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THE MAKING OF ASTRONOMY IN EARLY ISLAM

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RIASSUNTO

Lo studio dell'astronomia in Islam iniziò nel tardo ottavo secolo con influenze provenienti dall'Iran e dall'India. Durante il nono secolo si diffusero metodi e testi greci che condussero a un « rinascimento » nell'attività astronomica. Il centro di questa attività, che ebbe il sostegno (fra gli altri) del Califfo al-Ma'mūn, fu Bagdad. Nonostante la mancanza di testi sopravvissuti, possiamo ricostruire i risultati ottenuti in questo periodo dalle opere di al-Bīrūnī (morto ca. 1050), e di altri autori successivi. Conviene notare che un numero consistente di parametri basati su nuove osservazioni furono migliorati ma che i modelli sottostanti non furono mai messi in discussione. Il presente articolo propone 1) gli astronomi appartenevano alla classe media colta dei centri urbani della quale condividevano i valori e 2 che un pieno apprezzamento delle imprese di questi scienziati richiede una familiarità con il contesto in cui lavoravano.

I. *Introduction.*

It is traditional to begin the history of astronomy with the Pre-Socratics about whom we are informed by fragments preserved in later classical texts. Due in large measure to the efforts of O. Neugebauer, it is now evident that mathematical astronomy in the West derives from two different cultural settings, one Greek and the other Babylonian.[1] These two traditions merged during the Hellenistic period of late an-

[1] O. Neugebauer, *Astronomy and History: Selected Essays*, New York 1983, p. 130.

tiquity (i.e., after the death of Alexander the Great in 323 B.C.) and the most extensive witness to this new style of astronomy is Ptolemy's *Almagest*, written in Alexandria, ca. 150 A.D. For the period up to and including Kepler in the early seventeenth century virtually all serious astronomical works – written in Arabic, Hebrew, Byzantine Greek, or Latin – were strongly influenced by this text that serves as a key to understanding them. The origins and early history of both the Greek and the Babylonian traditions are not fully available to us due to the paucity of surviving texts, and the mode of transmission of Babylonian astronomy to the Hellenistic world has not been discovered. On the other hand, much that was believed to be known about early Greek astronomy has been based on an uncritical acceptance of unreliable late traditions that derive from authors who often lived as much as a thousand years after the fact.[2]

To complicate matters still further, Muslim scientists in the late eighth and early ninth centuries became aware of the Hindu tradition which also has its roots in Hellenistic antiquity, but developed quite differently from its western counterpart. Muslim astronomers accepted some aspects of this tradition in addition to the legacy of Greek texts.

The cultural context of early Islam is not to be ignored for an understanding of scientific developments in it. To be sure, the Koran does not deal with astronomy (though some astronomical terms appear in it), nor was astronomy an organized discipline among the Arabs at the time of Muḥammad (d. 632 A.D.). Two events shortly after the death of Muḥammad were critical for Islamic culture: (1) the relatively quick and easy conquest of Iran, the fertile crescent, and Egypt bringing vast populations under Islamic control and leading to their gradual conversion to Islam as well as the adoption of Arabic as their literary language; and (2) the formation of an urban learned middle class that formulated the principles of Islam and engaged in scholarly activities in many disciplines, as well as supplying the administrators, judges, and secretaries (i.e., civil servants) to govern the vast realm under Muslim domination. This learned class flourished in the great cities of Islam, foremost among them Baghdad, and its members were by no means exclusively the descendants of pre-Islamic inhabitants of Arabia. Rather, they were drawn from the diverse populations of the Islamic empire and, indeed, they had close ties to urban non-Muslims: Christians, Jews, and others.

[2] For Greek astronomy, see O. NEUGEBAUER, *A History of Ancient Mathematical Astronomy*, New York 1975. Despite its weaknesses, it is still useful to consult T. L. HEATH, *Aristarchus of Samos*, Oxford 1913.

