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The transmission of astronomical theories from the Islamic World into Europe: The roots of the Copernican paradigm

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Abstract

The Islamic Golden Age had influenced the European culture for many centuries. This influence was reached through several different ways. However, this paper majorly focuses on the Byzantine link (and its ramifications) which was manifested through a long process that lasted for many centuries. Unlike the impact of the translation movement that took place mostly in Toledo and Sicily, which is easy to trace back due to the existence of many manuscripts (Arabic, Latin, Greek, Hebrew, etc.) to compare and examine. When it comes to the late Islamic astronomical impact on Copernicus, the matter becomes more complex. Since in this area there is less concrete evidence for the claimed transmission. In this case different researching tools should be employed in order to highlight such elements of influence. Therefore, in this paper various methods are used to strengthen the paper's main argument. Indeed, the impact of early Muslims' astronomical books (9th-12th centuries) on Europe is easier to show. By contrast, the Muslims' astronomical impact made in the next centuries is harder to follow. For instance, the impact of Maragha School on Copernicus only started to be seriously examined in the last century. Thus, this paper aims to bring some important studies made in the last seventy years regarding this impact. In this sense, this paper can be an introduction to the new researcher of the following prospective research. In short, by tracing back some Islamic fingerprints of the mentioned impact, this paper will demonstrate how Muslim scientists have immensely contributed to the European astronomical development being ripened, so to speak, in the Copernican revolution. Finally, instead of disturbing the reader with the relevant technical terms this paper strives to approach the discussed topics in a kind of systematic method where the reader–in most cases–can find a somewhat general and chronological order of the relevant scientists, translators, intellectuals, and persons who had somehow established such contact between East and West at such critical times.

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İslam dünyasından Avrupa'ya astronomik teorilerin aktarımı: Kopernik paradigmasının kökenleri

Öz

İslam Altın Çağı, yüzyıllar boyunca Avrupa kültürünü etkilemiştir. Bu etkiye birkaç farklı yoldan ulaşıldı. Bununla birlikte, bu makale, büyük ölçüde, yüzyıllarca süren uzun bir süreç boyunca ortaya çıkan Bizans bağlantısına (ve bunun etkilerine) odaklanmaktadır. Ağırlıklı olarak Toledo ve Sicilya'da meydana gelen çeviri hareketinin etkisini anlamak, çok sayıda el yazmasının (Arapça, Latince, Yunanca vb.) varlığı nedeniyle oldukça kolaydır. Örneğin tercüme yerlerini, en önemli tercümanları ve Arapçadan Latinceye çevirdikleri kitapların isimlerini biliyoruz ve sadece birkaçını belirtmek gerekirse: Afrikalı Konstantin (ö. 1099), Sevilyalı John (ö. 1180), Toledolu Mark (ö. 1216), Toledolu Peter (ö. 1160), Kettonlu Robert (ö. 1160), Bathlı Adelard (ö 1152), Roger Bacon (ö. 1292) ve Cremonalı Gerard (ö. 1187). Örneğin, George Sarton (ö. 1956) *Bilim Tarihine Giriş*'inde Gerard tarafından çevrilmiş 87 Arapça kitap listeledi; Batlamyus'un *Almagest*'i, Al-Farabi'nin *Bilim Sınıflandırması*, al-Khwārizmī'nin *Cebir Üzerine* ve *Almuqabala* (*El Mukabele)*, al-Farghānī'nin *Astronominin Elementleri* ve al-Zarqālī, Jabir ibn Eflaḥ, the Banū Mūsā, Abu Kāmil Shujā' ibn Eslem, al-Kindī ve Ibn al-Heytham ve daha nice birçok önemli yazarın eserleri (Al-Hassan, 2001, s. 135-141). Kısacası, çeviri hareketinin Batı üzerindeki etkisini

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anlamak, Maragha okulunun batı astronomisi üzerindeki etkisini görmekten çok daha kolaydır. Bu alanda iddia edilen aktarım için daha az somut kanıt olduğundan Kopernik üzerindeki geç İslamın astronomik etkisine gelince, mesele daha karmaşık hale geliyor. Bu durumda, bu tür etki unsurlarını vurgulamak için farklı araştırma araçları kullanılmalıdır. Bu nedenle, bu makalede, incelemenin ana argümanını güçlendirmek için çeşitli yöntemler kullanılmıştır. Gerçekten de, erken dönem Müslümanlarına ait astronomi kitaplarının (9.-12. yüzyıllar) Avrupa üzerindeki etkisini göstermek daha kolaydır. Buna karşılık, Müslümanların sonraki yüzyıllarda yaptığı astronomik etkiyi takip etmek daha zordur. Örneğin, Maragha Okulu'nun Kopernik üzerindeki etkisi ancak son yüzyılda ciddi bir şekilde incelenmeye başlandı. Bu nedenle bu makale, bu etki ile ilgili olarak son yetmiş yılda yapılmış bazı önemli çalışmaları bir araya getirmeyi amaçlamaktadır. Bu anlamda, bu çalışma ileride bu alanda araştırma yapmak isteyen yeni araştırmacılara bir giriş olabilir. Kısacası, bu çalışma, sözü edilen etkinin bazı İslami parmak izlerinin izini sürerek, Müslüman bilim adamlarının Avrupanın astronomik gelişimine, deyim yerindeyse, Kopernik devrimin olgunlaşmasına nasıl büyük ölçüde katkıda bulunduklarını gösterecektir. Son olarak, bu makale, ilgili teknik terimlerle okuyucuyu boğmak yerine, tartışılan konulara, sistematik bir yöntemle yaklaşarak okuyucunun Doğu ve Batı arasında bir şekilde temaslar kurmuş olan aydınlar, ilgili bilim adamları, çevirmenler ve kişiler hakkında genel kronolojik bilgi bulabileceği bir çalışmadır.

Anahtar Kelimeler: Astronomi, İslamın Altın Çağı, Maragha Okulu, Avrupa Rönesansı, Kopernik Devrimi

Introduction

Needless to say that when Arabs worked on translating and developing the Greek science during the Abbasid era, they included people from different ethnics and religions: such as Arabs, Iranians, Christians, Jews, and others. Furthermore, the very flame of the translation movement itself can be traced back to the attempts made by the old Syrians. Especially in the period between the 6th and the 8th century (Villey, 2021, p. 205). "Syriac astronomical texts may be considered, along with Greek astronomical texts, the most reliable sources for helping historians to understand the real contribution of Christian scholars in the transmission of astronomical knowledge to the Arabs and within the Byzantine Empire" (Villey, 2021, p. 207). For instance, some Syriac scholars who dealt with Ptolemaic astronomy during that time are: Sergios of Reš'ayna (d 536), Severos Sebokht (d 665), Athanasios of Balad (d 687), Ya'qub of Edessa (d 708), and Giwargi of the Arabs (d 724) (Villey, 2021, p. 208-209).

These considerable efforts continued until they produced the greatest impact that took place in the 9th century, where the school of Ḥunayn ibn Isḥāq, his son and his nephew made the transmission of the most important Greek scientific books into Syriac and Arabic. And as George Sarton mentioned in his *Introduction to the History of Science*, this contribution of translating and commenting on the works of Galen, Hippocrates, Plato, Aristotle, Ptolemy and other Greek authors formed the cornerstone on which the edifice of Arabic science was built (Quoted in: Sa'di, 1934, p 409).

