Yantrarāja for Dāmodara
The Earliest Extant Sanskrit Astrolabe

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1.0 Introduction

The astrolabe enjoyed great esteem, as no other instrument did, in the medieval world between Geoffrey Chaucer's England and Firūz Shāh Tughluq's Delhi. Its origins are, however, rather obscure. All that is known with certainty is that it was designed sometime after 150 BC when the stereographic projection, on which its construction is based, was said to be have been invented by Hipparchus and that almost all its main components were fully developed by 530 AD when the earliest available work on it was composed by John Philoponus in Greek.[1] The Islamic world preserved the Greek science of the astrolabe, as it did the other areas of Greek learning, elaborated upon it and disseminated it westwards and eastwards.

Again, we do not have any definite information when the astrolabe was introduced into India. Al-Bīrūnī, who wrote extensively on the astrolabe, may have introduced it to his Hindu interlocutors in north-western India in the first quarter of the eleventh century. There are stray references to Muslim scholars, who migrated from Central Asia in the subsequent centuries, employing the astrolabe for astronomical and astrological purposes in Delhi.

Definite evidence is available from the fourteenth century onwards. Contemporary chronicles report that Sulṭān Fīrūz Shāh Tughluq (r.1351-1388) got several astrolabes manufactured at Delhi and sponsored the composition

[1]For an English translation of this work, see R. T. Gunther, *The Astrolabes of the World*, Oxford 1932, reprint: London 1976, vol. I, pp. 61-81.

of manuals on the astrolabe both in Persian and in Sanskrit.[2] In the following centuries, especially in the seventeenth, numerous astrolabes were produced in India with Arabic/Persian legends. These are generally classified as Indo-Persian astrolabes.[3]

Hindu and Jain astronomers were also highly enthusiastic about this exotic, but versatile, instrument which they hailed in Sanskrit as *Yantrarāja*, 'king of instruments'. They 'appropriated' it by composing more than a dozen Sanskrit manuals on it between the fourteenth and eighteenth centuries.[4]

The very first Sanskrit manual on the astrolabe was composed in 1370 by a Jain monk called Mahendra Sūri, who was a leading astronomer at the court of Firūz Shāh at Delhi. This work, entitled *Yantrarāja*,[5] consists of five chapters. The first chapter provides various trigonometric parameters and tables needed for the construction of the astrolabe. The second chapter discusses the components of the astrolabe. The construction of the common northern astrolabe (*saumya-yantra*) and other variants is described in the third chapter, while the next one deals with the method of verifying whether an astrolabe is properly constructed or not. The final chapter discusses the use of the astrolabe as an observational and computational device and dwells on problems in astronomy and spherical trigonometry that can be solved by means of the astrolabe. Mahendra Sūri's pupil Malayendu Sūri wrote a detailed commentary on the *Yantrarāja*. There survive today at least one hundred manuscript copies of the *Yantrarāja*, attesting to its great popularity.

Persian chronicles narrate that Firūz Shāh was interested not only in the commonly used northern astrolabe, but also in its variants, viz., the southern astrolabe and the composite astrolabe which is a combination of the two, and that he commissioned a very splendid specimen of the composite as-

[2] See Sreeramula Rajeswara Sarma, 'Sulṭān, Sūri and the Astrolabe' in: idem, *The Archaic and the Exotic: Studies in the History of Indian Astronomical Instruments*, New Delhi 2008, pp. 179-198.

[3] On Indo-Persian astrolabes, see Sreeramula Rajeswara Sarma, 'Astronomical Instruments in Mughal Miniatures' in: idem, *The Archaic and the Exotic*, op. cit., pp. 76-121; 'The Lahore Family of Astrolabists and their Ouvrage,' ibid., pp. 191-222; 'The *Ṣafīḥa Zarqāliyya* in India,' ibid., 223-239; *Astronomical Instruments in the Salar Jung Museum*, Hyderabad 1996; *Astronomical Instruments in the Rampur Raza Library*, Rampur 2003.

[4] These texts are discussed in Sreeramula Rajeswara Sarma, 'Yantrarāja: the Astrolabe in Sanskrit' in: idem, *The Archaic and the Exotic*, op. cit., pp. 240-256.

[5] Mahendra Sūri, *Yantrarāja of Mahendra Sūri together with the commentary of Malayendu Sūri, and Yantraśiromaṇi of Viśrāma*, ed. Kṛṣṇaśaṃkara Keśavarāma Raikva, Bombay 1936.

trolabe which was named Fīrūz Shāh's Astrolabe (*asṭurlāb-i Fīrūz Shāhī*). The difference between these varieties is as follows. In the northern astrolabe (Arabic: *asṭurlāb shumālī*, Sanskrit: *saumya-yantra*), the rete contains pointers for stars situated between the north celestial pole and the Tropic of Capricorn. As against this, the rete of the southern astrolabe (Arabic: *asṭurlāb janūbi*, Sanskrit: *yāmya-yantra*) has pointers for stars that lie between the south celestial pole and the Tropic of Cancer. The third variant combines the features of these two and is called the north-south astrolabe (Arabic: *asṭurlāb shumālī wa janubī*, Sanskrit: *miśra-yantra*). The two variants are actually theoretical constructs and have no real practical value. This is evident from the fact that out of some three thousand and odd Islamic, European and Sanskrit astrolabes that are extant today, the southern and north-south variants account for less than a score of specimens. Even so, most of the Sanskrit writers discussed all the three varieties. In fact, in 1423 Padmanābha composed an exclusive manual on the southern astrolabe under the title *Yantrarājādhikāra*.[6]

The next writer of note is Rāmacandra Vājapeyin[7] who devoted the major part of his *Yantraprakāśa* (1428)[8] to the astrolabe and declared that, if one knew the science of the astrolabe well, the entire universe would become comprehensible like the myrobalan fruit on one's own palm (1.9: *yasmin karāmalakavad vidite viditaṃ bhaved viśvam*).

The astrolabe received a great impetus from Sawai Jai Singh in the early eighteenth century. Although he preferred huge masonry instruments for astronomical observations, he had great esteem for the astrolabe on which he composed a manual in Sanskrit prose under the title *Yantrarājaracanā*.[9] Even after Jai Singh's time, the astrolabe continued to be discussed in several Sanskrit works.

These Sanskrit manuals on the astrolabe must naturally have been accompanied by the production of Sanskrit astrolabes, i.e., astrolabes with legends and numbers engraved in Sanskrit language and Devanāgarī script. In the

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[6]In his 'Early History of the Astrolabe in India,' *Indian Journal of History of Science*, 32 (1997) 199-295, Yukio Ôhashi offers an excellent edition, translation and mathematical commentary of Padmanābha's *Yantrarājādhikāra*.

[7]Sreeramula Rajeswara Sarma, 'On the Life and Works of Rāmacandra Vājapeyin' in: *Śrutimahatī: Glory of Sanskrit Tradition* (Professor R. K. Sharma Felicitation Volume), Delhi 2008, vol. 2, pp. 645-661.

[8]Together with an auto-commentary, available in MS G-1363 of the Asiatic Society, Kolkata, and MS 975/1886-92 of the Bhandarkar Oriental Research Institute, Pune.

[9]Kedāranātha Jyotirvid (ed), *Yantrarājaracanā of Jayasiṃhadeva* & *Yantraprabhā of Śrīnātha*, Jaipur 1953.

course of my project of surveying the extant specimens of pre-modern Indian astronomical and time-measuring instruments,[10] I have located nearly one hundred Sanskrit astrolabes in various museums and private collections in India, Europe and the US.

There is a basic difference between these Sanskrit astrolabes and the Islamic astrolabes. In Islamic culture, astrolabe making was not just a craft but a learned profession; the astrolabists were not mere metal workers, but also scholars well read in the literature on the instruments, well versed in astronomy, spherical trigonometry and other sciences. Here the same person prepared the technical design and then executed it from brass sheets. In the Hindu context, the technical design was drawn by the upper caste astronomer, and the actual manufacture was done by the lowly brass worker who may not even be literate. He managed to draw the lines and curves reasonably well, but often made mistakes in orthography.

Nevertheless, the large number of extant Sanskrit texts and Sanskrit astrolabes show the importance given to the astrolabe by the Hindu astronomers. We have noted that production of Sanskrit manuals commenced in the fourteenth century. Sanskrit astrolabes also must have been produced in that century, but those that survive are only from the seventeenth century onwards. I have identified the following ten astrolabes from the seventeenth century. Most of these were produced in Gujarat.

1. 1605 Made for Dāmodara, private collection, Brussels.
2. 1618 Anon, Raja Dinkar Kelkar Museum, Pune.
3. 1625 Made by Cakrapāṇi[11] (present location unknown).
4. 1638 Made by Murāraji for Haranatha, Bhandarkar Oriental Research Institute, Pune.
5. 1642 Made by Kalyāṇa of Girinārāyaṇa-jñāti for Puruṣottama (present location unknown).
6. 1643 Made for Maṇirāma, Royal Scottish Museum, Edinburgh.[12]

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[10] On this project, see Sreeramula Rajeswara Sarma, 'Indian Astronomical and Time-Measuring Instruments: A Catalogue in Preparation' in: idem, *The Archaic and Exotic*, op. cit., pp. 19-46.

[11] It was auctioned in 2002; cf. Skinner, Bolton, USA, Auction Catalogue 'Science & Technology featuring Mechanical Music,' April 13, 2002, no. 244, pp. 38-39; only the mater is extant.

[12] Cf. Sreeramula Rajeswara Sarma, 'Yantrarāja at Edinburgh: On a Sanskrit Astrolabe made for Maṇirāma in AD 1644,' to appear in S. R. Sarma & Gyula Wojtilla (ed), *Scientific Literature in Sanskrit*, (Proceedings of the 13th World Sanskrit Conference, Section 8), Motilal Banarsidass, Delhi, p. 77-110.

