FROM BAGHDAD TO BARCELONA

Studies in the Islamic Exact Sciences in Honour of Prof. Juan Vernet

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Estudios sobre Historia de las Ciencias Exactas en el Mundo Islámico en honor del Prof. Juan Vernet

SEPARATA

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THE *ṢAFĪḤA ZARQĀLIYYA* IN INDIA

Sreeramula Rajeswara Sarma

To this volume in honour of Professor Juan Vernet, I am happy to make a small contribution that traces a connection between the scientific traditions of his country and mine. The mediator who brough about this connection is Ḍiyā' al-Dīn Muḥammad, the most prolific and versatile instrument maker of Mughal India. He is the great grandson of Allāhdād, the patriarch of the famous astrolabist family of Lahore.[1] Ḍiyā's father Qā'im Muḥammad developed the art of casting the celestial globe in one piece by the *cire perdu* method.[2] His uncle Muḥammad Muqīm is known through more than forty extant astrolabes[3] including the one that is considered the smallest in the world with a diameter of just four and a half centimeters.[4] Ḍiyā' al-Dīn excelled in the production of both celestial globes and astrolabes. About forty five items crafted by him between the years 1637 and 1681 are extant today, scattered in various parts of the world.[5] His prolific work is also distinguished by superb craftmanship and innovation in design.

For a celestial globe made for the emperor Aurangzeb in 1679, he invented an entirely new design. The surface of the globe was cut *à jour*, as in the rete of the astrolabe, leaving out the outlines of the constellation figures, and the various circles. Star positions were indicated by small perforations. When lit from inside, the globe would have presented an

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[1] Cf. Sarma (iv); Savage-Smith, pp. 34-43.

[2] On this technique, Cf. Savage-Smith pp. 91-95.

[3] Cf. Gibbs *et al.*, *s.v.* M MUQIM B 6ISA; Brieux-Maddison, *s.v.* Muḥammad Muqīm b. ʿĪsā; Sarma (iv), pp. 211-212, 215-219.

[4] This tiny piece contains five finely engraved latitude plates as well, cf. Christie's Auction Catalogue, item 116, pp. 44-45.

[5] Cf. Gibbs *et al.*, s.v. DIYA AL-DIN M B KAIM M; Brieux-Maddison, *s.v.* Muḥammad b. Qā'im Muḥammad; Savage-Smith, *passim*; Sarma (iii); Sarma (iv).

is also composed of a single plate, with an open work *kursī* at the top. The rete and the alidade are, however, missing. The front of the plate contains a double projection of almucantars, azimuths, hour lines and so on for the latitudes 32° and 36°. On these is superimposed the northern projection of the ecliptic circle. On the back there is a quadruple projection for the latitudes 22°, 24°, 25° and 29° and upon these is superimposed the ecliptic circle in its southern projection. Some fifty stars are marked on both sides with dots enclosed in small circles. A.J. Turner remarks that "the multiplication of complexity and a delight in the unusual seem to be typical of the astrolabe makers of Lahore".[11] This statement is particularly true of Ḍiyā' al-Dīn Muḥammad.

Sultan Fīrūz Shāh Tughluq of Delhi (reign 1351-1388), who promoted the manufacture of astrolabes and sponsored the composition, in 1370, of the first manual on the astrolabe in Sanskrit, entitled *Yantrarāja* by Mahendra Sūri,[12] is reported to have got made in the same year a gigantic north-south astrolabe and named it *Uṣṭurlāb-i Fīrūz Shāhī*[13]. This astrolabe is no more extant but Fīrūz's interest in this genre is reflected in nearly all the Sanskrit texts on the astrolabe.[14] This continued interest may also have resulted in the manufacture of some north-south astrolabes, but Ḍiyā' al-Dīn's are the only specimens that are extant.

