Al-Qarawiyyin: Jurnal Ilmu Ushuluddin
p-ISSN: 3109-1946 | e-ISSN: 3109-1954
Vol. 1, No. 4, (December 2025), pages: 288-305
https://ejournal.albahriah-institut.org/index.php/al-qarawiyyin

OPEN ACCES

The Contribution of Astronomy in Determining the Direction of the *Qibla* and the Hijri Calendar in the 8th–14th Centuries CE

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Article History	Submitted	Revised	Accepted	Available Online
	2025-09-27	2025-12-03	2025-12-09	2025-12-25

Abstract
Astronomy from the 8th to 14th centuries CE played a crucial role in meeting the practical needs of Muslims, particularly in determining the direction of the *Qibla* and establishing the Hijri calendar, which requires precise geographical orientation and timing of worship. Although the traditional practice of *rukyat* (seeing the sun) has been used, modern literature has not systematically evaluated the contribution of classical astronomy theories and instruments to the accuracy of worship and religious administration. This study aims to describe the contributions of classical astronomers, such as al-Khwārizmī, al-Battānī, al-Bīrūnī, Naṣr al-Dīn al-Ṭūsī, Ibn Yūnus, and Ibn Shāṭir, in the development of instruments, observation methods, and mathematical calculations, and to evaluate their influence on the accuracy of the *Qibla* direction and the Hijri calendar. The technique used is qualitative-historical, with the exploration of classical astronomical works, manuscripts, and contemporary literature, analyzed critically and hermeneutically to assess astronomical instruments' methodological innovation and accuracy. The results of the study show that astronomical scientists such as al-Khwārizmī, al-Battānī, al-Bīrūnī, Naṣr al-Dīn al-Ṭūsī, Ibn Yūnus, and Ibn Shāṭir succeeded in developing the theory of spherical trigonometry, methods for measuring the sun's shadow, and observation instruments such as astrolabes and mural quadrants, thus ensuring the accuracy of the direction of the *Qibla* in various Islamic regions. In the context of the Hijri calendar, their innovations resulted in more accurate astronomical calculations to determine the beginning of the month, reducing dependence solely on traditional *rukyat* and supporting state administration and navigation. In conclusion, the contribution of classical astronomy was not only practical in supporting ritual needs but also provided a methodological foundation for modern

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astronomy, emphasizing the importance of integration between empirical observation and mathematical theory in the development of Islamic science.

Keywords: Astronomy; *Qibla* Direction; Hijri Calendar; Islamic Astronomy; Spherical Trigonometry

Abstrak

Ilmu falak pada abad ke-8 hingga ke-14 M memegang peran krusial dalam memenuhi kebutuhan praktis umat Islam, khususnya dalam penentuan arah kiblat dan penyusunan kalender Hijriah, yang menuntut ketepatan orientasi geografis dan pengaturan waktu ibadah. Meskipun praktik tradisional rukyat telah digunakan, literatur modern belum secara sistematis mengevaluasi kontribusi teori dan instrumen falak klasik terhadap akurasi ibadah dan administrasi keagamaan. Penelitian ini bertujuan menguraikan kontribusi ilmuwan falak klasik, seperti al-Khawārizmī, al-Battānī, al-Bīrūnī, Nāṣr al-Dīn al-Ṭūsī, Ibn Yūnus, dan Ibn Syāṭir, dalam pengembangan instrumen, metode observasi, dan perhitungan matematis, serta mengevaluasi pengaruhnya terhadap ketepatan arah kiblat dan kalender Hijriah. Metode yang digunakan adalah kualitatif-historis, dengan penelusuran karya-karya falak klasik, manuskrip, dan literatur kontemporer, dianalisis secara kritis dan interpretasi hermeneutik untuk menilai inovasi metodologis dan akurasi instrumen falak. Hasil penelitian menunjukkan bahwa ilmuwan falak seperti al-Khawārizmī, al-Battānī, al-Bīrūnī, Nāṣr al-Dīn al-Ṭūsī, Ibn Yūnus, dan Ibn Shāṭir berhasil mengembangkan teori trigonometri bola, metode pengukuran bayangan matahari, dan instrumen observasi seperti astrolab serta mural quadrant, sehingga memastikan ketepatan arah kiblat di berbagai wilayah Islam. Dalam konteks kalender Hijriah, inovasi mereka menghasilkan perhitungan astronomis yang lebih akurat dalam menentukan awal bulan, mengurangi ketergantungan semata pada rukyat tradisional, dan mendukung administrasi negara serta navigasi. Kesimpulannya, kontribusi ilmu falak klasik tidak hanya bersifat praktis dalam menunjang kebutuhan ritual, tetapi juga memberikan fondasi metodologis bagi astronomi modern, menegaskan pentingnya integrasi antara pengamatan empiris dan teori matematis dalam pengembangan sains Islam.

