Chapter 1

Astronomy
The whole universe obeys a strict order, howsoever variable its affairs might be, and there is harmony between all its parts, howsoever different they happen to be.

Ibn al-Haïtam (d. 432/1041)
(From: *Maqâla fi Kaifiyat ar-raṣad*)
[3] Introduction

Astronomy, in Arabic ‘ilm al-hai’a or ‘ilm al-falak, is one of the mathematical sciences (al-‘ulûm ar-riyâdîya) and is distinguished from astrology, ‘ilm ahkâm an-nu‘ûm or šinâ‘at ahkâm an-nu‘ûm (science or art of the laws of the stars). Before the advent of Islam, the Arabs possessed no scientific astronomy, but they did have a rich knowledge of the stars.¹ This knowledge is generally thought to be an offshoot of the Chaldean astronomy.² More than 300 stars are mentioned by name in old Arabic and early Islamic-Arabic poetry.³ Hommel’s view that some of the names go back to the Akkadian and Sumerian⁴ seems to be correct. It also seems to be certain that the Arabs knew the signs of the zodiac in the 1st/7th century,⁵ although it cannot be ruled out that this knowledge goes back to times prior to Islam.

Noteworthy in this connection is the caldarium in the bath wing of the small castle Qusair ‘Amra” (east of ‘Ammân in today’s Jordan), in the dome of which the fresco of a celestial atlas is preserved. Alois Musil dealt with the Umayyad palace from the time of 711–715 in his essays and monographs from 1902, and Fritz Saxl and Arthur Beer⁶ pointed out the importance of this star chart for the history of astronomy. It contains some 400 stars, constellations and signs of the zodiac with their celestial coordinates. Without going into the question of the prototype or the source of this representation, we may state that the artists had created a map of the heavens whose meaning [4] they had to explain, if need be, to their patron, an Umayyad prince.⁷

8 F. Sezgin, Geschichte des arabischen Schrifttums, vol. 6, pp. 11–12.
The important evidence of the fact that the representatives of the older cultures already found favourable circumstances in the new cultural circle of becoming active in the scientific sphere in the first century of Islam, includes a report by the universal scholar al-Biruni⁹ (d. 440/1048) stating that he knew of an old Žiğ text with astronomical tables on parchment. Here the dates were mentioned according to the Diocletian era (the Coptic calendar). The Žiğ contained, Biruni says, addenda by an anonymous author, among them horoscopes and solar eclipses from the years 90 and 100 of the Hijra (710 and 719 AD). The same hand also entered the latitude of the city of Bust as 32°. Al-Biruni thought it advisable to dispel possible doubts about the existence and authenticity of this old book by mentioning the name of its owner. Also through al-Biruni we learn that the Umayyad prince Ḥalid b. Yazid, who occupied himself with sciences,¹⁰ had the pseudo-Ptolemaic astrological work καυστός (Kitâb al-Tamara), which was not lacking in astronomical elements, translated into Arabic¹¹ before the end of the 1st/7th century. From the point of view of the early encounter of the Muslims with Aristotelian-Ptolemaic notions of the structure and the motion of the universe, it is instructive that the pseudo-Aristotelian tract περί κόσμου (Kitâb al-ʿĀlam) was already translated into Arabic under the rule of Hišâm b. ʿAbdalmalik (ruled 105/724-125/743). From its cosmological-geographical and meteorological contents, the Muslims learnt¹² that “the Earth was at the centre of the universe. It moved continuously with the entire heavens, therefore there had to be an axis between two opposite immovable points around which the celestial sphere could turn. The northern of these two poles was always visible as against the southern which was under the Earth. The substance of the sky and of the stars was called ether; it was an element and, unlike the four known ones, was everlasting. The fixed stars revolved together with the entire heavens; ‘in their midst the so-called zodiac is stretched diagonally through the tropics [5] as a girdle, divided into parts after the positions of the twelve animals of the circle.’ The number of stars was immeasurable for man. The others, the star planets, were seven in number. They differed from one another in their nature and speed as also in their..
distance to the Earth, and moved in their own orbits that lay inside one another and were surrounded by the sphere of the fixed stars.”

In 154/770 the time was already ripe enough for the voluminous Siddhânta by Brahmagupta13 with its complicated content to be translated from Sanskrit into Arabic at the behest of Caliph al-Manšûr. The time of the translation of the most important works of Indian astronomy may be considered the beginning of scientific astronomy in the Arabic-Islamic world. That it was possible even at such an early period to translate Brahmagupta’s Siddhânta into Arabic can only be explained by the fact that a kind of reception of the Greek, Indian and late Babylonian sciences had already commenced in Persia under the Sassanids several centuries prior to Islam, and that the translators of the Siddhânta were also among the youngest representatives of this eclectic school. They did not merely translate the text; they also began to improve and supplement it, and to compose their own astronomical works.14

The rapid development of astronomical knowledge led to the translation of Ptolemy’s main works into Arabic. In this process, his book of the “Handy Tables” (πρόχειρων κανόνες) was rendered15 from a translation that had originated in the Sassanid school.

The familiarity with scientific literature had already advanced so far that in the last quarter of the 2nd/8th century the translation of the complicated and voluminous Almagest of Ptolemy could be carried out. This happened on the order of the statesman Yahyā b. Hālid al-Barmaκī (120/738-190/805). To judge the level reached even at that time in the Arabic-Islamic area with regard to astronomy—in fact the sciences in general—it is revealing that the patron was not satisfied with the translation and commissioned others to undertake a second translation.16

The present state of research gives the impression that astronomical science in the Arabic-Islamic language area was already at the threshold of the period of creativity in the first quarter of the 3rd/9th century, when the reception and assimilation were not yet fully concluded. As indications of this we may mention the following: Caliph al-Ma’mûn assigned to the astronomer Yahyā b. Abî Mansûr17 (d. between 215/830 and 217/832) the task of verifying the data and observations of Ptolemy’s above-mentioned ‘Handy Tables’. The results of this undertaking were presented to the Caliph in the work az-Zâg al-Ma’mûnî al-muntahâh (“The Ma’mûnian verified Tables”).18 Research showed that Yahyā b. Abî Mansûr used an approximation method, which Ptolemy did not know,19 for the determination of eclipses. In the works of his contemporary Muḥammad b. Mūsâ al-Ḥwârizmī (active mainly at the time of Caliph al-Ma’mûn) indications can also be found for innovations in the field of applied astronomy. As an example, we may mention his procedure for determining the altitude of the pole, i.e. the local latitude, from the altitude of the upper and lower culminations of a circumpolar star.20 The evidence also includes the fact that, during an expedition by Caliph al-Ma’mûn against Byzantium, the astronomer and mathematician Sind b. ‘Alī21 employed a new method for the measurement of a degree of the meridian, which he undertook on the ruler’s orders. On a coast high above sea level, Sind b. ‘Alī measured the depression of the sun when it was setting and with that calculated trigonometrically the size of the Earth’s circumference.22 (see Fig. next page)

[6] Al-Birûnî also used this method on a mountain rising high above a plain. Later, the method was connected with the names of Francesco Maurolico (1558), Sylvius Belli (1565) and Francesco Giuntini (d. 1580).23

13 F. Sezgin, Geschichte des arabischen Schrifttums, vol. 6, pp. 118–120.
14 Ibid., vol. 6, pp. 122–127.
15 Ibid., vol. 5, p. 174; vol. 6, pp. 13, 95–96.
16 Ibid., vol. 6, p. 85.
17 Ibid., vol. 6, p. 136.
21 Ibid., vol. 6, p. 138.
22 Ibid., vol. 6, p. 138; vol. 10, p. 96.
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Calculation of the Earth’s radius by Sind b. ‘Ali.