Chronologically the last and technically the most remarkable of Ḍiyā' al-Dīn's productions is a universal Zarqālī astrolabe. The original prototype, as is well known, was invented by Ibn al-Zarqālluh (commonly known as Azarquiel) at Toledo in the eleventh century.[15] The astrolabe which he designed by making the vernal/ autumnal equinox the centre and

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[11] Turner, p. 83.

[12] Cf. Raikva.

[13] According to the anonymous *Sīrat-i Fīrūz Shāhī*, MS at the Khuda Bakhsh Oriental Public Library, Patna. For an analysis of the material in this manuscript concerning the astrolabes produced at the instance of Fīrūz, cf. Sarma (vii).

[14] Thus, for example, Mahendra Sūri discusses the north-south astrolabe at Raikva, pp. 60-61.

[15] Cf. Hartner, pp. 316-317; King; Puig (i); Turner, pp. 151-166.

the solstitial colure the plane of projection obviates the necessity of having a separate plate or *ṣafīḥa* for each terrestrial latitude. Consequently this one consists only of a single plate, called *Ṣafīḥa Zarqāliyya* (or *Saphea Azarchelis*), on which are engraved the equatorial and ecliptic coordinates as well as some fixed stars. A movable ruler serves as the oblique horizon. This *ṣafīḥa* can be used at all latitudes and hence it is called universal.

The Zarqālī astrolabe made by Ḍiyā' al-Dīn is now part of a large collection of instruments deposited in the stores of the Jaipur Observatory erected by Sawai Jai Singh.[16] The inscription[17] on the astrolabe records that it was manufactured at Delhi for Nawāb Iftikār Khān in the twentythird regnal year of Emperor Aurangzeb in 1091 AH, which corresponds to AD 1680-81.

It is a very large instrument, made out of a single sheet of brass, and measures 555 mm in diameter.[18] This large size naturally accomodates finer graduations and coordinates for shorter intervals. Thus the astrolabe is ideally suited for demonstration and computation rather than for actual observation. The *kursī* is cut from the same sheet as the astrolabe and bears simple ornamentation, with a pair of tulip-like flowers on both sides. There is a shackle, and a ring, both having diamond-shaped cross-section.

Originally the instrument must have been equipped with an alidade at the back for taking the altitudes, and a regula with a transversal cursor in the front for reading the coordinates of any point in either the equatorial system or in the ecliptic system. But these were missing in 1902

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[16] Garrett, p. 60, was the first to notice this instrument at the beginning of this century. He was not aware of its being a universal Zarqālī astrolabe but understood that it contained two sets of coordinates, and wrote: "This instrument was probably used as a star atlas, and also for the ready conversion of latitude and longitude into declination and right ascension and *vice versa*. Both sets of co-ordinates being engraved on the disc, one could be converted into the other by mere inspection, with an error of possibly a quarter of a degree". See also Kaye, pp. 27-30, 118, 124-125; Gunther, I, pp. 212-213; Savage-Smith, p. 43; Sarma (v).

[17] The inscription is reproduced in Brieux-Maddison, *s.v.* Muḥammad b. Qā'im Muḥammad, no. 39.

[18] The diameter is given wrongly by Kaye, p. 27, as two feet; Brieux-Maddison, *loc. cit.* and Savage-Smith, p. 43, as 610 mm.

when the instrument was first noticed by Garrett.[19] Subsequently, some time before 1918, an alidade with a sighting tube in brass was mounted in the front, and cross-bars consisting of four arms at right angles, also in brass, were pivoted to the back.[20]

The Zarqālī projection is engraved on the front side of the instrument (see fig. 1). Here the outer rim is graduated for every three degrees and numbered in *abjad* notation in clockwise direction, starting at the top. The next concentric ring is graduated for every degree and numbered in Arabic numerals, separately for each quadrant from 1 to 90, also in clockwise direction, starting at the top. Next there are divisions for every one-sixth of a degree. Inside these degree scales, two sets of coordinates are drawn: the equator with its circles of declination and right ascension, and the ecliptic with its corresponding circles of longitude and latitude. The circles of declination and those of latitude are drawn for every degree and numbered from the centre to the poles. The circles for right ascension and those for longitude are drawn for every three degrees. Dotted lines are used for the equatorial system and simple lines for the ecliptic system, so that these two can be clearly distinguished (see fig. 2).