Having established such a cursory background regarding the beginning of science in the Islamic world now we can look at the way it was transferred to the West. Indeed, the transmission of science from the Islamic world into Europe took place through different means, places, and times. The role played through the centuries by the Byzantine Empire was seriously effective. Needless to say that the 12th century translation movement was the most influential route through which the Islamic scientific books and ideas arrived to the West. But when we want to see the later impact of Islamic Science, we have to look at other routes.[1] In fact, other

[1] For example, we know the places of translation, the most important translators, and the names of the books they majorly translated from Arabic into Latin, and just to mention a few: Constantine the African (d 1099), John of Seville (d 1180), Mark of Toledo (d 1216), Peter of Toledo (d 1160), Robert of Ketton (d 1160), Adelard of Bath (d 1152), Roger Bacon (d 1292) and Gerard of Cremona (d 1187). For instance, in his *Introduction to the History of Science*, George Sarton (d 1956) listed 87 Arabic books translated by Gerard, including Ptolemy's *Almagest*, Al-Farabi's *Classification of Science*, al-Khwārizmī's *On Algebra and Almuqabala*, al-Farghānī's *On Elements of Astronomy*, and many significant works of al-Zarqālī, Jābir ibn Aflaḥ, the Banū Mūsā, Abū Kāmil Shujāʿ ibn Aslam, al-Kindī and Ibn al-Haytham (Al-Hassan, 2001, p. 135-141). In short, comprehending the impact of the translation movement on the West is much easier to display than seeing the effect of Maragha school on the western astronomy

means of communication between the Islamic world and Europe at the time must have also affected this transmission in a somewhat slighter manner. For instance, the trade between some of the European countries and Muslims, the diplomatic delegations and even the crusade impact must have played a vital role. Nevertheless, such effects can never reach the level of the impact of Byzantium as a medium between the two sides, starting from the 9th until the 16th century. Needless to say that the transmission of Islamic knowledge to Europe included several fields such as medicine, chemistry, philosophy, physics, geography, botany, alchemy, occultism, etc. Yet, this paper specifically focuses on astronomy. The contributions of the Maragha School in astronomy had made the greatest change in the scientific scene in Europe whose fruit, so to speak, can be seen in the Copernican revolution in the 16th century.[2]

Throughout the ages, mathematics and astronomy were always praised and given a priority above all other fields. It was famously said that Plato put a sign above the door of his Academy: "Let no-one ignorant of mathematics/geometry enter here" (Qtd in Boyer, 2011, p. 75), whereas astronomy was often considered by the ancients as "the Queen of all sciences". Furthermore, what made those two fields more crucial to Muslims is their direct connection to Muslims' daily religious requirements such as: Knowing the time of prayers, time of fast, direction of the Kiblah, and so on. That is why as we will see, when Muslims received the Greek astronomy, they gave it a kind of a mathematical dress which makes it more practical than the Greek theoretical calculation. With al-Khwārizmī putting the very foundation of algebra, many new fields emerged such as Trigonometry and Combinatorial Analysis, those disciplines when applied on astronomy makes it much easier for the practitioner to scientifically attain the pursued goals.[3]

This article mainly focuses on the areas where the biggest astronomical leaps had occurred. Therefore, at first, we will look at the route from which knowledge was transmitted and after mentioning the most important and relevant information and characters, the article will then narrow the scope in order to explain Muslims' most revolutionary achievements in the above-mentioned field. After establishing such a background, the article will demonstrate more details by looking at the way European intellectuals employed those Islamic inventions and likewise how such discoveries have changed the European astronomy forever. This will undoubtedly include the names of some individuals suggested by scholars of being the direct or indirect link between East and West at the time.

1. The beginning of the Arabic Scientific and Philosophical impact on Byzantium

To find an original Byzantine scientific book is rare. The Byzantine science was a product of two sources: The first included the books of antiquity coming from Alexandria, Athens, and Syria. And the second source was the foreign material, mainly of Islamic origin. The influence of the Arabic civilization on Byzantium was somehow denied particularly by the scholars of Byzantium, who often argue that the Byzantines' sudden interest in science which took place after or at the same time with the Abbasid interest in science and translation, was "just a

[2] In 1514 Copernicus (d 1543) wrote his *Little Commentary* in Latin and circulated copies to his friends, but it was never printed during his lifetime. In this brief outline, Copernicus mentioned for the first time the early version of his revolutionary heliocentric theory of the universe. Copernicus's ideas were matured and presented in his *On the Revolutions of the Heavenly Spheres*, published in 1543.

[3] In fact, to speak about the Islamic contributions in mathematics means to speak about al-Khwārizmī (d 850) and his many followers, who revolutionized the way scientists process equations. Many Muslims mathematicians, whose works will not be discussed in this short article, further developed mathematics and algebra. Those mathematicians built upon al-Khwārizmī's paradigm. To mention but a few: Abū Kāmil Shujāʿ ibn Aslam (d 930), al-Karajī (d 1029), Omar Khayyam (d 1123), Al-Samawal (d 1180), Sharaf al-Dīn al-Ṭūsī (d 1213), Ibn al-Bannāʾ al-Marrākushī (d 1321), Jamshīd al-Kāshī (d 1429) and many others. Al-Khwārizmī, in a nutshell, became the cornerstone of the creation of new chapters in mathematics, which were mostly mixable with the astronomical disciplines.

remarkable coincidence”.[4] Recently, this approach was challenged by Dimitri Gutas, notably in his book *Greek Thought, Arabic Culture* where he suspected that these two movements, which occurred almost simultaneously and which were in many ways very similar, could have been entirely unrelated. Gutas brought all evidence which confirm that the Byzantines were familiar with the philosophical and scientific movement in Baghdad; since it was clear to him that the Byzantines were under Arabic influence (Gutas, 1999, p. 175-186; Sypianski, 2012, p. 188).

In fact, Gutas made a very spectacular comparison between the books that were copied or translated in the 9th century Byzantium on the one hand, and those that were translated during the Abbasid caliphate on the other hand. His systematic list contains the names of the books and dates of their ever first official entrance to the Byzantine systematic library and beside them he put the same details of the same books’ date of their translation into Arabic (Gutas, 1999, p. 180-184). The symmetry between them is striking.[5] That is to say, the Byzantines seemed to translate or copy the ancient books into Greek after or at the same times in which Arabs translated the same books into Arabic at Baghdad. Gutas gave two possible explanations for such similarities (Gutas, 1999, p. 184-185). The first explanation is somehow ideological; the Greek manuscripts could have been copied at Byzantium in the ninth and tenth centuries through a kind of an imitation or as a response to the Arabic translation of these very same works. The Byzantines wanted to prove their superiority on Arabs in science and philosophy. However, the second explanation is somewhat financial; the manuscripts could have been copied in Byzantium because of a frequent Arabic demand for such works. Arabs were obsessed with Greek philosophy at that time. And many of the Abbasid caliphs captured every opportunity to get some Greek manuscripts[6]. Being aware of this, the Byzantines apparently anticipated the events and thus prepared the fresh copies of Greek learning to the Arabs. Therefore, each of the two proposed explanations bids us to give some credit to the Islamic Golden Age.

In fact, this is only the historical early roots of the impact. As we will see, the influence of the Islamic world will continue during the next centuries[7], where it will make its highest astronomical manifestation in Europe with the effect of the Maraga Group which arrived to Byzantium and later travelled to Italy, following the conquering of Istanbul. The Maraga Group included many great figures, but this essay will hugely focus on the ones whose theories entirely changed the way of approaching astronomy, that is to say, Muʾayyad al-Dīn al-ʿUrdī (d 1266), Naṣīr al-Dīn al-Ṭūsī (d 1274) and Ibn al-Shāṭir (d 1350).

