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INDIAN ASTRONOMICAL AND TIME-MEASURING INSTRUMENTS A CATALOGUE IN PREPARATION

SREERAMULA RAJESWARA SARMA
Aligarh Muslim University, Aligarh

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The value of scientific instruments as a source for the history of science and technology cannot be underestimated. In India, various kinds of astronomical and time-measuring instruments have been in use since time immemorial. Their construction and use are discussed in a number of Sanskrit texts. While a few such texts have been published, the instruments themselves did not receive much scholarly attention.

As a first step towards facilitating the study of Indian scientific instruments, I am preparing a Descriptive Catalogue of Indian Astronomical and Time-Measuring Instruments. This catalogue will contain a comprehensive account of all extant instruments in India and abroad. Such a catalogue will serve as a useful research tool. It will not only supplement the textual material but may also throw light on the geographical spread of instrument types and on the centres of their manufacture. Finally, it is hoped that the survey will create a better awareness about the importance of these instruments as cultural documents.

In 1991, I made an exploratory survey of the museums at Hyderabad, Jaipur, Varanasi and Patna. In 1992 and 1993, I catalogued all the known Indian instruments in the US and UK. In the next two years, I hope to complete the study of the instruments in the various collections in India.

This paper offers an overview of the project, with brief historical surveys of some major instrument types.

0.1 Like literary documents, scientific instruments also constitute a valuable source for the history of science and technology of a people. In India, from the earliest times up to the beginning of the present century, various kinds of instruments have been in use for measuring time, or for taking the altitude and azimuth of heavenly bodies, or for visually demonstrating the apparent motion of the heavens. The construction and use of these pre-modern scientific instruments are described in several Sanskrit texts. A number of actual instruments are also extant in various collections in India and abroad. While a few Sanskrit texts have been published,[1] the instruments themselves did not receive much scholarly attention.[2] A disproportionately large corpus of literature exists no doubt on the gigantic masonry instruments erected by Sawai Jai Singh in the early eighteenth century, but hardly anything on their antecedents.[3] Indeed not much was known about the portable metal instruments designed or collected by Jai Singh and his son Madho Singh, until I catalogued them in 1991.[4] But these extant instruments are a valuable part of our cultural heritage.

In the first quarter of the seventh century, Brahmagupta devoted an entire chapter of his *Brāhmasphuṭasiddhānta* to the instruments. In this chapter called appropriately *yantrādhyāya,* he gave the first systematic account of a large number of instruments, namely *ghaṭikā, śaṅku, cakra, dhanuś, turyagola, yaṣṭi, pīṭha, kapāla* and *kartarī.*[5] Following his example, subsequent astronomers like Lalla in the eighth century, Śrīpati in the eleventh and Bhāskara in the twelfth, adopted the same instruments and observational and computational techniques. Now the question arises whether these instrument types were ever actually manufactured and used in observation, or whether they were mere designs whose execution was never tested in practice, as in the case of the automata described in several texts.

Of course, even the design per se can be important in the history of ideas. Lynn White had argued that the Indian concept of the perpetual motion machine eventually led to modern power technology,[6] and the present writer has shown that the first perpetuum mobile was designed by Brahmagupta in the seventh century and not by Bhāskara in the twelfth, as Lynn White had supposed.[7] Likewise, on the basis of the Indian method of determining the cardinal points *(diksādhanā),* the Arabs developed an instrument for finding out the meridian and the qibla which they called the "Indian Circle".[8]

In the reverse direction, contact with Islamic astronomy led, from about the fourteenth century onwards, to the composition of texts exclusively devoted to instruments. The earliest work of this nature is the *Yantrarāja* written by the Jaina monk Mahendra Sūri at the court of Fīrūz Shāh Tughluq in Delhi in 1370. The composition of all these texts must have been accompanied by the manufacture of actual instruments.

For a proper understanding, then, of the role played by the instruments in the development of scientific thought in India, the texts on instruments have to be studied together with the actual specimens. Sanskrit astronomical texts, like all Śāstric texts, are notoriously brief. Even a lengthy compendium like Rāmacandra Vājapeyin's *Yantraprakāśa,* written in 1428 with an elaborate auto-commentary,[9] stands nowhere near the Arabic treatises on instrument-making with their precise and practical directions such as Mu'ayyad al-Dīn al 'Urḍī's account of the instruments he made for the Marāgha Observatory towards the middle of the thirteenth century,[10] or al-Jazarī's *Book of Ingenious Devices.*[11] Again, Sanskrit texts give only a general description of the instrument, but the variety in its execution and the geographical extent of its spread can only be known from the study of actual instruments.

Thus, on the one hand, actual specimens may help in understanding the often too brief texts. Conversely, textual knowledge helps in identifying an instrument and in dating its original design. Finally, this combined approach will throw better light on trans-cultural exchanges, especially between the Hindu and Islamic traditions of instrumentation during the medieval period.

0.2 I may illustrate this point with an example. Some time ago I was tantalized by a Mughal portrait of a roadside astrologer, which shows him holding a circular hoop-like object in his hand.[12] For those familiar with European astronomical instruments, it is not difficult to identify this hoop as the ring dial,[13] although of a larger kind. But why show it in a Mughal miniature painting, where one would normally expect an astrolabe, the instrument *par excellence* of the Islamic world? The same ring dial appears again and again in several other Mughal miniatures, which depict the birth of a royal personage, and the astrologers casting his horoscope.

The ring dial was common in Europe, especially in southern Germany and Austria where it was called *Bauernring* "farmers' ring", but it was not known to the Islamic world. Did it then obtain in India? The answer was soon furnished by Sawai Jai Singh's *Yantraprakāra* which I was then editing. It contains a long description of the ring dial under the name *Cūḍā-yantra,* together with a set of tables to be used for the latitude of Delhi.[14] About the same time, I also heard of the existence of two actual specimens in the stores of the Jaipur Observatory. Attached to one of them is a tablet on which the name *Cūḍā-yantra* was inscribed. Finally, an investigation into its antecedents showed that it was known to many earlier astronomers from Āryabhaṭa onwards. Varāhamihira calls it *Valaya-yantra.* In his *Yantraprakāsa* composed in 1428, Rāmacandra discusses three variants, one of which he designates as *Cūḍā-yantra.* Therefore, what the roadside astrologer in the Mughal miniature held in his hand was not the European ring dial but the traditional Indian *Cūḍā-yantra.*

Thus, here we have a unique case in the history of scientific instrumentation where Sanskrit texts, Mughal miniature paintings and actual specimens from Sawai Jai Singh's observatory collectively document the history of the ring dial and its popularity through some twelve centuries from Āryabhaṭa to Jai Singh.