The equator is graduated for every three degrees and numbered, on the northern side from 1 to 180 running from the top to the bottom, and on the southern side from 181 to 360 in the reverse direction. The ecliptic is marked with the zodiacal signs from Capricorn to Gemini in the north and from Cancer to Sagittarius in the south, so that Aries and Pisces lie at the centre. Each sign is divided for every three degrees.

Several star positions are marked with dots enclosed in circles and

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[19] Thus in 1902, Garrett, p. 60, writes: "There is a round hole in the centre of the disk which probably indicates the former existence of some kind of sighting bar for taking altitudes, but if so, this has now been lost".

[20] In 1918, Kaye, p. 27, speaks of the cross-bar but not of the alidade with the sighting tube. But the latter also must have existed then, for both are of the same workmanship.

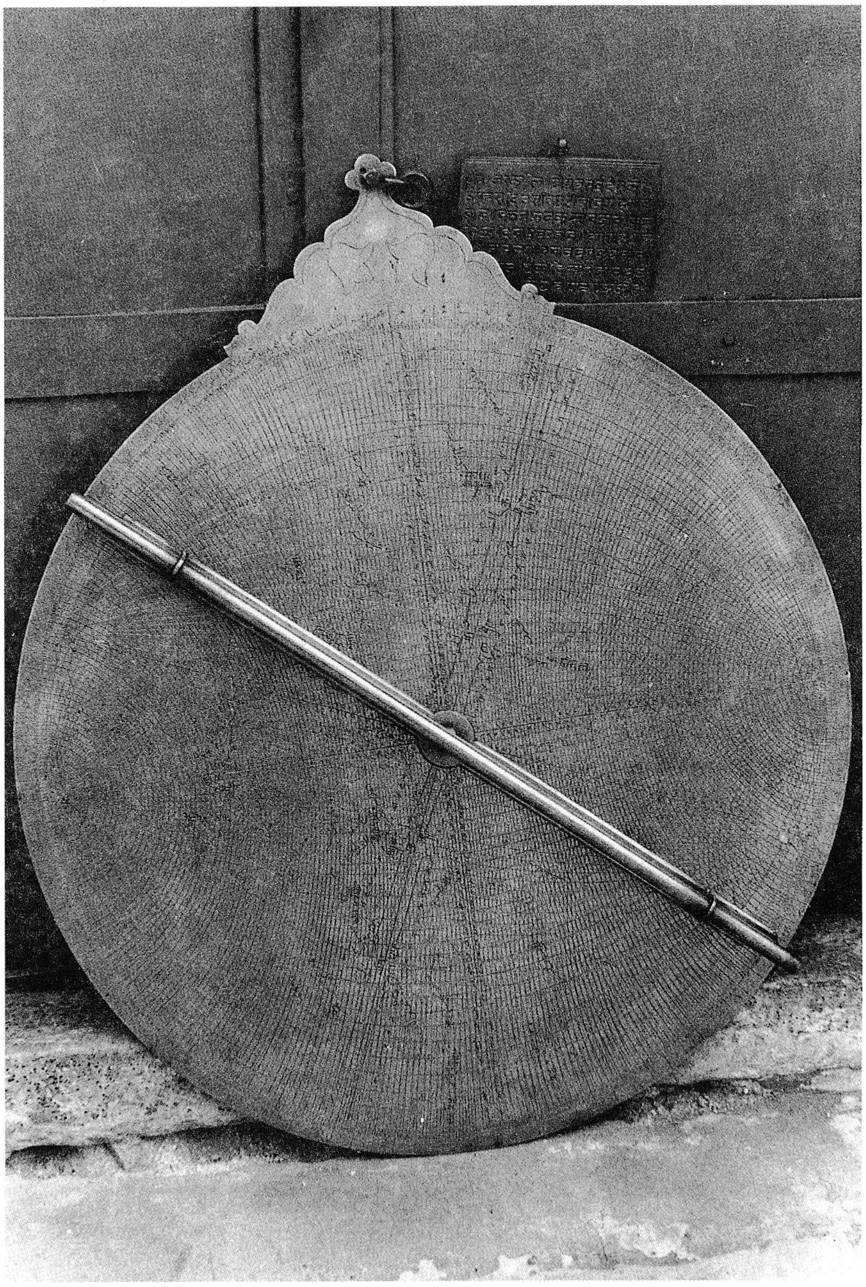

Fig. 1 The Zarqālī astrolabe by Ḍiyā' al-Dīn. Front view.

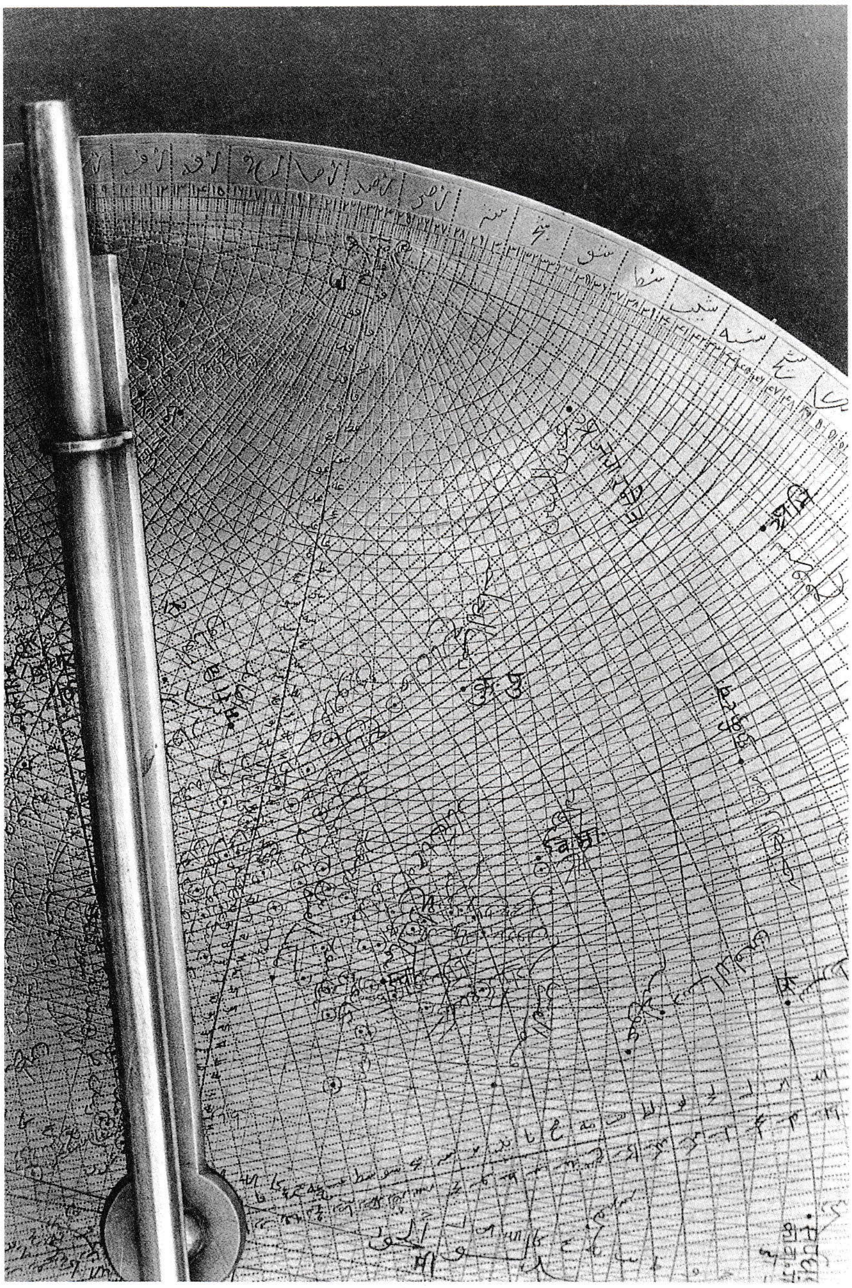

Fig. 2 Front of the astrolabe. Detail from the upper left quadrant.

