On errors with Measuring instruments

"Since in the manufacture of measuring instruments it is not possible to achieve the desired precision, be it with the evenness of the surfaces or with the marking of the divisions or holes at the right place, it is but natural that errors occur, as with the adjustment of the instruments. In almost every construction inaccuracies exist, whether visible or hidden. If the instrument is made of wood, then it will warp, particularly when it stands at a place exposed to Sun and humidity. The errors are larger or smaller, according to the theoretical knowledge, craftsmanship and experience. Added to this, there is the expertise of the observer in setting up and measuring, the precision of the adjusting apparatus and much more. Whosoever believes that anybody can execute measurements on order and without previous practice, and that each measuring instrument delivers correct results, is in error. Whosoever wishes to achieve this must, first of all, spend a long time on the study of the instruments and on the practice in measuring, until finally his measurement rests on the knowledge of the precision of his instrument and on his experience in measuring."

Ibn Yūnus¹ (d. 399/1009); translation after Eilhard Wiedemann².

The astrolabe

The astrolabe, the most widely-spread and most popular instrument in the history of astronomy, reached the Arabic-Islamic world from Persian, Syrian and other centres of science in the eastern Mediterranean area, where Greek sciences were cultivated prior to Islam and in early Islamic times. In its simplest form it was already known to the Greeks presumably already in the 2nd, perhaps even already in the 4th c. B.C. The names Hipparchus (2nd c. B.C.), Apollonius (2nd c. B.C.), or Eudoxus (4th c. B.C.) are linked with its invention. In any case, it is mentioned by Ptolemy in his tract on the projection of the spherical surface on the plane surface. The astrolabe also seems to have passed through a certain process of development in Late Antiquity. The science historian Ibn an-Nad¬m (4th/10th c.) knew a work by Theon of Alexandria (4th c. A.D.) on the use of the astrolabe (Kitâb al-'Amal bi-l-asturlâb). This seems to be identical with a book which was translated in the 2nd/8th c. under the title Kitâb fi Dât as-ṣafâ‘i‘ih wa-hiya l-asturlâb as a work by Ptolemy and which was described as such in detail by the historian al-Ya‘qûbî (3rd/9th c.).

The astrolabe itself has been known in the Arabic-Islamic area, if not already in the 1st/7th century, then in the first half of the 2nd/8th century. The Arabic titles of books known to us, the extant fragments and books convey the impression that the books on astrolabes which originated in the Islamic world in the 2nd/8th and 3rd/9th century contributed to the development of a constantly improving literature on applied astronomy. The theoretical element preserved in this literature shows that we can place the beginning of the creative period of the Arabic-Islamic culture in the history of the astrolabe in the first half of the 3rd/9th century.

“The astrolabe is a portable instrument which adjusts itself into an exactly vertical position through a type of Cardanic suspension. One of its main parts is a stationary disc on which the horizon is projected with its parallel circles and vertical circles (muqantarâ and azimuthal circles) from a point, mostly from one of the celestial poles. The horizontal line divides the disc into two parts, into an upper part with the projections of the muqantarâ and azimuthal circles, which corresponds to the half of the celestial sphere above the earth, and into a lower part that corresponds to the half of the celestial sphere beneath the earth. On this lower part several arcs are drawn from the centre of the disc up to the rim; these are designated as hour lines. It has to be kept in mind that the counting of the hours begins with sunrise, according to ancient customs. The other main part of the instrument is a movable disc which, however, is not solid but an open-work piece. On it are seen the projection of the ecliptic (of the zodiac) which, corresponding with the number of the signs of the zodiac, is divided into 12 parts; these are further subdivided into 30 degrees. There are also the projections of a number of the largest and most well-known fixed stars.”

“The movable disc, called spider or net ['ankabût or šabaka], can be rotated around an axis at its centre upon the stationary disc. By rotating the spider, the daily rotation of the heavenly bodies at a given local horizon can be simulated. If the spider is set up in a particular position, it is possible to read off the altitude above the horizon and the azimuth directly on the disc which is under the spider, for each of the stars and signs of the zodiac represented on the spider, for the Sun and, in a certain sense, the planets included, and can read off the hours, which have elapsed since sunrise or sunset, from the intersection with the hour lines of the point of the zodiac sign where the Sun is situated just then, or of the point in the zodiac diametrically opposite to the Sun …”

“The astrolabe makes it possible to directly determine the stars in the following main positions. It is only necessary to see which heavenly body lies, with a [80] particular position of the spider, on the eastern or western part of the horizon, on the
upper or lower part of the meridian line, which is the vertical diameter of the disc. In order to be able to situate the spider at a position corresponding with the given position of the celestial sphere, it is necessary to know one of the above-mentioned astronomical data, be it e.g. the altitude of a star or of the Sun above the horizon, be it the hour that has elapsed since sunrise. By rotating the spider, the star is placed on the muqantara in accordance with its altitude, or at night by giving the hour, and that is to say the hour of the night, the position of the Sun in the zodiac, and with the time of the day, the point situated diametrically opposite the Sun’s position upon the respective hour line. The spider then shows the desired position. Besides these few problems mentioned, quite a number of other astronomical and astrological problems can be solved mechanically with the astrolabe, almost without calculation\footnote{Josef Frank, Zur Geschichte des Astrolabs, pp. 4–5 (reprint, op. cit., pp. 4–5).}

The enormous development in professional, technical, artistic and literary respects which this chief instrument of Arabic-Islamic astronomy underwent through the centuries has been dealt with more comprehensively by modern research than most other topics of Islamic history of science. The common astrolabe or planispheric astrolabe, Arabic āsturlâb masuṭṭah or āsturlâb saṭḥi, has one to nine discs (ṣafīha, pl. ṣafā’ih), which are valid for the degrees of latitude of those places whose horizontal coordinates are engraved. The other parts are called ‘urwa or ḥabs = handle; ḥalqa or ilâqa = ring; huqra, kufa or tawq = the raised, circular rim or limb; ‘umm = “mater”, the main part of the instrument in which the discs and the spider are stacked; ‘ankabūt or šabaka = spider or net; waḏḥ = the inner side of the mater; ḥahr = “back” of the mater; ‘idāda = alidade, diopeter; ṣaṭbatān or ṣaṭziyatān = the two tips of the alidade; liḥba, daffa or hadaf = sight vanes; ṭuqbatān = the two apertures of the sight vanes; miḥwar, qutb = axis, pin which is inserted through a hole at the centre of the mater, of the discs and of the spider and which holds these together; faras = “horse”, a wedge that is pushed through a hole at the tip of the axis and holds tight the discs and the spider in the “mater”\footnote{Franz Woepcke, Über ein in der Königlichen Bibliothek zu Berlin befindliches arabisches Astrolabium, Berlin 1858, p. 1–3 (reprint in: Islamic Mathematics and Astronomy, vol. 86, pp. 3–5).}.

The signs of the advanced development which the astrolabe underwent in the Arabic-Islamic period include its numerous variants. The types known until the turn of the 4th/10th to the 5th/11th century are described by Abu r-Raiḥän al-Bīrūnī in his book Isti‘āb al-wuqūḥ al-mumkinā\footnote{v. F. Sezgin, Geschichte des arabischen Schrifttums, vol. 6, p. 268.} in which he leans heavily on a book by his teacher Abū Sa‘īd Aḥmad b. Muḥammad as-Siǧzī (2nd half 4th/10th c.). From the studies on the various types of astrolabes done so far, it is evident that there is a connection between their origin and the concept of the mixed astrolabes (mīzāĝ al-āsturlāb). This has to do with the combination of the features of the northern and the southern astrolabe in a single one. As early as in the first half of the 3rd/9th century, the Arabs were—in the words of J. Frank\footnote{Ibid. pp. 225–226.}—”not content with the form adopted from their predecessors where the part of the celestial sphere to the north of the tropic of Capricorn is projected upon a plane parallel to the celestial equator or upon itself from the south pole. They also attempted stereographic projection from the north pole of that part of the celestial sphere which lay south of the tropic of Cancer and called an astrolabe thus produced the southern astrolabe, as distinct from the northern astrolabe. When exactly the southern one originated cannot be ascertained any more, but in any case before Farqānī, who also provides the theory for this astrolabe.”

Al-Bīrūnī\footnote{Zur Geschichte des Astrolabs, op. cit., p. 8 (reprint p. 8).} describes the variants of the northern and southern astrolabe in his book in the chapter kaiyīfāt ǧam‘ nau‘ā‘ī l-āsturlāb aš-šīmālī wa-l-ġanūbī wa-mīzāĝ aš-šūkhā ba’dhā bi-ba‘d.}
They are “named after the objects which the shape of the spider, particularly that of the zodiac, calls to mind. The outer form of the astrolabe does not differ in this regard from that of the common astrolabe.”

The variants described by al-Biruni are: *al-asturlāb* al-*muṭabhal* (the astrolabe shaped like a drum, on the right in the following picture), *al-asturlāb al-āsī* (the astrolabe shaped like a myrtle, on the left in the picture); here the drawings of their spiders or retes:

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*Al-asturlāb*  
*al-*musartan*  
(the astrolabe shaped like a crab) has the following rete:

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The parallels of altitude of the crab-shaped astrolabe:

\[\text{Al-\text{\textae}l\text{\textae}b az-zauraqi} (the ship-shaped astrolabe) has the following rete: \]

\[\text{Al-\text{\textae}l\text{\textae}b al-mistari} (the ruler-shaped astrolabe) has the following rete: \]

\[\text{Al-\text{\textae}l\text{\textae}b a\text{-}\text{\textae}l\text{\textae}b} (the cross-shaped astrolabe) has the following rete: \]
Al-āsturlāb al-laulābī (the spiral-shaped astrolabe) has the following rete:

From *Libros del saber de astronomía*.

Less than a quarter of a century after al-Bīrūnī’s death (d. 440/1048), there appeared universal astrolabes which were no longer provided with discs designed for specific latitudes. The first known step in this direction was taken by Abu l-Ḥasan ‘Alī b. Ḥalaf. The astrolabe that carries his name was called in later centuries *ṣakkāziya*. We know the rete of the instrument11 through an illustration in the *Libros del saber de astronomía*:

The upper half of the rete forms a net of almucanters and azimuth circles, the lower half carries star positions. We learn the details about ‘Alī b. Ḥalaf’s instrument from the Castilian translation of his treatise in the *Libros del saber de astronomía*.12 The history of astronomy knows another astrolabe with similar projection, designed at about the same time in Andalusia and known under the name of the great astronomer Ibrāhīm b. Yahyā az-Zarqālī (or Zarqallū, 2nd half 5th/11th c.). His astrolabe, known in the Arabic-Islamic world as *ṣafīha zarqāliya* and in modern research as the universal disc, is also described in detail in the *Libros del saber de astronomía*. There az-Zarqālī’s tract is reproduced in the Castilian translation of the [84] original version13 dedicated to the ruler al-Mu’tamid b. ʿAbbād (ruled 461/1068–484/1091) (below, p. 118).


Az-Zarqālī’s astrolabe “consists only of one single disc on which the celestial equator and the ecliptic with their parallel circles and vertical circles are projected from the first point of Aries or that of Libra upon the plane of the solstitial colure. Since the first point of Aries or that of Libra constitute at the same time the east and the west points of every horizon, the disc is valid for all latitudes. The horizon itself is projected through a straight line passing through the centre of the projection; the straight line is represented by a ruler, movable around the centre and provided with divisions. With the help of the division of degrees on the rim of the disc the ruler can be assigned any location according to the position occupied by the horizon on the celestial sphere in relation to the equator. The back is usually that of the common astrolabe, except that there is also a smaller circle on it through which the orbit of the moon can be represented.”

‘Ali b. Ḫalaf’s book and astrolabe did not have as much impact as az-Zarqālī’s book and instrument on the further development of the astrolabe. The extent of this impact on astronomical literature and on the art of astrolabe making was described brilliantly by Emmanuel Poullé in his study on *Un instrument astronomique dans l’occident latin, la “saphea”*. The impact lasted from the beginning of the 13th century into the 16th century, which means that Europe had already known about az-Zarqālī’s universal disc and his tract for more than half a century before it was included in the *Libros del saber de astronomia* of Alfons X. The most recent and artistically most delicate specimens of this type of astrolabe, which were made in Europe, include those of Walter Arsenius (ca. 1570), Erasmus Habermel (ca. 1585) and John Blagrave (ca. 1585), the first two of whom are represented with models in our Museum (below, p. 113 ff.). In this connection we may recall the important statement by Emmanuel Poullé, namely that in Europe the practical interest in these astrolabes by no means aimed at contributing to astronomical observations or precise calculations.

