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and

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Yantrarāja at Edinburgh
On a Sanskrit Astrolabe made for Maṇirāma in AD 1644

Sreeramula Rajeswara Sarma

1 Introduction

As a highly sophisticated and versatile observational and computational instrument, the astrolabe held a pre-eminent position among the pre-modern astronomical instruments.[1] It was employed for measuring the altitude of the sun in the daytime and that of several bright stars at night; it was also used for measuring heights and distances in land survey. More important still, it can simulate the motion of the heavens at any given locality and time. It can also be used as an analog computer for solving numerous problems in spherical trigonometry. Therefore, the astrolabe was rightly termed as the 'universe within one's palm.' Writing in 1428 at Naimiṣāraṇya, Rāmacandra Vājapeyin declares that if one knows the science of the astrolabe well, the entire universe

[1] On the history and function of the astrolabe, see, inter alia, Michel 1947, Hartner 1985, Gibbs & Saliba 1984, Turner 1985, King 1987. See also Khareghat 1950.

will become comprehensible like the myrobalan fruit on one's own palm (*karāmalakavad*).[2]

Though the astrolabe was invented in Hellenistic Greece around the second century BC, it was the Islamic world which preserved this Greek knowledge, elaborated upon it and then disseminated it eastwards up to India and westwards up to England. In fact, the astrolabe is thought to have been a major vehicle through which the Greek science of astronomy was transmitted to Europe, together with Arab innovations. Thus the astrolabe held sway over the medieval world, transcending the boundaries of geography, culture and language.

In his *India*, al-Bīrūnī claims to have composed a manual on the astrolabe in Sanskrit verse.[3] The work does not survive, but it is quite probable that al-Bīrūnī had brought the astrolabe with him and taught its working principles to his Hindu interlocutors at Multan in the first quarter of the eleventh century. With the establishment of the Sultanate in Delhi in the next century, Muslim scholars began migrating to Delhi in great numbers. Some of these scholars brought astrolabes and employed them for teaching astronomy and also for astrological purposes. Since astronomy formed a regular part of Muslim education, the ability to use the astrolabe was expected of every good scholar. A few thirteenth century astrolabes from the Middle East, which must have been

[2]Rāmacandra Vājapeyin, *Yantraprakāśa*, 1.11 (MS folio 3r):
sulabhākhyayantarājaṃ sāvayavaṃ pūrvam eva pravadāmi |
yasmin karāmalakavad vidite viditaṃ bhaved viśvam ||
'First I shall describe the king of instruments called *Sulabhā* together with its components. If this instrument is understood [well], then the universe will become comprehensible like the myrobalan fruit on one's own palm.'

[3]Cf. Al-Bīrūnī 1964: I.137: 'Most of their books are composed in *Śloka*, in which I am now exercising myself, being occupied in composing for the Hindus a translation of the books of Euclid and of the Almagest, and dictating to them a treatise on the construction of the astrolabe, being simply guided herein by the desire of spreading science.'

brought here by the immigrant scholars, are still extant in Indian collections.[4]

In the latter half of the fourteenth century, Fīrūj Shāh Tughluq promoted the study of the astrolabe. He not only got several astrolabes manufactured at Delhi— probably for the first time in India—, he also encouraged the composition of manuals on the construction and use of the astrolabe both in Persian and in Sanskrit.[5] During the next five hundred years, a large number of astrolabes were manufactured in India with Arabic/Persian legends. These are generally classified as Indo-Persian astrolabes. I have discussed this class of astrolabes in several publications.[6]

The astrolabes and the Persian manual commissioned by Fīrūj do not survive any more, but the Sanskrit manual named *Yantrarāja* which this monarch sponsored is extant. It was written in 1370 by a Jaina monk, Mahendra Sūri, who was a leading astronomer at the Tughluq court.[7] Mahendra was so impressed by the versatile functions of the astrolabe that he called it *Yantrarāja*, king of instruments, and it is under this name that the instrument is known in India. Subsequent Hindu and Jaina astronomers were no less enthusiastic about this remarkable instrument imported from the Islamic world. Thus, for example, Viśrāma, in his *Yantraśiromaṇi* (composed in 1615), extols the

[4]In Indian collections, there are three Kufic astrolabes which were originally produced in the Middle East. (i) An astrolabe made by al-Sarrāj Damishqī in 623 AH/AD 1226 is now at the Salar Jung Museum, Hyderabad; cf. Sarma 1996: 23-24; (ii) Another astrolabe made by the same al-Sarrāj Damishqī in 626 AH/AD 1228-9 (CCA 3765) is at the Rampur Raza Library; cf. Dube 1928; Sarma 2003: 25-33; (iii) An anonymous astrolabe is in the Archaeological Museum, Red Fort, Delhi. Kaye assigns it to ca. AD 1289; cf. Kaye 1921: Astrolabe A, pp. 2-5 and Pl. 1 and 2.

[5]See Sarma 2000.

[6]Sarma 1992, 1994, 1996a, 1996b, 2003.

[7]Mahendra Sūri, *Yantrarāja*. On this text, cf. Pingree 1978: 626-28; Plofker 2000.

astrolabe as the lord of instruments (3.56: *yantreśvara;* 3.61: *yantrendra*).[8]

The response of the Indian *jyotiṣīs* towards the astrolabe was twofold: first, between 1370 and 1870, some fifteen manuals were composed in Sanskrit on the construction and use of the astrolabe. Second, this activity of composition was accompanied by the manufacture of astrolabes on which the legends and numbers were engraved in Sanskrit language and in Devanāgarī script.[9] I classify this group as 'Sanskrit astrolabes'.[10] Today there are extant some 100 Sanskrit astrolabes in various collections all over the world.

This impressive number of Sanskrit manuals and Sanskrit astrolabes produced during the half millennium from 1370 to the end of the nineteenth century makes it abundantly clear that the Indian *jyotiṣīs* were greatly impressed by this versatile instrument. But the earliest surviving Sanskrit astrolabes are from the seventeenth century. I have identified some nine specimens produced in that century.

2 Maṇirāma's Astrolabe

By a happy coincidence, one of these nine early Sanskrit astrolabes is preserved in the Royal Museum of Scotland (Acc. No. 1986.20) in the city of Edinburgh where the 13th World Sanskrit Conference was held. The Museum acquired the astrolabe in 1986 at an auction held by Christie's of London.[11] As one of the earliest extant Sanskrit astrolabes, this specimen is important for the history of the astrolabe in India. Therefore, in this paper, I

[8] Viśrāma, *Yantraśiromaṇi*, pp. 112-113.

[9] They also reworked several Arabic-Persian astrolabes with additional legends in Sanskrit. These will be discussed in a future publication.