Again, our sources for the early developments of Islamic scholarship are inadequate, for hardly any relevant Arabic text survives from the first two centuries of Islam. Thus, we are forced to depend on later fragmentary references, often written in a polemical context. However, for matters concerning astronomy in early Islam, we are most fortunate that a brilliant scholar, al-Bīrūnī (d. ca. 1050), provides us with so many details that we can reconstruct these formative stages with a reasonably high degree of confidence.[3] Other Arabic texts add corroborating evidence that helps to round out the picture presented by al-Bīrūnī.

Before the arrival of the Hellenistic astronomical legacy in Islam, there were folk traditions from pre-Islamic Arabia (largely dealing with star-names, the lunar mansions, and certain features of the calendar), as well as some religious duties that were later (if not initially) seen to involve astronomy, notably the times for Muslims to pray (five times a day), the direction to face while praying (the *qibla,* i.e., the direction towards Mecca), and the Muslim festivals particularly the beginning of the fast of Ramaḍān. While these matters are important for Islam in general, as well as for the astronomers within that culture, we will concentrate on some secular aspects of astronomy, i.e., on the responses in Islam to the Hellenistic heritage and the parallel aspects of the Hindu tradition that were predominantly the concerns of professional astronomers. For this purpose a firm grasp of Ptolemaic astronomy is required, for that was clearly the point of departure for this learned tradition.[4]

In the early stages of Islam there was a centralized administration, first with Muḥammad, then the four « righteous caliphs » who succeeded him, followed by the Umayyad dynasty based in Syria (661-750), and the Abbasid dynasty based in Iraq beginning in 750. However, as early as the ninth century various forces combined to separate Islam into distinct regions and effective power was no longer in the hands of the caliphs. Similarly, although Baghdad was unrivaled in the ninth century, in later centuries we find scholars engaged in the sciences from Spain to India.

The range of subjects included in medieval astronomy is surprisingly vast. It involved many aspects of mathematics such as computational techniques and trigonometry (which became highly developed), optics (for the understanding of astronomical observations and instruments), cosmology and natural philosophy, geography (including map-projections

[3] On al-Bīrūnī, see E. S. Kennedy, *Al-Bīrūnī*, in *Dictionary of Scientific Biography*, New York 1970, 2, pp. 147-158.

[4] For a detailed discussion of Ptolemaic astronomy, see O. Pedersen, *A Survey of the Almagest*, Odense, Denmark 1974.

and the determination of local coordinates), the design of instruments both for observation and computation, the techniques of observation, chronology and the study of ancient calendars, and astrology (considered as an applied science with respect to astronomy). All this in addition to what one might call the core of medieval astronomy: the analysis of the daily rotation, the theories for the motions of the Sun, Moon, planets, and the fixed stars, the calculation of solar and lunar eclipses, the determination of cosmic dimensions, and the treatment of observations.

Medieval Islam was remarkably tolerant both of non-Muslims and of divergent sects within Islam. To be sure, there were tendencies towards intolerance but, for the most part, their impact was limited geographically and short-lived. Among the astronomers there was generally a spirit of cooperation between Muslims, Jews, Christians, and members of other tolerated groups.

II. *Astronomy in the ninth century.*

One of the most important events in the history of science was the transmission of the Greek heritage to the Islamic world. As O. Neugebauer has pointed out, al-Battānī's *Astronomy* (ca. 900), written in Raqqa in northern Mesopotamia, closely parallels Ptolemy's *Almagest* (composed ca. 150) and reflects a clear understanding of its principles.[5] Indeed, al-Battānī's work served as the basis for much of the later modifications of Ptolemaic astronomy in the Islamic world. History, however, is rarely straightforward, and the path from Ptolemy to al-Battānī was certainly not direct. In particular, astronomy from the fifth to the eighth centuries remains largely obscure due to the low rate of survival of texts from that period on the eve of Islam and its early years. However, by the patient and painstaking piecing together of fragmentary information, much has been recovered from later sources that cite lost treatises from this period. The picture that has emerged is anything but simple. One problem that faces us is to analyze models and parameters of diverse origin that were merged without regard to their consistency.

