

THE ASTRONOMICAL TRADITION OF MARAGHA: A HISTORICAL SURVEY AND PROSPECTS FOR FUTURE RESEARCH

GEORGE SALIBA

To: 2;31 ≠ e

INTRODUCTION

Ever since the discovery in 1957 of *Nihāyat al-Sūl fī Taṣḥīh al-Uṣūl*¹ of Ibn al-Shāṭir of Damascus (d. 1375), the most remarkable aspect of Arabic astronomy has been the one dealing with the recovery of the revolutionary astronomical results reached by a group of medieval astronomers commonly referred to as the Maragha School.

The crucial issue with regard to the identity and background of the Maragha School members was already raised by Ibn al-Shāṭir in his introduction to the *Nihāyat al-Sūl*, just mentioned. The names of al-Majrīṭī (d. 1007), Jābir Ibn Aflaḥ (12th cent.), Mu'ayyad al-Din al-'Urḍī (d. 1266), Naṣīr al-Dīn al-Ṭūsī (d. 1274), and Quṭb al-Dīn al-Shīrāzī (d. 1311) were all mentioned by Ibn al-Shāṭir as having produced astronomical models that were different from the standard Greek Ptolemaic models. Other astronomers such as Ibn al-Haytham (d.c. 1040), al-Walīd al-Maghribī (i.e. Abū al-Walīd ibn Ruṣḥd?) (d. 1195), and Yaḥyā Ibn Abī al-Shukr al-Maghribī (d. 1283) were also noted in the introduction of another of Ibn al-Shāṭir's later astronomical works *al-Zīj al-Jadīd* (The New Astronomical Handbook) as having criticized the Ptolemaic models. Some of the works of these forerunners of Ibn al-Shāṭir have been identified and partially studied, while others have yet to be located and discussed. As far as I know, works of astronomers who were similarly critical of Ptolemy and were either contemporary or posterior to Ibn al-Shāṭir have thus far received very little attention, if any.

¹The *Ultimate Quest regarding the Rectification of [Astronomical] Principles*. A critical edition of this text using all the extant manuscripts is now completed by the present author. There exists an English translation based on one manuscript, completed by Victor Roberts more than twenty years ago but never published. A new comprehensive translation of the critically edited text and a commentary on the whole work are now in preparation by the present author.

I would like to describe here the status of our knowledge regarding the Maragha School astronomers, outline the most important results recovered so far, and then suggest a course of future research. I hope to demonstrate that the most important statement that can be made at this time about this revolutionary development in Arabic astronomy is that it was neither limited to Maragha, in northwestern Iran, from which the school takes its name, nor confined to the thirteenth and the fourteenth centuries, but that it was the main feature of Arabic astronomical research stretching at least from the eleventh to the sixteenth century.

THE MARAGHA SCHOOL STUDIES

In what follows, I describe in some detail the present status of research on the Maragha School astronomers. To start with, I should mention that it was Otto Neugebauer who first drew attention to the importance of the Maragha result.² But, quite independently, legend has it that Ibn al-Shāṭir's most important work, the *Nihāyat al-Sūl*, was stumbled upon by Edward Kennedy, while he was at the Bodleian Library waiting for Ibn al-Shāṭir's *Zīj*. What seems to be certain, however, is that it was the convergence of Kennedy's accidental discovery and Neugebauer's on-going research which gave the initial impetus to the Maragha studies. Furthermore, since the real significance of the Maragha School astronomy is usually seen in terms of its relationship to Copernican astronomy, the beginnings of serious research on the Maragha School could then be dated to 1957 when both Neugebauer and Victor Roberts published their respective works: the former the appendix to his second edition of the *Exact Sciences in Antiquity*, and the latter his first article in *ISIS* (48: 428–432) devoted to the solar and lunar models of Ibn al-Shāṭir. In Roberts' article, which was inspired by Edward Kennedy, Ibn al-Shāṭir's model was referred to as a "Pre-Copernican Copernican model." Roberts duly credited the discovery of the Copernican connection to Neugebauer in

² O. Neugebauer, *Exact Sciences in Antiquity* (Providence, RI, 1957), Appendix, pp. 197, 203–204. Neugebauer was already working on the Maragha results from a French translation of a text by Naṣīr al-Dīn al-Ṭūsī (d. 1274) describing the "Ṭūsī Device" and Ṭūsī lunar model. It was Baron Carra De Vaux who first made that text available in French as Appendix VI to P. Tannery's *Recherche sur l'histoire de l'astronomie ancienne* (Paris, 1893), pp. 337–361.

the second footnote of the same article. At the same time, Neugebauer had by then already noted other similarities between the works of Copernicus and another member of the Maragha School, namely Naṣīr al-Dīn al-Ṭūsī.³

In the years that followed, Victor Roberts, Edward Kennedy, and Fuad Abbud, either independently or jointly managed to publish notices about Ibn al-Shāṭir's remaining models and about the possible connection with Copernicus.⁴ Abbud went as far as to compare the numerical parameters of Ibn al-Shāṭir's *Zīj* and Copernicus's *De Revolutionibus*, and concluded that although the tables of Ibn al-Shāṭir were similar to those of Copernicus, the latter's were not a direct copy of the first, despite the fact that they both deviated in the same direction from Ptolemy's tables.

In 1966, while summarizing the results achieved up to that date, Kennedy coined the term "Maragha School," and identified the models of two more astronomers of that school, namely, Ṭūsī,⁵ and Quṭb al-Dīn al-Shīrāzī. It was later shown that Shīrāzī's model for the upper planets, as described in Kennedy's article, was indeed composed by Mu'ayyad al-Dīn al-'Urḏī, the third member of the Maragha School,⁶ (figs. 1 and 2). Since then, a critical edition of 'Urḏī's work, together with a translation and a commentary on the whole text, have been prepared for publication by the present author and are now in press.⁷

As a result of these studies, the works of the Maragha School astronomers which were actually subjected to some analysis are:

³ Neugebauer, O., *Exact Sciences*, note 2.

⁴ All these articles are now gathered together in E.S. Kennedy *et al.*, *Studies in the Islamic Exact Sciences* (American University of Beirut, Beirut, 1983), pp. 50–107.

⁵ The important chapter in Ṭūsī's work, where the description of his lunar model is to be found, was already published in translation by Carra De Vaux, see note 2 above.

⁶ See, for example, G. Saliba, "The Original Source of Quṭb al-Dīn al-Shīrāzī's Planetary Model," *Journal for the History of Arabic Science* (1979) 3: 3–18.

⁷ Urḏī's text, *Kitāb al-Hay'a*, was first used by Noel Swerdlow in his unpublished Ph.D. dissertation, "Ptolemy's Theory of the Distances and Sizes of the Planets: A Study of the Scientific Foundation of Medieval Cosmology" (Yale, 1968), and identified simply as the "Anonymous Astronomical Treatise in Bodleian Arabic Ms March 621." Later, the same manuscript was used by B. Goldstein and N. Swerdlow in "Planetary Distances and Sizes in an Anonymous Arabic Treatise Preserved in Bodleian Ms March 621," *Centaurus* (1970–1971) 15: 135–170. The present author finally identified this Bodleian MS as being the work of 'Urḏī in "The First non-Ptolemaic Astronomy at the Maragha School," *ISIS* (1979) 70: 571–576.