In the Arabic-Islamic world the universal disc also had a rather wide impact. Its extent, in literary as in practical fields, was discussed by Emilia Calvo Labarta in her study on and edition of *Risālat as-Ṣaḥīfa al-ḡāmi‘a* by al-Ḥusain b. Bāṣūh (d. 716/1316), which contains a detailed description of the instrument.

The development outlined here led to the emergence of the astrolabe of ʿAbd b. Bakr Ibn as-Sarrāḡ (d. ca. 730/1330), who was active in Syria. His instrument combines in itself the advantages of the conventional planespherium with those of the universal disc and, beyond that, embodies the highest mathematical-astronomical standard that the astrolabe ever achieved in the East and in the West (below, p. 119).

Finally mention may be made of two other types of astrolabe developed in the Arabic-Islamic area. One of them is the spherical astrolabe, the other the linear astrolabe. We can trace the origin of the spherical astrolabe back to the second half of the 3rd/9th century. It is assumed that it was invented by Ḥābir b. Ṣinān al-Ḥarrānī. He was followed [85] after a short time by several astronomers like Ḥābaš al-Ḥāsib (still alive around 300/912) and ʿUsayn b. Lūqā (d. around the turn of the 3rd/9th to the 4th/10th c.) and al-Fadl b. Ḥātim an-Nairizi (early 4th/10th c.) as well as subsequent scholars like Abu r-Raiḥān al-Bīrūnī (d. 440/1048) and Abu l-Ḥasan al-Marrākūšī (2nd half of the 7th/13th c.). This type of astrolabe also went through a long development in the Arabic-Islamic world. It appears, however, that it either did not come to the knowledge of scholars in Europe outside Spain or was not taken account of. The construction of the

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17 *Un instrument astronomique*, p. 510.


19 v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 162.

20 Ibid., pp. 173-175.

21 Ibid., pp. 180-182.

22 Ibid., pp. 191-192.

23 Ibid., pp. 261-276.
spherical astrolabe and its use will be dealt with in connection with the reconstructed models (below, pp. 120-133).

As far as the linear astrolabe is concerned, which we will also discuss in connection with a model (below, p. 134), it represents in principle nothing but the attempt to take observations that are normally made with the planespheric astrolabe by means of a graduated rule. The scholar who made this attempt was ʿArfadd al-Muʿaffar b. Muḥammad al-Ṭūsī (d. ca. 610/1213), to whom an important position is also due in the history of mathematics.

While summing up, we may cite the comparative verdict on the astrolabes from the Arabic-Islamic world and those from Europe of a young and unbiased scholar in his study on Die Astrolabi-ensammlungen des Deutschen Museums und des Bayerischen Nationalmuseums: 25 “Study of the Islamic pieces provides evidence of the progress of Islamic instrument making which impressed me and shows the power of technical innovations of the Islamic instrument makers. The Islamic instruments always prove themselves to be pieces that combine the highest astronomical utility and, at the same time, elegant artistic grace. The study of Islamic astrolabes brings to light only few specimens which are not in keeping with this general statement.”

“The European astrolabes, on the other hand, lack a constantly high quality spanning centuries. Some European instruments testify to a high standard of astrolabe construction. Other pieces which, as far as the workmanship is concerned, are often not inferior to the astronomically valuable specimens, testify on the other hand to the elementary astronomical incomprehension of their creators. This reflects the differences in the tradition of astronomical knowledge in Europe and the incompleteness of the transmission of this knowledge from the medieval Islamic area.”

24 Ibid., p. 399.
The Astrolabe of Nāṣīlūs

Nāṣīlūs, with the names Muhammad b. Muḥammad (or ʻAbdallāh), seems to have lived in the last quarter of the 3rd/9th and in the first quarter of the 4th/10th century. He was among the most well-known astrolabe makers of his times and is also said to have been the inventor of the so-called eclipse disc (aṣ-ṣafīha al-kusīfiya). His famous astrolabe was in the possession of Alain Brieux in Paris in the last century. Meanwhile another astrolabe from the first half of the 4th/10th century became known, the mater of which seems to be by Nāṣīlūs. In the catalogue of the Museum of Islamic Art in Cairo Nāṣīlūs al-Wāṣiṭī is mentioned as its maker.

The astrolabe described here is today in the possession of the Islamic Archaeological Museum in Kuwait. It was made in 315/927, has a diameter of 173 mm and a thickness of 4 mm. It has a single disc, one side of which at 33° is meant for Baghdad and the other for a place with the latitude of 36°. The rete shows 17 fixed stars.

The Second
Astrolabe
of Naṣṭūlus

A part of another astrolabe by the same Naṣṭūlus (Muḥammad b. Muḥammad or ʿAbdallāh) is preserved in the Museum of Islamic Art in Cairo. It consists of the “mater” (umm) together with the rim (huğra) and the “throne” (kursī). The name Naṣṭūlus is engraved on the back of the kursī. What is surprising in this astrolabe is that the names of 64 cities with their latitudes are inscribed on the inner surface of the umm. Its diameter is 13 cm.

Our model:
Brass, etched.
Mater with a diameter of 130 mm.
Without rete, alidade or disc.
(Inventory No. A 2.26)

The astronaut Abu r-Rabi’ Ḥāmid b. ‘Ali from al-Wāsiṭ seems to have lived in the first half of the 4th/10th century. The famous astronomer ‘Ali b. ‘Abdarrāḥman Ibn Yūnis’ (d. 390/1009) referred to him and to ‘Ali b. ʿĪsā al-ʿAṣṭurlābī as the two most important astrolabe makers. In his extant treatise on the use of the spherical astrolabe, Ḥāmid al-Wāsiṭī stresses the advantages of this type of astrolabe over the planispheric type. A mater from his astrolabes is preserved in the Museum of Islamic Art in Cairo (Inv. No. 15354).

Unfortunately, a rete has been affixed inseparably to the mater with the result that it is not possible to examine the inner side of the latter. The rete seems to date from the 8th/14th century. The mater carries, on three quadrants at the back, the names of the signs of the zodiac in Arabic script and furthermore their symbols, which are called hudūd al-Miṣrīyin. The last quadrant is designed as a sine quadrant. The diameter of the mater is 11 cm.


2 v. F. Sezgin, op. cit., vol. 6, p. 207.
Astrolabe

Constructed on the basis of an original made in ca. 340/950 by Ahmad b. Ḥalaf. According to the inscription, it was made for Ga‘far b. (‘Ali) al-Muktafi (b. 294/906, d. 377/987), a son of the ‘Abbāsid Caliph al-Muktafi (d. 295/908). This astrolabe has some similarity with the astrolabe made for, or ascribed to, Pope Sylvester II (380/990, below, p. 94).

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 130 mm.
4 discs for the latitudes 21°/24°; 30°/31°; 34°/36°; 37°/39°.
Rete with 17 star pointers.
Double pointer with sights on the back.
(Inventory No. A 2.14)

(Original in la Bibliothèque nationale, Paris, Ge.A.324)

The Astrolabe of al-Ḥuṣandi

The astrolabe made in 374/984 by the great astronomer and mathematician Abū Maḥmūd Ḥāmīd b. al-Ḥīd al-Ḥuṣandi (2nd half of the 4th/10th c.) is probably the most beautiful and most interesting among the oldest extant astrolabes. Apart from this, we know of the “comprehensive instrument” (al-āla aš-šāmila, below, p. 151) invented by him and of the great sextant with a diameter of about 20 metres which he constructed in Raiy (in the south of modern Tehran) for determining whether the inclination of the Earth’s axis is variable or constant (above, p. 25).

Besides the mater and the rete, the astrolabe contains five discs for the latitudes of 21° (Mecca), 27° (al-Quzum or Hormoz ?), 30° (Cairo), 33° (Baghdad), 36° (Raiy ?) and 39° (Buchara ?). One more disc was made for the latitude 66°17’ of a place with the longest possible daylight of 24 hours. One more additional disc was meant for astrological purposes (maṭṭah aš-šu’ār) and for the latitude of Baghdad (33°).

The astrolabe was in the possession of the Moradoff family in 1929. After R. T. Gunther had erroneously described it in 1932 as an astrolabe made in the year 778/1376 by a certain Ahmad b. al-Ḥīdr an-Naḡdī, it disappeared into unknown possession. L. A. Mayer could not ascertain anything more about its location in 1956. After some time the instrument reached Paris and was identified correctly by Marcel Destombes. It was in Alain Brieux’s collection and later passed into the possession of Gāsim al-Humaizi in Kuwait. At present it is said to be in the National Museum of Qaṭar.

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3 *Islamic Astrolabists*, p. 45 (reprint., op. cit., p. 179).
5 I am indebted to my colleague David King for photographs of the astrolabe.
Astrolabe

Based on a Catalan model from the 10th century A.D. It is the oldest Latin astrolabe and a copy of an original Arabic astrolabe. What is remarkable is that the Latin lettering represents a transcription of originally Arabic alphabet numbers: on the discs this applies to the numbers of the latitudes, on the mater to the division into twelve hours.

(Original in the Institut du Monde Arabe, Paris)


Our model:
Brass, engraved.
Mater with bracket and suspension ring.
Diameter: 152 mm (with engraving for the latitude of 36°).
2 discs for the latitudes 39°/41°30’; 45°/47°30’.
Rete with 20 star pointers.
Double pointer with sights at the back.
Calendars and shadow square.
Latin lettering.
(Inventory No. A 2.18)
Our model was made after the illustrations in the *Sententiae astrolabii* by Lupitus of Barcelona (manuscript in the Bongarsiana Burgerbibliothek Bern, Cod. 196). This work emerged from a partial adaptation and partial free rendering of the Arabic model, the book on the astrolabe by Muhammad b. Mūsā al-Hwārizmi (active under Caliph al-Ma’mūn, ruled 198/813–218/833). Except for two, the 27 star names occurring on the rete are Arabic in Latin script, likewise the names of the lines of unequal hours. It is interesting that the 360 degree scale on the limb is executed threefold: in Arabic alphabet numbers, the same in Latin transcription, and in Latin numbers. On the other hand, the calendar circle (365 days) on the back is engraved only in Arabic alphabet numbers (though not faultlessly). In the manuscript two discs are described (front and back of each for the climates 3, 4, 5 and 6).

Illustrations from Cod. 196, Burgerbibliothek Bern.
(Fleury? Ottonian, ca. 390/1000)
Astrolabe

Based on an original which was allegedly made in France in 380/990 and attributed to Pope Sylvester II.

(Original in the Museo di Storia della Scienza in Florence)

The original betrays the character of an Arabic astrolabe from the 4th/10th century. The authorship of Pope Sylvester is merely a later conjecture. All numbers and the names of the fixed stars on the spider, on the rim of the mater and on the discs are written in Arabic script. Only the two latitudes 30° and 42° were provided additionally with European numerals. The names of the zodiac signs, the names of the months and the numbers of the degrees on the back are given in Latin or European (Arabic) numerals.

Our model:
Brass, engraved.
Mater with bracket and suspension ring, outer diameter 130 mm.
Rete with 25 star pointers.
2 discs for the latitudes 30°/42° and 36°/38°.
On the back calendars and shadow square.
Double pointer with sights.
(Inventory No. A 2.11)

Astrolabe

Based on a specimen made in Toledo by Muḥammad b. as-Saffār in 420/1029.

The discs were made for the following cities: Ghana (Ḡāna), Sana’a (Ṣan‘ā’), Mecca, Medina, al-Qulzum, Cairo, Cairuan (al-Qairawân), Samarra (Surra-man-rā’a), Samarqand, Cordova, Toledo, Zaragoza and Constantinople, as well as for the island of Sarandib (Sri Lanka) and for the northern boundary of the inhabited part of the earth.