We should also mention here the subsequent measurements of the Earth’s circumference that were done on Caliph al-Ma’mūn’s orders. He repeatedly tried to ascertain the length of a degree of the meridian as accurately as possible. The measurements were taken by several astronomers either in the plains of Sinḡār or between Raqqa and Tadmur (Palmyra). The task was accomplished with instruments for determining the position of the Sun and the line of the meridian, and with the help of staves and ropes. After repeated measurements had produced values between 56 1/3 and 57 miles, it was decided to take the mean value of 56 2/3 as the length of a degree of the meridian. The result differs just minutely from today’s accepted value. According to C. A. Nallino, this was the first scientifically achieved measurement, accomplished by an effort that lasted over a long period of time. From the point of view of the rapid development of astronomical science in the following centuries, it was undoubtedly of great significance that al-Ma’mūn established observatories in Baghdad and also on Mount Qāsiyūn, north of Damascus. These were probably the first regular observatories run by the state.

The attempt to find new astronomical data as exactly as possible and to verify older data characterizes the main goal of Arab-Islamic astronomers in the 3rd/9th and 4th/10th centuries. Since they possessed—as compared to their Greek, Indian and Sassanid-Persian predecessors—better methods of computation, better instruments for measuring and observation, and a better technique of observation, they came remarkably close to this goal. If we are to mention some of the relevant results achieved by the astronomers of those days, then we must count the substantially improved value for the precession of the equinoxes at 1° in 66 years, that is to say 55” in one year, which already appears in Tābit b. Qurra’s works. Ptolemy, following Hipparchus, had calculated this phenomenon with 1° in one hundred years, which corresponds to 36” in one year. Later astronomers, beginning with al-Battānī, improved the value. Naṣrāddīn at-Ṭūsī (d. 672/1274) calculated it as 1° in 70 years, i.e. 51” in one year, a value “which the modern period could almost adapt as its own.”

Towards the end of the 3rd/9th century, there arose in the circle of Arabic-Islamic astronomers the view that the Sun’s apogee (augh aš-sans) moves in the direction of the ecliptic (i.e. in the direction of the increasing longitudes of the heavens). Tābit ibn Qurra’s works. Ptolemy, following Hipparchus, had calculated this phenomenon with 1° in one hundred years, which corresponds to 36” in one year. Later astronomers, beginning with al-Battānī, improved the value. Naṣrāddīn at-Ṭūsī (d. 672/1274) calculated it as 1° in 70 years, i.e. 51” in one year, a value “which the modern period could almost adapt as its own.”

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In the second half of the 5th/11th century Ibrāhīm b. Yahyā az-Zarqālī found

\[ \cos \alpha = \frac{r}{r + h} \]

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26 Ibid., vol. 6, p. 20.
27 This has to do with the annual advance of the vernal equinox, which is measured according to its longitudinal distance from Spica. Modern astronomy considers the precession of the equinoxes to be caused by the flattening of the Earth; v. R. Wolf, Handbuch der Astronomie, ihrer Geschichte und Literatur, vol. 1, Zurich 1890 (reprint Hildesheim 1973), pp. 440–442.
28 The question of the earliest knowledge of this phenomenon seems not yet to have been answered definitively; v. Otto Neugebauer, The alleged Babylonian discovery of the precession of the equinoxes, in: Journal of the American Oriental Society (Ann Arbor) 70, 1950, pp. 1–8; Peter Huber, Über dem Nullpunkt der Babylonischen Eklip tik, in: Centaurus (Copenhagen) 5, 1956–58, pp. 192–208.
30 R. Wolf, Handbuch der Astronomie, p. 441.
33 Ibid., vol. 6, p. 263.
the value of the forward movement of the apogee to be one degree in 279 years, i.e. 12.09° in one year, which approximates to the present value.\textsuperscript{34} As a consequence of their continuous observation of the sky, the astronomers of the Islamic world achieved other important results. İbrahim b. Sinân b. Tābit (lived between 296/909 and 335/946) was obviously the first person to realize that the obliquity of the ecliptic is not constant. He explained the deviations noticed in the results of his observations in the course of time as a consequence of sudden and irregular movements of the world’s axis.\textsuperscript{35} His contemporary Abū Ğafar al-Ḥāzin reached the same conclusion.\textsuperscript{36} Their younger contemporary, Ḥamîd b. al-Ḥijr al-Ḫuγândî, motivated his patron, the Buyid ruler Fâraddaula (ruled 366/976-387/997), to build an observatory with a sextant with a radius of ca. 20 m in Raiy (in the south of modern Tehran) to obtain a more accurate result on the question of the obliquity of the ecliptic. His observations, made possible through this, led him to the conviction that the obliquity of the ecliptic declines continuously in the course of time.\textsuperscript{37}

Even before al-Ḫuγândî’s explanation, the attempt to reconcile the changes in the obliquity of the ecliptic with the precession had led Tābit b. Qurra to propound the hypothesis of the trepidation, a forward and backward movement of the fixed stars (\textit{harakat al-iqbâl wa-l-idhâr}).\textsuperscript{38} This hypothesis proved to be more of a stimulus for astronomers in Europe than for those in the Arabic-Islamic world. As far as the advances made in respect of topics like the total solar eclipse, variability of the Sun’s diameter, eccentricity of the Sun’s orbit, computation of the parallaxes, as well as the computation of the first visibility of the crescent Moon, I restrict myself to a reference to the relevant pages in the Geschichte des arabischen Schrifttums (vol. 6, pp. 27-28). Only the case of fixed star astronomy may be briefly mentioned here.

As stated already, before the advent of Islam the Arabs possessed quite a good knowledge of the fixed stars. In Islamic times there was at first a remarkable philological comprehension of this subject. Only after the acquaintance with the Ptolemaic Almagest, did a preoccupation with fixed star astronomy proper begin. After the work accomplished by the Greek predecessors, this branch of astronomy reached a new climax in the second half of the 4th/10th century in the work of ‘Abdarrahmân aš-Šûfî,\textsuperscript{39} in particular through his Kitâb Suwar al-kawâkid at-tâbîta.\textsuperscript{40} This eminent astronomer verified the data in the catalogue of Hipparchus-Ptolemy on the basis of his own observations and measurements, and compiled a new catalogue with largely revised scales of brightness, coordinates and magnitudes of stars. A further revision of the star catalogue was made on the basis of fresh observations at the observatory of Ulûg Beg (d. 853/1449) in Samarqand. This new catalogue distinguished itself from its predecessor primarily through more precise coordinates.