labelled.[21] This celestial map is also made to serve geographical purposes. Treating the celestial equator and the polar axis as the zero degree latitude and longitude respectively, a number of town names were inscribed at appropriate distances. These include Ḥalab, Ṭūs, Kābul, Jahānābad (i.e. Delhi) and Lahore.[22]

On the back there are many scales and tables arranged in annular circles on the rim (see fig. 3). Reading from the outer circumference to the centre, the annuli contain the following scales and tables. (i) The periphery of the two upper quadrants is graduated for every three degrees, numbered in *abjad*, then in single degrees numbered in Arabic numerals from 1 to 90, and then in one-sixths. The periphery of the two lower quadrants contains shadow scales, the 12-scale on the left and the 7-scale on the right. (ii) The next complete annulus contains the signs of the zodiac, divided in the succeeding circles into 3°, 1° and 10' respectively. (iii) Circle of lunar mansions. (iv-ix) Planets, arranged respectively twelve, nine,... to each sign, with varying graduations. (x) Shadow scales. (xi) Names of European months with a scale showing the days of each month. Here the first point of Aries is placed at 10 March, which is a correct value for the year AD 1680-81, when the instrument was made.

In the central part, the quadrant on the lower right contains a sine graph. The other three quadrants contain orthogonal projections of the great circles inclined to the meridian. Strangely enough the "Circle of the Moon", considered to be a special invention of al-Zarqālluh for finding the lunar distances,[23] is not engraved on the back of this astrolabe; nor is the circle mentioned in the Sanskrit manual on the Zarqālī astrolabe to be discussed below.

There are not many Zarqālī astrolabes extant today and none of these is from the East. Again none of the surviving ones is comparable to the magnificent creation of Ḍiyā' al-Dīn Muḥammad. While this piece at Jaipur is thus very unique, its subsequent history is also of great interest for the transmission of ideas. Within half a century of its manufacture, it

[21] Kaye, p. 118, gives the names and coordinates of only 14 fixed stars, but there are more. A full star list has yet to be made.

[22] Cf. Kaye, pp. 28-29.

[23] Cf. Puig (v).