(Original in the Staatsbibliothek, Berlin)

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 135 mm.
9 discs for the latitudes ca. 6°/10°; 14;30°/17;30°; 21;40°/25°; 28°/30°; 32°/34°; 20°; 36°; 30°/38°; 30°; 40°/42°; 45°/66°, and one projection for the latitude of 72°.
Rete with 29 star pointers.
Double pointer with sights on the back.
Calendar circle, shadow square.
(Inventory No. A 2.12)

Astrolabe

Based on a specimen made in Zaragoza (Spain) by Aḥmad b. Muḥammad an-Naqqāš in 472/1079.

(Original in the Germanisches Nationalmuseum, Nuremberg WI 353)
Astrolabe

Based on an original made in Valencia (Spain) by Ibrāhīm b. Sa‘īd as-Sahlī in 478/1086.

The six discs, made for twelve different latitudes, carry under the Arabic numerals for degrees Roman numbers that were engraved later. The mater contains a 13th engraving for latitude 72°.

(Original made of bronze in the Naturwissenschaftlich-technische Sammlung in Kassel)


Our model:

Brass, engraved.
Mater with bracket and suspension ring with a diameter of 176 mm.
8 discs for the latitudes 13°/19°; 25°/32°; 30°/38°; 32°/35°; 37°/39°; 30°/40°; 38°/41°; 66°/42°.

Rete with 28 star pointers.
Double pointer with sights, length 166 mm.
Arabic inscription on the back: “Constructed by Ibrāhīm, son of Sa‘īd, in Valencia”.
(Inventory No. A 2.05)
Astrolabe

The astrolabe was made in 613/1216 in Sevilla by Muḥammad b. al-Futūḥ al-Ḥamāʿīrī (cf. below, p. 100). The special importance of the astrolabe which we constructed after this original lies in the fact that one of the five discs is prepared for 48°22′, i.e. for the latitude of Paris and that, moreover, the spider and the raised rim of the mater (limbus, ḥuġra) were provided, for the use of an European, with the Latin rendering of the Arabic names of select fixed stars and, in the place of alphabet numerals, with Arabic numerals. For this purpose the spider and the rim of the astrolabe were ground and freshly inscribed, much later, perhaps after the 16th century. The assumption of a relatively late date of the new legends rests on the fact that the [99] outermost circle with a division into 24 parts (2 ×
1-12) presupposes knowledge of the hour angle in Europe. The Latin disc, prepared for 48°22', also seems to have been added later. On the remaining four discs latitudes were added subsequently in Arabic numerals (in the European way of writing), as an aid for reading, which are, however, incorrect. In the following table these are juxtaposed with the correct numbers of the original:

<table>
<thead>
<tr>
<th>Latitude in original</th>
<th>Latitude in European figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>21°40'</td>
<td>25°</td>
</tr>
<tr>
<td>33°30'</td>
<td>37°30'</td>
</tr>
<tr>
<td>38°30'</td>
<td>34°30'</td>
</tr>
<tr>
<td>35°30'</td>
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<td>b</td>
<td>48°22'</td>
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At a later point, the astrolabe travelled from Europe to Istanbul. There it was described in all detail and reproduced in five drawings by the Ottoman statesman (şadı’s-ı a’zām) Gazi Ahmed Muhtər Paşa (1839-1919) in his Rıyād al-Muhtər, mir’āt al-miqyās wa-l-adwār ma’a mağmū‘at al-aškāl (Cairo 1303, pp. 222-228). The astrolabe, together with other instruments and books, was presented as a gift by Sultan Selim III (ruled 1203/1789-1222/1807) to the then Mühendisşâne, the college of engineering and the precursor of today’s Technical University in Istanbul1.

1 See Kâzım Çeçen, Astrolab, in: Lâle (İstanbul) 2/1984/7-11.
Astrolabe

This astrolabe was made in 626/1228, also by Muḥammad b. al-Futūḥ al-Ḥamāʾiri from Sevilla, one of the most prolific and most interesting astrolabe makers. A total of fourteen instruments by him are extant at present. The signs of the zodiac, the names of the months and the rims of the tangents were re-engraved some 100-200 years later with Latin designations. However, the most important feature of the astrolabe lies, as in the previous one, in the engraving on the back of the mater which contains both an Islamic and a Christian calendar, besides a concordance, which H. Sauvaire and J. de Rey-Pailhade described in detail. Original in the Museum for Islamic Art, Cairo.

Our model:
Brass, etched.
Diameter: 165 mm.
5 discs for the latitudes:
30°30'/32°30'; 33°30'/34°30';
35°30'/36°30'; 37°30'/38°30'; 39°30'/40°.
(Inventory No. A 2.31)

Photo of the original, the inner side of the 'mater' (amm).

The astrolabe
of the Marine Museum in Istanbul

This is the largest extant astrolabe from before 1000/1600. It is in the Maritime Museum (Deniz Müzesi) at Istanbul and carries the Inventory No. 264. It measures 56 cm in diameter and 1.1 cm in thickness. The astrolabe was constructed in 619/1222 in Damascus for the Ayyubid sultan al-Mu'azzam 'Isā b. Abī Bakr b. Aiyūb. Its maker was called 'Abdārrahāmān b. Sinān al-Ba'labakkī an-Naṛā. The mathematical-astronomical values were contributed by 'Abdārrahāmān b. Abī Bakr at-Tibrizī. The silver inlay work was done by as-Sirāq ad-Dimāsqī. The instrument has two discs, one for the latitudes 30° and 35° and the other for the latitudes 40° and 41°. The obliquity of the ecliptic is based on a value of 23°51'. The rete carries relatively few star positions, altogether twenty. David King called it an important feature of this astrolabe that the rete within the southern ecliptic carries a short equatorial bar as compared to the much longer one below the northern ecliptic; he added that this element appeared here for the first time on the rete of an Arabic astrolabe and recalled certain medieval French instruments; therefore the question arose “whether the basic rete design might have been copied from an instrument brought to the Ayyubid realms during the Crusades.” I hope D. King would not today describe this connection any more as he did then, but would rather be inclined to assume that this pattern, on the contrary, reached France through Arabic astrolabes from Syria and through the mediation of the crusaders. Instructive in this respect is the statement by Burkhard Stautz that the form of the star pointers as well as the lower equatorial bar and the knob for turning the rete next to the pointer for the star α CMa recall the forms of early Islamic astrolabes.


2 Die Astrolabiensammlungen des Deutschen Museums und des Bayerischen Nationalmuseums, p. 43. Some time after I had written these lines I had the opportunity to ask Prof. King if he was still of the same opinion. He said he had revised his opinion shortly after writing the study mentioned and that he had expressed this in his book The Ciphers of the Monks (Stuttgart 2001, p. 395). There (note 10) he regrets his earlier assumption and comes to a new one: “Possibly it was inspired by a Syrian astrolabe seen by a French Crusader.” Although our positions thus come closer, I consider it more probable that a French Crusader brought an astrolabe with him and that it was imitated in France.
Our model:
Brass, etched;
diameter: 56 cm.
(Inventory No. A 2.24)
Astrolabe

Based on a specimen made in Egypt in 650/1252, by ʿAbdalkarīm al-Miṣrī for the Ayyubid ruler al-Aṣraf Muẓaffaraddīn Mūsā.

(Original in the Museum of the History of Science, Oxford)

Our model:
Brass, engraved. Mater with bracket and suspension ring with a diameter of 280 mm. 3 discs for the latitudes 30°/44°; 33°/40°; 36°/66° 30°. Rete with 25 inscribed star pointers. Double pointer with sights on the back. Calendars, quadrants.
(Inventory No. A 2.15)

1 Not 630 H.

Astrolabe

Based on an original made in Hama (Hamāh, Syria) by as-Sahl al-Asṭūrābī an-Nisābūrī in 698/1299.

According to the inscription, the astrolabe was made for the Ayyubid ruler al-Malik al-Muzaffar Maḥmūd Taqīyāddīn. The German astronomer Regiomontanus acquired it prior to 1460, during his stay in Italy, probably in Padua, brought it to Nuremberg and provided it with two additional discs for the latitudes 42° (incomplete), 45°, 48° and 51°. Regiomontanus apparently removed two original discs meant for places south of 30° to make space for the additional discs of the three European cities.

(Original in the Germanisches Nationalmuseum, Nuremberg WI 20)

Our model:
Brass, engraved.
Mater with bracket and suspension ring with a diameter of 161 mm.
4 discs (30°/33° and 36°/39° of Arabic origin; 45°/48° and 51° for European latitudes with Latin additions; 42° obviously meant for Rome, not completed).
Rete of silver (spider with figures).
On the back, the alidade with sights, and a pointer attached at right angles.
(Inventory No. A 2.17)

Gunther, The Astrolabes of the World, p. 280, no. 137;
Mayer, Islamic Astrolabists, pp. 82–83; Schätze der Astronomie, pp. 33–35; Focus Behaim Globus (Germanisches Nationalmuseum, Exhibition catalogue ), Nuremberg 1992, pp. 570–574.
Astrolabe

Based on an original made by al-Malik al-Asraf in Yemen in 690/1291. Al-Asraf 'Umar b. Yusuf (ruled 694/1295–696/1297), a ruler from the Rasulid dynasty in Yemen, himself wrote books on the astrolabe and made instruments (with his own hands). On the back of the mater three groups of symbols are marked. The outer ring shows the signs of the zodiac. They are additionally represented in Arabic script too. The second ring carries the symbols of the astrological *arbāb al-wuğūh* and refers to the 36 decans of the zodiac. The signs in the third ring represent the triplicities (*muṭallaṭāt*) of the planets.

(Original in the Metropolitan Museum of Art, New York)

Our model:
Brass, engraved.
Mater with bracket and suspension ring, outer diameter 155 mm.
4 discs for the latitudes 13°/15°; 13°37'/14°30'; 21°, and 7th climate degree /24° and 6th climate degree.
Rete with 20 star pointers, diameter 130 mm, 22 star positions.
On the back alidade with sights, length 140 mm.
Arabic legend on the back.
(Inventory No. A 2.07)

Astrolabe

Based on an Arabic model, probably dating back to the 7th/13th century.

(Original in the British Museum in London)


Our model:
- Brass, engraved.
- Mater with bracket and suspension ring, diameter 150 mm.
- 3 discs for the latitudes 21°/24°; 27°/33°; 30°/31°.
- Rete with 29 star pointers, diameter 120 mm.
- The back carries a double pointer with sights, length 140 mm.

(Inventory No. A 2.06)
Astrolabe

Replica of one of the five extant astrolabes made towards the end of the 9th/15th century by Šamsaddin Muhammad Šaffār.

The original of our reconstruction is in the Museum for Islamic Art, Cairo; it is dated 884/1477. The other four instruments by Muhammad Šaffār are in Cambridge, Oxford (2 specimens) and Brussels.¹

Our model:
Brass, etched.
Mater with bracket and suspension ring,
outer diameter 120 mm.
2 discs for the latitudes 33°/36° and 72°.
(Inventory No. A 2.33)

² See Mayer, Islamic Astrolabists, pp. 75–76.
Astrolabe

Based on the original made by Muhammad Muqim al-Yazdi for Shah 'Abbás II of Persia in the year 1057/1647. (Original in the Evans Collection, Museum of the History of Science, Oxford)

Our model:
Brass, engraved.
Mater with bracket and suspension ring, diameter 30 cm (second specimen with a diameter of 45 cm).
In the mater the coordinates of 46 cities between Baghdad and Balkh (Balkh) are engraved, whose longitudes are counted from a prime meridian that lies 28°30' to the west of Toledo, or 17°30' to the west of the Canary Islands.
4 discs (the original has 5) for the latitudes 23°/43°; 29°/30°; 33°/37°; 36°/37°.
Rete with 46 star pointers inscribed with the names of stars in the Persian language, with which the astrolabe allows extensive measurements of time.
Double pointer with sights on the back.
Sine quadrant, zodiacal quadrant and two shadow squares.
(Inventory No. A 2.16)

An Ottoman Astrolabe

The instrument was made in the year 1091/1680 for a certain Sultan b. A‘zam b. Bâyazid, probably a descendant of the Ottoman Sultan Bâyazid II (d. 918/1512). It has four discs for 21° (Mecca), 30° (Cairo), 34° (Damascus), 36° (Aleppo), 41° (Istanbul) and 42° (Edirne). The inner surface of the mater is empty. The back carries a sine quadrant and a tangent quadrant.