‘Abdarrahmân aš-Šûfî, together with Ptolemy and Argelander (d. 1875), is considered to be one of the three great pioneers of fixed star astronomy. For centuries, he deeply influenced the subject not only in the Islamic world but in Europe as well.\textsuperscript{41} The fixed star catalogue in the Alfonsine compendium \textit{Libros del saber de astronomia} (ca. 1277) is nothing but a free Castilian rendering or revision of ‘Abdarrahmân aš-Šûfî’s work. An Italian translation, prepared after the Castilian version in 1341 [8] has been known since 1908.\textsuperscript{42}

“In what high esteem Şûfî was held in the Occident as late as at the beginning of the modern age can be seen from the fact that Albrecht Dürer mentions him under the name of Azophi as one of the four great representatives of astronomy”\textsuperscript{43} (see Fig. next page).

\textsuperscript{34} F. Sezgin, \textit{Geschichte des arabischen Schrifttums}, vol. 6, pp. 26-27.
\textsuperscript{35} Ibid., vol. 6, p. 194.
\textsuperscript{36} Ibid., vol. 6, p. 189.
\textsuperscript{37} Ibid., vol. 6, pp. 220-222.
\textsuperscript{38} Ibid., vol. 6, p. 164.
\textsuperscript{39} F. Sezgin, \textit{Geschichte des arabischen Schrifttums}, vol. 6, pp. 212-215.
\textsuperscript{40} Facsimile edition of Institut für Geschichte der Arabisch-Islamischen Wissenschaften, Frankfurt 1986.
\textsuperscript{41} F. Sezgin, op. cit., vol. 6, p. 212.
The remaining names in Dürer’s wood-cut of the celestial map of 1515 besides Azophi Arabus are Aratus Cilix, Ptolemeus Aegyptius and M. Manilius Romanus. In connection with fixed star astronomy, we may also mention that the question of whether or not the Milky Way formed part of the fixed stars was clearly decided and discussed by Ibn al-Haitam (d. 432/1041),

In general, we may cite here the impression already gained in a relatively early stage of modern research on Arabic-Islamic astronomy by the scholar C. A. Nallino on the great progress made by the Arabic astronomers, as against their predecessors, in the development of observational instruments and new methods: “Lastly, in the application of trigonometrical formulae, in the number and the quality of their instruments, in the technique of their observations the Arabs have splendidly outstripped their predecessors the Greeks. In the number, continuity and precision of the observations we mark the most striking contrast between Greek and Muslim astronomy.”

Another set of noteworthy topics were the views and hypotheses of the Arabic-Islamic astronomers on the question of the Earth’s rotation and on their planetary theories. The Greek notion that the Earth was formed as a sphere reached them at the latest with the pseudo-Aristotelian tract περὶ ἀλέσιης towards the end of the 1st/7th century and was accepted without any opposition whatever. From it they learnt that the Earth lay at the centre of the universe and that the latter moved continuously together with the entire heavens (above, p. 4). It seems the question of the Earth rotating around itself was discussed again and again from the 3rd/9th century onwards—not only by astronomers but by philosophers as well. But for a meagre statement by Plutarch (d. ca. 120 to 125 AD) in the Placita philosophorum, no other impulse seems to have come on this subject from the side of the Greeks. In any case, Aristarchus’s view of a heliocentric system does not seem to have reached them. On the other hand, they learnt at the latest through al-Biruni about the view of the Indian astronomer Aryabhata (ca. 499 AD) on the Earth’s rotation. The geographer Ibn Rustah (last quarter of the 3rd/9th c.) speaks, among other things, about the theory that the Earth is situated in the universe, but not at its centre, and that it rotates, but not the Sun nor the outermost sphere. From al-Biruni we learn the names of two Muslim scholars who advocated the idea of the Earth’s rotation. They are Ahmad b. Muḥammad as-Siḡzi (2nd half of the 4th/10th c.) and Gaʿfar b. Muḥammad b. Ǧarir (4th/10th c.). Starting with this notion, they both are said to have built an astrolabe in the form of a boat.
Al-Bīrūnī appears to have seriously tried to reach a satisfactory clarification of this question. He wrote a treatise on this issue entitled “On the Rest or Motion of the Earth” (Kitāb fi Sukūn al-ard au harakatihā), which is not extant. For a long time he was probably vacillating as to whether or not he should decide for the Earth’s rotation, but towards the end of his life he reached the conviction that the Earth, after all, was at rest. In his work on India (written ca. 421/1030) he says: “The rotation of the Earth does in no way harm the results of astronomical science, but the things which belong here are logically connected (even with this assumption) in the same way. There are other reasons which should make this assumption impossible.” Ibn al-Haıtām also deals with the question in his commentary on the Almagest and declares himself against the rotation.

It should be noted further that in the first half of the 4th/10th century Abū Ǧa’far al-Ḫāzīn found a new explanation for the apparent non-uniformity of planetary revolutions, as can be seen from al-Bīrūnī’s citations. In the model proposed by him he rejects the theories of eccentricity and epicycles, and replaces them with the assumption of variations of the respective planetary orbits up to the plane of the ecliptic. A similar model is proposed by Heinrich of Langenstein (1325-1397).

In the course of the geometrical representation of the planetary motions in continuation of the work by their Greek predecessors, the Arab astronomers postulated a wealth of theories from the second half of the 4th/10th century onwards which were to bear their most important fruit in the work of Copernicus.

Abū Naṣr b. ʿIrāq, the teacher of al-Bīrūnī (2nd half of the 4th/10th c.), discusses from various aspects the possibility of elliptical planetary orbits with very small difference between the lengths of the two axes and the possibility of the actual non-uniformity of revolutions. As against the view of a colleague, to which he refers here, he himself is convinced of a constant, uniform motion of the planets. The apparent non-uniformity and the variations in the diameter of the planetary orbits, noticed in observations, were to be explained with eccentricity. Obviously he did not consider it necessary to take the help of epicycloidal motion.

At the beginning of the 5th/11th century Ibn al-Haıtām introduces the theory of spheres of the Ptolemaic Hypothesis into Arabic astronomy. Accordingly the mathematical model of the heavenly motion had to be replaced with the concept of tangible hollow spheres. Without doubt this recasting of the traditional presentation of the Almagest, which was largely followed until the 16th century both in the Islamic world and in the Occident, was in a way a retrograde step. However, with this attempt by Ibn al-Haıtām an entirely new explanation of the planetary motions becomes evident. He states this in the following words:

“1. The natural body on its own does not perform more than one single natural motion.”

“2. The natural simple body does not perform a motion of variable speed, [10] i.e. it always covers the same distances in the orbits during the same periods of time.”

“3. The body of the heavens is not susceptible to any influence.”

