Tarikh-e Elm, 9(2011), pp. 21-48

Shabnumā-wa-Rūznumā
A Rare Astronomical Instrument Extant in Two Specimens

Sreeramula Rajeswara Sarma
Formerly Professor of Sanskrit, Aligarh Muslim University, India
sr@sarma.de

Mohammad Bagheri
Institute for the History of Science, University of Tehran, Iran
mohammad.bagheri2006@gmail.com

(received: 05/07/2011-accepted: 20/09/2011)

Abstract

In India, there are extant two nineteenth century specimens of an otherwise unknown astronomical instrument called *Shabnumā-wa-Rūznumā* with which observations can be done both in the day and at night. While the *Rūznumā* is nothing but a sine/horary quadrant, the *Shabnumā* appears to be inspired by the Sanskrit instrument *Dhruvabhrama-yantra* which was invented by Padmanābha in the first quarter of the fifteenth century in Central India. After a brief description of the *Dhruvabhrama-yantra,* the two specimens of the *Shabnumā-wa-Rūznumā* are described in detail.

Keywords: Ascendant, culmination, *Dhruvabhrama-yantra, Shabnumā-wa-Rūznumā,* horary quadrant**.**

Introduction

One of the fascinating aspects of the history of science is the transmission of ideas and instruments across geographical boundaries, cultures and languages. The most notable example is the astrolabe, which was invented sometime before the Common Era in the Hellenistic antiquity, and which was received, preserved and enriched in the Islamic world, and transmitted westwards up to England and eastwards up to India, where it was hailed as the "king of instruments" (*yantra-rāja*) in Sanskrit. In India, the cultivation (i.e. the study, use and production) of the astrolabe ran in two parallel streams. While the Muslim astronomers studied the Arabic and Persian manuals on the astrolabe and produced /made use of astrolabes with Arabic/Persian numerals and legends, the Hindu and Jain astronomers had to overcome the linguistic barrier of Arabic/Persian. They composed Sanskrit texts on the astrolabe and got made astrolabes with legends in Sanskrit language and Devanagari script (cf. Sarma, "Yantrarāja: The astrolabe in Sanskrit").

A reverse case of transmission is exemplified by a Sanskrit instrument called *Dhruvabhrama-yantra* which appears to have inspired the production of the *Shabnumā-wa-Rūznumā* by the Muslim astronomers of India. Two nineteenth century specimens of this rare instrument are extant in Indian collections, which will be described in the following pages. Before discussing these two specimens, it is necessary to introduce the *Dhruvabhrama-yantra* briefly.

The *Dhruvabhrama-yantra* of Padmanābha

The *Dhruvabhrama-yantra* was invented in the first quarter of the fifteenth century by Padmanābha.[1] He wrote three small tracts on the construction and use of three different instruments, viz. *Yantrarājādhikāra*[2] on the southern astrolabe (Sanskrit *yāmya-yantra*, Arabic *asṭurlāb janūbī*), the *Dhurvabhramādhikāra* on the *Dhruvabhrama-yantra* and the *Diksādhana-yantra* on an instrument of the

1. On the Sanskrit works by this and the other astronomers to be mentioned below, see the relevant pages of Pingree's *Census of the Exact Sciences in Sanskrit.*
2. Yukio Ohashi prepared an excellent critical edition, English translation and mathematical commentary of this work in his *The Early History of the Astrolabe in India* (see References).

same name. The southern astrolabe is an unusual variety of astrolabe,[1] whereas the *Diksādhana-yantra* is a simple instrument to determine the cardinal directions.[2] Padmanābha wrote also commentaries on the *Yantrarājādhikāra* and *Dhruvabhramādhikāra.*

We know very little about Padmanābha's personal life, save that he belongs to a family of astronomers. Both his father Nārmada and his son Dāmodara authored works on astronomy. In his *Dhruvabhramādhikāra* (verses 21-26), Padmanābha gives the meridian altitudes (*madhyonnatāṃśas*) of the lunar mansions for the terrestrial latitude of 24º. He must, therefore, belong to some place in Central India, close to this latitude. Again, in his *Yantrarājādhikāra,* he gives the precession (*ayanāṃśa*) for the Śaka year 1345 (= 1422-23 AD), which can be the year of composition of this work (Ohashi, *The Early History*…, pp. 217 and 249). Padmanābha's son, Dāmodara, composed his *Sūryatulya* in Śaka 1339 (=1416-17 AD). Thus both Padmanābha and his son must have flourished in the first quarter of the fifteenth century somewhere in Central India.

The *Dhruvabhramādhikāra* is a small tract of 31 verses, which is accompanied by an auto-commentary in prose. Some seventy manuscript copies are known to exist, but the work is not yet published. The text describes the construction and use of the *Dhurvabhrama-yantra,*[3] which is a kind of nocturnal, i.e. a dial to be employed at night. *Dhruvabhrama-yantra* literally means the instrument (*yantra*) based on the rotation (*bhrama*) around the Pole (*dhruva*), that is to say the rotation of the stellar sphere around the Pole. Hence the construction of this instrument is

1. Nearly all the surviving astrolabes are northern astrolabes (*asṭurlāb shamālī*) where the centre of projection is at the South Pole. The centre of the northern astrolabe represents the North Pole and stars marked on the rete are those which are situated to the north of the Tropic of Capricorn. As against this, in the southern astrolabe (*asṭurlāb janūbī*), the centre of projection is at the North Pole. The centre of the astrolabe represents the South Pole and the stars marked on the rete are those which are situated to the south of the Tropic of Cancer. The southern astrolabe is a theoretical curiosity; there are hardly any extant specimens.

2. On 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; see Ohashi, *The Early History of the Astrolabe in India*, p. 217.

3. For a description of the instrument, see Garrett & Guleri, 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.

based on the diurnal rotation of the stellar sphere around the celestial poles. If the two stars Polaris (α Ursae Minoris) and Kochab (β Ursae Minoris) are joined by an imaginary straight line, this line would rotate like the hand of a clock, making a full circle in a sidereal day of 23 hours and 56 minutes. The *Dhruvabhrama-yantra* creates an artificial straight line joining α UMi, which is close to the North Pole, with β UMi and measures the amount of the rotation made by the straight line in degrees of arc and then translates these arc-degrees into time units.

