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Astronomical Instruments in Mughal Miniatures

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0.1 The rich treasures of the Mughal miniature paintings have been studied quite fruitfully in recent years for reconstructing the material culture of the period.[1] Some of these paintings offer information also on astronomical instruments used in Mughal India in the sixteenth and seventeenth centuries. In a pioneering interpretation of a manuscript illustration from the *Hamzānāma*, Eric Forbes identified two Arab navigational instruments: a *kamāl* for measuring the stellar altitudes on the high seas and a portable mariner's compass with the magnetic needle suspended on a pivot.[2] In this paper, I shall discuss the astronomical instruments depicted in other miniatures. These miniatures can be grouped into two categories: while one group consists of miscellaneous scenes, the theme of the other group is the joyous celebration of the birth of a royal prince — be it Timūr, Akbar, or his sons Jahāngīr or Murād.

0.2 There are some seven miniatures, commissioned originally for illuminating the manuscript copies of the dynastic chronicles like the *Tīmūrnāma* and the *Akbarnāma*, which depict the birth of a prince in quite an elaborate manner. These are composite pictures consisting of several panels, each of which shows a different scene connected with the joyful event: the contented queen with the baby; maids attending hurriedly to various tasks; musicians and dancing girls performing with gay abandon; gifts being brought for the exalted new-born; distribution of alms to the poor; and, of course, astrologers casting the prince's horoscope. (See Plates 1-5).[3] The importance of the last-mentioned activity can ge gauged from the

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[1] Cf. Som Prakash Verma, *Art and Material Culture in the Paintings of Akbar's Court*, New Delhi 1978; Ahsan Jan Qaisar, *The Indian Response to European Technology and Culture (A.D. 1498-1707)*, Delhi 1982; idem, *Building Construction in Mughal India: The Evidence from Painting*, Delhi 1988.

[2] E. G. Forbes, "A 16th Century Indian Miniature illustrating two Arab Navigational Instruments" in: *Papers Presented [at the] International Conference on Science and Islamic Polity: Islamic Scientific Thought and Muslim Achievements in Science*, Islamabad 1983, Vol. II, pp. 330-337.

[3] Besides the five miniatures reproduced here in Pls. 1-5, there are two more that depict the birth of a prince: (i) *A Catalogue of the Indian Collection in the Museum of Fine Arts, Boston*, Part VI: Mughal Paintings, by Ananda K. Coomaraswamy, Cambridge, Mass. 1930, Frontispiece and Pl. IV. The bottom part of the painting where Hindu and Muslim astrologers are

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prominence given in the composition to the astrologers' panel. Indeed, the compositions look as if they have two focii: the queen with the new-born prince on the one hand and the astrologers with their professional equipment on the other. The latter are shown measuring the birth time with a water clock or sand clock, determining the sun's altitude with a ring dial, finding the ascendant by consulting books of astronomical tables, and finally preparing the prince's horoscope.

0.3 Thus these miniatures represent more vividly what, for example, Abū 'l-Fazl records about Akbar's birth, in the typical courtier's style:

> When the victory-seeking standards [i.e. Humāyūn] were leaving the fort of Amarkōṭ, Maulānā Cānd, the astrologer, who was possessed of great dexterity in the science of the astrolabe, in the scrutinizing of astronomical tables, on the construction of almanacs, and the interpretation of the stars, — was deputed to be in attendance at the portals of the cupola of chastity (Miryam Makānī, Akbar's mother) in order that he might ascertain exactly the period of birth. He reported in writing to the exalted camp that, according to the altitudes taken by the Greek astrolabe, and by calculations based on the Gurgānī tables (Canons of Ulugh Beg), the figure of the nativity was as follows.[4]

What are the measurements Maulānā Cānd took? In Abū 'l-Fazl's words, Akbar's birth occurred when the altitude of Procyon was 38° and when 8 hrs. and 20 m. had passed from the beginning of the night of ... Sunday 5th Rajab 949, lunar era, and [corresponding] to 6th Kārtik 1599, Hindū era, ... 4 hrs. 22m. of the said night were remaining.[5]

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seated is slightly damaged, but a ring dial held aloft by a Muslim astrologer can still be seen clearly. For a description of the painting, see *ibid.*, pp. 17-18. (ii) *Timūrnāma*, f. 284a, Khudabaksh Library, Patna. Two astrologers are seated in a kiosk outside the palace gate. One is holding a book. Next to the other is a circular object suspended from a tripod. In the rotograph copy of the Ms. in Maulana Azad Library, Aligarh, it is not clear whether the circular object is a ring (= ring dial) or a disc (= astrolabe).

[4] *Akbarnāma*, I, p. 69. The "Greek" astrolabe is a pedantic allusion to the Greek origin of the instrument.

[5] *Ibid.*, I, pp. 53-54. Akbar's birth date is recorded in five different eras. I cite only the two relevant ones. Maheśa Ṭhakkura translated an abridged version of the *Akbarnāma* into Sanskrit, for which service he is said to have received the kingdom of Mithila from Akbar, cf. *Sarvadeśavṛttāntasaṃgraha or Akabaranāmā of Mahāmahopādhyāya Maheśa Ṭhakkura*, ed. Subhadra Jha, Patna 1962, pp. xiii-xvi. If so, it is quite a heavy price, when one considers the quality of translation. The passage dealing with Akbar's birth is rendered thus (*ibid.*, p. 17):

> *asmin samaye viṃśatighaṭikāsu viṃśatipalayutāsu vyatītāsu ... ekonapañcāśad-adhika-śatanavake 'tīte cāndramānasya pañcamarātrau ravivāsare, navanavaty-adhika-pañcadaśaśateśv atīteṣu vikramārkarājyāt kārtike māsi ṣaṣṭhyāṃ tithau ... dvāviṃśatipalādhika-daśaghaṭikāvaśeṣāyāṃ rajanyām ...*

Actually 8 h. 20 m. are equal to 20 *ghaṭikās* and 50 *palas* (and not 20 *gh.* 20 *p.* as the Sanskrit reads); 4 h. 22 m. are equal to 10 *gh.* 55 *p.* (not 10 *gh.* 22 *p.*). Maheśa, therefore, converted only the hours into *ghaṭikās*, but in the *palas*' place just put the same number as that of minutes!

That is to say, Akbar was born on the night between the 14th and 15th of October 1542 (Julian), 8 hours 20 minutes after the local sunset and 4 hours 22 minutes before the next local sunrise. These measurements of time and of the altitude of the star Procyon can easily be taken by means of an astrolabe.

One would, therefore, expect that in these miniatures the royal astrologers are shown holding the astrolabe, in accordance with Abū 'l-Fazl's report. This is also the customary mode of depicting the astrologers/astronomers elsewhere in the Islamic world.[6] But the Mughal artist seems to have other notions, and one rarely sees the astrolabe in these miniatures. This is surprising on several counts.

1. Astrolabe (Yantrarāja)

1.1 In Islamic culture, the astrolabe[7] enjoyed a high reputation as the "jewel of mathematics". It is a highly versatile instrument, capable of several functions. While the ring dial can be used only in the daytime for measuring the sun's altitude and time, with the help of the astrolabe time can be measured both in the daytime and at night, in equal hours or in unequal hours. One can take the altitudes, and read directly from the dial the ascendant (*lagna*), i.e. the point on the ecliptic which is just above the horizon at the desired moment. In horoscopy, the ascendant is of great importance, because it is from this point that the zodiac circle is divided into 12 houses, and the planetary configuration in each house has a bearing on a specific aspect of the child's life. The astrolabe enables one to read the configurations without having to make long and tedius computations.

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[6] Cf. e.g., miniatures illustrating the "Birth of Child" and the "Casting a Horoscope" from the Ms. of al-Harizi's *Maqāmat*, Bibliothèque Nationale, Paris, reproduced in: René Taton, *Ancient and Medieval Science*, tr. into English by A. J. Pomerans, London 1963, Pls. 33 and 34 between pp. 416-417. The former is reproduced also in Turner, I.1, p. 27. See also the oft-reproduced miniature "Astronomers at Work" from the Ms of *Kitāb Rasda al Munajjimin*, of A. H. 813 (A.D. 1410/11), Istanbul University Library, F-1418, Pl. 1b.

[7] On the astrolabe, see Robert T. Gunther, *The Astrolabes of the World*, Oxford 1932; Willy Hartner, "The Principle and Use of the Astrolabe", and "Aṣturlāb", reprinted in: *Oriens-Occidens*, [vol. I], Hildesheim 1968, pp. 287-319; Turner, I.1; David A. King, "Astronomical Instrumentation in the Medieval Near East," reprinted in his *Islamic Astronomical Instruments*, London 1987, article no. I.

1.2 The astrolabe was introduced into India apparently during the reign of Fīrūz Shāh Tughluq in the second half of the fourteenth century. His contemporary biographer Shams-i-Sirāj 'Afīf reports that Fīrūz always had a *nisfī* astrolabe by his side.[8] Fīrūz also had an astrolabe painted on his banners. One such banner was hung on the Aśoka pillar, which he got transported from the Shiwalik hills and set up on a specially constructed building in his citadel at Delhi.[9]

Of the Mughal emperors, Humāyūn (reign 1530-56) is said to have "extraordinary excellence in the astrolabe, globe and other instruments of the observatory."[10] His sister reports that he "took the astrolabe into his blessed hand" and himself chose the propitious moment for his marriage.[11] More important is the fact that under his active patronage, astrolabe manufacture started at Lahore. Specimens of astrolabes produced by several generations of a single family are extant today. The earliest member of this astrolabist family is Ustād Shaikh Allāh-dād Āsṭurlābī Humāyūnī Lāhūrī. From this name, Suleiman Nadvi conjectured that Humāyūn invented a special type of astrolabe called Humāyūnī asṭurlāb and therefore the family of its manufacturers bore the title Āsṭurlābī Humāyūnī.[12] The extant astrolabes produced by this family, however, do not bear out Nadvi's contention; they are modelled quite faithfully after the contemporary Persian instruments.[13] But there is no doubt that Humāyūn promoted the manufacture of astrolabes, and also of celestial globes. We have also seen that Maulānā Cānd was an expert in the use of the astrolabe.

1.3 Hindu and Jaina astronomers were no less enthusiastic about the advantages of the astrolabe, and wrote a number of manuals on its construction and use. The first such work, entitled *Yantrarāja*, was written by the Jaina monk Mahendra

[8] I.e. a bipartite astrolabe having 45 almucanter lines, each one representing 2° of altitude, cf. Gunther, *op. cit.*, I, pp. 7-8.

[9] Syed Athar Abbas Rizvi, *Tughluq-kālīna Bhārata*, part 2, Aligarh 1957, p. 146 (Hindi tr. of 'Afīf's *Tārīkh-i Fīrūz Shāhī*); see also S. A. K. Ghori, "Scientific Exchanges between Soviet Central Asia and India during Medieval Times" in: B. V. Subbarayappa (ed.), *Indo-Soviet Seminar on Scientific and Technological Exchanges between India and Soviet Central Asia (Medieval Period)*, New Delhi 1985, pp. 78-89, esp. 87-88.

[10] Syed Suleiman Nadvi, "Some Indian Astrolabe-Makers," *Islamic Culture*, 9 (1935), pp. 621-631, esp. 622-23.

[11] *The History of Humāyūn (Humāyūn-Nāma) by Gul-Badan Begum*, tr. A. S. Beveridge, Delhi 1972, p. 51.

[12] Nadvi, *op. cit.*, p. 626.

[13] Turner, I.1, p. 26.

Sūri in 1370. In this book, Mahendra Sūri calls the astrolabe the "king of instruments" (*yantrarāja*).[14] His pupil Malayendu Sūri wrote a commentary on this work in about 1382, where he informs that Mahendra was associated with Fīrūz Shāh Tughluq's court. Apparently Fīrūz was not only interested in using the astrolabe himself but he also encouraged the Jaina Sūri to compose a work on it in Sanskrit.