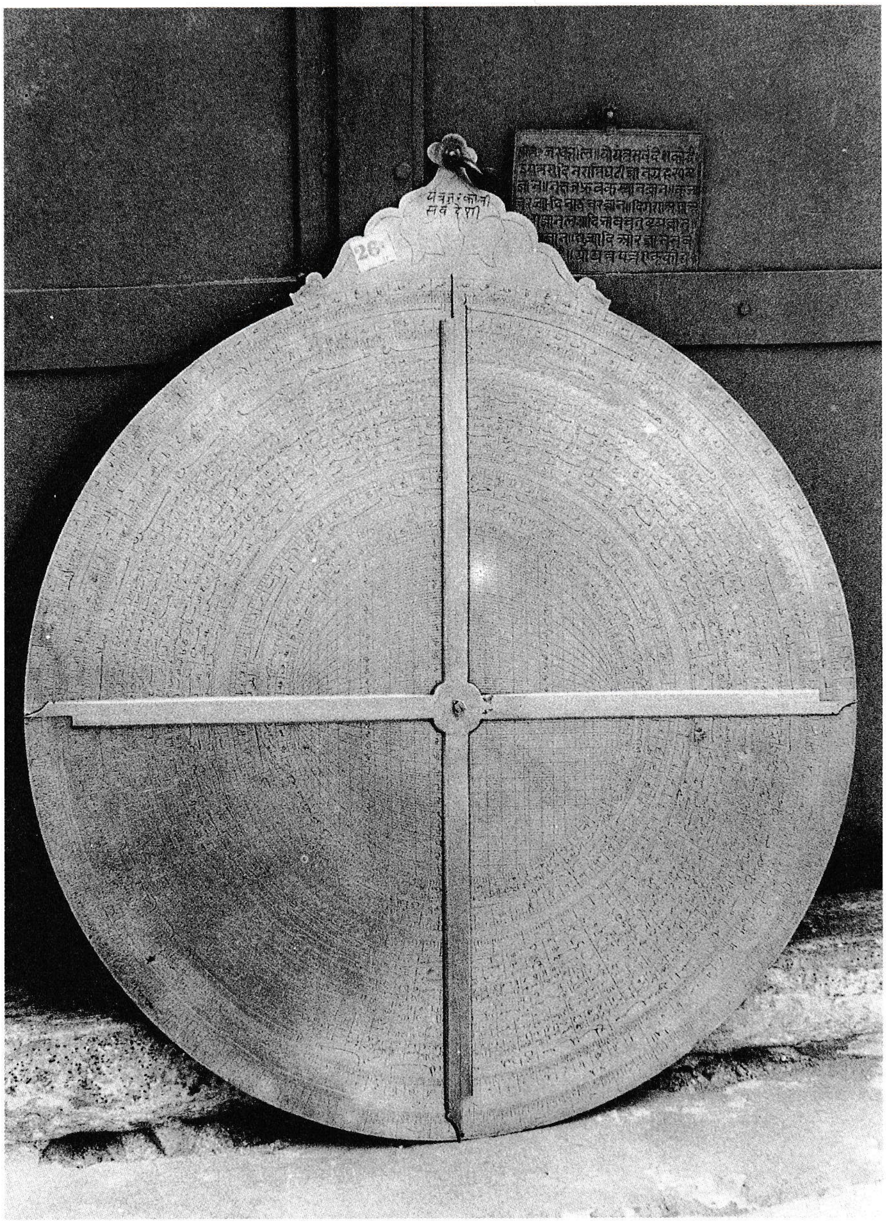

Fig. 3 Back view of the astrolabe.

Fig. 4 Back of the astrolabe.
Detail showing the inscription on the crown, and the plaque.

was acquired by the astronomer-king Sawai Jai Singh of Jaipur (1688-1742), who is well known for the huge astronomical instruments in masonry which he erected at five principal towns of northern India, viz. Delhi, Jaipur, Varanasi, Ujjain and Mathura.[24] He also collected some exquisitely crafted Mughal astrolabes, including the Zarqālī astrolabe which his court astronomers avidly studied. Under Jai Singh's orders, a Sanskrit/ Rājasthānī name was engraved in Devanāgarī script at the back[25] of the crown of the Zarqālī astrolabe thus: *yantra jarakālī sarvadeśī*, literally "instrument Zarqālī universal". The first letters of the Sanskrit names of the zodiacal signs were also engraved at appropriate places on both sides of the ecliptic. Besides, a number of new star positions were marked with simple dots and their Sanskrit names were inscribed. Also a copper plaque was attached to the astrolabe, on which all the functions of this universal instrument were enumerated in Rājasthānī (see fig. 4). The plaque, measuring 150 × 110 mm, reads as follows:

> One instrument [called] Zarqālī. This instrument is for all latitudes. This instrument provides [i] the knowledge of [time in] *ghaṭīs* in the day and at night; [ii] knowledge of the true [longitudes of the] planets; [iii] knowledge of the longitudes of the fixed stars; [iv] knowledge of the earth-sine, [v] sine of the ascensional difference, [vi] half duration of daylight, [vii] ascensional difference; knowledge of [viii] the azimuth, [ix] amplitude and [x] the terrestrial latitude; [xi] knowledge of the four *bhāvas* beginning with the ascendant; [xii] knowledge of the gnomon shadow; [xiii] knowledge of the day sine, and all other kinds of knowledge. This instrument consists of a single plate.

