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Instrumentation for Astronomy and Navigation in India at the Advent of the Portuguese

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One of the challenges encountered in any study of India's past, with its multiplicity of knowledge systems, is to trace the inter-relationship between any two systems of knowledge or, more specifically, the interface between the theoretical writings in the pan-Indian Sanskrit on the one hand, and the practices specific to the region and/or caste of the practitioner on the other. Often it is difficult to say how much a local or caste-specific practice or technology was benefited by the input from the theoretical deliberations in Sanskrit; conversely, how far the theoretical writings in Sanskrit were based on the experiences gained by the practitioners of the art concerned. The second type of insight would be of great value in evaluating Sanskrit sources.

This problem becomes all the more acute while tracing the history of navigation in India. Sea voyages are mentioned often in Sanskrit *belles-lettres* but Sanskrit theoreticians hardly touch upon the techniques or tools of navigation. Much was made of the sole Sanskrit text called *Yuktikalpataru*,[1] allegedly from the pen of the polymath Bhoja, who ruled Malwa in the first half of the 11th century.[2] However it has been shown that neither was the text composed by Bhoja nor does the information it contains on ships have any value for the history of Indian shipping.[3] This is a classic example of the dichotomy between the *śāstrin's* theory and the *śilpin's* practice. More useful information can be gleaned from the Tamil text *Kappal Sāttiram*, but it is a late text belonging to the 17th century.[4] In the absence of written records, one has to fall back on the ethnographic records of recent times and then project the data into preceding centuries. The results thus obtained cannot but be tentative.

There is, however, a large body of literature in Sanskrit on astronomical instruments and a large number of instruments themselves are available. Luckily, we also have some knowledge of the interaction between the Indian system of astronomical instrumentation and other systems. Fortunately too, there are one or two areas where the astronomical instrumentation may have come close to navigational techniques or tools. However, in all these respects, it is difficult to draw a continuous and coherent picture; there are many gaps in our knowledge and gray areas abound. This problematique of the historiography of instrumentation is the theme of this paper.

Starting from the *Vedāṅga-jyotiṣa* of about the 5th century BC, the Sanskrit astronomical texts generally discuss various kinds of instruments for time-measurement and astronomical observation. In the 5th century AD Āryabhaṭa described a variety of interesting instruments, in a work that is now lost, save for the chapter on the instruments.[5] In the first quarter of the 7th century, Brahmagupta devoted an entire chapter of his *Brāhmasphuṭa-siddhānta* to the instruments, where he gave the first systematic account of a large number of instruments: water clocks of the sinking bowl type, several kinds of sundials with the dial projected on plane or hemispherical surfaces, instruments for measuring the altitude like the quadrant and the double quadrant, and so on.[6] He even provided a design for constructing a perpetual motion machine.[7] But what is more important is that Brahmagupta elaborately discussed the various methods of using the instruments with emphasis on the underlying trigonometric relations. Thus he laid the foundations of gnomonics. Following his example, subsequent astronomers like Lalla in the 8th century, Śrīpati in the 11th and Bhāskara in the 12th, adopted the same instruments as also observational and computational techniques.

However, instrument making *per se* did not interest these astronomers as much as did the underlying theory. One has the impression that instruments were used more for demonstration than for regular observation. Thus Bhāskara somewhat arrogantly proclaims that a clever astronomer does not need any special instrument but just a straight piece of stick with which he can make all the measurements.[8]

Contact with Islamic astronomy led to a kind of paradigm shift and astronomers began to lay stress on the importance of instruments. Thus Rāmacandra Vājapeyin states in his *Yantraprakāśa*:

> Body without eyes, royal capital sans the king, lakes devoid of lotus flowers, woman without a lover, night without the moon, river bereft of birds – so is astronomical learning without instruments.[9]

An important outcome of the interaction with Islamic astronomy is the introduction of the astrolabe into India by Al-Bīrūnī in the 11th century. After the establishment of the Delhi Sultanate, Muslim scholars migrated to India in large numbers from Central Asia in the following centuries. These scholars brought astrolabes with them and used them in India for calendrical and astrological purposes. By the mid-14th century, the instrument was sufficiently well-known among the Muslim elite of northern India. In the same century, astrolabe manufacture also commenced under the patronage of Fīrūz Shāh Tughluq (1351-1388). The *Sīrat-i Fīrūz Shāhī*, an anonymous chronicle of his rule composed in 1370, has a long account on the astrolabes manufactured under instructions from Fīrūz Shāh.[10] However, none of these astrolabes survive today. The extant astrolabes pertain to the Mughal period and it is in this period that astrolabe manufacture reached its pinnacle both in quantity and quality.[11]