Within a quarter century after the Sūri's work, i.e. about 1400, Padmanābha wrote the *Yantracintāmaṇi* (also known as *Yantrakiraṇāvalī*) and devoted the first chapter to the astrolabe.[15] Then in 1428, Rāmacandra Vājapeyin, a resident of Naimiṣāraṇya (near modern Lucknow) discussed the astrolabe quite extensively in his *Yantraprakāśa*.[16] This unique text describes the construction and use of some 35 astronomical instruments — perhaps the largest number ever dealt with in a Sanskrit work. Some of these are traditional Indian instruments, or their variants, and some are clearly of Islamic origin. As we shall see in the following pages, the value of the *Yantraprakāśa* cannot be underestimated in tracing the history of individual instruments. The major part of this work is devoted to the astrolabe, which is called here *sulabhā*, another significant name meaning that with this instrument several types of measurements become easy.

In the reception of scientific ideas from Islamic culture and in their dissemination in India, Jaina monks seem to have played a prominent role. About the end of the fifteenth century, another Jaina monk, Muni Megharatna, pupil of Vinayasundara of Vaṭagaccha, wrote the *Usturalāvayantra* in 38 stanzas, replete with Arabic-Persian technical terms.[17]

[14] *The Yantrarāja of Mahendra Sūri*, with the commentary by Malayendu Sūri, and *the Yantraśiromaṇi of Daivajñacūḍāmaṇi Viśrāma*, ed. K. S. Raikva, Bombay 1936. David Pingree, *Jyotiḥśāstra. Astral and Mathematical Literature*, Wiesbaden 1981, p. 53, observes that "After Mahendra a number of other texts describing traditional Indian instruments were composed in Sanskrit, almost all of them in Gujarat and Rajasthan, but the astrolabe was generally neglected." In fact, the astrolabe received the greatest attention, even outside Gujarat-Rajasthan region, as the following lines will show.

[15] On this and the following texts, see Yukio Ohashi's comprehensive survey, "Sanskrit Texts on Astronomical Instruments in the Delhi Sultanate and Mughal Periods," which will apear in *Studies in History of Medicine and Science*, 10-11 (1986-87).

[16] Ms. no. 975 of 1886/92 of the Bhandarkar Oriental Research Institute, Poona (BORI); and Ms. no. G-1363 of the Asiatic Society, Calcutta (ASB). See also § 3.1 and § 5.5 below.

[17] Cf. Ambalal P. Shah, *Jaina Sāhitya kā Bṛhad Itihāsa*, vol. V, Varanasi 1969, p. 180; Agar Chand Nahata, "Usturlāva Yantra saṃbandhī eka Mahatvapūrṇa Jainagrantha," *Jaina-Siddhānta-Bhāskara*, XVIII.ii, pp. 119-128. Shri Hazari Mull Banthia (Kanpur) very kindly obtained a xerocopy of this article for me. The only Ms of the *Usturalāvayantra*,

Two seventeenth century texts discuss the astrolabe along with other instruments. Thus Viśrāma devotes the third chapter of his lucidly written *Yantraśiromaṇi* (1615) to the astrolabe.[18] It was also discussed in Nityānanda's *Siddhāntarāja*, which was completed in 1639.[19]

In the first half of the eighteenth century, astronomers at the court of Sawai Jai Singh (1688-1743) translated several books on astronomical instruments from Arabic or Persian into Sanskrit, and also wrote some independent works. Four of these deal with the king of instruments. The *Yantrarājaracanā*, attributed to Jai Singh himself, deals exclusively with the astrolabe.[20] The eighth chapter of a compilation entitled *Yantraprakāra* also explains the use of this instrument.[21] Furthermore, Naṣīr ud-Dīn aṭ-Ṭūsī's *Risālah-i Bīst Bāb dar Ma'rifat-i Usṭurlāb* was rendered into Sanskrit under the title *Yantrarājavicāraviṃśādhyāyī*.[22] Jai Singh also caused the composition of the *Sarvadeśīya-jarakālīyantra* on the universal plane astrolabe invented by the Moorish astronomer al-Zarqāl in Spain at the end of the eleventh century.[23]

Three more works were composed after Jai Singh's time. Śrīnātha Chagāṇī wrote the *Yantraprabhā*,[24] which is an abridged version in verse of Jai Singh's *Yantrarājaracanā*. In 1772 Nandarāma composed the *Yantrasāra* in which

with a Sanskrit commentary and Rājasthānī gloss, is in the Anup Sanskrit Library, Bikaner.

[18] See n. 14 above.

[19] See Ohashi, *op. cit.* (n. 15).

[20] *The Yantrarājaracanā of Jayasiṃhadeva*, ed. Kedāranātha Jyotirvid, Jaipur 1953, to which is appended, on pp. 17-19, the *Yantraprabhā* of Srīnātha.

[21] *Yantraprakāra of Sawai Jai Singh*, ed. & tr. S. R. Sarma. Supplement to *Studies in History of Medicine and Science*, 10-11 (1986-87), pp. 20-21, 61-63.

[22] *Yantrarājavicāraviṃśādhyāyī of Nayanasukhopādhyāya*, ed. Vibhuti Bhushan Bhattacharya, Varanasi 1979. The grounds for the attribution of this translation to Nayanasukha are quite doubtful. At the end of the Ms. on which this edition is based, there is an addendum by a later hand: *iti Nayanasukhopādhyāyakṛta-Yantrarājavicāraviṃśādhyāyī Arabītaḥ Samskṛte nītā* (see the facsimile reproduction). No other Ms. has this colophon, nor was the work translated from the Arabic (the original is in Persian).

[23] I have seen Ms. no. 5483 of the Khas Mohor Collection of the Maharaja Sawai Mansingh II Museum, Jaipur. An identical text is inserted into the Spaṣṭādhikāra in: *Siddhāntsamrāṭ Jagannāthasamrāḍ-viracitaḥ*, ed. Muralidhara Caturveda, Sagar 1976, pp. 96-105.

[24] See n. 20 above.

the astrolabe was discussed along with a number of other instuments.[25] Finally, Mathurānātha Śukla wrote his *Yantrarājaghaṭanā* in 1782.[26]

Manufacture of the "Hindu astrolabes", i.e. astrolabes with markings in Devānāgarī script and with the time scale divided into *ghaṭīs* instead of hours received encouragement through Jai Singh's astronomical activities, but earlier specimens are also known.

1.4 In spite of its popularity among the Muslim scholars and in spite of its enthusiastic adoption by Hindu and Jaina astronomers, none of the nativity paintings depict the astrolabe. In the other group, an astrolabe can be seen in two miniatures only. In the "Noah's Ark" (Plate 11), the ship's pilot is seated on the poop deck on the left-hand side of the picture and is taking the altitude by means of an astrolabe. In front of him, there is an open book on a stand, presumably a book of astronomical tables. Again, in a miniature depicting a venerable astronomer in idyllic surroundings (Plate 9), a small astrolabe can be seen on the mat in front of him. But in both cases, the astrolabe is poorly drawn; it is just the outline without any details.

A. J. Turner thinks that "astrolabes were far from being widely spread in Mughal society, and perhaps remained exclusive preserve of a court coterie."[27] In view of the large number of Sanskrit works written on this instrument, it is not possible to agree with Turner. Yet it is difficult to explain the Mughal painter's reluctance to draw this instrument, except to say that perhaps the ring dial was more widely used.

2. Water Clock (Ghaṭikāyantra)

2.1 Before taking up the ring dial which our miniature painters prefer to the astrolabe, it will be convenient to deal with two types of time-measuring instruments in these miniatures. In two nativity paintings (Pls. 1, 5), the astrologers use the sand clock for determining the birth time. In two others (Pls. 2, 3), there are finely drawn water clocks of the sinking bowl variety.[28] While the sand clock in the Mughal miniatures has been noticed and commented upon, the water clock escaped the attention of art historians until now.

This type of water clock consists of a hemispherical bowl, with a fine aperture at

[25] I have used Ms. 504 of 1892/95 from BORI.

[26] Cf. Ohashi, *op. cit.* (n. 15).

[27] Turner, I.1, p. 26.

[28] On water clocks in general, see Turner, I.3.

the exact centre of its bottom. When this bowl is placed on the surface of the water in a larger vessel or basin, water enters the bowl through the hole, fills the bowl gradually and causes it to sink to the bottom of the basin. The hole is so made that the bowl fills up and sinks in a specific interval of time, usually 24 minutes, called *ghaṭī* or *ghaṭikā* in Sanskrit.

In Plate 2, which depicts Akbar's birth, two astrologers are seated in front of the emperor and are explaining to him the infant's horoscope, which is presumably written on the sheet(s) of paper lying on the carpet between the two. A ring dial is also on the carpet, to the right of the horoscope. A step below, just in front of the horoscope, one can see the water clock; the floating bowl and the larger vessel are carefully executed.

The subject of Plate 3 is the birth of Salīm, the future Jahāngīr. Four astrologers are seated on a carpet outside the entrance to the harem. In front of the carpet can be seen the water clock, with a highly ornamental basin. Both the bowl and the basin appear to be gilded or golden, which is but appropriate in the instrument for measuring the birth time of the heir to the Mughal throne.[29]

2.2 I have discussed elsewhere[30] the history of this type of water clock, spanning some 1600 years from the fourth century to the nineteenth. Known as *Ghaṭikāyantra* or *Ghaṭīyantra*, it was described by almost all astronomers since Āryabhaṭa. In the seventh century, it wholly replaced an older type, viz. the cylindrical outflow clock called *Nāḍikāyantra*. In royal palaces, Buddhist monasteries and other public places, time was regularly measured by means of the *Ghaṭikāyantra* and broadcast at certain intervals by beating drums and blowing conch-shells. Public and private endowments were made for the maintenance of this institution. The same situation prevailed in north-western India in al-Berūnī's time.

Subsequently, but before the fourteenth century, the drum and conch-shell were replaced by the gong to announce the passage of time intervals. Fīrūz Shāh Tughluq was so impressed by this method of measuring and announcing time that he set up a water clock and gong (*ṭās-i ghariāl*) on the entrance gate of his palace. He also got this device depicted on some of his gold coins, which he used as gifts to persons of high rank.[31] Fīrūz's enthusiasm implies that no such instrument was known to the Islamic world.

[29] Writing in 1615, Viśrāma in fact recommends that the whole apparatus be gilded (*hemāṃbuliptaṃ sakalaṃ vidheyam, Yantraśiromaṇi* 2.3, cf. n. 14).

[30] "Water Clocks and Time Measurement in India," to appear in *Aligarh Journal of Oriental Studies* 6 (1989).

[31] Syed Athar Abbas Rizvi, *op. cit*,. pp. 108-109.

This conclusion is reinforced by Bābur's (reign 1526-30) detailed description of this device in his memoirs. He readily adopted the instrument and also the Indian division of time into *praharas, ghaṭīs* and *palas*, and introduced an innovation in the method of striking the "hours".[32] Thus the *Ghaṭikāyantra* was in regular use at the Mughal court, and not just on special occasions. The two miniatures just mentioned are unique in that they contain the only pictorial representation of this water clock.

3. Sand Clock (Kācayantra)

3.1 In other paintings, time is measured with a sand clock instead of the water clock. The appearance of the sand clock in several Mughal miniatures from the end of the sixteenth century led historians to conclude that it was imported from Europe during Akbar's reign.[33]

However, the sand clock was known in India much before these miniatures were painted. It was described for the first time in 1428 by Rāmacandra Vājapeyin in his *Yantraprakāśa*. He calls it *Kācayantra*, "glass instrument", and explains that it measures one *ghaṭī*. I give below his description of the *Kācayantra*, along with his own commentary on it:

kācasya pātryau vadane yute sṛjet
ūrdhvām bhṛtāṃ vālukayāvadhārayet /
ghaṭyāṃ tu tatpātata eva vālukā-
dharordhvagā śvetatarā punas tathā //

ghaṭyāṃ vālukāmokṣayogyāsya-samapramāṇa-kācapātryor ekāṃ vālukāpūrṇāṃ kṛtvā tayor mukhaṃ yutaṃ baddhvā bhṛtopari dhāryā / ghaṭyāṃ sikatāpāte upariṣṭhā śvetādhaḥsthā kṛṣṇā / punar vinimayatvāt sthāpane ghaṭyante tathā /[34]

"Make two glass ampoules (*pātrī*) joined mouth to mouth. The upper one should be filled with sand. Owing to its trickling down, after one *ghaṭī* [all] the sand will be below, and the upper [ampoule becomes] white. [Do] the same again."