This instrument consists of an oblong metal plate with a narrow horizontal slit close to the upper edge and parallel to it (see Fig. 1). Below the slit are drawn several concentric circular scales with divisions and labels. The outermost annulus or circular scale is divided into 60 cells, each of which represents the traditional Indian time unit of *ghaṭī* of 24 minutes. These *ghaṭī*s 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 22nd *ghaṭī*.[1] To put it differently, if we divide the circle into 360º from topmost point which indicates the beginning of the 22nd *ghaṭī* and number the degrees serially clockwise, then the *ghaṭī* scale and all other scales commence from 234º.[2] The innermost annulus is divided into 12 unequal units, in accordance with the oblique ascensions of the 12 signs of the zodiac, relative to the place of observation. The middle scale is divided into 12 equal units to represent the right ascensions of the zodiac signs. There are additional scales in between containing the names of these two sets of the zodiac

1. Cf. Garrett & Guleri, pp. 63-64: "Now when Beta Ursae Minoris is due east of the Pole Star, the sidereal time is approximately 8 hours 48 minutes or 22 *ghaṭī*s. But the Hindus reckon their time from the instant of the rising of the equinox on the eastern horizon, whereas we reckon from the equinox on the meridian. The difference is evidently six hours. Hence subtracting 6 hours or 15 *ghaṭī*s, we get 2 hours 48 minutes or 7 *ghaṭī*s as the Hindu sidereal time. If now the Dhruvabhrama Yantra be held in a vertical plane, so that the Pole Star and Beta Ursae Minoris are both seen through the slit, which in this case will be horizontal, then the west indicator must point to 7 *ghaṭī*s, as in the plate, and having fixed the west point in this manner, the whole ring is divided into the usual graduation of 60 *ghaṭī*s of 6 degrees each. Then the other rings can be graduated as described above."

2. Padmanābha does not explain the reason for choosing 234º as the starting point for all the scales, but he must have empirically arrived at this arrangement of the *ghaṭī* scale by observing the position of the stars α and β Ursae Minoris at his place situated on the latitude of 24º.

signs, their sub-divisions, and also the lunar mansions (*nakṣatra*s) pertaining to these two sets.

Fig. 1: *Dhruvabhrama-yantra*, Obverse showing the *Dhruvabhrama*
Jai Singh's Observatory, Jaipur

Loosely pivoted to the centre of the plate is a metal index with four arms or pointers, projecting into the four cardinal directions. These pointers should be at right angles to one another and of unequal length. The eastern pointer is the shortest one and reaches up to the innermost scale of the zodiac signs rising at the observer's latitude (i.e. oblique ascensions). The northern pointer is of middle length to reach the central scale to point the signs culminating at the upper mid-heaven. The western pointer is the longest one and reaches the outermost scale of *ghaṭī*s. The southern arm is actually not a pointer but a plumb. Either a separate plumb is attached to this arm, or the arm itself is made considerably heavier than the others, so that it always points downwards, irrespective of the tilt of the plate. It thus offers a vertical line of reference against a scale of 360 degrees.

Method of Observation

At night, the instrument is held in the vertical plane and so rotated that the two stars α and β of Ursa Minor become visible in a straight line through the slit. Then the tip of the eastern arm will indicate the ascendant, i.e., that point of the zodiac sign which is rising in the east at that moment. The middle arm will show the culmination or the upper mid-heaven, i.e., the point of the a zodiac sign which is crossing the meridian.

Finally, the western arm will show the sidereal time on the *ghaṭī* scale. Let the point on the *ghaṭī* scale where the pointer rests be called *A*. The *ghaṭī*s, it must be remembered, are not counted from the midnight or midday, which are constant, but from the sunrise and sunset, which are variable according to one's location and the seasons, or according to the sun's longitude. Therefore, certain manipulations are necessary to find out the time in traditional terms. First, find out the sun's longitude for that day from an almanac. Move the eastern arm to the sun's longitude as measured on the scale of oblique ascensions. Note the position of the western pointer. Let it be *B*. Then the distance *BA* represents the *ghaṭī*s to come in the night up to the sunrise (*eṣya-ghaṭī*s). Again move the eastern arm by 6 signs and note the new position of the western arm. Let it be *C*. Then the distance *AC* gives the number of *ghaṭī*s that have elapsed in the night up to the time of observation (*gata-ghaṭī*s). Thus at the moment of observation, *AC ghaṭī*s elapsed in the night since the previous sunset, and *BA ghaṭī*s are yet to pass up to the next sunrise, then *BC* is the duration of the night.

As mentioned before, at the time of observation, the eastern arm points to the ascendant and the middle arm to the culmination. These two points on the ecliptic, where it intersects the local horizon and the local meridian respectively, are important in preparing horoscopes. Horoscopy requires the calculation of the four points on the ecliptic where it intersects the horizon and the meridian for a given moment. These points, called the four pivots (Arabic *awtād*), are the following:

1. The ascendant (Sanskrit: *lagna,* Arabic: *ṭāli*[c]), i.e. the degree of the ecliptic that is on the eastern horizon;
2. The descendent which is diametrically opposite the ascendant (Sanskrit: *asta-lagna, saptama-bhāva*; Arabic: *al-sābi*[c]*, watad al-ghārib*), i.e. the degree of the ecliptic that is on the western horizon;
3. The culmination or the degree of upper mid-heaven (Sanskrit: *daśama-bhāva*; Arabic: *al-*[c]*āshir, wasaṭ al-samā'*), i.e. the degree of the ecliptic that is on the upper meridian;
4. The lower mid-heaven which is diametrically opposite the upper mid-heaven (Sanskrit: *pātāla, caturtha bhāva*; Arabic: *al-rābī*[c]*, watad al-'arż*), i.e. the degree of the ecliptic that is on the lower meridian.

To compute these four points mathematically is a tedious process. But they can be read off, without any computation, directly from the dial of the *Dhruvabhrama-yantra,* just as they can be read off from the astrolabe. When these four key points are known, the twelve astrological houses (Sanskrit: *bhāva*; Arabic: *buyūt*) can be easily determined and the various planets assigned to them.

Sine Quadrant on the Reverse

The plate of the *Dhruvabhrama-yantra* described so far can be used only at night. Padmanābha desires that it can be used also in the daytime. Therefore, he prescribes that the reverse side of the oblong plate is fashioned as a sine quadrant. This is the first mention of the sine quadrant in Sanskrit. It was invented at Baghdad in the ninth century. Later 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 Common Era. Padmanābha explains the construction and use of the sine quadrant. The sine quadrant can measure the time, the altitudes of heavenly bodies, and solve trigonometric problems. Though primarily meant for use in the day-time, it can also be employed at night by sighting a fixed star whose meridian altitude is known.

Thus the *Dhruvabhrama-yantra* designed by Padmanābha in the first quarter of the fifteenth century is a multi-purpose instrument. With the *Dhruvabhrama* engraved on the obverse side of the plate, one can find out the sidereal time and read off the four points on the ecliptic which is essential for preparing horoscopes. From the sine quadrant inscribed on the reverse, one can find the elevation of heavenly bodies, measure time in the day or at night, and solve trigonometric problems.

Extant Specimens of the *Dhruvabhrama-yantra*

About twenty specimens of the *Dhruvabhrama-yantra* are extant in different collections in India, Europe and the US. In 2010, a nice specimen came for auction at the Sotheby's of London (Sotheby's, lot 125, pp. 90-91). In these specimens, there is much variation, not only in the outer form of the plate and the design of the four-armed index, but also in the configuration of the concentric scales. Although Padmanābha prescribes that the reverse side should be prepared as a sine quadrant (Fig. 3), there are also specimens which contain a horary quadrant instead of the sine quadrant (Fig. 2).

