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Muslim Astronomers in the 11th–13th Century and Their Contributions

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ABSTRACT

This study explores the intellectual continuity and scientific innovations of Muslim astronomers during the 11th–13th centuries, a period often considered the golden age of Islamic civilization. While many modern narratives attribute the birth of scientific empiricism to the European Renaissance, this research highlights that foundational elements of observation, experimentation, and mathematical modeling had already been established centuries earlier within the Islamic world. Using a historical and comparative methodology, this study analyzes primary sources such as Kitab al-Manazir (Ibn al-Haytham), Al-Qanun al-Mas'udi (Al-Biruni), Jami' al-Mabadi wa al-Ghayat (Al-Marrakusyi), and At-Tadhkira fi Ilm al-Hay'ah (Nashiruddin al-Thusi). Findings reveal that these astronomers pioneered systematic experimentation, field measurement, and theoretical modeling, which later influenced European scientists such as Roger Bacon, Kepler, and Copernicus. Their works established principles of reproducibility, empirical validation, and collaborative research that prefigured the modern scientific Method. The study concludes that Islamic astronomy of the 11th–13th centuries did not merely preserve Greek knowledge but transformed it into an empirical and mathematical discipline, forming an essential foundation for modern astronomy and physics.

I. Introduction

The development of modern science cannot be separated from the contributions of Islamic civilization, especially during the Middle Ages. However, the historical narrative of the world's science often presents the European scientific revolution as the starting point of scientific progress, as if it emerged suddenly without the foundations laid by previous civilizations. In reality, the scientific progress in the West is the continuation of the intellectual heritage of Muslim scientists, especially in astronomy. This historiographical gap raises a significant problem: there is still a lack of understanding and recognition of the role of Muslim astronomers of the 11th to 13th centuries in shaping the foundations of modern astronomy.

This issue is increasingly relevant in the contemporary academic context, where the study of Islamic astronomy is being redeveloped to bridge the integration of modern science with classical scientific heritage. Many studies remain descriptive, focusing on the biographies of scientists without examining how the scientific Method and their discoveries shaped the experimental astronomy paradigm. In fact, in the 11th to 13th centuries, the Islamic world had already applied methods of observation, experimentation, and mathematical rationalization, long before Galileo and Kepler introduced them in Europe.

The need to address this topic is also driven by a renewal in research on the history of Islamic science, which now highlights the importance of analyzing epistemic continuity, that is, the methodological continuity between Muslim scientists and modern Western scientists [1]. Recent studies in Islamic Science Studies show that the Maragha observatory and the work of Nashiruddin al-Thusi were the direct inspiration for Copernicus's heliocentric model [2].

Similarly, Ibn al-Haytham's optical analysis (Figure 1) is recognized as the basis for the development of light theory and telescope design [3]. Thus, tracing the contributions of Muslim astronomers of the 11th–13th centuries is crucial not only for history but also for reconstructing the origins of modern scientific methods.

