-yantra,* I found some twenty specimens in different collections. In these specimens, there is much variation in the outer form of the plate, in the design of the four-armed index and also in the configuration of the concentric scales. Though all the surviving specimens of the *Dhruvabhrama-yantra* belong to the nineteenth century, the wide variety in the style of execution, in the specification of the scales, and the wide geographical distribution indicate the popularity of the instrument which may be true in the earlier centuries as well.

Padmanābha, as we saw, prescribed an oblong plate for the instrument. A majority of the extant specimens have oblong plates. A finely made example is at the Raja Dinkar Kelkar Museum, Pune (Acc. No. KM 31-13). The plate measures 104 x 112 mm. On the front side (see Figure 1) is the *Dhruvabhrama-yantra* with a horizontal slit at the top, below which are seven concentric scales. At the centre is pivoted a beautifully crafted four-armed index. In the middle of the index is engraved a lotus with eight petals in each of the four layers. The shortest arm, on which a face is engraved, has a hole at the bottom for suspending the weight which keeps it in a vertical position always. On the reverse side (see Figure 2) is the sine quadrant (*Turīya-yantra*), where 24 vertical lines are drawn (instead of 30) which are partly obliterated. There is a degree scale on the arc. Beyond the arc is the elegant outline of an eight-petalled lotus which matches with the lotus on the observe side. Originally there was an index, but it is now lost. The copper pin which held the index can be seen at the apex of the quadrant.

Fortunately there are some important inscriptions on this instrument which tell where and for whom this instrument was made. On the front, above the horizontal slit, is engraved *akṣabhā 4|20.* To the left of the slit is engraved *pa ḷāṃśa* 20. This means that this *Dhruvabhrama-yantra* was prepared for the latitude of 20 degrees where the equinoctial shadow (*akṣabhā*), that is the shadow thrown by a gnomon of 12 *aṅgulas* at equinoxes measures 4 *aṅgulas* and 20 *vyaṅgulas.* On the reverse side, above the horizontal slit, is engraved *ukala-grāma-sthita yado josi,* "Yado Joshi, resident of Ukala village." Yado Joshi must be the astronomer for whom this instrument was made. It is very likely that Ukala, his place of residence, is the same as the modern Akola which lies roughly on the latitude of 20 degrees (lat. 20⁰ 42′ N, long. 77⁰ 02′ E). However, there is no inscription stating when it was made and by whom.

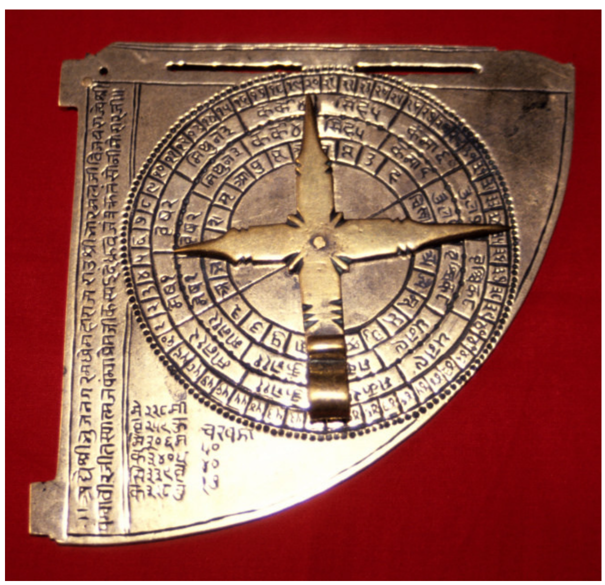

Figure 3: *Dhruvabhrama-yantra*
made by Soni Morarjī for Paṇḍyā Premajī
in 1815 at Bhuj, latitude 22⁰30′.
Paris Observatory.