2. The Maragha School and Copernicus

Indeed, we cannot talk about the medieval astronomy without starting with Ptolemy (d about 170 AD). Ptolemy’s *Almagest* was very dominant that the works of his predecessors suddenly disappeared leaving this book, and his other works, as the basic of astronomy. Even Ptolemy’s original Greek books will later be lost, and they will mostly be revived through their Arabic translations. Ptolemy employed a kind of Aristotelian understanding of the universe where Aristotle claimed that earth is in the center of the existence. Nevertheless, Ptolemy recognized the contradictions produced by using such system. Moreover, Aristotle had stated that if a body

[4] This view is of the famous French Byzantinist Paul Lemerle (d 1989) discussed in his *Byzantine Humanism: The First Phase* (Qtd in Sypianski, 2012, p. 188). In fact, Sypianski’s inspiring article explains the prospective aspect of Gutas’s book very well.
[5] The list can be seen in the First Illustration at the end of the essay.
[6] For example, “Al-Ma’mun had correspondences with the Byzantine emperor asking him to send him Greek books of lore” (Ibn al-Nadim, No year, p. 244, My translation).
[7] Gutas mentioned in more details how in the 13th century “numerous Arabic and Persian scientific works were translated from Arabic into Byzantine Greek” (Gutas, 1999, p. 186). Furthermore, Bisaha reported more than one story regarding the Byzantine imitation of the Eastern clothing style, which explains the impact of the Islamic civilization at the time (Bisaha, 2004, p. 106).

moves uniformly around any point, it cannot do the same with another point, thus the epicyclic center must move in non-uniformly way around itself, which represented another problem to Ptolemy. Another of many mistakes caused by using the Aristotelian system is the Sun model which has its own problems. Ptolemy realized that since we have different changeable seasons through the year that simply means that earth is not at the very center and therefore, he took another imaginary point to be the center of the universe. The earth is very near to the center, yet the earth is not at the very center. Needless to say that such a system also had its own contradictions.

Muslim scientists were forced to create a theory regarding the movement of the planets and the reason behind the contradiction between the mathematical models and the physical reality presented by Ptolemy. So, Muslim scientists and from relative early times started criticizing Ptolemy's astronomical system. In fact, the very roots of challenging the Ptolemaic paradigm can be found in the works of early pathfinders such as al-Khwārizmī (d 850), Ḥabash al-Ḥāsib (d 874) who composed two non-Ptolemaic zijes, and Thābit ibn Qurrah (d 901). However, the works of these figures were yet to be continued by another generation of astronomers like: Abū al-Wafā Būzhjānī (d 998), Abū Sahl al-Qūhī (d 1000), Ibn Yunus (d 1009), Kūshyār ibn Labbān Gilani[8] (d 1029), Mansur ibn Iraq (d 1036), and al-Bīrūnī (d 1050). At any rate, the open systematic refutation of Ptolemy occurred around that time. The most influential work is *Shukūk ʿalā Baṭlamyūs (Doubts on Ptolemy)* by Ibn al-Haytham[9] (d 1040), followed by *Tarkib al-Aflak* by Abū ʻUbayd al-Jūzjānī (d 1070). Then a tradition of criticizing Ptolemy's system will further continue among the Maragha Group through the 13th and 14th centuries[10]. Thus, the likelihood of Copernicus coming up independently with the same complex models seen in the Islamic works–that were accumulated through several centuries of challenging the Ptolemaic theories–is extremely slim. In short, the Greek astronomical tradition was hugely examined before it was accepted. Indeed, Muslim scientists didn't only fix the old astronomical system, but they also created "an alternative astronomy" (Saliba, 2007, p. 150).

In his masterpiece *Kitab Al-Hay'a*, al-ʿUrdī fixed Ptolemy's system of the upper planets, by defining a new deferent[11] with a new center (Saliba, 2007, p. 153).[12] By this change al-ʿUrdī allowed that deferent to carry a small epicycle. Accordingly, the movement of the planets became more logical for the beholder as well as for the scientific mathematical calculations. In other words, al-ʿUrdī reconstructed the Ptolemaic system fundamentally. Moreover, he treated this issue with a quite strict mathematical method. This revolutionary notion is simply called "ʿUrḍī Lemma". Furthermore, with "Tusi Couple"[13] the old astronomical paradigm is destroyed. Al-Ṭūsī's idea refuted the typical Aristotelian argument which claimed that a body could either move in a linear, or in a circular movement. Because this couple easily demonstrates the opposite. It simply includes two circles; the first is double sized of the second.

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[8] Kūshyār ibn Labbān was influential mathematician on the European thought, especially in terms of his elaboration on trigonometry. It was him, who continued the investigations of Abū al-Wafā Būzhjānī, which can be found in his *Az-Zij al-Jami wal-Baligh*. Also, his *Astrological Introduction* is of invaluable importance in connection with its effect on the Latin Europe. Moreover, his *Kitab fi-Usul Hisab al-Hind* is the second-oldest book extant in Arabic about Hindu arithmetic using Hindu-Arabic numerals.

[9] Ibn al-Haytham's *on the Configuration of the World* influenced the quest of European astronomers for a physical interpretation of the celestial orbs (Ragep and Feldhay, 2017, p. 8).

[10] And this approach continued later on by Ali al-Qushji (d 1474), Taqī al-Dīn (d 1585) and many other Ottoman astronomers.

[11] Deferent is the large circular orbit followed by the center of the small epicycle in which a planet was thought to move.

[12] And for further information regarding al-ʿUrdī's theory, the reader can see the photo in the Second Illustration at the end of the essay.

[13] Al-Ṭūsī firstly presented his theorem in his 1247 *Taḥrīr al-majisti (Commentary on the Almagest)* and later in his 1261 *Al-Tadhkira fī ilm al-Hay'a (Memoir on Astronomy)*. But the term "Tusi Couple" is a modern one, coined by Edward Stewart Kennedy in 1966.

Thus, the smaller moves in double-speed of the bigger, consequently the way the circle moves in a circular movement produces a linear movement.[14] This simply solved many astronomical problems. The only area in which Tusi Couple failed is in Mercury whose movement is rather erratic since it was close to the Sun and hard to see. Al-Ṭūsī was aware of that. He said that elsewhere later on he would solve the problem of the equant[15] of Mercury the way he solved the equant problem of the models of the Moon and the upper planets. But he didn't do. It was Ibn al-Shāṭir who did solve the Mercury model (Saliba, 2007, p. 161). Like many scientists[16] Ibn al-Shāṭir took the opportunity to use the theories of the formers; al-ʿUrdī and al-Ṭūsī. It turned out that by using ʿUrḍī Lemma and Tusi Couple one could solve any astronomical problem especially when the user applies them properly (Saliba, 2007, p. 155). Therefore, "it may not have been entirely accidental that Copernicus ended up relying so heavily on the works of Ibn al-Shāṭir when he used, among other things, a lunar model that was identical to that of Ibn al-Shāṭir, and used the same Tusi Couple, in the same fashion was done by Ibn al-Shāṭir, in order to account for the motion of Mercury" (Saliba, 2007, p. 164).

Copernicus used ʿUrḍī Lemma in his calculation of the motions of Mercury and the motions of the latitude, "[a]nd since Copernicus had used the same models for the upper planets that was used by Ibn al-Shāṭir with the additional transposition of the center of the universe to the sun course, in that sense Copernicus too ended up using ʿUrḍī's Lemma, as Ibn al-Shāṭir had done before him" (Saliba, 2007, p. 204). In short, what Copernicus did was to take Ibn al-Shāṭir's models, hold the sun fixed and then allow the earth's sphere, together with all other planetary sphere that were centered on it, to revolve around the sun instead. He simply used the same geocentric models similar to those of Ibn al-Shāṭir and then translated them to heliocentric (Saliba, 2007, p. 193). "Indeed, it is now generally agreed that Copernicus's great new conception of the order of the universe was not built on any stunning new observations or new mathematical techniques that were not available to the Arabs" (Huff, 2003, p. 326). "The Copernican revolution was then a purely metaphysical leap that the Arabs were either unwilling or unable to make – despite their having had nearly two centuries of previous experience with the observational problems which the planetary models posed" (Huff, 2003, p. 327). Actually, there are many mutual notions between Copernicus's works and the Maragha Group's. Mentioning the important resemblances could be fruitful to anyone who wants to have a speed review about this significant impact.