7. 1651 Made for Jīvatāpana, Oriental Institute, Vadodara.[13]
8. 1669 Made for Rāghavajit (present location unknown).[14]
9. 1673 made for Indrajī, Pitt Rivers Museum, Oxford.[15]
10. Anonymous, not dated, but attributable to the seventeenth century, Sanskrit University, Varanasi.[16]

2.0 Dāmodara's Astrolabe

The earliest of these, in fact, the earliest extant Sanskrit astrolabe, is the subject of this paper. It was produced at Ahmedabad for Dāmodara, son of Caṇḍīdāsa, and is now in a private collection in Brussels. There has been some controversy about its date and authenticity. I shall first describe the astrolabe as it is available today, comparing its construction, where necessary, with the other seventeenth century Sanskrit astrolabes and also with Indo-Persian astrolabes. I shall then explain the controversy, and finally establish its authenticity.

Since this is the earliest extant Sanskrit astrolabe, some extracts from the earliest Sanskrit manual on the astrolabe, viz. the *Yantrarāja* of Mahendra Sūri, dealing with the construction of the astrolabe, are given in the appendix. As stated above, this text was immensely popular in India. It will be shown that its influence is clearly discernable in the Sanskrit astrolabes of the seventeenth century, including the present astrolabe.

2.1 The Front of the Astrolabe

The present astrolabe is a large massive piece with a diameter of 276 mm, a height of 380 mm and a thickness of 10.3 mm. The body is surmounted by an elaborately pierced suspension bracket or crown (*kirīṭa*) with a very

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[13] Cf. Sreeramula Rajeswara Sarma, *Sanskrit Astronomical Instruments in the Maharaja Sayajirao University of Baroda*, M.S. University Oriental Series No. 24, Oriental Institute, Vadodara, 2009, pp. 23-32, Figs. 11-19.

[14] In 1936, it was in the possession of Raikva, who published 13 detailed illustrations of this astrolabe in his edition of Mahendra Sūri's *Yantrarāja* (see n. 5 above) immediately after his introduction. Its present location is unknown.

[15] Cf. R. T. Gunther, *Early Science in Oxford*, vol. II: Astronomy, Oxford 1923, pp. 187-199, esp. 198; idem, *The Astrolabes of the World*, op. cit., p. 211, Fig. 110.

[16] Cf. Sreeramula Rajeswara Sarma, 'Kaṭapayādi Notation on a Sanskrit Astrolabe' in: idem, *The Archaic and Exotic: Studies in the History of Indian Astronomical Instruments*, New Delhi 2008, pp. 257-272.

wide base that stretches to about 106 degrees of arc (see Figure 1[17]). The crown is worked *à jour* to produce an ornate pattern with a human figure entwined in vines and leaves. The surface of the crown is, however, plain and undecorated, and no attempt was made to smoothen and polish the sharp edges. There is a hole at the top of the crown through which passes a shackle (*kaṇṭaka*) with ornate terminals. A small ring (*mudrikā*) passes through the shackle. The shackle and the ring make it possible to suspend the astrolabe vertically and to rotate it all around. The ring is, however, much too small for this large astrolabe. Both the shackle and the ring have diamond-shaped cross-sections as in the contemporary Indo-Persian astrolabes. At the top of the crown, immediately below the hole is an inscription in Sanskrit in Devanāgarī letters which reads *śrī-divyacakṣuṣe namaḥ*, 'salutation to the divine eye,' i.e. the sun.

The main body of the astrolabe, consisting of a thick brass disc with an upraised rim and the crown, was cast in one piece. It is called mater (*koṣṭhakāgāra*, lit. store-house, repository) because the recess inside the upraised rim accommodates several latitude plates and above them the perforated star map called rete. The upraised rim carries the degree scale in two columns or bands. The narrow inner band is graduated in single degrees of arc; the wider outer column is divided into groups of 3 degrees each and labelled with very elegant Devanāgarī numerals of western Indian style.

2.2 The Back of the Astrolabe

The back of the astrolabe (*yantra-pṛṣṭha*) (Figure 2) carries the diopter or alidade with which the celestial bodies are viewed and the angle of their elevation or altitude is measured. The alidade, which is pivoted to the centre, is a straight metal bar without any counter-change and is 265 mm long. It has pointed ends. A sighting tube is attached to it by means of two upright supports. The tube measures 290 mm and is slightly longer than the diameter of the astrolabe. This tube facilitates the sighting of the heavenly bodies and is a typical feature of Sanskrit astrolabes.

Islamic astrolabes, whether in India or outside, do not have sighting tubes attached to their alidades. The same is the case with European astrolabes.

[17] Photo credits: Figure 2 is from Christie's, South Kensington, *Time Measuring Instruments from THE TIME MUSEUM*, for sale by Auction, Thursday 14 April 1988, Catalogue, no. 157, pp. 98. Figures 3 and 4 are by the courtesy of Anthony Turner. The remaining photos are by me.

The Sanskrit astrolabes, however, carry a sighting tube in most of the cases. In India, the sighting tube was used as an independent device to view celestial bodies.[18] It was called *Nalaka-* or *Nālikā-yantra* and was described in several Sanskrit texts.[19] Apparently Hindu astronomers decided, at quite an early period, to combine the already known sighting tube with the newly imported astrolabe. This, no doubt, facilitates the sighting, but prevents the calibration of the upper surface of the alidade and thus divests it off the trigonometric functions envisaged for the alidade in Islamic tradition. No Sanskrit text appears to mention this innovation.

The surface of the back is divided into four quadrants by the diameters drawn in the south-north and east-west directions. The edge of the entire surface is occupied by a degree scale. As in the front, here also the inner band of the scale is graduated in single degrees and the outer band is divided into groups of three degrees. But here the groups of three degrees are labelled separately for each quadrant, starting from the east or west points and proceeding towards the south or west points. The degrees scales in the upper half, starting from the east and west points and reaching the south point, are useful for measuring the angle of altitude of a heavenly body situated to the east or west of the meridian. Those in the lower half can also be used for the same purpose, but are actually redundant. Islamic astrolabes carry cotangent scales in the lower half, but these are not met with in Sanskrit astrolabes.

The spaces inside the circular scale in the four quadrants are filled with different trigonometric graphs. The upper left quadrant contains a sexagesimal sine graph, with sixty horizontal parallel lines drawn at equal intervals. These are numbered serially, three at a time, on the right along the vertical radius, starting from the centre and proceeding upwards as 9, 12, 15, ... 54, 57, 60. While the angle of altitude is measured on the circular degree scale on the left edge, the sine of the angle can be directly read off the vertical scale on the right. An arc is drawn at 24° inside the quadrant to mark the obliquity of the ecliptic. The quadrant is divided by three radii into three sectors of 30° each. In these sectors are engraved the numbers 1 to 12 in the following manner. In the first row immediately next to the arc of the obliquity are the numerals 1, 2, 3, written in each sector. The tops of these numerals are towards

[18]It was also known to the Greeks and Arabs; cf. Peter Schmalzl, *Zur Geschichte des Quadranten bei den Arabern*, München 1929; reprint in: *Islamic Mathematics and Astronomy*, vol. 90 (Astronomical Instruments and Observatories in the Islamic World: Text and Studies VI), Frankfurt 1998, pp. 189-331, esp. 218-219.

[19]Cf. R. N. Rai, 'Astronomical Instruments,' *Indian Journal of History of Science*, 20 (1985) 308-336, esp. 333-336: The Nalaka-yantra.

Figure 1: The Front of the Astrolabe

Figure 2: The Back of the Astrolabe

the degree scale in the circular edge. In the next row are the numerals 6, 5, 4 (as read from left to right). These are upside down (i.e., the tops are towards the centre). In the third row are 7, 8, 9 with orientation as in the first row. The fourth row has numbers 12, 11, 10, with orientation as in the second row.[20]

The upper right quadrant contains a series of curves for unequal hours, which are numbered from 1 to 12. Of the seventeenth-century Sanskrit astrolabes, only the astrolabe made for Indrajī in 1673 has this feature. Otherwise it occurs rarely in Sanskrit astrolabes and also in Indo-Persian astrolabes.[21]

In the lower half are engraved shadow squares, on the left for a gnomon of 12 digits, and on the right for a gnomon of 7 digits. The scales are numbered, but there are no labels.

The seventeenth century Indo-Persian astrolabes contain, besides these trigonometric graphs, much astrological data on the back. The Sanskrit astrolabes rarely follow this practice, and the present astrolabe is no exception.

On the inner side of the mater, on the meridian line below the centre and somewhat close to the rim, is a pin affixed at right angles to the surface of the mater. This pin holds the latitude plates firmly in position and prevents them from rotating around the centre.

On the same inner side, in the upper half is an inscription, mentioning the name of the patron who caused this astrolabe to be made and the date of manufacture. The inscription will be discussed below in section 3.

2.3 The Latitude Plates

The recess formed by the upraised rim of the mater accommodates six thin circular plates. These are called in Sanskrit *akṣa-patra* or *akṣāṃśa-patra*, because each face of the plate carries stereographic projections of the heavens

[20] Probably these numbers refer to the 12 signs of the zodiac. In a sine quadrant made by Jamāl al-Dīn Muḥammad 'Alī al-Ḥusaynī in AH 1273 (AD 1856-57), in the space between the arc of the quadrant and the corner of the plate are engraved the names of twelve signs in the same order. However, I am unable to explain the arrangement. Does this have to do with some type of classification of the signs? The quadrant is now with the Rampur Raza Library; cf. Sreeramula Rajeswara Sarma, *Astronomical Instruments in the Rampur Raza Library*, op. cit., pp. 76-77 and Fig. 9.1 on p. 75.