While a majority of the *Dhruvabhrama-yantras* have the oblong shape, there are some in the shape of a quarter circle, imitating the outline of the quadrant engraved on the reverse. For example, there are two nearly identical specimens in quarter circle format. One of these is now preserved in the Museum of the History of Science at Oxford. The other is with the Paris Observatory[1] (Figure 3). There are inscriptions stating that a goldsmith named Morarjī made these for an astronomer called Paṇḍyā Premajī, on Saṃvat 1872 (elapsed) Śaka 1738 (current) Jyaiṣṭha vadi 11 (= Friday, 2 June 1815). The instrument was calibrated for the city of Bhuj, in Gujarat, situated on the latitude of 22 degrees and 30 minutes.

Figure 4: *Dhruvabhrama-yantra,* anonymous, not dated. Obverse.
Shri Sanjay Sharma Memorial Museum, Jaipur.

1. On this specimen, cf. Verdet.

Besides the oblong and quarter circle format, there are also specimens engraved on circular plates. The Sanjay Sharma Memorial Museum, Jaipur, has two such specimens, one of which is illustrated here (Figure 4). It has a diameter of 242 mm. The index is rather large, in the form of a stepped up rectangle, with pointed tips in the four cardinal directions. On the three arms are written, in careless script, the elements to be indicated by each arm. Thus the arms indicate, for any moment of the night, the culmination (*daśama-bhāva*), the ascendant (*lagna*) and the sidereal time in *ghaṭīs* respectively. To the southern arm are attached two formed strips of metal, with large slits in the middle. The two strips are joined by a hinge so that the second one can be folded back when not in use or stretched out when in use. These two strips weight the southern point and pull it downwards.

Likewise, there is much variation in the configuration of the circular scales. Of the seven scales prescribed by Padmanābha, three are essential, viz. the *ghaṭī* scale, the scale of right ascensions and that of the oblique ascensions. Often the instrument makers leave out the scales with *nakṣatras.* In one specimen at the Victoria and Albert Museum, London, the scale of the right ascensions is left out, so also the middle pointer in the index. Consequently, this specimen is designed to measure just the sidereal time and the ascendant.

As regards the four-armed index, each instrument maker usesd his own imagination and created highly interesting designs, as can be seen in Figures 1, 3 and 4.

Padmanābha prescribes a sine quadrant for the reverse side. But several specimens contain horary quadrants to measure time directly on separate scales for each season. The sine quadrant is more sophisticated but the horary quadrant is more practical.

The *Dhruvbhrama-yantra* attracted the attention also of some Muslim astronomers who are familiar with the elements of Sanskrit astronomy. They produced similar instruments with Persian legends and numerals. They called this instrument with the Persian name *Shabnumā-wa-Rūjnumā,* which means "night-indicator and day-indicator", because the observe side of the *Dhruvabhrama-yantra* is the "night-indicator" and the reverse side is the "day-indicator". We do not know who made such instruments first and when. All that we know are two specimens of this Persian version. One, made by Naṣīr al-Dīn Ḥusayn in 1803 is with the Khuda Bakhsh Oriental Public Library, Patna.[1] The other, made by Mīrzā Afḍal 'Alī 'Āmil, is in the Rampur Raza Library.[2] This one is not dated, but must have been made in the nineteenth century, like many surviving specimens of the *Dhruvabhrama-yantra.*