[10] Sarma 1999a, 1999b.

[11] See Christie's Catalogue 1986: 66, item no. 358. There are several errors in the description printed in the catalogue. These will be mentioned at the appropriate places below.

shall first describe this astrolabe in detail and then try to situate it within the history of the astrolabe in India.

2.1 Ownership and Provenance of the Astrolabe

The astrolabe was made by an unnamed artisan for one Maṇirāma in 1644. On the front side of the suspension bracket, there are two inscriptions engraved one below the other (see Figs. 1 and 5). Both are in Sanskrit language and in Devanāgarī characters. The first inscription in three lines reads thus : *Saṃvat* 1700 *caitra kṛṣṇaikādaśyāṃ maṇirāmeṇa kāritaṃ*, 'caused to be made by Maṇirāma on the 11th day of the dark half of [the month] Caitra in Saṃvat [year] 1700.' It means that an astronomer named Maṇirāma prepared the technical design and got it made for his own use by a metal worker whose name is not recorded. The date translates to 2 April 1644.

Christie's consultant read the Saṃvat year 1700 as 1900. There is no apparent reason for this mistake because the digit 7 is quite clear. Even elsewhere in the astrolabe, 7 and 9 are clearly distinguished by the engraver. This will be evident by comparing it with the numerical symbols appearing on the circular scale immediately below the crown, where the numbers 7 and 9 occur several times. Based on their consultant's decipherment, Christie's announced it as a nineteenth century product in their catalogue. But when I studied the astrolabe in August 1993 in connection with my project of cataloguing extant Indian astronomical instruments,[12] I immediately saw that it was older by 200 years than it was thought to be; I also realised that it was one of the earliest surviving Sanskrit astrolabes.

Below this inscription, there is a second inscription, in a different hand and cut more deeply into the metal: *śrīlīlānāthajyotirvido* [']*yam*, 'this [instrument is the property] of the illustrious as-

[12]On this project, see Sarma 1994.

trologer (*jyotirvid*)[13] Līlānātha'. He must be a subsequent owner, but we do not know when he lived. On the plate calibrated for the latitude of Jodhpur (see Fig. 4), there is an addition, where the writing resembles the calligraphy of this line and is cut likewise more deeply than the rest. This too must have been an addition caused to be engraved by Līlānātha. The addition reads *nepāle* [']*pi*, 'also in Nepal,' that is to say, the plate could be used also in Nepal, or more precisely in the capital city Kathmandu. The modern values for the latitudes of Jodhpur and Kathmandu are $26;18^\circ$ N and $27;42^\circ$ N respectively. Therefore, it was a reasonable approximation to say that these two cities lie on the same latitude. Līlānātha's addition on this plate suggests that he may have been from Kathmandu and may have used it there. If this hunch is correct, then this would be the only known astrolabe that was ever used in Nepal.

About Maṇirāma, the original owner of the astrolabe, we have no other information. But it is quite certain that the astrolabe, like many other early extant Sanskrit astrolabes, was produced in Gujarat. It is a neatly crafted piece made of brass with a diameter of 128 mm. There are some lacunae in execution. For some unknown reason, the astrolabe was left unfinished in three respects. (i) On the inner side of the mater the astrolabe maker drew a grid but did not fill it in with the geographical gazetteer. (ii) On the back, a grid was drawn likewise on the upper right side quadrant, but was not filled in. (iii) The upper left quadrant was left completely blank, where a sine-cosine graph is generally engraved.

Now I shall describe the different components of this astrolabe and their functions; thereafter I shall attempt to situate this astrolabe within the seventeenth century traditions of astrolabe manufacture in India.

[13] *Jyotirvid*, 'knower of the celestial luminaries,' is a common title of astrologers.

2.2 The Front

The main body of the astrolabe, called mater, consists of a thick circular plate with an upraised rim all around. It is surmounted by a triangular piece like a crown.[14] A shackle and a ring are added to the top of the crown so that the astrolabe can be suspended in a vertical plane for observation. In the present specimen, the ring and the shackle are missing: otherwise the astrolabe is in a good state of preservation. The main body (*koṣṭhakāgāra, āgāra*),[15] the rim (*pālī, parikhākāra-vṛtta*) and the crown (*kirīṭa*) are cast as a single piece (Fig. 1). The rim carries a double band of scales. While the inner and narrower band is graduated in single degrees, the outer band is calibrated in groups of 6° and numbered separately for each quadrant from 6 to 90, starting from the east and west points and reaching up to the south and north points.[16]

The crown is high and solid, rising above the circumference of the body by 46 mm. The left and right profiles of the crown are artistically contoured with a succession of lobes. A hole is bored in each of the two top lobes. These holes have no real function. They were made as decorations in Kufic astrolabes of the thirteenth century, and were occasionally emulated by later astrolabe makers. There is another hole at the very top of the crown. Into this was inserted the shackle, which is now missing.

[14]The triangular suspension bracket on the top of the main circular body of the astrolabe is called in Arabic *kursī*, 'throne,' in an allusion to the *Āyah al-Kursī*, 'Verse of the Throne,' at Qur'ān 2.255 ('His Throne doth extend/Over the heavens/And the earth'). Sanskrit writers, however, see in it the *kirīṭa*, 'crown', because of its position on the top of the main body and also because of its shape and ornamentation.

[15]This and the following Sanskrit terms for the different parts of the astrolabe are taken mainly from Mahendra Sūri's *Yantrarāja* and from the *Yantrarājavicāra-viṃśādhyāyī* (a Sanskrit rendering of Nāṣir al-Dīn al-Ṭūsī's celebrated Persian work, the *Bist Bāb*).

[16]In Arab cartography, the south is shown at the top. The same convention is followed in the astrolabes as well.

The meridian (south-north line) drawn on the body is extended on to the crown on both the sides. Otherwise the back of the crown is blank. The front of the crown bears the two inscriptions mentioned above.

2.3 The Rete

In the space created inside the upraised rim, there are inserted a number of circular discs. On the top is a perforated plate, generally known as rete (*bhacakrapatra, bhapatra*).[17] The rete contains the ecliptic and a star map with pointers indicating the positions of some bright stars. Beneath the rete are to be found a series of plates (*akṣāṃśapatra, akṣapatra*)[18] which are specific to particular terrestrial latitudes and display stereographic projections of the local horizon, equal altitude circles or almucantars, azimuth circles, hour curves etc. When the rete is correctly set and made to rotate upon the plate of a particular latitude, the astrolabe simulates the motion of the heavens above the localities situated on that latitude.