[21] Mahendra Sūri, *Yantrarāja* 3.3 (see Appendix) mentions that the quadrants on the back should be filled with a sine graph, a declination graph and shadow squares. So does Rāmacandra Vājapeyin, *Yantraprakāśa* 2.7d: *kecit procur apakramāṃśa-guṇa-śankvābhā-sthitiṃ tatra ca*, 'Some prescribe there the setting up (*sthiti*) of the declination (*apakrama*) [graph], sine (*guṇa*) [graph] and gnomon shadow (*śankvābhā*) [squares].'

related to a specific terrestrial latitude (*akṣa, akṣāṃśa*).[22]

These six plates (Figures 3 and 4) have a diameter of 252 mm. There is a hole at the centre through which passes the pin that holds together all the components of the astrolabe. This pin, like the centres on all the plates, defines the north celestial pole. Below the centre, on the lower half of the meridian, there is another hole. When the plates are stacked together inside the recess, the short pin projecting from the lower half of the mater passes through this second hole in the plates and holds them firmly in position.

On both faces of all the six plates, the projections are drawn in the following manner. First the four cardinal directions are marked on the face of the plate, by means of the east-west diameter (*pūrvāparasūtra*) and south-north diameter; the latter represents the meridian line (*khamadhya-sūtra*) or the 12 o'clock line (*madhyāhna-rekhā*).

Then taking the radius of the plate as 30 units, three concentric circles are drawn with radii of 30, 19;38 and 12;51 units respectively. The outermost circle with the radius of 30 units forms the periphery of the plate and defines the tropic of Capricorn (*makarāhorātra-vṛtta*). The middle circle with the radius of 19;38 units represents the celestial equator. The inner circle with the radius of 12;51 units is the tropic of Cancer (*karkāhorātra-vṛtta*).

Against this grid is drawn the local or oblique horizon (*kṣitija-vṛtta*). Above the arc of the horizon circle, the equal altitude circles or almucantars (*unnata-vṛtta*) are drawn for each 3 degrees of arc,[23] with varying radii and varying centres (which are all situated on the meridian).[24] All the equal altitude circles are numbered on the right as well as on the left, as 3, 6, 9 . . . 90. The rows of the numbers form a pattern that looks like a rounded Roman character 'M', as in the Indo-Persian astrolabes.

It is worth noting that no azimuth lines (*digaṃśa-vṛttas*) are drawn on any

[22]On the construction of the latitude plates, see Mahendra Sūri, *Yantrarāja* 3.5-7, Appendix.

[23]In Islamic tradition, astrolabes are classified according to the number of almucantar circles drawn on the latitude plates. Mahendra Sūri also mentions this classification at *Yantrarāja* 3.1, (see Appendix). Therefore this astrolabe belongs to the tripartite (Arabic: *thulthī*) class. The tripartite arrangement can be seen also in the degree scale on the front and back of the mater, in the vertical scale of sines in the upper left quadrant on the back, and in the subdivision of the signs in the ecliptic ring on the rete.

[24]Mahendra Sūri teaches the method of computing the radii (*vyāsārdha*) and the eccentricities (*kendra*) of different altitude circles in his *Yantrarāja* 1.18-21. In his commentary (pp. 19-25) Malayendu Sūri provides the values of the radii and eccentricities, at six degree intervals, for six towns, viz. Tilaṅga (lat. 18°), Tryambaka (21°), Aṇahillapattana (lat. 24;30°), Tīrabhukta (lat. 27°), Dillī (28;39°) and Nepālapura (31°).

plate, which are usually to be met with in Islamic astrolabes. In contrast, Sanskrit astrolabes rarely carry azimuth lines.

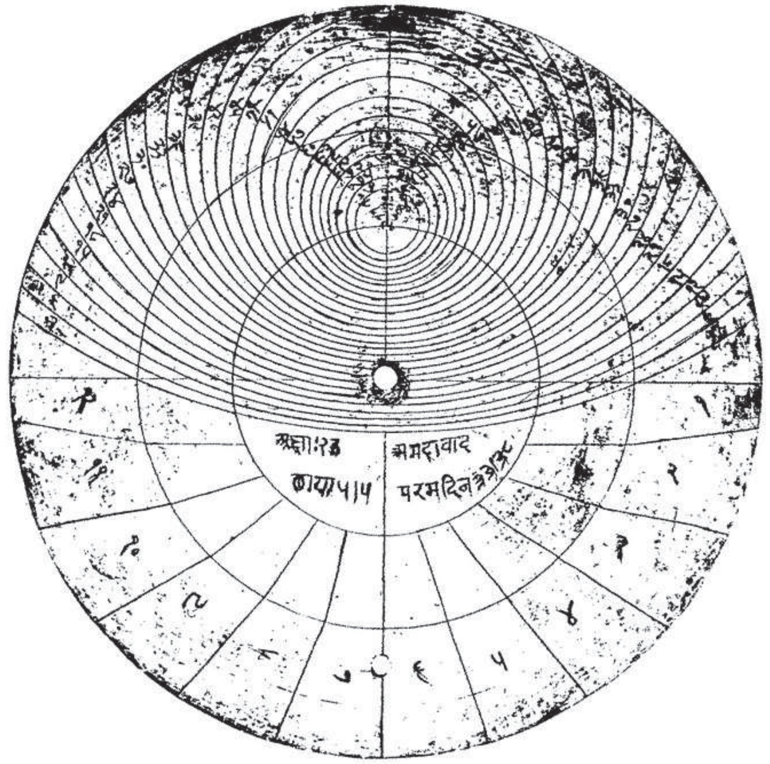

Figure 3: Plate for the Latitude of Ahmedabad

In the lower half of the plate, the arcs of the three circles representing the tropic of Capricorn, the equator and the tropic of Cancer lying below the oblique horizon are divided into 12 parts each. The corresponding points of division on the three arcs are joined, not by arcs as is the general practice, but by two straight lines. That is to say, the first point of division on the tropic of Cancer is joined to the first point on the equator by a straight line, and the first point on the equator is joined to the corresponding point of the tropic of

Capricorn by another line. These lines are designated as unequal hour lines or seasonal hour lines.[25] The unequal hours (*viṣama-horā*) are numbered with the numerals 1 to 12, starting at the western horizon and going up to the eastern horizon. The Hindus and Jains in India did not reckon time in unequal or equal hours, but in equal *ghaṭīs* (of 24 minutes each) and began the day with the sunrise. Lines for equal *ghaṭīs*, as commensurate with the actual practice in India, can easily be drawn, but strangely this has never been attempted in any Sanskrit astrolabe, although some Indo-Persian astrolabes have such lines.

Mahendra Sūri mentions only the curves for unequal hours as counted from the western horizon.[26] But he also teaches a simple method for measuring time in equal *ghaṭīs* as follows. First measure the sun's altitude with the alidade on the back of the astrolabe. Note the sun's longitude (*ravyaṃśaka*) for the day from some almanac and locate that point (S) on the ecliptic in the rete. Rotate the rete in such a way that the point S touches the eastern horizon. Note where the first point of Capricorn (*mṛgāsya*) touches the circular scale on the rim. Then rotate the rete once again so that S rests on the altitude circle corresponding to the sun's altitude jut measured. Note again where the first point of Capricorn touches the circular scale on the rim. The interval between the two positions is in degrees of arc. Divide it by 6. The result in *ghaṭīs* is the time elapsed since sunrise.[27]

[25]The unequal hours are obtained by dividing the duration of the daytime and that of the night separately by 12. Except on the days of equinox, such hours vary from the day to the night, and from one day to the next, according to the seasons.

[26]Mahendra Sūri, *Yantrarāja* 3.9 (see Appendix).

[27]Ibid., 5.3-4ab:

ravyaṃśakaṃ prāgapare ca bhūje dhṛtvonnatāṃśoparige kṛte'smin |
dvisthānasaṃlagnamṛgāsyamadhye kālāṃśakaiḥ paṅkti 10 palapramāṇaiḥ ||
ṣaḍbhir vibhaktair divasasya yātaṃ śeṣaṃ ca ghaṭyādi parisphuṭaṃ syāt |

"[Rotate the rete in such a way that] the sun's [longitude in] degrees (*ravy-aṃśaka*) [as seen in the ecliptic, on the desired day] falls on the eastern horizon (*bhūja*) [if it is the forenoon] or on the western horizon [if it is the afternoon, and then rotate again so that the longitude] falls on the altitude degrees. The time degrees between the two positions of the first point of Capricorn (*mṛgāsya*), each of which equals 10 *palas*, are divided by 6. The quotient in *ghaṭīs* etc. is the time elapsed or the time to come in the day [in the forenoon and in the afternoon respectively].

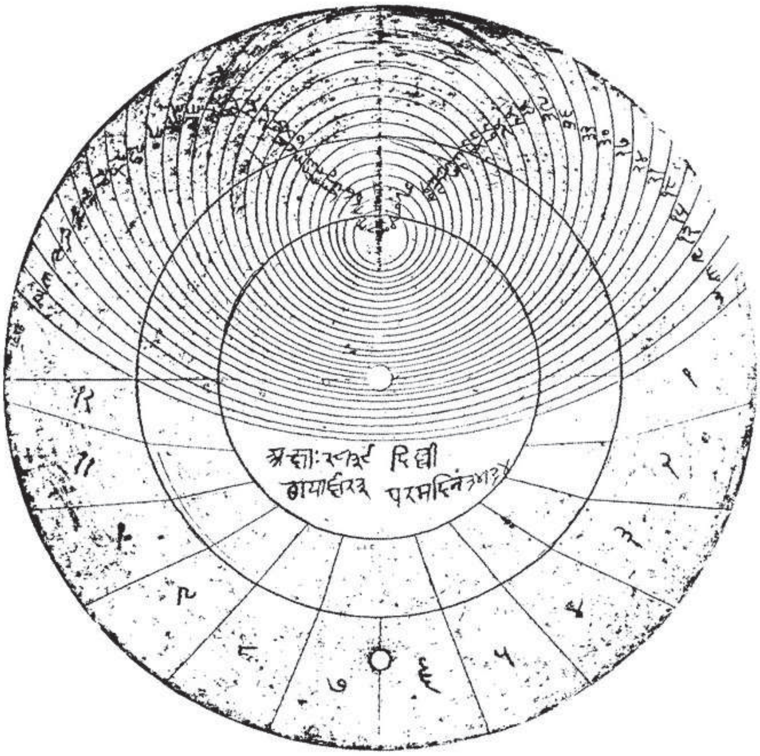

Figure 4: Plate for the Latitude of Delhi

Finally, in the space between the oblique horizon and the tropic of Cancer on each face are engraved four items of data regarding the projections drawn on this particular face, viz. (i) the name of a town, (ii) its latitude (*akṣāḥ*, φ) in degrees and minutes, (iii) the length of the midday equinoctial shadow (*chāyā*, tan φ), in *aṅgulas* and *vyaṅgulas*, thrown by a gnomon of 12 *aṅgulas* and (iv) the length of the longest day at this latitude (*paramadina*)[28]