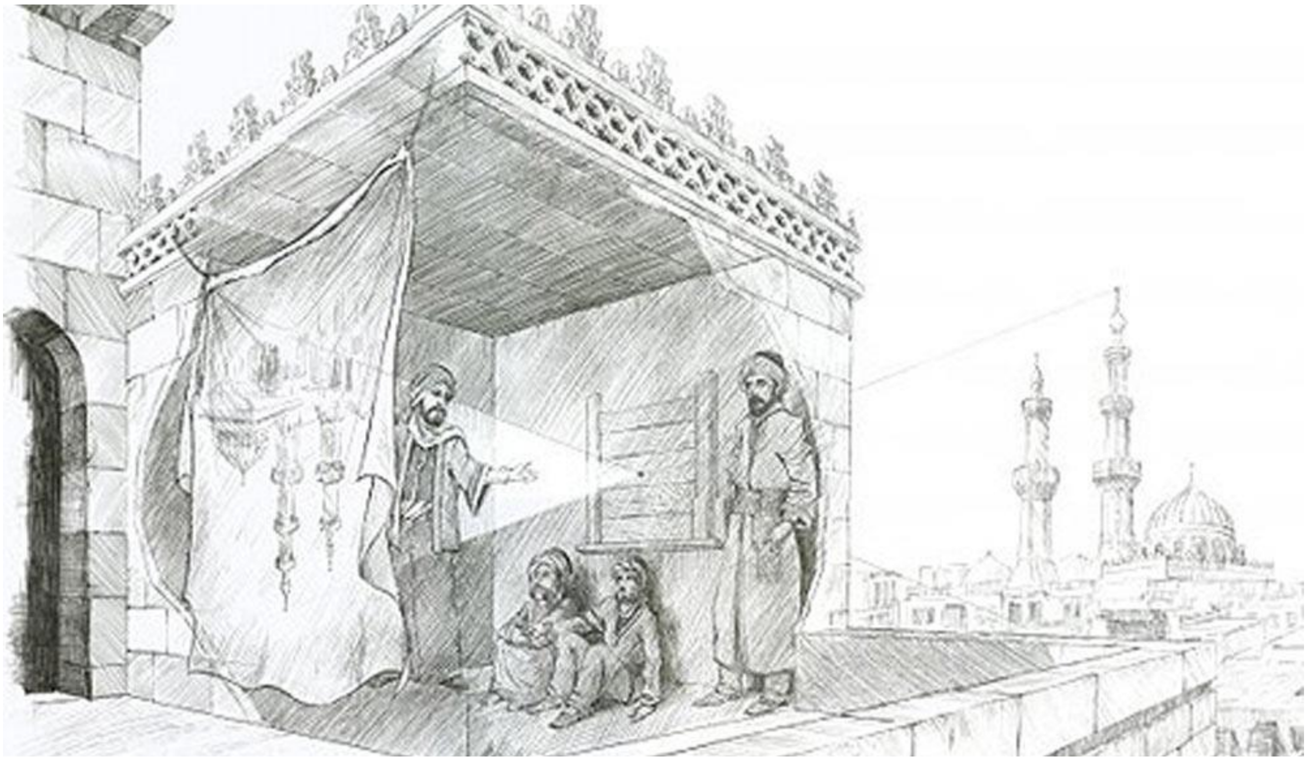

Figure 1. Ibn al-Haytham's optical analysis

In addition, the socio-political context of the Islamic world at that time also accelerated scientific progress. The support of the Abbasid caliph, the establishment of Bayt al-Hikmah, and the establishment of observatories in Baghdad, Maragha, and Cairo created a productive scientific ecosystem. Scientists did not simply copy Greek texts; they criticized and updated them, and developed new models of cosmology that better aligned with observational results. This empirical approach became a hallmark of medieval Islamic astronomy and marked a shift from a speculative-philosophical to a data-driven, experimental science.

Based on this background, this study seeks to highlight the role and contribution of some of the leading figures of Muslim astronomy in the 11th to 13th centuries, namely Ibn al-Haytham, Al-Biruni, Al-Marrakusi, and Nashiruddin al-Thusi. These four figures were chosen because they represented four main aspects of the progress of Islamic astronomy: (1) the innovation of scientific methods and optics (Ibn al-Haytham), (2) the formation of cosmological and geodesic theories (Al-Biruni), (3) the systematization of knowledge and the instrumentation of time (Al-Marrakusyi), and (4) the development of mathematical models and scientific observatories (Al-Thusi). By examining their contributions, this study seeks to provide a more comprehensive understanding of how Islamic civilization in the 11th–13th centuries laid the foundation for the birth of modern astronomical science.

II. Method

This research uses a historical and comparative approach, with an emphasis on tracing primary and secondary literature on Muslim astronomers from the 11th to 13th centuries AD. The primary data are obtained from classics such as Al-Biruni's Al-Qanun al-Mas'udi, Nashiruddin al-Thusi's At-Tadhkira fi Ilm al-Hay'ah, and Al-Marrakusyi's Jami' al-Mabadi wa al-Ghayat fi Ilm al-Miqat. Historical approaches are used to reconstruct the social, political, and scientific context behind the development of Islamic astronomy.

Furthermore, a textual analysis of the content and structure of these works was carried out to identify their scientific and methodological contributions to classical and modern astronomy. The comparative Method compares the theories and instruments developed by Muslim scientists with the findings of Western scientists after the Renaissance. The final stage of the research involves verifying the literature in the latest scientific journals and academic books with DOIs to ensure the data are relevant to the development of contemporary astronomical studies. With this Method, the research seeks to provide a comprehensive picture of the intellectual continuity between Islamic astronomy and modern science.