Fig. 2: *Dhruvabhrama-yantra*, Reverse showing the Horary Quadrant, Jai Singh's Observatory, Jaipur

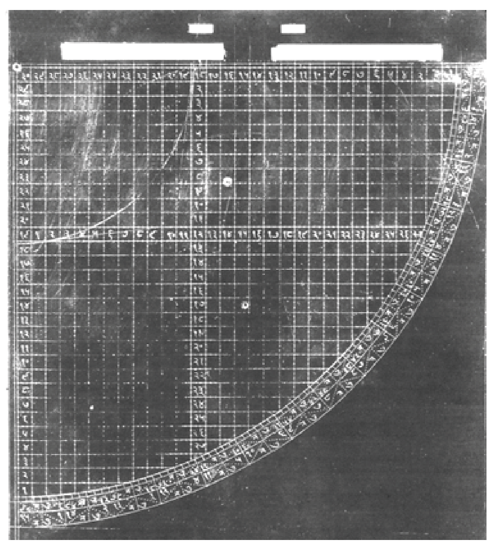

Fig. 3: *Dhruvabhrama-yantra*, Reverse showing the Sine Quadrant, Columbia University, New York

Almost all the surviving specimens of the *Dhruvabhrama* belong to the 19th century. The wide variety in the style of execution and in the arrangement of scales indicates the popularity of the instrument in the nineteenth century; this may be true of the earlier centuries as well. In fact, it appears to be the most popular instrument after the astrolabe.

***Farqadayn* in Navigation**

At the beginning and end of his work, Padmanābha boasts that, while other instruments make use of the sun or of the fixed stars, his is the only instrument which makes use of the Pole Star or Polaris.[1] With this statement he seems to imply that his invention is an improvement on the astrolabe, which uses only the sun or some fixed stars for observation, but not the Pole Star. It may be recalled that Padmanābha wrote also a manual on the southern astrolabe and thus was well versed in the science of the astrolabe. Moreover, the sine quadrant which Padmanābha prescribes for the reverse side of his *Dhruvabhrama-yantra* is borrowed from the sine quadrant usually inscribed on the back of the astrolabe. But whether his newly invented *Dhruvabhrama-yantra* is an improvement over the astrolabe is open to question. Even among Hindu astronomers, the astrolabe which they called "king of instruments" (*Yantrarāja*) was very popular. Judging from the number of surviving specimens, the *Yantrarāja,* that is, the astrolabe with Sanskrit notations, was produced far more frequently than the *Dhruvabhrama-yantra*. On the other hand, the *Yantrarāja* did not completely suppress the *Dhruvabhrama-yantra* which continued to be produced and used well into the 19th century.

Be that as it may, in designing the *Dhruvabhrama,* Padmanābha may have been inspired by the navigational practices in the Indian Ocean area. The *Dhruvabhrama-yantra* makes use of the phenomenon of the apparent diurnal rotation of the stellar sphere around the poles; in particular, the rotation of the star Kochab (β UMi) around the Polaris (α UMi). This phenomenon may be noticed

1. *Dhruvabhramādhikāra,* verse 1, commentary: "All the instruments measure time and other elements according to the sun or according to the fixed stars. This one, however, shows time according to the Pole Star. Therefore it is called best of the instruments." Ibid, verse 31: "[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, this has been done [by us]."

more clearly on the sea or in a desert. If one joins the Pole Star with Kochab by an imaginary line, this line appears to rotate like the hand of a clock. So does a line joining α and β in the constellation Ursa Major and the Pole Star (α UMi).

Therefore, sailors made use of these or related phenomena for geographical orientation and for time measurement. For Arab sailors, β UMi (*anwar al-Farqadayn,* "the brighter of the two calves," i.e., the star on the front leg of the Small Bear) and γ UMi (*akhfā al-Farqadayn,* "the more obscure of the two calves," i.e., the star over the shoulder of the Small Bear) were important. These two were known as *Farqadayn*, the "two calves" or the "two guards of the Pole". On the use of the *Farqadayn* in navigation, Tibbets, p. 337, remarks as follows:

> "The *Farqadān* [=*Farqadayn*] were most important in the Indian Ocean navigation because they were the brightest stars in the vicinity of the Pole, were circumpolar and never at any great distance from the meridian. They were thus the most prominent objects on the northern horizon immediately after the Pole Star has disappeared and measurements taken from them in any position were relatively accurate. Like the Mediterranean navigators the Arab navigators recognized eight positions of the Guards [i.e., *Farqad*s], two horizontal, two vertical together with the two culminations and two extreme positions of the Greater *Farqad* (β Ursae Minoris). There were four other positions being the culmination and extreme positions of the smaller *Farqad*, but they were not so important."

The same phenomenon gave rise to another related instrument, viz. the European nocturnal. While the *Dhruvabhrama-yantra* makes use of α and β of Ursa Minor, the European nocturnal makes use of α and β of Ursa Major. More precisely, the construction of the *Dhruvabhrama-yantra* is based on the diurnal rotation of the imaginary line joining the α and β of Ursa Minor, whereas the construction of the European nocturnal is based on the diurnal rotation of the line joining the α and β of Ursa Major with the Pole Star, i.e. α UMi. The European nocturnal was first mentioned by Martin Cortes in *Arte de Navegar* in 1551A.D. (Wynter & Turner, 69; Bud, 414-418), that is, about one and half centuries after the invention of the *Dhruvabhrama-yantra.* In the present state of knowledge, it is difficult to decide whether Padmanābha's *Dhruvabhrama-yantra* has inspired the European nocturnal, but it is certain that it has inspired an instrument called

Shabnumā-wa-Rūznumā. It is also reasonably certain that the latter was designed in India by Muslim astronomers who were familiar with the elements of Sanskrit astronomy and calendar, because the *Shabnumā-wa-Rūznumā* makes use of Indian units of time measurement, viz. *ghaṭī* and *prahara.* The *ghaṭī,* as has been mentioned above, is the one-sixtieth part of the nychthemeron and equals 24 minutes; the *prahara* (Hindi *pahar;* Persian *pās*) is the one-fourth part of the day or of the night and varies according to seasons. We do not know exactly when and by whom this instrument was designed. It does not seem to have been mentioned in any Arabic or Persian text. The *Jāmi*[c] *Bahādur Khānī* by Ghulām Ḥusayn Jaunpūrī (1790-1882 AD), which is an encyclopaedia of mathematics and astronomy, describes the construction and use of twelve contemporary astronomical instruments in the second chapter of the fifth book (cf. Ansari & Sarma), but it does not mention the *Shabnumā-wa-Rūznumā.* All that we know about this instrument is from two extant specimens which were produced in northern India in the 19th century. These will be described in the following pages.