[32] *Bābur-Nāma (Memoirs of Bābur)*, tr. Annette Susannah Beveridge, reprint: Delhi 1979, I, pp. 516-517. Strangely enough, Abū 'l-Fazl's description of the water clock is rather inaccurate and this is further aggravated by Jarrett's translation and Sarkar's annotation (*Ā'īn-i Akbarī*, III, pp. 17.18, n. 15a). Abū 'l-Fazl says that the bowl measures "twelve fingers in height and breadth." If a hemispherical bowl measures 12 fingers in breadth (i.e. the diameter at the mouth), its height will be 6 fingers only. These measurements are given in almost every Sanskrit source, see my paper mentioned in n. 30.

[33] S. P. Verma, *Art and Material Culture* ..., p. 112; Qaisar, pp. 36-37.

[34] BORI 975 of 1886/92, f. 70r; ASB G-1363, f. 90v. Orthography silently emended.

"Of two glass ampoules of equal size, having mouths capable of discharging [a certain amount of] sand in one *ghaṭī*, fill one with sand, join the mouths and tie the juncture securely, and then set up [the apparatus] so that the full ampoule is above. When [all] the sand trickles down [into the lower ampoule] within one *ghaṭī*, the upper [ampoule becomes] white (i.e. empty and transparent) and the lower one dark (as it is full of sand). Then exchange their places (i.e. put the clock upside down); after the lapse of one *ghaṭī*, the same [thing happens once again]."

This is an unambiguous description of the sand clock. It may be noted that Rāmacandra's clock measures the Indian time unit of *ghaṭī*, while the European sand clocks were made to measure the hour, its multiples or fractions. If the sand clock was transmitted from Europe to India, where it was adapted to the Indian system of reckoning time in *ghaṭī*s, such a transmission ought to have taken place quite some time before 1428, at the latest by 1400. Even today adapting an imported technology to suit local conditions requires a long time.

3.2 In Europe itself the first indisputable mention of the sand clock occurs in the English naval records of 1345/46 and its pictorial representation, in a fresco at Sienna in Italy, pertains to about the same period. Of course, in the fifteenth century, the sand clock became a common object of daily life. It was employed in measuring the length of the lesson at school and university, and more particularly, the length of the sermon at church. Also, in painting and sculpture, it became the symbol of Father Time.[35]

Now, if Europe had been the source of the sand clock which was described by Rāmacandra in 1428, the only possible means of its transmission, say between 1350 and 1400, should be through the Islamic world, but there is no trace of such mediation having taken place. The Islamic world itself did not know the sand clock until the late sixteenth century when it was imported from Europe: in the well-known painting of Taqī ad-Dīn's observatory (1577/78) at Instanbul, one can see two sand clocks of different sizes.[36]

Therefore, Rāmacandra's description of the sand clock is based neither on a European source, nor on an Islamic prototype. Furthermore, Jñānarāja in his *Siddhāntasundara* describes both the sinking bowl type of water clock (*ghaṭī*) and the sand clock (*kācayantra*) in two halves of a single verse as though the two

[35] Lynn White, *Medieval Technology and Social Change*, Oxford 1962, pp. 103, 165-66; idem, *Medieval Religion and Technology*, Berkeley 1978, pp. 193, 220, fig. 5; Turner, I.3, pp. 75-84; R. T. Balmer, "The Operation of Sand Clocks and Their Medieval Development," *Technology and Culture*, 19 (1978), pp. 615-32.

[36] Reproduced often, e.g. in Syed Hossein Nasr, *Islamic Science, An Illustrated Study*, London 1976, Pl. 65, p. 113; Turner, I.1, p. 25.

instruments were equally popular at his time.[37] His book is dated 1503, i.e. almost a century before the European travellers could have brought sand clocks to India as gifts or as articles of sale. Hence, we must conclude, at least tentatively, that the sand clock developed independently both in India and in Europe.

3.3 This is not to suggest that all the sand clocks depicted in the Mughal miniatures are of Indian origin. At the end of the sixteenth century, Europeans brought to India sand clocks that measured the hour or its fractions,[38] and these were accepted at the Mughal court. Although the Mughals had adopted the traditional Indian division of time into *praharas, ghaṭīs* and *palas* they did not give up the hours and minutes which prevailed in the Islamic world. Probably they reckoned time in *ghaṭīs* and *palas* for the daily routine as the local people did, but used hours and minutes for scientific or scholarly purposes. The astrolabes made at Lahore had the time scale divided in hours. It may also be recalled that Abū 'l-Fazl recorded the time of Akbar's birth in hours and minutes wheras Maheśa Ṭhakkura converts them into *ghaṭīs* and *palas* in his Sanskrit rendering of the *Akbarnāma*.

Therefore, the Mughal court may have used the European sand clocks side by side with the indigenous ones to measure hours with the one and *ghaṭīs* with the other. *Ghaṭīs* are mentioned in the *Ā'īn-i Akbarī* quite often, e.g. in connection with the game of polo, it is stated that after each *ghaṭī*, two players retired and their place was taken by two other fresh players.[39] These *ghaṭīs* may have been measured by the water clock or with the indigenous sand clock.[40]

In 1668-72, John Marshall noticed such indigenous sand clocks. He says that "In

[37] *Siddhāntasundara* 17.30:
ghaṭadalaghaṭitā ghaṭī niruktā talasuṣirā palaṣaṣṭhitaḥ kapūrṇā /
murajasamam athācchakācayantraṃ talasuṣiraṃ kṣaradalaśarkarāḍhyam //
"The *Ghaṭī[-yantra]* is defined as the one which is made of a hemispherical bowl with a hole at the bottom and which fills with water (*ka*) in 60 *palas* (= 1 *ghaṭī*). Next, the transparent *Kācayantra* is shaped like the *muraja*-drum with a hole at the bottom (i.e. mouth of the ampoule) and is filled with sand which trickles down." The text is from India Office Library Ms. no. 2002. A transcript was kindly sent by Mr Yukio Ohashi (Tokyo).

[38] Qaisar, pp. 36-37. 76-77.

[39] *Ā'īn-i Akbarī*, I, p. 309.

[40] The advantage of the sand clock is that it is easily portable, say to the polo field. But it cannot be graduated to read fractions of its duration. Instead, one has to use a set of two, four, six, or eight sand clocks of different durations, but such variants do not seem to have been in vogue in India. The water clock, on the other hand, is a bit cumbersome to carry, but it is possible to graduate the bowl empirically.

some places, as at Patna, they have glasses with sand in them, made like our houre-glasses in England, which are exact gurry (*ghaṭī*)."[41] Here Marshall is making a clear distinction between the English sand clock that measured the hour and the Indian device that measured the *ghaṭī*.

But it is difficult to say whether the Mughal court began using the sand clock only after the advent of the Europeans or even before that. In any case, the European sand clocks seem to have become quite popular. The Persian word for the sand clock *shīsh-i sāat*, literally "hour glass", shows that the designation was clearly inspired by the European specimens. It is under this name that the device was described for the first time in a dictionary by Faizī Sarhindī in 1598.[42]

3.4 Coming to the depiction of the sand clock in the Mughal miniatures, it occurs in six paintings (Pls. 1, 5, 6, 8, 9 and 10) but its iconography varies from painting to painting. The European sand clocks are invariably housed in a protectice and supporting frame made of metal or wood. Moreover, until the beginning of the eighteenth century, i.e. during the period with which we are concerned here, sand clocks were manufactured in Europe in the following manner. The two ampoules were blown separately, then a perforated diaphram of brass was inserted between the mouths of the two ampoules and the joint was "secured by pitch, wax or putty bound over with canvas or another fabric and lashed tight with crisscrossed thread or gilt wire."[43] Thus in the iconography of the European sand clock, there are three main elements: the frame, the triangular ampoules, and the bulging joint crisscrossed by lines.

Since we do not know how the Indian sand clock was manufactured except what Rāmacandra informs us, it is not certain if the absence of any of these three iconographic elements should point to an indigenous make. In our miniatures, there are cases where one or two elements are missing. Thus in two miniatures (Pls. 5, 10), the clock consists of just two ampoules without a frame.[44] In Plate 1, there is a frame, but the whole picture is highly stylised, the sand clock in a frame being represented by just a rectangle with its two diagonals. In Plate 9, the sand clock is faintly visible — to the proper left of the astronomer, at the back wall of the hut, upon a small table and serving as a stand for an open book — but there is no doubt

[41] As cited in Qaisar, p. 76.

[42] Irfan Habib, "Cartography in Mughal India," *Medieval India, A Miscellany*, 4 (1977), pp. 122-134, esp. 132.

[43] Turner, I.3, pp. 75-76.

[44] This may not prove anything. Of the sand clocks drawn in the painting of Taqī ad-Dīn's Istanbul observatory, the larger one is with a frame but the smaller one is without.

that the frame is of European make.

In Plate 6, the highly embellished sand clock has an allegorical role. Jahāngīr is seated on a giant sand clock and is naturally conscious of the "falling sands of time". That is why he prefers the company of the Sūfī saint to that of the kings, as the caption of the painting declares. The gilt frame and the middle crisscrossed by gold thread suggests that the picture was drawn after an ornate European sand clock that was received in gift by the emperor.[45]

Finally, the portrait of the astrologer with all his paraphernalia (Pl. 8) has a finely drawn sand clock, but it has two remarkable features. In this monochrome marginal painting, only sand was given a different colour — sky blue. This may have been inspired by the European specimens, for the filling was rarely real sand in Europe. One experimented with various substances and these may have also been coloured. The second feature is that the two ampoules appear to have been blown as one single piece, because one can see the continuous stream of the falling sand. But this technique of manufacturing sand clocks commenced in Europe only from 1760-1770,[46] whereas our picture was painted in Jahāngīr's atelier between 1605 and 1627. Does this mean that this new technique was available in India a century earlier than in Europe, or is this a case of artistic licence? Until actual specimens can be examined, it is safe not to draw too many conclusions from a single painting.

To conclude this account of the sand clock: though it was known in India since 1428, its pictorial representation in the Mughal miniatures appears to have been largely influenced by the specimens imported from Europe.

4. Celestial Globe (Bhagolayantra)

4.1 A globe is depicted in two miniatures. In Plate 9, the astronomer in his country idyll is surrounded by various astronomical instruments, including a globe on his proper right. In Plate 7, there are two soaring angels, one holding a globe and the other a ring dial (on the interpretation of this picture, see § 5.2 below). In both paintings, the globe is a solid spherical mass, without any markings or supporting stand, but there is no doubt that it is supposed to represent the celestial globe, known to the Islamic world as *al-Kura* or *al-Kursī*.[47]

[45] Stuart Cary Welch, *Imperial Mughal Painting*, London 1978, p. 82: "Like the hour-glass throne, which may have been based on a small gilt-bronze and glass original, the idea of allegorical state portraits came from Europe, as did the cupids ..."

[46] Turner, I.3, pp. 75-76.

[47] King, *op. cit.*, p. 4 (cf. n. 7 above).