The original is in the Museum for Islamic Art in Cairo.

Our model:
Brass, etched.
Diameter 183 mm.
4 discs.
Alidade with sights.
(Inventory No. A 2.32)
In the possession of the Institute, made in Iran (Esfahan ?) in the year 1118/1706. The four discs are meant for the latitudes 21°10', 21°10' (a second time), 22°40' and 39°15'. The latitudes of 36 Persian cities are engraved on the inner side of the mater. Most of these values are incorrect. Thus our model forms an interesting example of the period of decadence in the use of the astrolabe in the Arabic-Islamic area, when people were no longer able to use it as an instrument for astronomical observations.
Astrolabe

Based on a Spanish-Gothic instrument from the 14th century A.D.

“The European instrument is obviously closely related to the Arabian area. Thus the star names, with a few exceptions, are of Arabic origin. Even the Latin name Cadens = “plunging” (eagle) is a reference to an Arabic constellation” (M. Brunold).

Original in the Society of Antiquaries, London.


Our model:
Brass, engraved.
Gothic numerals.
Mater with bracket and suspension ring, outer diameter 120 mm.
2 discs for the latitudes 36°/40° and 44°/48°.
The rete with arabesques and quatre foil ornament shows 17 star positions.
Ruler with a radius of 60 mm.
On the back, ecliptic circle and calendar circle, with a shadow square and a diagram for determining the weekday at the beginning of the year.
Double pointer with sights.
Made by M. Brunold (Abtwil, Switzerland).
(Inventory No. A 2.08)
Astrolabe

Made by Martin Brunold (Abtwil, Switzerland) in the style of a European astrolabe of ca. 1500.

Our model: Brass, engraved. Mater with bracket and suspension ring, diameter 100 mm with horizontal coordinates for the latitude of 48°. Without discs. Rete with 14 star positions and an hour scale for which there was no space on the narrow rim of the instrument. Ruler in the radius of 50 mm, back with ecliptic circle and calendar circle, shadow square, diagram of the unequal hours and double pointer with sights.

(Inventory No. A 2.09)

Astrolabe

Made on the basis of a prototype manufactured in the workshop of Gualterus Arsenius around 1570. This was in the collection Gréppin and was auctioned in Paris in 1980 together with the Linton collection.

Our model:
Brass, engraved.
Mater with bracket and suspension ring,
outer diameter 156 mm.
3 discs for the latitudes 39°/42°, 45°/48° and 51°/54°.
Rete with 37 star-positions, intertwined ribbons and the “form of an angel” in the centre. Double pointer with sights.
Back with az-Zarqāli-projection with 2.5° grid and 25 star positions. Over these a horizontal bar rotates with the twilight border, together with a cursor and brachiolus.
4 x 90° division on the rim. Latin lettering.
(Inventory No. A 2.10)

Detailed description in a brochure by Martin Brunold (Abtwil, Switzerland), the maker of our model.
Astrolabe

Made on the basis of an instrument manufactured around 1600 A.D. by Erasmus Habermel. Our model:

Brass, engraved.
12-cornered mater with bracket and suspension ring, diameter 210 mm.
3 discs for the latitudes 39°/42°, 45°/48° and 51°/54°.
Rete with 30 star positions.
Double pointer with sights, length 210 mm.
On the back a horizontal bar with a cursor and brachiolus.
(Inventory No. A 2.04)

On the back “the disc of az-Zarqäli” is reproduced. The original, on which our specimen is modelled, is now in the Museum of the History of Science, Oxford.


Made by Martin Brunold (Abtwil, Switzerland).
Astrolabe

Made by Martin Brunold
(Abtwil, Switzerland)
for didactic purposes.
**THE UNIVERSAL DISC**

This instrument, known in Europe under the name saphaea (as-safiha az-zarqaliya), “consists only of a single disc on which the celestial equator and the ecliptic with their parallel circles and vertical circles are projected from the first point of Aries or that of Libra upon the plane of the solstitial colure. Since the first point of Aries or that of Libra constitute at the same time the east or the west points of every horizon, the disc is valid for all latitudes. The horizon itself is projected through a straight line passing through the centre of the projection; the straight line is represented by a ruler, movable around the centre and provided with divisions. By means of the division of degrees on the rim of the disc the ruler can be assigned any location according to the position occupied by the horizon on the celestial sphere in relation to the equator. The back is usually that of the common astrolabe, except that there is a small circle on it through which the orbit of the Moon can be represented.”


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**Universal Disc**

Based on an original made 650/1252, in Murcia (Spain), by Muḥammad b. Muḥammad b. Huḍail.

(Original in the Observatorio Fabra, Barcelona)
It is one of several universal discs, called safiha zargāliya or šakkāziya, made by Muhammad b. al-Futūḥ al-Ḥamā’īri. He made it in Sevilla in the year 613/1216. It has a diameter of ca. 216 mm. 33 names of fixed stars are engraved on it.

In the first half of the 19th century, the instrument was acquired by Almerico da Schio in Valdagno near Vicenza (Veneto). Now it is in the possession of the observatory (Osservatorio Astronomico) in Rome (No. 694 II).

Our model:
Brass, etched.
Diameter 185 mm.
Length of the alidade 185 mm.
Ruler with divisions into degrees, length 165 mm.
Arabic alphabet numerals.
(Inventory No. A 2.34)

Universal Disc

Reconstruction after the illustration and description in the *Libros del saber de astronomía*, a collection of texts compiled by several scholars in Andalusia at the behest of King Alfonso X of Castilia.

Illustration of the universal disc of az-Zarqālī from the *Libros del saber de astronomía*. 

Diameter: 185 mm. Thickness: 3 mm. Calendars and sine lines. Roman numerals. (Inventory no. A 2.02)
Universal Astrolabe

Based on the astrolabe made by Ahmad ibn as-Sarrāq (d. 729/1329), which combines in itself the possibilities of the universal disc of az-Zarqālī and those of the common astrolabe. The instrument is considered the climax in the development of astrolabes.

(Original in the Benaki-Museum in Athens)

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Spherical Astrolabe

According to the present state of our knowledge of the history of astronomy, the spherical astrolabe seems to have been produced for the first time in the Arabic-Islamic period. The astronomers of the Arabic-Islamic area adapted devices like the armillary sphere, the celestial globe or the simple flat astrolabe directly or indirectly from the Greeks and maintained a continuous development and improvement of these instruments. The spherical astrolabe, on the other hand, seems to be one of the inventions of the new Arabic-Islamic culture. However, in Arabic sources the spherical astrolabe is not infrequently mistaken for the armillary sphere and therefore Ptolemy is mentioned as its inventor, as in the *Fihrist* of Ibn an-Nadim (d. 380/990). A reference by al-Biruni allows the assumption that Gâbir b. Sinân al-Harrânî² (2nd half of the 3rd/9th c.) was the inventor of the spherical astrolabe. In his *Kitab Isti’âb al-wu‘ûnh al-mumkina fi san’at al-asturlâb*,³ al-Biruni states: “I have seen an astrolabe which Gâbir ben Sinân al Harrânî had made. The spider is not needed here, because he had drawn the horizon and the parallels of altitude on the sphere and bored holes in the latter corresponding to the latitude on the two quadrants diametrically opposite to each other. Then he had attached 3 rings which had the same size as the largest circles on the sphere: one of them, the equator, was affixed to the other equator on the sphere, the other one was the zodiac which is inclined at the equator by the same amount as the zodiac against the equator; the third was the circle which went through the 4 poles which are on the sphere; i.e. that which goes through the poles of the first two circles. In that third circle he bored 2 holes at the poles of the equator and put an axis into them and into the holes that are to be taken into consideration for the latitude on the sphere, and attached a clamping screw to this axis.”⁴

This instrument is seldom dealt with in contemporary research on the history of Arabic-Islamic astronomy; in 1846 Louis-Amélie Sédillot was the first to make it known through the French translation of the relevant part of the *Gâmi’ al-mabâdi’ wa-l-gâyâr* by Abu l-Hasan al-Marrûkûshî (2nd half of the 7th/13th c.).⁵ In the second decade of the 20th century, C. A. Nallino gave a short description of the instrument in his article *Aṣṭurlâb* in the *Enzyklopaedie des Islam*.⁶ A detailed and excellent treatment of the subject was provided by Hugo Seemann and Theodor Mittelberger in their study *Das kugelförmige Astrolab nach den Mitteilungen von Alfonso X. von Kastilien und den vorhandenen arabischen Quellen* (1925). Without their descriptions and drawings it would not have been possible to construct our models. The instruments discussed here are those of:

1. Abu l-‘Abbâs al-Faṣl b. Ḥâtîm an-Nairizî (d. at the beginning of the 4th/10th c.).
2. Abu r-Raḥûn Muḥammad b. Ṭâḥîd al-Bîrûnî (d. 440/1048).
3. al-Ḥâsān b. Ṭâlî al-Marrûkûshî (7th/13th c.).
4. The instrument shown in the *Libros del saber de astronomia*, written jointly by many scholars on the order of Alfonso X of Castilia (b. 1221, d. 1284 A.D.).

Besides the detailed description of the four spherical astrolabes with the drawings of their “spiders” (‘anqabût), the respective instruments of the above-mentioned Gâbir b. Sinân al-Harrânî and of Qûṣṭâ b. Lûqâî (3rd/9th c.) are also discussed in this study.⁸

Some information on the “principle” and “general description” of the instrument is extracted from

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² v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 162.
³ MS Istanbul, Süleymaniye Kütüphanesi, coll. Carullah 1451, fol. 38a.
the study by the two scholars Seemann and Mittelberger:

“The most graphic device with which it is possible to represent and define numerically the daily motions of the celestial sphere against the terrestrial system of horizontal coordinates of the parallels of altitude and the azimuthal circles consists in letting an appropriately cut out hollow hemisphere, on which a number of the better known stars and the zodiac are inscribed, rotate upon a firmly fixed sphere in which the system of horizontal coordinates and perhaps also other systems of lines are inscribed.”

"… On a firmly fixed sphere the horizon is drawn as a large circle; its poles are zenith Z and nadir Na. It divides the sphere into two halves. On the one upper hemisphere the system of the parallels of altitude, which are parallel to the horizon, and the system of the azimuthal circles (or vertical circles), which are perpendicular to the horizon, are inscribed, as well as the meridian circle …"

“Of the movable celestial sphere, for reasons of greater clarity of the device, generally only one half is executed as a thin, hollow hemisphere (hemi-spherical bowl), which is called the spider.”

“In order to obtain a device with which it is possible to undertake the necessary demonstrations and measurements, the spider and the sphere are combined in the following way. (This is demonstrated graphically in Fig. 2 for the geographical latitude b). The spider is placed upside down upon the sphere so that it covers, with its inner concave area, over half of the sphere’s surface area. A rod, representing the celestial axis PP’, is inserted through the pole, bored for this purpose, of the equator P or P’ on the spider and through two holes G and G’, made diametrically opposite on the meridian circle of the sphere (corresponding to the given geographical latitude), so that either G and P or G and P’ come into congruence. A whole series of such pairs of holes can be made on the sphere, thus making the device practicable for different geographical latitudes.”

The advantages and disadvantages in the use of the spherical astrolabe over the flat astrolabe are summed up by al-Bīrūnī as follows: “I maintain that, even if this one (i.e. the spherical) is easily manufactured and that which we have discussed before is not needed, the flat astrolabe still obviously has advantages; thus the ease with which it can be taken along while travelling. Furthermore, it can frequently be stored at places where this is not possible with the spherical one, e.g. in the sleeves, the bosom of garments, the inside of boots, the appendages of girdles etc. At the same time it withstands strong knocks easily which is not the case with the one shaped like a sphere even with the slightest blow, knock or fall. On the other hand, the representation of that which is on the sphere and the form of the motion taking place on it are more easily visualised on the spherical astrolabe.”