The centers of activity in this period of transition were Athens (where a series of observations were made between 475 and 510), Alexandria, Constantinople, Syria, Iran, and India.[6] In the eighth cen-

[5] O. Neugebauer, *The Exact Sciences in Antiquity*, Providence 1957, pp. 205-206.

[6] D. Pingree, *The Greek Influence on Early Islamic Mathematical Astronomy*, « Journal of the American Oriental Society », 93, 1973, pp. 32-43.

tury, when astronomical activity began in the Islamic world, three main traditions were current, all of which derived from Hellenistic sources in one way or another: the Ptolemaic, the Sasanian, and the Indian traditions. Of these the most obscure is the Iranian tradition that developed during the period of the Sasanian dynasty (224-651) because our information is entirely based on later citations. Of special interest is the *Royal Canon* or *Ziki Shahriyan* that was composed ca. 450, later revised under reign of Khusrau Anushirwān in 556, and again under the reign of the last Sasanian ruler, Yazdijird III (632-651). The models used in these tables are not known, but from the parameters cited by later Arabic authors, their eclectic character is evident, revealing both Greek and Indian influence. Apparently, the Sasanian astronomers sought to facilitate the computation of astronomical phenomena without explaining the underlying models, in the literary tradition of Ptolemy's *Handy Tables* rather than the *Almagest*.

The Indian tradition in this period is quite rich and many texts are available from it. In particular, we may mention the *Khaṇḍakhadyaka* composed by Brahmagupta in 665, a version of which was translated into Arabic in 735 with the title *Zīj al-Arkand*.[7] Indian astronomy largely reflected pre-Ptolemaic Hellenistic models using eccentrics and epicycles with some special features known only from Indian sources. The Sanskrit texts are written in verse and contain little explanatory material.

The Indo-Iranian traditions were known to the astronomers at the early Abbasid court and were used for the astrological determination of the appropriate moment to begin building the new capital, Baghdad, under the caliph al-Manṣūr (they advised beginning on 30 July 762).[8] The principal text produced at this time was the *zīj al-Sindhind al-kabīr* (not extant) composed by al-Fazārī whose contact with an Indian astronomer is cited by al-Bīrūnī.[9] The Indian astronomer was a member of an embassy at the court of al-Manṣūr in Baghdad ca. 773. This collaboration led to a work whose character is largely Indian with some Greek and Iranian elements. Its impact on early Arabic astronomers was substantial, and this tradition continued in Spain long after it had been displaced by Ptolemaic astronomy in the eastern Islamic regions.[10] Un-

[7] D. PINGREE, *art. cit.*, p. 37.

[8] *Ibid.*

[9] On al-Fazārī, see D. PINGREE, *The Fragments of the Works of al-Fazārī*, « Journal of Near Eastern Studies », 29, 1970, pp. 103-123.

[10] Cfr. D. PINGREE, *The Indian and Pseudo-Indian Passages in Greek and Latin Astronomical and Astrological Texts*, « Viator », 7, 1976, pp. 141-195.

fortunately, all the relevant early texts are lost, forcing us to depend on scattered references and on some late texts that survive.