Kata Kunci: Ilmu Falak; Arah Kiblat; Kalender Hijriah; Astronomi Islam; Trigonometri Bola

Introduction

Astronomy was a branch of science that played a central role in classical Islamic civilization, both as a theoretical study of celestial phenomena and as an applied discipline serving the ritual needs of Muslims (Mahmud, 2024; Muhammad, Izzuddin, & Muhammad, 2025). Since the founding of major intellectual institutions such as the Bayt al-Ḥikmah (House of Wisdom) in Baghdad in the 9th century and the Maragha observatory, founded in the 13th century, Muslim scientists developed instruments, observational methods, and astronomical tables (*zīj*) that spread throughout the Islamic world (Mozaffari, 2025). Material evidence, including *zīl* manuscripts, astrolabes preserved in European and Middle Eastern library collections, and historical records of the establishment of observatories, suggests that astronomy was not merely a marginal science but an integral part of a widespread scientific infrastructure from the 8th to the 14th centuries CE (Bardi, 2024).

As Islam expanded into North Africa, Persia, Central Asia, and al-Andalus, a fundamental practical challenge emerged: determining the direction of the *Qibla* and establishing the beginning of the Hijri month in areas far from Mecca (Schumm, 2020). This geographical difference made it impossible to determine the *Qibla* by relying on simple local practices; adequate geodetic and astronomical calculations were required (Rakhmadi, Putraga, & Ritonga, 2025). Similarly, the lunar-based Hijri calendar system involves a combination of observation (*rukyat*) and calculation (*ḥisāb*) to determine the beginning of Ramadan, Shawwal, and Zulhijjah; without reliable scientific procedures, socio-religious consistency risks fragmentation (Kasim, Abbas, Adhha, & Mutmainnah, 2024).

There is concrete evidence that classical figures and works contributed directly to the improvement of these practices. Al-Battānī (850–929 CE) compiled tables (*zīj*) that improved the accuracy of solar and lunar positions; al-Khwārizmī (780–850 CE) developed a method of calculation, and the *zīj* books introduced the hisab procedure; al-Bīrūnī (973–1048 CE) made geographical and trigonometric measurements relevant to the calculation of the *Qibla* and discussed techniques for measuring latitude and longitude (Kohar, 2025). The establishment of observatories, such as Maragha (13th century), and the widespread presence of astrolabes across the Islamic world demonstrate a concrete technical capacity (Mozaffari, 2018). This evidence shows how the mathematical and observational advances of the Golden Age had direct implications for refining the *Qibla* and developing the Hijri calendar.

Previous studies have examined different aspects of the relationship between astronomy and religious practice. Some emphasize the technical dimensions of instruments: for example, Islam, Sultan, and Hasanuddin's (2023) study, which highlights the use of astrolabes and *zīj* for *Qibla* determination, demonstrates technical progress but limits its discussion to instrumentation. Anzaikhan and Roni's (2021) study emphasizes the link between astronomical developments and the practical needs of worship. Still, it does not delve deeply into how religious authorities adopted or rejected these astronomical findings. Faid et al. (2025) map the dynamics of *ḥisāb-rukyat* in the formation of the Hijri calendar and its socio-political implications, but tend to focus on the post-classical period and administrative context, rather than the historical roots of the golden age. Ritonga et al. (2024) investigate the synchronization of *ḥisāb* and *rukyat* in a modern context, while Walker and Chinigò (2018) compare the Islamic astronomical tradition with Western astronomical traditions. Both are useful, but tend to position Islamic astronomy as a comparative element rather than as an autonomous knowledge system. From these various findings, it appears that previous research tends to place astronomy within a technical framework rather than an epistemological one, leaving the door open for integrative studies.