“4. Empty space does not exist.”

An important step in the elucidation of the Ptolemaic planetary model was again taken by Ibn al-Haıtām. In his tract on the doubts about Ptolemy, he is the first to notice that, in his explanation of planetary motion, Ptolemy violates the basic principle of uniform motion by introducing the equant, because after this the motion of the centre of the epicycle in the deferent does not remain uniform any more. As we learn from a quotation, Ibn al-Haıtām developed his own planetary theory in which he...
enumerate the conditions for the uniform motion of the planets. The context of this introduction does not permit us to trace the lasting influences which resulted from this attempt.

The well-known representatives of the new planetary models of the 7th/13th and the 8th/14th centuries were Naṣīraddin at-Ṭūsī (d. 672/1274), Qūṭbāddin aṣ-Ṣarāżī (d. 710/1311) and ‘Alī b. Ibrāhīm Ibn aṣ-Ṣāṭīr (d. ca. 777/1375). Their attempts to free the system of planetary motions from Ptolemaic defects, each through his own kinematic model, reached their climax with the latter scholar. In his models, Ibn aṣ-Ṣāṭīr removes eccentricity and lets the vector (one for each planet) start from the centre of the universe, while accepting at-Ṭūsī’s principle of double circles. Particularly important is his model of Mercury. He also succeeds very well in his attempt to create a better model than his predecessors for lunar motion. While creating the uniform circular motion of the Moon, he corrects Ptolemy’s grave mistake by exaggerating the variation of the Moon-Earth distance.

In the 6th/12th century in the western part of the Arabic-Islamic cultural sphere opposition to the Ptolemaic image of the world arose, the arguments of which were more of a philosophical than a kinematic-geometrical nature. The philosopher Ibn Bāḡga (Avempace, d. 533/1139) rejected the existence of epicycle and thought that the force of eccentricity would account for all planetary orbits. About half a century after him, Ibn Tufail (d. 581/1185) intervened in the discussion and rejected the theory of eccentricity as well as that of epicycles. He believed to have found his own explanation but does not seem to have put it to paper.

His contemporary Muḥammad b. Ahmad Ibn Ruṣd (Averroes, d. 595/1198) also rejected the theories of eccentricity and epicycles. According to his view, the planets followed a spiral motion (haraka laulabiya).

The youngest representative of the Western school in the Arabic-Islamic world was Nūrāddīn al-Bītrūḡī (d. 600/1204). He too rejected the theories of eccentricity and epicycles, and was of the opinion that the planetary spheres must lie concentrically around the centre of the Earth, and that the planets, as with Ibn Ruṣd, move in a spiral around different axes. While proposing this, he disavowed the west-east motion of the celestial bodies; it was merely an optical illusion that came about because the planets moved from the east to the west, but much more slowly than the celestial sphere.

The work of al-Bītrūḡī (Alpetragius), after its translation into Hebrew and Latin, “progressively influenced scientific-astronomical thinking” in the Occident from the 7th/13th to the 9th/15th century.

When I now proceed to give an idea of the process of reception and the continuation of astronomy in the Occident in broad outlines, [11] I will restrict myself to taking up a few points from what I discussed rather extensively (pp. 37-59) in the sixth volume of my Geschichte des arabischen Schrifttums twenty-five years ago.

Like the other sciences and the philosophy of the Arabic-Islamic world, astronomy too reached Europe mainly through the paths of Spain, Sicily/Italy and Byzantium, if one leaves aside the knowledge, the books, instruments and also maps that reached the West through human contacts, particularly during the Crusades.

According to the state of our knowledge, the notion may be correct that, at the latest in the 4th/10th century, there existed in the parts of the western Occident bordering on the Arabic-Islamic world, the desire to take over the foreign knowledge through translations, and that conditions had been created for such translations. The earliest translator known by name was Lupitus of Barcelona, who rendered an astronomical treatise into Latin under the title Liber de astrologia for Gerbert of Aurillac in the year 984 AD. Likewise from the 10th century a
compendium of scientific topics is preserved in Barcelona which contains among others tracts on *De mensura astrolabii* and *De utilitatis astrolabii* and a *Geometria*. There is no doubt that these treatises are free translations or adaptations of Arabic models. The second oldest known author of a tract on the astrolabe in the Occident (*De utilitatis astrolabii*), Gerbert, obviously used these and perhaps other treatises as his basis. He retains the Arabic technical terms and the form of the Arabic astrolabe. His adaptation of Arabic texts on the astrolabe led to further books on the same subject in the 11th century.

While the city of Toledo (under Muslim rule from 711 to 1085) was the most important centre of reception of Arabic-Islamic sciences in the 10th and the 11th centuries, cities like Chartres, Toulouse, Reims, Tours, Montpellier and Paris became centres of reception and assimilation in the 12th century. From the first half of the 12th century more important and more voluminous works of Arabic astronomy already became accessible in translations.

The handbook of astronomy by al-Battânî, which contains substantial innovations and corrections of Ptolemy’s *Almagest*, was translated into Latin by Plato of Tivoli around 1120. Through it for the first time the Ptolemaic image of the world also became known to a large extent among scholars of the Occident. This was followed by the translation of al-Fargâni’s (1st half of the 3rd/9th c.) popular handbook of astronomy by Johannes Hispaniensis (Hispalensis) around 1134. The astronomical tables of al-Ḥwārizmī (1st quarter 3rd/9th c.) were translated around 1120-30 by Adelard of Bath.65

While the process of reception of Arabic-Islamic astronomy in the Occident was not yet over, towards the middle of the 12th century certain signs can be noticed for the beginning of an assimilation of the newly gained knowledge. The gradual transition from one stage to the other and finally to that of the Occident’s own creative activity took around half a millennium from the 10th century. This [12] process is made vivid for the reader through the material from Latin and Hebrew translations which P. Duhem compiled and interpreted in the third and other volumes of his work *Le système du monde*.

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65 F. Sezgin, op. cit., vol. 6, p. 39 s.
66 F. Sezgin, op. cit., vol. 6, p. 42.
67 Ibid., vol. 6, pp. 42–44.
Toledan Tables in the Occident. Of special interest is the fact that he attempted, in an elucidation of Ptolemaic astronomy under the title Astrologia, to present the theory of trepidation by Tābit b. Qurra and az-Zarqāli as well as al-Bītrūǧi’s system, very clearly differentiated from one another.68

At the beginning of the 13th century, this circle of scholars already knew from other translations—besides Gābir b. Aflah’s critique of the Almagest—about the battle fought by the philosophers of the western part of the Islamic world against the Ptolemaic image of the world. Michael Scotus (d. ca. 1235) not only translated al-Bītrūǧi’s work on astronomy, but also Ibn Ruṣd’s commentaries on Aristotle’s Metaphysics and De caelo, where Ibn Ruṣd spoke against eccentricity and epicycles, and emphasised the necessity of projecting a new world system. With this, the translator Michael Scotus was the first to introduce into the Latin world the basic principles of the anti-Ptolemaic theories of Ibn Ruṣd and al-Bītrūǧi. For his contemporaries, it was quite confusing that he put together the exposition of Ibn Ruṣd and al-Bītrūǧi in a text under the title Quaestiones and circulated them under the authorship of Nicolaus Damascenus (b. 64 B.C.).69