The most important text in the Greek astronomical tradition was Ptolemy's *Almagest*, and a series of translations from Greek and Syriac were under taken beginning at the time of the Caliph Hārūn al-Rashīd (786-809). The earliest surviving translation is that completed by al-Ḥajjāj ca. 830 under the reign of the Caliph al-Ma'mūn (813-833).[11] The peculiar feature of astronomy under al-Ma'mūn was an interest in the systematic redetermination of astronomical parameters based on new observations made in Baghdad (828-830) and in Damascus (831-833).[12] Indeed, new parameters for the Sun were incorporated in several of the zījes (sets of astronomical tables) produced by participants in this scientific enterprise. Thus, in the first half of the ninth century two main traditions emerged: one based on the Indo-Iranian heritage now represented by the *Zīj al-Sindhind* of al-Khwārizmī (early ninth century) which largely replaced the works of al-Fazārī on which it depended, and the other based on the models of Ptolemaic astronomy incorporating parameters based on the new observations with some influence from the Indo-Iranian heritage in those cases where such methods seemed better suited to the needs of computation. The results were not internally consistent and the underlying models were not completely understood. It seems that Ḥabash al-Ḥāsib (fl. ca. 850), who also engaged in observational activity, played an important role in the clarification of the Ptolemaic models. The culmination of this phase in Arabic astronomy was attained with the publication of the *Zīj al-Ṣābi* by al-Battānī (d. 929-930, one of the few such texts available in a modern edition with commentary.[13] Moreover, in the second half of the ninth century an entirely new translation of the *Almagest* was made by Isḥaq ibn Ḥunain (d. 910) who belonged to a famous Christian family of translators, later revised by Thābit ibn Qurra (d. 901) originally from Ḥarran and an adherent of the Sabian religion.

Rather than dwell on the problems of transmission, let us turn to the scientific activities sponsored by the Caliph al-Ma'mūn, for they are truly remarkable. It is customary to describe this period in Baghdad as the ninth century renaissance, and in fact it is an apt expression. The

[11] F. SEZGIN, *Geschichte des arabischen Schrifttums*, Band VI: *Astronomie*, Leiden 1978, p. 89.

[12] A. SAYILI, *The Observatory in Islam*, Ankara 1960, p. 50 ff.

[13] C. A. NALLINO, *Al Battānī sive Albatenii Opus astronomicum*, 2 vols., Milan 1903-1907; cfr. E. S. KENNEDY, *A Survey of Islamic Astronomical Tables*, « Transactions of the American Philosophical Society », n.s., 46, 1956.

scholars under al-Ma'mūn did not seek to understand the newly available Greek texts by literary analysis alone, but by observational activity as well. These observations characteristically were made by groups of scholars working together: nothing like this is known from Greek antiquity, and it certainly was not something that could be learned from scholars of the immediately preceding period. The emphasis in this work was on the revision of the solar parameters, and considerable success was achieved. It seems that the inspiration for starting with the solar parameters derives from a careful reading of the *Almagest* where the fundamental character of these parameters is apparent. We are told that the first and most basic parameter to be investigated was the obliquity of the ecliptic, for which there were three values in the antecedent tradition: 24° according to the Indian texts; 23;51° according to the *Handy Tables* (available in the version by Theon of Alexandria); and 23;51,20° according to the *Almagest*. In al-Bīrūnī's *Book on the Determination of the Coordinates of Cities* Ptolemy's method for finding the obliquity (*Almagest* I.12) is described, followed by a discussion of similar observations made in the period beginning with al-Ma'mūn:[14]

After Ptolemy, we have no record of any astronomer's observation [of the obliquity] up to the time of al-Ma'mūn who ordered Yaḥyā b. Abī Manṣūr to make a new determination. Yaḥyā made it at Shammāsīya [a suburb of Baghdad] and it is well known that he found the maximum declination to be 157 parts out of 2400 of a circle. This gives 23;33°, and on this basis Yaḥyā constructed his *zīj*. That was reported by al-Khwārizmī who was an eyewitness to the observation. They found that the maximum [solar] altitude is 79;6° and that the minimum solar altitude is 32;0°. Therefore, the difference between them is 47;6° and half of this amount is 23;33°. That was in the year 213 A.H. or 197 A.Y. [828 A.D.].