The astrolabe was received by Hindus and Jainas with great enthusiasm. Mahendra Sūri, a Jaina monk, wrote the first Sanskrit manual in 1370 under the auspices of Fīrūz Shāh at Delhi. In his work, Mahendra Sūri called the astrolabe *Yantrarāja*, "king of astronomical instruments", and it is under this name that the astrolabe came to be known in Sanskrit and other Indian languages. Hindu astronomers who came later were no less enthusiastic. Between the 14th and 18th centuries, more than a dozen manuals were composed in Sanskrit on the astrolabe.[12]

The composition of these Sanskrit manuals must have been accompanied by the manufacture of Sanskrit astrolabes as well, that is, astrolabes with legends in Sanskrit and the time scale divided into *ghaṭīs* of 24 minutes instead of hours of 60 minutes. But again no Sanskrit astrolabes of the 14th, 15th or 16th century appear to have survived.[13] Nearly eighty astrolabes produced in the subsequent centuries are preserved today in various collections. It must also be noted that astrolabes of both varieties, i.e., with Arabic/Persian and with Sanskrit legends, continued to be produced until the end of the 19th century.

The 15th century saw the composition of two Sanskrit texts which are important for the history of instrumentation in India: the *Yantraratnāvalī* composed by Padmanābha in central India in 1423 and the *Yantraprakāśa* written five years later by Rāmacandra Vājapeyin in northern India in 1428. While Padmanābha's work introduces two instruments, one indigenous and the other a variant of the astrolabe, Rāmacandra's compendium discusses a large assortment of instruments, the history of which still awaits a detailed study.

The first chapter of Padmanābha's *Yantraratnāvalī* deals with an unusual variety of astrolabe known as the southern astrolabe.[14] The second chapter discusses the *Dhruvabhrama-yantra*,[15] which is a kind of nocturnal and, as I shall argue, may have been the forerunner of the European nocturnal. This *Dhruvabhrama-yantra* consists of an oblong metal plate with a horizontal slit at the top. A four-armed metal index is pivoted to the centre of the plate, around which there are concentric circles containing various scales. At night, the instrument is so held that one can see the Pole Star and β Ursae Minoris through the slit. When these two stars are sighted in a straight line by appropriately tilting the instrument, the arms of the index will point respectively to the sidereal time in *ghaṭīs* and *palas*, to the *lagna* or ascendant for this moment, and to the culminating point of the ecliptic. Thus with this instrument one could read off from the dial, for any given moment at night, the corresponding sidereal time, ascendant, and culmination. The reverse side of this instrument usually contained a quadrant (*turīya-yantra*) for measuring the solar altitude during the day, or a horary quadrant for measuring time directly. There are extant about a dozen well-crafted specimens of this instrument in collections in India and outside. There is much variation in these specimens, not only in the outer form of the plate and the design of the four-armed index but also in the number and the nature of the concentric scales. Though all these surviving specimens belong to the 19th century, the wide variety in the style of execution, in the specification of the scales, and wide geographical distribution indicate the popularity of the instrument which may be true in the earlier centuries as well.

We have seen that the astrolabe was adapted for the use of Hindu astronomers with Sanskrit legends and Indian time units. In the reverse direction, the *Dhruvabhrama- yantra* was modified for the use of Muslim astronomers with Persian legends. Two specimens have come to light so far, one at the Khuda Bakhsh Oriental Public Library of Patna[16] and the other at the Raza Library of Rampur. In these versions, the obverse side, calibrated as nocturnal, is called *Shanumah*, "night indicator" and the reverse side with the quadrant is called *Rūznumah*, "day indicator". These two specimens are manufactured in the 19th century but there must have been forerunners in the earlier periods of which we do not yet know. Nor do we know at present whether these are discussed in any Persian or Arabic manual, though it is clear that this version was inspired by the *Dhruvabhrama-yantra* and that this adaptation took place within India itself. However, the exact path of transmission still remains to be mapped.