Under the influence of Michael Scotus, William of Auvergne (Guillaume d’Auvergne), bishop of Paris (1228-1249), who fought Averroism in the field of theology, also adapted al-Bītrūǧi’s system of the configuration of the world in his De universo. In De universo he propounded the view that al-Bītrūǧi’s thesis was suitable to show that the entire heaven was moved according to the principle of a sole mover.70

About the middle of the 13th century a fierce dispute between the adherents of Ptolemy and those of al-Bītrūǧi was already raging. Robert Grosseteste (d. 1253) belongs to the important personalities of the assimilation process of Arabic sciences. That his scholarship must be judged under this aspect was made clear by P. Duhem71 for the field of astronomy. In his Compendium sphaerae, Grosseteste, as the first in the Christian Occident, introduces the principles of Tābit b. Qurra’s work on the eight spheres, among them the theory of trepidation, and discusses the views of Ptolemy and al-Battānī. He speaks about “al-Bītrūǧi’s discovery” which he also calls “the system of Aristotle and al-Bītrūǧi”. According to Duhem,72 Grosseteste does not know Aristotle’s system of homocentric spheres. He identifies it with that of al-Bītrūǧi to which alone his exposition refers. Also the treatises Opuscula and Tractatus de inchoatione formarum, circulated under his name, clearly show al-Bītrūǧi’s influence.73 Duhem74 states that the indecision towards the principles [13] of astronomy is shared by Grosseteste and many of his contemporaries: on the one hand he followed the (Arab) adherents of Ptolemy in questions that have to do with the motion of the planets and the preparation of the calendar, and accepted the theories of eccentricity and epicycles; on the other, he let himself be enticed by the simplicity of al-Bītrūǧi’s homocentric spheres.75

Albertus Magnus (ca. 1200-1280), one of the most famous Occidental scholars of his century, in his far-reaching scholarship discussed anew al-Bītrūǧi’s system of the world and introduced it to wider circles in a simplified and partly modified form. In his dispute with the Ptolemaic system he is mainly dependent on Arab astronomers, particularly on Tābit b. Qurra.76

The vacillating attitude of the Dominicans around Albertus Magnus towards a decision for or against one of the two systems also applies to a large extent to the Franciscans around Roger Bacon (ca. 1219-1292). As Duhem77 saw quite rightly, Bacon attempted throughout his life to reach a decision about the one system or the other, but he remained forever undecided. He knew the astronomy of al-Faḡānī and al-Battānī rather well, preferred Tābit’s value of the precession to that of Hipparchus and Ptolemy, accepted Ibn al-Haṭam’s concept of solid spheres, and considered on the antagonistic side not only al-Bītrūǧi but also Ibn

72 Ibid., vol. 3, p. 283; F. Sezgin, op. cit., vol. 6, p. 46.
75 F. Sezgin, op. cit., vol. 6, p. 47.
Rušd as representatives of the concentric image of the world.  

The decision in favour of the teachings of Ptolemy and his Arab adherents was taken by another Franciscan, Bernardus de Virduno (late 13th c.) in Paris namely on the basis of Ibn al-Haïtam’s concept of solid spheres which he called "ymaginatio modernorum". With this, the victory of the Ptolemaic system with its eccentric spheres over that of al-Bittegü was once and for all assured among the Franciscans.

Among the Parisian scholars, Levi ben Gerson rejected from the traditions which his—mostly elder—colleagues cherished, particularly the homocentric system of spheres of al-Bittegü to whom he refers otherwise as the "master of the new principles of astronomy". With him, something new makes its appearance in the Parisian school, namely the critique of the Almagest. It is well known that, while doing so, he uses once again the objections that his predecessor Ǧābir b. Aflah had already raised. Furthermore, Ben Gerson also leans on al-Kindī, Ṭābit b. Qurra, al-Battānī and others. Moreover, the other achievements connected with his name, such as the invention of the Camera obscura, of the Jacob’s staff and of the law of the spherical sines as well as the formulation of the proof for the parallel postulate have long since been known from his Arabic predecessors.

The practice of circulating the knowledge from the Arab astronomers in the form of pseudo-epigraphs can also be noticed in the 14th century. Duhem demonstrated, for instance, that the tract Demonstrationes Campani super theoricas ascribed to Campanus of Novara (d.1296) is an inferior work from the 14th century which disseminated primarily the representation of the solid spheres by Ibn al-Haïtam, although under a different name. What is particularly striking is the high esteem in which this representation of the solid spheres was held among the astronomers of the schools of Paris and Oxford. This is also the starting point for the well-known Subtilissimae quæstiones in Libros de caelo et mundo by Albert of Saxonia (ca. 1316-1390). The position of astronomy in Italy is described by Duhem in a masterly way. The Italian astronomers had not participated in the debates held in the 13th century in Paris and Oxford on the systems of Ptolemy and al-Bittegü. Only in the middle of the 14th century did this topic begin to interest them, and the debate lasted for about two centuries. It is characteristic of the working method of astronomers in the 14th and 15th century in almost the entire Christian Occident that besides translations of Arabic sources, compilations and adaptations were also attempted. Although these made future work easier, they also through their own mistakes quite frequently again caused new mistakes among their successors. The most decisive effect of these mediating treatises, it appears to me, is that they result in the real authors and inventors falling into oblivion, since the sources are mostly passed over in silence. Moreover, from the 14th century onwards a battle of anti-Arabism is fought in full earnest. Not infrequently were works by al-Battānī, al-Fargānī, Ṭābit b. Qurra and Ibn al-Haïtam cited as the Almagest. The narrow scope of this introduction requires us to leave unmentioned many topics which are not without importance. But at least the question of the relationship that Nicolaus Copernicus (1473-1543) had to Arabic-Islamic astronomy will be touched upon here. This leads us to the above-mentioned Byzantine transmission of Arabic sciences on their way to Europe. H. Usener was the first to detect traces of the reception transmitted along this path and he made known his findings in his Ad historiam astronomiae symbolorum (Bonn 1876). After a relatively long interruption, the subject again attracted the interest of research. Through a series of publications by David Pingree (since 1964) and from the Département d'études grecques, latines et orientales...
of the University of Louvain, we are today quite well informed about the working methods of the Byzantines and their treatment of Arabic sources.\textsuperscript{88} It is possible that the Byzantines already had contacts with Arabic sciences in the 9th century, but with certainty in the 10th century. This happened at first in the older centres of sciences, such as Alexandria, Antioch, Aleppo, Damascus, Jerusalem and Palermo. From the 13th century places like Maragha and Tabriz were added. From there the path led via Erzurum and Trabzon (Trapezunt) to Constantinople and further to Italy, to Central and Eastern Europe. According to our present state of knowledge, a number of works were translated at different times from the Arabic into Byzantine-Greek. Quite frequently it so happened that new books came into circulation which carried the names of ancient Greek scholars as the authors, on the basis of Arabic material. In the field of astronomy J. Mogenet’s view\textsuperscript{89} is very revealing which states: “What the Byzantines lack is the proper understanding of the importance of the observations which the Arabs began from the moment they became acquainted with Ptolemy’s work and continued until the end of the 12th century, and which they concretised in their tables that they continued to make available for discussion.”