In fact, the very first acknowledgement of the connection between Copernicus and the Maragha astronomers was made in 1906 by the Danish astronomer J. L. E. Dreyer (d 1926). Dreyer just noted that the new device invented by al-Ṭūsī was also used by Copernicus in his *De revolutionibus* (Ragep, 2007, p. 65-66). In 1957 another mutuality between Copernicus and the Maragha works was noticed by Edward Kennedy (d 2009), who shared this discovery with Otto E. Neugebauer (d 1990) (Saliba, 2007, p. 196-198). It was discovered that Ibn al-Shāṭir's[17]

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[14] For further information of Tusi Couple, the reader can see the photo in the Third Illustration at the end of the essay.

[15] In the Ptolemaic system "Equant" is the imaginary circle introduced with the purpose of reconciling the planetary movements with the hypothesis of uniform circular motion.

[16] For example, Qutb al-Din al-Shirazi (d 1311) made use of ʿUrḍī Lemma twice (Saliba, 2007, p. 158). In fact, Al-Shirazi's contributions as well as those of Shams Al-Din Al-Khafri (d 1550) were hugely important and relevant. Al-Khafri wrote *Al-Takmila fi Sharh al-Tadhkira (The Complement to the Explanation of the Memento)*, which as its name clearly shows, employs a typical Islamic method of completing the work of a previous scholar, which is done by editing some old book and fixing its mistakes based on the new updated knowledge.

[17] The extent of the influence of Ibn al-Shāṭir's planetary models on Copernicus has been discussed and debated over the years. Among the most important studies, listed chronologically from 1957 to 2007: Roberts, "Solar and Lunar Theory"; Kennedy and Roberts, "Planetary Theory"; Abbud, "Planetary Theory"; Roberts, "Planetary Theory"; Kennedy, "Late Medieval Planetary Theory"; Swerdlow, "Derivation and First Draft"; Swerdlow and Neugebauer, *Mathematical Astronomy*; F.J. Ragep, "Copernicus"; Saliba, "Theory and Observation,"

lunar model was identical in every respect to that of Copernicus.[18] Ibn al-Shāṭir's model survived in the text *Nihāya Al-Sūl Fī Tashīh Al-'Usūl (Final Quest Regarding the Corrections of Astronomical Principles)*. Other important hint of Copernicus' borrowing from the Maragha Group can be implied by looking at the way Copernicus inserted al-Ṭūsī's theory, "al-Ṭūsī knew that he was introducing a new theorem in 1247 and again in 1260-61, which was nowhere to be found in any earlier Greek source, and said so, while Copernicus silently went ahead and described the same theorem and produced a very similar proof, without mentioning that he had invented the theorem or the proof himself, nor that he had seen it in any other source" (Saliba, 2007, p. 199).

In 1973 the Copernican Eurocentric supporters received another blow by another discovery made this time by Willy Hartner (d 1981). He discovered that Copernicus had used the same alphabetic designators for the essential geometric points used earlier by al-Ṭūsī at the same Tusi Couple. Where al-Ṭūsī's proof designated a specific point with the Arabic letter "Alif", Copernicus used an equivalent of Latin "A" and when al-Ṭūsī used Arabic "Ba", Copernicus used Latin "B" and so on. The pattern can be noticed with the other letters, except in one case where al-Ṭūsī had Arabic "Zain", Copernicus had Latin "F".[19] In a nutshell, the letters used there by Copernicus didn't follow the typical Latin alphabet but the Arabic's. Accordingly, Hartner concluded that Copernicus must have known about al-Ṭūsī's work–be it directly or indirectly–while in Italy. It goes without saying that we are not sure whether Copernicus could read Arabic, nor whether al-Ṭūsī's text was translated into Latin at that time. But Hartner was of the opinion that Copernicus must have recruited someone who could explain to him the diagram, while he took notes and used those notes later when he came to write the *De Revolutionibus* (Saliba, 2007, p. 199).

Another attack on Copernicus' so-called revolution was made by Noel Swerdlow when Swerdlow (d 2021) studied Mercury's model in Copernicus' *Commentariolus* (written before 1514), he immediately realized that Copernicus was not aware of the full significance of mercury he was describing. As mentioned earlier this is the very specific model which was almost identical with Ibn al-Shāṭir's, Copernicus even copied the same mistake committed by Ibn al-Shāṭir regarding mercury model, the major difference is the shift from the geocentrism to heliocentrism. Consequently, Swerdlow concluded: "His misunderstanding must mean that Copernicus did not know the relation of the model to Mercury's apparent motion. Thus, it could hardly be his own invention for, if it were, he would certainly have described its fundamental purpose other than write the absurd statement… The only alternative, therefore, is that he copied it without fully understanding what it was about. Since it is Ibn al-Shāṭir's model, this is further evidence, and perhaps the best evidence that Copernicus was in fact copying without fully understanding from some other source, and this source would be a yet unknown transmission to the west of Ibn al-Shāṭir's planetary theory" (Saliba, 2007, p. 209).

All the same, Swerdlow's study ended up with the same conclusion, that is to say, Copernicus has used the same ideas of al-ʿUrdī, al-Ṭūsī and Ibn al-Shāṭir with one addition

"Astronomical Tradition," "Arabic Planetary Theories," and *Islamic Science* [which this essay largely depended on].

[18] For further details of Ibn al-Shāṭir's lunar model, the reader can see the photo in the Fourth Illustration at the end of the essay.

[19] For further details regarding the alphabetic similarities, the reader can see the photo in the Fifth Illustration at the end of the essay. However, according to Saliba's elaboration on this specific issue, even the copying of "Zain" into Latin "F" asserts that Copernicus was reading from al-Ṭūsī's work, since both the Arabic "Zain" and "Fa" are very similar, consequently, Copernicus, or the one who read for him, took the Arabic "Zain" as a "Fa" and therefore copied it into Latin "F". Saliba provided photos of medieval manuscripts where Arabic "Zain" is written like "Fa'" which according to non-Arabic reader would be easily thought to be the same (Saliba, 2007, p. 201). So, the letters on the diagram of Copernicus and al-Ṭūsī were totally identical. Saliba's evidence can be seen in the Sixth Illustration at the end of the essay.

which is the heliocentric. And as Swerdlow asserted, we should ask, "not whether, but when, where, and in what form" Copernicus learned of the Maragha theories (Huff, 2003, p. 55). Knowing that Copernicus–who never mentioned any of the last three astronomers–had cited some of the older Islamic astronomers whose theories and observations he used in *De Revolutionibus*, namely Thābit ibn Qurrah (d 901), al-Battānī[20] (d 929), al-Zarqālī (d 1087), Ibn Rushd (d 1198), and Al-Biṭrūjī (d 1204). Actually, the reason behind mentioning the first generation of Muslim scientists and keeping silence on the latest generation could be that the old generation belonged to an old, defeated enemy (Arabs) whereas the latest one belonged to a current rival (Ottomans). On the one hand, Celenza had analyzed some European historical documents just to realize that it was a typical thing at the time to borrow from other people's ideas. On the other hand, Copernicus had openly referred to it in his *De revolutionibus orbium coelestium*, that is, in the dedication to Pope Paul III, he stressed that, dissatisfied with the uncertainty of the mathematics that had been handed down, "I took it as my task to reread whatsoever books I could get my hands on of all the philosophers..." (Celenza, 2017, p. 24). A thing which asserts the fact that Copernicus read whatever he could find and wherever it came from.

Swerdlow and Neugebauer succinctly summarized Copernicus's use of the various devices invented by al-Ṭūsī.[21] But instead of going into the technical details of the similarities, this paper will only establish a kind of a bird's-eye view of the most interesting areas of the relevant studies. However, Copernicus himself mentioned "some people" who referred to the al-Ṭūsī device as producing "motion along the width of a circle," but it was crossed out in his autograph, which indicates that the device was used by others, and almost certainly is not of his own making (Ragep, 2017, 185).