0.3 The study of scientific instruments in other culture areas is well developed. In the West, there are excellent museums of history of science and technology, such as the Museum of History of Science at Oxford, the Adler Planetarium at Chicago, or the Astronomisch-Physikalische Kabinett at Kassel in Germany. Also the literature on medieval European instruments and instrument-makers is truly impressive, beginning with Ernst Zinner's clasic study *Deutsche und Niederlaendische Astronomische Instrumente.*[15] Islamic astronomical instruments like the astrolabe and the celestial globe have been studied[16] or catalogued in several publications, notably in *A Computerized Checklist of Astrolabes* by Derek Price and his associates[17] and in the *Islamicate Celestial Globes, their History, Construction, and Use* by Emilie Savage-Smith.[18] These two surveys cover specimens manufactured in India as well. But the authors depended more on the scantily published notices rather than on physical examination in India, with the result that their listing of astrolabes and celestial globes in India is rather inadequate. Professor David King of the University of Frankfurt is currently engaged in cataloguing medieval European and Islamic astronomical instruments,[19] but his project will touch Indian instruments only in the periphery.

0.4 In India, no comparable work has been done on the existing instruments. While studying Jai Singh's masonry instruments in the early part of this century, Garrett and Kaye paid some attention to the portable instruments at Jaipur.[20] In 1921 Kaye also studied the four instruments acquired by the Archaeological Museum at Delhi.[21] The first one to attempt a survey all over India was Syed Sulaiman Nadvi. In his article of 1935, he threw light on a hitherto unknown family of astrolabe-makers of Lahore who produced astrolabes and celestial globes for four generations, and received patronage from the Mughal rulers from Humāyūn to Aurangẓeb. Nadvi counted eight astrolabes and four celestial globes manufactured by the various members of this family between the years 1567 and 1663 A.D.[22] In the '70s, Professor S.N. Sen undertook a more systematic survey of "Astronomical Instruments of Historical Importance," and published a valuable study on the astrolabe.[23] Beyond this, nothing more came out of the project.[24] Moreover, it should be emphasized that nearly every study up till now concerned itself only with the astrolabes and celestial globes and ignored all other instruments. No doubt, these two are highly complex instruments and sought after by collectors, but for a history of Indian astronomical instruments, even simpler instruments deserve to be noticed.

0.5 Therefore, it is essential to make a comprehensive survey of all pre-modern Indian instruments preserved in private and public collections in India and abroad, and to prepare a descriptive catalogue with facsimile illustrations of all significant objects. Such a catalogue will serve as a useful research tool. It will supplement the data from the Sanskrit texts and may also add new variations not known to the texts. It may throw light on the geographical spread of instrument types and the methods and centres of their manufacture. For example, in the stores of the Jaipur Observatory, there are several astrolabes in various stages of completion, which yield interesting clues to the process of astrolabe making. Finally, it is hoped that the survey will lead to a better preservation of the instruments, especially in museums in India.

0.6 With these aims in mind, I made an exploratory survey, in 1991, of the instrument collections at Salar Jung Museum and State Museum of Archaeology, Hyderabad; Jantar Mantar Observatory, Hawa Mahal, City Palace Museum, and the Museum of Indology at Jaipur; Bharat Kala Bhavan and Sampurnanand Sanskrit University at Varanasi; and the Khuda Bakhsh Oriental Public Library at Patna. The results were highly encouraging. Everywhere I found many more items than I had anticipated. Equally gratifying has been the cooperation readily offered by the authorities of all these institutions.

Then in 1992-93 I had the opportunity to study and catalogue all the known Indian instruments in the US and UK. In the US, the main collections of Indian instruments are at Harvard University, Cambridge; Columbia University, New York; Adler Planetarium, Chicago; Time Museum, Rockford; and the Smithsonian, Washington.[25] The holdings of the Time Museum[26] and the Smithsonian[27] are described in published catalogues as also the holdings of an important private collection owned by Mr Leonard Linton.[28]

Indian instrument collections in Britain[29] are naturally the largest and well preserved.[30] In London, the British Museum, Victoria & Albert Museum, Science Museum, The Museum of the Worshipful Company of Clockmakers, and the National Maritime Museum at Greenwich possess many Indian instruments. There are also good collections at Oxford, in the Museum of History of Science and in the Pitt Rivers Museum. Small collections exist at the Whipple Museum of History of Science, Cambridge; Welsh Museum, Cardiff; and the Royal Scottish Museum, Edinburgh.[31] The Museum of History of Science at Oxford has also extensive archives containing photographs and descriptions of scientific instruments that came for sale in the various auction houses of London such as Christie's and Sotheby's.[32]

0.7 Now remains the daunting task of searching the length and breadth of India, locating private or public collections that may contain astronomical and time-measuring instruments, seeking the permission of the authorities to study the instruments and so on, which I hope to accomplish in the coming years. While the major Indian museums possessing instruments are known, information is welcome about local museums where instruments may be lying unidentified or uncatalogued.

0.8 The proposed catalogue will contain a comprehensive account of all extant Indian instruments in all private and public collections in India and abroad, with historical surveys of the development of each instrument-type, its use and geographic spread, and a full technical description of each specimen with art-historical notes on the decorations and ornamentation. Since this will be the first work of its kind on Indian instruments, attempts will be made to provide also a full photographic documentation of each specimen.

0.9 For the sake of collecting material, I have tentatively classified the Indian instruments into the following categories.

- 1.1 Water Clocks, Outflow Type
- 1.2 Water Clocks, Sinking Bowl Type
- 2.1 Sun Dials with Vertical Gnomon
- 2.2 Sun Dials with Horizontal Gnomon
- 2.3 Equinoctial Sun Dials
- 2.4 Column Sun Dials
- 2.5 Other Kinds of Sun Dials
- 3.1 Sand Clocks, calibrated for *Ghaṭīs*
- 3.2 Sand Clocks, calibrated for Hours
- 4.1 Quadrants, Sanskrit

0.10 In the following pages I shall present brief historical surveys of some major instrument types and invite attention to some important specimens I have come across.