The rete in our astrolabe has a diameter of 108 mm (Fig. 2). It contains the circles representing the tropic of Capricorn, the equator and the ecliptic, one inside the other. The outer circumference of the rete is constituted by the tropic of Capricorn and the centre by the north pole. The tropic of Capricorn is not completely represented; the upper part where it touches the ecliptic tangentially is not shown. Likewise the equator is not fully shown. Only a small part of the equatorial belt is shown below

[17]Because the openwork resembles the spider's web, it is called *ᶜankabūt* (spider) in Arabic and 'rete' (net) in Latin. As against this, the Sanskrit expressions *bhacakra-patra*, lit. 'the disc of the stellar region' and *bha-patra*, 'disc of the stars,' are more meaningful.

[18]The plate is called *ṣafīḥa* (pl. *ṣafa'iḥ*) in Arabic, and 'plate', 'disc', 'tablet', 'tympan' in English. Once again the Sanskrit terms *akṣāṃśapatra* and *akṣapatra*, lit. 'latitude plate or disc', are more expressive than the Arabic or English terms.

Figure 1: The front of the astrolabe with the two inscriptions on the crown. This and the following photos courtesy of the National Museums of Scotland, Edinburgh.

the ecliptic. Here it is distorted in the middle to join an upturned tulip flower (for decorative reasons). The equinoctial bar is complete and plain without any counter changes. The ecliptic circle (*krāntivṛtta*), placed off centre, is fully represented. It is divided into 12 unequal divisions to represent the signs of the zodiac, which are named, but not always correctly inscribed: *meṣa, vṛsa, mithūna,* (sic! read *mithuna*), *karka, siṃha, kanā* (sic! *kanyā*), *tulā, vṛścaka* (sic! *vṛścika*), *dhana* (*dhanuṣ*), *makara, kumbha, mīna.* Each sign is further subdivided into 6° and the divisions are numbered as 6, 12, 18, 24, 30. In the bevelled edge of the ecliptic ring, these are further halved to form divisions of 3° each. The divisions are not always uniform.

On both sides of the ecliptic, there are several points to represent the bright stars to the south and north of the ecliptic. The points are joined by a tracery representing vines, leaves and tulip-like flowers. Some tips of leaves and flowers constitute star pointers (*nakṣatra-cañcu*), but not all. The maker aimed at mirror symmetry so that the rete rotates smoothly around the central pin.

Of these pointers, 12 are named. On these pointers the names of the respective stars are engraved in abbreviated form, obviously due to shortage of space. Seven of these are situated outside the ecliptic circle (i.e. to the south of the ecliptic; these stars consequently have southern latitudes) and five inside (i.e. to the north of the ecliptic; these stars have northern latitudes). Interestingly these abbreviated forms of the star names are followed by certain numbers, e.g. *ro 8*, meaning *rohiṇī* 8. *Rohiṇī* or α Tauri is the fourth lunar mansion, then why 8 after the name? It took me some time to realise that 8 is the serial number assigned to this star by Mahendra Sūri in his *Yantrarāja.* This work contains a catalogue of 32 stars together with their longitudes and latitudes for the use of astrolabe makers.[19] Of these 32, Maṇirāma

[19]Mahendra Sūri, *Yantrarāja*, 1.22-39, pp. 25-28; see Pingree 1978: 628,

chose just 12 stars for his astrolabe. More would have cluttered the rete. But by adding Mahendra's serial numbers to the star names of his astrolabe, Maṇirāma is conferring a canonical status to Mahendra's work. Indeed it deserves this status. It was extensively read throughout the centuries; we know of at least 100 surviving manuscripts of this work.[20]

In the ecliptic circle, at the first point of Capricorn, a small projecting tip is formed. This is the point where the ecliptic touches the tropic of Capricorn. This point or mark is called the head (lit. face) of Capricorn (*makarānana*).[21]

Leaving aside the tropic of Capricorn, the ecliptic circle, the star pointers and the tracery joining all these and thus supporting the frame, the rest of the plate is cut out so that through the resulting gaps the lines and graduations on the plate below can be read. On the north point of the rete at the intersection of the meridian, there is a knob. It is the handle to facilitate the rotation of the rete around the centre (*bha-patra-bhrāmaka-kīla*). The named stars and their identification are shown in Table 1.

The engraver, by mistake, interchanged the names of two stars. What is labelled as *kṛtti* 5 (=*kartitakara*, β Cassiopeiae) does in fact point to the star *Samudrapakṣī* (ι Ceti), and that which is inscribed as *samu* 32 pertains to *kartitakara*, β Cassiopeiae.[22] Otherwise, the star pointers are correctly positioned

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Table XI.3.

[20]Cf. Pingree 1981: 393-95; Pingree 1994: 296; see also Sarma 2000: 144.

[21]There is no exact English equivalent; European astrolabes do not have a prominent tip. The Arabic word is *murī' ra's al-jadī*, lit. 'head of Capricorn'. In Sanskrit, it is called the 'face' of Capricorn (*makarānana, makarāsya*).

[22]Incidentally the name of this star is translated also as *rañjitakara*, which is actually the correct rendering of the Arabic name *al-kaff al-khaḍīb*, 'dyed hand,' i.e. a hand dyed with henna (*lawsonia inermis*); cf. Savage-Smith 1985: 147. But Mahendra Sūri renders it as *kartitakara*, probably thinking that a hand which is red must have been stained by blood from a cut! These are the pitfalls of trans-cultural translations.

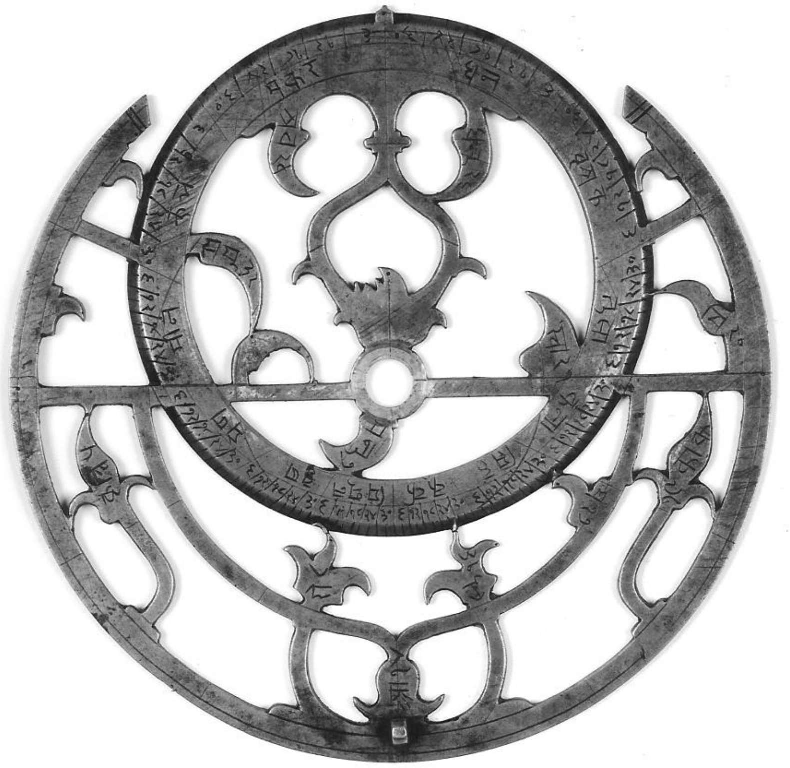

Figure 2: The rete of the astrolabe with the named star positions

for the time when the astrolabe was made.