Shabnumā-wa-Rūznumā by Nadhīr al-Dīn Ḥusayn 1218 AH/1803 AD

The Khuda Bakhsh Oriental Public Library at Patna[1] owns a specimen, which is probably the earlier of the two extant pieces (Sarma, "A Brief Introduction to the Astronomical Instruments Preserved in Khuda Bakhsh Library, Patna"). The inscription on it states that it was made by Nadhīr al-Dīn Ḥusayn on the orders of Munshī (secretary/clerk) Ṣāhibwālā-Sha'n (the honourable) Lāleh Pīārī La[c]l in *Rabi*[c] *al-awwal* 1218 AH (= 20 June-19 July 1803 AD) at Bareilly. The instrument was calibrated for the latitude of 28º N, which is approximately the latitude of Bareilly (modern values are 28º 22' N and 79º 27' E). Bareilly is situated in the present federal state of Uttar Pradesh (India). The workmanship on this instrument is neat and the instrument is well preserved. The instrument consists of an oblong copper plate measuring 178 x 174 mm.

1. Khuda Bakhsh Oriental Public Library (http://kblibrary.bih.nic.in/) is an Institution of National Importance and is administered by the Ministry of Culture, Government of India. It is an important repository of Indo-Islamic art and literature in India, with some 21,000 manuscripts and 250,000 printed books. Originally it was the personal library of Maulavi Khuda Bakhsh (1842-1908) who dedicated it to the public in 1891.

Shabnumā

The obverse side of the plate is engraved as the *Shabnumā* or the night indicator (Fig. 4). There are eight concentric circles forming seven annuli. At the centre are pivoted two copper strips, measuring 95 and 90 mm respectively. These function as the indices. On these are engraved the arguments of the annuli, i.e. labels explaining the divisions marked on the seven annuli. For the sake of reference, we divide the circles into 360º from the topmost point.

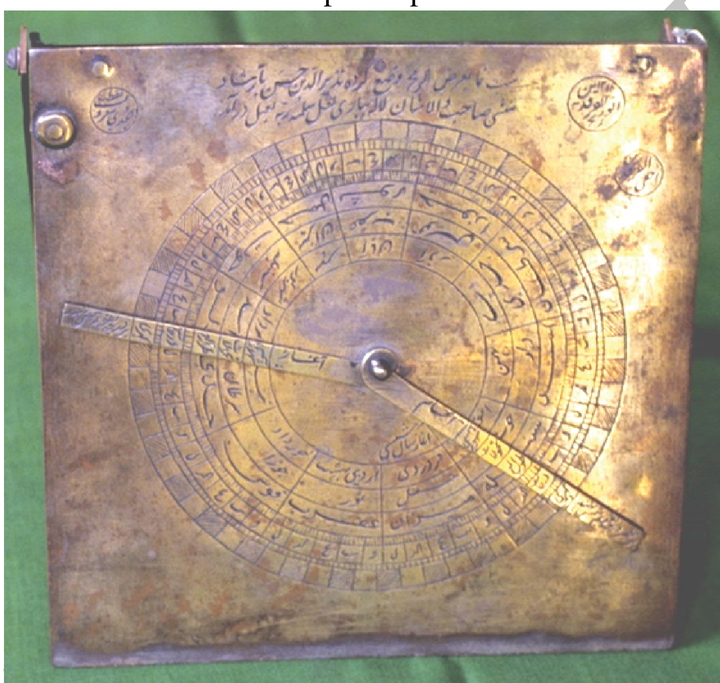

Fig. 4: *Shabnumā-wa-Rūznumā,* Observe showing the *Shabnumā*
Khuda Bakhsh Oriental Public Library, Patna.

Reading from outside, the seven annuli contain the following scales.

1. Label *gahrī* (Sanskrit: *ghaṭī*). The circle is divided into 60 cells, each cell representing one *ghaṭī.* Every alternative cell is hatched with fine lines parallel to the diagonal. This facilitates the counting of the *ghaṭī*s. The cells are not numbered.

2. Subdivisions of *ghaṭī*s. Here each *ghaṭī* is subdivided into 4 parts of 6 minutes each.
3. Label *darajāt* (degrees). The circle is divided into 12 signs, and each sign is divided into 5 units of 6º each. These 5 units are labelled in *abjad* notation as 6, 12, 18, 24, 30 in the clockwise direction.
4. Degree scale. Each group of 6º in the previous scale is further divided into single degrees.
5. Label *ṭawāli*ᶜ (ascendants). The circle is divided into 12 units and on each the name of a zodiac sign is written in clockwise direction. The first sign *Ḥamal* (Aries) starts at 325º. We do not know the significance of this starting point.
6. Label *taḥwīlāt* (sun's passages from one sign to the other). The circle is divided into 12 units and on each the name of a zodiac sign is written in clockwise direction. Here the first sign Aries starts at 145º, i.e., at a point diametrically opposite the point where Aries starts in the previous scale. Thus the signs in these two scales are separated by 6 signs or 180º.
7. Label *shuhūr shamsī* (solar months). The circle is divided into 12 units and on each the name of an Iranian solar month is written in clockwise direction. The starting point is the same as in the previous annulus, because the solar months are based on the sun's entry into each zodiac sign.

The divisions in last three scales (5, 6, 7) are congruent, but not of uniform magnitude. The difference arises, because these were drawn according to rising times of the signs at the latitude of 28º at Bareilly. The elements of these three scales are arranged below vertically, with corresponding units in each row. The first column (I) corresponds to the label "ascendants" on the two indices, the second column (II) to the label "transfers", and the third (III) to the label "solar months" (see below). The third column provides the names of the Iranian (solar) months. Just above the name of the first Iranian month (*Farvardīn*), it is engraved آغاز سال شمسی (beginning of the solar year).

	I	II	III
1	میزان (Libra)	حمل (Aries)	فروردین (*Farvardīn*)
2	عقرب (Scorpio)	ثور (Taurus)	اردیبهشت (*Urdībihisht*)
3	قوس (Sagittarius)	جوزا (Gemini)	خرداد (*Khurdād*)
4	جَدی (Capricorn)	سرطان (Cancer)	تیر (*Tīr*)
5	دلو (Aquarius)	اسد (Leo)	مرداد (*Murdād*)
6	حوت (Pisces)	سنبله (Virgo)	شهریور (*Shahrīvar*)
7	حمل (Aries)	میزان (Libra)	مهر (*Mihr*)
8	ثور (Taurus)	عقرب (Scorpio)	آبان (*Ābān*)
9	جوزا (Gemini)	قوس (Sagittarius)	آذر (*Ādhar*)
10	سرطان (Cancer)	جَدی (Capricorn)	دی (*Day*)
11	اسد (Leo)	دلو (Aquarius)	بهمن (*Bahman*)
12	سنبله (Virgo)	حوت (Pisces)	اسفندار (*Isfandār*)

Inscriptions

The obverse side constituting the *Shabnumā* carries the following inscriptions. On the top of the instrument is engraved the following in two lines:

شب نما بعرض کز مح وضع کردهٔ نذیرالدین حسین بارشاد منشی صاحب والاشأن لاله پیاری لعل سلّمه ربّه بعمل در آمد.