Based on this review, the research problem to be studied is: how did astronomy contribute to determining the direction of the *Qibla* and the Hijri calendar from the 8th to the 14th centuries? And how did this contribution shape scientific authority and strengthen Islamic civilization? The purpose of this study is to elucidate the practical and theoretical contributions of astronomy to the worship and social aspects of Islamic society, while also highlighting its position as an integral part of the Islamic epistemological framework. The initial argument of this study emphasizes that astronomy is not merely a technical astronomical discipline, but rather reflects an Islamic epistemological paradigm that unites revelation and reason. Thus, the expected contribution will not only enrich the historiography of Islamic science but also provide a new analytical framework for the study of the integration of science and religion in a modern context.

Method

This study employs a historical qualitative method, incorporating textual, contextual, and historiographical analysis, to examine the contribution of astronomy in determining the direction of the *Qibla* and the Hijri calendar during the Islamic Golden Age (8th to 14th centuries CE). Primary data sources include classical manuscripts, works by astronomy scholars, Islamic astronomical records, and documents related to the intellectual journeys of Muslim scientists, such as those of al-Khwārizmī, al-Battānī, al-Bīrūnī, Nāṣr al-Dīn al-Ṭūsī, Ibn Yūnus, and Ibn Shāṭir. In contrast, secondary sources include modern literature and peer-reviewed journal articles discussing the development of astronomy. Data collection techniques included identifying and recording information relevant to the practice of determining the *Qibla* and calendar, as well as organizing the findings according to the study theme. This was followed by cross-validation to ensure credibility and minimize bias. Data analysis was conducted through critical content analysis, which involved interpreting the text within the socio-intellectual context of the time, followed by a hermeneutic interpretation that linked the concept of astronomy to the development of global astronomy and its relevance to the accuracy of determining the *Qibla* and the preparation of the Hijri calendar. All findings were analyzed systematically through source triangulation, with sequential steps: identification of themes, classification of astronomy practices, comparison with global astronomical references, and interpretation of historical contributions, so that this study can provide a comprehensive picture of the significant role of astronomy in classical Islamic civilization.

Results and Discussion

The Development of Astronomy Science in the Islamic Golden Age

The development of astronomy from the 8th to the 14th centuries CE was the result of a dynamic synthesis between the religious needs of Muslims and the structural support of Islamic civilization, particularly during the Abbasid period

(Americo, 2024). Political stability and the emergence of Baghdad as a center of power not only created a cosmopolitan space but also formed an epistemic ecosystem that facilitated the growth of practical (*ʻilm al-Ḥayʻah al-ʻAmaliyyah*) and theoretical (*ʻilm al-Ḥayʻah al-Naẓariyyah*) astronomy (Abdullah & Ibrahim, 2023). Scientists such as al-Fazarī (746-806 CE) and Yaʻqūb ibn Ṭāriq (d. 796 CE) began to compile *zīj* (astronomical tables) for worship needs such as determining prayer times and the direction of the *Qibla*, indicating that astronomy did not develop based on abstract contemplation, but rather as a response to the needs of Islamic law (Blois, King, & Samsó, 2012).

The Bayt al-Ḥikmah in Baghdad played a crucial role in establishing the scientific foundations of astronomy by translating, critiquing, and developing classical texts. Greek astronomical works such as Ptolemy's Almagest were not only translated but also reanalyzed using the *taḥqīq al-Maʻrifah* approach typical of Muslim scholars (Americo, 2024). Figures such as al-Farghānī (1997) (d. 861 CE) simplified the Ptolemaic geocentric model in his *Jawāmiʻ ʻIlm al-Nujūm*, adapting it to calculate the longitude and latitude of Islamic cities in relation to the direction of the *Qibla*. At this stage, the Bayt al-Ḥikmah did not stand as a passive institution, but rather as a conceptual laboratory where the transition from translation to scientific innovation took place. Scientific activities within it gave birth to an independent astronomical discipline that was no longer a branch of Greek mathematics but became an applied science with relevance to Islamic jurisprudence (Hullmeine, 2024).