There are 8 more pointers which are not named. These are α Leporis, β Gemini, α Corona Borealis, α Librae, α Lyrae, ζ Cygni, δ Capricornis, δ Aquarii. Notable among these is *Abhijit* (α Lyrae, Vega). In the Islamic tradition this star is named *al-nasr al-wāqiʿ* ('falling eagle'), which expression degenerated to

'Vega' in European languages. In the Islamic tradition, this star cluster is seen as a falling eagle. In this context, there developed a tradition of depicting the position of this star with a pointer shaped like a bird. The earliest surviving example is to be found in a Byzantine astrolabe of 1062,[23] but there must be earlier Islamic prototypes for this.[24] In any case, this bird-shaped star pointer is right in the middle of the rete of our astrolabe, but is not named. The bird and its surroundings in our astrolabe rete have a further significance, which will be discussed later.

In 1990, these star positions were examined by Ronald Torode, who had devised 'A Mathematical System for identifying the Stars of an Astrolabe and Finding its Age.'[25] Applying this system to the star pointers of our astrolabe, he came to the following conclusion: 'The positions indicated by the pointers were compared with the positions of the same stars given in a recent nautical almanac, the difference in ecliptic longitude being attributed to precession and so to the age of the instrument. A date was calculated from each pointer ... and the mean calculated as AD 1640.'[26] It should be noted that this happened before I had deciphered the inscription in 1993 and found that it was made in 1644. In 1990, the Museum was still under the impression that the instrument was made in 1843 as Christie's consultant opined. Therefore Torode thought that the 200 hundred years' difference between his estimate based on the star positions and the alleged date of the astrolabe 'suggests some inaccuracy in the making of

[23]Gunther 1976: No. 2, pp. 104-108, Fig. 57.

[24]David King, however, observes that 'Vega as a bird appears for the first time in a Byzantine astrolabe of 1062 (Museo dell 'Età Christiana, Brescia) which is free of Islamic influence. No contemporary Islamic astrolabe has this feature, no surviving Islamic astrolabe from the period 900-1100 shows it. Muslim astrolabists may have borrowed this feature later from Greek astrolabes or come up with the idea independently;' cf. King 1993: 29-52, esp. 30.

[25]Torode 1989.

[26]The Museum kindly provided me a copy of Torode's report.

this instrument.'

But now we know that the difference is just four years which is negligible. This shows that Maṇirāma must have computed the longitudes of these stars afresh by adding precession up to his time. Therefore, our astrolabe is reasonably accurate for the time it was produced.

2.4 The Plates

Below the rete are stacked six plates (*akṣāṃśapatra, akṣapatra*) each with a diameter of 108 mm (Figs. 3 and 4). While the rete can rotate around the central pin, the plates have to stay firmly in position, providing the steady reference points to the variable positions of the rete. For this purpose, all these plates are endowed with a projecting bit at the top (southern point) which goes into a slot cut into the side of the rim.

Each face of these plates is calibrated for a different terrestrial latitude. While making observations, the observer chooses the face of the plate which is meant for his own location and places it on the top of the other plates, so that the rete rotates just above this one. Then the plate represents the observer's location on the surface of the earth, while the rete, when rotated to the appropriate angle (according to specific rules) represents the starry heavens above the observer at the given point of time.

The outer periphery or circumference of the plate is constituted, as in the case of the rete, by the diurnal circle or tropic of Capricorn (*makarāhorātravṛtta*). Inside this, at appropriate intervals are drawn the diurnal circle of Aries and Libra (*meṣāhorātravṛtta*) which is the same as the equator, and inside this the diurnal circle of Cancer (*karkāhorātravṛtta*). All the three circles have the same centre.

Then the oblique horizon, i.e. horizon (*kṣitija*) pertaining to the terrestrial latitude, is drawn as an arc cutting across the three circles mentioned above. Above the horizon and parallel to it are drawn equal altitude circles or almucantars (*unnatāṃśavṛttas*). On the plates of our astrolabe, these are drawn for each 6° and labelled as 6, 12, 18, ... 78, 84, 90 along the periphery on the left hand side as well as on the right.

The semi-circular space below the horizon is divided into 12 equal divisions by means of arcs. These divisions are numbered from 1 to 12, starting from the western horizon, and represent the twelve unequal or seasonal hours of the day and also of the night, as counted from sunset. In Islamic culture, the day commences from sunset, from which the hours of the day are counted. Thus our astrolabe is designed for measuring seasonal hours in Islamic fashion; but it cannot measure equal hours of 60 minutes each, nor equal *ghaṭīs* of 24 minutes each, though it is possible to measure both these types of time units by drawing the appropriate curves. Some of the Mughal astrolabes indeed contain lines for measuring such time units. But Sanskrit astrolabes generally have only hour lines (for equal hours, or unequal hours, or both) but never *ghaṭī* lines, in spite of the fact that the Hindus reckoned in equal *ghaṭīs*.

Besides these, Indo-Persian astrolabes contain azimuth lines. But these are not drawn on the plates of our astrolabe.