We now come to the question of the possible influence on Copernicus of Arabic-Islamic astronomers whose works can have reached him on the Persian-Byzantine path. The fact that Copernicus also stood in the tradition of dependence on Arabic-Islamic astronomers was realised particularly in the second half of the 20th century. It is not only connected with impulses for the changing of the geocentric system to the heliocentric one, or with the fact that he used\textsuperscript{90} data and tables of his Arabic sources which were accessible in Latin translations and compilations, but rather it has to do with the fact that he must also have known the achievements of later Islamic astronomers of the 7th/13th and the 8th/14th century, even if their works, [15] as far as we know, have not been translated into Latin. He received the basic idea, namely to restore the principle of the uniform motion of the planets that had been impaired by Ptolemy, which led him finally to the decisive step, namely the heliocentric system, from those Arabic predecessors. There is also the fact that the attempts at solutions and the models of these scholars must also have reached Copernicus.

The common features ascertained so far between Copernicus and his Arab predecessors in the attempt to restore the principle of uniform motion of the planets can be summed up as follows:

1. Copernicus as well as Naṣīrād-dīn at-Ṭūsī and Qūṭādīn aṣ-Ṣirāzī accept without reservation the principle that each planetary model requires as the basis a mechanism of motion where equal distances are covered by equal vectors with equal angular velocity.

2. Copernicus and his Arab predecessors equip their planetary model with a mechanism of a double vector with a length of half the eccentricity in order achieve the effect of the equant.

3. The lunar model of Copernicus is the same as that of Ibn aṣ-Ṣārīt; both of them differ in their dimensions substantially from that of Ptolemy.

4. The model of Mercury by Copernicus is, with minor changes in the length of the vectors, the same as that of Ibn aṣ-Ṣārīt.

5. Copernicus in the Mercury model uses the mechanism of at-Ţūsī’s double epicycles which Ibn aṣ-Ṣārīt also does.\textsuperscript{91}

To explain this dependence, G. Rosińska\textsuperscript{92} pointed out in 1973 that in the 15th century the achievements of Naṣīrād-dīn at-Ṭūsī and Ibn al-Shāṭir, which interest us here, must have been known to some extent in Cracow. Sandivogius of Czechel (1430) and Adalbert of Brudzavo (1482) are quite familiar with those theories as is evident from their commentaries on Gerhardus’ Theoricae planetarum and Peurbach’s Theoricae novae planetarum respectively.


\textsuperscript{89} L’influence de l’astronomie arabe à Byzance, p. 55.


\textsuperscript{91} F. Sezgin, op. cit., vol. 6, pp. 55–56.

Some manuscripts of Greek translations of Persian astronomical works dealing with the new planetary theories are preserved in European libraries.\(^9\)

The brief presentation of the connecting line between the European, Arabic-Islamic and Greek-Byzantine astronomers may be concluded here with Copernicus, and with a reference to the concrete example of the reconstructed instruments from the observatories of Maragha (ca. 1270), Istanbul (ca. 1574-1577) and that of Tycho Brahe on the island of Hven (1576-1597), which aim to make this connecting line visible.

\(^{9}\) v. F. Sezgin, op. cit., vol. 6, pp. 56–57.
The

Planetarium

of as-Sīghzī

The Arabic-Islamic astronomers who believed that the Earth turns around itself included Abū Sa‘īd Ahmad b. Muhammad as-Sīghzī\(^1\) (2nd half of the 4th/10th c.). As al-Birūnī reports,\(^2\) as-Sīghzī also constructed an astrolabe in the form of a boat (al-āsturlāb az-zauraqī) according to the principle of the Earth’s rotation. Whether as-Sīghzī himself built a planetarium is not known; our model serves to illustrate his ideas on the Earth’s motion.

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Our model:
Brass and wood, painted;
meridian ring tangentially movable.
7 planets with an inclination of 23.5°
arranged around the globe that can be rotated on its axis.
The globe is designed as a Ma‘mūn-globe.
Total height: 1.63 m.
(Inventory No. A 1.05)

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\(^2\) v. ibid., vol. 6, pp. 224.
The Celestial Globe of 'Abdarrahmān aš-Šūfi

'Abdarrahmān b. 'Umar b. Muḥammad aš-Šūfi' (b. 291/903, d. 376/986) is considered by modern research, together with Ptolemy and Argelander (d. 1875), to be one of the three great scholars in the field of fixed star astronomy. In comparison to Ptolemy, he enlarged the celestial atlas not only on the basis of the contributions by his Arabic predecessors and his own observations, but also furnished it with new data on the positions and grouped it according to new scales of brightness. As one of his contemporaries reports, there was in the year 435/1044 in Cairo a silver celestial globe which aš-Šūfi had constructed for the statesman 'Aḍuddaddaula'.

Our model was made according to the manuscript at Oxford, Bodleiana, Marsh 144. This was copied, together with the illustrations of the constellations, by Husain, a son of the author in the year 400/1010.

Aš-Šūfi gives two illustrations for each constellation. One shows it from the horizontal plane, the other is a reversed image of the first illustration, produced by tracing through the former.

3 The manuscript was published in facsimil by the Institute for the History of Arabic-Islamic Science, Frankfurt 1986.
The Celestial globe of Coronelli

The Franciscan priest Vincenzo Coronelli (1650-1718), who had made a name for himself as a cartographer and globe maker, produced a celestial globe with a diameter of 3.85 m for Louis XIV. The star map inscribed on it is based on the depiction of 'Abdarrāhman aṣ-Ṣūfī (4th/10th c., above, p. 7). The fourteen constellation figures in the southern hemisphere are based on subsequently acquired knowledge. The work on the globe was executed between 1681 and 1683 in Paris. The constellations figures were painted by Jean-Baptiste Corneille (1649-1695). They are painted on papier-mâché. The names of the constellations are written in Greek, Latin, French and Arabic.

The original made for Louis XIV is preserved today in the Bibliothèque nationale in Paris. It must have been very popular, because some 60 smaller replicas with a diameter of 110 cm exist so far in European museums and libraries.