The second significant text of the 15th century is the *Yantraprakāśa* composed by Rāmacandra Vājapeyin in 1428 at Pātrapuñjanagara on the 27° latitude, close to modern Sitapur in Uttar Pradesh.[17] In this work, which is available only in two manuscripts of poor quality, Rāmacandra describes the method of construction and use of some forty instruments, the largest number ever discussed in a Sanskrit manual. Besides the large number, what really distinguishes the *Yantraprakāśa* is Rāmacandra's genuine interest in instrument-making. The Indian astronomers, in general, were not interested in the practical aspects of instrument construction. In comparison, Rāmacandra's description,

especially in his commentary, is much more detailed. He first describes the basic design and then mentions the variants that are possible. He also pays attention to the tools needed in instrument-making.

The major part of the *Yantraprakāśa*, i.e. the first four of the six chapters, is devoted to the astrolabe. The fifth chapter describes the gnomon, staff and the trigonometric problems connected with their use. The sixth and final chapter discusses some thirty-six varieties of instruments which can be classified into the following categories: (i) traditional instruments as taught by Brahmagupta and Bhāskara, (ii) the same with improvements, most likely by Rāmacandra himself, (iii) those inspired by Islamic models, and (iv) instruments mentioned here for the first time and which must have been invented in India after Bhāskara during the 12th and 13th centuries, or by Rāmacandra himself. Above all, Rāmacandra's treatise throws up many challenging problems in connection with the transmission of the knowledge about several instrument-types. In the following, I should like to examine the case of three instruments, viz., column dial, ring dial and sand-glass.

Rāmacandra is the first Indian astronomer to describe a series of shadow instruments made in the shape of weapons like the whip, scimitar, sword and arrow. All these are variants of the column dial or cylindrical dial. The column dial consists of a column or prism made of wood, ivory or metal. At the top of each facet of the prism, there is a hole for inserting a horizontal gnomon that throws its shadow on the facet below. The facet is graduated in degrees for measuring the sun's altitude and/or in hours to measure the local time directly. But since these two vary according to seasons, the column usually has twelve vertical scales, one for each month. A rope is tied to the top of the column so that it can be suspended vertically, and this makes it a handy, portable instrument.[18]

According to Ernst Zinner, the column dial was originally invented in Germany. In the 11th century, Hermann the Lame described its construction for the latitude 48° N.[19] It was quite popular in the middle ages as a travelling clock, evident from its Latin name *horologium viatorum*.[20] From Europe, it was transmitted to the Islamic world through Spain and Morocco. In 1282 Abul Hasan of Morocco described it for the first time in his celebrated work on instruments.[21]

Because the cylinder and the suspensory rope look respectively like the handle and the lash of the horse-whip, the instrument appears to have received in the Islamic world the designation *cābuk*, meaning 'whip' in Persian. The instrument reached India either through Abul Hasan's manual or through actual specimens, and here the word *cābuk* was translated literally into Sanskrit as *Kaśā-yantra*, *Pratoda-yantra* or as the simple transliteration into Sanskrit, *Cābuk-yantra*. Rāmacandra then is the agent of this transmission into India, or more precisely, he is the first Hindu astronomer to adopt this instrument.

There are, however, problems in this scenario of transmission. Zinner's view of its dissemination from Europe to Morocco is contested today. On the other hand, it seems quite likely that the instrument was brought to India from the Islamic world. But the expression *cābuk* for this instrument is not attested in any source. Is it then a name given in India?

The next instrument of Rāmacandra that I wish to highlight is called *Cūḍā-yantra*. Āryabhaṭa and Varāhamihira describe a ring dial in which the sunlight enters a hole in the breadth of the ring and falls on the inner concave surface on the opposite side, indicating the sun's altitude.[22] Into this archaic design, Rāmacandra introduced great improvements by providing a variable hour scale to also measure time directly. Furthermore, Rāmacandra designed three variants of different sizes, viz., *Valaya-yantra* measuring a cubit in diameter, *Cūḍā-yantra* a span or less in diameter, and *Mudrikā-yantra* the size of the finger ring. As I have shown elsewhere, the middle one called *Cūḍā-yantra* was quite popular at the Mughal court. In a series of Mughal miniature paintings the astronomers are depicted measuring the sun's altitude with this ring dial.[23] Then in the early 18th century, Sawai Jai Singh also used it extensively. In a compilation called *Yantraprakāra*, Jai Singh provides a long description of the *Cūḍā-yantra* together with an elaborate set of tables prepared for the latitude of Delhi.[24]