III. Results and Discussion

The progress of Islamic astronomy in the 11th to 13th centuries AD was marked not only by technical discoveries but also by the emergence of a new scientific paradigm that emphasized direct observation, experimentation, and mathematical validation. This tradition was a turning point in the speculative approach inherited from classical Greek philosophy. Ibn al-Haytham (965–1038 AD), for example, in his Kitab al-Manazir, introduced a systematic experimental method that placed empirical observation as the basis of scientific truth [4]. He used optical devices and geometric models to prove that light travels in a straight line and that vision occurs when light reflects from objects to the eye, not the other way around, as Ptolemy believed.

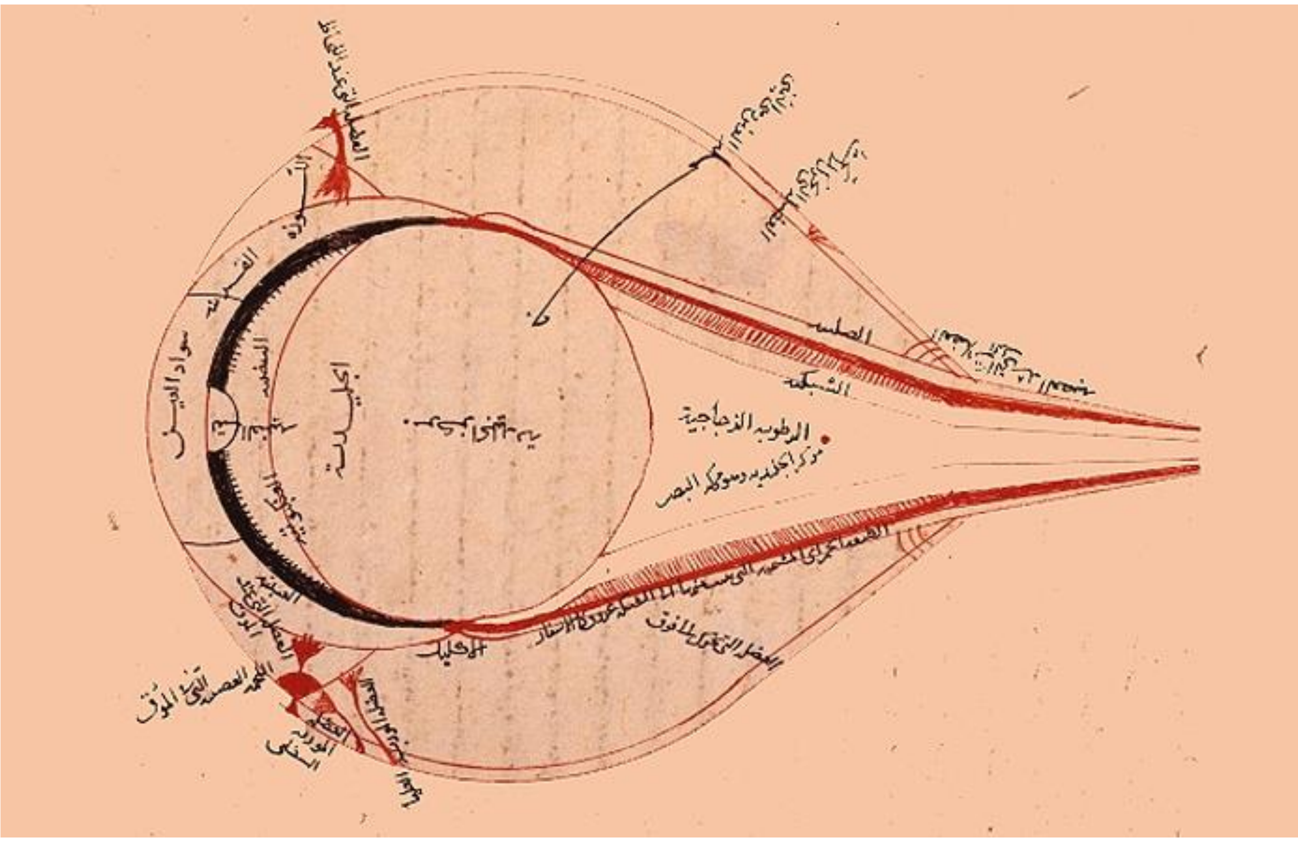

Figure 2. Vision occurs when light reflects from objects to the eye

Ibn al-Haytham's experimental Method later inspired European scientists such as Roger Bacon and Johannes Kepler [5]. Bacon explicitly quoted Ibn al-Haytham in the Opus Magi, and Kepler used the same optical principles to explain the eye's mechanism and the formation of images, as shown in Figure 2. Thus, the scientific approach rooted in Ibn al-Haytham's empiricism was one of the methodological foundations of the 16th-century scientific revolution [6].