In the space between the horizon and the tropic of Cancer are engraved three items of data: the locality for which this face of the plate is calibrated, its latitude and the duration of the longest day at this latitude (*paramadina*) in *ghaṭīs*. Thus on the plate for Delhi, the inscription reads as follows:

Ḍhillī	*paramadina*
28/39	34/35

It means that the latitude of Delhi is 28; 39° N and that the duration of the longest day at this latitude is 34 *ghaṭīs* and 35

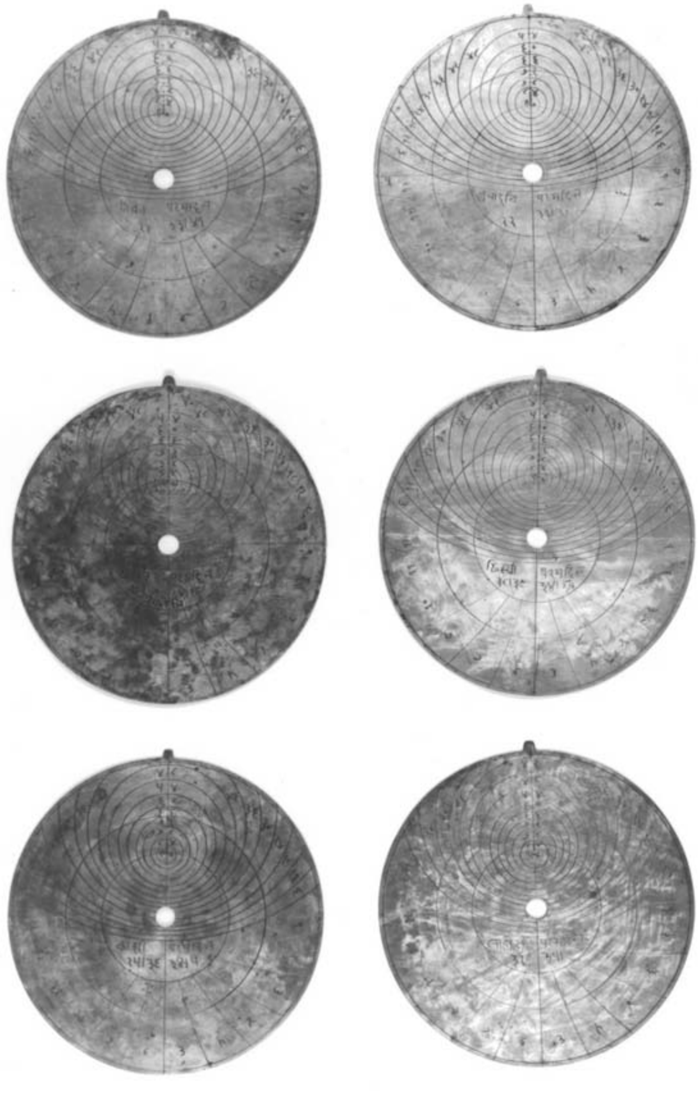

Figure 3: The six plates, obverse

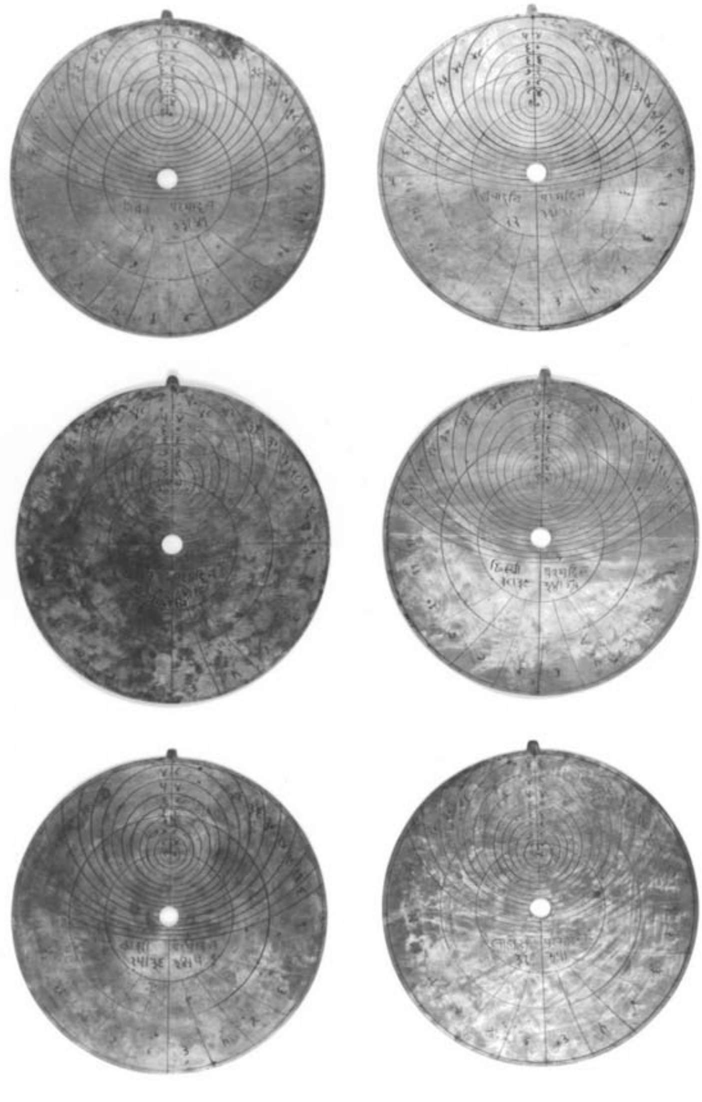

Figure 4: The six plates, reverse

palas (= $13^{\mathrm{h}}\ 50^{\mathrm{m}}$).

The geographical data given on the 12 sides of the 6 plates is shown in Table 2. Accordingly, the plates are calibrated for 12 different localities, ranging from Devagiri in the south (lat. 20;34° N) to Kāśmīra in the north (lat. 35° N). The plates are locality specific rather than latitude or climate specific. Usually among the plates, there is included a special plate, one face of which is calibrated to the latitude $66°30'$ (= 90 − obliquity = $90 - 23°30'$). On this the ecliptic coordinates of the star pointers on the rete are measured. It is called *ṣafīḥa mīzān al-^{c}ankabūt*. The other face contains sets of multiple horizons, which can be used for taking observations at latitudes for which no plate is available. Such a special plate was not made for this astrolabe though it can be seen in some other Sanskrit astrolabes of the seventeenth century.

2.5 Geographical Gazetteer

Usually a geographical gazetteer is engraved on the inner side of the mater. Maṇirāma also intended to have a gazetteer engraved on his astrolabe, for which purpose ten concentric circles were drawn (Fig. 5). But for unknown reasons, the blank spaces have not been filled in. As we shall see, there are other areas on the back which were not filled in.