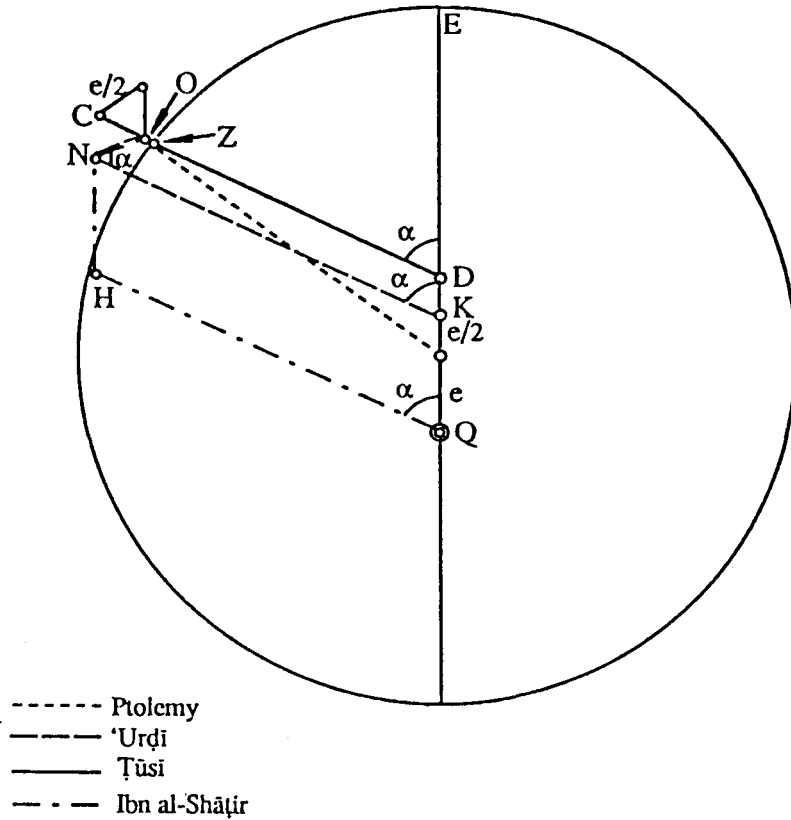


Fig. 1. A revised summary of the models of the upper planets as interpreted by Kennedy in the 1966 publication. The model designated as that of 'Urđi here was ascribed to Shīrāzī by Kennedy.

i) Ibn al-Shāṭir's *Nihāya*, the main source, and through it all the planetary models of Ibn al-Shāṭir, was studied between the years 1957 and 1966.

ii) The lunar model of Ṭūsī⁸ as well as his model for the upper planets were studied by Carra De Vaux in 1893, and by Kennedy in 1966 (fig. 3).

iii) The models of Quṭb al-Dīn al-Shīrāzī (d. 1311) were also studied by Kennedy in 1966. With the exception of the model for the upper planets, just mentioned, Shīrāzī's other models, namely, the lunar and the Mercury models (figs. 4 and 5) are up till now considered to be his own genuine models. But a

⁸In reality it was Carra De Vaux who first published Ṭūsī's lunar model, see note 2 above.

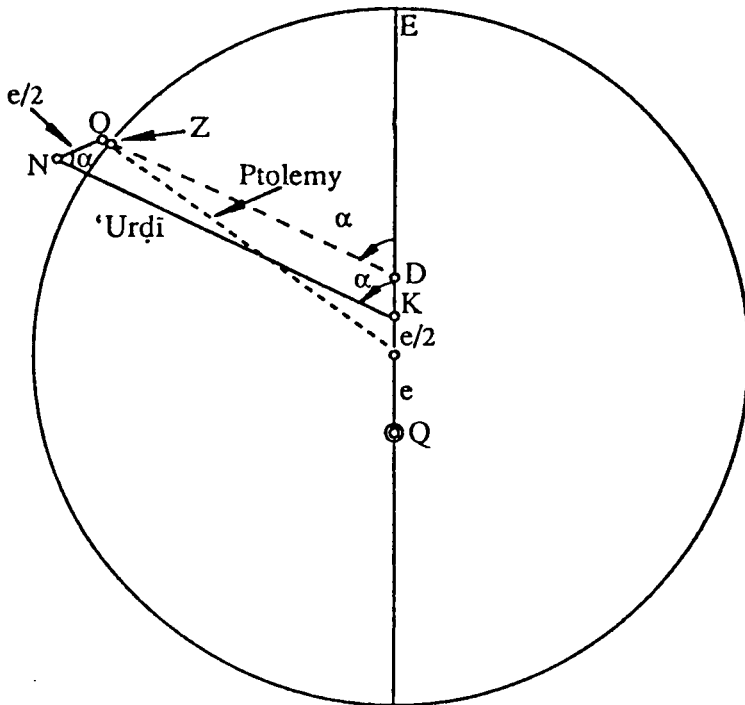


Fig. 2. Urđi's Model superimposed over that of Ptolemy.

close reading of Kennedy's article, where he admits that he had great difficulty in disentangling the genuine work of Shīrāzī, as well as a reading of the two most important surviving works of Shīrāzī, namely the *Nihāyat al-Idrāk* (The Ultimate Understanding) and the *al-Tuhfa al-Shāhīya* (The Shāhī Precious [Gift]), lead me to believe that future studies may very well change the picture that we now have of Shīrāzī's contributions to the Maragha Studies.

iv) 'Urđi's models for the upper planets and the moon (figs. 2 and 6) were published by the present author in 1979⁹ and 1989¹⁰ respectively.

Of all the studies so far mentioned, the only one that included a working edition of the original text was the article describing 'Urđi's model for the upper planets. The other texts remain unpublished, in any form, up to this very day. Besides the critical edition of the work of 'Urđi, just mentioned, and its

⁹ See note 6.

¹⁰ G. Saliba, "A Medieval Arabic Reform of the Ptolemaic Lunar Model," *Journal for the History of Astronomy* (1989) 20: 157–164.

English translation, I have recently completed a critical edition of the *Nihāya* of Ibn al-Shāṭir. Other than that, I am only aware of a work in progress on an edition of Ṭūsī's *Tadhkira* (Memento), but cannot at this point say anything about its status.¹¹ This is more or less the sum total of our knowledge of the texts of the Maragha School so far.

The works of earlier astronomers, which are related to the Maragha School, and have come to light within the last two decades are:

i) Ibn al-Haytham's criticism of Ptolemy. The text of this extremely significant work has been published in a working edition by 'Abd al-Ḥamīd Sabra and Nabil Shehaby,¹² but has not yet been formally translated into any language, nor has it really been fully studied. I am aware of one translation of this text which was presented as a Ph.D. dissertation at the University of Chicago, but it is hard to assess the quality of this translation at this time, or to say whether it will ever be published.

All we can say at this point is that Ibn al-Haytham's text has raised, among other things, the question of the importance of the Arabic translations of the Ptolemaic texts, namely the texts of the *Almagest* and the *Planetary Hypothesis*. Since Ibn al-Haytham's criticism of Ptolemy depends in great part on the nuances of the Ptolemaic texts, and since Ibn al-Haytham knew these texts in their Arabic translations, it is only reasonable to say that a real appreciation of the exact nature of Ibn al-Haytham's criticism can only be fully understood after a detailed analysis of the Arabic translations of the Ptolemaic texts. Unfortunately, none of these texts are as yet edited in any critical fashion.¹³

ii) Another text, which is related to the activities of the Maragha School in that it also represents a criticism of

¹¹ Parts of the *Tadhkira* were edited, translated into English, and supplied with a commentary by F. Jamil Ragep as a Ph.D. dissertation at Harvard University, 1982. Since then, I understand that the same author has undertaken to edit the whole work and to translate it into English and comment upon it.

¹² See Ibn al-Haytham, *Al-Shukūk 'alā Baṭlamyūs*, edited by A. Sabra and N. Shehaby (Dubitationes in Ptolemæum) (Cairo, 1971).

¹³ The present author is aware of the facsimile edition produced by B. Goldstein, "The Arabic Version of Ptolemy's Planetary Hypothesis," *Transactions of the American Philosophical Society* (1967) 57, and of an on-going project, conducted by Régis Morelon, the aim of which is to produce a critical edition of the *Planetary Hypothesis*.

research on the Maragha astronomers can now show.¹⁵ In fact, Swerdlow and Neugebauer have recently referred to Copernicus as the “most noted follower of the Maragha School,” specifically because he, like the Maragha astronomers before him, was concerned with developing models that *preserved* the effect of the equant, and was not attempting to abandon it.¹⁶

Finally, the formal statement concerning the actual relationship between Copernicus and the Maragha astronomers was made by Neugebauer in a technical article devoted to the astronomy of Copernicus in 1968. In that article, Neugebauer spoke of the “Islamic antecedents of the Copernican methods,” and went as far as to assert that “the basic identity of the Copernican methods with the Islamic ones needs no special emphasis in each individual case.”¹⁷

Within the five years that followed, Willy Hartner and Noel Swerdlow each pursued that relationship further, and devoted at least five major works to Copernicus and the Maragha School.¹⁸ Hartner went so far as to assert that there was an actual textual transmission at least in regard to the specific mathematical theorem called the aṭ-Ṭūsī Device by Neugebauer, and later the “Ṭūsī Couple.”¹⁹ In 1973, Hartner devoted an article to the representational diagrams of the “Couple” and attempted to show that both Ṭūsī and Copernicus had used the same alphabetic references to refer to identical geometric points

¹⁵ Koyré’s statement, in R. Taton, *Histoire générale des sciences*, vol. 2, p. 64, was also quoted in O. Neugebauer, “On the Planetary Theory of Copernicus,” *Vistas in Astronomy* (1968) vol. 10, p. 89, reprinted in O. Neugebauer, *Astronomy and History: Selected Essays* (New York, Berlin, Heidelberg, Tokyo, 1983), pp. 491–505. See also *infra*.