The transformation of astronomy reached its peak when empirical observation began to replace geocentric speculation. The Baghdad Observatory during the time of al-Maʻmūn (786–833 CE) became a center for celestial observation (*rasd*) to test the accuracy of the theories inherited from Ptolemy (Blake, 2016). Al-Battānī, in his *al-Zīj al-Ṣābiʻ*, corrected the length of the tropical year and the position of the solar apogee using systematic observation methods (Mozaffari, 2019). In the 13th century, the Maragha Observatory, led by Naṣr al-Dīn al-Ṭūsī (1201–1274 CE), developed mathematical models such as the Tusi Couple and Urdi Lemma to correct anomalies in the Ptolemaic system without abandoning the geometric structure of the cosmos. Tools such as the astrolabe, mural quadrant, and armillary sphere were not only technical instruments, but epistemic instruments that allowed for data verification and generated new *zīj* used for the calculation of the direction of the *Qibla* and the calendar (Memmedova, 2024).

The development of astronomy cannot be separated from the scientific patronage granted by the Abbasid rulers, although its influence was not linear. Al-Maʻmūn's policy of sending scientists to measure the length of one degree of the earth in the Sinjar desert demonstrates the state's support for scientific experimentation (Şenel, 2025). However, patronage was not only in the form of material facilities, but also epistemic legitimacy that allowed astronomy to develop as an autonomous discipline alongside fiqh and *kalām*. Al-Bīrūnī (2002), in *al-Qānūn al-Mas'ūdī*, demonstrated freedom of criticism of Ptolemy, an indication that patronage opened up space for scientific debate. However, the Mihnah phase also demonstrates that power relations can be intervening (Aniq, 2023). This confirms that the progress of astronomy arose from the dialectic between political authority and academic autonomy, not simply financial protection.

With the close interaction between scientific institutions, methodological innovation, and the support of power, Islamic astronomy entered a stage of maturity as a scientific discipline that went beyond mere adoption. The integration of the *zīj* table, the theory of planetary motion, and the practice of determining the direction of the *Qibla* became the basis for the development of modern astronomy. The uniqueness of Islamic astronomy lies in its success in combining mathematical deduction with sensory observation to achieve scientific certainty, an epistemic orientation not found in Hellenistic astronomy. The foundations laid during this period served as the starting point for astronomy's contributions to determining the direction of the *Qibla* and establishing the Hijri calendar, demonstrating the practical dimension of this science within the Muslim religious sphere.

The Contribution of Astronomy in Determining the Direction of the *Qibla*

Since the early spread of Islam, the direction of the *Qibla* has been determined by the need for worship orientation, which requires precise orientation of the Kaaba (Schumm, 2020). The initial phase of *Qibla* determination relied on empirical observations of natural phenomena, such as the direction of sunrise and sunset or the positions of the stars *Suhayl* (Canopus) and Polaris (Akbar & Mustaqim, 2022). This approach was intuitive and local, not yet based on a global coordinate system (Kohar, 2025). A significant transformation occurred during the golden age of astronomy, when scientists began to formulate the direction of the *Qibla* through mathematical and astronomical approaches, as documented in *zīj* and astronomical treatises (King, 2024). This shift from indicative to computational methods marked the unification of worship traditions with systematic scientific discipline.

Spherical trigonometry formulas are the primary foundation for determining the direction of the *Qibla*. Astronomers define the *Qibla* as the azimuth angle between a location and the Kaaba based on the difference in latitude and longitude (Kabir et al., 2022). The spherical equation illustrates the basic principle:

$$tan\ Q = \frac{sin(\Delta\lambda)}{cos\varphi 1 \cdot tan\varphi 2 - sin\varphi 1 \cdot cos(\Delta\lambda)}$$

$$\left(\begin{array}{c} Q\ as\ the\ angle\ of\ the\ Qibla, \varphi^1 the\ latitude\ of\ the\ location, \\ \varphi^2 the\ leeway\ of\ the\ Kaaba, and\ \Delta\lambda\ the\ difference\ in\ longitude \end{array} \right)$$

With this formulation, determining the *Qibla* no longer relies on geographical intuition but can be scientifically replicated across regions (Armienti & Venger, 2018). The application of this calculation has impacted mosque architecture in various Islamic cities; for example, the reconstruction of the *miḥrab* direction in the Mosque of Cordoba and the correction of the *Qibla* direction in mosques in Fez and Cairo in the 10th and 11th centuries demonstrate how astronomical disciplines influence religious spatial planning (Bonner, 2016).