"Night[-time] indicator for the [geographical] latitude 27 [degrees and] 48 [minutes], designed by Nadhīr al-Dīn Ḥusayn, implemented under the guidance of the esteemed Munshī Ṣāḥib Lāleh Piārī –may his God save him."

To the left of the above inscription, there is a circle containing the following label:

الجُدَی معروف بقطب

"Polaris known as the Pole [Star] (α Ursae Minoris)."

To the right of the inscription, there are two circles containing the following labels:

أنور الفَرقَدین

"The brighter one of the two Guards [of the Pole] (β Ursae Minoris);"

أخفى الفَرقَدين

"The fainter one of the two Guards [of the Pole] (γ Ursae Minoris)."

On the two indices pivoted at the centre, the following labels are engraved, starting from the centre and reaching up to the lower end:

انجام	آغاز
End	Beginning
شهور شمسی	شهور شمسی
(solar months)	(solar months)
تحویلات	تحویلات
(transfers)	(transfers)
طوالع	طوالع
(ascendants)	(ascendants)
درجات	درجات
(degrees)	(degrees)
گهری	گهری
(Gahrī)	(Gahrī)
بر نظیر درجهٔ تقویم شمس نهند	بر درجهٔ تقویم شمس نهند
(to be placed on the opposite of the degree of the sun's true longitude)	(to be placed on the degree of the sun's true longitude)

Method of observation with the *Shabnumā*

A plumb line is suspended from the centre. At night the instrument is held in a vertical plane and tilted so that α and β or α and γ of Ursa Minor are visible just above the upper edge above the circles carrying their names.[1] Then the position of the plumb line on the *ghaṭī* scale is noted. Let it be *A*. From the almanac the sun's

1. The Rampur *Shabnumā,* to be described below, clearly states that α and β UMi or α and γ UMi should be above the edge. The *Dhruvabhrama-yantra* employs only α and β UMi. The *Shabnumā* takes γ UMi also into account.

true longitude is noted and the index on which is written “beginning” and “to be placed on the degrees of the sun’s true longitude” is moved to the point of sun’s true longitude as can be seen on the circle marked *taḥwīlāt.* Let the point at which this index intersects the *ghaṭī* scale be *B*. The other index on which is written “end” and “to be placed on the opposite of the degree of the sun’s true longitude” should be moved to a point opposite to *B*. Here “opposite” does not mean at a distance of 180 arc-degrees, but at a distance of 6 signs on the circle of *taḥwīlāt.* In this circle, all the signs do not occupy the uniform distance of 30 arc-degrees. Therefore the distance of 6 signs can be sometimes more than 180º, sometimes less and sometimes equal to 180º, depending on the sun’s longitude. Let the point where the second index intersects the *ghaṭī* scale be *C*. Then *C* indicates the previous sunset, i.e. beginning of the current night; *CA* shows the number of *ghaṭī*s elapsed since the previous sunset. *B* indicates the end of the current night, i.e. the next sunrise. *AB* indicates the number of *ghaṭī*s to elapse up to the next sunrise. Therefore *CB* is the duration of the night. The point where the plumb line touches the scale of the *ṭawāli*ᶜ shows the ascendant for the moment of observation. Likewise the point where the plumb line touches the scale of *taḥwīlāt* indicates the *taḥwīl.*

This procedure is illustrated in Fig. 4a. Here the sun’s longitude is taken to be the first point of Virgo; the corresponding point on the *ghaṭī* scale is *B*. The index marked *X* on which is written “to be put on the degrees of the sun’s true longitude” is moved to *B* and the index marked *Y* to the point *C* which is removed by 6 signs from *B*. Now *C* indicates the previous sunset, i.e. beginning of the current night. *CA* shows the number of *ghaṭī*s elapsed since the previous sunset, which in the present case is 14 ¾ *ghaṭī*s (= 5 hours and 54 minutes). *B* indicates the end of the current night, i.e. the next sunrise. *AB* indicates the number of *ghaṭī*s to elapse up to the next sunrise, viz. 17 ¼ *ghaṭīs* (= 6 hours and 54 minutes). The time of observation, therefore, is 5 hours and 54 minutes after the sunset or 6 hours and 54 minutes before the sunrise. The ascendant at this moment is 18º Scorpio and the *taḥwīl* is Taurus 18º.

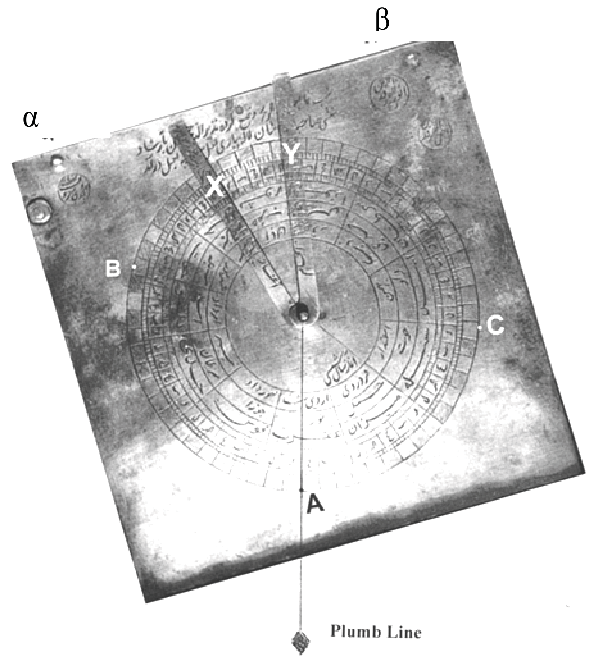

Fig. 4a: Measuring time with the *Shabnumā* at night

Rūznumā

The reverse side of the plate, designated as *Rūznumā,* is actually a sine quadrant (*rub*^{c} *al-mujayyab*) (Fig. 5). A thick bar is welded at the top of the plate, the ends of which are bent at right-angles to the surface of the plate. These two bent portions, each containing two small holes, constitute the sights of the quadrant. The upper hole is larger for sighting the stars at night. The smaller hole is meant for sighting the sun. A long inscription in two lines is engraved on the bar (for the text of the inscription, see below).