4.2 Described originally by Ptolemy in his *Almagest* (Book VIII, Chapter 3) for plotting and marking the star positions, it was adopted and improved upon both in medieval Europe and in the Islamic world. European portraits of the astronomer show him usually with a pair of compasses plotting the star positions on the celestial globe, e.g. in Jost Amman's illustration to Hans Sachs' doggerel on the "Astronomus".[48] During the Renaissance, automatically rotating celestial globes with clockwork mechanism were made in great numbers.[49] In the Islamic world also various treatises were written on this instrument and innovations were made in its construction.[50]

4.3 Of all the instruments under discussion here, the celestial globe is the one instrument that was introduced into India by Mughals, more specifically by Humāyūn whose expertise in its use was already mentioned above. Under his patronage, the Lahore family of astrolabists produced some celestial globes also, and the extant specimens were surveyed by Suleiman Nadvi in 1935.[51] These were made of bronze, and the star positions were marked by inlaid silver points.

As compared to the astrolabe, it had a limited reception among the Hindu astronomers. The only mention that I know of is by Nṛsiṃha who gives a fairly long description in his commentary (written in 1621) on Bhāskara's *Siddhānta-śiromaṇi*.[52] Likewise, there do not seem to be many "Hindu" globes, i.e. with the markings in Devanāgarī script. Sawai Jai Singh got one made which is now deposited in the storerooms of his Jaipur observatory. Another was once in the personal collection of David Eugene Smith and was supposed to have been made ca. 1600.[53]

[48] *Jost Ammans Stände und Handwerker mit Versen von Hans Sachs*, Frankfurt a.M. 1568, reproduced in: Ludolf von Mackensen, *Die erste Sternwarte Europas mit ihren Instrumenten und Uhren; 400 Jahre Jost Bürgi in Kassel*, München ²1982, p. 21.

[49] *Ibid.*, passim.

[50] R. Lorch, "al-Khāzin's Sphere that Rotates by itself," *Journal for the History of Arabic Science*, 4 (1980), pp. 287-329.

[51] "Some Indian Astrolabe-Makers," *Islamic Culture"*, 9 (1935), pp. 621-631.

[52] *Siddhānta-Śiromaṇi of Bhāskarācārya* with his autocommentary *Vāsanābhāṣya* and *Vārttika* of Nṛsiṃha Daivajña, ed. Murali Dhar Chaturvedi, Varanasi 1981, p. 438.

[53] For a picture, see his *History of Mathematics*, II, Boston 1925, p. 365. After writing the above, I had occasion to consult Emilie Savage-Smith, *Islamicate Celestial Globes, Their History, Construction, and Use*, Washington, D.C., 1985, where this globe is described (pp. 226-227) and reproduced (Fig. 15, p. 40). It is not a "Hindu" globe but one crafted by the prolific Ziauddin Muhammad in 1657/58.

5. Ring Dial (Cūḍāyantra)

5.1 Now we come to the observational instrument so consistently depicted in most of our miniatures. In six of the seven known paintings of the nativity (Pls. 1-5),[54] the ring dial is clearly drawn. In Plate 3, the thickness of the ring and the inner concave surface can be clearly seen.

In the other group of miniatures, there is a portrait of the astrologer with all his equipment arrayed around him (Pl. 8). With his left hand, he is holding aloft a ring dial, the markings on which are clearly visible. This painting belongs to a series of portraits of different professions with their tools of trade accurately drawn. It is significant that this professional portrait of the astrologer, like the nativity paintings, should depict him holding the ring dial in a characteristic posture, and not with the astrolabe as was done elsewhere in the Islamic world. In Mughal India then, at least in popular conception, the ring dial was the emblem par excellence of the astrologer/astronomer.

5.2 In a miniature painted for Shāh Jahān (1628-1658), the simple ring dial is elevated to become the symbol of Time itself. Shāh Jahān commissioned a series of portraits of his forefathers, which contain highly interesting assemblage of marginal pictures. On the top margin of each portrait, there is a pair of angels holding various objects. In the portrait of Humāyūn, with which we are concerned here, he is shown seated in a landscape.[55] On the top margin, two angels are holding a crown over his head, suggesting his universal sovereignty. In addition to the crown, one angel is holding a globe and the other a ring dial, perhaps as symbols of cosmic Space and Time (Pl. 7).

The motif of soaring angels holding a crown above the head of a personage is no doubt borrowed from the European paintings of the Madonna which were popular at the Mughal court.[56] But the ring dial did not belong to the European motif, it was added by the Indian artist. Thus in the conception of the Mughal artist — for at least three generations from Akbar to Shāh Jahān — the ring dial was inseparable from the astronomer.

5.3 It may have been so in real life as well, because it is a handy tool, though not very accurate, for measuring the sun's altitude. A small hole in the breadth of

[54] On the other two miniatures, see n. 3 above.

[55] Cf. Constance A. Bond, "A Priceless Collection Rediscovered," *SPAN*, 30.2 (May 1989), pp. 2-5 and the cover page.

[56] Cf. Qaisar, pp. 88-94-

the ring allows the sunlight to pass through and fall upon the inner concave surface on the opposite side, which is graduated in degrees to measure the altitude. Local time can also be measured directly if the inner surface is provided with separate scales for each month, and each scale is divided into so many *ghaṭīs* as there are in a half day (from the sunrise to the noon) in that month.

5.4 But what are the antecedents? Because of its frequent occurrence in paintings depicting the Mughal court, one is apt to think that it may have been of Islamic origin. But according to competent authorities on Islamic astronomical instruments whom I consulted, the ring dial was not known to the Islamic world.[57] On the other hand, the Sanskrit astronomical texts show that it has almost as long a history in India as the *Ghaṭīkāyantra*.

It was first described by Āryabhaṭa around the beginning of the sixth century in his *Āryabhaṭasiddhānta*. He calls it *Cakrayantra* and prescribes two holes in the breadth at diametrically opposite points.[58] The instrument is described by Varāhamihira also, in the middle of the sixth century, in his *Pañcasiddhāntikā*. He does not give it a name, but provides only a single hole and intends it to be used for measuring the sun's meridian zenith distance:[59]

> Take a circular hoop, on whose circumference the 360 degrees are marked, whose diameter is equal to one hasta, and which is half an aṅguli broad. In the middle of the breadth of that hoop make a hole. Through this small hole made in the circumference allow a ray of the sun at noon to enter in an oblique direction. The degrees, intervening at the lower half of the circle between (the spot illumined by the ray and) the spot reached by a string hanging perpendicularly from the centre of the circle, represent the degrees of the zenith-distance of the midday sun.[60]

Of course, a string cannot be suspended from the "centre" of a ring, but a string let down from the topmost point of the ring will pass through the notional centre and represent the vertical.

5.5 In the *Yantraprakāśa*,[61] Rāmacandra describes three varieties of this instrument, viz. *Valaya* (literally "ciruclar hoop"), *Cūḍā* (bracelet[62]) and *Mudrikā* (finger- or signet-ring). All the three work on the same principle, but differ in size as their names suggest. Rāmacandra prescribes that the *Valaya-yantra* should measure a cubit in its diameter, the *Cūḍāyantra* a span or less, and the *Mudrkāyantra* much smaller. The inner concave surface is gradutated in *ghaṭīs* for measuring time and the rim in 360 degrees for measuring altitudes.

5.6 Of the three sizes, the middle one, viz. *Cūḍāyantra*, seems to have been more popular, as the ring dials in our miniatures correspond to this size. We have also now evidence that Sawai Jai Singh, otherwise known for his gigantic astronomical instruments in masonry, used the *Cūḍāyantra* quite extensively. Before designing the masonry instruments that adorn his observatories now, he got compiled a Sanskrit manual on instruments from diverse sources, both Indian and Islamic. This text entitled *Yantraprakāra* contains not only a detailed description of the *Cūḍāyantra*, but also an elaborate set of tables to be used in conjunction with this instrument (*Cūḍāyantrasya Sāraṇī*). There are 19 separate tables, one for each decan of the zodiac, and prepared for the latitude of Delhi (28; 39°).[63]

5.7 Through a happy coincidence, Dr A. G. Kulkarni, while preparing an inventory of portable instruments and small scale models deposited in the storerooms of Jai Singh's observatory at Jaipur, located two actual specimens (one larger and the other smaller, Pl. 12) of the *Cūḍāyantra*, which appear to have been manufactured for Jai Singh himself.[64]

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[57] Professors E. S. Kennedy (Princeton) and David A. King (Frankfurt).

[58] The *Āryabhaṭasiddhānta* is no longer extant, but its chapter on instruments survives in quotations, notably in Rāmakṛṣṇa Ārādhya's commentary (1327) on the *Sūryasiddhānta*. K. S. Shukla gathered the stanzas of this chapter and interpreted in: "Āryabhaṭa I's Astronomy with Midnight Day-reckoning," *Gaṇita* 18 (1967), pp. 83-105.
Āryabhaṭa describes the *Cakrayantra* thus (*ibid.*, p. 93):

> *bhagaṇāṃśāṅkitaṃ cakraṃ sarandhraṃ viṣuvaty atha* // 10//
> *dhanū ravyunmukhaṃ kṛtvā cāpavac cakrayantrakam* /
> *kalpayel lambaśaṅkor vā chāyānāḍyaś ca yaṣṭivat* // 11//

[59] *Pañcasiddhāntikā* 14.21-22:

> *samabhagaṇāṅkakacakram ardhāṅgulabahalam āyataṃ hastam* /
> *vistāramadhyabhāge chidraṃ tadgāmi tiryak ca* //
> *madhyāhnārkamayūkhaṃ praveśya sūkṣmeṇa paridhivivareṇa* /
> *madhyāvalambisūtrāt talāntarāṃśās tad anyākṣaḥ* //

[60] Translation by Thibaut and Dvivedi, cf. *The Pañcasiddhāntikā of Varāhamihira*, ed. tr. G. Thibaut and Sudhākara Dvivedī, Varanasi ²1968, p. 80.

[61] BORI Ms., ff. 61-62.

[62] *Cūḍā* in the sense of a bracelet is attested from the 10th century onwards. Thus Dhanapāla's *Pāiālacchīnāmamālā* (972/3 A.D.) 272b: *cūḍao valayabāhū*; *Medinīkośa* (13th c.), p. 41, v. 13ab: *cūḍā valabhau śikhāyāṃ bāhubhūṣaṇe* /

[63] *Yantraprakāra of Sawai Jai Singh* (cf. n. 21), pp. 27-28, 79-82, 101, 105-114.

[64] The following description of the instruments is based on the notes kindly sent by Dr A. G. Kulkarni.

The smaller *Cūḍāyantra* has a diameter of 10.1cm and a height of 4.9cm. The circumference is graduated in 360 degrees. The inner concave surface is divided into 12 circumparallel columns, on which presumably the *ghaṭīs* in each solar month can be read. There are three apertures, through which the sun's rays fall upon the inner surface on the opposite side.

The larger instrument (Pl. 13) measures 12.9cm in diameter and is 8.8cm high. It has a name plate on which is engraved *cūḍāyantra dinajñāna ko*, "*Cūḍāyantra* for determining the time of the day". There are nine apertures in the breadth, and corresponding to these are nine circumparallel columns upon the inner concave surface on the side opposite the holes. The columns are graduated in *ghaṭīs*. Thus there is one aperture and a corresponding column of *ghaṭīs* for each 20 days. These columns are used successively for the first six months of the year, starting from the time when the sun enters the sign of Cancer; then in the reverse order for the second half of the year. The columns show the *ghaṭīs* in a half-day, i.e. from sunrise to midday or from midday to sunset. In the first column the numbers are from 1 to 17, which means that the duration of the day is 34 *ghaṭīs*, or 13 hrs. 36m. This is the duration of the longest day when the sun is at the first point of Cancer. The ninth and last column has numbers 1 to 13, implying that the shortest day, when then sun is at the first point of Capricorn, comprises of 26 *ghaṭīs* or 10 hrs. 24m. These two *Cūḍāyantra* were mostly likely made for the latitude of Jaipur.

Thus a continuous tradition in Sanskrit astronomical texts, a series of Mughal miniatures and two actual specimens combine to provide us with a full picture of this *Cūḍāyantra*, which was hitherto entirely unknown.