2.6 The Back of the Astrolabe

The back of the astrolabe (Fig. 6) is divided into four quadrants by the vertical and horizontal diameters. The outer periphery of the top left quadrant contains a double-banded scale as in the front, the inner band displaying single degrees, and the outer band groups of 6°. These are numbered as 6, 12, 18 . . . 78, 84, 90, starting from the east point and going up to the south point. This is the scale on which the altitude of the sun or of some bright star is measured by means of the alidade, which is

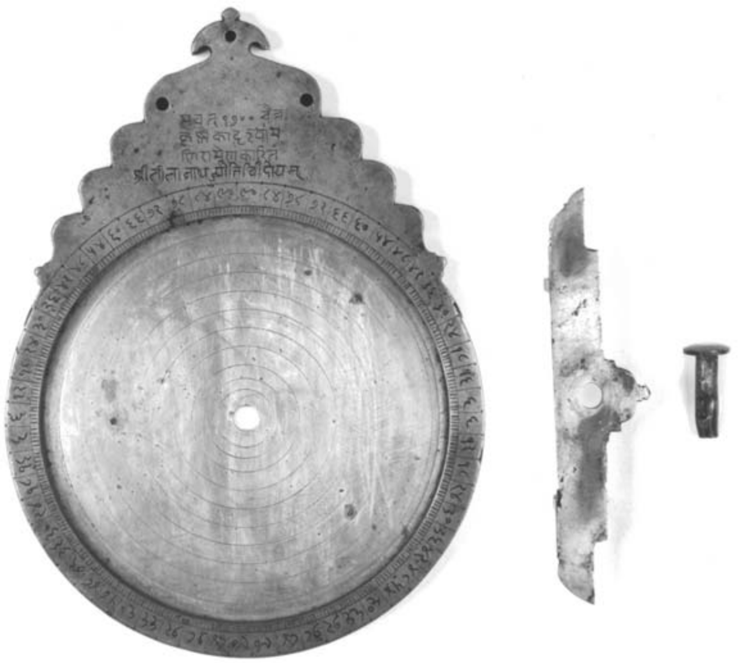

Figure 5: The inner side of the body with an empty grid; alidade and pin.

pivoted at the centre. In Fig. 6, the alidade is pointing to 61° on the scale. The alidade (*bhujā, vedhapaṭṭī*) is 110.5 mm long. It is solidly built and is without any graduations. The two sighting vanes (*dṛṣṭikā-śakala*) have one hole (*chidra*) each through which the sighting is done. A pin holds the alidade in position and also the plates and the rete on the other side. This pin represents the celestial north pole and is accordingly called in Sanskrit *meru-kīla* or *dhruva-kīla*.

In the front of the astrolabe, the pin is held in position by a transverse wedge (*tiryak-kīla*) which is inserted into the hole in the pin. In Islamic astrolabes this wedge is generally shaped like a horse and is called the horse (*aśva-mukha-kīla*), but ours is a plain one with a thicker end for a better grip.

Normally the four quadrants at the back contain various trigonometric and astrological tables, though the configuration of the tables varies from astrolabe to astrolabe. Usually, the top quadrant at the left contains a sine grid or cosine grid, or both, so that the angle of altitude measured by the alidade can be converted directly into the corresponding sine or cosine. In the present astrolabe, this place is blank. In the quadrant on the top right, there are concentric arcs, creating eight bands alternately broad and narrow. Each pair appears to form a particular scale. The top two are divided into 15 cells each; the next two into 13 cells each, the next two into 10 cells each; and the last two into 6 cells each. But these cells are not filled. Probably this grid was meant for a table as in the two quadrants below, but it was left empty.

The quadrant on the lower right has inscribed on it a table of declinations for each 2° from 1° to 89°. The table is inscribed upside down, i.e. starting from the circumference and going down up to the centre, in four concentric rows. Around the hole near the centre is the label *krāntayah*, 'declinations'. This table of declinations is derived also from Mahendra's *Yantrarāja*; or more exactly, from Malayendu's commentary on the *Yantrarāja*, where he introduces this table with the words: *atha rāśitrayasya paramakrāntikoṣṭakāḥ sāntarā likhyante*, 'now will be written the tables of maximum declination for three signs (=90°) together with their differences.'[27] In this table, the declinations are given for each degree from 1° to 90°; the maximum obliquity being 23;35°. The declinations are in minutes and seconds; these are followed

[27] Mahendra Sūri, *Yantrarāja*, pp. 7-9

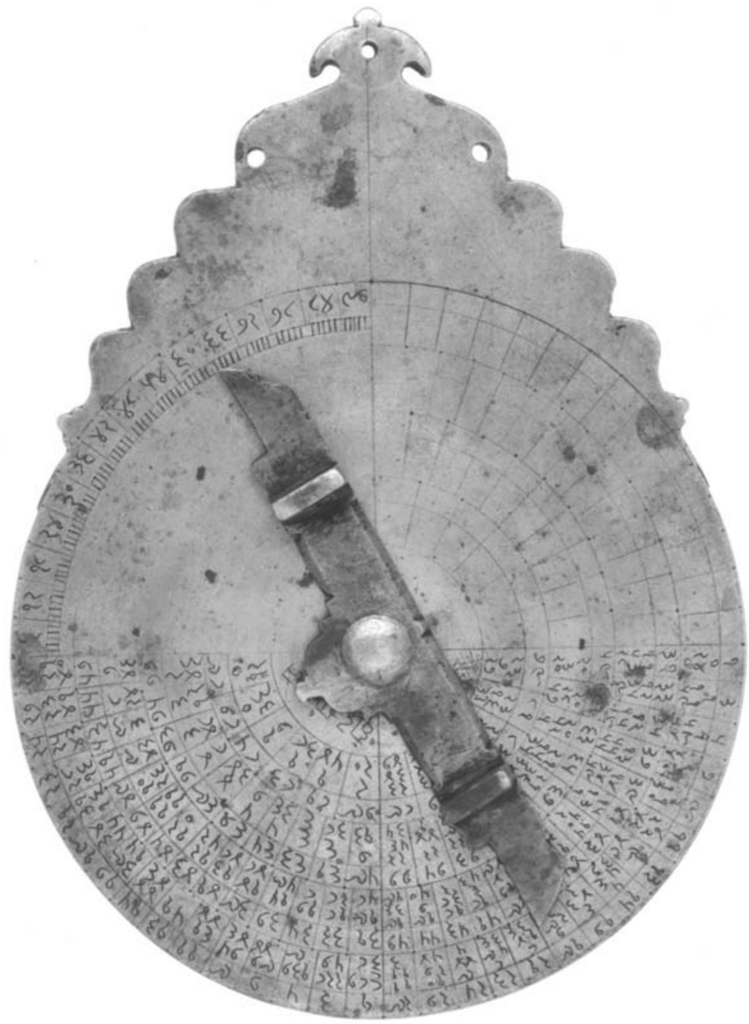

Figure 6: The back of the astrolabe with the tables; note that the alidade is pointing to 61° on the altitude scale.

by the differences (*antara*) between each two successive values of declinations. On our astrolabe, this table is abridged for the purpose of engraving in the following manner. The values are given not for each degree but for each 2 degrees and the differences are omitted. While Malayendu gives the declinations in minutes and seconds of arc, the astrolabe has them in degrees, minutes and seconds. The table is carefully engraved on the very small area of the astrolabe, but there are some errors. These are indicated at the appropriate places in the footnotes. The table is reproduced as Table 3. The first row shows the degrees of solar longitude, and the next three rows display respectively the corresponding degrees, minutes and seconds of the sun's declination.