1.1 I may begin with the common time-measuring devices. The oldest known instruments are the water clock (*Nālikā-yantra*) and the gnomon (*śaṅku*), both derived from Mesopotamian models. It is to these devices that the *Kauṭilīya Arthaśāstra* refers when it states that the king should divide the day and the night into eight periods each and perform various tasks in each period. The king is to measure these time divisions either with the water clock[33] or with the shadow of the gnomon.[34] The water clock mentioned here is of the outflow type and this is the earliest type used in India:[35] it consisted of a hollow cylinder with a minute perforation at the bottom, through which it discharged a certain amount of water in course of 24 minutes or one-sixtieth part of a nychthemeron (*ahorātra*). It is this type of water clock which is known to the *Vedāṅgajyotiṣa*. Hollow tube is called *nala* in Sanskrit. The dimunitives *nālī/nāḍī; nālikā/nāḍikā* designate both the instrument and the time duration it measures.

1.2 Sometime around the fourth century A.D., this type of water clock was replaced by another variety known as the sinking-bowl type.[36] This consists of a hemispherical copper bowl with an extremely 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 (see Fig. 1). 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 of each immersion is 24 minutes. In Sanskrit, the bowl is called *ghaṭī* or *ghaṭikā* and these two terms designate also the duration of time measured by this device. The whole apparatus was accordingly called

Fig. 1. Water Clock made of coconut shell, Government Museum, Madras. Photo: Courtesy of Professor S. Ramaratnam who floated it in a bucket of water and found that it takes exactly 24 minutes to sink.

Ghaṭī-yantra or *Ghātikā-yantra*. It was described for the first time by Āryabhaṭa in his *Āryabhaṭasiddhānta*. After him, nearly every author of a *siddhānta* described it in his chapter on instruments.[37]

From the fifth century onwards, institutions for time-keeping are attested at Buddhist monasteries, royal palaces, town squares etc., where time was measured constantly with this water clock and the passage of each *ghaṭī* and completion of each quarter of the day (*prahara*) or of the night (*yāma*) was broadcast regularly by means of drums and conch-shells. In the medieval period, the drum and the conch-shell were replaced by the gong, which was called *ghaḍiyāla* in the Middle Indic.

The institution was so popular that Muslim rulers adopted not only the device but also the time units *prahara, ghaṭī*, and its sub-multiple *pala*. Thus in the latter half of the fourteenth century, Fīrūz Shāh Tughluq, whose interest in sciences and engineering is well known, set up at his palace gate the *ṭās-i ghariyālā* (literally, "the bowl and the gong") which, in the words of his chronicler Shams Shiraz Afif, "aroused the wonder of people from Khurasan to Bengal." Fīrūz also had the picture of this water clock engraved on his coins and used them as ceremonial gifts to dignitaries.[38]

Two centuries later, the Mughal emperor Bābur gives a detailed description of this device in his memoirs. In every major town of Hindusthan, says he, there existed a class of people known as *ghariyālīs* whose profession it was to keep time with this water clock and announce it by means of the gong. Bābur not only adopted this device, he also made improvements in the mode of announcing the *pahars* and *gharis*.[39]

Abūl-Fazl's *Ā'īn-i Akbarī* has a long account of the Institution of Ghariyālā. It informs that time keeping and announcing was the royal prerogative under Akbar.[40] More important, Akbar's painters depicted the water clock in two miniature paintings. Indeed these are the only pictorial representations of this device.[41]

Subsequently, minor nobles also began to maintain water clocks at their palace gates and to regularly announce time. This continued until the beginning of this century. Even now it is occasionally used for ritual purposes. In 1979, it is reported that in the mausoleum of Shaikh Usman, popularly known as Qalandar Saheb, at the City of Sehvan in Sind, time is still measured by the water clock for performing the various rituals. Possibly the practice is still continuing.[42]

1.3 Considering the universal popularity of this water clock, there ought to be hundreds of specimens extant. But in India brass or copper objects which are no longer in use are immediately recycled. Consequently not many seem to have survived. The largest collection is in the Pitt Rivers Museum at Oxford. In India, I have counted so far only six.

Except in one case, it has not been possible for me to actually measure time by floating the bowls on water. However, most of the bowls I have seen appear to have been made for measuring one *ghaṭī*. But how did one measure fractions of a *ghaṭī*? It is of course possible to divide the inner surface of the bowl empirically, if not into 60 divisions, at least into 10 or 6 units. In recent literature, there are references to such graduated bowls[43] but I have not seen one so far. Likewise, not a single basin (Sanskrit *kuṇḍa*) in which the perforated bowl is made to float seems to have been preserved. Nor unfortunately were any gongs collected.[44] In literature larger cups for measuring more than one *ghaṭī* are attested, but none has been noticed so far.

2.1 I have mentioned that the other common time-measuring device was the gnomon or sundial. In the course of centuries, several kinds of sundials developed with a variety of dials and gnomons. The most common form is the horizontal dial with a vertical gnomon, which can also be made temporarily by inserting a stick into the ground. So far I have seen permanent structures of this kind only in mosques (Fig. 2). In fact, every mosque is supposed to have a sundial to determine the times of prayer. Here too there can be a wide variety in the design. But these are being removed at an alarming rate. There is an urgent need of preserving these scientific instruments.