5.8 In Europe, there is a similar instrument called ring dial or poke (short for "pocket"!) dial, or Bauernring in German. It is said to have been invented by Georg Peuerbach (1423-1461) and improved upon by his pupil Regiomontan (1436-1476). The latter also wrote a description of its construction and prepared tables of solar altitudes to be used with this instrument. The Bauernring was very popular until the last century, especially in Austria, but it is small in size like the signet ring.[65] Since the ring dial was not known to the Islamic world, there does not seem to be any connection between the European ring dial and the Indian *Cūḍāyantra*. Thus, in this case also, we are led to conclude that the ring dial and the *Cūḍāyantra* may have developed independently in Europe and India.

[65] Ernst Zimmer, *Deutsche und Niederländische Astronomische Instrumente des 11. bis 18. Jahrhunderts*, München 1979, pp. 120-122, Pl. 45.2; Charles Singer et al, *A History of Technology*, III, Oxford 1957, p. 598, fig. 351.

6. Professional Portraits of the Astrologer/Astronomer

6.1 Having thus identified the instruments depicted in the Mughal miniatures and traced their antecedents, we can now approach some paintings where the astrologer/astronomer is portrayed along with his professional equipment. Plate 8 shows an astrologer in a landscape of flowering plants, and is from the broad ornate border (*hāshiya*) of Jahāngīr's personal album. The border contains a number of professions including the astrologer. He is holding up a ring dial or *Cūḍāyantra* in his left hand taking the sun's altitude. There is a bottle of ink with apen near his feet. An open book is in front of him, presumably a book of astronomical tables like the one compiled at the instance of Ulugh Beg. Behind these items is a large circular disc, supported on four legs. The disc is divided into 12 segments on which the twelve zodiac figures are painted according to the Islamic fashion. What is the purpose of this zodiac board? It cannot be an instrument for time-measuring, nor for observation, nor for computation or instruction. Its only possible use is to announce that here is an astrologer ready to offer his services; in other words, it is a professional sign-board of the astrologer.[66]

6.2 There is another portait of the astrologer (Pl. 10), this time quite an ironic one, in a miniature from the manuscript copy of the *Akhlāq-i Naṣīrī*. Here the astrologer is surrounded by female clientele from whom he amassed many bags of coins, and thus can afford a thick carpet, a broad sunshade and a servant to fan him.[67] Around him can be seen his tools of trade: a longish box for writing implements, three bags of money, a sand clock, a book stand from which he is lifting up a tome to read from it, a water pitcher, and a circular board suspended from a tripod. Goswami and Fischer identify this object as an astrolabe.[68] Like the astrolabe this disc is also surmounted by a crown (*kursī*) but unlike the former, this one is divided into 12 segments on which the zodiac signs seem to have been painted. Perhaps this too is a sign-board as in the previous painting.

6.3 While the attitude of the Mughal artist in these two paintings varies from the mildly ironic to the strongly sarcastic towards the street astrologer, he shows great reverence to another member of this profession. In Plate 9, there is the portrait of

[66] S. P. Verma, *op. cit.*, p. 113, considers this to be an astrolabe. The only feature common in this object and the astrolabe is that both are circular.

[67] Compare this picture with François Bernier's vivid account of the charlatanry practised by the roadside astrologers in Delhi, in his *Travels in the Mogul Empire A.D. 1656-1668*, tr. Archibald Constable, Westminster 1891, pp. 243-245.

[68] B. N. Goswamy and Eberhard Fischer, *Wunder einer Goldenen Zeit, Malerei am Hof der Moghul-Kaiser: Indische Kunst des 16. und 17. Jahrhunderts aus Schweizer Sammlungen*, Zürich 1987, Pl. 58 and its description.

a venerable old scholar in an idyllic countryside. There is a Persian wheel behind his hut and a lake on front of it with a pair of Saras cranes. He is surrounded by his disciples or mystics. There are also a number of instruments around him: a celestial globe to his proper right, a small astrolabe in front of him,[69] and also an ink bottle; to his left, close to the back wall of the hut is a small table upon which stands a sand clock, supporting an open book.

He is clearly not a professional astrologer or astronomer, but rather a saintly recluse living away from the bustle of life. What then is his connection with this assortment of astronomical instruments? Does the artist imply that these are not just measuring tools but emblems of secret knowledge which reveal cosmic mysteries to the astronomer-philosopher?[70]

The charm of these paintings lies in the variations they offer on the theme of the astrologer/astronomer as they show him soliciting custom on the roadside, or solemnly casting the horoscope of a prince in the royal palace, or, transcending these two mundane locations, as immersed in cosmic meditation.[71]

7. Hindu Astrologers at Akbar's Court

7.1 It will be noticed that the present exercise did not bring to light any Islamic astronomical instrument that may represent an intermediary stage of development between the observatory instruments of Maragha and Samarqand on the one hand and those of Sawai Jai Singh on the other. But then these miniature throw fresh light on three pre-Islamic Indian instruments, viz. *Ghaṭīkāyantra, Kācayantra* and *Cūḍāyantra.* Though archaic in design, these instruments remained in vogue for a long span of time.

7.2 There is another likely gain. Plate 3 allows us an insight into another culturally significant area. This miniature is at the Museum of Fine Arts, Boston, and depicts the birth of Salīm in 1569, who assumed the name Jahāngīr after ascending the throne in 1605. Ananda Coomaraswamy attributes this miniature to

[69] *A la Cour du Grand Moghol,* Paris 1986, Nr. 24, wrongly identifies this as a pendulum.

[70] It is instructive to compare our painting with Hans Holbein's "The Ambassadors" (1533), where the French ambassador to England and his friend are portrayed with a number of contemporary astronomical instruments, which appear to be symbols of wordly wisdom and power.

[71] This composition appealed to a later artist so much that he copied parts of it in order to create the right ambience in his "Shāh Jahān visiting a Religious Teacher". He repeats the Persian wheel, the table with the sand clock and book, and also the cranes in the foreground, but without the lake. Cf. J. V. S. Wilkington, *Mughal Painting*, London 1948, Pl. 9.

Akbar's atelier,[72] while Stuart Cary Welch opines that Jahāngīr commissioned this painting of his own birth by Bishndas.[73]

Be that as it may, the painting shows, among other scenes, four astrologers seated on a carpet just outside the red curtain covering the entrance to the harem. A lady of high birth (note her clothes and head-dress) has just brought the glad tidings of the long-awaited birth of the heir to the Mughal throne, and the astrologers have set out to measure the time of birth with the *Ghaṭīkāyantra*, the sun's altitude with the *Cūḍāyantra* and to cast the horoscope.

The two astrologers on either side in the foreground are Muslims and the two in the middle are Hindus, clearly distinguishable from the clothing and make-up.[74] Starting from the left, the first one in a dark green cloak is measuring the altitude with the *Cūḍāyantra*. The second, dark-complexioned, with gold lace on his turban, is the one whom the lady of the harem is addressing. He is the principal member of the panel of astrologers, which is indicated also by the fact that he is shown somewhat higher than the others. The third one, in white dress with a red shawl thrown over his shoulder, is holding in his left hand a scroll with Devanāgarī letters and with his right hand drawing the birth chart on a greyish board with chalk. The chart is drawn in north Indian Hindu fashion.[75] The fourth astrologer, wearing a dark blue shawl, is holding a paper with Persian lettering.

The dress and features of these four astrologers are so highly individualised that their pictures look like the true-to-life portraits of four prominent astrologers of Akbar's court, and it is tempting to identify them. The seniormost Muslim astrologer at Akbar's court was Maulānā or Mullā Cānd, who drew up the horoscopes of both Akbar and his son Jahāngīr.[76] Abū 'l-Fazl's glowing tribute to him

[72] *Op. cit.*, (cf. n. 3), pp. 16-17.

[73] *Imperial Mughal Painting,* London 1978, pp. 70-71.

[74] Apart from the Śaivite sectarian mark on the forehead, note especially how the jackets (*jāma*) are closed. The upper flap of the jacket of the Muslims runs from left to right and is fastened under the right armpit, while that of the Hindus runs from right to left. The *Akbarnāma* (III, p. 342) reports that, according to Hindu notions, "wearing the *jāma* fastened on the left side" is one of the twelve things that adorn a man. Akbar ordered that the *jāma* be tied on the right side only (*Ā'īn-i Akbarī*, I, p. 94), but this order seems to have been followed only by the Muslims. The contrary ways of closing the jacket by Muslims and Hindus correspond respectively to the modern sartorial norms of European men and women.

[75] On the different modes of drawing the horoscope charts in India, see Hans Georg Türstig, *Jyotiṣa, Das System der indischen Astrologie,* Wiesbaden 1980, pp. 4-5.

[76] On Maulāna Cānd, cf. *Akbarnāma*, I, p. 69; II, p. 506. He also wrote a commentary on the tables of Ulūgh Beg under the title *Tashīlāt-Mullā-Chānd-Akbar-Shāhī. Sarva-*

has been cited at the beginning of this article. In our miniature the elderly person on the right with white beard and blue shawl may well be the likeness of Maulānā Cānd. His colleague on the left can either be Fathullāh Shirāzī[77] or Maulānā Alyās,[78] both of whom are reported to have prepared Akbar's horoscope.

7.3 Regarding the identity of the two Hindu astrologers in the middle, the choice is limited and likely to be more certain. In Abū 'l-Fazl's *Akbarnāma* and in Jahāngīr's memoirs, there is frequent mention of a Jotik Rāi (Sanskrit: *Jyotiṣa-rāja/rāya*). Abū 'l-Fazl states that Maulānā Cānd and Jotik Rāi prepared Akbar's horoscope, each according to his own tradition.[79] Jahāngīr records how Jotik Rāi's forecasts often came true.[80]

However, Jotik Rāi is not the name of an individual but an official title conferred by the Mughal emperor on the foremost Hindu astrologer of the day.[81] Thus the Jotik Rāi of Akbar's time and the one mentioned in Jahāngīr's memoirs must be two different persons. The astrologer who made true forecasts for Jahāngīr and was weighed against silver and gold coin by the grateful monarch was Keśava, son of Kaṃhara Śarman of Kaliñjara. Keśava's son Īśvaradāśa states that his father

deśavṛttāntasaṃgraha, p. 141, describes him as *jyotirvicchreṣṭhaḥ mullācāndaḥ*.

[77] On this highly talented engineer and astronomer, see M. A. Alvi and A. Rahman, *Fathullah Shirazi, A Sixteenth Century Indian Scientist*, New Delhi 1968.

[78] Cf. *Akbarnāma*, I, p. 126.

[79] *Ibid.*, I, pp. 85-86: "The scheme of holy nativity is hereby set down in accordance with the writing of the foremost of Indian atsrologers, the Jotik Rai, who was one of the servants of the royal household." But there was a disagreement between the two traditions: Maulānās Cānd and Alyās put Akbar's birth under Virgo and Jotik Rāi under Leo. Akbar had the horoscope of his three sons, Salīm, Murad and Dānyal, prepared by Hindu and Muslim astrologers (*Ibid.*, I, p. 85, n. 2) and again there was a discrepancy in Salīm's horoscope (*Ibid.*, II, p. 505). Interestingly, Akbar's aunt Gul-Badan Begum, in her memoirs, mentions Leo as the ascendant at the time of Akbar's birth, thus following the Jotik Rāi's horoscope (*The History of Humāyūn*, pp. 157-158).

[80] *The Tūzuk-i-Jahāngīrī or Memoirs of Jahāngīr*, tr. Alexander Rogers, ed. Henry Beveridge, II, (reprinted: Delhi 1978), pp. 160, 203, 213, 235. Jahāngīr records three forecasts of Jotik Rāi that came true and refers to many of his judgements which proved to be correct. Once Jahāngīr weighed him against 6500 silver rupees and another time against 500 gold muhurs and 7000 silver rupees and gave all this money to the astrologer. As we shall see below (n. 82), Jotik Rāi gave away the money to Brahmins.