Thus, here is a unique case in the history of scientific instrumentation in India, where literary documents, miniature paintings and actual specimens converge together and help us map the developments of the ring dial, spanning some 12th centuries from Āryabhaṭa to Jai Singh. Rāmacandra plays a crucial role in this development because he devised the variant *Cūḍā-yantra* in metal. From its depiction in the Mughal miniatures, it would appear that it was more popular than the astrolabe at the Mughal court. But unlike the astrolabe this instrument is never mentioned in Persian sources. The extant specimens also belie the impression created by the miniature paintings; while there are more than 150 Indian astrolabes with Arabic/Persian legends and nearly 80 with Sanskrit notations, only three ring dials are known. Therefore, we ought to be very cautious in the interpretation of our sources.

But what is its relationship with the ring dial, so popular in Austria and Bavaria? Ernst Zinner opines that it was invented by Georg Peuerbach (1423-1461) and improved by his pupil Regiomontanus (1436-1476),[25] a few decades after Rāmacandra's writings in India. Is there any connection between the Indian and European ring dials? It was not known to the Islamic world and therefore a transmission either way through this intermediary is ruled out. For the time being we have to rest content with the hypothesis that the ring was developed independently in India and Europe.

Rāmacandra also gives a detailed and unambiguous description of the sand clock (*kāca-yantra*) which measures the Indian time unit of *ghaṭī* of 24 minutes. European sand clocks, on the other hand, are made to measure the hour of

60 minutes, its multiples or fractions. Therefore, if the sand clock was transmitted from Europe to India, where it was adapted to the Indian system of reckoning time in *ghaṭīs*, such a transmission ought to have taken place before 1428.

In Europe itself the first undisputed mention of the sand clock occurs in the English naval records of 1345/46 and its pictorial representation, in a fresco at Siena in Italy, pertains to about the same period. If Europe had been the source of the sand clock which was described by Rāmacandra in 1428, the only possible route of transmission, say between 1350 and 1400, should have been through the Islamic world. But the Islamic world did not know of the sand clock until the late 16th century when it was imported from Europe. Therefore, one must conclude in this case as well, that the sand clock developed independently in India and in Europe.[26]

I discussed these three cases in order to illustrate the difficulties in delineating a comparative and coherent history of several instrument types in the present state of our knowledge. Historians of technology do not approve of the idea that the same technique could develop independently in two different geographical areas and insist that there must be some linkage between these two places. But establishing mere priority in time does not reveal the whole story unless one can map the exact path of transmission.

However, there is no denying the fact that towards the end of the 15th century or the advent of the Portuguese, India had a rich repertoire of astronomical and time-measuring instruments. Some had been developed indigenously, some had been borrowed from the Islamic world and yet others were modified versions of the Islamic prototypes. Rāmacandra's compendium of instruments provides only a partial glimpse of this rich repertoire.

At the beginning of this paper I said that there are one or two instances where the astronomical instrumentation may have had a consonance with navigational techniques and tools. One of these is the water clock of the sinking bowl variety.[27] This consists of a hemispherical copper bowl with a small perforation at the bottom. When this bowl is placed on the surface of water in a larger basin, the water enters the bowl from below through the perforation. As soon as the bowl is full, it sinks to the bottom of the basin with a clearly audible thud. The weight of the bowl and the size of the perforation are so adjusted that the bowl sinks sixty times in a day-and-night. That is to say, the duration between each two immersions is 24 minutes. The instrument was in use throughout India and the neighbouring regions for about sixteen hundred years from the fourth century AD to the beginning of the 20th century. Even now it is occasionally used for ritual purposes by all the major religions at Mathura in a Krishna temple, at Jhalesar in a Jain temple, across the border in Sind, at the mausoleum of Qalandar Saheb, and so on.

Considering its widespread use, there ought to be hundreds of specimens extant but unfortunately it is not so. The Pitt Rivers Museum at Oxford has the largest collection, consisting of seven pieces. One of these is made of a coconut shell. In the Madras Museum also there is one made of coconut shell. This fact suggests the genesis of this instrument. Coconut shell is naturally endowed with a hole at one end and this might have provided the inspiration for designing this instrument. Therefore, its origin must be sought in the Indian Ocean region.