The quadrant on the lower left contains a table of shadow lengths for a gnomon of 12 digits (*aṅgulas*). This too was engraved in four rows, starting from the outer periphery and reaching up to the centre. Around the hole at the centre is the label: *dvādaśāṃgulaśaṃko*[*ś*] *chā*[*yāḥ*], 'shadows of the gnomon of 12 *aṅgulas*.' The first row shows the degrees of solar altitude, for each 2° from 1° to 89°; the second and third rows the corresponding lengths of the gnomon shadow in *aṅgulas* and their sexagesimal submultiples. The table is reproduced as Table 4.

2.7 Tables of Declinations and of Shadow Lengths on Astrolabes

Such tables on the back of an astrolabe are a very unusual feature not met with on any Islamic astrolabe. But they occur on other Sanskrit astrolabes besides the present one. In an astrolabe made for Indrajī in 1673,[28] the lower left quadrant is filled with a table of declinations. This too was taken from Malayendu's commentary on the *Yantrarāja*. Here the declinations are given for

[28] The astrolabe is now in the Pitt Rivers Museum of Ethnology at Oxford, acc. no. 1893.4514. For a brief description, see Gunther 1923: 198-99; see also Gunther 1976: No. 79, p. 211, fig. 110.

each 6°; the values are in minutes and seconds as in Malayendu's commentary. An identical table is engraved on the lower left quadrant of an anonymous astrolabe.[29] A much larger table with declinations (in degrees, minutes and seconds) for each degree of arc from 1° to 90° is engraved on the two lower quadrants at the back of an astrolabe made by Vīrabhadra in 1805.[30] In 2002, the auction house Skinner, Bolton, Mass., offered a Sanskrit astrolabe for sale. It was made by Cakrapāṇi in 1625 (*Saṃvat* 1682 *Mārgaśīrṣa Śuklapakṣa* 1 Sunday = 20 November 1625). The back of this astrolabe is covered by a badly engraved table of gnomon shadow lengths for each degree of solar altitude.[31] I suspect the gnomon used here is one of seven units (*saptāṅgula-śaṅku*) while the table in our astrolabe is meant for a gnomon of 12 units (*dvādaśāṅgula-śaṅku*). Thus these tables are not a unique feature of our astrolabe but occur in other Sanskrit astrolabes as well. At the moment, I am unable to say how and where this custom originated, except to record this as a deviation from the standard Indo-Persian astrolabes.

2.8 Pattern of the Rete

A large majority of the Indo-Persian astrolabes were produced by a single family of astrolabe makers from Lahore.[32] Maṇirāma's

[29]This astrolabe is now preserved in the Victoria & Albert Museum, London, and is accessioned under I.M.407 and IPN 2467.

[30]Now in the National Museum of American History, Washington D.C. It is described and illustrated in Gibbs & Saliba 1984: 181-184, figs. 121-123, esp. fig. 123.

[31]Skinner Catalogue 2002: item no. 244, pp. 38-39. The catalogue says: 'This appears to be a mater started by Sri Cahrapani (sic!) but not completed which was then restarted later by someone else for an unknown purpose as the markings on the back do not seem to be related to the uses of an astrolabe.' The late Professor David Pingree, who deciphered the astrolabe in 2002 for Skinner, kindly sent me his full notes from which it is evident that the markings on the back are shadow lengths.

[32]Sarma 1994b.

astrolabe and other Sanskrit astrolabes produced in the seventeenth century differ from the Lahore astrolabes in several respects, including the configuration on the back as mentioned in the previous section. The Lahore astrolabes display a large number of stars on their retes, and these are joined by very decorative floral traceries.[33] In contrast, the Sanskrit astrolabes have a much smaller number of stars, about half the number. While no two retes look alike in Lahore astrolabes, most of the contemporary Sanskrit astrolabes display a rete similar in pattern to Maṇirāma's astrolabe.

The distinctive pattern of the rete is as follows. From the circle of Capricorn, from the east-west bar and so on, arise what look like leaf clusters or tulip-like flowers with two or more outstretched petals, the tips of which point to different bright stars. In the centre, there is a characteristic pattern. The star *Abhijit* (α Lyrae, Vega) in the form of a bird appears to be seated in a cage. In our astrolabe, it is not named. Above the cage, there is a rounded M-like figure. The lower tips of the M-figure terminate in the star pointers of *Dhanuḥśarāgra* (α Opiuchi) and *Śravaṇa* (α Aquilae). Tentatively I call this 'Bird in the Cage' pattern. This pattern occurs in several Sanskrit astrolabes of the seventeenth century. Therefore, in this respect, as also in others, these Sanskrit astrolabes must be following a tradition which is clearly different from that of the Lahore astrolabes.

The same pattern of the rete also occurs in a massive (diameter 402 mm, thickness 13 mm, about 5 kg in weight) bilingual (Arabic-Persian and Sanskrit) astrolabe produced in the 11th regnal year of Jahangir (= 1616 AD).[34] The maker's name is

[33]For example, an astrolabe made by Ḍiyā' al-Dīn Muḥammad of the Lahore family in 1073 AH/AD 1662 has 43 stars in the rete; cf. Gingerich 1982; while another astrolabe made by the same astrolabist in 1060 AH/AD 1650 displays as many as 53 star positions; cf. Savage-Smith 1992: 22-23

[34]This astrolabe is preserved in the Sarasvati Bhavan Library of the Sanskrit University at Varanasi.

recorded in Persian as 'a. . . w'; in the absence of diacritical points, it is indecipherable. But the name is followed by the suffix 'pandit'. As I shall argue in my forthcoming study of this astrolabe, he must be a Brahmin apprentice of a Muslim master astrolabe maker. Unfortunately we do not know who this master was; but he represents a tradition which is markedly different from that of the much more famous Lahore family of astrolabe makers who produced more than 125 astrolabes that survive. However, the majority of the surviving seventeenth century Sanskrit astrolabes and some more of other periods, follow the style of the bilingual astrolabe of 1616. Hence it is important to find its antecedents, which elude me so far.

2.9 Workmanship of the Sanskrit Astrolabes

The other notable aspect in which Sanskrit astrolabes differ from the Indo-Persian astrolabes is in the matter of workmanship. The Islamic astrolabes, whether in India or outside, were crafted by people who were both astronomers as well as artisans. The same person made the technical design and then executed it from brass sheets. In the Hindu context, the design was drawn by a Brahmin astronomer (who was usually not a good draughtsman), and the actual manufacture was done by a brass worker who may not even be literate. Therefore, the calligraphy is generally of poor quality, often with orthographic errors. The Brahmin astronomers may be good in the theoretical aspect of astronomy and mathematical computations, but there has not been a tradition among them of draughtsmanship as is evident from the almost total absence of diagrams in astronomical and mathematical manuscripts. This dichotomy between the theoretician (*śāstrin*) and the artisan (*śilpin*) is more pronounced in the case of astronomical instrument making, because this craft never developed into a hereditary tradition as other craft forms like sculpture did.