¹⁶ N. Swerdlow and O. Neugebauer, *Mathematical Astronomy in Copernicus’s De Revolutionibus* (New York, Berlin, Heidelberg, Tokyo, 1984), p. 295.

¹⁷ O. Neugebauer, “On the Planetary Theory of Copernicus,” p. 90, note 15.

¹⁸ See, for example, W. Hartner, “Naṣīr al-Dīn al-Ṭūsī’s Lunar Theory,” *Physis* (1969) 11: 287–304; “La science dans le monde de l’Islam après la chute du califat,” *Studia Islamica* (1970) 31: 135–151; “Copernicus, the Man, the Work, and its History,” *Proceedings of the American Philosophical Society* (1973) 117: 413–422; “The Islamic Astronomical Background to Nicholas Copernicus,” *Ossolineum 1975, Colloquia Copernica III*, Nadbitka, 7–16 [all now reprinted in W. Hartner, *Oriens-Occidens II* (1984)]; N. Swerdlow, “The Derivation and First Draft of Copernicus’s Planetary Theory: A Translation of the Commentariolus with Commentary,” *Proceedings of the American Philosophical Society* (1973) 117: 423–512.

¹⁹ See, W. Hartner, “Copernicus, the Man,” note 18.

on their respective diagrams.²⁰ In the same year, and in the same issue of the *Proceedings of the American Philosophical Society*, Swerdlow articulated the most daring conclusion regarding the relationship between Copernicus and the Maragha School thus far. In the context of a detailed commentary on the *Commentariolus* of Copernicus, Swerdlow noted that the extent of indebtedness between Copernicus and the earlier Maragha astronomers could not be attributed to coincidence.²¹

Technically, this relationship depended on two basic mathematical theorems, namely the Ṭūsī Couple, and the lemma that I have elsewhere referred to as the ‘Urđī Lemma (figs. 7 and 8).²² The importance of these theorems cannot be overemphasized, for the first allows for the transformation of circular motion into linear motion, and the second is a developed form of the Apollonius theorem which allows for the transformation of eccentric models to epicyclic ones. The real Copernican indebtedness to the Maragha astronomers not only lies in the fact that he uses these same theorems to build his own models, but that he also uses them at the identical points in the models where they were used earlier by the Maragha astronomers. The question is whether it was possible for Copernicus to know of these two theorems, and if so, through which channels?

The only concrete evidence for the actual transmission of the Maragha School works to the Latin west was once more first uncovered by Neugebauer. In his monumental work, *A History of Ancient Mathematical Astronomy*, Neugebauer published the photographs of a page from a Byzantine Greek manuscript, which eventually entered the Vatican Collection sometime after the fall of Constantinople in 1453.²³ On that

²⁰ Hartner continued to explore this connection between Copernicus and the Maragha astronomers till the last years of his life. Just before he died, he published, for example, “Ptolemaische Astronomie im Islam und zur Zeit des Regiomontanus,” *Regiomontanus-Studien*, Österreichische Akademie der Wissenschaften, Philosophisch-Historische Klasse, Sitzungsberichte, 364. Band (1980), Herausgegeben von Günther Hamann, 109–124.

²¹ N. Swerdlow, “Derivation,” note 18.

²² For a detailed analysis of the use of ‘Urđī’s Lemma by the Maragha astronomers and its eventual use by Copernicus, see G. Saliba “Arabic Astronomy and Copernicus,” *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* (1984) 1: 73–87, esp. pp. 78–79.

²³ See *A History of Ancient Mathematical Astronomy* (New York, Heidelberg, Berlin, 1975), p. 1456 for plate IX of *Vat. Graec.* 211, fol. 116r.

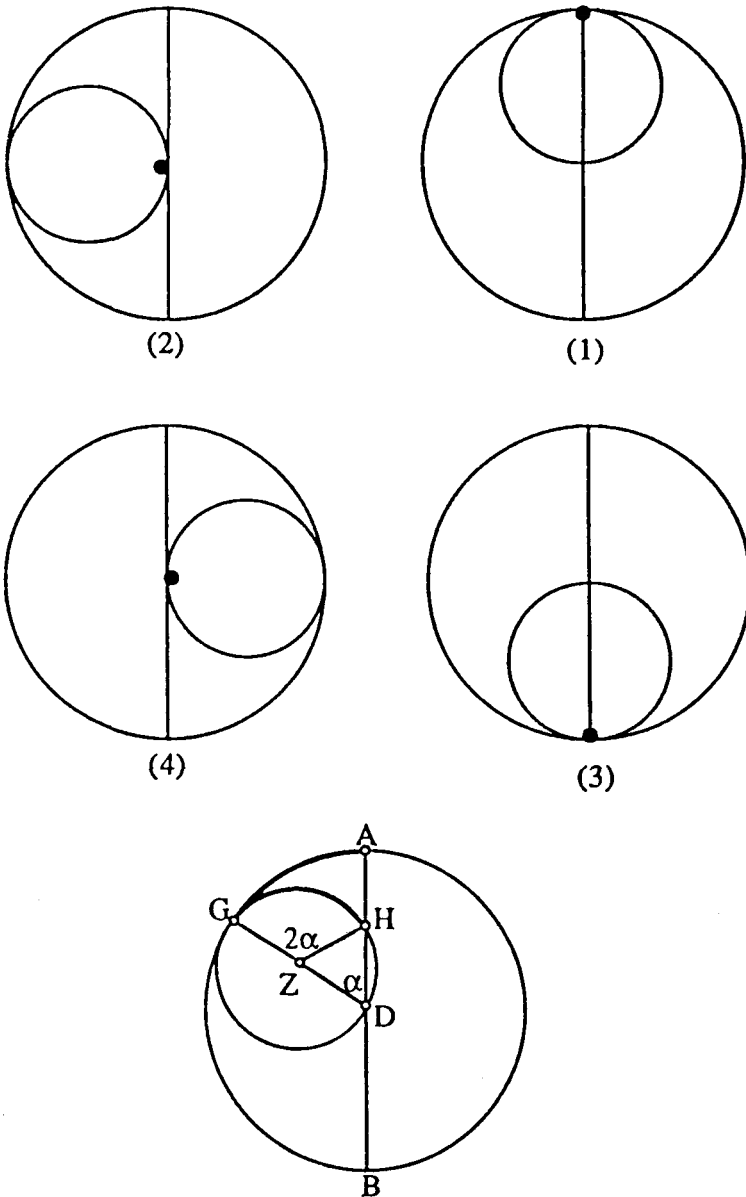


Fig. 7. The Tūsī Couple. As the big sphere moves by an angle α , and the small sphere moves in the opposite direction by an angle 2α , the common point H will oscillate back and forth along diameter AB. Hartner drew attention to the similarities between the lettering used by Copernicus and that used by Tūsī to prove the same theorem.

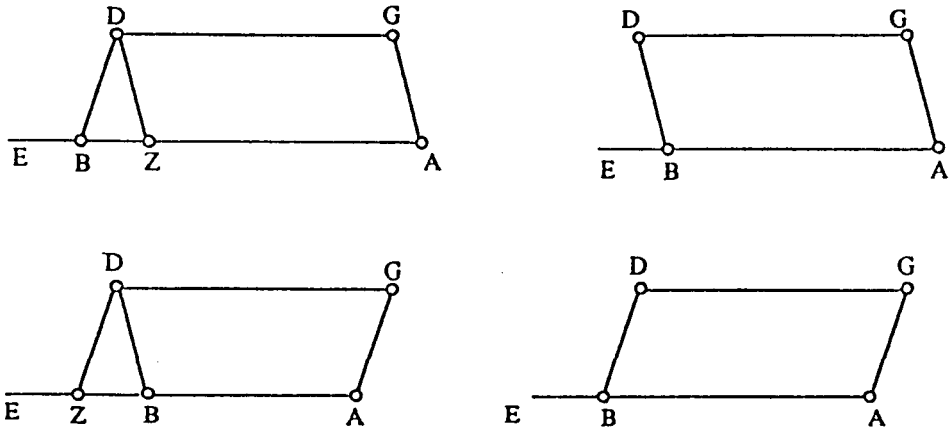


Fig. 8. 'Urđī's Lemma. If any two equal lines AG , BD , describe equal angles with respect to line AB , whether internally or externally, then line GD , which joins the extremities of the two said lines will always be parallel to line AB .

page, Neugebauer noted the clear representation of the Ṭūsī Couple, and used that diagram to point to the possible route of the textual transmission which brought the results of the Maragha astronomers to Europe. He did not point, however, to the diagram on the upper part of the same page, which seems to be a poor rendering of Ibn al-Shāṭir's lunar model as seen in solid spheres. The real significance of Neugebauer's discovery, however, lies in the fact that these results, which finally reached Italy – a country where Copernicus took residence for a few years – could have been made available to Copernicus at the various stages of their transmission, since they were written in Greek, a language that Copernicus could read. It remains to show that Copernicus, at one time or another, saw this specific Greek manuscript, or discussed its contents with someone who had studied it.