The horizontal radius of the quadrant is divided into 31 equal units (it ought to have been exactly 30 units) and from each point of division a line is drawn perpendicular to the radius. Two horizontal lines are drawn parallel to the radius, cutting these perpendiculars at right angles. The upper one is labelled as *ẓill aqdām* *ma'kūs* (umbra versa in [seven] feet), the lower one *ẓill aṣābi*ᶜ *ma*ᶜ*kūs* (umbra versa in [twelve] digits). On these horizontal lines the perpendiculars are numbered in *Abjad* (Arabic alphanumerical) letters, on the upper line from 1 to 30 and on the lower line from 1 to 28 (in both cases starting from the vertical radius). Horizontal parallels are not drawn, but they are marked on two vertical scales (i.e. nos. 7 and 12, as counted from the vertical radius). On these vertical scales, the horizontal parallels are numbered in Persian numerals. The seventh horizontal parallel is labelled as *ẓill aqdām mustawī* (umbra recta in [seven] feet) and the twelfth parallel *ẓill aṣābi*ᶜ *mustawī* (umbra recta in [twelve] digits). Thus the sine quadrant incorporates the shadow squares of 7 and 12 units which are usually engraved on the back of the astrolabe.[1]

Fig. 5: *Shabnumā-wa-Rūznumā,* Reverse showing the *Rūznumā*
Khuda Bakhsh Oriental Public Library, Patna

1. It is interesting that on this sine quadrant two shadow squares are superimposed; one for the shadows thrown by a gnomon of 7 feet, when the gnomon is vertical and when it is horizontal; the other is for the shadows cast by a gnomon of 12 digits, when the gnomon is vertical and when it is horizontal. On the back of astrolabes, the upper left quadrant usually carries a sine quadrant and the lower half the two shadow squares. Here it looks as if the upper left quadrant and the lower half of the astrolabe are combined. The index also carries two scales, one of 12 divisions and the other of 7 divisions, to be used in combination with the shadow squares. This is a very unusual combination rarely to be seen on the sine quadrant.

Three circular scales are engraved on the arc of the quadrant. The innermost scale is divided into 15 units; each unit is further subdivided into 6 single degrees. The groups of 15 degrees are numbered as 6, 12, …, 90 in Persian numerals.

The two lower scales do not cover the entire quadrant; they cover only half the quadrant, from 3º to 48º, starting from the side where the sights are. The lowermost scale carries the names of the zodiac signs in two rows as follows. In the first row the Persian/Arabic names of Gemini, Taurus and Aries are written so the letters stand upright when the apex of the quadrant is upwards; these are followed by the three names Libra, Scorpio and Sagittarius upside down. Below this row are written Cancer, Leo and Virgo upside down; Pisces, Aquarius and Capricorn in upright fashion. This grouping of signs into groups of three is based on the fact that the signs in each column have the same rising times at the equator.

There is a degree scale above these two rows of names. The first unit corresponding to Gemini and Cancer occupies only 3º. It is divided into three parts numbered in Persian numerals as 10, 20, 30 in anti-clockwise direction. The next four units occupy 6º each. Each unit is divided into 5 divisions and numbered both in Persian numerals and in *Abjad* notation as 6, 12, 18, 24, 30 in anti-clockwise direction. The sixth unit corresponding to Sagittarius and Capricorn occupies, like the first unit, just 3º and is divided and labelled like the first.

A 176 mm long graduated index is pivoted at the centre of the quadrant. This index, like the longer index on the obverse, is fashioned as a circle at one end. There is a hole at the centre of the circle, into which the pin at the centre is inserted. The index carries two scales. One scale is divided into 12 units, numbered in Persian numerals. At the end is the label *niṣf al-nahār* (midday). In the other scale there are 7 serially numbered divisions, followed by the label *yak-pās* ("one quarter of the day"); again 7 serially numbered divisions followed by the label *do-pās* ("two quarters of the day").

Inscriptions

At the top of the quadrant, it is explained how to use this instrument at latitudes other than the latitude for which it was made:[1]

روزنما بعرض کح

> "Day[-time] indicator for [the geographical] latitude of 28 [degrees]"

در بلاد دیگر که عرض آن ناقص از کح باشد قدر نقصان تا تمام نود بر غایت ارتفاع کح افزایند و مازاد علیه را از نود بکاهند.

> "In other localities where [the geographical] latitude is less than 28 [degrees], the amount of the deficiency [from 28 degrees] should be added to the maximum altitude [of the sun at the geographical latitude] of 28 [degrees] up to a sum of 90 [degrees]; and [whenever the sum exceeds 90 degrees,] the amount of the excess over it (i.e. over 90 degrees) should be subtracted from 90 [degrees]."

و اگر عرض فاضل بر کح باشد قدر فضل را از غایت ارتفاع کح بکاهند.

> "If the [geographical] latitude is more than 28 [degrees], the amount of the excess should be subtracted from the maximum altitude [of the sun at the geographical latitude] of 28 [degrees]."

Below the arc, to the right of the two scales, in the following inscription:

ربیع الأوّل سنه ۱۲۱۸ هجری فی بلده بریلی

> "[constructed in the Arabic month] *Rabī*^{c} *al-awwal* of the year 1218 of Hejira [era] in the city of Bareilly."

The month *Rabī*^{c} *al-awwal* of the year 1218 AH [era] lasts from 20 June to 19 July 1803. Therefore, the instrument was made some times during this period.

Method of Observation with the *Rūznumā*

The innermost scale calibrated in degrees is for finding the altitude of the sun at any moment of the day. For this purpose, the instrument is held in a vertical position and turned in such a way that the two sights are aligned towards the sun and the index hangs freely (in vertical position). Then the altitude of the sun can be read on the innermost scale. The middle and outermost scales indicate the midday altitude of the sun on any day of the year (when the sun is in the indicated zodiac sign). Since the span of variation of sun's altitude is twice its maximum

1. Padmanābha also proposes a similar method for using the *Dhruvabharma-yantra* at latitudes other than that for which it is calibrated.

declination (2 times 23.5 equal to 47 degrees) the middle and outer scales cover 47 degrees.

The midday altitude is calculated by adding the declination of the sun (on the given day) to the complement of the geographical latitude of the locality. The declination at the summer solstice is 23.5° and at the beginning of Gemini or at the end of Cancer it is a little more than 20°. The change of 3° in the declination leads to a change of 3° in the midday altitude. The same holds true for the change of midday altitude from beginning of Sagittarius to the winter solstice and from winter solstice to the end of Capricorn. Based on the above formula for the midday latitude, for any other locality the difference in geographical latitude should be added to (or subtracted from) the midday altitude at the latitude of 28°. This is mentioned in the inscription.

Now for finding the time of the day, we align the two sights towards the sun. If it is mid-day, the vertically hanging index will touch the position on the outer scale relating to the position of the sun on the zodiac signs. If it is not midday, the altitude is less and the index will touch the scales somewhere to the right of the position of the sun on the zodiac signs. We mark this position on the innermost scale. Let the point be *A*. Then we move back the index to its midday position for that day and using the parallel lines on the quadrant we find a point on the index corresponding to the marked point on the inner scale *A*. The reading shows the time of the day.