[28]Christie's: South Kensington, *Time Measuring Instruments from THE TIME MUSEUM*, for sale by Auction, Thursday 14 April 1988, Catalogue, no. 157, pp. 98-99, mentions erroneously that the plates carry the length of **half** the longest day, but it is actually the length of the full day.

in *ghaṭīs* and *palas*. In fact, (iii) the length of the midday equinoctial shadow and (iv) the duration of the longest day are dependent on (ii) the latitude and are its functions. Sanskrit astronomical texts provide formulas for converting any one of the three values into another.[29] Islamic astrolabes generally mention only the latitude (*al-arḍ*) and the longest day (*al-sā'āt*). Mahendra Sūri indeed recommends that these four items be engraved on the astrolabe plates.[30]

The relevant inscriptions are reproduced below. The serial numbers for the plates and the designation of the two faces of the plates as 'a' and 'b' respectively have been added by us.

1a	*akṣāḥ*	*18*	*vījāpura*	*chāyā*	*3/45*	*paramadinaṃ*	*32/52*
1b	*akṣāḥ*	*22/30*	*ujjani*	*chāyā*	*4/9*	*paramadinaṃ*	*33/34*
2a	*akṣāḥ*	*20/30*	*bahrānapura*	*chāyā*	*4/30*	*paramadinaṃ*	*33/16*
2b	*akṣāḥ*	*23*	*amadāvāda*	*chāyā*	*5/5*	*paramadina*	*33/38*
3a	*akṣāḥ*	*25/52*	*kāśī*	*chāyā*	*5/45*	*dinamānaṃ*	*34/5*
3b	*akṣāḥ*	*27/40*	*ḍhākā*	*chāyā*	*6/20*	*paramadina*	*34/24*
4a	*akṣāḥ*	*25/56*	*yodhapura*	*chāyā*	*5/51*	*paramadinaṃ*	*34/8*
4b	*akṣāḥ*	*31/50*	*lāhora*	*chāyā*	*7/30*	*paramadina*	*35/20*
5a	*akṣāḥ*	*26/24*	*āgarā*	*chāyā*	*6/*	*paramadinaṃ*	*34/12*
5b	*akṣāḥ*	*28/39*	*dillī*	*chāyā*	*6/23*	*paramadinaṃ*	*34/34*
6a	*akṣāḥ*	*29/40*#	*mulatāṇa*	*chāyā*	*6/47*	*paramadi°*	*34/44*
6b	*akṣāḥ*	*35/20*	*kaśmīra*	*chāyā*	*8/6*	*paramadi*	(not filled)

It looks as if the latitude value of Multan was first engraved as 39/40 and then corrected to 29/40. The values given for the equinoctial shadow and the longest day match the latitude value of 29/40. Pingree read the latitude as 39/40 and this wrong reading was reproduced by Turner in his catalogue.

This material is arranged and interpreted in Table 1. The towns are rearranged according to increasing latitude.

Interestingly these plates are town specific and not latitude or climate specific. Except in the case of Dhaka, the latitude values are reasonably close to modern values. The Islamic astrolabes generally contain, besides the plates calibrated to specific latitudes, one more plate, one face of which is designated as *ṣafīḥa mīzān al-'ankabūt* (plate for the measures on the rete) and

[29] Mahendra Sūri, *Yantrarāja* 3.25-27, gives formulas for converting local latitude into the duration of the longest day and the longest day into equinoctial shadow.

[30] Cf. Mahendra Sūri, *Yantrarāja* 3. 8 (see Appendix).

S. No.	Town Name as engraved	Modern Name	Latitude (*akṣāḥ*)	Modern Coordinates	Equinoctial shadow (*chaya*)	Longest Day (*paramadina*) in *ghaṭīs* and *palas*	Longest Day in hours and minutes
1a	bījāpura	Bijapur	18	16;50° E 75;47° N	3;45	32;52	13;08.48
2a	bahrānapura	Burhanpur	20;30	21;17° N 76;16° E	4;30	33;16	13;18.24
1b	ujjani	Ujjain	22;30	23;09° N 75;43° E	4;09	33;34	13;25.36
2b	amadāvāda	Ahmedabad	23	23;03° N 72;40° E	5;05	33;38	13;27.12
3a	kāśī	Varanasi	25;52	25;20° N 83;00° E	5;45	34;05	13;38
4a	yodhapura	Jodhpur	25;56	26;18° N 73;04° E	5;51	34;08	13;44.12
5a	āgarā	Agra	26;24	27;10° N 78;05° E	6;00	34;12	13;40.48
3b	ḍhākā	Dhaka?	27;40	23;43° N 90;26° E	6;20	34;24	13;45.36
5b	dillī	Delhi	28;39	28;38° N 77;12° E	6;23	34;34	13;49.36
6a	mulatāna	Multan	29;40	30;12° N 71;31° E	6;47	34;44	13;53.36
4b	lahora	Lahore	31;50	31;37° N 74;26° E	7;30	35;20	14;08
6b	kaśmīra	Kashmir (actually) Srinagar	35;20	34;06° N 74;51° E	8;06	—	—

Table 1: Geographical Data engraved on the Plates

the other as *ṣafīḥa al-afāqiyah* (plate of horizons). The former is a projection for the latitude which is the complement of the obliquity of the ecliptic, i.e. 90-23;50 = 66;30° or roughly 66°. This plate enables us to measure the longitudes and latitudes of all the stars marked on the rete. The plate of horizons contains the projections of families of horizons at several latitudes and is used for determining the times of sunrise and sunset at latitudes other than one's own, or to determine the latitude from the time of sunrise or sunset. The present astrolabe does not have such a plate.

In sum, the plates in this Sanskrit astrolabe are generally calibrated as those in Islamic astrolabes, but differ from the latter in three details, viz. there is no plate for the *ṣafīḥa mīzān al-ʻankabūt* and the *ṣafīḥa al-afāqiyah*, they do not have azimuth lines, and on each face is engraved the length of the equinoctial shadow in addition to the usual data.

On all the six plates, the almucantar circles are well drawn. However, the calligraphy of the legends and numerals is not the same as that on the mater and is considerably inferior. The workmanship of these plates is also rather inferior to that of the mater.

2.4 The Rete

On the top of the six latitude plates rests the rete (*bha-patra*, *bhacakra-patra*), an openwork disc, somewhat thicker than the latitude plates (Figure 5). It carries the stereographic projection of the sphere of the fixed stars.[31] With its 250 mm diameter, it is slightly smaller than the latitude plates. As on the latitude plates, here also the three concentric circles are drawn to represent the tropics and the celestial equator. The ecliptic (*krānti-vṛtta*) is drawn with radius of 21;26 units from a centre situated on the meridian at 8;34 units south of the centre of the plate,[32] so that it touches the tropic of Capricorn at the top and the tropic of Cancer below.

Some space is added inside the three circles of Capricorn, equator and ecliptic so that they have the shape of bands. The circular bands of Capricorn and equator are represented almost fully in the rete. The former is interrupted where the ecliptic touches it tangentially, while the band of the

[31] Mahendra Sūri explains the construction of the rete in his *Yantrarāja* 3.10-16, Appendix.

[32] Mahendra Sūri, *Yantrarāja* 1.66:

bhāgā bhacakrakendrasyāṣṭau liptā vedavahnayaḥ |
vyāsārdhasya dharādoṣo rasanetrāṇi ca kramāt ||

'The eccentricity (*bhacakra-kendra*) is 8 degrees and 34 minutes (i.e. actually 8;34 units where each unit is 1/30th of the astrolabe's radius) and the radius (*vyāsārdha*) 21;26 [units].'

equator has interruptions at two symmetrical places in the east and west. The ecliptic band is shown completely. The three bands are held together by the horizontal equinoctial bar which is without counter-change. The band of Capricorn and the lower segment of the equatorial band are joined together by a vertical bar on the meridian. This bar carries a short copper knob for rotating the rete around the centre.