Neugebauer continued to trace this line of transmission in his publication, ten years later, of another page of the same Greek manuscript in which it became clear that the Greek manuscript also contained the lunar model of Ṭūsī, as well as a diagram demonstrating the transformation of the Ṭūsī Couple to a configuration of solid bodies.²⁴ Of course, no serious discussion regarding the role of this manuscript can be launched until a critical edition of the entire Greek text is produced. I

²⁴ Noel Swerdlow and Otto Neugebauer, note 16, figs. 5 and 6.

understand that the edition is currently being completed by David Pingree of Brown University.

THE MARAGHA SCHOOL AND ARABIC ASTRONOMY

The texts of Ibn al-Shāṭir raised more questions than they answered. It was quickly learned from those texts that the crucial work, which was completed by Ibn al-Shāṭir before he wrote the *Nihāya* (i.e. the work that he called *Taʿlīq al-Arṣād* (Record of Observations) was not available for investigation, and as of now is assumed to be lost. We now have an excellent idea of the subject matter of that text, for we have several references to it in Ibn al-Shāṭir's other works. But we still lack a full-fledged treatment of the relationship between observation and theory which was apparently discussed in great detail in this text.

We also learned from the texts of Ibn al-Shāṭir that the history of the criticism of Ptolemy was an old one in Arabic astronomy, and that several astronomers were already engaged in that debate in one way or another for several centuries before the time of Ibn al-Shāṭir. The picture that comes out is not that of a maverick Ibn al-Shāṭir dreaming up models of his own without any tradition to refer to.

Other aspects of Arabic astronomy were also brought into focus by the on-going Maragha studies. The issue of the chronology of the works of the individual astronomers, whenever that constituted a problem, became very important because it was needed for the demonstration of the logical progress of the mathematical theorems and the step by step development of the models themselves. In the final analysis this chronology was also crucial to determining the real reason that triggered the criticism of Ptolemy. From this perspective, it is important to note that the "Ṭūsī Couple," for example, was first invented to attend to the desperately flawed Ptolemaic theory of planetary latitudes and was not intended to solve the problem of the equant in the other planetary models themselves, as it later did.²⁵

The implications of the Maragha School research for the

²⁵ See, for example, G. Saliba, "The Role of the *Almagest* Commentaries in Medieval Arabic Astronomy," *Archives Internationales d'Histoire des Sciences* (1987) 37: 3–20.

general history of Arabic astronomy, however, have not always been correctly perceived.

First, we note that although the Maragha studies were conducted with the best of intentions, they nevertheless had their own share in legends and false interpretations which have now unfortunately reached the secondary and tertiary literature.²⁶ One such legend concerns the goal of the Maragha astronomers and by implication the purpose of the whole Arabic tradition to which they belonged. The most common interpretation in this regard is to state that all this activity of model building was motivated only by the desire to preserve the uniform motion of the Aristotelian homocentric spheres, i.e. by philosophical considerations, and not by the empirically oriented activity of observation.

Although one could argue that most of the new models that were being proposed to replace the Ptolemaic models were essentially motivated by the need to preserve uniform circular motion, which was so well entrenched in the classical Greek philosophical tradition, one cannot (1) argue that *all* the models were so motivated, nor (2) that the real purpose was to attend only to the problem of uniform circular motion, which was so blatantly violated by Ptolemy. In a recent article, I have argued that Ibn al-Shāṭir, for example, had explicitly stated that he had no objection against the solar model of Ptolemy, and yet he felt he had to replace it with a new model (fig. 9), simply to account for the observations.²⁷ Ptolemy's statements regarding the apparent size of the solar disk – as being $0;31,20^\circ$ – that it remains constant at all its distances, and remains equal to the apparent size of the lunar disk when the moon is at its farthest distance from the earth, are not philosophical statements, and could be easily countered by one example of an annular eclipse. Although the issue of the annular eclipse was not raised at all, the whole solar model of Ibn al-Shāṭir was specifically constructed to account for the variation in the apparent size of the solar disk.

²⁶ Most of these interpretations are now grouped together for the reader's convenience in one article by Owen Gingerich, "Islamic Astronomy," *Scientific American* (1986) 254: 74–83. This article was later translated into Arabic with many gross mistakes in the Arabic and published in the Arabic version of the *Scientific American Majallat al-'Ulūm*, 1.1: 8–19.

²⁷ G. Saliba, "Theory and Observation in Islamic Astronomy: The Work of Ibn al-Shāṭir of Damascus (d. 1375)," *Journal for the History of Astronomy* (1987) 18: 35–43.

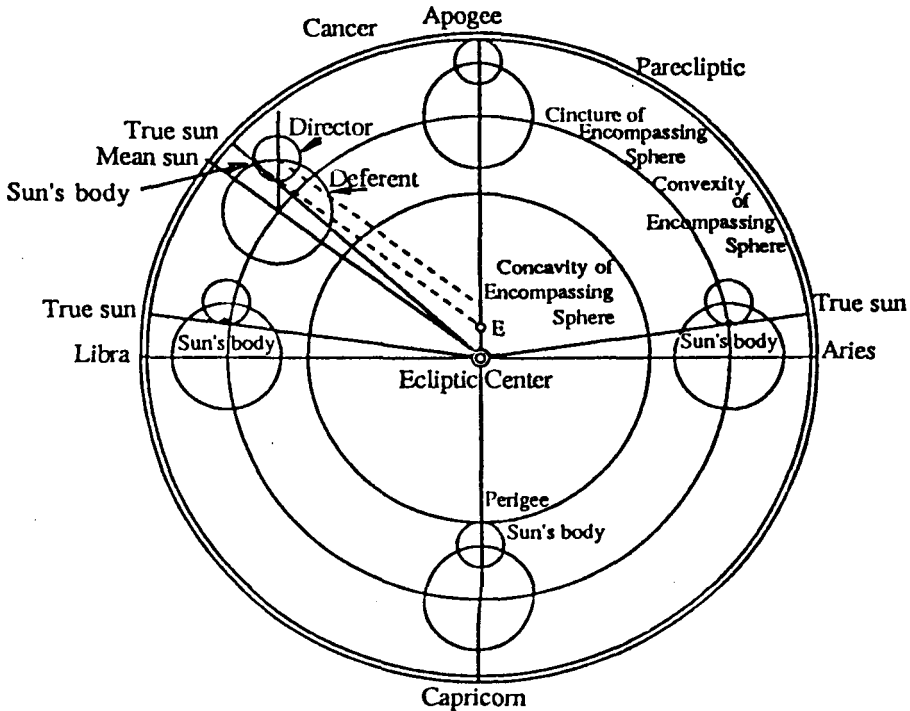


Fig. 9. The solar model of Ibn al-Shāṭir. By using 'Urđī's Lemma note that the sun will look as if it is moving around point E rather than around the ecliptic center. This allows for the eccentricity of the sun. At the same time it also allows for a considerable variation in the solar disk for an observer at the center of the world.

In the same article, I also drew attention to the fact that Ibn al-Shāṭir was equally aware of the observational problems connected with the Ptolemaic lunar model, where, according to that model, the moon at quadrature is supposed to look almost twice as large as the full moon. Ibn al-Shāṭir objected to that specific feature of the Ptolemaic model by saying that the moon “was not seen to be so” (*lam yurā kadhālika*). And in his own model he resolved this contradiction with observation.

In another article, I have also demonstrated that Ṭūsī's Couple was first proposed in the *Tahrīr* (Reduction) in order to solve the kinematic problems in Ptolemy's latitude theory, and was not then used for model building.²⁸ This is not philosophy!