Another remarkable and relevant study that shed light on more resemblances is F. Jamil Ragep's "Ibn al-Shāṭir and Copernicus on Mercury: The Uppsala Notes Revisited". That essay is significant because it masterfully examines Ibn al-Shāṭir's so-called geocentric system and explains how Ibn al-Shāṭir's models in fact have a "heliocentric bias" that made them particularly suitable as a basis for the heliocentric and "quasi-homocentric" models found in Copernicus' *Commentariolus*. Elsewhere Ragep referred to al-Ṭūsī's argument where al-Ṭūsī maintained that there was no way for any astronomer, using mathematics and observation, to arrive at the "proof of the fact" that the Earth was either moving or at rest. This–according to Rageb–was contrary to Ptolemy's position expressed in the *Almagest* (Ragep, 2007, p. 73). However, this uncertainty itself can be taken as an attempt towards weakening geocentrism.

Some of the famous skeptics of the Maragha effect on Copernicus are Ivan Nikolayevich Veselovsky (Copernicus and Naṣīr al-Dīn al-Ṭūsī); Di Bono (Copernicus, Amico, Fracastoro); Andre Goddu (*Copernicus*); Toby Huff (*Rise of Early Modern Science*). Those scholars often asked for more concrete evidence for the transmission, before passing judgment. Therefore, having mentioned some of the resemblances, it would be inevitable to answer the skeptics' question: "and how could these Islamic books/ideas arrive to Copernicus at that time?" In fact, many possibilities were suggested by scholars through the last few decades. A strong possibility is the Byzantine astronomer Gregory Chioniades (d 1302) who had travelled to the Islamic lands in order to collect the latest developments in the Islamic astronomy and to report his findings back to his Greek fellowmen. "Today, it seems beyond doubt that Copernicus knew, somehow, about the achievements of the Maragha School; he probably became acquainted with it during his stay in Padua between 1501 and 1503 where he might have obtained, directly or indirectly, information from Byzantine manuscripts such as MS. Vat. Gr. 21 1, a translation

[20] Al-Battānī presented the most precise observations, so the Medieval Latin thinkers used to praise him more than anyone else.
[21] Discussed in detail in (Ragep, 2017, p. 183).

from an unidentified Arabic source made by Gregory Chioniades, which contains al-Ṭūsī's lunar model as well as the famous Tusi Couple" (Samso, 2001, p. 233-234).

Moreover, a speed glimpse at the terminology adopted by this scholar–and by his fellow citizens–is enough to realize that those Byzantine works are closer to the Islamic rather than to the Ptolemaic Greek ones. Furthermore, in the preface of *The Persian Syntaxis*, written about 1347, George Chrysococces relates that a person named Gregory Chioniades had decided to travel to Persia via Trebizond in order to learn astronomy. Having done so, he returned to Trebizond with Persian works that he translated into Greek. These translations came into the possession of a priest of Trebizond named Manuel, who was the teacher of Chrysococces, author of the mentioned account. The discussed book was based on a zij originally made by al-Ṭūsī (Tihon, 2013, no page number). However, those works that were accumulated through the years will be taken with the Byzantine scientists who immigrated to Europe after 1453 (Saliba, 2007, p. 194). All the same, another possible chain of contact is Leo the African (d about 1554), a contemporary of Copernicus, and a man of great Arabic knowledge who taught Arabic at bologna [Italy]. Therefore, he might have come across people who knew Copernicus, "For Bologna fell along the famous corridor from Venice to Florence, along which many Renaissances intellectual activities took place" (Saliba, 2007, p. 226). Saliba provided other possibilities such as the members of the orientalist Jean-Albert Widmanstadt (d 1559), who knew Arabic and was an acquaintance with Leo (Saliba, 2007, p. 227).

Other possible links suggested by Saliba is the Venetian physician Andreas Alpagus (d 1525) who worked and died in Padua. And Guillaume Postel (d 1581) who was a traveller between Italy and the Islamic world and whose Arabic manuscripts had survived in many European collections, "Some of those manuscripts, for among its collections there is the famous Postel copy of al-Ṭūsī 's *Tadhkira*, which is now kept under the shelf number MS Vat. arab. 319. This work of al-Ṭūsī includes the most mature version of the Tusi Couple, full of clear statement of the theorem and the detailed proof that was used by Hartner for the comparison with the Copernican proof" (Saliba, 2006, p. 370-372). Saliba wonders if Copernicus had met those two gentlemen or their Arabic teachers, or could he meet Leo the African, who worked at Bologna, the first Italian university visited by Copernicus, and who could have been one of his collaborators in deciphering Arabic texts.

Another interesting possibility regarding the transfer of the Maraghan astronomical theories into Greek was presented by Mavroudi. According to her, in 1265–six years after the foundation of the Maragha Observatory–Maria (daughter of emperor Michael VIII Palaiologos) was sent to marry Hülegü. But when she arrived Hülegü was dead. Thus, she married his son and successor, Abaqa, and when the latter died in 1282, Maria returned to Constantinople. "It is only reasonable to assume that news of the scientific activity in the realm of the Mongols must have reached Constantinople, if not through any other channel of commercial and diplomatic contact. At least through Maria's entourage" (Mavroudi, no year, p. 65).

Next to the Greek Byzantine impact as well as the Italian/Spanish/European translations, there is another medium which might have also affected this transmission. Michael H. Shank talked about the role of the Jews as scientific intermediaries in the European Renaissance. This link is further explained in the work of Tzvi Langermann and Robert Morrison[22], as well as by İhsan Fazlıoğlu who pointed to something often overlooked, namely "the important role of the Ottoman courts of Mehmed II, who was the conqueror of Constantinople, and of his son and successor Bayazid II in promoting scientific and philosophical study, which included providing

[22] Morrison compared the Judeo-Arabic Book *The Light of the World* with the works of European astronomers. He explained how this book transformed from al-Andalus to Istanbul and then arrived to Padua, where Copernicus studied medicine in 1501-1503. He also described other ways that Jews functioned as intermediaries for Renaissance astronomers' knowledge of astronomy such as their rule as a medium between the Republic of Venice and the Ottoman Empire following 1453 (Morrison, 2017, p. 199-200).

patronage for Christian and Jewish, as well as Muslim, scholars" (Ragep, 2017, 194). This had occurred even before the other event in which Jews left Andalusia immigrating with their Arabic-origin books to Netherlands and Poland. Thus, some translators benefited from the diaspora of some Jewish scholars who had cultivated Islamic learning. Recent studies also demonstrate the existence of a more influence of the scientific enlightenment in the earlier mentioned Trabzon between the 13-15th centuries, which had likewise played a significant role in the discussed transmission.

Also, it has been suggested that the astronomical information from the observatory of Maragha[23] in the Mongol realms arrived at the Spanish court of Alfonso X of Castile (d 1284) (Burnett, 2013, no page number).[24] And such possibility corresponds with the historical events. In other words, such intellectual exchange became possible in the 13th century. Some intellectuals of the Jewish and the Islamic world shared their common knowledge with the Christendom where they transcended political and religious borders. Such closeness might have been resulted by the translation movement which pushed Europeans to consider "the others" based on their intellectual rather on their beliefs.

Not forget the contibutions of Maimonides (d 1204) on the West. Also, Levi ben Gerson (d 1344) who lived in Southern France. He made different innovations in astronomy, including unique astronomical instruments. He proposed a realist theory of astronomy, which is to say "he believed that physical observation sought to correspond to mathematical models and worked toward that goal" (Huff, 2000, p. 191).[25] Another relevant and interesting book is *Puzzles of Wisdom*, a compendium of Renaissance knowledge composed by Moses ben Judah Galeano around the year 1500. The author was a physician, astronomer, and translator, active at the court of Bayazid II, who spent some time in Italy and Crete as well. This book included different areas of science but what concerns us here is the discussion of some astronomical models in which the author included the system of Ibn al-Shāṭir, which displays a strong resemblance to Copernicus' models. *Puzzles of Wisdom* offers the first evidence that someone who knew Ibn al-Shāṭir well was present in Italy.