[122] Of our four spherical astrolabes made after the drawings and explanations of Seemann and with reference to originals, the one by Nairız does not have an alidade. Al-Bīrūnī describes two variants, one with and one without an alidade; al-Marrākušī does not allude to the existence of an alidade and the Libros del saber de astronomía contain the description of an alidade which—leaving aside a missing element—resembles al-Bīrūnī’s second variant. The sighting of the stars was done with the instruments described by an-Nairızī and al-Marrākušī and with al-Bīrūnī’s second variant by observing the heavenly bodies through two holes situated opposite each other which lead through the two poles of the sphere that represent the North and South pole. The Sun’s altitude was measured, according to the same three sources, by employing a gnomon, placed at the north or south point of the horizon. It could be moved in the recess by rotating the sphere.

9 Das kugelförmige Astrolab, p. 2 (reprint, op. cit., p. 364).


Al-Biruni’s version with an alidade, which also appears in our replicas, is insofar more practical since the arc of the circle divided into 180° is reinforced by another arc of the circle which is affixed to it perpendicularly. Thus it is guaranteed that the concave area of the alidade remains in contact with the convex side of the spider and that the observation will not be affected; we cannot expect this with the alidade described in the Libros del saber de astronomía.

This type of alidade possesses a certain advantage over the others. However, it has disadvantages because of its sights which consist of metal strips that are affixed to the ends of the alidade and stand upright, parallel to one another beyond the radius of the spider. Most of all because of this inconvenient alidade, the spherical astrolabe will have appeared disadvantageous to those astronomers who desired to carry in their travels an easily manageable device, as the one described by al-Biruni.

The original instrument, preserved from the year 885/1480, testifies not only through its excellent alidade to the fact that the spherical astrolabe went through a further development in the Arabic-Islamic area even after the 7th/13th century. According to our present knowledge this type of instrument seems not to have attracted the attention of European astronomers. In any case, leaving aside Islamic Andalusia, no specimen made in Europe is known to us so far, nor any Latin or Hebrew translation of an Arabic treatise on the spherical astrolabe. The Libros del saber de astronomía too do not seem to have exercised any further influence.
The book dealing with this type of astrolabe, Kitāb fi l-ʿAmal bi-l-asturlāb al-ḵurāwī by an-Nairīzī, is preserved in a single manuscript. H. Seemann considers this treatise “the best and most detailed” amongst the other known Arabic texts on this topic.

In the movable spider set up on the sphere, only the northern celestial sphere is taken into account. “At the ecliptic pole of the spider the ‘largest kursī’ is affixed. This is probably an openwork circular disc, which is made fast around the ecliptic pole of the spider, as in the case of the one by Alfonso of Castilia (below, p. 129). One more, the so-called ‘small kursī’, is affixed at the pole of the spider’s equator and is probably also an openwork circular disc, like the large kursī at the ecliptic pole. The so-called ‘suspension’ (Arabic ʿilāqa) is put on it, which is essentially probably nothing more than the broadened end of the celestial axis, which … is called the ‘nail’; perhaps with the suspension meaning the celestial axis itself …”

“For measuring altitudes, a device is affixed on the circular rim of the spider; this device is called maqrā in the text (we call it altitude quadrant). It is a quadrant strip with a recess in the middle that serves as a groove. The strips on both the sides of the recess are divided into 90°. At the 90° point of division, at one end of the quadrant, the so-called ‘kursī of the altitudes’ is situated, an attachment on which probably a suspension ring is affixed, with which the astrolabe was suspended while altitudes were measured, just as in the astrolabe of Alfons. No mention is made of an alidade.— On the method of measuring altitudes, tasks 1 and 31 (from Nairīzī’s book) give information which we wish to discuss here because of the context. The spider is made fast in the pole of the

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1 Spain, Escurial 961/6 (fol. 45a–68b, 863 H.), v. F. Sezgin, Geschichte des arabischen Schriftums, vol. 6, p. 192.
2 Das kugelförmige Astrolab, p. 32 (reprint, op. cit., p. 394).
ecliptic on the poles of the horizon on the sphere, so that the circular rim of the spider, to which the altitude quadrant is affixed, is congruent with the horizontal circle of the sphere. ... For determining of the Sun’s altitude a gnomon is affixed to the north or south point of the horizon, which can be moved in the groove by rotating the sphere. Then the astrolabe is aligned to the Sun by holding it suspended freely from the kursî of altitude and the gnomon is shifted until it does not throw a shadow and the sunlight falls into the cavity of the gnomon. To determine the altitudes of stars, the sights are aligned on the star through the holes situated diametrically opposite to each other at the north and south points of the horizon, whereby one of the two holes moves in the groove just like the gnomon during the observation of the Sun’s altitude.”

Our model was made after the drawing and explanations of H. Seemann.

Illustration from H. Seemann, Th. Mittelberger, Das kugelförmige Astrolab, p. 68 (reprint, p. 430).

2 Ibid., p. 68 (reprint, p. 430).
In his “Comprehensive treatment of the possible methods while manufacturing the astrolabe” (*Istīʿāb al-wuqūḥ al-mumkina fī ṣanʿat al-ʾasturlāb*), al-Bīrūnī gives a description of the spherical astrolabe which was translated after the Leiden manuscript¹ into German.² Here, we cite his statements on the southern hemisphere and the device for measuring altitudes: “The southern spherical astrolabe differs from it [the northern one] through the spider, that is to say, it differs to the extent that half the equator, which lies on the hemisphere of the spider, is taken from the first point of Aries up to the first point of Libra, and that we mount on the southern spherical astrolabe the stars of the southern latitude (i.e. of negative latitude). The axis we insert through the celestial pole of the spider and through the holes that are under the horizon. Then the procedure is the same with both astrolabes. Among astrolabe makers there are some who are satisfied with that.”

“Moreover, we also mention an apparatus for measuring altitudes. Whosoever wishes to measure the altitude must suspend the astrolabe on the zenith so that the parallels of altitude are parallel to the Earth’s horizon. Then on the degree of the Sun, we set up a small gnomon which stands...”

¹ Bibliotheek der Rijksuniversiteit, Or. 591 (p. 47–175, 614 H.), v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 268.
² H. Seemann, Th. Mittelberger, *Das kugelförmige Astrolab*, pp. 40–44 (reprint, pp. 402–406); we also consulted the Istanbul manuscript, Carullah 1451, fol. 36b ff.
perpendicularly [126] on the sphere and on the spider, and rotate it, i.e. the degree of the Sun with the gnomon, which is done by rotating the spider until the gnomon shades itself and does not throw a shadow upon another spot of the sphere but only upon itself. Then the ascendant coincides with the eastern horizon. It is more convenient to operate this arrangement on the sphere than on the spherical astrolabe."3

After this al-Bīrūnī describes the use of the spherical astrolabe for measuring the altitude of the Sun or that of a star by means of the above-mentioned alidade (above, p. 122): “Amongst the artists [i.e. the astrolabe makers] there are some who make an arc of the circle, whose inner surface touches the convex side of the spider; on its two ends on the convex side they attach a semicircle which is divided into 180 equal parts and then they mount that arc on the axis of the astrolabe, so that its inner surface touches the outer surface of the spider. At the end of the axis an alidade is fastened whose pointer touches the circumference of the semicircle, which is the circle on which the altitude is measured.”4

Our model was made after the drawing and explanations by H. Seemann,5 while using the original Arabic text.

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4 Ibid.
5 Ibid. p. 69 (reprint, op. cit., p. 431).

Illustration from H. Seemann, Th. Mittelberger, 
Das kugelförmige Astrolab, p. 69 (reprint p. 431).
Al-Marrâkûšî describes the instrument in his book Ġamî‘ al-mabâdi’ wa-l-gâyât fi ‘ilm al-miqât;¹ a French translation of this passage is to be found in L. A. Sédillot’s work² and explanations to it in the study by H. Seemann.³ There we read: “For using the astrolabe at different latitudes, holes are bored into the sphere in the well known manner. According to al-Marrâkûshî it is advisable to bore holes corresponding to each of the parallels of altitude drawn on the sphere at their intersections with the meridian quadrant from the zenith up to the north point of the horizon and at the points of the sphere which lie diametrically opposite to these. Then the number of pairs of holes corresponding to the latitudes agrees with the number of parallels of altitude inscribed on the sphere.”

“Al-Bîrûnî’s qualifying remark on discontinuing the hour lines when the astrolabe is prepared for use in various latitudes is not to be found in the work of al-Marrâkûshî nor of Alfons …”

“Al-Bîrûnî’s qualifying remark on discontinuing the hour lines when the astrolabe is prepared for use in various latitudes is not to be found in the work of al-Marrâkûshî nor of Alfons …”

“The apparatus for measuring the altitude is again of a different kind than in the cases discussed so far. The measuring apparatus proper is in the form of a very small, isosceles spherical triangle; its concave area touches the convex surface of the spider. In Arabic, it is called safîha (disc). The line bisecting it from the apex up to the middle of the base should be equal to a quadrant of a great circle on the spider. Into the two end points [128] of this bisecting line, that is to say, into the apex A and the middle of the base B, holes are bored of the same size as the holes present on the sphere.

Our model:
Brass, etched,
diameter: 8 cm.
(Inventory No. A 1.10)

² Mémoire sur les instruments astronomiques des Arabes, pp. 142 ff. (reprint, pp. 188 ff.).
for the latitudes. The ṣafiha is pivoted through the hole at the middle of the base to the pole of the equator of the spider. Into the hole at the apex of the ṣafiha a small cylindrical gnomon is inserted, which is always aligned to the centre of the sphere. The apex of the ṣafiha with the gnomon then glides above half of the equator, which is divided into 180 degrees, on the spider. For suspending the astrolabe correctly while measuring altitudes by means of the apparatus discussed above, a suspension device is attached at the 90th division of the equator on the spider. Al-Marrākūshī does not say anything about how this apparatus is used to measure altitudes. In any case, he proceeds in principle exactly as Alfons does [see next page]. However, instead of aligning the sights to the Sun with the alidade, the ṣafiha and the astrolabe is rotated; in doing so the latter is freely suspended with the suspension apparatus until the gnomon throws a shadow on itself; this happens when the axis of the gnomon is aligned to the Sun. The altitude thus determined is read off at the divisions of the equator, at that spot where the tip of the ṣafiha with the gnomon rests. About the method for determining the altitude of stars which cannot be done with the gnomon, nothing is mentioned unfortunately, although al-Marrākūshī also speaks also of the determination of the altitudes of stars. — At the end al-Marrākūshī observes that in the same way as the equator it was also possible to use the ecliptic as ‘the circle at which the altitude is measured’, which is also the case with Alfons. Then the ṣafiha has to be attached at the ecliptic pole and the suspension apparatus mounted on the ecliptic in a suitable manner."

Our model was made after the sketch by H. Seemann and after his elucidation of the description by al-Marrākūshī.

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6 Ibid. p. 69 (reprint, p. 431).
4.
The spherical astrolabe

after the *Libros del saber de astronomía*

(7th/13th c.)

The fourth treatise of the Alfonsine compendium devoted to astronomical instruments contains in 2 books and numerous sub-chapters a detailed description of the spherical astrolabe. The treatise, like the other parts of the compendium, is said to have been written at the behest of King Alfons X (d. 1284) by a certain Rabiçag (Isak Ibn Sid) in the old Castilian language. Leaving aside the fact that it is not known whether this person was a Muslim, a Christian or a Jew, the question has also not yet been settled satisfactorily as to whether the work was translated from Arabic originals or was written independently in Castilian, on the basis of Arabic texts. It seems that Moritz Steinschneider with his explanation given in 1848 came closest to the facts of the case. According to his view, Arabic texts were first translated by Jews and then, on the basis of these translations, Christian scholars produced appropriate redactions and revisions. This treatise which H. Seemann examined and described in detail enables us to get an idea of how far its content agrees with the extant Arabic treatises on the instrument. In many respects it shows indeed a close relationship with an-Nairızî’s text written some four hundred years earlier. However, in comparison to its predecessors known so far, the Castil-
ian tract is substantially more detailed and more lucid in presentation. In my opinion we would, however, make a mistake if we wanted to understand this improvement as the result of an advance made by the Castilian redactors themselves. I am rather inclined to trace back the Castilian form to a younger Arabic version which, for its part, was already more elaborate. At the same time we should also take into account that one of the extant historical specimens of the spherical astrolabe (below, p. 131) dates from 1480 and turns out to be more advanced than all earlier literary descriptions as far as they are known to us. The testimony given by Alfonso X from the preface to the first book on the spherical astrolabe, “that he, since he had not found any book dealing with the manufacture of the spherical astrolabe, had given an order to the famous Isaak Ibn Sid to write such a work,” is more than doubtful. It is difficult to imagine that just on the basis of a specimen of the instrument type that may have reached Spain, a description of this nature should have been possible, leaving aside the fact that the entire text betrays its dependence on Arabic sources.