The second interpretation has to do with the relationship between this new activity of model building and the parameters

²⁸ Saliba, “The Role of the *Almagest* Commentaries,” note 25.

used by the astronomers in question in their respective astronomical handbooks (*Zījes*). One finds modern historians of Arabic astronomy lamenting the fact that although a specific astronomer produced a new set of models, the arrangement of the tables in his *Zīj*, or sometimes even the parameters used in these tables, exhibit only very slight variations from the parameters of Ptolemy or the arrangement of Ptolemy's *Handy Tables* as they were known in Theon's version.²⁹ In consequence, this interpretation led to the conclusion that all this activity had no tangible implications in practice.

Now to succumb to this interpretation, and to say that the model builders intended to translate their models into tabular forms so that they could incorporate them in practical *Zījes*, is to miss the whole purpose of the activity of model building. In fact, there were some astronomers, such as Mu'ayyad al-Dīn al-'Urḏī, who did not even write a *Zīj*, and yet produced one of the more extensive reformulations of Greek astronomy, and a drastic modifications of the Greek models, as I have shown in 'Urḏī's lunar model mentioned above.³⁰

To understand Why 'Urḏī was doing this, one has to examine the details of the criticism of Ptolemy. No one of the Maragha School astronomers that I know of ever complained about the inaccuracy of the Ptolemaic models in terms of their ability to predict the positions of the planets concerned. Whatever criticism they had in that regard was restricted to minor observational details such as the inclination of the ecliptic, the precession value, or the mobility of the solar apogee, which are passed over very quickly. In fact, most of these minor criticisms were already raised and answered as early as the ninth century, some four to five hundred years before the time of the Maragha astronomers. Hence, on that ground alone, there was no need to reformulate the Ptolemaic models.

The more dramatic criticism to which the Ptolemaic models were subjected had to do with a much more serious problem inherent in Ptolemaic astronomy. Ptolemy had accepted at the beginning of the *Almagest* uniform circular motion as the only motion which was befitting to the celestial bodies, and then went ahead to describe that motion in a mathematical language (i.e. by using mathematical models) that did not allow for this

²⁹ See Roberts, note 4.

³⁰ See note 10.

uniform circular motion. The problem was therefore a problem in consistency. And it is immaterial whether one believed the universe to be made of spherical shells, as was propounded by Ptolemy in the *Planetary Hypothesis*, or of complete spheres which was the general belief of most astronomers of antiquity and medieval times. The problem was to be able to represent whichever system one believed in a mathematical language that could possibly account for the motion of that system. One could not accept a set of principles regarding the spheres that constitute the universe, as Ptolemy did, and then produce models like the Ptolemaic models that force these spheres to move uniformly on axes that do not pass through their centers.

To say that such a requirement of rigorous consistency is only a philosophical requirement, and has nothing to do with the science of astronomy *per se*, is to trivialize the distinction between philosophical issues and the methodological consistency required in any scientific discipline. A careful analysis of the works of the Maragha astronomers readily reveals that their concern was not restricted to preliminary philosophical doctrines relating to the nature of the universe and its appropriate motions. It went beyond that to include the development of a mathematical methodology that could describe, in a mathematical language, whatever philosophical doctrine one held. In a very real sense, this concern with the consistent mathematical formulation to describe empirical observations is different from the philosophical concern with the nature of the universe and its appropriate motion.

Therefore, the Maragha astronomers were holding themselves to a rigorous requirement of consistency, and were attempting to produce models that would solve the Ptolemaic contradictions. In essence, they required a consistent mathematics that accounted for the observable physical world, irrespective of the doctrines regarding the nature of the world. Hence their criticism was not directed at the predictability aspect of the Ptolemaic system, which for all practical purposes was quite satisfactory.

As a result, the Maragha astronomers were willing to accept the observational accuracy of Ptolemy, use machinery similar to Ptolemaic machinery, or slightly improve it, but they all questioned the veracity of the Ptolemaic models in regard to their consistency with the Ptolemaic presuppositions themselves. Someone like 'Urđī would explicitly state that he had

no objections to the Ptolemaic observations *per se*, but that he had considerable objections to the methods used by Ptolemy to describe the motions of the spheres that he had already posited. He would even go as far as saying that the observations themselves can be accounted for by various mathematical models; those posited by Ptolemy were inadequate for the purpose.

Once the consistency issue mentioned above is properly understood, one would not require the Maragha astronomers to translate their models to tables that would differ in form or even content from the Ptolemaic tables. One could simply say: let the planets be at the critical points cited by Ptolemy, at exactly the points where Ptolemy says they were (for they were not too far off the true positions), the question remains how does one produce a mathematical model that allows the planets to be at those points, and accommodate the new observations that were different from those of Ptolemy, without falling into inconsistencies.

As an example, we can refer to Victor Roberts who published an early version of the solar model of Ibn al-Shāṭir and had this to say about it: "Ibn al-Shāṭir gives no motivation for his adoption of two epicycles, and it is difficult to see how this model constitutes an improvement over the Ptolemaic one."³¹ Since the need for the two epicycles was not perceived by Roberts, one has to assume that he thought the purpose of the model was to improve the predictability in the solar longitude, i.e. improve the table for the solar equation in the *Zīj*. Ibn al-Shāṭir's model did not do that for there was no marked difference between the observations and the solar longitudinal positions predicted by the Ptolemaic models. The model did in fact improve the value for the solar eccentricity, just so slightly, thus also modifying the maximum solar equation, but in a marginal way. The main concern of Ibn al-Shāṭir's model, however, was to explain the variation in the apparent size of the solar disk, and was purposely supposed to retain the longitudinal predictions of the Ptolemaic model. The fact that these features have no major direct implications for the form of the tables of the solar equations in the *Zīj*es, was totally missed by Roberts and those who followed him.

³¹ Victor Roberts, note 4, p. 430.

Despite all that, the following results have been established so far:

a) Arabic astronomy can no longer be perceived as being merely a storehouse for Greek astronomy. Even those who do not believe in the validity of the Ptolemaic criticism have to admit that these criticisms were pervasive, and at times extremely original.

b) Arabic astronomy, after the Maragha Studies, can no longer be considered marginal to Medieval or Renaissance astronomy. The theoretical connection with Copernicus not only forces us to reconsider our traditional channels of contacts between Europe and the East, but it also forces us to reconsider the periods of contacts as well as the modes of these contacts. Such contacts did not apparently stop with the end of the thirteenth century, nor was the mode of transmission only through the translations of Arabic texts into Latin.

c) By the same token, the whole issue of periodization of Arabic astronomy, traditionally accepted to constitute periods of translation, assimilation, creativity, and decline, had to be abandoned, for most of the original results of the Maragha School fell well within the traditional period of decline.³²

d) Once the periodization paradigm is abandoned, one could look at the so-called age of decline and expect to find original results. In fact, a preliminary study of the period of "decline" has already yielded many interesting findings: the most important of these is that it can now be asserted that Ibn al-Shāṭir's criticism from Damascus was contemporary with another criticism issuing from the city of Bukhara in Central Asia. The author of this criticism, the religious scholar and linguist Tāj al-Sharī'a (d. 1347), was himself continuing the tradition already started by 'Urḍī, Ṭūsī and Shīrāzī, and was building models of his own.³³ The equally important works of later astronomers will be discussed below.

³² For a more detailed treatment of the problem of periodization in Arabic astronomy, see G. Saliba, "The Role of Maragha in the Development of Islamic Astronomy: A Scientific Revolution Before the Renaissance," *Revue de Synthèse* (1987) 3.4: 361–373.

³³ For a short survey of Tāj al-Sharī'a's models, see G. Saliba, "Islamic Planetary Theories After the Eleventh Century," to appear in a book devoted to the history of Arabic science edited by R. Rashed. See also the edition, translation, and commentary on Tāj al-Sharī'a's works in the Ph.D. dissertation of Aḥmad al-Dallāl, Department of Middle East Languages and Cultures, Columbia University (1990).

Beginnings of Ptolemaic Criticism

This activity stretches back to the beginning of Arabic astronomy. One may not have enough sources to trace it to the times before the ninth century. But some systematic effort has to be exerted in order to explain the methodological criticism that led, beginning with the ninth century, to the correction of the Ptolemaic precession, solar eccentricity, and solar apogee during that century.