The construction of our model was made possible through a CD-Rom published by the Bibliothèque nationale.¹

Perhaps there is no other field of astronomy—neither that of the constantly improving instrumentation, nor the literary genre of the tables of observations, nor the finely honed theoretical models which come ever closer to reality—that can help us so well to understand the decisive steps of development in this science, developing from the contributions of individual culture areas than that of the observatories. The question that has been raised again and again for the last two hundred years about traces of the possible existence of an “institution” of observatories prior to Islam was answered in 1931 by Ernst Zinner, one of the most renowned historians of astronomy, in the following words: “No observatories like those of the Babylonians existed or, if they did, only for a short time, since the prerequisites, namely the compulsion to watch all the celestial phenomena for centuries, were absent among the Greeks. Here we have instead the activity of individuals who according to their preference paid attention to one or the other celestial phenomenon. It is reported that Eudoxus had an observatory near Heliopolis and later on Knidos, obviously influenced by the Egyptians. For centuries, an equatorial ring was to be seen in the rectangular hall in Alexandria and was probably used for teaching; but that cannot be taken to be an observatory. Hipparchus could take his observations with portable instruments. Likewise, as far as the observations by Ptolemy are concerned, we should neither assume a stationary installation of instruments nor the existence of an observatory.” “It is remarkable that the generosity of the Ptolemaic rulers did not connect their name with an observatory. Nor is there any report of any of the many wealthy men of Antiquity making a name for themselves through the establishment of an observatory. Their partiality for science exhausted itself in donations of clocks.”

Zinner describes the situation to the point. We can quite agree with his reasoning as well. But his reproachful remark that none of the Ptolemaic rulers and none of the wealthy men of Antiquity had made a name for themselves by founding an observatory does not seem quite fair. Of course, astronomy cultivated for millennia in diverse cultures had reached a high standard under the Greeks and particularly with Ptolemy, but the development of the subject had not yet advanced so far and the overall conditions were not yet so favourable that a ruler or a statesman would have hit upon the idea that there was any necessity for establishing an observatory. We can understand this state of affairs better if the details of the process of the origin of the first two regular observatories established in Islam are known. An excellent book by Aydın Sayılı that appeared in 1960 in Ankara under the title The Observatory in Islam and its Place in the General History of the Observatory saves us the trouble of investigating the history of its origins. It is particularly striking that the foundation of the Baghdad observatory in the a·∞amm®s¬ya quarter and of the Damascus observatory on Mount Q®siy’n could be only realised in the last five or six years of Caliph al-Ma’mün’s reign (ruled 198/813-218/833). The reports in question indicate that Caliph al-Ma’mün, who occupied himself with astronomy and used to commission and even take part himself in the astronomical observations and measurements which he considered important and who had the necessary instruments constructed, did not entertain the idea of an observatory for a long time. It appears that the more intensified astronomical work, the increasing number of astronomers participating in it and the gradually enlarged range of instruments, the fact that the maintenance of the instruments and making them available for observations had to be assured, and especially the increased urge for enlarging and

1 Die Geschichte der Sternkunde von den ersten Anfängen bis zur Gegenwart, Berlin 1931, p. 149.

2 A. Sayılı, op. cit., pp. 50–87.
improving the measuring instruments \cite{20} finally made it unavoidable that a suitable building was set aside for the observatory. What is remarkable in the report on the origin of the observatory at aš-Šammāsiya is that it consisted of a former temple, more likely a synagogue.\footnote{\textit{Ibn an-Nadim}, \textit{Fihrist}, p. 275; Ibn al-Qiftī, \textit{Taʾrīkh al-hukmāʾ}, Leipzig 1903, pp. 206–207; A. Sayılı, op. cit., pp. 51–52.} It was set up under the supervision of the converted Jew, Sind b. ʿAli,\footnote{V. A. Sayılı, \textit{op. cit.}, p. 57.} who belonged to the closest circle of astronomers around the Caliph. The astronomical work was becoming difficult to accomplish without a suitable building and the Caliph’s state of health was deteriorating: perhaps it was both these factors that led to this step. In this connection it should to be noted that a (former) sacral building was also used for the observatory on the Qāsiyūn near Damascus, in this case the monastery Dair al-Murrān.\footnote{V. Ibn an-Nadim, \textit{Taʾrīkh al-Ωukam®’}, defendant.} Moreover, both observatories were established shortly after one another, almost about the same time. Perhaps the desire to be able to do simultaneous observations or to achieve comparative values independently from each other by eminent astronomers using first rate instruments also played a role. As early as in 1877 L.-A. Sedillot\footnote{V. F. Sezgin, \textit{op. cit.}, vol. 5, p. 242–243; vol. 6, p. 138.} pointed to an observation which was possibly carried out in both places at the same time. The accounts preserved for us show that almost all the great astronomers of the time were working in the two observatories. These included Yahyā b. Abī Maṣūr, al-ʿAbbās b. Saʿīd al-Gauhari, Muḥammad b. Māsā b. ʿHwārizmi, Hālid b. ʿAbdalmalik al-Marwārunā and Sind b. ʿAli. Sind b. ʿAli’s manifold duties included the improvement of the observational instruments (iṣlāḥ ʿalā ar-raṣād).\footnote{V. A. Sayılı, \textit{op. cit.}, p. 57.} The famous astronomer Aḥmad b. ʿAbdallāh Ḥabās,\footnote{Histoire générale des Arabes. Leur empire, leur civilisation, leurs écoles philosophiques, scientifiques et littéraires, vol. 2, Paris 1877 (reprint Paris 1984), p. 8, 186; cf. A. Sayılı, \textit{op. cit.}, p. 56.} a younger contemporary of the above-mentioned astronomers, informs us that al-Maʿmūn ordered the astronomer Hālid b. ʿAbdalmalik al-Marwārunā to observe the celestial bodies with the best possible instruments at the observatory of Damascus for a whole year.\footnote{Ibn al-Qiftī, \textit{Taʾrīkh al-hukmāʾ}, p. 206.} One of the most interesting examples of the active interest taken by the Caliph personally in the equipment and instruments in his observatories is reported by al-Birūnī:\footnote{V. F. Sezgin, \textit{op. cit.}, vol. 5, p. 101; A. Sayılı, \textit{op. cit.}, p. 116.} al-Maʿmūn had an iron gnomon of ca. 5 m (10 ells) length erected on the Qāsiyūn (Dair Murrān). He had it justified in the daytime and measured again at night, and because of the difference in temperature he found it shorter by a “barley-corn” (ṣāʿira). He was disappointed that therefore this gnomon could not be used for determining the precise length of the year.