Al-Bīrūnī goes on to tell us that in the following year the result was 23;35°. Al-Ma'mūn was not completely satisfied and had subsequent observations made at Damascus (831-833) by Khālid supervised by Sanad with new instruments. The noon solstice altitudes of the Sun now yielded an obliquity of about 23;34°. This was clearly a confirmation of the previous results, and most later astronomers accepted a value for the obliquity in the range from 23;33° to 23;35° (the modern value recomputed for the ninth century in about 23;35°).[15] This episode tells

[14] J. ALI, *The Determination of the Coordinates of Cities: Al-Bīrūnī's Taḥdīd al-Amākin*, Beirut 1967, p. 60; for the meaning of « A.Y. », see note 35.

[15] O. SCHIRMER, *Studien zur Astronomie der Araber*, « Sitzungsberichte der physikalisch-medizinischen Sozietät zu Erlangen », 58, 1926, pp. 33-88 (especially pp. 60-61).

us a great deal about the level of astronomy at the time. Unfortunately, there seems to be no source that speaks directly to the question of the motivation of al-Ma'mūn and his astronomers. It has been suggested that al-Ma'mūn had an interest in astrology but that, even if true, hardly suffices to explain this new attitude to astronomy. Religious reasons may have played a role for, as we already noted, astronomy enters the discussion of certain religious obligations of the Muslims. But scientific curiosity and a desire to understand exactly what the ancient Greeks had accomplished must be given some share in the matter of motivation. To be sure, the stated goal was to produce a set of « accurate » astronomical tables. There is no evidence to suggest that the astronomers were shocked to find values for the obliquity without ancient precedent, and they did not cast doubts on Ptolemy's theories which they accepted. The differences between the various determinations were somewhat disturbing, and such small divergences remained problematic until a proper theory of experimental error was formulated at the beginning of the nineteenth century.

Al-Bīrūnī also gives details on a method to determine the obliquity of the ecliptic that was based on observations made at Damascus at noon on three successive days in June 832.[16] This method is not found in the works of Ptolemy (or any other ancient source): indeed, Ptolemy offers no explanation for his claim that summer solstice took place on 24-25 June 140 about 2 hours after midnight.[17]

The determination of the obliquity was closely tied to finding the terrestrial latitude of the places of observation. So, al-Bīrūnī tells us that the latitude of Damascus is 33;30,18° (modern value 33;30°).[18] Then, by a method that depends on the difference in the noon altitudes of the Sun on the same day in two different cities, he reports that the latitude of Baghdad is 33;24,8° (based on observations in Damascus and Baghdad on 1 May 832), or 33;25,22° (based on observations in Damascus and Baghdad on 3 August 832).[19] Further, al-Bīrūnī tells us that al-Ṣaghānī (d. 990) found the latitude of Baghdad to be 33;20° (which is also the modern value) and the obliquity to be 23;35°.[20]

It is certainly noteworthy that greater accuracy was achieved both for the obliquity and for terrestrial latitudes than the values found in

[16] J. Ali, *op. cit.*, pp. 61-63.

[17] *Almagest* III.1; trans. G. J. Toomer, *Ptolemy's Almagest*, New York 1984, p. 138.

[18] J. Ali, *op. cit.*, p. 56; E. S. Kennedy, *A Commentary upon Bīrūnī's Kitāb Taḥdīd al-Amākin*, Beirut 1973, pp. 29-30.

[19] E. S. Kennedy, *A Commentary* cit., p. 30.

[20] J. Ali, *op. cit.*, p. 69.

the *Almagest*. Ptolemy took the obliquity to be 23;51,20° (modern value for his epoch: 23;40,50°) [21], and his value for the latitude of Alexandria was 30;58° (modern value: 31;12°).[22] The early Islamic astronomers found values within a few minutes of the true amounts, and this is about as good as naked eye observations can get.[23] The most accurate pre-telescopic observations were made by Tycho Brahe in the sixteenth century, and these were the earliest to exceed the accuracy achieved in the ninth century.