In the eleventh century, criticism of Ptolemy seems to have become more systematized, and full-length books were apparently written on that subject. We have already hinted at the extant work of Ibn al-Haytham in that regard. But no effort should be spared to locate two similarly important books: one by an anonymous Spanish author, and the other by the famous Bīrūnī. In the case of the Spanish author, we have some idea of the contents of his book *al-Istidrāk ‘alā Baṭlamyūs* (Recapitulation in Regard to Ptolemy), and if that is ever found it will illuminate the Arabic astronomical literature immensely, for it will shed light on the critical activity itself and its early motivation, as well as shed some very important light on the origins of the Spanish school of criticism.³⁴

The title and description of Bīrūnī’s work, on the other hand, has just come to light, but has not yet been located. All we know so far comes from a relatively unknown text by Shīrāzī, called *Fa’altu Fa-lā Talum* (I Have Done [what I did] so Don’t Blame Me). While discussing the Ptolemaic theory of planetary latitudes, Shīrāzī refers to Bīrūnī in these words: “For that reason Ustādh Abū al-Rayḥān has stated in the book of *Ibṭāl al-Buhtān bi-Īrād al-Burhān* (Disqualifying Falshood by Expounding Proof), the following: ‘As for the motions of the five epicyclic apogees in inclination, as it is commonly known (*al-mashhūr*), and is mentioned in the *Almagest*, that would require motions that are appropriate for the mechanical devices of Banū Mūsā, and do not belong to the principles of Astronomy (*uṣūl al-hay’a*).’”³⁵

³⁴ The only reference we have to this book comes from an elementary treatise called *Kitāb al-Hay’a* (A Book on Astronomy), by the same anonymous Spanish author, now preserved at the Osmania University Library, Hyderabad, MS N^o 520RH.

³⁵ Cf. Arabic manuscript Aḥmad III 3338, fol. 4v, in the Topkapı Library, Istanbul.

This stray remark, ambiguous as it is, leaves no doubt regarding the identity of the author or the purpose of his book. We do not know of this book from any other source. But it is not unlikely that Bīrūnī would have devoted a book to the difficult latitude theory of Ptolemy. Since we have a list of Bīrūnī's works, written by Bīrūnī himself, one has to assume that this work, in which Bīrūnī seems to criticize the Ptolemaic theory, was probably composed towards the end of his life.

As was stated above, we still have to explore the extant work of Ibn al-Haytham, which comes from the same century. The text should be properly edited, translated, commented upon, and fully integrated into our body of knowledge on Arabic astronomy.

We noted already that a work of Majrīṭī, which was already mentioned in the introduction of Ibn al-Shāṭir's *Nihāya*, was also critical of Ptolemaic astronomy. That work, which obviously belongs to the end of the tenth century or the beginning of the eleventh, needs to be identified and studied.

We also mentioned the work of Biṭrūjī from the next century, and pointed to the historical significance of that work in connection with the Spanish School of criticism. In general, the Spanish school deserves much more than the very few cursory studies it has received so far,³⁶ and Biṭrūjī's work deserves to be integrated within that school. Similarly, the work of his contemporary Jābir Ibn Aflaḥ, extant in Arabic and Latin, needs to be fully incorporated with that school.³⁷

All of these works are indeed precursors to the works of the Maragha astronomers, and it would be highly presumptuous to think that we can formulate a coherent statement regarding the purposes of the Maragha astronomers without giving full credit to the works of these earlier authors.

The Remaining Works of the Maragha Astronomers

I have noted above that most of the Maragha studies which have appeared so far were based on the analysis of the extant

³⁶The latest of these studies is A.I. Sabra, "The Andalusian Revolt against Ptolemaic Astronomy," in *Transformation and Tradition in the Sciences*, edited by Everett Mendelsohn (Cambridge, 1984).

³⁷The last study of N. Swerdlow, "Jābir Ibn Aflaḥ's Interesting Method for Finding Eccentricities and Direction of the Apsidal Line of a Superior Planet," in *From Deferent to Equant*, edited by D. King and G. Saliba, *Annals*, New York Academy of Sciences (1987) 500: 501–512, explains the methodological sophistication of Jābir, but does not touch directly upon the issues raised here.

texts of Ibn al-Shāṭir, Ṭūsī, and Shīrāzī. In addition, I noted that the work of 'Urḍī is now in press and that the critical edition of Ibn al-Shāṭir's text, the *Nihāya*, is also completed and awaits publication. Furthermore, I have hinted at the work in progress devoted to Ṭūsī's *Tadhkira*.

This, in effect, is all that has been done on that group of revolutionary texts. One immediately notices the inadequacy of the coverage and the difficulty one faces when assessing the total impact of those works. To start with, we do not even have all the extant works of the Maragha astronomers themselves in published form in order that we can all share in their discussion. In addition, very important texts of these astronomers are still waiting to be located.

For example, we definitely need to have critical editions of Ṭūsī's earlier works, especially the *Tahrīr* of the *Almagest*, and his Persian treatise, *Hall-i Ishkāl-i Mu'īniya* (Solution of the Mu'īniya Problem), for both of these texts bear heavily on the very issue of the purpose of the Maragha astronomers.³⁸

Of Shīrāzī's works, none has been published so far, and none is contemplated for the near future, as far as I am aware. The difficulty lies in the amount of labor it will take anyone to complete an edition of the voluminous works left by Shīrāzī. Each of Shīrāzī's major works is more than two hundred densely written folios. And to use Kennedy's words, when he tried to describe Shīrāzī's planetary models, each folio is "exasperating" by itself. After reading Shīrāzī's third work, namely his *Fa'altu Fa-lā Talum*, which is not yet studied in any depth, we know why. He himself admits that he had constructed "nine models to solve the problem of Mercury's equant, only the ninth is the correct one. The remaining eight, each has some fault." Shīrāzī goes on to say that he "exposed the faults of six of them in the *Tuhfa* [another one of his works] and intentionally left the faults of the seventh and the eighth in order to test whether those with intelligence will ever discover them."³⁹ The work is sufficiently difficult as it is without the author intentionally playing tricks with it.

But no matter how difficult the work is, the actual contribution of Shīrāzī to the Maragha School has to be determined,

³⁸ I have noted the importance of these texts and their interrelationship in the preliminary survey of the *Tahrīr*. See G. Saliba, "The Role of the *Almagest* Commentaries," note 25.

³⁹ Cf. Shīrāzī's text, Majlis Shūra-i Milli MS 3944, Teheran, fol. 7r.

and to do so these texts have to be studied at some point or other. More urgently, since I have noted above that I have determined quite some time ago that the model for the motion of the upper planets, which was attributed to Shīrāzī by Kennedy, was indeed that of 'Urḍī, one is left with the problem of determining the actual model of Shīrāzī. That in itself is an enormous task.

Ideally, one would like to have critical editions of the three extant works of Shīrāzī, namely the *Nihāya*, the *Tuhfa*, and *Fa'altu*, translations of them, with commentaries upon all the three works, and a full analysis of the nature of the mathematical models for all the planets. This has to be done in order to understand the full originality of Ibn al-Shāṭir's work itself. But before we reach that final stage of analyzing the texts belonging to the Maragha tradition, much more work needs to be done on the present manuscripts themselves.

Finally, the last member of the Maragha School, who was mentioned by Ibn al-Shāṭir as having contributed some models of his own, is Yaḥyā Ibn Abī al-Shukr al-Maghribī (d. 1283). The works intended by Ibn al-Shāṭir's remark have not yet been identified. The study which I have recently devoted to Maghribī's *Talkhīṣ al-Majisṭī* (Summary of the *Almagest*) revealed that this work does not contain the kind of models mentioned by Ibn al-Shāṭir.⁴⁰

Post Ibn al-Shāṭir Period

I have noted above that the works of astronomers who were either contemporaries with Ibn al-Shāṭir, or came after him, have so far received very little attention. In addition, once we re-orient ourselves to cease to think of the centuries after Ibn al-Shāṭir as centuries of decline, the study of the works of the astronomers of this period may produce novel results. In fact, just a cursory survey of these particular works, which I have conducted in a few of the manuscript collections of Istanbul during two months of the summer of 1989, has already revealed the following important works which need to be located and studied:

1) Among the works attributed to 'Alī al-Qushjī (d. 1474) there are two treatises that are of particular importance to our

⁴⁰ See *ISIS* (1983) 74: 388–401 and *Centaurus* (1986) 29: 249–271.

discussion. The first is a treatise dealing with the solution of the problems of the Ptolemaic lunar model, apparently called “*Hall Ishkāl al-Qamar*” (The Solution of the Lunar Problem).⁴¹ Nothing was said about the contents of this treatise, except that Ulugh Beg himself, who was originally sceptical about its importance, finally praised it when he heard it read to him by the author. There is a very good chance that manuscripts of this treatise will soon be recovered from among the immense collections of Arabic manuscripts still in the Middle East.

The second treatise is extant in many copies, and deals with the solution of Mercury’s model.⁴² In a forthcoming article, the present author intends to publish a critical edition of this treatise with translation and commentary.