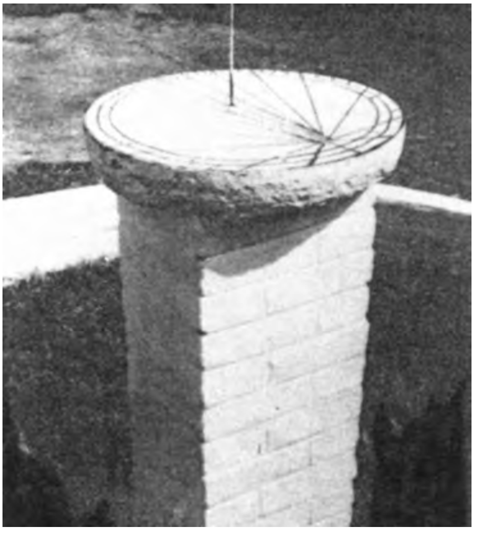

Fig. 2. Vertical gnomon on a horizontal dial, dated 1294 AH/AD 1875, from Firdaus Manzil, Mangal Talab, Patna

2.2 In late medieval times, a variant of the horizontal dial with a triangular gnomon seems to have become popular. The hypotenuse of the gnomon is elevated from its base by an angle equal to the local latitude, and thus it lies in the plane of the celestial equator. The *Yantraprakāra of Sawai Jai Singh* calls it *Palabhā-yantra,* and teaches the method of constructing this type of sundial for the latitude of Delhi (28;39°) and for that of Amber (27°).[45] A small *Palabhā-yantra* is erected on the top of the *Nāḍīvalaya-yantra* of the Jaipur Observatory. I have also seen a very beautiful specimen in the Khanqah Emadia at Patna. It was designed by Janab Faridul Emadi, the present head of the Khanqa.[46]

3.1 Horizontal gnomon is usually attached to vertical walls. But in one variant, it is inserted into a hole at the top of a circular or prismatic column of wood. Below the hole is a scale to measure the shadow of the gnomon in terms of hours or *ghaṭīs* from the sunrise or up to the sunset. But as the sun's altitude varies according to seasons, separate scales with separate holes are provided for each season. Usually there is one scale for each month or each pair of months. The instrument is said to have been invented in the Islamic world whence it spread both to Europe and India. In India it was introduced under the name *Cābuk* or whip instrument. Sanskrit texts literally translate the word as *Kaśā-yantra* or *Pratoda-yantra,* or just transliterate as *Cābuka-yantra*. The first description in India occurs in Rāmacandra's *Yantraprakāśa* of 1428.[47]

In India, I have seen so far only one crude specimen in the stores of Jaipur Observatory. It is about three feet long and has a scale for each month. The scales are painted on the wood but now the paint has all peeled off.[48] In the US, the Time Museum at Rockford has a highly ornate column dial made of ivory. In the Museum of History of Science at Oxford, there is an exquisitely crafted column dial made of damascened steel. All these three were manufactured in western India.

3.2 A somewhat different variety of wooden column dial was very popular in Nepal-Darjeeling region in the last century.[49] I have seen some ten specimens in the various museums in UK. Here the numbers on the scales and the names of the months for which each scale is meant are carved in relief in the wood (Fig. 3). Apparently these dials were called Āṣāḍha sticks, because the longest day occurs in the month of Āṣāḍha and consequently the scale for this month is the longest. Only one of these, at the Horniman Museum, Forest Hill, London, is signed. It carries an inscription to the effect that Jemangala engraved it on Saṃvat 1941 Pauṣa sudi 6.

4.0 Coming to the astronomical instruments proper, one instrument with a long history is the quadrant (*Turīya-yantra*) (Fig. 4). Brahmagupta includes it in his list though he prefers a double-quadrant for measuring the altitude and time. There are not many specimens extant, as this instrument is incorporated on the one hand in the *Dhruvabhrama-yantra* (see 5.0) and on the other in the astrolabe. Outside India, there are two or three Sanskrit quadrants made in the nineteenth century. In India I have seen so far one at Jaipur and another at Varanasi. A Turkish style wooden

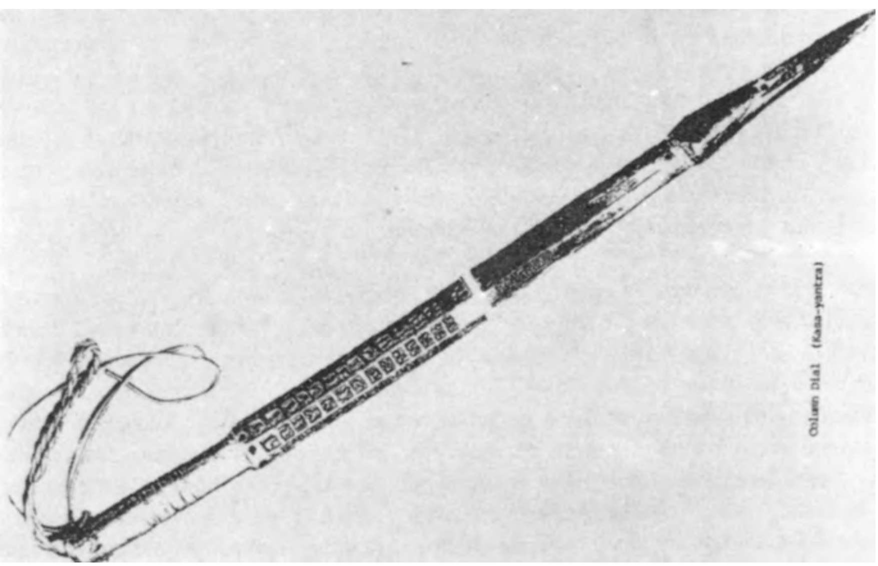

Fig. 3. Carved wooden column dial, a composite picture

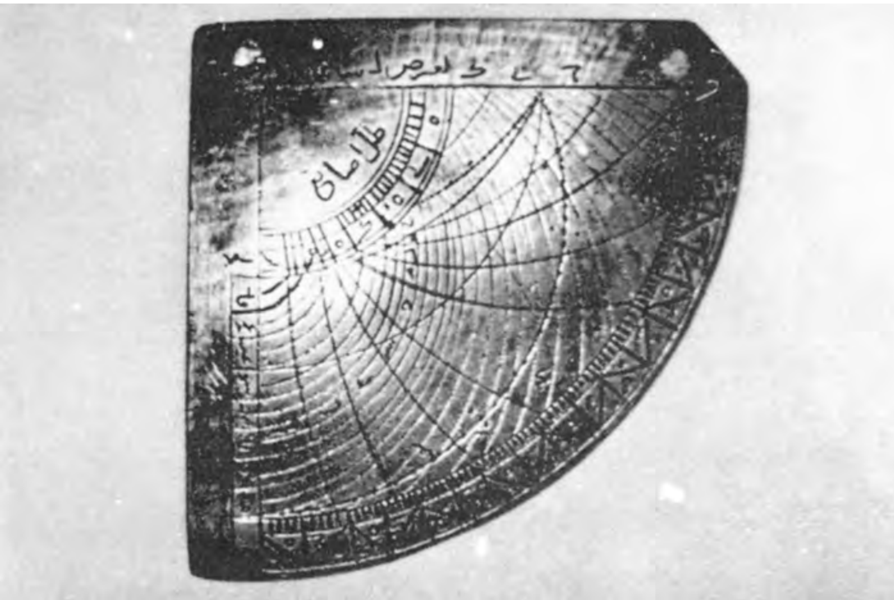

Fig. 4. Indo-Persian (?) quadrant, unsigned, undated. National Maritime Museum, Greenwich, Acc. No. 9204

quadrant made for the latitude of Samarqand is in Bombay.[50]