Another possible transformation relates to Cardinal Basilios Bessarion (d 1472). As a refugee from Constantinople and a cardinal in the service of several popes, he recognized the need to find an expert on astronomy like Regiomontanus to re-translate Ptolemy's *Almagest* from Greek to Latin, while possibly also carrying translations of Islamic books of astronomy that found their way to his library in Rome. So, it has been posited that Bessarion's teacher in Mistra, George Gemistos Pletho, was directly acquainted with the Ottoman learning (Bisaha, 2017, p. 57). In this context, we must dwell on the case of Qushji (d 1474) who showed how to transform the epicyclic models of Mercury and Venus into eccentric models, which may have affected Copernicus's transformation of a geocentric system into a heliocentric one. This "proposition also appears in the 1496 printing of Regiomontanus's *Epitome of the Almagest*, with a diagram quite close to that of the extant Turkish manuscripts" (Chen-Morris, 2017, p.

[23] During the Islamic ages, there were observatories in Damascus, Bagdad, Cairo, Samarqand, Istanbul, and other cities. The Maragha observatory, in particular, was pretty prestigious that it inspired the creation of other observatories, "[i]n his letters to his father, Jamshīd al-Kāshī implied that Sultan Ulugh Beg established the Samarqand Observatory mainly as a result of having visited the Maragha Observatory when he was a child" (Qtd in Fazlıoğlu, 2008, p. 13). Therefore, it is no wonder that the established observatories in Europe where under the impact of Muslim astronomers. "[C]ertain aspects of the Islamic observatory and its instrumentation were adopted by Europeans in later centuries" (Huff, 2003, p. 173).

[24] This diplomatic activity is also mentioned in: (Ragep, 2017, p. 189).

[25] Huff said that there were other scientists and notable intellectuals in the Jewish communities spread out as they were during that time, "but they were not able to make contributions to scientific progress equivalent to those mentioned [Bīrūnī, Ibn al-Haytham and Thābit ibn Qurrah, etc.]" (Huff, 2000, p. 191) "When the Iberian Jewish community revived in the Ottoman empire after being driven out of Spain at the end of the 15th century, it soon recovered and began teaching both the secular sciences and the traditional religious sciences" (Huff, 2000, p. 192).

156-157)[26], which is strongly suggestive of the close connections between Istanbul and Vienna circles.

In fact, historians have identified multiple sightings of the Tusi Couple in Latin Europe, starting in the fourteenth century. What follows is a chronological list, prepared by Ragep, showing the figures associated with these sightings. Avner de Burgos the Jewish philosopher (d 1340), Nicole Oresme (d 1382), Joseph Ibn Nahmias the author of *The Light of the World* (Ragep, 2017, p. 176-182). At any rate, other of Maragha impact–apart from Copernicus–can be seen in Georg Peurbach (d 1461), Johann Werner (d 1522), Giovanni Battista Amico (d 1538), and Girolamo Fracastoro (d 1553).

After tracing back, the most important theories adopted by Copernicus and after highlighting its origins in the Islamic world we arrive to Copernicus's main touch his heliocentric element. In his "Why Was Copernicus a Copernican?" Peter Barker considered the lack of a generally agreed and historically respectable answer to the question of why Nicholas Copernicus adopted heliocentrism, as a scandal. So, this sudden change in the European astronomy is ambiguous. Indeed, Muslim astronomers didn't mention the exact Copernican helio-theory but the discussion of the possibility of the Earth's motion can be found in Islam, Christendom and even India, prior to Copernicus. Some scholars would suspect the mentioned studies regarding Copernicus's Islamic roots and instead say that Copernicus has reached the same results by chance. But this claims itself contradicts the logical and the historical narration.

As it was mentioned so far, the important theories which were used by the Maragha Group, have their long historical development, reached by the significant accumulative efforts of many Muslim scientists–from whom we mentioned only the most important ones–who wrote several books through the centuries. Therefore, this longstanding tradition of Islamic criticism of Ptolemy and the proposal of alternative models have the history of more than five centuries of hard accumulative work. And the most important part is that we still have hundreds of manuscripts to examine this long tradition. And accepting such scientific development is more logical than to claim that Copernicus had arrived to these entire complex ideas by himself. Or as some scholar suggested that such knowledge was revealed to Copernicus on his deathbed! Especially when we know that the European Pre-Copernican astronomical tradition almost has little connection with Copernicus' theories. We know that pre-Copernican European scientists were familiar with Muslim astronomers; a relevant case is that of Johannes Regiomontanus who referred to al-Biṭrūjī and to others (Shank, 2017, p. 108). Moreover, Celenza reconstructed the typical mindset of pre-Copernican European Renaissance where some astronomers believed in spirits, ghosts, and superstations, moreover, some scholars including Copernicus's teacher and pupil practiced an astrology rather than astronomy, Celenza then asked how can this way of thinking just suddenly change into a full scientific opposite with one man? (Celenza, 2017, p. 21-22). How could Copernicus challenge Ptolemy when he lived in a context where there was no history of a sustained critique of Ptolemy? Based on Jerzy Dobrzycki and Richard Kremer's study (Peurbach and Maragha astronomy), even the non-Ptolemaic models developed by Peurbach (d 1461), and which may have arrived to Copernicus later, were created based on Islamic sources (Ragep, 2007, p. 69). Therefore, it is more logical to trace back the ideas used by Copernicus elsewhere, in a place where we still have their historical record, that is to say, in the Islamic world. It is where they needed numerous centuries before they mature, and likewise to find their final manifestation in the works of the Maraga School.

As mentioned before, Copernicus quoted several first-generation Muslim astronomers whose books were very widespread at that time. But when it came to the Maragha School he used them without giving them any credit. This could be so due to the complex relationship that prevailed between western Europeans, the Ottoman Empire, and the Byzantine refugees. The

[26] Furthermore, in p. 158, the author explains other similarities with a work of Jaghmīnī (d 1344).

prototypical European view at that critical time of Asia as "the other" could have caused Copernicus to use those ideas without acknowledging their sources. Other contributing factor was the dominant typical ideological idea of Europeans about Turks, at the time, as being interested in waging wars on knowledge. A conviction further strengthened by the sheer military might of the Ottoman Empire that often obscured other aspects of their creative and complex society, allowing contemporaries and later historians to view them as "better at war and less good at culture" (Bisaha, 2017, p. 34-41). Other arguments were suggested regarding such silence over the Maraghan astronomers. Maybe Copernicus never knew the authors of the ideas that were transmitted to him, their identities having been lost in the process (Bisaha, 2017, p. 31). Or maybe this lack of comment refers to a kind of transformation in the European state of mind. Those ideas travelled westward and were used, "but they were changed or cloaked, consciously or unconsciously, perhaps to make them fit with the growing belief among Europeans that their current scholarship had surpassed that of the East" (Bisaha, 2017, p. 40-41).

Conclusion

To sum up, after Muslims' touch, mathematics became a new language, so to speak, an efficient tool of astronomy. The unintended consequences of these unified models produced the considerable development that allowed them to be transferred into heliocentric models. Furthermore, the abundance of various genres of criticism, employed by Muslims, was so influential in pushing the wheels of astronomy forward. For instance, the Islamic distinguished genre of Takmila (Complement) of another scientific book–as Saliba indefatigably asserts–was more than just a trivial "commentary upon commentary", rather it was a revolutionary method of almost re-producing an entire new work. And as was seen in this article in the names of some Arabic astronomical books, there were numerous ways of approaching a work, such as: Sharh (Expounding), Takmila (Complement), Tahrir (Commentary), Islah (Correcting), Tafsir (Interpretation), and so on. It was such unique and colourful methods of approaching science practised by Muslim astronomers that facilitated the speed development of the astronomical knowledge at the time. Such commentaries were somewhat produced in the style of our modern time specialized scientific journals.