[81] Akbar seems to have instituted the system of conferring titles with the suffix *-rāya/rāi* to various types of Hindu scholars, and his successors continued the system. Given below are the few cases that I occasionally came across:

received the title Jyotiṣarāya from Jahāngīr.[82]

Two Hindu Jyotiṣīs come into question as the likely recipients of the title from Akbar: Nīlakaṇṭha[83] and Kṛṣṇa Daivajña.[84] They were not only the eminent astrologers of the time; they were also mediators between the Hindu and Muslim traditions of astronomy and astrology.

7.4 Nīlakaṇṭha was a protégé of Akbar's minister Ṭoḍarmal. In 1572 he wrote the *Jyautiṣa-saukhya* and some other sections of the *Ṭoḍarānanda*, an encyclopaedic compendium prepared at the instance of Ṭoḍarmal.[85] In 1587, Nīlakaṇṭha composed the *Tājikanīlakaṇṭhī*, a well known manual on Islamic

Emperor	Title	Recipient
Akbar	Kabi Rai	Mahesh Das *alias* Birbal
	Jotik Rai	(Nīlakaṇṭha ?)
Jahāngīr	Jotik Rai	Keśava, s.o. Kaṃhara Śarman
Shāh Jahān	Vedāṅgarāya	Mālajit, author of *Pārāśīkaprakāśa*
	Paṇḍitarāya	Jagannātha, author of *Rasagaṅgādhara* etc.
	Kabi Rai	Sundar Das, a Hindi poet from Gwalior
Muhammad Shāh	Jyotiṣarāya	Kevelarāma, associate of Sawai Jai Singh
	Paṇḍitarāya	Nayanasukha, associate of Sawai Jai Singh
Bahādur Shāh	Jotik Rai (?)	Sukhanand, court astrologer

[82] In the colophon to his *Muhūrtaratna*, which he completed in 1663, he gives the following information about his father Keśava:

tasmāt keśavaśarmābhūt khyātas triskandhavikramaḥ /
gajāśvarathasaṃgrāmair yo 'rcitas syān nṛpottamaiḥ //
so 'yaṃ jyotiṣarāyākhyaḥ jyahaṅgīrāvanīpateḥ /
svagūḍhapraśnasaṃvādair lebhe praśnavidāṃ varaḥ //
tulāpramukhadāneṣu yas tv asaṃkhyavasūni vai /
viprasāt kṛtavān kāle nārāyaṇaparāyaṇaḥ //

cited in M. M. Patkar, "Muhūrtaratna: A religio-astrological treatise, composed in the Reign of Aurangzeb," *The Poona Orientalist*, 3 (1938-39), pp. 82-85, esp. 85. See also, *CESS*, A-3, pp. 55-56.

[83] *Ibid.*, A-3. pp. 177-189.

[84] *Ibid.*, A-2, pp. 53-55.

[85] Cf. *Ṭoḍarānanda*, I, ed. P. L. Vaidya, Bikaner 1948, pp. 396-404.

astrology.[86] His son Govinda wrote a commentary on it in 1622, which he styled simply *Rasālā* (from Arabic *risālah*, "tract"). Elsewhere Govinda states that his father was an incomparable ornament of Akbar's court.[87] Govinda's son Mādhava, who also wrote a commentary on the grandfather's *Tājikanīlakaṇṭhī*, proudly proclaims that his grandfather Nīlakaṇṭha was honoured by Akbar and that his father Govinda was honoured by Jahāngīr.[88] I would like to imagine that the dark-complexioned astrologer with the Śaivite mark on his forehead and gold lace in his turban in our miniature is a true likeness of this Nīlakaṇṭha and that he held the title and office of Jotik Rāi at Akbar's court.

7.5 The other Jyotiṣī who is drawing the birth chart in the miniature then must

[86] David Pingree, *Jyotiḥśāstra: Astral and Mathematical Literature,* Wiesbaden 1981, pp. 98-99. Abū'l Fazl reports that "At the command of his Majesty, Mukammāl Khān of Gujarāt translated into Persian the Tājak, a well known work on astronomy" (*Ā'īn-i Akbarī,* I, p. 112). *Tājaka/tājika* is not the name of a book on astronomy but refers to a class of Sanskrit works on astrology which are Indian adaptations of Arabic/Persian astrology. The most famous of such works is the *Tājikanīlalaṇṭhī*. Is this the one that Akbar got translated into Persian? But it would indeed be strange to get a contemporary work on Arabic/Persian astrology translated again into Persian. Sir William Jones emends the word *tājak* into *jātak* (cf. Beveridge, *Akbarnāma,* I, p. 91n) and it is more likely that a Persian translation was commissioned of Varāhamihira's *Bṛhajjātaka* or some other popular manual on Indian horoscopy. However, manuscript copies of neither text in Persian rendering are listed in M. Habibullah, "Medieval Indo-Persian Literature relating to Hindu Science and Philosophy, 1000-1800 A.D.," *Indian Historical Quarterly,* 14 (1938), pp. 167-181.

[87] In his commentary called *Pīyūṣadhārā* (1603) on the *Muhūrtacintāmaṇi* (1600) of his paternal uncle Rāma, Govinda says the following about his father Nīlakaṇṭha:

> *sīmā mīmāṃsakānāṃ kṛtasukṛtacayaḥ karkaśas tarkaśāstre jyotiḥśāstre ca gargaḥ phaṇipatibhaṇitivyākṛtau śeṣanāgaḥ /*
> *pṛthivīśākabbarasya sphuradatulasabhāmaṇḍanaṃ paṇḍitendraḥ sākṣāc chrīnīlakaṇṭhaḥ samajani jagatīmaṇḍale nīlakaṇṭhaḥ //*

Cf. *Muhūrtacintāmaṇi* with the commentary *Pīyūṣadhārā* of Govinda, Bombay 1946, pp. 1-2 (verse 8 at the beginning of the commentary).

[88] Thus he says of Nīlakaṇṭha at the beginning of his commentary *Śiśubodhinī*:

> *triskandhaṃ jyotiṣaṃ ca samakṛta viśadaṃ ṭoḍarānandasaṃjñam /*
> *sāhityajñānapūrṇaḥ smṛtiṣu ca nipuṇo 'kabbarakṣmeśamānyaḥ //*

and of his own father Govinda that he was

> *nṛpativarajahāṅgīraśāhātimānyaḥ /*

Cf. *CESS,* A-4, pp. 415-417. Govinda's association with Jahangir's court was mentioned also by his other son Cintāmaṇi in his commentary on Raghunātha's *Muhūrtamālā,* written in 1661 during the reign of Aurangzeb (*rājye 'varaṅgajevasya*), cf. ibid., A-3, pp. 49-50.

be Kṛṣṇa Daivajña, son of Ballāla. His younger brother Raṅganātha states that Kṛṣṇa was honoured by Jahāngīr.[89] Raṅganātha's son Munīśvara also says that Kṛṣṇa was a favourite of Jahāngīr.[90] Kṛṣṇa wrote an excellent commentary on Bhāskara's *Bījagaṇita*.[91] In Akbar's translation bureau, where several representative Sanskrit works were translated into Persian and vice versa, Ulugh Beg's astronomical tables were translated into Sanskrit by the joint efforts of Muslim and Hindu scholars. The Muslims in the group were Fathullāh Shirāzī and Abū'l Fazl and the Hindus included Kṛṣṇa.[92] Kṛṣṇa also wrote a commentary on Śrīpati's *Jātakapaddhati*, a manual on preparing horoscopes.[93] In this commentary, Kṛṣṇa included the horoscope of Khān-i-Khānān Abdul Rahīm Khān, who was an influential courtier of Akbar, at one time tutor of Salīm, and himself

[89] At the conclusion of his commentary called *Gūḍhārthaprakāśa* on the *Sūryasiddhānta* (many editions), he describes his elder brother Kṛṣṇa thus;

> *tataḥ sa kṛṣṇo jahāṃgīrasarvabhaumasya sarvādhigatapratiṣṭhitaḥ /*
> *śrībhāskarīyaṃ vivṛtaṃ tu yena bījaṃ tathā śrīpatipaddhatiś ca //*

This was written in 1603, i.e. two years before Prince Salīm became the *sārvabhauma* and assumed the name Jahāngīr (cf. *Tūzuk-i Jahāngīrī*, I, pp. 2-3). Another case of forecast that came true?

[90] About his uncle Kṛṣṇa, Munīśavara states the following in his commentary on the *Siddhāntaśiromaṇi* of Bhāskarācārya:

> *yaḥ śrīkṛṣṇapadāmbujahitamatiḥ siddhāntavārāṃnidheḥ*
> *potaḥ śrījahagīrabhūmitilakasyānanaviśvāsabhūḥ /*
> *ṣaṭśāstreṣu kṛtaśramo 'khilagurur mānyo vadanyo vidāṃ*
> *śrīkṛṣṇaḥ kim u varṇanīyavibhavaḥ śrīkṛṣṇa evāparaḥ //*

Cf. M. M. Patkar, "Moghul Patronage to Sanskrit Learning," *Poona Orientalist*, 3 (1938-39), pp. 164-175, esp. 169.

[91] *Bījagaṇita* of Bhāskara with the commentary *Navāṅkurā* of Kṛṣṇa Daivajña, ed. V. G. Apte, Poona 1930.

[92] Cf. M. A. Alvi and A. Rahman, *Fathullah Shirazi,* p. 24: "A part of the *Zīji-i Jadīd-i Mīrzāi* (astronomical tables of Ulugh Beg) had been translated under his guidance [i.e Fathullah Shirazi] by Kishan Jotishi, Ganga Dhar, Mahesh Mahanand and Abul Fazl." This information stems from the *Ā'īn-i Akbarī,* but Blochmann's translation (I, p. 110) is hopelessly garbled. The Maharaja Sawai Man Singh II Museum, Jaipur, possesses the unique copy of Ulugh Beg's tables in Sanskrit rendering, entitled *Jīca Ulūgabegī* (Ms. no. 45). I have briefly examined it to see if the rendering stems from Akbar's court. Except on the last page, there is no text but only tables. On the last page, the method of finding out the weekday corresponding to a given date and the like are explained in Rājasthānī, thus suggesting that this version may have been prepared anew for Sawai Jai Singh.

[93] *Jātakapaddhatyudāharaṇa,* ed. Jatindra Bimal Chaudhuri, Calcutta 1955.

a famous man of letters.[94] It is therefore appropriate that Kṛṣṇa should be portrayed in our miniature as drawing the horoscope.

7.6 Even if my identification hits the mark only in parts, there can be no doubt that here we have a unique group portrait of the prominent scientists of Mughal India. Moreover, this assemblage of Hindu and Muslim men of learning in a painting commissioned by the emperor reflects Akbar's policy of encouraging the scientifc activity of both traditions and of promoting their synthesis. This miniature then is a graphic representation of the interaction between the Hindu and Islamic traditions of scientific knowledge.

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Abbreviations used:

Ā'īn-i Akbarī: The Ā'īn-i Akbarī by Abū 'l Fazl 'Allāmī. Vol. I. Tr. H. Blochmann; revised by D. C. Phillot. Reprint: Delhi 1977; Vols. II, III. Tr. H. S. Jarrett, revised and annotated by Jadunath Sarkar. Reprint: Delhi 1978.

Akbarnāma: The Akbar Nama of Abu-l-Fazl (History of the Reign of Akbar including an Account of his Predecessors). Tr. H. Beveridge. 3 vols. Calcutta 1910.

[94] Abdul Rahīm himself wrote a small tract on *Tājika* astrology in Sanskrit under the title *Kheṭakautuka*, in which he sprinkles Arabic/Persian technical terms. There are several editions of this work, cf. *CESS*, A-2, pp. 79-80.

CESS: David Pingree. *Census of the Exact Sciences in Sanskrit*. Series A, vols. 1-4. Philadelphia 1970-1981.

Qaisar: Ahsan Jan Qaisar. *The Indian Response to European Technology and Culture (A.D. 1498-1707)*. Delhi 1982.