In addition to mathematical calculations, astronomical observations, particularly the *istiwā‘ a‘ẓam* phenomenon, serve as a means of field verification (Zaki, Nawawi, Wahab, & Niri, 2019). When the sun is directly overhead the Kaaba on May 27–28 and July 15–16, the shadows of upright objects worldwide will point toward Mecca (Zhang, Liang, & Wang, 2019). This phenomenon serves as a direct observational instrument used to correct deviations in the direction of the *Qibla*. At night or under cloudy conditions, astronomers use constellations such as Canopus in the southern hemisphere and Polaris in the northern hemisphere to determine geographic directions (Zhang, Song, & Wu, 2022). The reliability of this observational method is strengthened by classical astronomical instruments such as the astrolabe, *rubu‘ mujayyab*, and *mizwala*, which allow for precise measurements of the sun's altitude and stellar declination (Hidayat, Rakhmadi, & Putraga, 2022).

Al-Battānī made a monumental contribution through his work *Kitāb al-Zīj al-Ṣābi‘*, in which he revised the astronomical data of Ptolemy and Hipparchus with new observations. He compiled tables of solar declination and ecliptic shifts that became references for calculating the direction of the *Qibla* (Mozaffari, 2025). One of his innovations was the application of the concept of spherical triangulation to determine the large circular distance between two points on the Earth's surface, which was then applied to calculate the direction of Mecca from Baghdad, Damascus, and Kufa (Aziz & Musta'id, 2022). Al-Battānī's *Zīj* became the primary reference for *muwaqqit* (prayer time managers) in the great Abbasid mosques (Saliba, 1995). In this context, al-Battānī was not only an astronomer but also the developer of a theoretical methodology that linked sacred space with cosmological coordinates.

Al-Bīrūnī further developed and refined this scientific tradition by integrating geodesy and astronomy. In *Tahdīd Nihāyāt al-Amākin* and *al-Qānūn al-Mas‘ūdī*, he formulated a procedure for determining the *Qibla* by combining the latitude and longitude of a location and the circular distance of the earth in the concept of the great-circle direction (Al-Bīrūnī, 1995; Al-Bīrūnī, 2002). Unlike al-Battānī, who emphasized tables, al-Bīrūnī introduced the method of triangulation and geodetic measurements through observations of mountain heights and the curvature of the earth (Ahn & Juraev, 2024). He emphasized the importance of accurate geographical data, writing: "An error of one degree of latitude deviates the direction of the *Qibla* by the distance of a day's journey" (Al-Bīrūnī, 1995; Al-Bīrūnī, 2002). His contribution ensured that the direction of the *Qibla* was not localized, but universal for the entire Islamic world, including Andalusia, India, and Central Asia (Kohar, 2025).

Al-Khwārizmī played a key role in the mathematical design of the *Qibla* direction. Through *al-Zīj al-Sindhind* and his arithmetic treatises, he introduced the decimal and algorithmic number systems, simplifying the *Qibla* calculation process (Dalen, 2014). His use of the sexagesimal (base 60) system for measuring angles facilitated the conversion of astronomical angles into practical directions (Wang, Ma, Cao, Luo, & Li, 2024). His algorithms transformed complex calculations into systematic steps that could be implemented by *muwaqqit* (Islamic scholars) without advanced theoretical skills (Burbano, 2025). This innovation paved the way for the standardization of *Qibla* calculations in madrasas and observatories, such as the Bayt al-Ḥikmah in Baghdad and the Maragha Observatory in Persia (King, 2021).

To clarify the epistemological shift from the traditional approach to astronomical science, the following table is presented as a methodological comparison:

Table 1.
Comparison of *Qibla* Direction Determination Methods: Traditional vs. Scientific Astronomy

Aspects of Determining the *Qibla*	Traditional Method	Classical Astronomy Method
Instrument	Natural estimates (sun, stars)	*Astrolabe, rubuʿ mujayyab*
Calculation Basis	Intuition and habit	Spherical trigonometry and coordinates
Accuracy	Relative (± a few degrees)	Precision (≤ 1 degree)
Validation	Not standardized	*Istiwāʿ aʿẓam* and *zīj* tables
Application	Directions to local mosque	Cross-regional correction (Córdoba, Baghdad)

The collective contribution of astronomers in determining the direction of the *Qibla* demonstrates the complete integration of astronomy, mathematics, and the practice of worship. Astronomical knowledge extends beyond theoretical formulations to the correction of mosque orientations and the development of instruments for measuring direction. This tradition laid the foundations for Islamic geodesy, which in turn became the precursor to modern technologies such as theodolites and GPS systems. The transformation of the *Qibla* determination method from simple observation to a global coordinate system demonstrates that Islamic civilization developed an epistemology of worship based on scientific rationality. Thus, astronomy serves not merely as a ritual enhancer but as a scientific medium connecting sacred space with the map of the cosmos.