Thus, the reason behind Copernicus' success in solving the old problems of the Greek astronomical tradition was attained by using the Islamic theories. Future studies will further explain with more strictness how Muslim astronomers' manuscripts arrived to Copernicus. As we have seen, the gradual Byzantium effect lasted for many centuries, and most importantly it lacks concrete material to compare. As was mentioned before, there is no strong evidence that Copernicus read Arabic or that the mentioned books were translated in Latin at the time. In fact, Saliba gave a logical explanation behind the lack of translated books in the European Renaissance era, and by the means of which we can conclude this study: "[i]n the Middle Ages people relied more on the translations and waited for them to be produced before they could use them. That was how the Latin translations of Averroes made their impact on Latin thinkers. But by the Renaissance time, men of science themselves apparently became Arabists and no longer needed the translations" (Saliba, 2007, p. 231).[27]

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[27] However, in the first chapter of *Islam in Europe*, Goody mentioned that when Europeans later went back to the Greek knowledge it was a reaction to their refusal of the Islamic culture which was very powerful, highly articulated by the dominant ideas of giants such as Ibn Sina, Ibn Rushd, etc.

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Appendix

First illustration. Gutas's list of the dates of books translated into Arabic during the Abbasid age as well as of their very first manuscripts that have gone through the process of transcription in the Byzantine scriptoria.

Date	*U/M*	*Author*	*Work*	*Greek MS*	*Earliest attested Arabic transl.*[59]
800–30	M	Theon	Comm. on Ptolemy's *Almagest*	Laurentianus 28, 18	"old transl." *F* 268.29;*GAS* V,186
800–30	M	Pappus	Comm. on Ptolemy's *Almagest*	Laurentianus 28, 18	* *GAS* V,175
800–30	U	Ptolemy	*Almagest*	Parisinus gr. 2389	transl. before 805; *GAS* VI,88
800–30	U	Dioscurides	*Materia Medica*	Parisinus gr. 2179	tr. Steph. b. Basil; *GAS* III,58
800–30	M	Paul Aegin.		Paris. suppl. gr. 1156,	before 814; *GAS* III,168
800–30	M	Paul Aegin.		Coislin. 8 and 123	before 814; *GAS* III,168
800–30	U	Aristotle	*Sophistici Elenchi*	Paris. suppl. gr. 1362	before 785; *DPA* I,527
813/20	U	Ptolemy	*Almagest*	Vaticanus gr. 1291	transl. before 805; *GAS* VI,88
813/20	U	Ptolemy	*Almagest*	Leidensis B.P.G. 78	transl. before 805; *GAS* VI,88
813/20	U	Theon	Comm. on *Almagest*	Leidensis B.P.G. 78	(see first entry above)
830–50	M	Ptolemy	*Almagest* and other works	Vaticanus gr. 1594	transl. before 805; *GAS* VI,88
830–50	M	Euclid	*Elements*	Vaticanus gr. 190	before 800; ch. 6.3 above
830–50	M	Euclid	*Data*	Vaticanus gr. 190	ca. 850; *GAS* V,116
830–50	M	Theon	Comm. on Ptolemy's *Canons*	Vaticanus gr. 190	before Ya'qūbī; *GAS* V,174, 185
830–50	M	Theodosius	*Sphaerica*, etc.	Vaticanus gr. 204	*GAS* V,154–6
830–50	M	Autolycus	*Sphaerica*, etc.	Vaticanus gr. 204	*GAS* V,82
830–50	M	Euclid		Vaticanus gr. 204	before 800; ch. 6.3 above
830–50	M	Aristarchus		Vaticanus gr. 204	*GAS* VI,75
830–50	M	Hypsicles	*Anaphorica*	Vaticanus gr. 204	*GAS* V,144–5
830–50	M	Eutocius		Vaticanus gr. 204	*GAS* V,188
830–50	M	Marinus	Comm. on Euclid's *Data*	Vaticanus gr. 204	? but cf. Euclid
830–50[60]	M	Aristotle	*PA, IA, GA, Long. vit., De Spir.*	Oxon. Corp. Chr. 108	ca. 800; *DPA* I,475
ca. 850	M	Aristotle	*Physics*, ff. 1r–55v	Vind. phil. gr. 100[61]	by 800 (ch. 3.2 above)
ca. 850	M	Aristotle	*De caelo*, ff. 56r–86r	Vind. phil. gr. 100	by 850 (ch. 6.3 above)
ca. 850	M	Aristotle	*De gen. et corr.*, ff. 86v–102r	Vind. phil. gr. 100	? but cf. *Physics*
ca. 850	M	Aristotle	*Meteorology*, f. 102v–133v	Vind. phil. gr. 100	by 850 (ch. 6.3 above)
ca. 850	M	Aristotle	*Metaphysics*, ff. 138–201	Vind. phil. gr. 100	by 842: *DPA* I,529
ca. 850	M	Theophrastus	*Metaphysics*, ff. 134r–137	Vind. phil. gr. 100	before 900[62]
ca. 850	M	Aristotle	*Hist. anim.* VI,12–17:ff. 13–14	Paris. suppl. gr. 1156[63]	ca. 800; *DPA* I,475
850–80	M	Ptolemy	[*Almagest*?]	Vat. Urbinas gr. 82	transl. before 805; *GAS* VI,88
850–80	M	Plato	*Tetralogies* VIII and IX	Paris. gr. 1807	never translated in full(?)
850–80	M	Maximus Tyr.		Paris. gr. 1962	?
850–80	M	Albinus		Paris. gr. 1962	never translated(?)
850–80	M	Proclus	Comm. on the *Timaeus*	Paris. suppl. gr. 921	*
850–80	M	Olympiodorus	Comm. on Plato	Marcianus gr. 196	never translated(?)
850–80	M	Simplicius	Comm. on the *Physics* V–VIII	Marcianus gr. 226	*
850–80	M	Philoponus	*Contra Proclum*	Marcianus gr. 236	*GAP* III,32, note 52
850–80	M	Damascius	Comm. on *Parm.* = *De principiis*	Marcianus gr. 246	never translated(?)
850–80	M	Alex. Aphrod.	*Quaest.*; *De an.*; *De fato*	Marcianus gr. 258	*DPA* I,132–3
850–80	M	Proclus	Comm. on the *Republic*	Laurentianus 80,9	*
850–80	M	Proclus	Comm. on the *Republic*	Vaticanus gr. 2197	*
850–80	M	Varii	geographies, doxographies	Palat. Heidelb. gr. 398	various translations
IX cent.		Aristotle	*De interpr.* 17a35–18a16	Damascus[64]	9th c.; *DPA* I,514

59 An asterisk (*) in this column means that though this particular book by an author is not mentioned in Arabic bibliographies and does not survive in independent ms tradition, other books by the same author on the same or related subjects were translated into Arabic.

60 Most scholars, though, date this ms significantly later; see *DPA* I,479.

61 Irigoin "L'Aristote de Vienne," 8 top.

62 The extant manuscript ascribes the translation to Isḥāq ibn-Ḥunayn (d. 298/910): I. Alon, "The Arabic Version of Theophrastus' Metaphysica," *Jerusalem Studies in Arabic and Islam*, 1985, vol. 6, p. 164.

63 Irigoin "L' Aristote de Vienne," 9 top.

64 Palimpsest discovered in the Umayyad mosque in Damascus; see Harlfinger, *Griechische Kodikologie*, p. 452.

Second illustration. Al-ʿUrdī's new model.