Turner: A. J. Turner. *The Time Museum, Catalogue of the Collection*. Vol. I, part 1: Astrolabes, Astrolabe-related Instruments; part 3: Water-clocks, Sand-glasses, Fire-clocks. Rockford 1984-85.

List of Plates

1. "Birth of Murad" by Bhurah and Baswan, ca. 1600, from the *Akbarnāma*. Victoria & Albert Museum, London, IS 2-1896, no. 80/117. Cf. S. P. Verma, *Art and Material Culture in the Paintings of Akbar's Court,* New Delhi 1978, Pl. XIII.

1a. "Astrologers casting the Horoscope", detail from Plate 1.

2. "Astrologers explaining the Horoscope to the King," detail from the "Birth of Akbar," *Akbarnāma,* British Library, Ms. Or. 12988, f. 20b. Cf. Geeti Sen, *Paintings from the Akbar Nama: A Visual Chronicle of Mughal India,* Calcutta 1984, Pl. 57, pp. 130-131.

3. "Astrologers casting the Horoscope," detail from the "Birth of Salīm," Museum of Fine Arts, Boston, 17.3112. Cf. Stuart Cary Welch, *Imperial Mughal Painting,* London 1978, Pl. 16, pp. 70-71.

4. "Astrologers casting the Horoscope," detail from the "Birth of Salīm," Chester Beatty Collection, Dublin. Cf. Herman Goetz, *India: Five Thousand Years of Indian Art,* Bombay 1959, pp. 212-213.

5. "Astrologers casting the Horoscope," detail from the "Birth of Timūr," *Akbarnāma,* British Library, London, Ms. Or. 12988, f. 34b. Cf. A. J. Qaisar, *The Indian Response to European Technology and Culture (A.D. 1498-1707),* Delhi 1982, Pl. 10.

6. "Jahāngīr seated on an Hourglass," by Bichitr, ca. 1625. Freer Gallery of Art, Smithsonian Institution, Washington, 45.15a. Cf. Stuart Cary Welch, *Imperial Mughal Painting,* London 1978, Pl. 22, pp. 82-85.

7. "Angels holding a Crown, Celestial Globe and Ring Dial," detail from a portrait of Humāyūn, Shāh Jahān's Album, ca. 1650. Sackler

Gallery of Art, Smithsonian Institution, Washington. Cf. Constanze A. Bond, "A Priceless Collection Rediscovered," *SPAN,* XXX.2 (May 1989).

8. "The Astrologer" from the border of Jahangīr's Album, Náprstek Museum, Prague. Cf. Lubo Hajek, *The Indian Miniatures of the Mughal School,* London 1960, Pl. 18.

9. "Astronomer with his Disciples," Shāh Jahān's Album, Musée Guimet, Paris, MA 2471. Chliché des Musées Nationaux-Paris.

10. "Bazar Astrologer with his Clients," detail from a manuscript illustration to the *Akhlāq-i Naṣīrī,* ca. 1590-95. Prince Sadruddin Aga Khan Collection, Museum Rietberg, Zürich. Cf. B. N. Goswami und Eberhard Fischer, *Wunder einer Goldenen Zeit. Malerei am Hof der Moghul Kaiser, Indische Kunst des 16. und 17. Jahrhunderts aus Schweizer Sammlungen,* Zürich 1987, Pl. 58.

11. "Noah's Ark," Freer Gallery of Art, Smithsonian Institution, Washington. Cf. Stuart Cary Welch, *Imperial Mughal Painting,* London 1978, Pl. 9.

12. Two *Cūḍāyantras* from Jai Singh's Observatory at Jaipur. Courtesy Directorate of Archaeology and Museums, Government of Rajasthan.

13. The larger *Cūḍāyantra* from Jai Singh's Observatory at Jaipur. Courtesy Directorate of Archaeology and Museums, Government of Rajasthan.