The Role of Astronomy in Determining the Hijri Calendar

Astronomy during the golden age of Islam served not only as a spiritual tool for determining the beginning of the religious month but also as a scientific discipline with an epistemological foundation that integrated empirical observation and mathematical calculations (Fitra, 2023). The establishment of the Hijri calendar during the Abbasid period and afterward underwent significant transformations along with the debate between the *rukyat* (observational) and *ḥisāb* (computational) approaches. *Rukyat* refers to sensory testimony of the crescent moon and is rooted in the Islamic jurisprudential tradition (Koto, Hati, Manurung, & Siregar, 2024), while *ḥisāb* relies on predicting the geometric position of the moon using astronomical calculations (Lusdianto, 2024). This paradigm shift is important to demonstrate that the Hijri calendar was not born solely from theological intent, but through a process of scientific rationalization pioneered by astronomers.

The advancement of *ḥisāb* theory demonstrated the ability of Muslim scientists to translate celestial motion into testable and repeatable mathematical formulations (Manzil, 2018). *Ḥisāb* did not stop at calculating the elongation or altitude of the moon alone, but included a synthesis of spherical trigonometry and ecliptic dynamics (Lusdianto, 2024). For example, the altitude of the crescent moon (h) relative to the horizon can be calculated using a simple formula used in classical astronomical tables:

$$H = arctan(sin(A) / (cos(A) * sin(\varphi) - tan(\delta) * cos(\varphi)))$$

Description: H (moon altitude), A (moon azimuth), φ (latitude), δ (moon declination).

This formula is used to determine the likelihood of the crescent's visibility before *rukyat* is performed, so *ḥisāb* does not replace *rukyat*, but provides a scientific projection that can be empirically verified (Manzil, 2018). In some Islamic kingdoms, the two were integrated: *ḥisāb* was used for prediction, while *rukyat* was used for confirmation (Manzil, 2018). This epistemological tension marks the maturity of astronomy as a bridge between religious belief and scientific demonstration.

Al-Khwārizmī's contribution was an important milestone in the preparation of astronomical tables (*zīj*) used for calendars. In his work *Zīj al-Sindhind*, he adapted Indian (*Siddhānta*) and Greek astronomy into a coordinate system relevant for the Islamic calendar (Faizah & Binti Roslan, 2023). He introduced the use of trigonometric functions, such as sine (*jāyb*) in place of the Indian bowstring, to calculate the height of the crescent moon and conjunction (Al-Rajab, Loucif, & Al Risheh, 2023). An example of a sine table contained in *Zīj al-Sindhind* shows the values:

Corner (°)	**Sine (*jāyb*)**
30°	0.5
45°	0.707
60°	0.866

Source: (Kennedy, 1956)

Within the calendar framework, al-Khwārizmī compiled tables of *ijtimāʻ* (lunar-solar conjunctions) to determine the beginning of the month. One of his significant contributions was the establishment of *taqwīm muḥtasab*, a computational calendar that eliminates the need for *rukyat* (Richichi et al., 2018). This was a milestone in the epistemic shift: from an observational calendar (based on testimony) to a predictive calendar (based on calculation). However, al-Khwārizmī accepted rukyat but rather positioned it as a verification of theoretical systems (Faid, Nawawi, Saadon, Ahmad, & Mat Zin, 2022). His work marked the integration of Indian, Persian, and Greek heritage within the Islamic astronomical tradition.

Ibn Yūnus (950–1009 CE), in his work *Zīj al-Ḥākimī*, compiled over 10,000 entries on the movements of the sun and moon based on observations in Cairo (Tolkah, Nurkhanif, & Safiai, 2024). These tables not only contain numerical data but also methods for error reduction (*ta'dīl*) through interpolation (Nurkhanif, Muttaqin, Imron, & Ahmad, 2022). For example, Ibn Yūnus's tables list the following daily elongation values:

Day	Sun-Moon Elongation (°)
1	12.5
2	24.8
3	37.1

Source: (King, 2004)

Such data allows for the determination of the beginning of the month without requiring visual evidence, while minimizing regional differences. Contrary to the narrative claim that it "transcended Europe," its significance lies in the integration of observation and prediction, allowing the Hijri calendar to be projected across the geographically diverse Islamic territories (King, 1988). This methodological innovation demonstrates that the calendar was not determined theologically, but by verifiable astronomical data.