5.0 The most ingenious instrument of pre-Islamic India is the *Dhruvabhrama-yantra* which functions as a kind of nocturnal (Fig. 5). It was described for the first time by Padmanābha about 1400 A.D. and may have been invented by him. It consists of an oblong metal plate with a horizontal slit at the top. Loosely pivoted to the centre of the plate is a metal index with four indicators projecting into the four directions. A plumb is suspended from the southern-most end so that it always points downwards. Around the centre are concentric circles containing various scales. At night, the instrument is so held that one can see through the slit the pole star and Beta Ursae Minoris. When these two stars are sighted in a straight line by appropriately tilting the instrument, the eastern indicator will point to the *lagna* or ascendant for this moment, the northern indicator will show the culminating point and the western indicator the sidereal time in *ghaṭīs* and *palas*. Thus with this instrument, one can read off from the dial, for any given moment at night, the corresponding time, ascendant, and culmination.[51]

The reverse side of this instrument usually contains a horary quadrant (*Turīya-yantra*) for measuring time during the day. In a specimen at Jaipur, there is a scale of degrees in the outermost arc, on which the solar altitude can be measured. In the other arcs there are separate *ghaṭī*-scales for directly measuring time in different

Fig. 5. *Dhruvabhrama-yantra*, unsigned, undated. Jantar Mantar Observatory, Jaipur

seasons. I have seen a few beautiful specimens of this instrument in UK and USA. In India, there is one at Jaipur and another at Varanasi. The Khuda Bakhsh Oriental Public Library at Patna has, what may be called an Islamic version, one side of which is called *Rūznumah* for the use in the daytime and the reverse is calibrated as *Shabnumah* for the night time. The piece was made in 1804 at Bareilly by Nasīr al-Dīn Hasan.

6.0 The most important medieval scientific instrument, however, is the astrolabe.[52] The astrolabe and the celestial globe were invented in Hellenistic antiquity but they reached their perfection in the Islamic world, whence they were transmitted westwards to Europe and eastwards to India. In the Islamic world these two were the most popular instruments, and the usual mode of describing a good astronomer was to say that he was adept in the use of the astrolabe and the celestial globe.

While the celestial globe was a teaching instrument, the astrolabe is a highly versatile observational and computational instrument. With it time can be determined both in the daytime and at night, both in seasonal hours and in equal hours. One can measure the altitudes of heavenly bodies or the heights of distant objects. More important still is that it works like an analogue computer. For any given moment, one can read off directly from the dial the four points of the ecliptic such as the ascendant etc., which are important in horoscopy. Jabir al-Sufi is said to have enumerated a thousand problems in spherical trigonometry that can be solved by means of the astrolabe.

6.1 When was the astrolabe introduced into India? Al-Berūnī, who wrote a number of tracts on this instrument, must have brought it to India in the eleventh century, and explained its working principles to his Hindu interlocutors at Multan. In the next centuries, Muslim scholars migrating from Central Asia to the court of the Sultans of Delhi brought astrolabes with them.

By the mid-fourteenth century, the instrument was sufficiently well known to be mentioned in a Persian work of fiction called *Basāṭīn al-Uns* written at Delhi.[53] In the same century, astrolabe manufacture also appears to have commenced in India under the active patronage of Fīrūz Shāh Tughluq. 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.[54] However, none of these survive today.

6.2 The earliest surviving astrolabes pertain to the Mughal period. Of the Mughal emperors, Humāyūn is said to have "extra-ordinary excellence in the astrolabe, globe and other instruments of the observatory." Under his patronage, manufacture of astrolabes and celestial globes commenced at Lahore. One family, in particular, distinguished itself in this pursuit. Seven members of this family, belonging to four generations, signed their names on about 87 astrolabes and 21 celestial globes (Fig. 9). There are also many unsigned pieces which can be attributed to this family.

Fig. 6. Astrolabe by 'Īsà ibn Allāhdād Aṣṭurlābī Lāhūrī Humāyūnī, 5 plates, not dated. Personal collection of Mr John N Didcock, Ely, Cambs, U.K. Photo: Courtesy of Mr Didcock

The patriarch of this family is Ustād Shaikh Allāhdād Aṣturlābī Humāyūnī Lāhūrī. He may have been the royal astrolabe maker of Humāyūn and hence received the title Aṣturlābī Humāyūnī, although the only dated piece by him was made in 1567, i.e. eleven years after Humāyūn's death. It is now in the Salar Jung Museum at Hyderabad.

Allāhdād's son Mullā 'Īsà is known through five astrolabes produced between the years 1600 and 1604 (Fig. 6). Of his two sons, Qā'im Muḥammad perfected the art of casting celestial globes in one piece through the lost wax process. Four of his globes are extant today. He also made five astrolabes, two of which jointly with his brother Muqīm. The latter has to his credit the largest number of astrolabes. I have counted some thirtysix astrolabes manufactured by him during the half a century of creativity between the years 1609 and 1659.

6.3 The most prolific and versatile member of this family is Qā'im's son Ḍiyā' al-Dīn Muḥammad, whose period of creative activity lasted from 1637 to 1680, and overlapped the reigns of Shāh Jahān and Aurangzeb. His oeuvre consists of about 29 astrolabes and 15 celestial globes - perhaps the largest number ever signed by a single instrument-maker of pre-industrial times. Today, these pieces are dispersed in all parts of the world: India, Egypt, Russia, France, Germany, UK and USA. His prolific work is distinguished by superb craftsmanship and innovation in design. Here one can see the harmonious combination of art, science and technology at its perfection.