The validity of this explanation is confirmed by the fact that for midday, we do not move the index backwards. In this case the point on the index relating to the altitude scale is where it is written *niṣf al-nahār* (midday).

This explanation of the functioning of *Rūznumā* is also consistent with the geometrical and astronomical configurations and inscriptions on the instrument.

Shabnumā-wa-Rūznumā by Mīrzā Fażl ᶜAlī ᶜĀmil, 19th Century
Rampur Raza Library,[1] Acc. No. 9395 (S. T. 688, dt. 19.9.95).

1. Founded by Nawab Faizullah Khan in 1774, it was declared an Institution of National Importance in 1975. Since then it is administered by the Ministry of Culture, Government of India. It is a leading repository of

The exemplar at the Rampur Raza Library is more elaborately designed (Sarma, *Astronomical Instruments in the Rampur Raza Library,* pp. 85-88). The *Shabnumā* contains more circular scales than the one at Patna. These include the scales containing the Sanskrit names of the zodiac signs and lunar mansions, the names of the English months (all these transcribed in Arabic/Persian script) and also scales to measure time in *ghaṭī*s as well as in hours and minutes. The *Rūznumā* here is not a sine quadrant, but a horary quadrant, with separate scales for different solar months. The instrument is made by Mīrzā Fażl ᶜAlī ᶜĀmil. No date is mentioned, but it is likely that it was made in the nineteenth century, possibly some time after the specimen at Patna was manufactured.

The instrument consists of an oblong wooden board, measuring 263 x 255 x 9 mm. Two iron struts (11 x 10 mm), with holes in the middle, jutting out of one of the shorter sides serve as the sights. The board is painted light brown in oil color, on which the circles and legends are drawn in black. The obverse side is calibrated as the *Shabnumā* and the reverse as the *Rūznumā*. At the centre of the circular scales in the *Shabnumā,* there is a short nail. To this nail must have been attached two indices as in the specimen at Patna, but these are missing now. There must also have been a plumb line which too is absent now. On the reverse side, at one of the top corners, is the apex of the quadrant. There is a hole into which the pin of the index for the quadrant must have been inserted. Both the pin and the index are now lost. There must have been a plumb line on this side also which is now missing. The paint on the wooden board is chipped off all along the edges. Many of the legends and inscriptions are difficult to read.

Shabnumā

On the obverse side (Fig. 6), meant to serve as the *Shabnumā*, there are several concentric circular scales. At the right hand side of the topmost edge, just below the sight, there is a small circle inside which is written *anwar al-Farqadayn* (β UMi). A little below to the right, there is another circle enclosing the writing *akhfā al-Farqadayn* (γ UMi). In the corner opposite, i.e., at the left edge, there was

manuscripts, paintings and printed books dealing mainly with Indo-Islamic art and literature. http://razalibrary.gov.in/

originally a similar circle; now only a small fraction of its circumference is visible. It is likely that here was written the name of the Pole Star as in the specimen at Patna.[1]

The instrument proper consists of eleven concentric circular scales. For the sake of reference, we divide the circles into 360º from the topmost point. Starting from the outside, these scales are as follows:

1. Contains 108 cells (these are probably the ¼ parts of the 27 lunar mansions called *nakṣatra-pāda* in Sanskrit) filled with some letters, but these are not the *Abjad* symbols.
2. Same number of cells, congruent with the above, but filled with different letters; here there occurs occasionally the *Abjad* symbol for 20 and the Persian numerals 2, 7 and 8.
3. Twenty-seven equal divisions containing the Sanskrit names of the lunar mansions (*nakṣatra*s), starting from about 145º and proceeding clockwise. (If the scales 1 and 2 contain 1/4th parts of these lunar mansions, the cells are not congruent.)
4. Twelve equal divisions containing the Sanskrit names of the zodiac signs.
5. Twenty-eight Arabic names of the lunar mansions, *Sharaṭayn, Buṭayn, …, Rishā',* starting from 135º and proceeding clockwise.
6. Names of the twelve English months, starting roughly from 60º and proceeding clockwise.
7. Black and white cells (12 x 12), to indicate hours and 1/12th parts thereof (i.e. 5 minutes).
8. Larger black and white cells (30 + 30), to indicate the 60 *ghaṭī*s.

9-11. These three scales are the same as the three scales 5, 6, 7 in the Patna instrument, and start roughly from 160º. Scale 9 here contains

1. In the same corner, just below the partly visible circle, there is some writing in Urdu in ink. It is now faded and illegible. In the diagonally opposite corner (i.e., bottom left) is written in ink "S. T. 688 / dt. 19.9.95." Thus these two inscriptions in ink must have been written by the librarian on 19.9.1895 when the instrument was acquired or accessioned.

Arabic names of the zodiac signs with a prefix *ṭulū*ᶜ (rising) meaning signs in ascendance.

Fig. 6: *Shabnumā-wa-Rūznumā,* Observe showing the *Shabnumā* Raza Library, Rampur.

Inscription

In the circular space enclosed within these eleven concentric circular scales is a long inscription in Persian in 8 lines, which reads as follows:

طریق دیدن شب چنانست که بقطب و یکی از فَرقَدین که قریب است بقطب شاخ شب نما را بنگاه راست
کند بوضعی که منظر بر دو نقطه گذراند پس نظر کند که تار شاقول بکدام خط رسید آنرا نگاهدارد و
آفتاب در هر درجه از بروج دوازده گانه که باشد آنجا شمار گهر ابتداء کند یکی سیاه و دیگر سفید تا
خط ریسمان مذکور آید بتحقیق همان قدر شب گذشته باشد و یا باقیمانده است دایره منطقه البروج و

معدل النهار را از پشت حجره اسطرلاب اخذ کرده بر چوب هذا ثبت نموده اند بعمل میرزا فضل علی عامل

"The way to see at night, it is so that the upper edge of the 'night-instrument' is to be aligned with the [north] pole (*quṭb*) and one of the two *Farqadayn* which is closer to the Pole, so that the two points are seen in one direction. Then one should see to which line (*khaṭṭ)* the plumb line (*tār-i shāqūl*) reaches, and should keep it [there]. Then one should start counting the *Kahar*s (*ghaṭī*s) which are alternately black and white from the relevant degree of any of the twelve zodiac signs where the sun lies up to where the above mentioned plumb line reaches; exactly the same amount has passed from the night (*guzashteh*) or remains from it (*bāqī māndeh*). The zodiac belt (*manṭqat al-burūj*) and the celestial equator (*muᶜaddil al-nahār*) are taken from the back of the mater of the astrolabe and registered on this board. Made by Mīrzā Fażl ᶜAlī ᶜĀmil".

At night, the board is so held that the two required stars are visible in one line just above the upper edge of the board. The plumb line which hangs vertically touches all the eleven scales at different points. These points provide the readings on these scales for the moment of observation.