A distinct institution, began by Hārūn al-Rashīd and continued by al-Ma'mūn, was the *Bayt al-Ḥikma* (i.e., *The House of Wisdom*), a library where scientific and philosophical works were translated into Arabic. We are told that al-Ma'mūn held regular weekly meetings with the staff that were considered to be of great value to the translators.[24] At least one important scientific expedition took place under the auspices of this academy, and its goal was to determine the length of 1° on a terrestrial meridian. Again, we depend on al-Bīrūnī for many details of this episode:[25]

As to the observations made under al-Ma'mūn, they were started after he had read in some Greek books that 1° of the meridian is equivalent to 500 stades, where a stade was the standard Greek unit for measuring distances. However, he found that its actual length was not satisfactorily known to the translators to enable him to identify it with local standards of length. Then, according to Ḥabash, who obtained his information from Khālid, al-Ma'mūn ordered a group of learned astronomers, expert carpenters, and workers in brass, to prepare the required instruments and to select a locality for a geodetic survey. They chose a spot in the plain of Sinjar in the neighborhood of Mosul, 19 farsakhs [where 1 farsakh equals 3 miles] from the town itself, and 43 farsakhs from Samarra. They liked its level ground, and transported their instruments there. They chose a site and observed the Sun's meridian altitude. Then they departed in two parties: Khālid with the first party of surveyors and artisans in the direction of the north pole, and Aḥmad b. al-Buḥtarī with the second party in the direction of the south pole. Each party observed the meridian altitude of the Sun until they found that the change in its meridian altitude had amounted to 1°, apart from the change due to the variation in the declination. While proceeding on their paths, they measured the distances they had traversed, and planted arrows at different stages of their

21 Cfr. J. BRITTON, *Ptolemy's Determination of the Obliquity of the Ecliptic*, «Centaurus», 14, 1969, pp. 29-41.

22 Cfr. O. PEDERSEN, *op. cit.*, p. 109.

23 E. S. KENNEDY, *A Commentary* cit., p. 37.

24 A. SAYILI, *op. cit.*, p. 54.

25 J. ALI, *op. cit.*, pp. 178-179.

paths. While on their way back, they verified, by a second survey, their former estimates of the lengths of the courses they followed, until both parties met at the place whence they had departed. They found that 1° of a terrestrial meridian is equivalent to 56 miles. He [Ḥabash] claimed that he had heard Khālid dictating the number to Judge Yaḥyā b. Aktham: so he heard of that achievement from Khālid himself. Also, a similar narrative was told by Abū Ḥāmid al-Ṣaghānī, who obtained his information from Thābit b. Qurra. But it is said that al-Farghānī has reported an extra 2/3 of a mile in addition to the [56] miles.

I have found all the other narratives in agreement about these 2/3 miles. However, I cannot ascribe the omission to an oversight in the manuscript because, upon examination, the circumference and diameter of the earth and all cosmic distances are based on the assumption of 56 miles. So, it is preferable to ascribe the difference in the two narratives to the two parties in the expedition ...

This passage is extremely rich in information on the scientific activities sponsored by al-Ma'mūn as well as on al-Bīrūnī's evaluation of them. First, there was a text stating that 1° = 500 stades, a value that goes back to Ptolemy who claimed that the circumference of the earth is 180,000 stades which, when divided by 360°, yields a value of 500 stades/degree. The determination of the length of the stade was then treated as a scientific problem and an expedition was organized to solve it. Note that once the new result was found there was no longer any need to refer to the stade, for al-Bīrūnī states explicitly that a mile is 4,000 black cubits, an official unit of length established by al-Ma'mūn.[26] In other words, the newly obtained length of a degree in miles had a precise definition that the old measure in stades lacked. The expedition is described in sufficient detail that one can hardly doubt that it took place. It is clear that al-Bīrūnī did not have direct access to a description written by one of the participants, and he takes care to indicate his sources and their relationship to eye-witnesses when that can be established, a common feature in Arabic historical writings. He goes on to report the variants and then offers an explanation for the disagreement in such a way that no source is declared unreliable. In the Islamic legal tradition, a report (*ḥadīth*) about the Prophet Muḥammad must always be associated with a chain of authorities that links an eye-witness to the collector of such reports several generations later.