Fig. 7. Sanskrit Astrolabe, single plate for the latitude 22;35.39 °N, dated 1941 VS/AD 1884, unsigned. Formerly in the collection of Saul Moskowitz, Marblehead, Mass., USA. Photo: Courtesy of Proessor David Pingree

6.4 Chronologically the last and technically the most remarkable of Ḍiyā' al-Dīn's astrolabes is the universal astrolabe he manufactured in 1680 for Nawāb Iftikār Khān of Jaunpur. Here separate plates are not needed for different latitudes, and the same plate is used for all localities. The original prototype was designed by Ibn al-Zarqāllu of Cordova in the eleventh century. There are not many specimens of this type extant today. Ḍiyā' al-Dīn's creation is nearly the largest and most elaborate one of all the extant specimens. It measures 555 mm across and is one of its kind in the entire east.[55]

While the piece itself is thus unique, its subsequent history is also of great interest for the transmission of ideas. Within half a century of its manufacture, it was aquired by Sawai Jai Singh, who used it for the instruction of the Hindu astronomers at his court. On the crown of the instrument, its name was engraved in Sanskrit/Rajasthani: *Yantra Jarakālī Sarvadeśī*. A copper plaque was attached to it with all its functions engraved in Rajasthani. Sanskrit equivalents of a number of star names were also engraved on it. More important still is that, inspired by this piece, Sawai Jai Singh caused a Sanskrit manual to be composed on the construction and use of this universal astrolabe.[56]

6.5 Thus the creations by the various members of the Allāhdād family are reasonably well covered. Besides this family, there were also other instrument makers who produced Indo-Persian astrolabes and celestial globes. As the survey progresses, it is hoped, more names will come to light. The tradition continued until the middle of the nineteenth century. The last great practitioner was Lālah Bahlūmal Lāhūrī, whose work will be discussed presently.

7.0 The astrolabe was received by Hindus and Jainas with great enthusiasm. I have mentioned that Mahendra Sūri wrote the first Sanskrit manual in 1370 under the auspices of Fīrūz Shāh Tughluq at Delhi. Mahendra Sūri was so impressed by the versatile functions of the astrolabe that he called it *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 fourteenth and eighteenth centuries, more than a dozen manuals were composed in Sanskrit on the astrolabe. These include the Sanskrit rendering of Naṣīr al-Dīn al-Ṭūsī's Persian manual in twenty chapters, popularly known as the *Bīst Bāb*.[57]

7.1 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* instead of hours (Fig. 7). The earliest known Sanskrit astrolabe was manufactured in 1607 by one Dāmodara. It came for sale at Sotheby's in 1976, but its present whereabouts are not known. Consequently, the earliest extant astrolabe in a public collection today is the one manufactured by Maṇirāma in 1643. It is now at the Royal Scottish Museum of Edinburgh. Pitt Rivers Museum of Oxford has one astrolabe made in 1673 for the astrologer Indrajī.

Fig. 8. Celestial Globe by Bahlūmal Lāhūrī, dated 1258 AH/AD 1842. The Science Museum, London, Acc. No. 1985-1257.

7.2 The manufacture of Sanskrit astrolabes received a great impetus from Sawai Jai Singh who had himself authored a book on its construction.[58] He had apparently a *kārkhānā* at Jaipur for the manufacture of astrolabes.[59] This manufactory produced some highly ornate astrolabes with multiple plates. But its main product were astrolabes with a single plate calibrated for 27 °N, which is the latitude of Jaipur. Hindu astronomers of Rajasthan found the astrolabe an excellent teaching instrument. Therefore, astrolabes continued to be manufactured in the 18th and 19th centuries in Rajasthan. These are mainly single plate astrolabes, calibrated for a single latitude, usually 27°. Besides Jaipur, Kuchaman (27;10 °N, 74;54 °E) seems to have been an important centre of production of these astrolabes.[60]

8.1 The celestial globe, the other important Islamic instrument, is a late comer to India.[61] It was probably introduced by Humāyūn into India (Fig. 8). As mentioned already, the descendants of Allāhdād manufactured globes of good workmanship. Allāhdād's grandson, Qā'im Muḥammad perfected the art of casting globes in one piece by the cire perdue process, and his son Ḍiyā' al-Dīn excelled in this technique. Besides some 15 ordinary celestial globes, he also designed a very unusual one for Aurangzeb in 1679. The surface of the globe was cut *à jour,* like the spider of the astrolabe, leaving out the outlines of the constellation figures, great circles, tropics and arctic circles. Star positions are indicated by small perforations. When lit from inside, the globe would present an illuminated view of the celestial sphere.

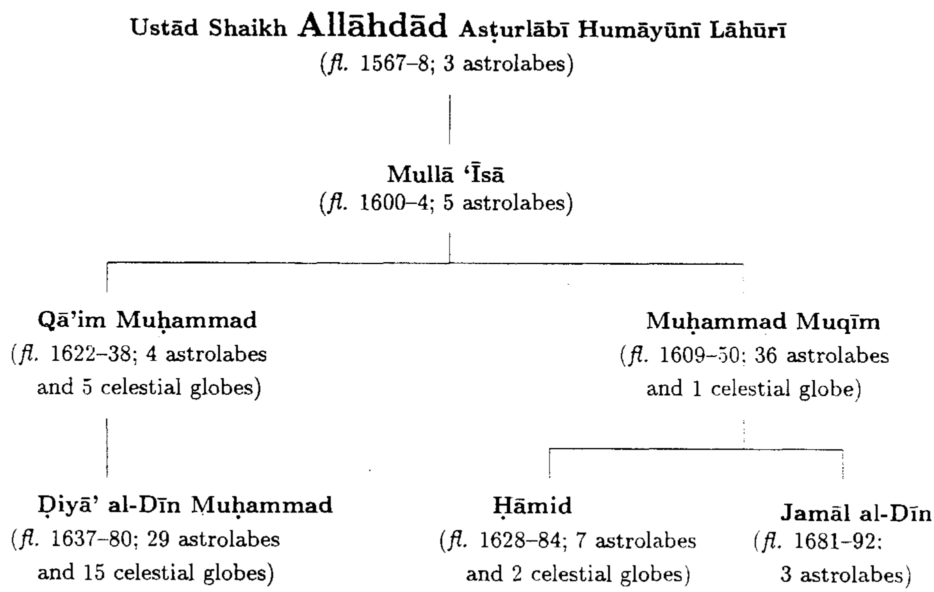

Fig. 9. The Astrolabist Family of Lahore and their instruments

8.2 Celestial globes were manufactured outside this family also. In fact, the earliest extant celestial globe was produced by one 'Ali Kashmīrī ibn Lūqmān during the reign of Akbar in 998 AH/AD 1589. Muḥammad Ṣālih of Thatta, a contemporary of Ḍiyā' al-Dīn, is known to have produced at least three globes.[62] Like the astrolabes, celestial globes also continued to be produced until the middle of the last century.