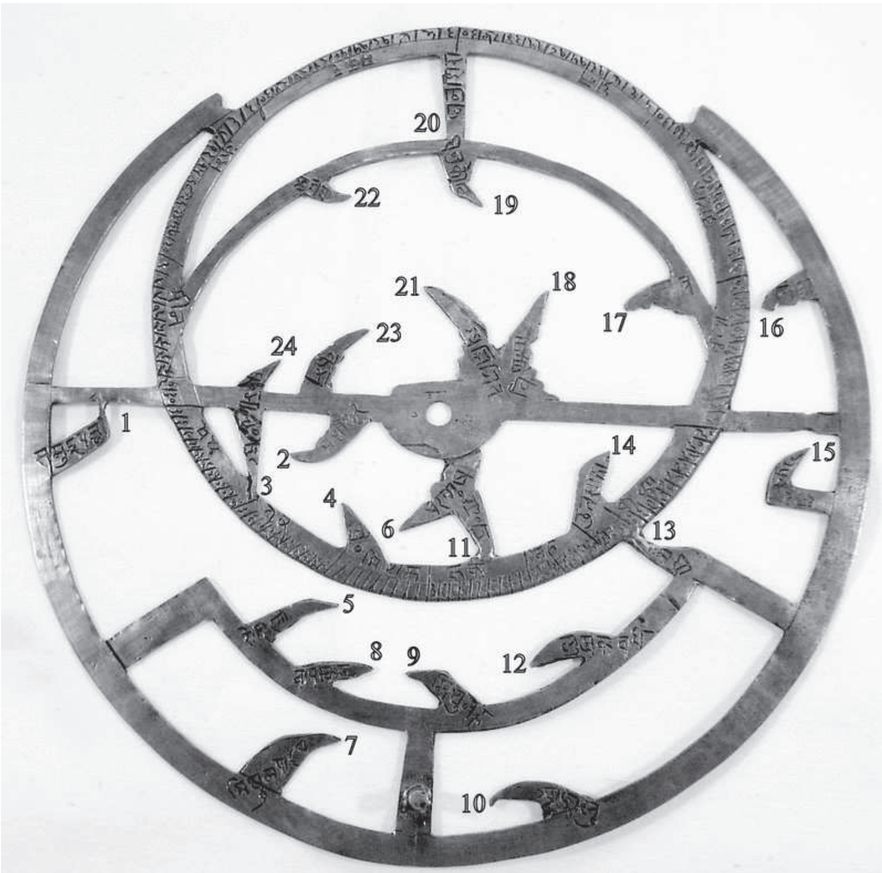

Figure 5: The Rete of the Astrolabe

The ecliptic circle is divided into the 12 signs of the zodiac, in unequal divisions in proportion to the rising times of the signs at the equator (*nirakṣodaya* or *laṅkodaya*), i.e. right ascensions. On each sign the respective Sanskrit names are engraved somewhat carelessly as *maṣa* (sic! read *meṣa*), *vaṣa* (*vṛṣa*), *mithana (mithuna)*, *karka*, *siṃha*, *kanyā*, *tulā*, *vṛścika*, *dhana* (*dhanuḥ*), *makara*, *kubha* (*kumbha*), *mīna*. Each sign is further subdivided into 10 units of 3 degrees each and numbered as 3, 6, 9…24, 27, 30 in counter-clockwise direction. The divisions under Gemini (*mithuna*), however, are not numbered.

On this grid the positions of 24 prominent stars are marked on the basis of their longitudes (*dhruvaka*) and latitudes (*vikṣepa*)[33] and these points are connected to the nearest circles or bars in the form of star pointers (*nakṣatra-cañcu*), curved like tiger's claws, with the names of the respective stars engraved on them. Ten of these are outside the ecliptic, i.e. to the south of it; while fourteen are inside the ecliptic circle, i.e. to the north of the ecliptic. The stars to the south of the ecliptic have southern declinations; those to the north of the ecliptic have northern declinations.

The names on the star pointers are generally correct, but with occasional errors. Sometimes, the vocalic symbols (*mātrās*) on the top and below are missing. The engraver replaces Sanskrit *kha* with *ṣa* and *ba* with *va*. All the star names are taken from Mahendra Sūri's *Yantrarāja*.

Table 2 below lists the stars on the rete, starting from the vernal equinox and proceeding in the order of increasing longitude

The designation of no. 10 (Sirius, α Canis Maioris) as *ārdrālu* (short for *ārdrā-lubdhaka*) is problematic. In his *Yantrarāja*, Mahendra Sūri enumerates 32 astrolabe stars with their longitudes and latitudes.[34] The 14th star in the list is *ārdrā* (p. 26, verse 28). In the tables appended to the commentary, this star is mentioned as *ārdrā-lubdhaka* (pp. 37, 41) and the corresponding Arabic name is given as *sorāmānī* or *serāimānī* . This is clearly an incorrect transcription of *shi'rà yamānīyaḥ*, i.e. Sirius (α Canis Maioris).

Besides the present astrolabe, several other seventeenth century astrolabes employ Mahendra's designation for Sirius. Thus an astrolabe produced in 1644 for Maṇirāma[35] employs the star names together with their serial numbers as assigned by Mahendra Sūri. Here Sirius is labelled as '*ā 14*,' i.e., the 14th star in Mahendra's list; therefore *ā* stands for *ārdrā-lubdhaka*. In an astrolabe produced in 1618[36] and in another of 1669[37] Sirius is labelled as '*ā.lu.*,' i.e., short for *ārdrā-lubdhaka*. The Sanskrit University of Varanasi

[33]Mahendra Sūri, *Yantrarāja*, 1. 22-37; see also the tables in Malayendu Sūri's commentary on pp. 36-43.

[34]Mahendra Sūri, *Yantrarāja* 1.22-37.

[35]See n. 12 above.

[36]This astrolabe is with the Raja Dinkar Kelkar Museum, Pune (acc. no. 106 PMC).

[37]See n. 14 above.

S. No.	Star Name as engraved	Star Name full/correct	Identification	Popular Name
1	*samudrapakṣī*		β Ceti	Deneb Kaitos
2	*maghodara*	*Matsyodara*	β Andromedae	Mirach
3	illegible			
4	*pre*	*Pretaśirāḥ*	β Persei	Algol
5	*rohiṇī*		γ Tauri	Aldeberan
6	*ṣaṇmuṣa*	*Ṣaṇmukha*	α Aurigae	Capella
7	*mithunapādapa*	*Mithuna-pāda-dakṣiṇa*	κ Orionis	Saiph
8	*vamaskada*	*Mithuna-vāma-skandha*	γ Orionis	Bellatrix
9	*mithunaha*	*Mithuna-hasta*	α Orionis	Betelgeuse
10	*ardrālu*	*Ārdrā-lubdhaka*	α Canis Maioris	Sirius
11	*pra.vā*	*Prathama-bāla-śīrṣa*	α Geminorum	Castor
12	*lubdhakavadha*	*Lubdhaka-bandhu*	α Canis Minoris	Procyon
13	*magha*		α Leonis	Regulus
14	*uttarāphā*	*Uttara-phālgunī*	β Leonis	Denebola
15	*kākāskanda*	*Kāka-skandha-pakṣa*	γ Corvi	Gienah
16	*citra*		α Virginis	Spica
17	*svāti*		α Bootis	Arcturus
18	*viśāṣā*	*Viśākhā-mātṛ-maṇḍala*	α Coronae Borealis	Alphecca
19	*dhanukoṭi*	*Dhanuḥ-koti*	α Ophiuchi	Rasalhague
20	*dhanuśirā*	*Dhanuḥ-śarāgra*	$\mu^{1,2}$ Sagittarius	
21	*abhijit*		α Lyrae	Vega
22	*śravaṇa*		α Aquilae	Altair
23	*kubha*	*Kakudapuccha*	α Cygni	Deneb/Arided
24	*pū bhā*	*Pūrvabhādrapadā*	β Pegasi	Sheat

Table 2: Stars on the Astrolabe Rete

owns an astrolabe which is not dated, but can be assigned to the seventeenth century. Here Sirius is labelled as *ārdrā*.[38]

However, *ārdrā* and *lubdhaka* are generally treated as two distinctly separate stars, the former standing for Betelgeuse (α Orionis) and the latter for Sirius. A large majority of Sanskrit astrolabes follow this nomenclature.[39] It needs further investigation to explain this discrepancy in the use of the name *ārdrā* for astrolabe stars. All that can be said at this moment is that Sanskrit astrolabes of the seventeenth century seem to follow Mahendra Sūri in naming α Canis Maioris as *ārdrā* or *ārdrā-lubdhaka*, while the astrolabes of the later period treat *ārdrā* and *lubdhaka* as two separate stars.

Leaving aside the circular and horizontal bands and the star pointers, the rest of the plate is cut off, so that through the resulting gaps the readings on the latitude plate just below can be read off. In the present rete, this task of removing the inner spaces is performed rather crudely. Furthermore, the tips of five pointers (Nos. 1, 3, 11, 13, 20) are not properly cut out so that the pointers are clearly visible. While the workmanship of the latitude plates is inferior to that of the mater, the workmanship of the rete is much worse. The calligraphy of the letters and numerals is also different from that on the latitude plates and on the mater.

Mahendra Sūri[40] recommends that the first point of Capricorn (*makarāsya*, Arabic: *murī ra's al-Jady*) should be shaped as a projecting point so that it touches the scale on the rim as the rete is rotated around the centre. This feature does not occur in the present rete.

3 Authenticity and the Date of the Astrolabe

3.1 The Inscription

On the inner side of the mater is an inscription in six lines in elegant Devanāgarī letters of western Indian style (Figure 6), which reads as follows:

[38]See Sreeramula Rajeswara Sarma, 'Kaṭapayādi Notation on a Sanskrit Astrolabe' in: *The Archaic and Exotic*, op. cit., pp. 257-272.

[39]For example, all the five Sanskrit astrolabes in German collections designate α Orionis as *ārdrā* and α Canis Maioris as *lubdhaka*; cf. Sarma Sreeramula Rajeswara Sarma, "Indian Astronomical Instruments in German Collections," *XXX. Deutscher Orientalistentag, Freiburg, 24.-28. September 2007.* Ausgewählte Vorträge, hrsg. im Auftrag der DMG von Rainer Brunner et al. Online-Publikation, Februar 2008. http://orient.ruf.uni-freiburg.de/dotpub/sarma.pdf, Figs. 7, 9, 10, 11, 16.

[40]Mahendra Sūrī, *Yantrarāja*, 3.16, Appendix.

śrīgaṇādhipati<r> jayatu ||
svasti śrī saṃvat 1663 varṣe śāke 1528 prava
rttamāne māghavadi 1 pratipadātithau ravidine
amadāvādanagare mahāsuratrāṇa pātasāha śrī
salīmasāharājye yaṃtrarāja jo° caṃḍidāsaiṃ
karāvyu | putra damodara paṭhanārthaṃ || śubhaṃ bhavatu ||

Figure 6: The Inscription on the Inner Side of the Mater

May the lord of the *gaṇas* (= Gaṇeśa) be victorious.