Was it ever used on ships for time-keeping? A.J. Qaiser answers in the negative. "We do not know what time-keeping devices were used by Indians aboard a floating ship. The sinking-bowl clepsydra was known, but it could not have been used on a ship rocking on unstable waves".[28] However, a very good authority saw its use on ships in the Malay archipelago in the last century and left a graphic report. A.R. Wallace states as follows:

> ... a watch of two or three on the poop look after the trimming of the sails and call out the hours by the water clock. This is a very ingenious contrivance, which measures time well in both rough weather and fine. It is simply a bucket half-filled with water, in which floats the half of a well-scraped coconut shell. In the bottom of this shell is a very small hole, so that when placed to float in the bucket, a fine thread of water squirts up into it. This gradually fills the shell, and the size of the hole is so adjusted to the capacity of the vessel that, exactly at the end of an hour, plump it goes to the bottom. The watch then cries out the number of hours from sunrise, and then sets the shell afloat again empty. This is a very good measurer of time. I tested it with my watch and found that it hardly varied a minute from one hour to another, nor did the motion of the vessel have any effect upon it, as the water in the bucket of course kept level. It has a great advantage. For a rude people in being easily understood, in being rather bulky and easy to see, and in the final submergence being accompanied with a little bubbling and commotion of water, which calls attention to it. It is also quickly replaced if lost while in harbour.[29]

A.R. Wallace thus attests to the use on the sinking-bowl water clock, made of coconut shell, on ships in the Malay Archipelago in 1869. Recently, a Latin manuscript was discovered which suggests that the sinking bowl was used at a much earlier date aboard the ships.[30] This manuscript (probably untitled) from the Abbey of Mont Saint Michel (numbered, "Avranches 235") of the 12th century describes a device known as the "lineless sounder" used for measuring the depths of the sea or the rivers.

The apparatus consists of two parts: a buoy and a ballast. The buoy is a metal sphere with a ring. The ballast is an iron plate with a hook and leg. The buoy is hooked to the ballast and the whole system is let down into the water. When it touches the bottom of the sea, the leg of the ballast rotates which causes the buoy to get unhooked and go up. The depth is deduced from the total immersion time, i.e. from the moment the system is immersed to the

moment the buoy resurfaces. How is this time measured? The manuscript says either with an astrolabe or with a sinking bowl clepsydra.[31]

Professors Catherine Jacquemard and Alain Hairie, a Latinist and an engineer of the Université de Caen, France, are studying this manuscript and examining the feasibility of the apparatus. Since the sinking bowl came from India, these scholars believe that the origin of the "lineless sounder" also should be sought in the Orient, and probably in India. What is immediately relevant to us is that the Latin manuscript envisages the use of the sinking bowl for measuring time on the ships as early as the 12th century. This is one linkage between the Sanskrit theory and navigational practice.

The second linkage I wish to explore is in connection with the genesis of the *Dhruvabhrama-yantra* which I described earlier. While the majority of the instruments described in the classical Sanskrit texts are based on gnomonics and trigonometry, the *Dhruvabhrama-yantra* makes use of the phenomenon of the apparent diurnal rotation of the stellar sphere around the poles; in particular, of the constellations Ursa Minor and Ursa Major around the north celestial pole. This phenomenon may be noticed more clearly on the sea or in a desert. If one joins the Pole Star (which is α Ursae Minoris) with β Ursae Minoris by an imaginary line, this line appears to rotate like the hand of a clock. So does a line joining á and ā in the constellation Ursa Major and the Pole Star.

Therefore, sailors made use of these or related phenomena in geographical orientation and time measurement. For Arab sailors, β and γ of the constellation Ursa Minor were important. These two were known as *Farqadayn* or "two calves". The position of the line joining the *Farqadayn* in relation to the Pole Star is used for determining the time, and sailors were supposed to be broadly familiar with six positions of the line for the sake of orientation.[32] Therefore, it is obvious that the inspiration for the design of the *Dhruvabhrama-yantra* on the basis of the diurnal rotation of the line joining á and ã Ursae Minoris did not come from the highway of astronomical theory but from the bylane of navigational practice.