8.3 To judge from the surviving examples, the celestial globe was not as popular among the Hindus as the astrolabe had been. So far, I have come across only three specimens, two at Jaipur and one at New York.

9.0 I have said that the survey may throw up new variants not mentioned in the texts, and it has indeed done so. Likewise, more and more details are emerging about hitherto little known instrument-makers. One such person is Lālah Buhloverma or Buhlomalla or Bahlūmal Lāhūrī, who flourished in the first half of the nineteenth century. A heir to the metallurgical techniques of the Allāhdād family and, at the same time, well-versed in the Sanskrit tradition of instrumentaiton, he produced astrolabes and celestial globes with legends either in Arabo-Persian or in Sanskrit. He also crafted *Dhruvabhrama-yantras* and *Turīya-yantras*, signing his name in pretty Sanskrit verses. In Bahlūmal then we can see the true and perhaps the last representative of both the Islamic and Hindu traditions of scientific instrumentation.

10.0 The survey also revealed that, although the telescope was widely available, instruments for naked-eye observation continued to be produced in the 19th century and some of these were copies of European prototypes, with legends in Sanskrit for the Hindu astrologers or in Persian for Muslim astrologers. At the Khuda Bakhsh Library of Patna, there is a universal ring dial, engraved in Sanskrit, and an adjustable equinoctial dial, engraved in Persian. As I proceed with this survey, more and more pieces of this nature are coming up. I found two more Sanskrit universal ring dials at the Columbia University, New York, and at the Smithsonian, Washington, D.C. The Adler Planetarium at Chicago has a very large adjustable equinoctial dial. When more such specimens are known, perhaps it will be possible to identify the manufacturers and their clients and to trace the context of this transmission.

11.0 Before closing this presentation, I should like to invite attention to an intriguing feature about the geographical spread of the instrument types. The sinking bowl type of water clock, of course, was used throughout South Asia. But all other pre-Islamic instruments, leaving aside the wooden column dials from the Nepal-Darjeeling area, emanate from the Rajasthan-Gujarat region only.[63] The Islamic instruments like the astrolabe and the celestial globes were made in the Lahore-Delhi area, and do not seem to have spread to the east and south. The outermost limit in the east is Tikari (24;57° N; 85;53° E) in Bihar, where Ghulām Hussain Jaunpurī made a celestial globe in 1810[64] (and perhaps also astrolabes). The southern limit is Auraṇgabad, where a Muhammad Mūsa Aṣturlābī flourished in the 18th century. A celestial globe made by his grandson Muḥammad Fazlullah in 1808 (presumably at Aurangabad) survives today. This is mounted on a European style stand into which a magnetic compass is incorporated.[65] On the other hand, 19th century Sanskrit/ Persian copies of European instruments were produced at Delhi, Bareilly and Patna. Equally intriguing is the following: Indo-Persian astrolabes and celestial globes produced in the 16th, 17th and 19th centuries have been found but not a single piece from the 18th century. Perhaps we will be able to answer these questions when the survey is complete. In the meantime, the author will welcome suggestions and, in particular, information about less known instrument collections.

Acknowledgements

This project would not have progressed this far without the cooperation of innumerable persons who went out of their way to help me, in particular the authorities and staff of all museums and libraries that I had visited. While acknowledgements will be made to all of them individually in the final catalogue, I may make a special mention here of the following scholars for their advice, encouragement and generous help: Dr R.G.W. Anderson, London; Professor S.M.R. Ansari, Aligarh; Dr A.K. Bag, New Delhi; Professor Owen Gingerich, Cambridge, Mass.; Professor David A. King, Frankfurt; Mr F.R. Maddison, Oxford; Professor David Pingree, Providence; Professor G.L. 'E. Turner, Oxford.

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2. See 0.4 below.

3. For an exhaustive bibliography on Jai Singh, see Sarma, Sreeramula Rajeswara (ed & tr), *The Yantraprakāra of Sawai Jai Singh*, supplement to *Studies in History of Medicine and Science*, **9-10**, pp. 122-131, 1986-87.

4. Cf. Sarma, Sreeramula Rajeswara, Portable Instruments at the Jaipur Observatory, paper read at the International Symposium on Indian and Other Asiatic Astronomies, Hyderabad-Jaipur 1991; idem, Manufacture of Portable Astronomical Instruments at Jaipur and the Contribution of Sawai Madho Singh, paper read at the XIX International Congress of History of Science, Zaragoza 1993.

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13. See Price, Derek, "Precision Instruments" in: Charles Singer (ed), *A History of Technology*, Vol. III, Oxford 1957, pp. 582-619, esp. p. 598, fig. 351.

14. *Yantraprakāra Sawai Jai Singh* (see n. 3 above), pp. 27-28, 79-82, 101, 105-114.

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16. Cf. in particular, King, David A., *Islamic Astronomical Instruments*, London 1987, and the bibliography therein.

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20. Garrett, A. ff., and Guleri, Chandradhar, *The Jaipur Observatory and its Builder,* Allahabad 1902, pp. 60-65; Kaye, G.R., *The Astronomical Observatories of Jai Singh,* Calcutta 1918, pp. 16-36.

21. Kaye, G.R., *Astronomical Instruments in the Delhi Museum,* Calcutta 1921.

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25. In these collections, there are over fifty Indian instruments, a report of which will be published elsewhere.

26. Turner, A.J., *Astrolabes, Astrolabe-related Instruments* (The Time Museum: Catalogue of collections, vol. I, part 1), Rockford 1985; idem, part 3: *Water-Clocks, Sand-Glasses, Fire-Clocks* (The Time Museum: Catalogue of collections, vol. I, part 3), Rockford 1984.