Finally, there is the general introductory work of Qushjī, called *al-Risāla al-Fathīya fī-l-Hay’a* (The Fathīya Treatise on Astronomy), composed for Muhammad al-Fātiḥ (1451–1481) on the occasion of his conquest (*fath*) of Iraq, which contains no radical criticism of the Ptolemaic models of the kind discussed here, but which gave rise to such criticism as we shall soon see.

2) Maḥmūd b. Muḥammad b. Qādīzādeh al-Rūmī, also known as Mīrem Çelebī (d. 1524)⁴³ was the grandson of Qushjī, on his mother’s side, and of Qādīzādeh Rūmī, on his father’s. Besides Çelebī’s commentary on Ulugh Beg’s *zīj*,⁴⁴ he had also written a commentary on *al-Fathīya*, the elementary treatise just mentioned of his grandfather Qushjī, which he apparently called *Dhayl al-Fathīya* (Appendix to the *Fathīya*). The text of this *Dhayl* has not yet been located. But its subject matter clearly belongs to the group of texts under discussion. In the only copy of Çelebī’s commentary on the *Fathīya* consulted by the present author so far,⁴⁵ the following remark is made in connection with the problems of Mercury’s model: “That which was added

⁴¹This treatise was mentioned by the biographer Taşköprü Zādeh (d. 1561), *al-Shaqā’iq al-Nu’māniya fī al-Dawla al-’Uthmāniya*, edited by Aḥmad S. Furāt, Istanbul Üniversitesi Edebiyat Fakültesi Yayınları N°: 3353 (Istanbul 1985), p. 159.

⁴²The existence of this treatise was first brought to my attention, in 1981, by A.I. Sabra, of Harvard University, who has kindly sent me a copy of his own handwritten selections from it. I gladly acknowledge his kind gesture.

⁴³See H. Suter, *Die Mathematiker und Astronomen Der Araber und Ihre Werke* (Leipzig, 1900), p. 188.

⁴⁴See L.P.E.A. Sédillot, *Prolégomènes des Tables Astronomiques d’Ouloug-Beg* (Paris, 1853).

⁴⁵Süleymaniye, Hüsrev Paşa MS 246.

by the moderns, may God look favorably upon their attempts, in regard to the spheres of the wandering planets and the moon, cannot be mentioned in this compendium. But my intention, if I am spared by death and granted good fortune by God almighty, is to mention all of them in the promised treatise, the *Dhayl*, if God grants mercy and success . . .”⁴⁶ A similar remark is made in connection with the reforms of the lunar model.⁴⁷ Therefore, the recovery of Çelebî’s treatise, the *Dhayl*, promises to yield some positive results regarding his own work on the subject as well as the works of his predecessors and contemporaries.

3) In the same century, and in the Persian city of Shīrāz, there flourished an encyclopedic scholar whose works may be of great interest to our subject. The scholar is a relatively obscure person by the name of Ghiyāth al-Dīn Manṣūr b. Muḥammad al-Ḥusainī (al-Dashtāghī?) al-Shīrāzī (d. 1542/3).⁴⁸ In a collection of texts, preserved at the Topkapı Seray, Istanbul,⁴⁹ this author attempted to encompass science (*‘ilm*), religious doctrines (*‘aqā’id*), as well as speculative theology (*kalām*). In this collection, the author includes a short treatise (fols. 85v-98v) with the title *al-Safīr fī ‘Ilm al-Hay’a* (The Ambassador: On the Science of Astronomy). The treatise in itself is an elementary introduction to Ptolemaic astronomy. But during the discussion of this astronomy, Ghiyāth al-Dīn has occasion to comment on the faults of such an astronomy, thereby leading us to other works of his which are more relevant to our discussion here. While discussing the motions of the lunar spheres, for example, he says: “The (fact that the) motion is uniform around the center of the world, rather than around its own center [meaning the motion of the deferent], that is one of the problems (*ishkālāt*) in this discipline. The ancients had nothing to say about it. Its solution, according to the opinion of the inquirer (*muḥaqqiq*) Ṭūsī, is by (using) the principle (*aṣl*) of the Large (sphere) [*al-kabīra*, a reference to Ṭūsī’s large and small spheres of the Ṭūsī Couple], and according to the opinion of the author of the *Tuḥfah* [i.e. Quṭb al-Dīn al-Shīrāzī], by the principle of the Encompassing (sphere) [*al-muḥīṭa*, a reference to ‘Urḏī’s Lemma, as this theorem is called in the *Tuḥfah* and

⁴⁶ *Ibid.*, fol. 46v.

⁴⁷ *Ibid.*, fol. 50v.

⁴⁸ See, for example, Suter, *Die Mathematiker und Astronomen*, p. 189, note 43 and C. Brockelman, *Geschichte der Arabischen Literatur* (Berlin, 1902), II, p. 414.

⁴⁹ MS Arabic Revan 1996.

the *Nihāya*]. I have various other excellent methods (for solving it), which I have explained in (the book) *al-Hay'a al-Manṣūrīya* (The Manṣūrī Astronomy), and I have also referred to (still) other marvellous methods in (the book) *al-Lawāmi' wa-l-Ma'ārij* (The Sparkles and the Ascensions).⁵⁰

At another point, while discussing the problem of prosneusis, he also says: "This prosneusis is also among the problems (*ishkālāt*). The famous solutions [proposed up till now] for it are impossible. People made many statements about it which are all fantasies and delusions. The truth (concerning it) is what I have established in *al-Hay'a al-Manṣūrīya*, which shines with the *Lawāmi'* (Sparkles) of lights."⁵¹

Later on, while discussing the problem of the equant, he also says: "This too is among the problems (*ishkālāt*), which *al-Hay'a al-Manṣūrīya* (The Manṣūrīya Astronomy) is capable of solving. The inquirer [i.e. Ṭūsī] had used the principle of the Large (sphere) in order to solve it, while the author of the *Tuhfah* used the principle of the Encompassing (sphere)."⁵²

In a commentary on 'Amilī's astronomy, discussed below, we also note the statement of the marginal commentator, who must have lived at least one century after Ghiyāth al-Dīn, when he says, regarding the problems of Ptolemaic astronomy: "Anyone requiring the solutions of these problems (*ishkālāt*) should seek them in the *Ma'ārij* [part] of the *Lawāmi'* of *al-Manṣūrīya*."⁵³

Therefore, there is no doubt that this Ghiyāth al-Dīn had composed two separate books specifically dealing with the reform of Ptolemaic astronomy, which have yet to be located and studied. The first book is called *al-Hay'a al-Manṣūrīya*, and the other is called *al-Lawāmi' wa-l-Ma'ārij*.

4) From the same century, a noteworthy book was composed by the Syrian astronomer Ghars al-Dīn Aḥmad b. Khalīl al-Ḥalabī (d. 1563),⁵⁴ apparently from the city of Aleppo. The book, of which the present author had not yet had a microfilm copy to study, is titled *Tanbīh al-Nuqqād 'alā mā fī al-Hay'a al-*

⁵⁰ *Ibid.*, fol. 90r.

⁵¹ *Ibid.*

⁵² *Ibid.*, fol. 92v.

⁵³ Istanbul University MS Arabçe 2466.

⁵⁴ See, Suter, *Die Mathematiker und Astronomen*, p. 190, note 43, where he gives a variant of the name as Chalīl b. Aḥmed el-Naqīb, Ġars ed-din Ḥalebī, but does not mention the work discussed here.

Mashhūra min al-Fasād (Warning the Critics in Regard to the Faults of the Generally Accepted Astronomy). As far as I can tell, a unique copy of this book is kept together with a collection of astronomical manuscripts at the Süleymaniye Library, Istanbul.⁵⁵ According to the present author's notes, the author says in this text: "Since the generally accepted astronomy is not free of doubts (*shukūk*), especially those regarding the eccentrics, I have confronted them in this treatise, not in order to belittle the principles of this craft (*ṣinā'a*), but (to point to) slips where the intention did not match (the results), and to have that as a proof for what we have written in *Tahrīr al-Wuṣūl ilā Nihāyat al-Sūl* (The Redaction of the Ascent to the Ultimate Request). I have composed (this treatise) in five chapters."⁵⁶ Chapter four of this treatise, subdivided into several sections, is devoted to the doubts (*shukūk*) regarding the spheres of the moon. The treatise itself is dated A.H. 958 (= 1551 A.D.).