Appendix

Classification of the Quadrilaterals

> DBAC 2: *āyataśabdena kim ucyate | caturasrāṇām eko bheda āyatam | pūrvaiś caturasraṃ ṣaṭprakāram uktam | tad yathā | prathamaṃ samacaturasraṃ dvitīyam āyatam tṛtīyaṃ viṣamacaturasram | tad api caturdhā | samānalambam asamāmānalambaṃ tulyakarṇam atulyakarṇaṃ ceti | eṣām caturṇāṃ madhye mukhyau dvau bhedau | tulyātulyakarṇatve samalambam asamalambam ceti dvau bhedau | evaṃ catuṣprakāraṃ caturasram uktam | etad uktaṃ bhavati| sarveṣāṃ bhujānāṃ dairghyasamatve karṇayoḥ samatve ca yac catuṣkoṇam utpadyate tat samacaturasram ucyate | ubhayor bhujapratibhujayor dairghyasamatve karṇayoḥ samatve ca yad utpadyate tad āyatacaturasram | bhujānām asamatve karṇayoś cāsamatve lambayoḥ samatve yad utpadyate tat samānalambaviṣamacaturasram | bhujānām asamatve karṇayor lambayor asamatve yad utpadyate tad viṣamacaturasram ity ucyate | tataḥ pūrvācāryaiś caturbhujasya kṣetraphalaṃ pṛthak pṛthak catuṣprakāram uktam | tad yathā |*
>
> *samaśrutau tulyacaturbhuje ca*
> *tathāyate tadbhujakoṭighātaḥ |*

1. For a description of this instrument, see Sarma, "A Brief Introduction to the Astronomical Instruments preserved in Khuda Bakhsh Library, Patna."
2. For a description of this specimen, see Sarma, *Astronomical Instruments in the Rampur Raza Library,* pp. 88.

caturbhuje 'nyatra samānalambe
lambena nighnaṃ kumukhaikyakhaṇḍam ||

atulyalambe bhujayogakhaṇḍaṃ
bhujonitaṃ tadvadhavargamūlam |

dvitrāṇi khaṇḍāni vidhāya yad vā
teṣāṃ phalaikyaṃ bhavati sphuṭaṃ hi ||

sarvāsamānām iti tac caturdhā
kṣetraṃ pradiṣṭaṃ trividham hi kaiścit ||

ity atrāyatam uktam |

What is an oblong (*āyata*)? It is a variety of quadrilateral (*caturasra*). Six varieties of quadrilaterals were mentioned by the ancients. The first is the square (*sama-caturasra*), the second the oblong (*āyata*) and the third the uneven quadrilateral (*viṣama-caturasra*). The last one is again fourfold: having equal altitudes (*samāna-lamba*) and having uneven altitudes (*asamāna-lamba*); with equal diagonals (*tulya-karṇa*) and with unequal diagonals (*atulya-karṇa*). Of these four, there are two main varieties: those with equal altitudes and those without, the diagonals being equal or unequal. Thus the quadrilateral is said to have four varieties. In this context, the following needs to be stated (*etad uktaṃ bhavati*). The quadrilateral, produced when the length of all [four] sides is equal and that of the [two] diagonals is equal, is called the square (*sama-caturasra*). That which is produced when the lengths of the two pairs of opposite sides are equal and when the two diagonals are also equal is called the oblong rectangle (*āyata-caturasra*). When the sides are unequal and the diagonals are also unequal but the altitudes are equal, the figure is called trapezium (*samānalamba-viṣama-caturasra*). When the sides are unequal, and the diagonals and the altitudes are also unequal, the figure thus produced is called an uneven quadrilateral (*viṣama-caturasra*). Therefore, the area (*kṣetraphala*) of the quadrilateral (*caturbhuja*) was taught in four different ways by the past masters thus:

"In the case of an oblong in which the diagonals are equal and the four sides are equal, [the area is] the product of the base (*bhuja*) and the perpendicular (*koṭi*). In other quadrilaterals, where the altitudes (*lamba*) are equal, [the area is] the product of the altitude and half the sum of the base and the face (*ku-mukhaikya-khaṇḍa*).

"When the altitudes are [also] unequal, [the area is] the square-root of the product of half the sum of [all fours] sides diminished [severally] by [each] side. Alternatively, make two or three [triangular] segments; the sum of their areas will clearly become [the area] of [quadrilaterals in which] all [the elements] are unequal (*sarva-asama*). Thus the area is stated to be fourfold, or threefold according to some [authorities]."

Thus the oblong (*āyata*) has been explained.

Acknowledgements

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