Our model was made after the drawing by H. Seemann and after the description in the Libros del saber de astronomía.

\[\text{Illustration from H. Seemann, Th. Mittelberger,} \]
\[\text{Das kugelförmige Astrolab, p. 68 (reprint p. 430).}\]
This spherical astrolabe found its way from the Arabic-Islamic area to Europe and was acquired by the Museum of the History of Science in Oxford at an auction in London in 1962. It had been made in the year 885/1480 by a master called Mūsā. The sphere is made of brass and has a diameter of 83 mm. It is enclosed by a rete (‘anḵabūt, šābāka), to which a suspension ring is attached at the celestial North Pole. Compared to all other representations known to us, this specimen has two innovations, the first of which is of special significance. Namely, that the altitude measurements of both the Sun and the stars were done by means of a coaster which can be moved along the meridian up and down in the recess of a quadrant attached to the spider. A sight added to the coaster enabled the astronomer to sight the desired celestial body over the lower edge of the hole in the suspension ring. According to the photographs of the Oxford specimen at my disposal, this sight seems to be missing there. It probably had the form of a thin rod with a flat head with a small hole in the middle. For observation the sight was inserted into the coaster; at other times it was probably left hanging on a string from the coaster. I imagine its form to be such that a second sight with a sufficiently small hole could have been inserted into the opening of the pole’s axis [132] because the slit at the suspension ring is too wide for accurate sighting.

The second innovation consists in a connecting mechanism between the spider and the sphere. That is to say, the spider can be moved in the vertical or horizontal direction for the purpose of observation without it losing contact with the convex surface of the sphere. This is assured by three brass arcs

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(which for their part are derived from a hemisphere with the same diameter as the spider), which, starting from the lower rim of the spider, enclose the lower part of the sphere.

The four photographs published by Maddison (above) convey a complete idea of the spherical astrolabe in Oxford.

A Spherical Astrolabe
from the year 1070/1660

The second extant spherical astrolabe, according to our knowledge, is in the possession of the Museum for Islamic Art in Cairo. It dates from the year 1070/1660 and was made for a certain Diya’addin Muḥammad b. al-Imād.

With this type of spherical astrolabe the essential information of the rete was transferred to the globe itself. The meridian ring carries several holes, made diametrically opposite, which make it possible by means of the axis to adjust the globe to corresponding circles of latitudes. The globe can also be used without its stand. It has a diameter of 8 cm.
The Linear Astrolabe

(aṣṭurlāb ḥaṭṭī)

The linear astrolabe, also called “at-Ṭūsi’s staff” (‘ašā at-Ṭūsī) is an invention of Šarafaddin al-Muẓaffar b. Muḥammad b. al-Muẓaffar at-Ṭūsī (d. after 606/1209)¹, who is considered in the history of mathematics to be a pioneer in the solution of numerical equations of any order.² A description of the instrument is preserved in the Gāmi‘ al-mabādi‘ wa-l-ḡayāt of Abu l-Ḥasan al-Marrākusi.³ Louis-Amélie Sédillot⁴ was the first to point this out in 1844. However, he thought that the inventor at-Ṭūsi meant Naṣiraddin at-Ṭūsi.⁵ In 1895 Baron Carra de Vaux examined the text in question and published it with a French translation.⁶ About half a century after Carra de Vaux, Henri Michel⁷ dealt with the same topic. He helped us to understand how this instrument, which had remained unknown for a long time, was to be used, and we are indebted to his preliminary work for being able to reconstruct it. The linear astrolabe consists of a staff upon which the projection of the planispheric astrolabe is transferred. Michel offers the following diagram:

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Our model:
Wood, paper, strings with brass-weights.
Length: 46 cm.
(Inventory No. A 1.14)
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⁴ Mémoire sur les instruments astronomiques des Arabes, pp. 27, 36, 191 (reprint, op. cit., pp. 73, 82, 237).
⁶ Ibid.
From his description we learn the following details:
The section MM' represents the intersection of the meridian circle with the horizontal plane on the disc of the common astrolabe. The distances of the curves from 0° to 180° of the circle with the radius MP are transferred to the staff. As an example the latitude of Brussels (50°50') was chosen.
Between starting point M and pole P we see on the right hand side of the scale the positions of the successive centres of the muqantarates (parallel circles) from 0° (horizontal plane) to 90° (zenith). After these, we see the intersections of the meridian with the altitude circles from 90° to the horizontal plane.
Then follow, provided with the signs of the zodiac, the intersections of the meridian with the declination circles at the entrance of the star to be observed into each of the signs. To the left of the scale there is a graduation which indicates between starting point M at 0° and end point M' at 180°, lengths of the arc each of 5° for the circle with the radius MP. Depending on the desired degree of precision and depending on the length of the staff, it is possible to subdivide the scales further. For using the instrument at night, it was also possible to add to the circles of the declination of the Sun some circles of the declination of the major fixed stars. The scales are transferred to a suitable staff and three strings are attached to it.

Michel\textsuperscript{1} explains the use of the instrument with the example of the determination of the Sun’s altitude:
At pole P a string with a lead weight is attached. The point N at a distance PN = PM is marked through a knot in the string. A second string is attached at the starting point M. Now the Sun is sighted along the length of the staff. In this position the second string is stretched from M to N and on it the intersection with N is marked. The length MN is measured with the scale; half of the result is divided by the known length PN = PM and the angle
\[ \alpha = \frac{90 - h}{2} \]

is obtained; from this follows \( h = 90 - 2\alpha \). The procedure of sighting sights could be done by means of a hole bored through the staff or with two sights set up on the staff, or with the help of notches on the upper part of the two knobs at the ends of the staff.

\textsuperscript{1} \textit{L'astrolabe linéaire d’al-Tūsi}, p. 106 (reprint, op. cit., p.336).
Sine Quadrant

Based on an original of the sine quadrant (ar-rub‘ al-muɡayiyah) made by Muhammad b. Ahmad al-Mizzi in 734/1334 and preserved in St. Petersburg.

Our model:
Brass, etched.
Radius: 135 mm.
(Inventory no. A 3.04)

Sine Quadrant

Based on an original which was in Damascus until shortly before 1859, when it was acquired by the Arabist Alois Sprenger for the London librarian William Morley. The quadrant was made in 735/1335 by a certain ‘Ali b. aš-Šiḥāb and was engraved by an engraver called Muḥammad b. al-Ḡuzūlī.

A «sexagesimal»

**Sine Quadrant**

from the Mağrib

The quadrant in the possession of our institute originates from the Mağrib and was presumably made in the 10th/16th or 11th/17th century. Its back is empty. It is divided into 60 equal parts, hence its name; the arc of altitude is divided into 90 degrees.

Besides the two systems of the *mabsūt* and the *mankūs* lines, it has two semicircular arcs (one above the sine line and the other above the cosine line) for converting the chord lengths into sine values, and a curve for determining the time of afternoon prayer (*'aṣr*). One of the two sights is missing.

Our model:
Brass, engraved.
Radius: 125 mm.
(Inventory No. A 3.09)
The Šakkāzīya with a double quadrant (rubʿ aš-šakkāzīya) was developed by Ğamāladdin ʿAbdallāh b. Ḥalīl al-Ṭarīqī (d. 809/1406) on the basis of az-Zarqālī’s universal disc (above, p. 116). It was devised so that computations in spherical astronomy could be done with this instrument. The instrument itself is not extant, but a book by al-Ṭarīqī exists with a description and directions for its use. Besides this description, which is not detailed enough and presupposes knowledge we lack now, we have made use of an extant European imitation (see the following page) for our replica. The spider has the form of a quarter circle with pointers for seven fixed stars. Beneath this are a massive plate and a net-like one, both containing the Zarqālī-projection.

Double Quadrant

Based on an extant European original that was obviously made in the 9th/15th century in imitation of the instrument by al-Māridini (see the previous page) or of another Arabic prototype. The other characteristics of the device correspond to those of the preceding Šakkāziya quadrant with the difference that the captions are in Latin here. The Šakkāziya quadrant is also known as a meteoroscope.

(Original in the Adler Planetarium, Chicago)
Meteoroscope
by Peter Apian

Made after the description by Peter Apian (1501-1552) in his Astronomicum Caesareum. It is now fairly established that Apian plagiarised the instrument of his predecessor Johannes Werner, whose Arabic prototype went back to az-Zarqālī’s universal disc.

Our model:
Brass, engraved.
Radius 150 mm.
A sine quadrant is located on the back, made with great precision, above it a movable ruler.
Replica by Martin Brunold (Abtwil, Switzerland) (Inventory No. A 3.02)

The Dastūr Quadrant (Arabic da‘īrat ad-dastūr or ad-dustūr) was made after an original with a diameter of 182 mm in the Museum for Islamic Art in Cairo. On the back it carries the projection of the horizontal plane of a place whose latitude could lie between 30° and 33°. Instead of the parallel and vertical circles, we see the basic circles and the positions of some select stars together with the chords. The instrument was made by ‘Alī b. Ibrāhīm al-Muṭṭā‘īm in the year 734/1334. The two alidades, missing in the original, were added by us.
Quadrant Disc

Our model:
Brass, engraved.
Radius 25 cm.
(Inventory No. A 3.11)

It is a combination of quadrants in a form so far unknown to me, which apparently originates from the Magrib. The instrument is in the possession of our Institute’s museum. Its circular disc of brass has a diameter of 250 mm and a thickness of 0.8 mm. On the upper rim at the back two quadrants are engraved, each of which is divided into 90°. Altitude measurements can be done with an alidade. On the front there is a sexagesimal quadrant with mabsūt and mankūs lines and two semicircular lines, one above the sine and the other above the cosine line for converting chord lengths into sine values. Given the whole configuration, I wonder whether this is perhaps not an incomplete piece.
Quadrant

Replica of a European quadrant from the 18th century.

Our model:
Brass, engraved.
Radius 120 mm.
(Inventory No. A 3.05)
Indian Circle
(ad-dāʿira al-hindiya)

A gnomon has been fixed at the centre of the circle. The direction of the meridian is determined by the straight line passing through the middle of the line between the point of entry of the shadow into the circle and the point of its exit and through the centre of the circle. The instrument was known to the Greeks and in other cultures.


Our model:
Brass, engraved.
Diameter: 250mm.
Height of the gnomon: 63 mm.
(Inventory no. A 4.25)
Instrument
For Determining the Meridian

In the first half of the 5th/11th century the two astronomers Abu r-Raiḥān Muḥammad b. ʿ Arbān al-Ḥasan and Abū Ḥasan Ibn al-Haṭṭām had, for the first time, clearly understood that the traditional graphical procedure for determining the direction of the meridian with the help of the shadow and by means of the “Indian Circle” was defective. While al-Ḥasan thought of some new procedures, Ibn al-Haṭṭām arrived at the method of determining the direction of the meridian through the corresponding altitudes of the fixed stars. From remarks in his treatise on his procedure and on the “instrument for determining the meridian” developed for this purpose (dāla ʿlā ʿṣiḥrāq ḥatt nisf an-nahār), it appears that this problem preoccupied Ibn al-Haṭṭām for a long time and that he is indeed the inventor of this instrument. No doubt the use of the angular distances of a fixed star before and after its culmination for determining the elevation of the pole was already known before Ibn al-Haṭṭām, but he seems to have been the first to have developed the operation with corresponding altitudes of fixed stars to a clearly defined, experimentally proven astronomical procedure. In the Occident the procedure appears for the first time in Regiomontanus’ work in the second half of the 15th century (v. R. Wolf, Handbuch der Astronomie I, 390–391). In the procedure with our device, half the sum of two horizontal angles is determined by observing a fixed star after dusk up to the culmination and from the culmination until shortly before dawn. What is decisive in this procedure is that the pointer below, when the connecting column is turned, produces converging angular distances, so that half the sum of the traversed angles on the lower horizontal semicircle determines the direction of the meridian.