The same phenomenon gave rise to another related instrument as well. The European nocturnal is based on the diurnal rotation of the line joining the α and β uMa with the Pole Star. It was first mentioned by Martin Cortes in *Arte de Navegar* in 1551.[33] The *Dhruvabhrama-yantra* and the European nocturnal have much in common in the basic principle as well as in the design. But the former is older by about one and a half centuries. Did then Padmanābha's *Dhruvabhrama-yantra* inspire the European nocturnal? If so, did the Portuguese contribute to this transmission?

ABBREVIATIONS

IJHS : Indian Journal of History of Science
SHMS : Studies in History of Medicine and Science

NOTES AND REFERENCES

1. Isvara Candra Sastri, ed., *Yuktikalpataruḥ Mahārāja-śrī-bhojaviracitaḥ*, Calcutta, 1917.
2. Radhakumud Mookerji, *Indian Shipping: A History of the Sea-borne Trade and Maritime Activity of the Indians from the Earliest Times*, London, 1912, p. ix: "... the *Yuktikalpataru* ... gives an account of Indian shipping, the like of which cannot perhaps be found elsewhere in the entire range of Sanskrit literature, ...".
3. Cf. Sreeramula Rajeswara Sarma, "The Sources and Authorship of the *Yuktikalpataru*", *Aligarh Journal of Oriental Studies*, 1986, pp. 39-54.
4. N.K. Panikkar and T.M. Srinivasan, "*Kappal Sāttiram*: A Tamil Treatise on Shipbuilding during the 17th century AD", *IJHS*, 1972, 7, pp. 16-26.
5. Kripa Shankar Shukla, "Āryabhaṭa I's Astronomy with Midnight Day-Reckoning", *Gaṇita*, June 1967, 18.1, pp. 83-105.
6. Cf. S.R. Sarma, "Astronomical Instruments in Brahmagupta's *Brāhmasphuṭa-siddhānta*", *Indian Historical Review*, 1986-87, 13, pp. 63-74.
7. Cf. S.R. Sarma, "Perpetual Motion Machines and their Design in Ancient India", *Physis: Rivista Internationale di Storia della scienza*, 1992, 29, pp. 665-76.
8. *Siddhāntasiromaṇi*, ed., Bapu Deva Sastri, revised by Ganapati Deva Sastri, Benares, 1929, *Golādhyāya*, *Yantrādhyāya*, verse 40, p. 244; see also S.R. Sarma, "Astronomical Instruments in Brahmagupta's *Brāhmasphuṭasiddhānta*", *op. cit.*, pp. 68-69.
9. *Yantraprakāśa*, MS, Bhandarkar Oriental Research Institute, No. 975/1886-92, f 3 r.
10. S.R. Sarma, "Sultān, Sūri and the Astrolabe" (forthcoming).
11. I have counted some 150 Mughal astrolabes in museums and private collections in various parts of the world (S.R. Sarma, "The Lahore Family of Astrolabists and their outrage", *SHMS*, 1994, 13, pp. 205-24).
12. S.R. Sarma, "*Yantrarāja*: The Astrolabe in Sanskrit", *IJHS*, 1996, 34, pp. 145-58.
13. The earliest extant Sanskrit astrolabe was produced at Ahmedabad for one Damodara and is dated 1 February 1607. It was formerly with the Time Museum, Rockford, Illinois and is now in a private collection in Brussels. Cf. A.J. Turner, *Time Museum: Catalogue of Collection*, Vol. I, part 1: Astrolabes and Astrolabe Related Instruments, Rockford, 1985, no. 15, pp. 120-23.
14. Cf. Yukio Ohashi, "The Early History of the Astrolabe in India", *IJHS*, 1997, 32, pp. 199-295, where the first chapter of the work dealing with the southern astrolabe is published with annotated translation.
15. This chapter is still unpublished. There are several independent manuscripts of this chapter. For a description of this instrument, see A.F. Garrett, and Chandradhar Guleri, *The Jaipur Observatory and Its Builder*, Allahabad, 1902, pp. 62-64, pl. X; Yukio Ohashi, "History of Astronomical Instruments of Delhi Sultanate and Mughal India", *SHMS*, 1986-87, 10-11, pp. 165-82, especially p. 167; S.R. Sarma, "Indian Astronomical and Time-Measuring Instruments: A Catalogue in Preparation", *IJHS*, 1994, 29, pp. 507-28, especially pp. 517-18; Jean-Pierre Verdet, "A propos de deux petits quadrants indiens" in W.D. Hackmann and A.J. Turner, eds., *Learning, Language and Invention: Essays presented to Francis Maddison*, Aldershot, 1994, pp. 309-21.