More important still is that Jai Singh caused the composition of a Sanskrit manual entitled *Sarvadeśīya-Jarakālī-Yantra* on the construction and use of this instrument.[26] Though there are several manuals in

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[24] On Jai Singh's masonry instruments, see Garrett; Kaye; Virendra Nath Sharma.

[25] That is why Kaye, p. 27, treats the side having the name as the front and the side with the Zarqālī projection as the reverse, and goes on to say: "The characteristic part of the instrument is engraved on the reverse".

[26] There are three independent manuscripts of this text: (i) Maharaja Sawai Mansingh II Museum, Jaipur, Khas Muhar 5483; (ii) Trinity College, Cambridge, R. 15.139, ff. 1-8; (iii) Bhandarkar Oriental Research Institute, Poona, 557 of 1899/1915. Besides these three, there

Sanskrit on the astrolabe,[27] this is the first time that the universal astrolabe invented in the eleventh century in far-off al-Andalus by Ibn al-Zarqālluh found an echo in Sanskrit writings.

There are forty sections in this work. The first section explains the construction of the front of the astrolabe, while the second lays down how to prepare the reverse side.[28] These two sections together are designated as *paribhāṣā*, "definition". The remaining part is called *gaṇita-prakāra*, "method of computations" and deals with the solving of various problems, such as finding the true longitude of the sun from the declination by three different methods; the converse of the problem, viz. finding the declination when the solar longitude is known, also by three different methods; finding the half duration of the daylight for any day at any latitude; finding the current ascendant and from it determining the same for any location or for another year, and so on.[29]

What are the sources of this text?. One source clearly is the actual astrolabe manufactured by Ḍiyā' al-Dīn. Its presence at Jaipur, the similarity in the Sanskrit name engraved on its crown and the title of the manual, the near identity of the contents of the plaque and the manual strengthens the hypothesis that the instrument inspired the composition of the Sanskrit text.

Besides the actual instrument, literary documents may also have been the source for the Sanskrit manual. Ibn al-Zarqālluh himself is said to have composed three versions of his account, respectively in sixty,

are some other manuscript copies, which seem to have got mixed up with the leaves of other texts composed about the same time at Jaipur and these were printed with those other texts. Thus our manual occurs abruptly in Ram Swarup Sharma, vol. 3, pp. 1252-1260; Caturveda, pp. 96-105.

[27] For the various Sanskrit texts on the astrolabe, see Sarma (ii), pp. 238-241.

[28] While explaining the construction of the instrument, the manual lays down that there should be an alidade with sighting vanes, and also a regula with a transversal cursor. This must indeed have been the case with Ḍiyā' al-Dīn's instrument when it was acquired by Jai Singh in the 1720s. The movable parts may have been lost after Jai Singh's time.

[29] The titles of the forty sections will be given in the Appendix.

eighty and one hundred chapters.[30] Did any of these reach Jai Singh's court? If so, the Sanskrit manual falls into the category of texts Jai Singh got translated from Arabic and Persian sources. As I have shown elsewhere,[31] this process of translation proceeded in three separate stages. First a Muslim astronomer explained the Arabic/ Persian text, sentence by sentence, to his Hindu counterpart in the local language. The latter immediately rendered each sentence into Sanskrit. In the third stage, one of the senior Hindu astronomers polished the translation, composed a preamble and a colophon, and signed it as his work. Our manual appears to be the product of the second stage. Only in one manuscript copy, the style has been polished, but no author put his signature on it.[32] Therefore it is clearly a translation or an adaptation of some Islamic text. A comparison then is essential of this Sanskrit text with Ibn al-Zarqālluh's three versions.