The astronomer and physicist 'Abdarrahmân al-Ḥazînî (1st half of the 6th/12th c.), in his Ittiḥâd al-alâ‘ al-râsâdiyya, describes among other astronomical instruments the “instrument with the triangle” (al-ālâ‘ dâ‘at al-muṭallat) which is used to solve the following two tasks:

1. Determining the altitude of celestial bodies, like a common quadrant.
2. Determining the angle of vision in which an object appears to us.

Al-Ḥazînî reports that al-Birûnî briefly mentioned this instrument in his Tahdîd nihâyât al-amâkin. Al-Ḥazînî deals with all the instruments which he introduces in three sections: 1. manufacture of the instrument, 2. its use, 3. reasons for the correctness of what was said. On the basis of the first chapter and part of the second chapter, which are preserved in an anonymous compilation on astronomical instruments in a Berlin manuscript (Sprenger 1877, Ahlwardt 5857, 124a f.), Josef Frank made known the instrument in 1921. Partly translating the author’s account, Frank describes its features thus: “In a right-angled triangle of wood or other material, around the centre of the hypotenuse, a semi-circle is drawn which touches the smaller sides of the triangle and is divided into 180 degrees. At the ends of the hypotenuse are mounted two vertical pieces which serve as the sights. By means of a hinge attached at the apex of the right angle, the triangle is attached to a base, a rectangular slab. The front side of this base is graduated; each part is equal to the sixtieth part of the height of the triangle. The instrument is basically a double quadrant and serves primarily to measure the magnitude of an angle. But in some respects it achieves more than the double quadrant, which can directly measure only that angle which a visual ray forms with the horizontal line. Whereas with the triangle instrument it is also possible to represent a vertical angle if the horizontal also lies within the area of the angle. The divisions on the base make it possible to determine the sine of any angle by means of the plumb line attached to the centre of the circle.”

Illustration from MS Istanbul, Bibl. univ., A.Y. 314.

Our reconstruction:
Brass, etched.
Hard wood. Plumb.
(Inventory No. A 4.24)
Three instruments for Measuring Altitudes

In his *Kāfīr al-munagginin wa-galatihim fi akār al-a‘māl wa-l-a‘hkâm*, known so far in two manuscripts, the universal scholar Abū Naṣr as-Samau‘al b. Yahiya al-Ma’ribi (d. ca. 570/1175) describes three instruments used by his predecessors for measuring altitudes, and he takes pains to point out their possible shortcomings.

1) With the first of the devices, one operates with an angle meter that consists of two arms of equal length, one of which is attached to the beginning of a ruler, set up horizontally, while the other one moves along the ruler on a movable rail on the table that carries the instrument. The altitude established by the two sights on the first arm is computed by means of the ratio between half of the distance between the tips of the two arms at the time of observation and the length of the arms. The ratio gives the cosine of the angle of altitude.

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1 v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 65.

Our model:
Table of hard wood,
length: 66 cm.
Scale mounted on the side,
engraved Arabic letters with
numerical values.
(Inventory No. A 4.33)
2) Two arms are used with the second instrument for measuring altitudes, one of which is equipped with a pointed end and two sights and is adjustable in its height at the hinge of the apex. The second arm is provided with a rail in which a movable ruler stands at an angle of 90°. On the ruler the angle of altitude is measured with the pointed end of the first arm by sighting. The ratio of the distance between the point on the ruler where the arm rests and its lower end to the known length of the arm results in the sine of the ascertained altitude.

From MS Oxford, Hunt. 539.
In the third instrument for measuring altitudes, two arms of equal length are joined to each other by a hinge, like the arms in a pair of dividers. One of the arms is firmly set in the horizontal plane and carries a measuring scale, while the other is equipped with sights. The height of the second arm can be adjusted; it carries a plumb line at its end. The ratio of the distance from the beginning of the horizontal ruler up to the point touched by the plumb line to the length of the movable arm yields the cosine of the angle of altitude of the object sighted.

From MS Oxford, Hunt. 539.
The universel instrument

(al-āla aš-šāmila)

The inventor of this instrument was the famous mathematician and astronomer Ḥāmid b. al-Ḥiḍr al-Ḥuḡāndi (2nd half of the 4th/10th c.). Before the discovery of the book’s manuscript in which al-Ḥuḡāndi described the instrument, quotations from it were known from al-Marrākušī (2nd half of the 7th/13th c.). In 1921 Josef Frank was able to describe the instrument almost realistically based on extracts from al-Ḥuḡāndi’s book in a Berlin manuscript:

“Our model:
Brass, etched.
Diameter = 42 cm,
inner radius = 17 cm.
(Inventory No. A 1.06)

The inventor of this instrument was the famous mathematician and astronomer Ḥāmid b. al-Ḥiḍr al-Ḥuḡāndi (2nd half of the 4th/10th c.). Before the discovery of the book’s manuscript in which al-Ḥuḡāndi described the instrument, quotations from it were known from al-Marrākušī (2nd half of the 7th/13th c.). In 1921 Josef Frank was able to describe the instrument almost realistically based on extracts from al-Ḥuḡāndi’s book in a Berlin manuscript:

“Basically the instrument consists of a hollow hemisphere and a disc of the size of one of its great circles. The circular rim of the hemisphere, divided into degrees, represents the horizon. On its inner surface the parallel and vertical circles of the horizon are drawn. This means the hemisphere is to be understood as that part of the celestial sphere which is under the horizon with the horizontal system of coordinates. The disc is divided into 360 degrees and rotates around the centre of the hemisphere like the plane of the ecliptic; thus the revolution of the zodiac is represented. To adjust the disc for each geographical latitude, the position of the axis attached to it can be moved through a slit in the hemisphere. For measurements on the celestial equator, a semicircle [on the inner surface of the hemisphere] is connected to the disc in its given position, the semicircle representing one half of the celestial equator. An alidade that can be rotated around the centre of the disc permits measurements of many different angles, either in the plane of the ecliptic for the determination of longitudes, or in the plane of the celestial equator to find right ascensions. For this, the axis is moved to a suitable position. When the disc is positioned vertically to the horizon, the altitude can be measured. However, generally with these measurements, the sight which is in the inside of the sphere makes the alignment of a star difficult. This drawback can be avoided if the disc is separated from the axis and is suspended it vertically. A hole on the rim of the disc at the 90th degree division serves perhaps just this purpose. Altitudes are measured with the disc in the same manner as with the back of the astrolabe. From the system of horizontal coordinates, the altitude and azimuth of the point of the ecliptic situated opposite the Sun can be read off, from which these coordinates for the Sun itself are obtained. With their help it is possible to represent on the disc the zodiac in its position in the celestial sphere for that moment. The circle of the equator allows the measurement of time …”
Therefore it is possible to consider the shâmila as a combination of the quadrant or of the rear of the astrolabe with the celestial globe. It already functions as a quadrant because of the features just mentioned; in contrast to the quadrant, it has the advantage that it facilitates the perception of space more clearly. While the châmila only makes it possible to directly perform the observations related to the Sun, similar observations can also be carried out in connection with fixed stars with the astrolabe and the celestial globe; because the positions of these stars, or at least of the most important of them, are marked on these instruments. Furthermore, the celestial globe makes it possible to represent the motion of the entire celestial sphere, while the shâmila only represents that of the zodiac and of the equator. Nevertheless, the factor of spatial perception in the châmila cannot be ignored. In other words, while with the celestial globe we have to imagine ourselves to be situated outside the celestial sphere, with the shâmila we see the situation as in factual reality. From the centre of the sphere we observe how, e.g. the zodiac moves past the muqantarâs and the azimuthal circles, which we see on the inner surface of the celestial globe.

For the construction of our model, we relied on the work of J. Frank and on al-Ḥujândî’s complete description from the manuscript Bursa, Haraççıoğlu No. 1217, which was not yet known to Frank. In addition, we constructed a 90 degree scale, which consists of an arc of a quarter circle, whose radius corresponds to the inner radius of the hemisphere. The scale is attached to the axis in such a way that it rotates with the turning of the axis and, while rotating touches the inner side of the hemisphere.

The scale can be seen in the photographs in the top right-hand corner. The scale enables us to read off the measurements in the inner side of the sphere by individual degrees. A corresponding subdivision of the celestial meridians and the parallel circles on the inner surface of the sphere would be technically difficult even now.

Construction drawings from the MS Bursa, Haraççöglu No. 1217
The Torquetum

Our model:
Brass, etched.
Diameter 30 cm.
Height 75 cm.
The device can be set around three axes.
The latitude can be adjusted.
(Inventory No. A 4.20)

The torquetum was developed by the Andalusian astronomer Ġābir b. Aflāḥ in the 6th/12th c. and enjoyed wide distribution from the 15th century in Europe, particularly among German astronomers. The instrument is described in Ġābir b. Aflāḥ’s Išlāh al-Magisti. It represents the celestial planes of horizon, equator and ecliptic, which can be rotated one above the other, and serves the following tasks:

1. Determination of the size of the arc of the meridian between the two tropics (miqdār al-qaus allatī bain al-munqalabain).

2. Determination of the altitude of the Moon (nihāyat mail al-qamar min falak al-burūq).

3. Determination of the two equinoxes (waqt kull wāḥid min al-i’tidālān).


The instrument was already known in Europe in the 13th century.

Our model with Arabic script and Arabic numerals was constructed on the basis of specimens extant in Europe.

The “ruby-casket” was constructed by the famous astronomer ‘Ali b. Ibrāhīm Ibn aṣ-Ṣāṭir (d. ca. 777/1375) in 767/1366 for one of the Mameluk governors in Damascus. It contains two sundials, a polar one and an equatorial one. The latter serves to determine the hour angle according to the position of the Sun or of a star outside the zone of the equator. Today the instrument is with the Auqaf Library at Aleppo. It was made known for the first time in 1939-40 by Siegmund Reich and Gaston Wiet.\(^1\) This enabled the authors of the *History of Technology*\(^2\) of 1957 to give a brief description. Then, in


1976, it was [156] shown in the exhibition Science and Technology in London. Subsequently it was examined and described by Louis Janin and David A. King. In this study the instrument is not only evaluated historically, but an anonymous incomplete treatise is also edited with it and translated into English, which the authors assume had been written by Ibn aš-Šāṭīr to explain the instrument. However, the two scholars come to the conclusion that the anonymous text cannot provide the anticipated help in removing the difficulties connected with understanding the instrument; particularly because of its incompleteness, it creates as many problems as it solves. I wonder if the reason for this might not lie with the identity of the author. Perhaps it was not Ibn aš-Šāṭīr himself but another scholar who described the instrument with certain deviations. The difficulties mentioned arise mainly because some accessories of the instrument are missing. It is to be regretted that the two sights of the alidade are missing, one of which was still extant at the London exhibition. But more important, no doubt, is the loss of the movable disc with the diagram of the sundial of which we can now have an idea only from the rubbing by Reich and Wiet (see picture p. 155). In our model we set up a gnomon at the intersection of the coordinates, the length of which corresponds to the distance between the centre point and the eight-hour line. On the lid we added two sights, for the length and height of which we relied on a photograph from the London exhibition. On one of the inner surfaces of the casket we drilled six cavities at which the names and latitudes of six cities are engraved; while doing so, we started with the assumption that [157] a small post existed as a support for adjusting the desired latitude; the adjustment was probably done by inserting the post between the movable disc and the cavities made at appropriate

Our model:  
Brass, etched.  
12 × 12 × 2, 5 cm.  
Disc with gnomon adjustable to different latitudes.  
(Inventory No. A 4.36)

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2 Ibid., pp. 188, 189.

places in the wall on the side of the casket; thus the post allowed an inclination of the disc corresponding to the respective latitude. In more advanced successors of the device, a graduated quadrant (below, p. 158) served to adjust the apparatus for the local latitude. The meridional alignment of the portable casket was done, according to the descriptive text, by means of a compass (‘ibra). Probably a compass of suitable size was installed at the bottom of the device.

Presumably this is how the apparatus was used: After opening the upper lid by 180° and aligning the casket to the meridian, the southern edge of the lower movable plate is lifted up to the latitude of the place of observation. After that, the increasing or decreasing length of the shadow is observed. The intersections of the shadow with the northern or southern time curve mark the passing of the local hours. Along the outer semicircle geographical places are recorded. They stand for the zones whose qibla direction can be ascertained according to the adjustment of the casket.