16. Cf. S.R. Sarma, "Brief Introduction to the Astronomical Instruments preserved in Khuda Bakhsh Library, Patna", *Khuda Bakhsh Library Journal*, December 1999, no. 118, pp. 1-10.
17. Cf. S.R. Sarma, "Astronomical Instruments in Mughal Miniatures", *Studien zur Indologie und Iranistik*, 1992, 16, pp. 235-76; David Pingree, *Census of Exact Sciences in Sanskrit*, Series A, Vol. 5, Philadelphia, 1995, pp. 467-79; Yukio Ohashi, "Early History of the Astrolabe in India", *op. cit.*, pp. 289-91.
18. On the column dial in India, see Yukio Ohashi, "The Cylindrical Sundial in India (Sanskrit text, English translation and exposition in Terms of Modern Mathematics)", supplement to *IJHS*, 1998, 33.4, pp. S147-S205.
19. Ernst Zinner, *Deutsche und Niederländische Asronomische Instrumente des 11.-18. Jahrhunderte*, München, 1979, p. 50.
20. It was also called cylinder sundial; Chaucer, for example, calls it "chillindre". Shepherds still use it in the Pyrenees between France and Spain. Hence it is also known as the "shepherd's dial".
21. Jean-Jacques Sédillot and Louis Amélie Sédillot, *Traité des instruments astronomiques des Arabes*, Paris, 1834, reprint: Frankfurt, 1984, pp. 433-37, fig. 71.
22. Yukio Ohashi, "Astronomical Instruments in Classical *Siddhāntas*", *IJHS*, 1994, 29.2, pp. 236-42.
23. S.R. Sarma, "Astronomical Instruments in Mughal Miniatures", *op. cit.*, pp. 249-52 and Pls. 1-4, 7, 8, 12, 13.
24. S.R. Sarma, ed. and tr., *Yantraprakāra of Sawai Jai Singh*, supplement to *SHMS*, 1986-87, 10-11, pp. 27-28, 79-92.
25. Zinner, *op. cit.*, pp. 120-22, Pl. 45.2.
26. S.R. Sarma, "Astronomical Instruments in Mughal Miniatures", *op. cit.*, pp. 243-46.
27. *Ibid.*, pp. 241-43; see also S.R. Sarma, "The Bowl that Sinks and Tells Time", *India Magazine*, September 1994, 14.9, pp. 31-36; S.R. Sarma, "Indian Astronomical and Time-Measuring Instruments: A Catalogue in Preparation", *IJHS*, 1994, pp. 512-14; Yukio Ohashi, "Astronomical Instruments in Classical *Siddhāntas*", *op. cit.*, pp. 273-79.
28. Ahsan Jan Qaisar, *The Indian Response to European Technology and Culture (AD 1498-1707)*, Delhi, 1982, p. 36.
29. A.R. Wallace, *The Malay Archipelago*, 1869 (ii. 169-70), cited in A.J. Turner, *The Time Museum, Catalogue of the Collection*, Vol. I, Part 3: Water Clocks, Sand Glasses, Fire Clocks, Rockford, 1984, p. 11. np. 71.
30. The following is based on a personal communication dated 22.10.98 from Professor Alain Hairie of the Université de Caen.
31. Some 20 other Latin manuscripts of the same kind belonging to the 11th to 13th centuries contain a description and drawing of this "lineless sounder", which has the same source as the apparatus described by Christoph Pühler in 1583.
32. Cf. Lotika Varadarajan, "The Question of the Anti-meridian: Economic and Technical Aspects", in A.T. Matos, L.F.R.R. Thomaz, eds., *A carreira da India e as rotas dos estreitos* (Actas do VIII seminario internacional de história indo-portuguesa), Angra de Heroismo, 1998, pp. 687-97, especially p. 691 and the literature cited there.
33. Harriet Wynter and Anthony Turner, *Scientific Instruments*, London, 1975, p. 69.