May it be well. In Saṃvat 1663, Śaka 1528 current, on *pratipadā*, the first lunar day of the dark fortnight (*vadi*) of Māgha, on Sunday, at the city of Ahmadabad, during the reign of the Great Sultān, the Badshāh, the illustrious Salīm Shāh (i.e., Mughal Emperor Jahangir), [this] astrolabe (*yantrarāja*, lit. king of instruments) was caused to be made (*karāvyu*) by the astrologer Caṇḍidāsa for the purpose of the reading of [his] son Damodara. Let it be auspicious.

The sentence begins in Sanskrit, but ends in medieval Gujarati for *caṇḍidāsaiṃ karāvyu* is medieval Gujarati (for Sanskrit *caṇḍīdāsena kāritam*). However, such linguistic mixture is not unusual in the 'popular' Sanskrit in medieval Gujarat.[41] The engraver spelt the name Dāmodara wrongly as Damodara. The name of his father who commissioned the astrolabe should properly be Caṇḍīdāsa, but Caṇḍidāsa is not incorrect either. He has the title *jo*°, which is an abbreviation of Joṣī, 'astrologer'.

Now we come to the provenance of this astrolabe and the history of interpretation of the inscription. Several years ago it was said to be in the private collection of a certain Roberto Riva and to have been exhibited at the Museum of Natural History, Houston, Texas.[42] In 1976 it reached the auction house of Sotheby's who consulted Francis Maddison, the then curator of the Oxford Museum of the History of Science which holds perhaps the largest collection of astrolabes. On 9 November 1976 Maddison wrote to David Pingree, Professor of History of Mathematics at Brown University, requesting him to decipher the Sanskrit inscriptions. In this letter Maddison describes the astrolabe as 'a fairly crudely made Indian astrolabe, presumably of the 19th century, which I do not think should be categorized as a fake.' Unfortunately, with this sentence Maddison set the course of the history of the subsequent interpretations. David Pingree translated the inscription and the data on the six plates, transcribed the names of the 24 stars marked on the star map and identified them.

The Time Museum at Rockford, Illinois, acquired this astrolabe soon afterwards, probably from Sotheby's. An excellent catalogue of the astrolabes in this museum was prepared by Anthony Turner in 1985.[43] While preparing the catalogue, Turner once more consulted David Pingree and also Jean-Pierre Verdet of the Paris Observatory.

Pingree took objection to the expression *paṭhanārthaṃ*, 'for the sake of reading,' in the inscription: after all, an astrolabe is not read but used in observation. Lover of manuscripts as he is —he must have read thousands of

[41] Professor Nalini Balbir, Paris, has kindly provided me this information on medieval Gujarati and assured that such mixture is not unusual in seventeenth century Gujarat. For documents of such 'popular' Sanskrit of earlier centuries in Gujarat, see Ingo Strauch, *Die Lekhapaddhati-Lekhapañcāsikā: Briefe und Urkunden im mittelalterlichen Gujarat*, Berlin 2002.

[42] Christie's, South Kensington, *Time Measuring Instruments from THE TIME MUSEUM*, for sale by Auction, Thursday 14 April 1988, Catalogue, no. 157, pp. 98-99.

[43] A. J. Turner, *Astrolabes, Astrolabe-related Instruments*, The Time Museum, Catalogue of Collection, Vol. I, Part 1, Rockford 1985. The present astrolabe is illustrated and described on pp. 120-123 (No. 15).

manuscripts in several classical languages— he immediately concluded that the inscription was copied from a manuscript, in order to lend a veneer of antiquity to the astrolabe. Following his interpretation, Turner states in the Time Museum Catalogue:

> The inscription on the *mater* engraved in a different hand can hardly be admitted as evidence for the date of the instrument. Indeed Pingree has suggested that the inscription was taken from a manuscript treatise (as the phrase 'for the purpose of reading…' would suggest) whence it was inaccurately copied, giving rise to some minor errors and one unreadable word. If this s ggestion be accepted, then one might hypothesize that the instrument was made at a relatively late date by a metal-worker who, having some knowledge of both Lahore astrolabes and of astrolabe literature, combined aspects of each with the Hindu tradition to produce this eclectic instrument.[44]

In 1988, the Time Museum decided to part with this astrolabe and several other instruments. Christie's held a special auction of these instruments on 14 April 1988 in London. The auction catalogue assigns the astrolabe to 'probably 19th century'. A footnote to the entry states:

> This astrolabe appears in most respects to belong to the nineteenth century tradition of astrolabes engraved in Sanskrit for use in the Hindu community. The inscription in the **mater** cannot reasonably be taken as the date of the astrolabe, but remains a puzzle. It has been suggested that it was copied from a manuscript treatise on the astrolabe.[45]

Therefore the auction house offered this astrolabe at a much lower price than it charged for a single plate Sanskrit astrolabe of the nineteenth century.[46] In this auction, it was acquired by Saul Moskowitz, a dealer in scientific instruments of Marblehead, Massachusetts, USA. After his death, his collections were disposed of and the present owner acquired the astrolabe in question.

In spite of the high esteem in which I hold Francis Maddison, David Pingree and Antony Turner, I have to differ from their view.[47]

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[44] Ibid, p. 122.

[45] Christie's, South Kensington, *Time Measuring Instruments from THE TIME MUSEUM*, op. cit., Catalogue, no. 157, pp. 98-99.

[46] Ibid, no. 149, pp. 86-87.

[47] Francis Maddison's writings enriched my knowledge of the history of the astrolabe in different cultures. I had the privilege of reading Mahenda Sūri's *Yantrarāja* with David Pin-

When these evaluations were made in the 1980s, nothing much was known about Sanskrit astrolabes. Things improved considerably since then. In the course of my project, I have identified more than a dozen Sanskrit works which discuss the astrolabe. I have also located nearly one hundred Sanskrit astrolabes in various museums and private collections.

Pingree et al thought that early seventeenth century is too early a date for Sanskrit astrolabes. But as mentioned above, I found nine other Sanskrit astrolabes produced in this century, most of them in Gujarat, and published some of these. In the light of this material, we have to draw a different conclusion about the date of the present astrolabe.

Turner thought that the astrolabe was made by a 'metal-worker who, having some knowledge of both Lahore astrolabes and of astrolabe literature, combined aspects of each with the Hindu tradition to produce this eclectic instrument.' I have explained already how Sanskrit astrolabes are produced. I have said that unlike in Islam, making scientific instruments did not develop into a specialized profession among the Hindu metal-workers. The initiative for the production of Sanskrit astrolabes came first of all from the astronomer, who prepared the initial drawings, and coaxed some reluctant brass worker to prepare the astrolabe according to his drawings. That is why there are often orthographic errors in the star names.

Furthermore, it is not customary in India for the artisans to sign their products. But in Islamic culture, there are many instances of metal workers signing their creations.[48] Islamic astrolabists, who enjoyed great prestige, naturally signed their products with their names. In fact, even the earliest surviving astrolabe produced in the Islamic world in 927 bears the name of its maker Nasṭūlus.[49]

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gree. It is from Anthony Turner's lucid writings that I learnt much of what I know today on the astrolabes. Moreover, all the three have helped me in various ways in my project of cataloguing Indian instruments.

[48]Cf. Kjeld von Folsach, *Islamic Art: The David Collection*, Copenhagen, 1990, p. 183: 'Except for the art of the book it is also in the field of metalwork that most artists' names were recorded, and in that of scientific instruments we nearly always know of the name of the maker.' The David Collection contains an astrolabe and a quadrant (p. 214, nos. 361 and 362), both of which are signed and dated by the respective makers, but more interesting is an ornate brass jug (p. 247, no. 347) which is inscribed with the name of Ali ibn Muhammad Ali Shahab al-Ghuri.

[49]David A. King, 'Early Islamic Astronomical Instruments in Kuwaiti Collections' in: Arlene Fullerton & Géza Fehérvári, *Kuwait: Arts and Architecture: A Collection of Essays*, Kuwait 1995, pp. 76-96.

Hindus, who were attempting to follow Muslims in the production of astrolabes, tried to emulate the custom of signing the products as well. It is reasonable to assume that the astrologer Caṇḍīdāsa commissioned the astrolabe for his son Dāmodara. He himself prepared the drawings and got them executed by an unnamed metal-worker. Caṇḍīdāsa also wanted to have the date and purpose of the instrument engraved on the astrolabe. In the Sanskritic culture of Hindus and Jains, such inscriptions occurred hitherto only in manuscripts. Therefore, Caṇḍīdāsa prepared the inscription for the astrolabe in the same style as was done in manuscripts. He did not *copy* the inscription from a manuscript as Pingree and Turner thought, but *imitated* the manuscript practice. Because Caṇḍīdāsa was consciously imitating the manuscript practice, he used the expression 'for the sake of reading' (*paṭhanārtham*).[50] One may also argue that Caṇḍīdāsa got this astrolabe made as a teaching tool for his son Dāmodara.[51] In any case, *paṭhanārtham* does not detract from the validity of the date in the early seventeenth century, especially in view of nine other Sanskrit astrolabes of this period. It has also been shown that what was thought to be an unreadable word (viz. *karāvyu*) is actually medieval Gujarati and that such linguistic mixtures were common in the popular Sanskrit employed in medieval Gujarat.

This is one of the first attempts, somewhat clumsy no doubt, of emulating the Islamic custom of engraving the date of manufacture and the name of the maker. Later the custom took deep roots in Sanskrit tradition and people began to versify the inscriptions as well.[52] It is worth noting that, while the inscriptions in Islamic astrolabes mention the maker of the astrolabe, those in Sanskrit astrolabes mention generally the patron who commissioned the

[50] What other expression would be more suitable for the astrolabe? The first reaction would be to say *vedhārdharthan*, 'for the sake of astronomical observation or measurement.' It is true that the astrolabe is used to sight a heavenly body and measure its altitude, but that is not the only function of the astrolabe; *gaṇanārthaṃ*, 'for the sake of computation' would not be entirely correct either because the astrolabe graphically shows the result that one would otherwise obtain by computation.