**Further developments**

Astronomers and admirers of astronomy had become aware of the function, the purpose and the task of an observatory through the forerunners at Baghdad and Damascus. One and a half centuries later the first successor appeared. It was erected by the Buyid ruler ʿAlāʾ al-Fawāris ʿṢirdī (ruled 372/983–379/989) in 378/988, once again at Baghdad. The founder desired that in this solid building erected for this purpose, the astronomical observations of the heavens and of the planets were to be continued in the same way as they had been begun under al-Maʿmūn. Šarafaddaula had entrusted the supervision of the observatory to the well-known astronomer and mathematician Abū Sahl Waṣgān b. Rustam al-ʿKūhī.\footnote{V. Ibn al-Qiftī, \textit{Taʾrīkh al-hukmāʾ}, p. 351; A. Sayılı, \textit{The Observatory in Islam}, pp. 112–117.} On the shape of the observatory we learn from al-Birūnī\footnote{Taḥdīd nihāyāt al-anākīn, p. 101; A. Sayılı, \textit{op. cit.}, p. 116.} that it had a dome with a diameter of ca. 12.5 m (25 ells) in the centre of which an opening had been left for the entry of the Sun’s rays so that the course of the Sun could be followed daily. Not longer than six years after the foundation of the second observatory...
in Baghdad, Faḫraddaula Abu l-Hasan ‘Ali b. Ruknaddaula, another Buyid (ruled 366/976–387/997), fulfilled the wish of the astronomer Ḥāmid b. al-Ḥīdīr al-Ḥuḡāndī and had a special observatory erected in 384/994 in Raiy (in the south of today’s Tehran). The sextant constructed into it with a radius of ca. 20 m with its division into minutes and seconds was to make possible an extremely accurate measurement of the position of the Sun, for ascertaining whether the obliquity of the ecliptic remains constant, decreases or increases (see below, p. 25).

About a quarter century afterwards an observatory was established in Hamadan, apparently by ‘Ala‘addaula b. Kājkūyā, a local ruler of the provinces of Isfahan, Hamadan and Yazd (ruled 398/1007–434/1041). Abū ‘Ali Ibn Sinā, who was on friendly terms with him, is said to have complained to him that the common ephemerides made on the basis of obsolete astronomical observations were imperfect. Thereupon Amir ‘Ala‘addaula gave the order to deal with the problem of observation in greater detail and made the required financial means available. It is said that Ibn Sinā undertook the task and his pupil Abū ‘Ubaid al-Ḡūzaḡānī was responsible for the production of the required instruments. Although observations were frequently interrupted by journeys (with ‘Ala‘addaula) and other impediments, Ibn Sinā recorded the results all the same in his Kitāb al-‘Ala‘ī. We do not learn the exact details about the building of the observatory, but the content of the brief report permits us to assume that it was a building suitable for the purpose to which the observations were carried out. This is confirmed by a further report from which it becomes clear that instruments not known until then were also developed for this purpose. Moreover, the observational instrument with its large dimensions (below, p. 26), which Ibn Sinā himself described in a special treatise, can be visualised only in the scope of an observatory.

Some forty years after the erection of the observatory by ‘Ala‘addaula, another observatory arose in Persia, this time at the behest of the Seljuk Malikšāh b. Alparslan (ruled 465/1072–485/1092). As the historian Ibn al-ʿAṭīr reports, it was already founded in 467/1075 and some of the eminent astronomers of the time like ʿUmar b. ʿĪbrāhīm al-ʿIṣayyām, Abu l-Muzaffar al-Īṣīzārī or Maimūn b. an-Naqīb al-ʿWāsītī are said to have worked there. The location of the observatory is not mentioned. Modern scholars assume that it could have been Isfahan, Nishapur or Raiy. Perhaps the observation of the heavens ordered by the founder of the observatory was continued after his death. According to one report the observatory is said to have been active for another thirty years. According to our knowledge the first observatory built in northern Africa goes back to the early 6th/12th century. It was founded in Egypt under the Fatimid al-ʿĀmir bi-āḥkām illāh Abū ‘Ali al-Maḥsūr (ruled 495/1101–524/1130). The initiator was the vizier al-Afdal Abu l-ʿQāsim ʿĀḥishāb b. Amir al-ḥuyūṣ Badr (d. 515/1121); it was completed by his successor Abū ʿAbdallāh al-Maʿmūn al-Batāʾiḥī (d. 519/1125). About the complicated and unfortunate history of this observatory the historian Taqīyaddīn al-Maqrīzī (d. 849/1441) reports in his al-Ḥīrat from an anonymous book about the building (Kitāb ʿAmāl ar-raṣāṣ). The vizier al-Afdal is said to have been motivated to take the decision to found an observatory in Cairo when some 100 ephemerides for the years 22 after 500/1107 had been brought to him from Syria and when he realised that these differed from the data produced by his own astronomers. In order to correct the errors, the astrono-

13 V. A. Sayılı, op. cit., pp. 118–121; F. Sezgin, op. cit., vol. 6, pp. 220–221.
The vizier al-Ma’mun (5 ells). The originally planned location for the observatory on the terrace of the Ge³i al-FilaΩ¬ (“Elephant Mosque”) was abandoned and the large ring was transported with great difficulty to the terrace of another mosque, the Ma³šid al-©uy’·¬.

The vizier al-Ma’mun al-Bafl®Ω¬ identified the particular spot. Af¥al was very angry about the failure, but let himself be pacified when Ibn Qaraqa pointed out that with an instrument of dimensions such as had never been manufactured before we should be content if its manufacture succeeded even after ten attempts.

The second anecdote narrates that al-Af¥al said to the leader of the project, Ibn Qaraqa: “‘If you had made the circle smaller, then the work would have been easier.’ Ibn Qaraqa replied: ‘If I could have made it of such size that one of its extremities were at the Pyramids and the other at the Tannår (a place near Cairo), I certainly would have done so. The larger the instruments, the greater the exactness of the observations. What, in fact, is the dimension of an instrument compared with the vastness of the celestial world!’”

The statements on the observatories were collected by Aydın Sayılı with remarkable diligence and a vast knowledge of the sources; he accomplished this difficult task admirably. His material and some of his remarks create the impression that our sources as a rule report only on those observatories whose foundation was connected with spectacular events or with the construction of instruments of extraordinary dimensions. Moreover, the term ra◊ad used for observatory also means “observation” which causes some difficulties in the assessment of the relevant statements. Thus the frequently occurring sentence ‘amala r-ra◊ad can be understood both in the sense of “he built the observatory” and “he observed.” This contributes to the fact that, despite Sayılı’s excellent work, a complete record of the Arabic-Islamic observatories remains practically illusory. Under [23] these constraints, Sayılı’s view seem to be correct that the countries of the Maghrib and Islamic Spain did not keep up with the developments which the observatory had attained in the eastern part of the Islamic world, and remained at best at the level of al-Ma’mun’s period. Like many other areas of science, the observatory with its institutions and instrumentation also reached a remarkable climax in its development in the 7th/13th century. The importance of the observatory founded in Maragha with its highly developed and partly newly designed instruments for the general history of science has not yet been adequately evaluated (see below, p. 38 ff.). This observatory and its successors in Samarqand (below, p. 69 ff.) and


21 Sayılı, op. cit., p. 398.
Istanbul (below, p. 53 ff.) are the institutions that led to the establishment of the first observatories proper in Europe. On the same path on which the knowledge of those observatories reached Europe, further new achievements, new theories of science and manuscripts of scientific works also travelled from the eastern part of the Islamic world to the Occident. Thus, in this connection we can hardly overestimate the importance of the fact that the original of the celestial globe from the Maragha observatory has been preserved at Dresden since at least 1562.