Therefore, notwithstanding the great enthusiasm shown by the Sanskrit *jyotiṣīs* towards the astrolabe, the specimens they got made were far from being precision instruments like the Islamic prototypes; at the most, they could be used as good teaching tools. Nevertheless, the testimony the *yantrarājas* offer to the intellectual exchanges that took place between the Islamic and Sanskrit traditions of astronomy and, more particularly, to the receptivity of Indian *jytotiṣīs* towards, and their appreciation of, foreign scientific notions cannot be underestimated. Among these *yantrarājas*, the one made for Maṇirāma in 1644 is an outstanding specimen.

Acknowledgements

For facilitating my study of the Sanskrit astrolabe which forms the subject of this paper and for providing the photographs published here, I am highly grateful to Dr Alison Morrisson-Low, Principal Curator, History of Science and Photography, National Museums of Scotland, Edinburgh.

Table 4: Stars named in the star map in the order of increasing longitude, read clockwise from the vernal equinox.

S. No.	Star Name as engraved on the rete	Full Form	Identification	Common Name
1[35]	*kṛtti* 5	*kartitakara*	β Cassiopeiae	Caph
2	*manu* 7	*manuṣyapārśva*	α Persei	Mirfak
3	*ro* 8	*rohiṇī*	α Tauri	Aldebaran
4	*ā* 14	*ārdrā lubdhaka*	α Canis Maioris	Sirius
5	*lu* 16	*lubdhakabandhu*	α Canis Minoris	Procyon
6	*ma* 17	*maghā*	α Leo	Regulus
7	*kāka* 19	*kākaskandhapakṣa*	γ Corv	Gienah
8	*ci* 20	*citrā*	α Virginis	Spica
9	*svā* 21	*svātī*	α Bootis	Arcturus
10	*dhanu* 26	*dhanuḥśarāgra*	μ 12 Sagittari	
11	*śrava* 28	*śravaṇa*	α Aquilae	Altair
12	*samu* 32	*samudrapakṣī*	ι Ceti	

[35] By mistake, the engraver interchanged the labels of 1 and 12.

Table 5: Geographical Data on the Plates

S.No.	City *nagaranāma*	Latitude *akṣāṃśa*	Longest day *paramadina*	Modern Name	Modern latitude N	Modern longitude E
1a	Devagiri	20;34°	33;[0]4 *gh*	Daulatabad	19;57°	75;15°
1b	Dhākā	23°	33;41*gh*	Dhaka	23;43°	90;26°
2a	Vuḍhānapura	21°	33;21*gh*	Burhanpur	21;17°	76;16°
2b	Khambhāici	22°	33;30 *gh*	Khambhaich (Cambay)	22:19°	72;39°
3a	Yodhapura Nepāle[']pi[36]	26;51°	34;16 *gh*	Jodhpur Kathmandu	26;18° 27;42°	73;04° 85;12°
3b	Ajamera	26;34°	34;[0]9 *gh*[37]	Ajmer	26;27°	74;42°
4a	Kurukṣetra	30°	34;48 *gh*	Kurukshetra	29;59°	76;49°
4b	Ḍhillī[38]	28;39°	34;35 *gh*	Delhi	28;38°	77;12°
5a	Agarā	26;27°	34;14 *gh*	Agra	27;10°	78;05°
5b	Kāśī	25;36°	34;[0]5 *gh*	Varanasi	25;20°	83;00°
6a	Kāśmīra	35°	35;34 *gh*	Kashmir (Srinagar)	34;06°	74;51°
6b	Lāhora[39]	32°	35;[0]6 *gh*	Lahore	31;37°	74;26°

[36]Added by another hand; see # 1.1 above.

[37]The latitude of Ajmer (26;34°) lies between those of Agra (26;27°) and Jodhpur (26;51°); therefore the duration of the longest day at Ajmer (34;9 sic!) should also be between those of Agra and Jodhpur, namely between 34;14 *gh* and 34;16 *gh*.

[38]Christie's Catalogue 1986: 66 reads it wrongly as Dhisi.

[39]Christie's Catalogue 1986: 66 reads it wrongly as Sahore.

Table 6: Table of Declinations

The first row displays the degrees of the solar longitude, the next three rows show respectively the degrees, minutes and seconds of the sun's declination.

1	3	5	7	9[40]	11	13	15	17	19	21	23	25[41]	27	29
0	1	1	2	3	4	5	5	6	7	8	8	9	10	11
24	11	59	47	11	22	9	56	43	29	14	59	44	27	11
0	59	54	40	30	42	48	37	2	2	36	36	5	54	3

31	33	35[42]	37	39	41	43	45	47	49[43]	51	53	55	57	59
11	12	12	13	14	15	15	16	17	17	18	18	19	19	20
43	35	15	55	34	13	50	26	0	34	6	38	7	36	3
28	9	59	55	59	1	2	1	48	49	53	2	50	19	20

61	63[44]	65	67	69	71	73	75	77	79	81	83	85	87	89
20	20	21	21	21	22	22	22	22	23	23	23	23	23	23
28	52	15	36	55	13	29	44	56	7	16	23	29	32	34
57	1	35	34	54	37	42	1	35	27	32	50	18	58	47

[40] This is actually the value for 8°; the correct value for 9° is 3;35,18.

[41] Malayendu: 9;44,4.

[42] Malayendu: 12;55,59.

[43] Malayendu: 17;34,29.

[44] Malayendu: 20;53,1.

Table 7: Table of Gnomon Shadows

The first row shows the solar altitude in degrees, the second and third rows the corresponding lengths of the gnomon shadow in *aṅgulas* and their sexagesimal submultiples.

1	3	5	7	9	11	13	15	17	19	21	23	25	27	29
687	228	137	97	75	61	51	44	39	34	31	28	25	23	21
38	57	9	44	46	44		46	15	55	16	16	43	41	40

31	33	35	37	39	41	43	45	47	49	51	53	55	57	59
19	18	17	15	14	13	12	12	11	10	9	9	8	7	7
58	28	8	59	48	48	52	0	11	26	43	3	24	46	13

61	63	65	67	69	71	73	75	77	79	81	83	85	87	89
6	6	5	5	4	4	3	3	2	2	1	1	1	0	0
38	6	36	7	34	8	48	12	46	20	54	38	7	36	12

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