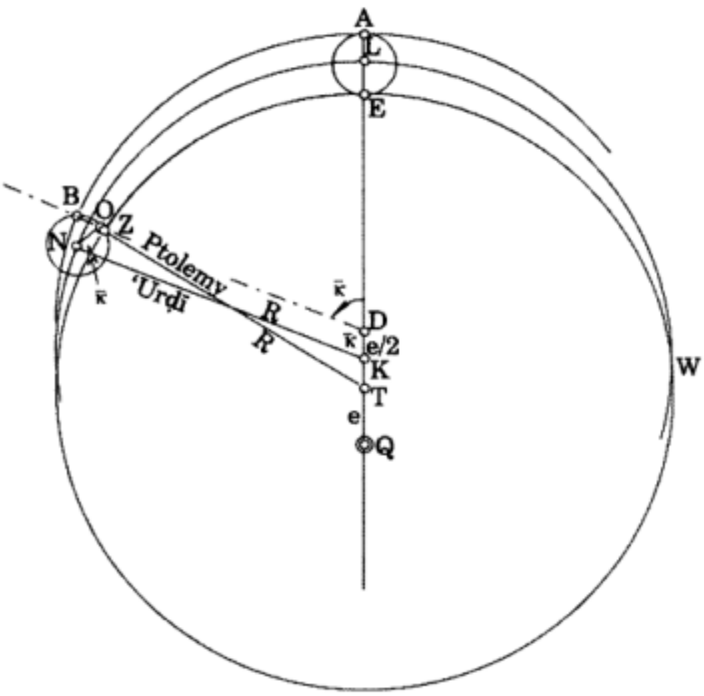

Figure 4.6

'Urḍī's model for the upper planets. By defining a new deferent with a center at *K*, halfway between the center of the Ptolemaic deferent *T* and the equant *D*, 'Urḍī allowed that deferent to carry a small epicycle whose radius was equal to *TK* = *KD*. He made the small epicycle move at the same speed as the new deferent, and in the same direction. By applying his own lemma, 'Urḍī could demonstrate that line *ZD*, which joined the tip of the radius of the small epicycle to the equant, would always be parallel to line *KN*, which joined the center of the new deferent to the center of the small epicycle. He could also show that point *Z*, the tip of the radius of the small epicycle, came so close to the point *O*, which was the center of the Ptolemaic epicycle, that the two points could not be distinguished. Then it was easy to see that the uniform motion of *O* that Ptolemy thought took place around point *D* was indeed a uniform motion around point *N* which in turn moved uniformly around *K*, thus making *Z* appear to be moving uniformly around *D* and satisfying the Ptolemaic observations.

Third illustration. Tusi Couple.

Fourth illustration. The lunar model of Ibn Ibn al-Shāṭir and Copernicus.

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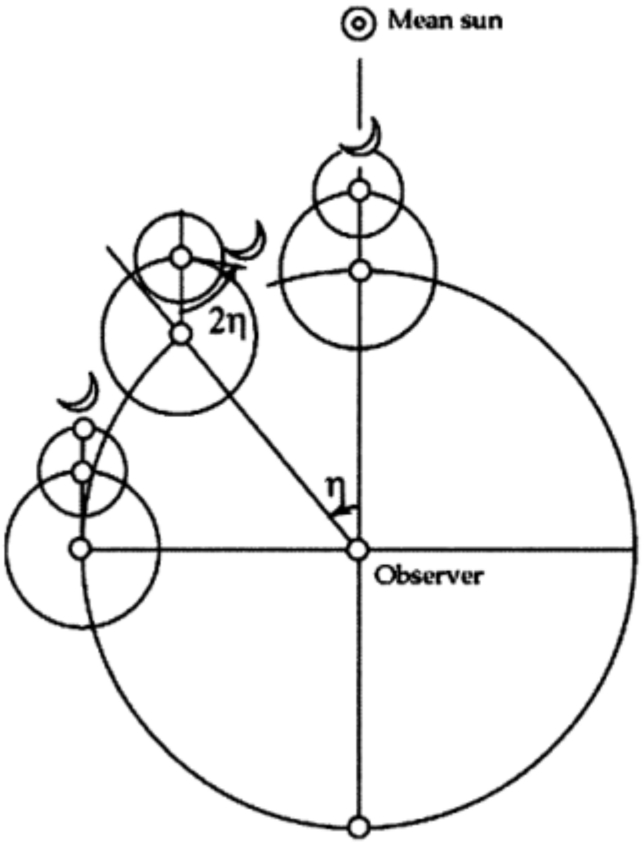

Figure 6.1
The lunar model of Ibn al-Shāṭir and Copernicus.

Fifth illustration. The alphabetic similarities in Tusi Couple as seen in the work of al-Ṭūsī (on the left) and Copernicus (on the right).

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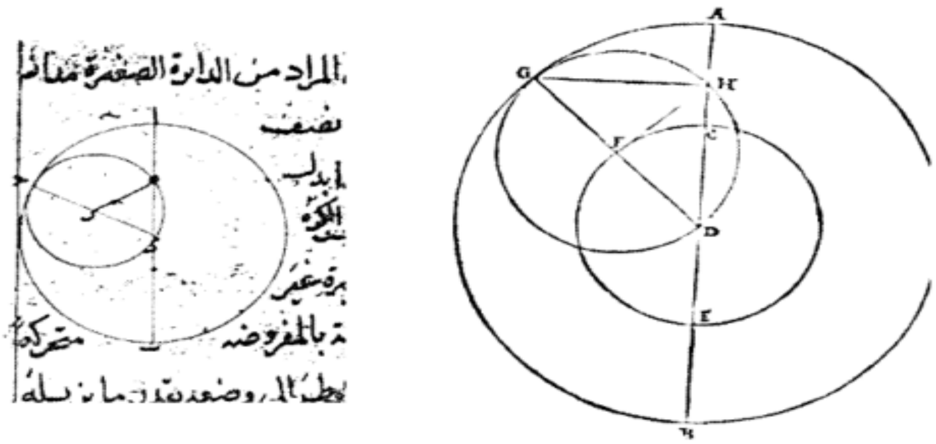

Figure 6.2
Proofs of the Ṭūsī Couple from the works of Ṭūsī (left) and Copernicus (right), showing the identity of the lettering of the diagrams. Wherever Ṭūsī had *alif* Copernicus had *A*, and wherever Ṭūsī had *bā* Copernicus had *B*, and so on, except that where Ṭūsī had *zain* for the center of the smaller sphere Copernicus had *F*. See figure 6.3.

Sixth illustration. The similarity of letter zain (z) and fa' (f) in some Arabic manuscript.

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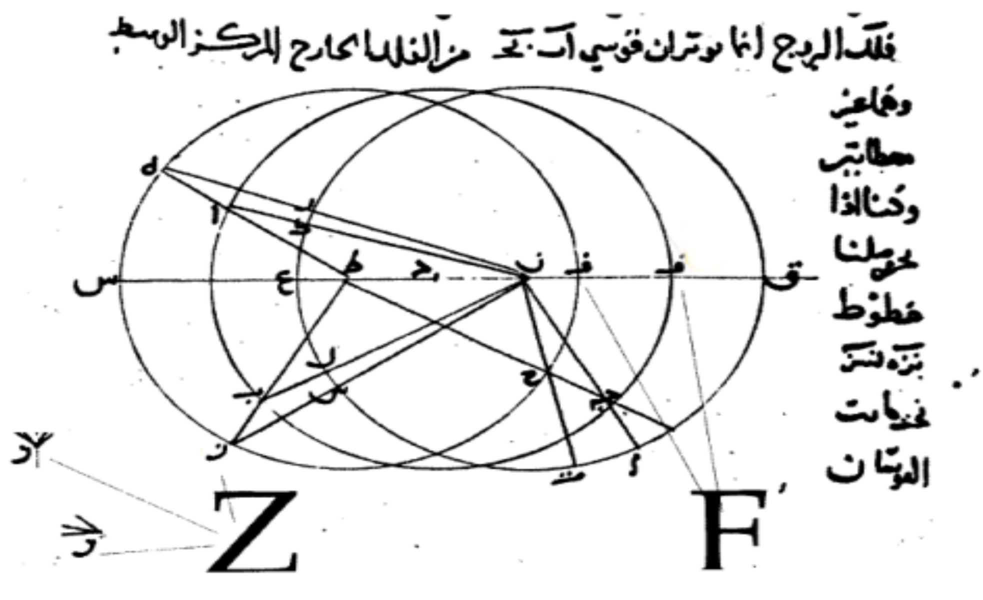

Figure 6.3
A medieval Arabic manuscript exhibiting the similarities between the letters *zain* = *Z* and *fā'* = *F*.