In the modern context, Ibn al-Haytham's observational Method can be seen as an early form of experimental physics in the study of optics and astronomy. Contemporary studies by Sabra (2003) and Rashed (2017) show that the optical experiments conducted by Ibn al-Haytham have a structure parallel to Galileo's scientific methodology, particularly in the use of hypotheses and empirical verification [7].

Abu Rayhan Al-Biruni (973–1048 AD) is known as a multidisciplinary scientist who combined astronomy, mathematics, and empirical geography. In Al-Qanun al-Mas'udi fi al-Nujum wa al-Hay'ah, Al-Biruni presents the measurement of the Earth's radius, latitude position, and rotation of the world on its axis, long before Copernicus proposed the heliocentric theory [8] as shown in Figure 3.

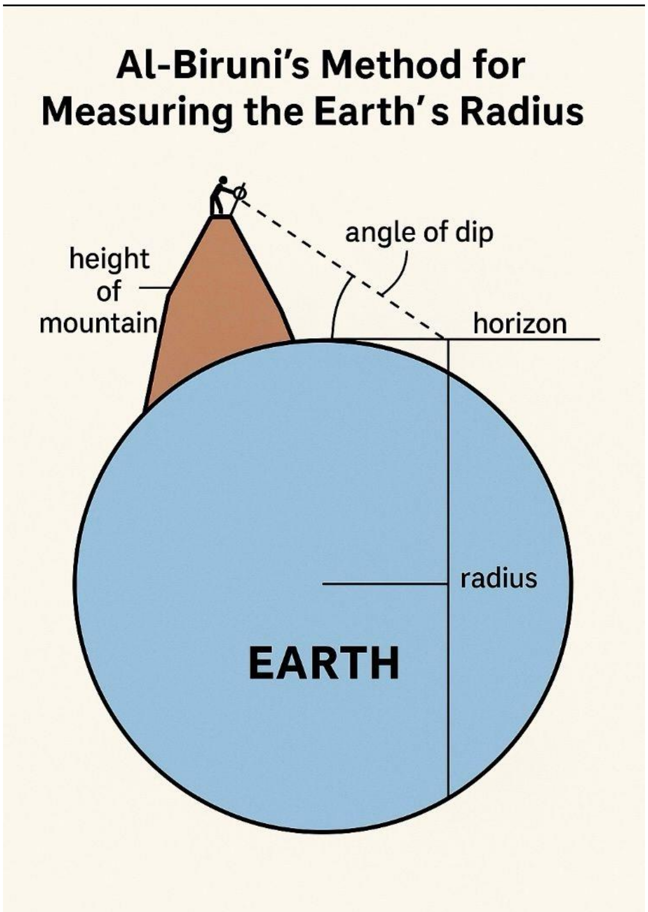

Figure 3. Al-Biruni's Method for measuring the Earth's radius

One of the crucial innovations of Al-Biruni was the application of triangulation to the measurement of distances and altitudes, as well as his arguments for the possible elliptical orbits of the planets. He asserted that the daily motion of stars can be better explained if the Earth rotates on its axis. Al-Biruni's thought has led to rational and empirical principles that are the main characteristics of modern astronomy [9].

In the study of contemporary geodesy, the Al-Biruni method is often considered the forerunner of field measurement in astronomy. Al-Biruni's approach contains scientific elements that meet the criteria of modern field research, namely repeated observation, latitude comparison, and mathematical validation [10]. In addition, the earth measurement model he produced had an accuracy of only 0.2% compared to modern GPS calculations, confirming the scientific validity of his approach.

Al-Marrakusyi (d. 1281 AD), through his monumental work Jami' al-Mabadi wa al-Ghayat fi 'Ilm al-Miqat, succeeded in compiling an astronomical encyclopedia that combines theoretical and practical aspects. He standardized the use of various astronomical instruments, such as the astrolabe, rubu' mujayyab, and mizwala, to determine the time, the direction of the qibla, and the positions of celestial bodies [11].

Al-Marrakusyi's contribution extended beyond compilations to the systematization of practical astronomical concepts into a methodological structure. This work served as the basis for the development of Islamic applied astronomy (miqat) and influenced the science of time (horology) in 14th-century Europe. George Saliba (2016) emphasized that the instrument system compiled by Al-Marrakusi became a model for the development of early mechanical time-measuring instruments in the West [12].