The provinces and localities Şa‘îd (Upper Egypt), Miṣr (Cairo), Gazza, Dīmaṣq (Damascus), Ḥalab (Aleppo), Baghdād, al-Ṭabāra, Fāris (the Persis), Kirmān and al-Ḥind (Central India) are mentioned. When the casket is closed, the lid performs the tasks of an astrolabe.

The special importance of the instrument for the history of astronomy lies in the fact that it proves to be a new step in the course of development towards that instrument which came to be known as the torquetum in Europe (above, p. 154). In the following centuries this type, under the name dâ‘īrat mu‘addil an-nahār, caused the emergence of numerous successors with their own individual courses of development. This also applies to their European followers. The successors of the “ruby casket” in the Arabic-Islamic area presently known are: Dâ‘īrat al-mu‘addil, described by its maker ‘Īzzaddîn ‘Abdal’azîz b. Muhammad al-Wafî (d. 874/1469). The Arabic description with Turkish and English translation was edited by Sevim Tekeli in 1960. Muhammad b. Abî l-Fathîs-Šûfî (still alive 943/1536), who had already described the “ruby casket” under the title al-‘Amal bi-šandîq al-yawâqît, also left behind the description of a device of great similarity to that of ‘Īzzaddîn al-Wafî. He called his work al-Mufâṣṣal fi l-‘amal bi-nîsîf dâ‘īrat al-mu‘addil.  

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8 Edited by David King, Ibn al-Shâṭir’s Şandîq al-Yawâqît, pp. 248-250.
The description of a more advanced type of this instrument was discovered by William Brice, Colin Imber and Richard Lorch in the treatise *Mir'ät-i kā'ınät min ālāt-i irtifā‘* of the well-known Ottoman navigator Sidi ‘Ali Re’îs (d. 970/1562). They prepared the following diagram of the device described by Sidi ‘Ali:

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Fig. from Brice/Imber/Lorch, *The Dā'ire-yi Mu’addel of Seydi ‘Ali Re’îs*, p. 5.

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What is most remarkable in this connection is that Sidi ‘Ali points out the necessity of taking the magnetic deviation of 7° of the meridian circle passing through Istanbul into account, while using the built-in compass. An instrument largely resembling the one described by Sidi ‘Ali is preserved in the National Museum in Damascus (No. 11741). Its semicircle bears the date 1050 (= 1640 A.D.) while, according to an inscription on the equatorial circle, it dates from the year 1104 (= 1693 A.D.). Therefore, it seems to have been assembled from two parts dating from two different times.

\[\text{Diagram of the instrument from Damascus, National Museum, No. 11741}^{11}.\]

\[\text{Diagram of the instrument from Damascus, National Museum, No. 11741}^{14}.\]

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On the further development of the instrument we may cite two more examples:

1) The specimen of the observatory of Kandilli in Istanbul\(^{15}\).

Dāʾirat al-muʿaddil, from Kandilli\(^{16}\).

2) Another type of equatorial clock (muʿaddil an-nahār) was made by the same instrument maker who made the device in Kandilli in the year 1061/1651\(^{17}\) for Sultan Mehmed IV. The specimen which was in the possession of Christie’s of London a few years ago is equipped with two additional sundials, but the sighting aperture is missing.


\(^{16}\) From D.A. King, An Islamic Astronomical Instrument, op. cit., p. 52.

\(^{17}\) The date was inadvertently engraved wrongly on the instrument. The year 1161 is written instead of 1061. The instrument in Kandilli, mentioned above, dates from 1066/1656, the maker of both instruments called himself ‘Al－ al-Muwaqqit Abu l-Fath, v. M. Dizer, The Dāʾirat al-Muʿaddil in the Kandilli Observatory, p. 258 and picture 2.

The instrument functions according to the principle that the latitude of the equatorial plane is aligned to the horizontal plane of the place of observation. Thus this European sundial is part of the tradition of the devices called dā‘irat mu‘addil an-nahār from the Arabic-Islamic world. This type seems to have been widespread in Europe in the 17th and 18th centuries. In the Amsterdam exhibition catalogue Time\(^9\) of 1990, two such specimens are shown. One of them is in private possession, not closely specified, the other is in the museum of Utrecht University (No. A 34). Our model was constructed by Martin Brunold (Abtwil, Switzerland).

He gives the following instructions for using of the instrument:
1) Direct the index on the movable suspension ring to the geographical latitude.
2) Adjust the date slide.
3) Lift the hour ring up to the stop. Now it is at right angles to the meridian ring. The hour ring corresponds to the celestial equator.
4) Let the sundial hang freely from the suspension ring. The rotating axis of the date slide represents the Earth’s axis…The instrument must be moved back and forth a little around the vertical axis until the Sun’s ray passes through the hole in the date slide and falls upon the middle of the inner edge of the hour ring. There the true local time can be read off. The date slide can be turned to and fro and must be placed vertically in the sunlight.

A Table Sundial

A demonstration model, constructed by Martin Brunold (Abtwil, Switzerland) on the basis of originals from the 17th century. In his instructions, he explains the procedure as follows: “The small table sundial is based on the principle of the torque-tum … The three most important celestial planes, horizon, equator and ecliptic (the Sun’s orbit) are arranged one upon the other, and can be rotated; they permit the representation of the celestial motions occurring at the respective place of observation. The bottom disc with its four feet corresponds to the horizontal plane. It is initially placed on a horizontal surface, approximately according to the points of the compass, with the hinge pointing to the north … Above the bottom disc follows the disc that represents the plane of the celestial equator; it can be lifted up. The tilting of this surface depends on the geographical latitude of the place of observation … The plane of the equator carries the hour circle above which rotates a date disc. When the instrument is aligned to the Sun, the true local time with the correct date can be read off.”
Another

Table Sundial

A clock based on the same principle as the previous one. It was also constructed by Martin Brunold (Abtwil, Switzerland).

Drawing by M. Brunold.
In his *Istīʿab,* a book on the manufacture of astrolabes, the universal scholar Muhammad b. ʿAlī Muhammad al-Bīrūnī (d. 440/1048) describes a mechanical-astronomical calendar called *huqūq al-qamar* ("moon-box"). He wants to use it "to determine the waxing and waning of the Moon, that part of the month which has elapsed and the approximate position of the two luminaries (namely the Sun and the Moon)." Eilhard Wiedemann ² deserves credit for having been the first to recognise the importance of the instrument and to have made it known through a detailed description.

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¹ v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, p. 268.
Al-Biruni solves the task by means of the combined action of eight cogwheels with a transmission ratio of


Our replica represents an approximate reproduction of the instrument as described by al-Biruni; its perfect form becomes intelligible through an extant version by Muhammad b. Abi Bakr al-Isfahani (below) from the year 618/1221. Al-Biruni does not claim to be the inventor of the instrument. He merely lays claim to the improvement of the mutual ratio of the cogwheels. Among his predecessors he mentions Bastitalus\(^3\) (Muhammad b. Muhammad al-Asturlabi) and al-Hasain b. Muhammad Ibn al-Adam\(^4\).

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\(^3\) Lived in the second half of the 3rd/9th century, v. F. Sezgin, 
*Geschichte des arabischen Schrifttums*, vol. 6, pp. 178–179, 288

\(^4\) Died probably around the turn of the 3rd/9th to the 4th/10th century, v. F. Sezgin, *Geschichte des arabischen Schrifttums*, vol. 6, pp. 179–180.
Instrument for Determining the Altitude of Stars in Minutes

Our model: Brass, etched, cogwheels and gear-rim of steel, diameter: 170 mm. Gear drive with 5 cogwheels and 2 balance cogwheels, transmission ratio 1 : 60. (Inventory No. A 2.21)
Zainaddin 'Umar b. Sahlān as-Sāwī, who officiated as judge in Nīsābūr in the first half of the 5th/11th century, bequeathed to us a hitherto unknown treatise on an instrument with which the altitudes of stars can be found correct to a minute. The text is called Ṣifat ʿala yūṣal bihā ilā maʿrifat irtifāʿ al-kawākib bi-daqāʾiq. It is preserved in a single manuscript in Istanbul that was recently made accessible through a facsimile edition published by the Institute for the History of Arabic-Islamic Science in Frankfurt. The result of the measurement found in degrees through the alidade and the degree scale of the astrolabe on the front of the apparatus is transmitted, according to the inventor, to the back of the device, by means of built-in cogwheels, where one can read off the minutes by means of one more pointer.

The transmission gearing consists of five cogwheels and two balance cogwheels (muʿaddila), whose exact diameters are given. The outermost cogwheel moves within the inner edge of the astrolabe in a gear-rim and covers 90° in each quadrant. The alidade moves around the axis of the central cogwheel. When it is moved up or down in the circle of degree divisions, the pointer at the back also turns and shows the subdivisions in minutes.

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Mechanical-Astronomical
Calendar

by Muḥammad b. Abī Bakr al-ʿIṣfahānī

Al-Bīrūnī’s mechanical-astronomical calendar lives on, with some further development, in a version dating from 618/1221 by a certain Muḥammad b. Abī Bakr al-ʿIṣfahānī. The original of this model is in the Museum of the History of Science in Oxford (No. 1221-22, CCL 5). Our institute owns two replicas that were made on the basis of the original; the first one of these is closer to the original. The spider carries the positions of 39 fixed stars. The only disc is meant for the latitudes 30° and 34°. The not visible gear-mechanism functions with eight cogwheels. Of the annular rings in the lower half of the back, the outermost one is meant for the zodiac signs, the second for the 30 days of the lunar month, the third is divided into 360°, the movable fourth ring shows the position of the Sun and the fifth the position of the Moon. The disc divided into black and white areas at the top of the back shows the daily waxing or waning of the Moon. The small window next to it tells the date. It is worth noting that Derek J. de Solla Price, in his study of 1959 on the origin of the clockwork, drew attention to a possible connection between the mechanical-astronomical instruments of the Arabic-Islamic world and the mechanical-astronomical devices appearing in the Latin world since Richard of Wallingford (1st half of the 14th c.). While suggesting this, Derek Price relied primarily on the great similarity between the French-Gothic cogged wheel astrolabes (below, p. 170) and the same of Muḥammad b. Abī Bakr al-ʿIṣfahānī.


First Model,
made by
Eduard Farré (Barcelona)

Diameter: 18.5 cm.
Brass, engraved.
(Inventoty No. B 3.07)

Second Model,
made by
Martin Brunold
(ABtwil, Schweiz)

Diameter: 12 cm.
Brass, engraved.
(Inventoty No. B 3.06)
With great probability the calendar emerged from the tradition that we know now from a description by al-Bīrūnī (above, p. 164) and from the mechanical-astronomical calendar by Muḥammad b. Abī Bakr al-Īṣfahānī. The great similarity between the gear mechanism of the French-Gothic calendar and that of Muḥammad b. Abī Bakr al-Īṣfahānī was already pointed out by Silvio A. Bedini and Francis R. Maddison.¹

What is particularly remarkable about the French-Gothic instrument is that the double digit numbers of the days of the month are written from right to left, creating the impression as if the imitator had attempted to reproduce with his numerals the Arabic numerals, without, however, knowing that these are written from left to right contrary to the direction of the common Arabic mode of writing.

The Instrument

with the Sphere that turns uniformly around itself

The astronomer and instrument maker Muḥammad b. Ahmad al-Ḥāzimi (made observations in Isfahan around 453/1061) describes this device in a treatise on the “Construction of a globe which turns in uniform motion around itself, according to the motion of the celestial sphere” (Maqāla fi ttiḥād kurātīn tadāru bi-dāṭihā bi-ḥaraka mutasāwiyā li-ḥarakat al-falak). A celestial globe with constellation figures, the ecliptic and the celestial equator is brought to uniform rotation as follows: Through a glass tube sand trickles down through a regulated nozzle and lets a weight resting on the sand sink downwards. A rope attached to the weight causes, through gears, the globe to turn once around on its own axis while the sand trickles out completely within 24 hours (in our model the process is accelerated). The time can be read off with a precision of four minutes on a scale that encloses the equator on the stand.