Although the text of Ghars al-Dīn, the *Tanbīh*, may be of great importance by itself, simply because it seems to deal with the problem of the eccentrics, it is also important because it comes from such a late date and from Syria. Its importance is further enhanced by the reference it makes to Ibn al-Shāṭir's *Nihāyat al-Sūl*, for it is clear that Ghars al-Dīn must have written a commentary on Ibn al-Shāṭir's *Nihāya*. The contents of this commentary, if they can ever be determined, may be extremely important, not only because this commentary seems to deal with the problem of the eccentrics, a problem mainly raised in Spanish Arabic astronomy as far as we know, but because it must also concern the study of Ibn al-Shāṭir's work and his possible influence on later generations of Syrian astronomers.

5) The astronomical work of Muḥammad b. al-Ḥusain Bahā' al-Dīn al-ʿĀmilī (d. 1622), called *Tashrīḥ al-aflāk* (Anatomy of the Spheres),⁵⁷ is indeed an elementary treatise on Ptolemaic astronomy. But at this late period the so-called problems (*ishkālāt*) of Ptolemaic astronomy were so well known that it was difficult for any astronomer, no matter how elementary was his work, not to mention them. While ʿĀmilī's own work may not have included a detailed discussion of the reform to

⁵⁵ MS Arabçe Yeni Cami 1181.

⁵⁶ *Ibid.*, fol. 174v.

⁵⁷ More on this author in Suter, *Die Mathematiker und Astronomen*, p. 194, note 43.

Ptolemaic astronomy, his commentators did indeed fill that gap. There is some evidence, however, that he himself may have after all discussed such issues in his book, *Sharḥ al-Ḥadīqa al-Hilālīya min Ḥadā'iq al-Ṣāliḥīn* (A Commentary on al-Ḥadīqa al-Hilālīya [part] of Ḥadā'iq al-Ṣāliḥīn), now kept in a collection together with a number of other mathematical and astronomical manuscripts.⁵⁸ In addition, this treatise of 'Āmilī does contain, among other things, a defense of the science of astronomy.

But the more promising field of research is in the works of the commentators who wrote marginal notes to al-'Āmilī's *Tashrīḥ*. The names of two such commentators, 'Abdallāh Fakhri and Muḥammad Bāqir, are mentioned on the flyleaf of one of the copies of al-'Āmilī's work.⁵⁹ And although it is difficult to tell with certainty which commentator is saying what, it is important to note that at least one of them did comment on the faults of Ptolemaic astronomy.

When al-'Āmilī mentions the motions of the lunar spheres, for example, he highlights the Ptolemaic description of that motion by saying that "the motion of each sphere is uniform with respect to its center except the sphere of the lunar deferent, which is uniform with respect to the center of the world."⁶⁰ On that occasion one of the commentators says: "This problem (*ishkāl*) is one of those about whose solution nothing was said by the ancients, from the time of Adam, peace be upon him, till the time of the inquirer Ṭūsī. He [i.e. Ṭūsī] solved it by using the principle of the Large and the Small (spheres) [i.e. the Ṭūsī Couple], and his student after him, the author of *al-Tuḥfah*, solved it with the principle of the Encompassing (sphere). Credit, however, should go to the first one who preceded in opening this guiding door to those with intelligence." Although this comment is not historically accurate, it nevertheless demonstrates the interest in the subject at this later date.

Either the same commentator, or someone else, recapitulated a few lines later by saying:

The first among the moderns who spoke about the solution of the insoluble (problems) was al-Waḥīd al-Jurjānī, the student of al-Ra'īs Abū 'Alī Ibn Sīnā

⁵⁸ Süleymaniye Library, Istanbul, Laleli Arabic MS 2126, fols. 64r–116v.

⁵⁹ Istanbul University, MS Arabçe 2466.

⁶⁰ *Ibid.*, fol. 6v.

[sic., meaning 'Abd al-Wāhid al-Jūzjānī].⁶¹ He wrote a treatise, which he called *Tarkīb al-Aflāk* (The Structure of the [Celestial] Spheres), and in which he mentioned the models with which these problems (*ishkālāt*) could be solved. After him came Abū 'Alī Ibn al-Haytham, then the inquirer Ṭūsī, and then the learned Shīrāzī, who collected from his contemporaries such as Muḥyī al-Dīn al-Maghribī – because the Principle of the Inclined (*al-mumayyila* or *al-mumīla*) is copied from him – and then the Excellent master Shams al-Dīn Muḥammad b. 'Alī b. Muḥammad al-Ḥammādī (?). You should note that the statements of Abū 'Ubayd are very weak, and nothing could be solved with Ibn al-Haytham's words, as it was already stated in the *Tadhkira* by the inquirer Ṭūsī. With the words of the inquirer (Ṭūsī) himself, as we have copied their gist, the problems of the prosneusis, Mercury's equant, and the latitudes of the cinctures (*manāṭiq*) of the epicycles and the deferents cannot be solved. As for the author of the *Tuḥfah*, he had elaborated too much. Master Muḥammad al-Munajjim al-Ḥammādī composed a treatise, in which he claimed that these problems (*ishkālāt*) could all be solved with one hundred and forty spheres. He indeed established three principles, which are, in reality, erroneous. Anyone requiring (more information about) them he should seek them in *al-Ma'ārij* [part] of the *Lawāmi'* of *al-Manṣūrīya*.⁶²

Besides the interesting titbits that this comment brings to light, it attempts a more accurate historical picture than the previous one. In addition it sheds some light, although faintly, on the intriguing personality of al-Ḥammādī(?) who was in turn mentioned in Shīrāzī's text *Fa'altu*. It also tells us more about the importance of the just mentioned work of Ghiyāth al-Dīn. And finally, it does demonstrate the general awareness regarding the history of these problems, and gives some form of an adumbrated bibliography for the student seeking more information about them.

6) Another commentator on 'Āmilī's text, *al-Tashrīḥ*, is Muḥammad Ṣadr al-Dīn b. Ṣādiq al-Ḥusainī, otherwise unknown but who must have lived after 1622 A.D. In contradistinction to the other commentators, who were mainly recorders of the histories of the Ptolemaic problems, this one was a participant in the solutions. He does explicitly state at one point: "I have two respectable methods for the solution of the problems of the Moon and Mercury. If they [i.e. these two methods] are not better than those offered by other people, they are not worse than them. I have recorded them in a separate treatise."⁶³ The

⁶¹ See, G. Saliba, "Ibn Sīnā and Abū 'Ubayd al-Jūzjānī: The Problem of the Ptolemaic Equant," *Journal for the History of Arabic Science* (1980) 4: 376–403.

⁶² Istanbul University, MS Arabçe 2466, fol. 6v.

⁶³ *Ibid.*, fol. 7r.

recovery of such a treatise may carry this discussion beyond the middle of the seventeenth century.

In summary, with the scanty and scattered evidence which has been collected so far, one can positively state that the future research regarding the reform of Ptolemaic astronomy promises to uncover still wider areas of interest than the ones presently identified. The conclusion that can be drawn at this point is that the Maragha School results did indeed reach a very wide circle of astronomers, and managed, in the later centuries, to reach even the less sophisticated astronomers and commentators. One could safely state that after the fourteenth century no professional astronomer could afford to remain ignorant of the results of the Maragha School. In a different context, I intend to show that this wide-spread consciousness of the problems afflicting Ptolemaic astronomy, while it urged good astronomers to continue their research and to find new answers, may also have given ammunition to some religious scholars who saw in this continuous revision of astronomy enough reasons to doubt the validity of the discipline altogether.⁶⁴

The Copernican Connection

Finally, the trail left by Neugebauer regarding the connection between Copernicus and the Maragha astronomers – now a much larger group than we originally thought – needs to be deepened and followed more systematically. One awaits, with great anticipation, the complete publication of the works of Gregory Chioniades (end of the thirteenth–beginning of the fourteenth century) by David Pingree of Brown University, for the Byzantine manuscript, which contains the diagrams of the Ṭūsī Couple and the lunar model that were published by Neugebauer, also contains most of the works of Chioniades; one of these works in particular is devoted to theoretical astronomy and preserves the models referred to in the diagrams.

This does not mean that we should abandon the search for other channels of contact between Renaissance Europe and the East, nor should we always think of the contacts as taking place along textual lines, or think that the historical significance of

⁶⁴In this context I am thinking of the work of the Ḥanbalite theologian Ibn Taymīya al-Ḥarrānī (d. 1328) who did make such statements in his *Dar' al-Ta'āruḍ Bayn al-'Aql wa-l-Naql*, but this is the subject of another article.

this tradition should be seen only in terms of its European repercussions.