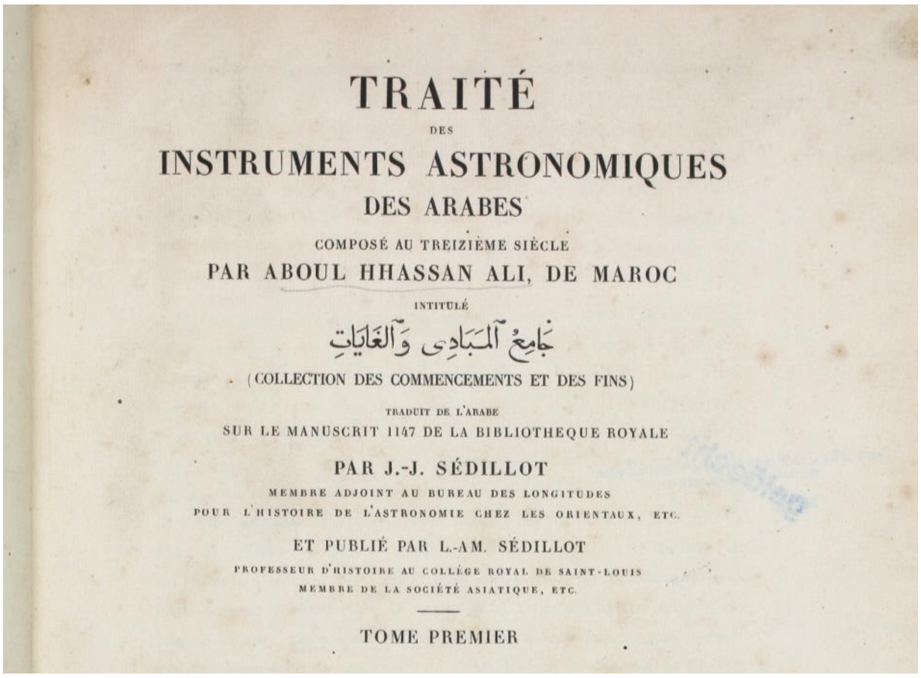
TRAITÉ
DES
INSTRUMENTS ASTRONOMIQUES
DES ARABES
COMPOSÉ AU TREIZIÈME SIÈCLE
PAR ABOUL HHASSAN ALI, DE MAROC
INTITULÉ
جامع المبادى والغايات
(COLLECTION DES COMMENCEMENTS ET DES FINS)
TRADUIT DE L'ARABE
SUR LE MANUSCRIT 1147 DE LA BIBLIOTHEQUE ROYALE
PAR J.-J. SÉDILLOT
MEMBRE ADJOINT AU BUREAU DES LONGITUDES
POUR L'HISTOIRE DE L'ASTRONOMIE CHEZ LES ORIENTAUX, ETC.
ET PUBLIÉ PAR L.-AM. SÉDILLOT
PROFESSEUR D'HISTOIRE AU COLLÉGE ROYAL DE SAINT-LOUIS
MEMBRE DE LA SOCIÉTÉ ASIATIQUE, ETC.
TOME PREMIER

Figure 4. Karya translasi Jami' al-Mabadi wa al-Ghayat fi 'Ilm al-Miqat

In addition, the astronomical data structure used by Al-Marrakusi demonstrates the integration of manual observation with the principles of spherical trigonometry, thereby bridging Islamic astronomy and modern celestial mechanics.

Nashiruddin al-Thusi (1201–1274 AD) was a key figure in the development of Islamic celestial mechanics. His monumental work, At-Tadhkira fi 'Ilm al-Hay'ah, introduced a new mathematical model known as the Thusi Couple, a geometric mechanism that explains how two circular motions can produce linear motion, as shown in Figure 5. This model replaces Ptolemy's inconsistent epicycle system with empirical observations.