[51] This recalls the case of Geoffrey Chaucer who wrote his book on the astrolabe for his little son Louis. Cf. Geoffrey Chaucer, *The Treatise on the Astrolabe in: The Complete Works of Geoffrey Chaucer*, ed. Walter W. Skeat, vol. III, Oxford, impression of 1996.

[52] For example, a *Dhruvabhrama-yantra* made in 1785 (now in a private collection in Brussels) carries an inscription in *Indravajrā* metre:

munyabhravāraikamite śakābde śrī-kīrticandrasya nṛpādhipasya |
ājñānusārād akarot suyaṃtraṃ śrī-motilālābhidha-śilpisiṃhaḥ ||

'In the Śaka year 1707 (= AD 1785), following the orders of the lord of the kings, śrī Kīrticandra, śrī Motilāla, the lion among artisans, made this excellent instrument.'

astrolabe.[53]

The calligraphy of the numerals in the inscription matches perfectly with the numerals in the degree scales on the front and the back of the mater. The letters of the inscription are quite similar to those engraved on the top of the crown (Figure 7). Thus the numerals and letters in all the engravings on the mater, namely the short inscription on the crown, the long inscription on the inner side of the mater, the degree scales on the front and the back of the mater are all alike, and belong to the western Indian style of Devanāgarī of the early seventeenth century. Moreover, the graph of unequal hours in the upper right quadrant at the back indicates an early date.

Figure 7: The Inscription on the Crown

The actual problem is not with the inscription on the mater, nor with the mater itself. The mater, a piece of excellent workmanship, and excellent calligraphy, in spite of minor errors in the inscription, fits very well in the early seventeenth century. The problem is with the remaining parts. For the numerals and letters on the six plates do not match with those on the mater; again the numerals and the letters on the rete do not match with those on the mater (Figure 8) or with those on the plates.

There is also a difference in the workmanship in these three components. The mater is elegantly produced. The plates do not show such good work-

[53]There are of course a few cases where the makers themselves signed their names on Sanskrit instruments. Thus Sonī Morārjī of Saurāṣṭra, Gujarat, inscribed his name on two identical *Dhruvabhrama-yantras* which he produced in 1815. Likewise Bhālūmal (*fl.* 1839-1850) of Lahore produced some twenty instruments of diverse types and inscribed them in Arabic/Persian or Sanskrit. Five of these carry Sanskrit legends and signatures in *Anuṣṭubh* metre.

manship, even though the almucantars lines are well engraved there. The rete displays very poor workmanship. Francis Maddison's observation that it is 'a fairly crudely made Indian astrolabe' applies especially to the rete. The rete is indeed very crude and does not match with the workmanship of the mater.

Figure 8: Above the Numerals on the Rim of the Mater; below the Numerals on the Rete

Clearly these three components, viz. mater (and the alidade with the sighting tube), plates and rete, are by three different hands and belong to three different periods. But the mention of the equinoctial shadow in addition to the longest day on the plates fits in well with the seventeenth century practice, as we have shown above. Likewise, the designation of Sirius as *ārdrā-lubdhaka* on the rete indicates an early period. The only conclusion that can emerge from this is that the plates and the rete were made at later periods to replace the damaged original components. The persons who commissioned these replacements did not design the plates and the rete anew, they had access to the original damaged parts which they got copied as best they could. Thus the plates and the rete, through prepared in later periods, retain some elements of the seventeenth century Sanskrit astrolabes. Therefore these replacements are also valuable as indirect witnesses to the seventeenth century practice.

3.2 The Date

The inscription reads 'Saṃvat 1663, Śaka 1528 current, on *pratipadā*, the first lunar day of the dark fortnight of Māgha, on Sunday'. Pingree converted this date to 1 February 1607. But when this date is reconverted using the

PANCANGA program,[54] we get Thursday Māgha śukla 5 Śaka 1528, instead of the original date. This happens because Pingree apparently did not pay attention to the expression *pravarttamāne* (current) in the inscription.

When we now convert Māgha kṛṣṇa 1 (*pūrṇimānta*) in the current Śaka year 1528 with the PANCANGA program, we get Monday, 26 December 1605. When this date is adjusted for the weekday, the result is Sunday, 25 December 1605. On that day the *pratipadā tithi* commences after sunrise.[55]

There is one more reason in support of the earlier date. Just two months previous to this date, i.e. on 24 October 1605 Salīm Shāh ascended the throne at Agra and assumed the name Nūr al-Dīn Jahāngīr. But the title is still new. Therefore the use of Salīm Shāh was more appropriate two months later on 25 December 1605 than fifteen months later on 1 February 1607.

Thus it cannot be doubted any more that the astrolabe was indeed produced originally in 1605. Until some other piece turns up, this *Yantrarāja* commissioned by the astrologer Caṇḍīdāsa for his son Dāmodara remains the earliest extant Sanskrit astrolabe. It is also worth noting that the original design of this astrolabe closely follows the prescriptions given in the earliest Sanskrit manual on the astrolabe, viz. the *Yantrarāja* by Mahendra Sūri.

Appendix

Mahendra Sūri's *Yantrarāja* on the Construction of the Astrolabe[56]

2.1-6: Constitution of the Astrolabe

ādau yantraṃ mṛṇmayaṃ dhātujaṃ vā vistīrṇaṃ ca svecchayā kārayitvā |
dairghyavyāsau pālivrittasya tasminn āryaiḥ kāryau yantracakrānumānāt ||1||
yāmye bhāge 'sya trikoṇaṃ kirīṭam īdṛg yantraṃ koṣṭhakāgāram uktam |
madhye tasya sveccayākṣāṃśakānāṃ patrāṇy anyāny unnatāṃśāśritāni ||2||
ekaṃ patraṃ connatāṃśasya patrād dvighnaṃ piṇḍe sādhanīyaṃ tato 'nyat |
laṅkotpannā rāśayo meṣamukhyāḥ saṃsthāpyante yatra dhiṣṇyaiḥ sametāḥ ||3||
patrāṇy evaṃ koṣṭhakāgāramadhye muktvā sādhyās teṣu pūrvādikāṣṭhāḥ |
pṛṣṭhe yantrasyāyate dve bhujāgre sūkṣme kṛtvā chidram antarbhujaṃ ca ||4||

[54] http://www.cc.kyoto-su.ac.jp/~yanom/pancanga/index.html created by M. YANO and M. FUSHIMI.

[55] Prof. Michio Yano of Kyoto Sangyo University, the co-author of the PANCANGA program, has kindly confirmed my conversion.

[56] The printed text (see n. 5 above) has many errors which are silently corrected here.

agre paścāt tasya cānte 'bdhikoṇe kḷptvā chidre yantranetre niveśye |
chidre kḷptvā merukīlaṃ dalāliṃ tena kṣiptvā ghoṭikā saṃniveśyā ||5||
kṛtvā chidraṃ sūkṣmam asya trikoṇe tatra kṣiptvā kaṇṭakaṃ vṛścikābham |
tasya prānte mudrikāṃ lambikākhyaṃ sūtraṃ deyaṃ yantraniṣpattir evam ||6||

First get an instrument (i.e. disc) (*yantra*) of desired size (*vistīrṇa*) prepared out of clay or of metal. Then the noble persons should fix on that [disc an upraised] rim (*pālivṛtta*) with height and breadth appropriate to the size of the astrolabe.

On the southern (i.e. the upper) part of the disc, [there should be] a triangular crown (*kirīṭa*). Such a component is called the mater (*koṣṭhakāgāra*, lit. store-house, repository). Inside this [are placed] as many latitude plates (*akṣāṃśakānāṃ patrāṇi*) as one wishes, which are endowed with [circles of equal] altitudes (*unnatāṃśa*).

Prepare another plate with double the thickness of the plates bearing the [circles of] altitudes. On this plate will be marked the zodiac signs starting from Aries, according to their rising times at the equator (*laṅkā*) together with [some prominent] fixed stars (*dhiṣṇya*).

Insert these plates inside the mater (*koṣṭhakāgāra*) and mark on [each face of] them the cardinal directions like east etc. At the back of the instrument, [attach] a long arm (i.e. alidade) with pointed tips and a hole at the middle.

At the front and back [of the arm] (i.e. on either end of the arm) set up (*niveśye*) two rectangular (*abdhikoṇa*) sights (*yantra-netra*), having made (*kḷptvā*) holes in them. Into the hole [at the middle of the alidade], insert the pin which represents the north celestial pole (*meru-kīla*) so that it passes through the series of latitude plates (*dala*). Into [the other end of] this pin, insert a horse-headed wedge (*ghoṭikā*).

In the triangle [of the crown], make a small hole at [the apex of] the triangular [crown], insert into it the shackle (*kaṇṭika*), which is shaped like the scorpion's sting, into it a ring (*mudrikā*) and then pass through it a string called the suspender (*lambika*). Thus is the astrolabe constituted.

3.1: Varieties of Astrolabes

yantraṃ proktaṃ ṣaḍvidhaṃ hy ānavatyā eka-dvi-trīṣv-aṅga-paṅkty-aṃśa-kḷptyā |
dvedhāpy etat saumyayāmyaprabhedāt tanmiśratve miśrasaṃjñaṃ paraṃ ca ||1||

The astrolabe is said to be of six kinds [according as the altitude circles] are drawn (*kḷpti*, lit. arrangement) up to ninety [degrees], [with one circle] for each one (*eka*), two (*dvi*), three (*tri*), five (*iṣu*), six (*aṅga*), [or] ten (*paṅkti*) degrees (*aṃśa*). It is also of two varieties, northern (*saumya*) and southern (*yāmya*). When these two are combined, there is one more variety called the composite (*miśra*).