27. Gibbs, Sharon L., *Planispheric Astrolabes from the National Museum of American History,* Washington, D.C., 1984.

28. *Collection Leonard Linton et de divers amateurs,* Auction Catalogue, Paris 1980.

29. There are some hundred items, the report of which will appear elsewhere.

30. Some of these were displayed in the Festival of India at London 1972. See the Exhibition Catalogue compiled by Anderson, R.G.W., *Science In India: A 'Festival of India' Exhibition at the Science Museum, London, 24 March-1 August 1982,* London 1982.

31. The task of locating historical scientific instruments is much facilitated by the recent publication of Holbrook, Mary, Anderson, R.G.W., and Bryden, D.J., *Science Preserved: A Directory of Scientific Instruments in Collections in the United Kingdon and Eire,* London 1992.

32. Thus I have seen a large part of Indian instruments abroad. There are still about thirty or more instruments in France and Germany, besides single specimens in Russia and the Middle-Eastern countries.

33. On the history of water clocks in India, see my forthcoming monograph, *Water Clocks and Time Measurement in India.*

34. *The Kauṭilīya Arthaśāstra,* ed & tr, R.P. Kangle, Part 1, second edn, Bombay 1969, 1.19.6: *nālikābhir ahar aṣṭadhā rātriṃ ca vibhajec chāyāpramāṇena vā.*

35. On the classification of water clocks, see Needham, Joseph, *Science and Civilisation in China,* vol. 3: Mathematics and the Sciences of the Heavens and the Earth, Cambridge 1959, p. 315; Turner, A.J., *Water-clocks, Sand-glasses, Fire Clocks* (See n 27 above), p. 1.

36. Sarma, Sreeramula Rajeswara, Astronomical Instruments in Mughal Miniatures, (see n. 12 above), pp. 241-243.

37. Several of these descriptions are collected in Subbarayappa, B.V. and Sarma, K.V., *Indian Astronomy: A Source-Book,* Bombay 1985, pp. 86-99.

38. Cf. Sarma, S.R., and Alam, Ishrat, Announcing Time: the Unique Method at Hayatnagar, 1676, *Proceedings of the Indian History Congress, 52nd Session, New Delhi, 1991-92,* Delhi 1992, pp. 426-431.

39. Beveridge, Annette Susannah (tr), *Bābur-Nāma (Memoirs of Bābur),* Delhi 1979, vol. I, pp. 516-517.

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44. In the last century, a German nobleman collected a gong, but its current whereabout are unknown. Cf. Schlagintweit-Sakuenluenski, Hermann von, Eine Wasseruhr und eine metallene Klangscheibe alter indischer Construction, *Sitzungsberichte der mathematisch-physikalisch Classe der k.b. Akademie der Wissenschaften zu Muenchen,* **1,** 128-139, 1871.

45. *Yantraprakāra of Sawai Jai Singh* (n. 3 above), pp. 26, 76-77.

46. There is a small marble *Palabhā-yantra* in the City Palace Museum, Jaipur, and another at Bharat Kala Bhavan, Varanasi.

47. Cf. Sarma, Sreearamula Rajeswara, Rāmacandra Vājapeyin's Contributions to Astronomy and Mathematics (n. 9 above); see also Sharma, S.D., *Pratoda-Yantra by Ganesha Daivajña,* Kurali 1982. I am now convinced that the Indian column dial is basically different from the Islamic and European versions.

48. Cf. Sarma, Sreeramula Rajeswara, Portable Instruments at the Jaipur Observatory (n. 4 above).

49. Cf. Winter, H.J.J., A Shepherd's Time-Stick, Nāgarī Inscribed, *PHYSIS,* **4,** 377-384, 1964.

50. Khareghat, K.P., *Astrolabes,* Bombay 1950, pp. 75-82.

51. Cf. Garrett, op. cit., pp. 62-64; pl. X.

52. The literature on the astrolabe is very extensive. The best accounts are Hartner, Willy, The Principle and Use of the Astrolabe, in: idem, *Oriens-Occidens,* Hildesheim 1968, pp. 287-311; North, J.D., The Astrolabe, *Scientific American,* **230,** 96-106, January 1974. On the history of the astrolabe in India, see Sarma, Sreeramula Rajeswara, Astronomical Instruments in Mughal Miniatures (n. 12. above), pp. 237-241.

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54. This will be discussed in my forthcoming "Sultan, Sūri and the Astrolabe".

55. Kaye, G.R., *The Astronomical Observatories of Jai Singh,* pp. 27-30.

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59. Cf. Sarma, Sreeramula Rajeswara, Portable Instruments at the Jaipur Observatory (n. 4 above).

60. In the archives of the Museum of History of Science at Oxford, there is a large collection of photographs of Sanskrit astrolabes that came for sale in the auction houses of London in the past two or three decades. Though the current location of these astrolabes is not known, from the photographs I could build up a large repertoire of the names of persons who designed, manufactured or owned Sanskrit astrolabes.

61. Cf. Savage-Smith, Emilie, *Islamicate Celestial Globes: Their History, Construction, and Use,* Washington, D.C. 1985; Sarma, S.R., Ansari, S.M.R. and Kulkarni, A.G., Two Mughal Celestial Globes, *Indian J of History of Science,* **28,** 55-65, 1993; Sarma, Sreeramula Rajeswara, From al-Kura to Bhagola: On the Dissemination of the Celestial Globe in India, to appear in the *Studies in History of Medicine and Science* (1994).

62. Cf. Sarma, S.R. et al, Two Mughal Celestial Globes (n. 61 above).

63. Kerala has a tradition of observational astronomy, and there is a specific mention of an armillary sphere erected at the observatory of Mahodayapura in the ninth century, Cf. Sarma, K.V., *Observational Astronomy in India,* Calicut 1990, pp. 41-42. Do any instruments survive in Kerala today?

64. Cf. Ansari, S.M.R. and Sarma, S.R., Ghulam Husain Jaunpuri -- An Astronomer and Instrument Maker of 19th C. India, paper read at the International Symposium on Indian and Other Asiatic Astronomies, Hyderabad-Jaipur 1991.

65. Preserved at the Salar Jung Museum, Hyderabad. This globe will be described in greater detail in my report on the instruments at the Salar Jung Museum, which is under preparation.