PLATE 1

PLATE 1A

PLATE 2

PLATE 3

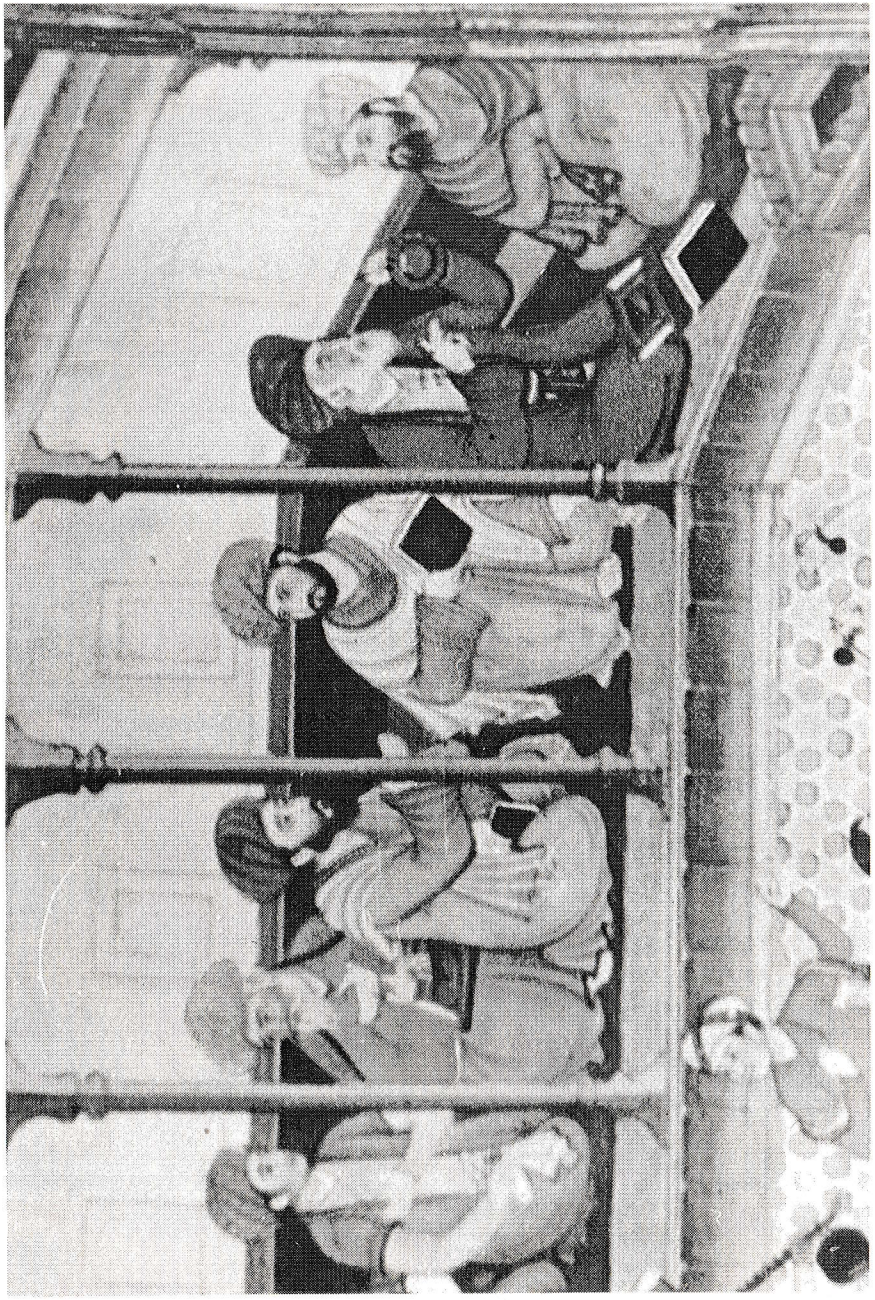

PLATE 4

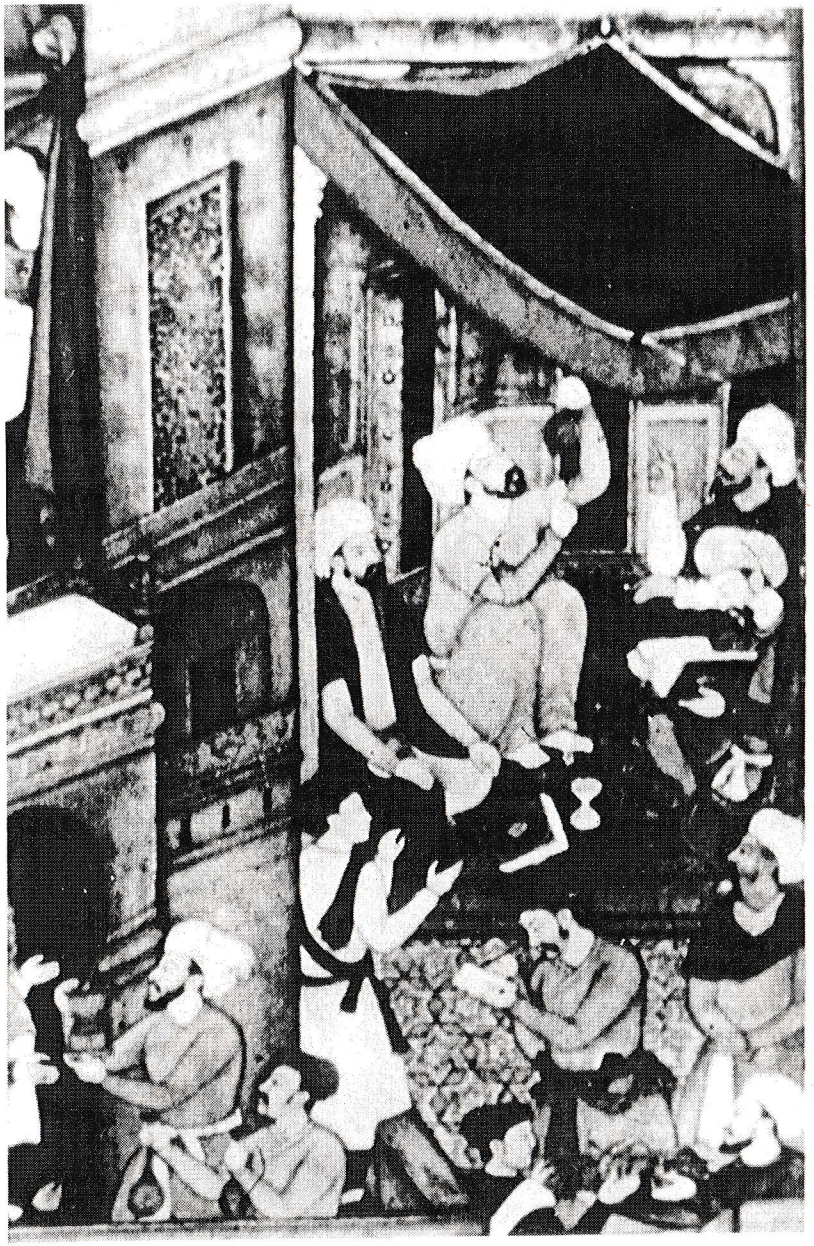

PLATE 5

PLATE 6

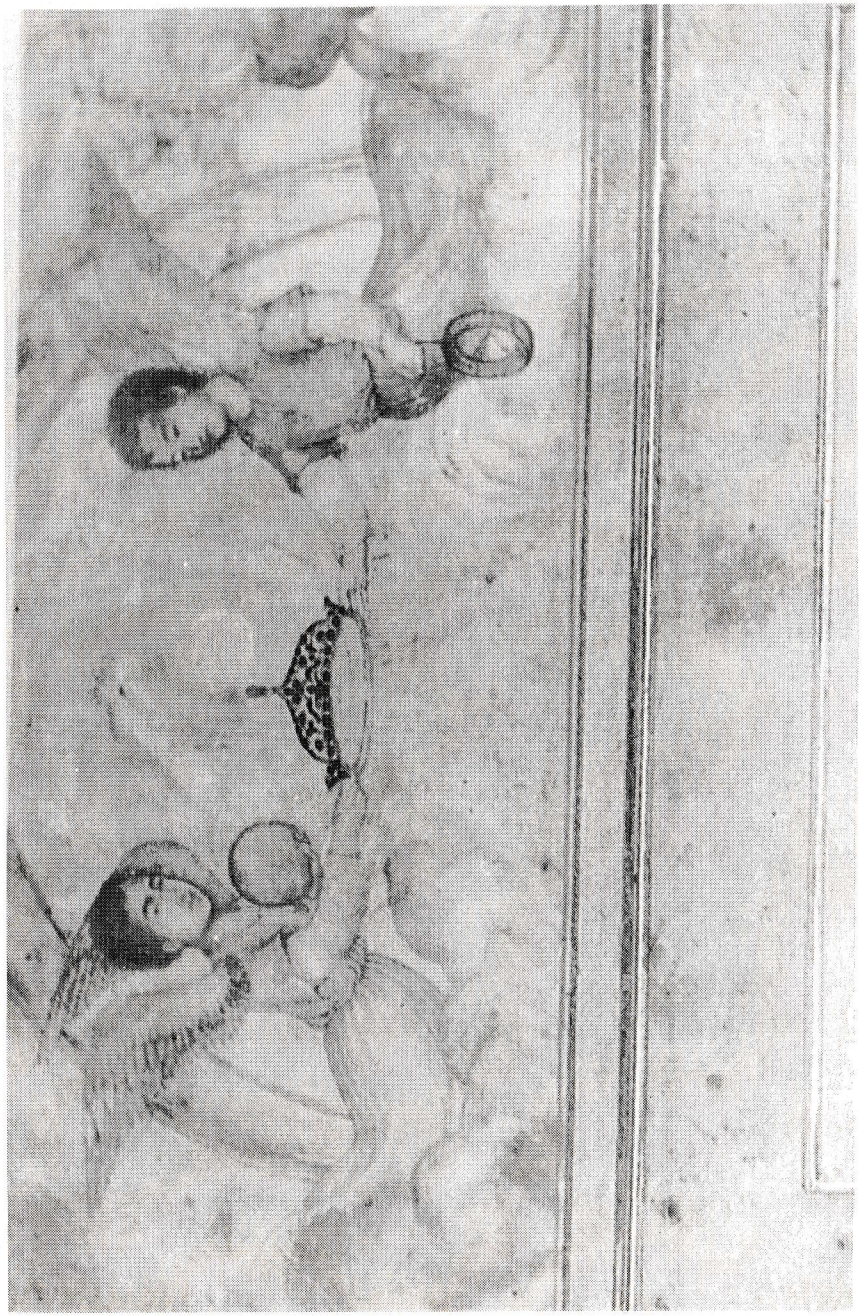

PLATE 7

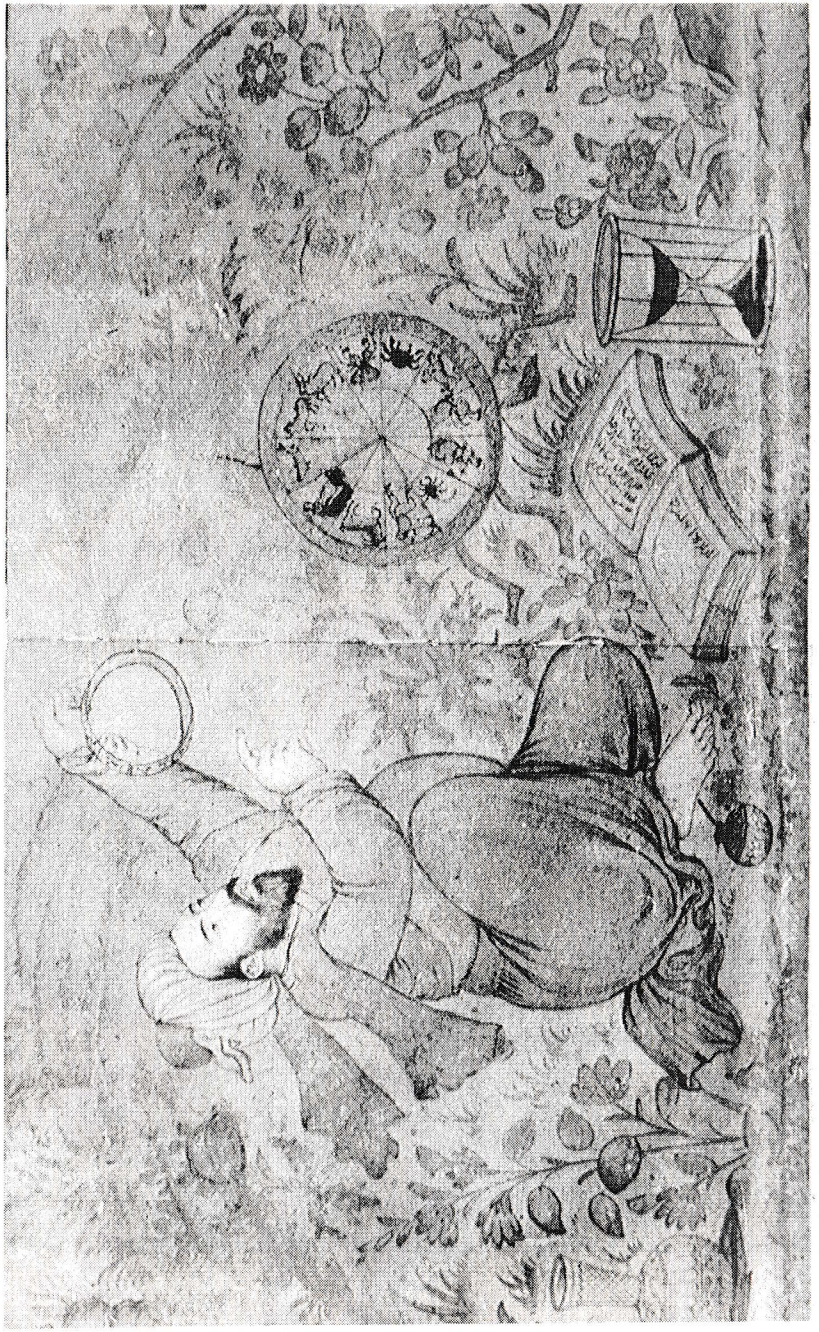

PLATE 8

PLATE 9

PLATE 10

PLATE 11

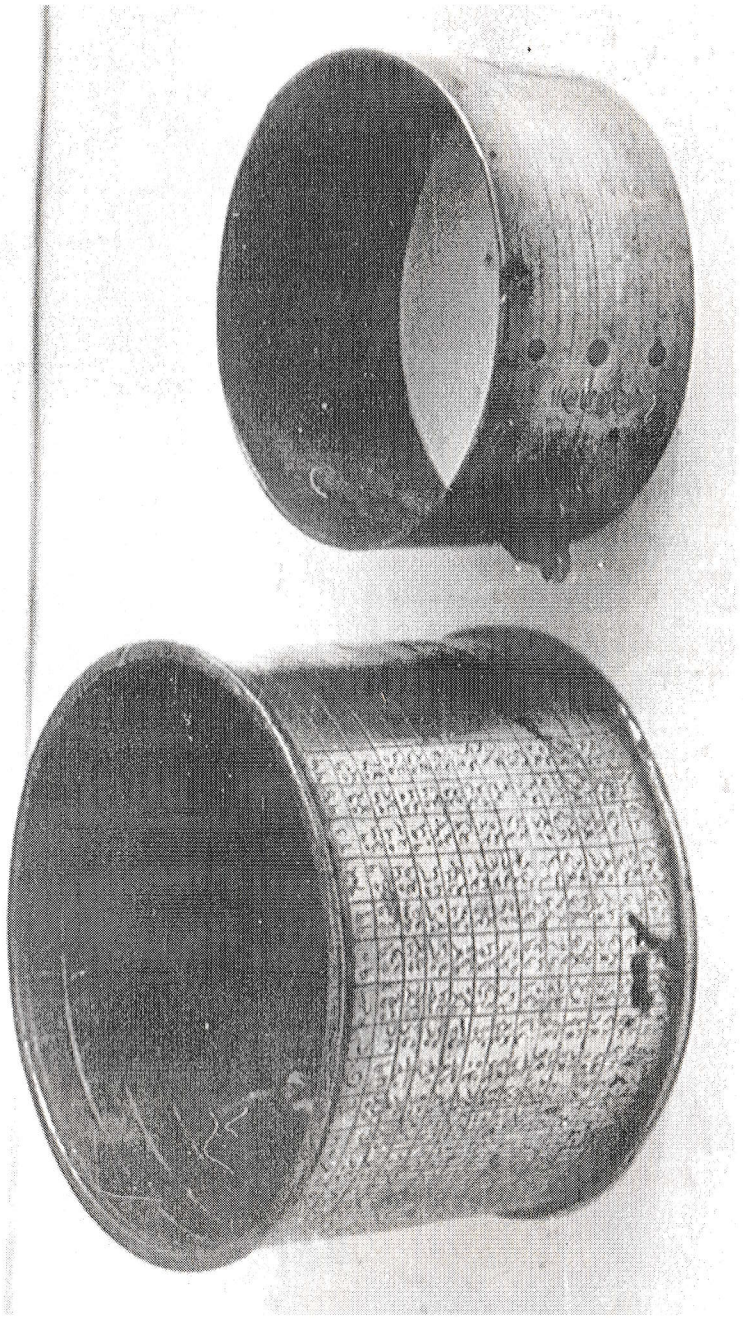

PLATE 12

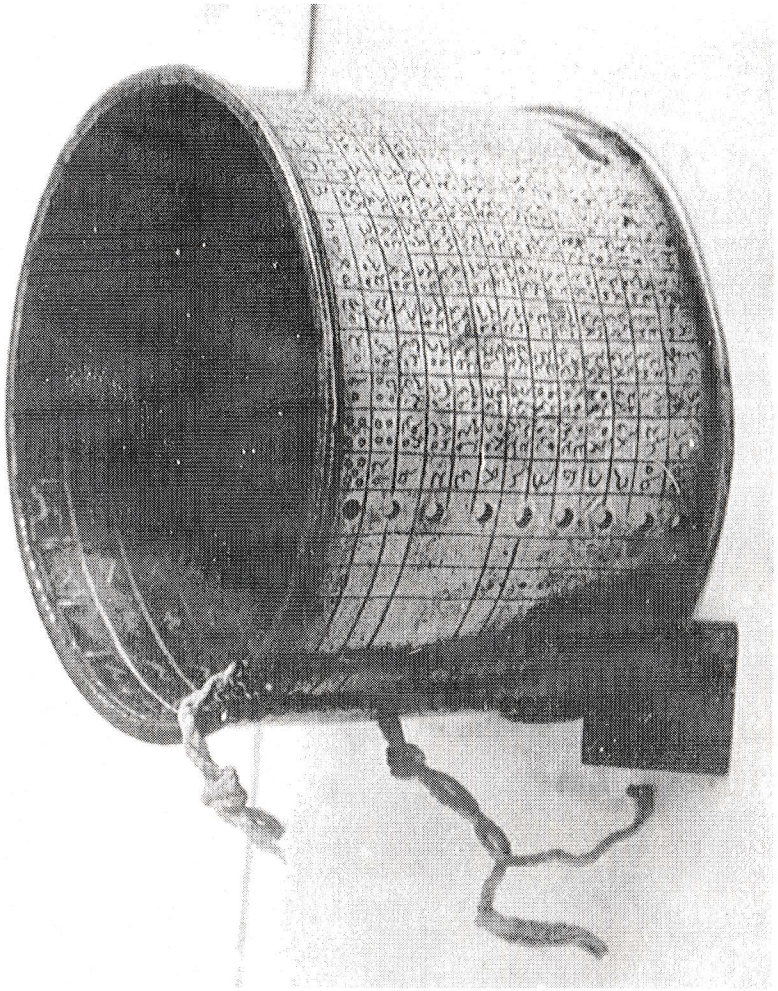

PLATE 13