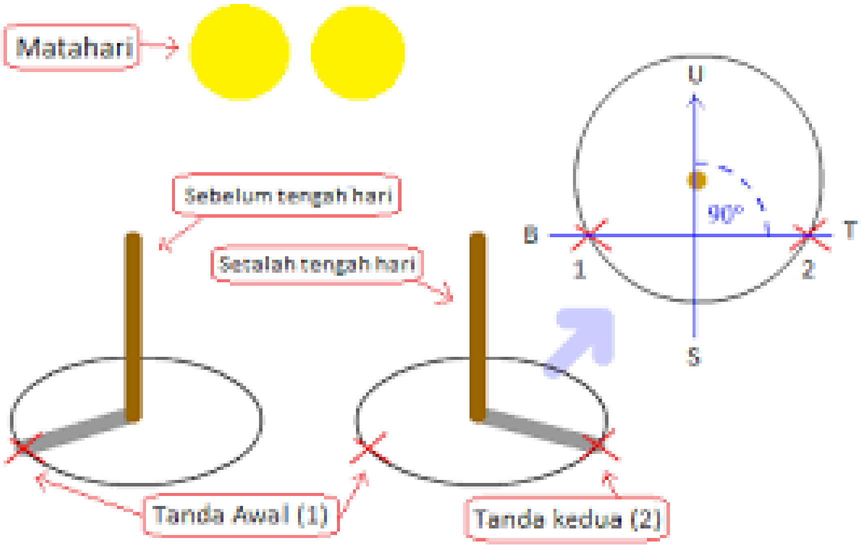

Figure 5. Thusi Couple

The Thusi Couple model is shown to have structural similarities to the model used by Copernicus in De Revolutionibus Orbium Coelestium (1543), which shows a transfer of knowledge from the Maragha observatory to Europe [13]. Documentary evidence discovered by George Saliba and F. Jamil Ragep corroborates that Copernicus was most likely inspired by al-Thusi's work, which had been translated into Latin before the 15th Century [3]. Furthermore, the Maragha observatory led by al-Thusi was the first scientific institution to operate with a system of collective research and the division of scientific tasks. It reflects the embryo of modern research institutions. According to Nasr (1997), the structure of the Maragha observatory demonstrates the university's function and serves as a modern astronomical data center [1] [14].

The epistemological continuity between Muslim astronomers and modern European scientists is not merely a textual adoption, but a methodological continuation. The systematic observational models, controlled experimentation, and mathematical formulations developed by Muslim scientists became the initial framework for the modern scientific Method [15].

Ibn al-Haytham introduced experiments as a tool for empirical verification; Al-Biruni extended them to quantitative measurements based on field data; Al-Marrakusi standardized the practice of observational astronomy, and Al-Thusi established the basis for theoretical calculations of celestial bodies. Conceptually, these four figures show that Islamic civilization had applied the principles of scientific reproducibility and empirical validation before the scientific revolution in Europe [12].

Thus, the results of this study confirm that Islamic astronomy of the 11th–13th centuries AD played a role not only in the transmission of Greek science, but also in transforming the scientific paradigm from metaphysics to experimentation, from traditional observation to mathematical analysis, and from scientific individualism to institutional collaboration. It is what makes Islamic civilization not only the guardian of knowledge but the main driver for the birth of modern science.

The contributions of Muslim scientists in the 11th–13th centuries were not only technical, but also methodological. They introduced observational experiments into a scientific tradition previously predominantly deductive-philosophical. Their works were translated into Latin during the Toledo period and became an inspiration for European scientists such as Roger Bacon and Kepler. A comparison with modern research shows that Al-Thusi's model has mathematical similarities to Kepler's theory of planetary motion. Meanwhile, the Islamic observatory system reflects the pattern of scientific collaboration found in contemporary research institutions (e.g., the European Southern Observatory). Thus, Muslim astronomers of the 11th–13th centuries laid the foundations for the modern scientific revolution, both in methodology and in the development of instruments.

IV. Conclusion

Muslim astronomers of the 11th to 13th centuries AD played a central role in building the scientific foundations that later became the basis for modern science. Through his scientific works and methods, figures such as Ibn al-Haytham, Al-Biruni, Al-Marrakusi, and Nashiruddin al-Thusi introduced new paradigms in the observation, experimentation, and mathematical formulation of celestial phenomena. Ibn al-Haytham developed the Method of optical experiments, which became the forerunner of experimental physics; Al-Biruni introduced a quantitative approach to geodesic measurements and the Earth's rotation; Al-Marrakusi standardized astronomical observation systems and instruments; while Al-Thusi introduced the Thusi Couple mathematical model, which influenced the Copernican heliocentric system. These four figures not only represent individual brilliance but also form a scientific network that transforms astronomy from a speculative tradition into an empirical and collaborative discipline.

Thus, the results of this study refute the notion that scientific progress began in Europe alone. In fact, medieval Islamic civilization inherited a system of knowledge that was empirical, reproducible, and collaborative, a key characteristic of the modern scientific Method. These findings also reinforce the importance of integrating the study of the history of Islamic science into the global narrative of science, to show that the world's scientific awakening is a continuation across civilizations, not a revolution in itself.

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