The procedure followed by the astronomers working for al-Ma'mūn cannot be found in any ancient text and thus represents an important achievement of the ninth century. Indeed, it is highly unlikely that the ancient estimates of the size of the earth were based on any geodetic survey at all; rather, they seem to have been derived using some rough scheme of approximation that did not involve precise measurement.[27] Finally, one can say that the new results were highly accurate: Nallino has argued that the estimate of $56\frac{2}{3}$ miles/degree exceeds the correct value for the length of a degree on the meridian (between 35° and 36° latitude) by only 877 meters where the modern value is about 111 kilometers.[28]

According to Ibn Yūnus (fl. ca. 1000), in addition to finding the obliquity, Ma'mūn's astronomers also determined the maximum solar equation, the solar apogee, and the solar mean motion in a Persian year of 365 days.[29] At Baghdad Yaḥyā and his associates found 1;59°, Gemini 23;39°, and 359;45,44,14,24° for these three parameters, whereas in Damascus Sanad b. 'Alī and his associates found 1;59,51°, Gemini 22;1,37°, and 359;45,46,33,50,43°. By way of contrast, in the *Almagest* the same parameters are given as 2;23°, Gemini 5;30°, and 359;45,-24,45,21,8,35°. Again, Ptolemy's values have been rejected, and slight differences can be seen between the parameters based on observations in Damascus as opposed to those made in Baghdad a few years earlier. According to *On the Solar Year*, attributed to Thābit b. Qurra (d. 901) but probably composed by Muḥammad b. Mūsā b. Shākir (ninth century) [30], Ptolemy's method for finding the solar eccentricity and solar apogee was modified by Ma'mūn's astronomers: Ptolemy depended on observations of solstices and equinoxes, whereas Ma'mūn's astronomers introduced the idea of depending on observations of intermediary points on the solar orb. The precise moment of solstice, i.e., when the Sun reaches its maximum (or minimum) declination, is difficult to determine because the change in declination at that time is extremely small (a few seconds of arc per day). As our text says: « Ptolemy did not protect himself sufficiently from error. We find the mid-points between each of the solstices and equinoxes more suitable for this inquiry ».[31] Our author

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26 J. Ali, *op. cit.*, p. 178; and E. S. Kennedy, *A Commentary* cit., p. 133.

27 B. R. Goldstein, *Eratosthenes on the 'Measurement' of the Earth*, « Historia Mathematica », 11, 1984, pp. 411-416.

28 C. A. Nallino, *op. cit.*, I, p. 165.

29 J. J. A. Caussin, *Le livre de la grande table Hakémite*, Paris 1804, pp. 38-40.

30 C. E. Sachau, *The Chronology of Ancient Nations of Albīrūnī*, London 1879, p. 61; cfr. R. Morelon, *Les textes astronomiques arabes de Thābit b. Qurra*. Thèse pour le doctorat de III^e cycle, Université de la Sorbonne Nouvelle-Paris III (unpublished), 1982 (especially I, p. 136).

31 O. Neugebauer, *Thābit ben Qurra 'On the Solar Year' and 'On the Motion of the Eight Sphere'*, « Proc. Am. Philos. Soc. », 106, 1962, p. 275.