Rūznumā

On the reverse side of the board (Fig. 7) is drawn the *Rūznumā* in the form of a horary quadrant. The quadrant consists of eight concentric quarter-circle scales. The outermost one is graduated in single degrees and numbered in Persian numerals from 1 to 90. On this scale, the altitude of the sun can be measured in degrees. Below this are seven *ghaṭī* scales for different solar months as detailed below:

1. سرطان (Cancer), 1-17 *ghaṭī*s.
2. جوزا و اسد (Gemini and Leo), 1-17 *ghaṭī*s.
3. ثور و سنبله (Taurus and Virgo), 1-16 *ghaṭī*s.
4. حمل و میزان (Aries and Libra), 1-15 *ghaṭī*s.

5. عقرب و حوت (Scorpio and Pisces), 1-14 *ghaṭī*s.
6. قوس و دلو (Sagittarius and Aquarius), 1-13 *ghaṭī*s.
7. جدی (Capricorn), 1-12 *ghaṭī*s.

Fig. 7: *Shabnumā-wa-Rūznumā,*
Reverse showing a Horary Quadrant as the Rūznamā.
Raza Library, Rampur.

Each of these scales is used for one or two months. Depending on the length of the day in the corresponding solar month, these scales are divided into so many number of *ghaṭī*s as there are in half a day of that month. Thus when the sun is in Cancer, the day is the longest. It has the duration of 34 *ghaṭī*s (= 13 hours 36 minutes). The scale for this month is divided into 17 *ghaṭī*s, which is the length of half a day. When the sun is in Capricorn, the days are the shortest: 24 *ghaṭī*s (= 9 hours 36 minutes). Accordingly the scale is divided into 12 *ghaṭī*s.

A plumb line is fixed to the centre of the quadrant and the quadrant is held so that the sun's rays pass through the holes in the two iron struts. Where the plumb line touches the outermost scale, it will show the sun's altitude in degrees. Where it touches the scale of the zodiac sign in which the sun is situated, it will show the number of *ghaṭī*s that elapsed since the sunrise or the *ghaṭī*s that still remain up to the sunset.

Inscriptions

The area between the apex of the quadrant and the *ghaṭī* scales is filled by a diagram and several inscriptions.

At the upper right corner, close to the centre of the quadrant are three lines in Persian which read as follows:

حمل میزان جدی سرطان منقلب‌اند (Aries, Libra, Capricorn [and] Cancer are tropical)

ثور اسد عقرب دلو ثابت‌اند (Taurus, Leo, Scorpio [and] Aquarius are fixed)

جوزا سنبله قوس حوت ذوجسدین‌اند (Gemini, Virgo, Sagittarius [and] Pisces are bicorporal)

For an explanation of these attributes of the zodiac signs see (al-Bīrūnī, p. 231).

The remaining legible Persian phrases are not sufficient for a consistent and meaningful restoration. The same problem exists for the long inscription in two lines along the arc of the quadrant.

Though clearly based on the *Dhruvabhrama-yantra,* the two extant specimens of the *Shabnumā-wa-Rūznumā* differ from the former in the following respects.

1. There is no horizontal slit in the *Shabnumā-wa-Rūznumā* as in the *Dhruvabhrama-yantra*; instead the upper edge is used as the reference.
2. There is no four-armed index in the *Shabnumā-wa-Rūznumā*; instead there are two indices in the specimen at Patna. If there were any indices in the Rampur specimen, they are missing now.
3. Initial points of the scales. In the *Dhruvabhrama-yantra*, the 21st *ghaṭī* division ends and the 22nd *ghaṭī* division begins just below the slit. Therefore the starting point of this scale is 234º. This is also the starting point in the scales of right ascensions and oblique ascensions. But the *Shabnumā-wa-Rūznumā,* especially the specimen at Rampur has several starting points, the significance of which is not clear.

4. The *Dhruvabhrama-yantra* determines, in addition to time, the ascendant and the culmination. On the other hand, the *Shabnumā-wa-Rūznumā* measures, besides the time in *ghaṭī*s, the ascendant and the *taḥwīl.*

References

Ansari, S. M. R. & Sarma, S. R., "Ghulam Hussain Jaunpuri's Encyclopaedia of Mathematics and Astronomy," *Studies in History of Medicine and Science,* 16 (1999/2000), pp. 77-93.

Al-Bīrūnī, *The Book of Instruction in the Elements of the Art of Astrology*, English tr. by R. Ramsey Wright, London, 1934.

Bud, R. et al, *Instruments of Science: An Historical Encyclopedia,* New York & London 1998.

Garrett, A. F. Folliott & Guleri, Chandradhar, *The Jaipur Observatory and its Builder*, Allahabad, 1902.

Ohashi, Y., "The Early History of the Astrolabe in India," *Indian Journal of History of Science*, 32 (1997), pp. 199-295.

———, "History of Astronomical Instruments of Delhi Sultanate and Mughal India," *Studies in History of Medicine and Science,* 10-11 (1986-87), pp. 165-182.

Pingree, D., *Census of the Exact Sciences in Sanskrit,* Series A, vols. 1-5, Philadelphia, 1970-1994.

Sarma, S. R., "A Brief Introduction to the Astronomical Instruments preserved in Khuda Bakhsh Library, Patna", *Khuda Bakhsh Library Journal,* no. 118, December 1999, pp. 1-10.

———, *Astronomical Instruments in the Rampur Raza Library,* Rampur Raza Library, Rampur, 2003.

———, "Indian Astronomical and Time-Measuring Instruments: A Catalogue in Preparation," *Indian Journal of History of Science,* 29 (1994), pp. 507-528; reprinted in: *The Archaic and the Exotic* (see below), pp. 19-46.

———, *The Archaic and the Exotic: Studies in the History of Indian Astronomical Instruments,* Manohar, New Delhi, 2008.

———, "Yantrarāja: The Astrolabe in Sanskrit," *Indian Journal of History of Science,* 34 (1999), pp. 145-158; reprinted in: *The Archaic and the Exotic* (see below), pp. 240-256.

Sotheby's, *Arts of the Islamic World, Including Fine Carpets and Textiles, London 14 April 2010,* London 2010; see also, http://www.sothebys.co.uk/pdf/2010/29956/L10220.pdf.

Tibbets, G. R., *Arab Navigation in the Indian Ocean before the Coming of the Portuguese, being a Translation of Kitāb al-Fawā'id fī uṣūl al-baḥr wa'l-qawā'id of Aḥmad b. Mājid al-Najdī, together with an Introduction on the History of Arab Navigation, Notes on the Navigational Techniques and on the Topography of the Indian Ocean, and a Glossary of Navigational Terms*, The Royal Asiatic Society of Great Britain and Ireland, London, 1981.

Wynter, H. & Turner, Anthony, *Scientific Instruments*, London, 1975.