3.2-3: Back of the Astrolabe

vṛttadvayaṃ karkaṭakena pṛṣṭhe yantrasya nirmāya catur diśo 'ṅkyāḥ |
prāgyāmyagāḥ koṣṭhagatās tataś ca sthāpyāḥ kha-nanda-pramitonnatāṃśāḥ ||2||
vṛtte dvitīye likhitonnatāṃśā rekhā vilekhyā pratibhāgajātāḥ |
pakṣatraye 'apakramajā vibhāgāḥ śaṅkuprabhā prāg gaditā tathā jyā ||3||

On the back of the astrolabe, draw two annuli (*vṛtta*, lit. circle) with a pair of compasses (*karkaṭa*) and mark the four cardinal directions. Then between the east and west points, mark out ninety (*kha-nanda*) degrees of altitude in separate cells (*koṣṭha*).

In the second annulus, mark the lines for each degree corresponding to the degrees of altitude written [in the first annulus]. Then in three quadrants (*pakṣa*) draw respectively the units of declination (*apakramaja vibhāga*), gnomon shadows (*śaṅkuprabhā*) and the afore-mentioned sines (*jyā*).[57]

Thus the calibration of the back of the astrolabe (*pṛṣṭabhāgasādhana*) is complete.

3.4: Front of the Mater

atha yantre koṣṭhakāgārasya pūrvapakṣasādhanam āha |
vṛttatraye pāligate kṛte prāg vṛtte kirīṭāntarato ghaṭīś ca |
aṃśān abhīṣṭān kha-rasāgni-saṃkhyān rekhās tadīyās tadadho vilekhyāḥ ||4||

[57]There is some confusion here in the specifications for the four quadrants. Both the text and the commentary appear to be mentioning only three quadrants. The commentary states that units of declination should be drawn in the south-western quadrant (*dakṣiṇapaścimāntarāla*), shadow squares in the north-western quadrant (*pascimasaumyāntarāla*) and the sine graph (*jīvānkāḥ*) in the north-eastern quadrant (*uttarapūrvāntarāla*). This makes sense only if is clearly stated that the shadows squares are drawn in the *two* lower quadrants. Moreover, the sine graph is usually drawn in the south-eastern quadrant, some times also in the south-western quadrant, but never in the north-eastern quadrant, as the commentary recommends.

Now he teaches the calibration of the front of the mater (*koṣṭhāgārasya pūrvapakṣa-sādhana*) of the astrolabe (*yantra*).

Having drawn three [concentric] circles on the rim (*pāli*), in the first circle, mark the *ghaṭīs*, starting from the middle of the crown (*kirīṭa*). [In the middle circle] mark 360 degrees at desired intervals. Below that, draw the lines of their subdivisions.

3.5-8: Latitude Plates

atha saumyayantre iṣṭākṣāṃśapatreṣūnnatavalayānāṃ sādhanam āha |
yantre ca saumye viracayya kaṃbāṃ patrānumānena vilikhya tatra |
bhāgān kharāmān racayed tadāṃśaiḥ karkādivṛttatritayaṃ daleṣu ||5||
digaṅkiteṣv eṣu ca madhyakendrād avācyarekhopari kendramānaiḥ |
cihne kṛte tacchirasaḥ pṛthutvamānena vṛttāni likhet sphuṭāni ||6||
bhūjākhyam ādyaṃ bhavatīha vṛttaṃ tataḥ paraṃ connatamaṇḍalāni |
teṣāṃ likhed ānavater vibhāgān śuddhān inādyunnatatāvagatyai ||7||
madhyāhnarekhām abhito 'sya karkavṛttasthite prāgapare vibhāge |
kramāl likhed bhāṃ paramaṃ dinaṃ taddeśābhidhānena tathākṣabhāgān ||8||

Now he teaches how to draw the altitude circles (*unnata-valaya*) in the desired latitude plates (*akṣāṃśa-patra*) in the northern astrolabe (*saumya-yantra*).

In the [case of the] northern astrolabe, prepare a ruler (*kambā*) according to the size of the plate (i.e. as long as the radius of the plate) and graduate it into 30 (*kha-rāma*) units (*bhāga*). With these units (*aṃśa*) draw the three circles of Cancer etc. upon the plates (*dala*).

On these plates, on which the cardinal directions have been marked [by means of N-S and E-W lines], make marks on the south line, starting from the centre, at distances measured by the values of eccentricity (*kendra*). Then from each of the marks as the centre draw clear circles with the measure of the radius (*pṛthutva*) [as given in the tables].

The first of such circles here is called the horizon (*bhūja*). Above that will be circles of altitude (*unnata-maṇḍala*). These [altitude circles] may be drawn clearly (*śuddha*) up to ninety degrees for determining the altitude (*unnatatā*) of the sun and other [celestial bodies].

On both sides, i.e., in the eastern and the western sides of the meridian or midday line (*madhyāhna-rekhā*) situated inside the tropic of Cancer, one should write successively the equinoctial shadow (*bhā*), maximum daylight (*paramadina*), the name of the locality (*deśābhidhāna*) and the degrees of latitude (*akṣa-bhāga*).

3.9: Unequal Hour Lines

atha saumyayantre horāsthāpanam āha |
kujād adho dvādaśadhā vibhajya mṛgādikarkāhvayamaṇḍaleṣu |
vidhāya vṛttāny abhitaḥ pratīcyā aṅkair niveśyā dvidaśāpi horāḥ ||

Now he teaches the construction of hour (*horā*) [lines] in the northern astrolabe.

Divide [the arcs of] the [three] circles of Capricorn, Aries and Cancer, which are situated below the horizon (*kuja*), into 12 parts each. Draw on both sides [of the meridian line, arcs of] circles (*vṛtta*) [through the respective points of division on these three circles] and number them from the west as the 12 hours (*horā*).

3.10-16: Rete

atha saumyayantre bhacakrapatre karkādivṛttatrayasādhanam | bhacakra-kendrapramāṇena bhamaṇḍalasādhanaṃ tatra nirakṣameṣādilagnānām iṣṭa-bhāgānāṃ sthāpanam āha |
bhacakrapatre 'pi puraiva kḷpte vṛttatraye 'bhyantarato 'ṣṭabhāgān |
hitvā kalāś cābdhiguṇān avācye vyāsārdhamānena vidhāya vṛttam ||10||
nirakṣameṣādivilagnamānān pūrvoditān prāci niveśya caindryāḥ |
vṛtte dvitīye tadadho niveśyās tadaṅkasaṃkhyā gaṇakair nijeṣṭāḥ ||11||
meṣe bhāgā kalāś cāpi dhiṣṇyāni gaganeṣavaḥ |
vṛṣe nandadṛśo 'bdhyakṣā yugme dantāḥ ṣaḍindavaḥ ||12||
vyutkramād eta eva syuḥ karkasiṃhakanīṣv api |
kanyādiṣaṭkamānaṃ syāt tulādau vaiparītyataḥ ||13||
vyāsākhyavṛtte 'jamukhāni santi lagnāni laṅkodayajāni yatra |
rekhā hy uḍūnāṃ pratibhāgajātās tatraiva kendrābhimukhā vilekhyāḥ ||14||
kendrāt pratīpaṃ viracayya cihnaṃ dyujyāpramāṇena ca karkaṭena |
tatraiva dhiṣṇyasya yathoditasya niveśyam asyāgram atīva sūkṣmam || 15||
dhanurmṛgāntar niśitaṃ vidheyaṃ cihnaṃ prasiddhaṃ makarāsyanāmnā |
yadbhrāmyamāṇaṃ gaṇakena viṣvaṅ muhur muhuś cumbati nāḍivṛttam ||16||
evaṃ saumyayantre bhacakrasādhanaṃ saṃpūrṇam ||

Now he teaches how to draw the three circles of Cancer and others on the rete (*bhacakrapatra*), how to draw the ecliptic circle (*bha-maṇḍala*) by means of the given value of the eccentricity of the ecliptic circle (*bhacakra-kendra*) and how to mark there the divisions of the zodiac signs according to their ascendants at zero degree latitude (*norakṣa-lagna*).

On the rete (*bhacakra-patra*) also, after having drawn the three circles [of Capricorn, Aries and Cancer] as before, leave out from the centre of the plate 8;34 units [which is the eccentricity of the ecliptic] in the south (*avācya*) (i.e. on the southern radius) [and with this point as the centre] draw a circle with the measure of the radius [of 21;26 units as shown in 1.66].

[On this circle], after having marked, from the east point onwards (*aindryāḥ*), the lengths of the right ascensions of the zodiac signs which have been mentioned before, in the second circle below the [previous one] the astronomer may mark their subdivisions according to his liking.

For Aries (*meṣa*) the degrees (*bhāga*) and minutes (*kalā*) [of right ascension] are 27/50; for Taurus (*vṛṣa*) 29/54 and for Gemini (*yugma*) 32/16.

The same in reverse order pertain to Cancer (*karka*), Leo (*siṃha*) and Virgo (*kanī*). The values of the six signs beginning with Virgo (*kanyā*) will apply in the reverse order to the six starting with Libra (*tulā*).

In the ecliptic circle (*vyāsākhya-vṛtta*) where there are the right ascensions (*laṅkodayajāni lagnāni*) of Aries and others, there draw the lines of stars, with the subdivisions, towards the centre.

With the measure of the day sine (*dyujyā*) make a mark away from the centre with the pair of compasses on that line. There at that point, create a very fine tip (*sūkṣmam agram*) for [pointer of] the afore-mentioned star.

Between Sagittarius (*dhanu*) and Capricorn (*mṛga*) affix the well-known mark called the *makarāsya* (face, or the first point of Capricorn), which touches the hour circle (*nāḍivṛtta*) again and again, when the rete is rotated all around by the astronomer.

Thus the preparation of the rete in the northern astrolabe is complete.