goes on to list 3 observations made in 832 when the Sun entered 15° of Aquarius, Taurus, and Leo, respectively. As noted here, Ptolemy's method for finding the eccentricity and apogee from observations of solstices and equinoxes can be applied without modification to these observations of intermediary points, because they lie at 90° intervals on the zodiac. According to our author, these observations lead to a maximum solar equation of 1;58° and an apogee of Gemini $22\frac{3}{4}$ i.e., Gemini 22;45° [32], which differ somewhat from the results cited by Ibn Yūnus. As to the solar motion in 365 days (a Persian year), one should note that observations of solstices and equinoxes in 831 and 832 are reported from which the solar motion was computed by comparing them with observations of the same phenomena recorded in the *Almagest*.[33] A problem arises when one wishes to compare later results with *Almagest* values for mean motions because many Arab astronomers including the author of this text preferred the sidereal year to the tropical year used by Ptolemy.[34] In calculating the length of the sidereal year our text compares an observation of the star Regulus made by Hipparchus in June - 127 (*Almagest* VII.2) with one made in 199 A.Y. (i.e., 830-831) by an unnamed astronomer.[35] As we learn from the studies of E. S. Kennedy, of all the astronomical parameters known from Arabic sources, mean motions show the greatest variation.[36] To be sure the differences are small, but they are extremely useful for the historian seeking links between various astronomical works. Moreover, Neugebauer has found numerous inconsistencies and small mistakes in calculation in our text that obscure the relationship between the observations and the parameters ostensibly derived from them.

With regard to the precession of the equinoxes, Ptolemy derived a value of 1° per century, whereas Yaḥyā (one of Ma'mūn's astronomers)

[32] Neugebauer (*art. cit.*, 1962, p. 276) notes textual variants of Gemini 22;54° and Gemini 20;55°.

[33] O. NEUGEBAUER, *art. cit.*, 1962, pp. 269-270.

[34] The sidereal year is defined by the return of the Sun with respect to the fixed stars, and the tropical year is defined by its return with respect to the vernal equinox. The difference between them is due to the precession of equinoxes: for a list of year lengths according to various Islamic astronomers, see E. S. KENNEDY, *op. cit.*, 1956, p. 147, where those greater than 365;15 days are sidereal years and those less tham 365;15 days are tropical years.

[35] O. NEUGEBAUER, *art. cit.*, 1962, p. 279. The Persian calendar consisted of years each containing 365 days and counted from the beginning of the reign or Yazdijird III in 632 A.D. This era is designated « A.Y. » (Anno Yazdijird); cfr. O. NEUGEBAUER, *The Astronomical Tables of al-Khwārizmī*, Copenhagen 1962, pp. 83, 88.

[36] E. S. KENNEDY, *op. cit.*, 1956.

established the value of 1° in $66 \frac{2}{3}$ years, based on his observation of an autumnal equinox and the position of the star Regulus.[37] However, Pingree suggests that this parameter was borrowed from Indian sources and perhaps only confirmed by observation.[38] This value for precession was widely accepted by Arab astronomers and once again, we find an improvement over Ptolemy's value.[39]

III. *Conclusion.*

Scientific activity in the ninth century received strong support from the Caliph, al-Ma'mūn, and significant improvements in the parameters for the solar model, geographical latitudes, and the length of a terrestrial degree were obtained. It should, however, be noted that Ptolemy's solar model was accepted and, further, that the models for the Moon and the planets were invoked without any comparably profound discussion of their parameters.

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SUMMARY

The study of astronomy in Islam began in the late eighth century with influences from Iran and India. Greek methods and texts became known in the ninth century, and led to a « renaissance » in astronomical activity, centered in Baghdad and supported by the Caliph, al-Ma'mūn (among others). Despite the paucity of surviving texts, we are able to reconstruct the results produced in this period from the works of al-Bīrūnī (d. ca. 1050), and other later authors. It is noteworthy that a number of parameters were improved based on new observations, but that the underlying models were not challenged. It is argued here (1) that the astronomers belonged to the urban learned middle class and shared their values, and (2) that in order to appreciate fully the achievements of these scientists, it is essential to gain familiarity with the context in which they worked.

37 See n. 34, above.

38 D. Pingree, *Precession and Trepidation in Indian Astronomy Before A.D. 1200*, « Journal for the History of Astronomy », 3, 1972, pp. 27-35.

39 C. A. Nallino, *op. cit.*, I, p. 292; and A. Sayili, *op. cit.*, p. 78.

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