The universal astrolabe was discussed also in another contemporary work called *Yantrarājaracanā* which is attributed to Jai Singh himself. This work deals with the construction and use of the common northern astrolabe, but towards the end there is a section entitled "The method of observation with the universal astrolabe".[33] The problems solved in this section correspond to sections 3-16, 18 of the *Sarvadeśīya Jarakālī-Yantra*.

Until recently it was thought that Ḍiyā' al-Dīn's was the only universal astrolabe to have been produced in India and perhaps the only one of its size. In September 1992, Christie's of London offered for auction a yet larger universal astrolabe.[34] It has a diameter of 920 mm and is perhaps the largest known astrolabe in the world. The grid, however, is said to be of the *Shakkāziyya* type. The names of the zodiacal signs are engraved both in Arabic and Sanskrit, so also the arguments on

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[30] Cf. King, p. 253; Turner, pp. 155-156.

[31] Cf. Sarma (i), pp. 6-7; Sarma (vi).

[32] MS Poona. Pingree, p. 319, attributes the translation to Nayanasukha.

[33] Kedāranātha, pp. 13-17.

[34] Christie's Auction Catalogue, item 119, pp. 48-49.

the various legends. Other legends and numbers are written in Sanskrit only. On the reverse, close to the centre, there is a table of astrological "faces" and "limits", which is likewise written only in Sanskrit. There does not appear to be any maker's signature, nor any mention of the date or place of manufacture. Is it once again a product of the Lahore astrolabist family, on which Sanskrit legends were added later on, or is it a bilingual astrolabe manufactured wholly at Jai Singh's court? Whatever be the case, it is interesting that the most spectacular specimens of the *Ṣafīḥa Zarqāliyya* and the *Ṣafīḥa Shakkāziyya* should come from the fringes of Eastern Islam.

Appendix

The Forty Sections of the *Sarvadeśīya Jarakālī-Yantra*.

1. Method of preparing the first side.
2. Method of drawing lines on the second side.
3. Finding the true longitude of the sun from the declination.
4. Another method.
5. Yet another method.
6. Finding the declination when the sun's longitude is known.
7. Another method.
8. Yet another method.
9. Finding the ascensional difference and the half duration of daylight.
10. Determining the time till/ from noon (*natakāla*) and the time from sunrise or till sunset (*unnatakāla*).
11. Finding the altitude from the time till/ from noon.
12. Finding the amplitude.
13. Determining the right ascensions at the equator.
14. Determining the ascendant from the right ascensions at the equator.
15. Determining the oblique ascensions.
16. Determining the ascendant from the oblique ascensions.
17. Determining the first visibility correction.
18. Determining the position of a planet or of a fixed star on the instrument.

19. Determining the ascensional difference, amplitude, half daylight of planets and fixed stars.

20. Determining the second visibility correction.

21. Finding the longitudinal difference of a planet that has moved from a given position.

22. Determining the altitudes of the planets and fixed stars.

23. Determining the true declination and the altitude from the time till/ from noon.

24. Determining the time elapsed at night from the altitudes of the planets and fixed stars.

25. Determining the altitudes of the planets and fixed stars from the time elapsed at night.

26. Determining the ascendant.

27. Determining the time elapsed in the day or at night from the culmination.

28. Determining the ascendant from the culmination.

29. When the ascendant and the culmination are known, determining the altitude for each degree of the ecliptic.

30. Determining the culmination from the ascendant.

31. Determining the degrees of the ecliptic from the altitude.

32. Determining the time difference between a planet and the meridian and, from that difference, determining the azimuth and altitude.

33. Determining the azimuth from the altitude.

34. Determining the time till/ from noon and the declination from the azimuth.

35. Finding the direction of another city in relation to a given city.

36. Finding the arc intercepted by two planets.

37. If the time till/ from noon in one city is known, finding the same for another city.

38. Finding the shadow from the altitude and vice versa.

39. When the ascendant in one year is known, finding it for other years.

40. Finding the ascendant at another latitude from the ascendant at one's own latitude.

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