The peak of systemization occurred during the era of Naṣīr al-Dīn al-Ṭūsī through *Zīj Īlkhānī* at the Maragha Observatory (Memmedova, 2024). Armed with instruments such as the mural quadrant and armillary sphere, al-Ṭūsī introduced a correction model to Ptolemy's theory through the Tusi Couple, which allowed for the simulation of lunar motion without excessive epicycles (Raina, 2025). This model enhanced crescent prediction by dynamically adjusting longitudinal and latitudinal data (Ehgamberdiev, 2025). For example, it used the principle of crescent visibility:

$$(The\ crescent\ moon\ is\ visible\ if: h > 5\circ\ and\ E > 8\circ)$$

Description: h is the height of the moon at sunset, and E is the elongation of the moon.

This parameter provides the scientific basis for distinguishing between the "existent crescent" (*wujūd al-Ḥilāl*) and the "visible crescent" (*imkān al-Rukyat*), a debate that continues to be a major issue in the global calendar. This model had a direct impact on the Hijri calendar by providing corrections for the conjunction and elongation of the crescent, which were previously unaccounted for (Poskett, 2022). Al-Ṭūsī's methodological boldness demonstrated that the calendar could not be maintained solely through static calculations but must be continuously updated in accordance with celestial dynamics.

The existence of the Hijri calendar during the golden age of Islam had a significant impact on social life. The calendar became a tool for coordinating public policy: determining the start of Ramadan determined the distribution of *zakat*, while Zulhijjah regulated the mobilization of Hajj pilgrims from various regions (Garosi, 2023). Throughout the 10th to 13th centuries, discrepancies in sightings between Baghdad and Andalusia often resulted in a one-day difference in the celebration of Eid al-Fitr, prompting the caliphs to intervene politically and standardize the calculation (Gharaybeh, 2025). In Mamluk Egypt, the qadi even issued decrees to adopt the calculation calendar when weather prevented sightings (Mahamid, 2023). This demonstrates that the Hijri calendar had become a state project requiring scientific legitimacy to maintain legal and economic order.

Thus, the role of astronomy in establishing the Hijri calendar during the Golden Age of Islam reflects the unique synergy of Islamic civilization: theology as a normative foundation, astronomy as a predictive tool, and administration as a vehicle for implementation. *Ḥisāb* and *rukyat* were not opposed, but rather interwoven within a network of scientific institutions such as the Baghdad and Maragha observatories. The presence of *zīj* works was not merely an individual achievement, but rather a collective manifestation of the scientific community's commitment to maintaining the order of space and time. The Hijri calendar, born from this tradition, was not merely a calendrical tool but a cosmological instrument that maintained humanity's connection to the divine cycle and a knowledge-based social order.

The Relevance of Astronomy to the Development of Modern Science

The journey of astronomy from the Islamic world to the modern scientific stage cannot be understood simply as the transfer of astronomical data, but as a complex process of epistemological transmission. Andalusia, particularly the scientific centers of Toledo, Córdoba, and Granada, became a crucial node in this transfer of knowledge through the movement of Arabic manuscripts translated into Latin in the 12th century (Ainiyah & Setiawan, 2024). Manuscripts such as al-Battānī's *Zīj al-Sābiʻ*, the Latin version of *al-Ṣābiʻi's Zīj al-Ṣābiʻi* (De Scientia Stellarum), and al-Zarqālī's astronomical tables (1029–1100 CE), later known as the Toledan Tables, provided the computational foundation that European scientists used to correct the Ptolemaic system (Toomer, 1987). David A. King (2024) and George Saliba (2007) demonstrate that European astronomers not only borrowed data but also absorbed the observational methodologies and mathematical corrections developed within the Islamic astronomical tradition.

The profound influence of astronomy is evident in the foundations of Nicolaus Copernicus's heliocentric theory. Ragep's (2007) study reveals that the Tusi Couple model introduced by al-Ṭūsī in his treatise *al-Tażkira fī ʻIlm al-Hayʻa*, as well as the planetary motion model of Ibn al-Shāṭir (1306–1375 CE) of Damascus, have nearly identical geometric correspondences to illustrations in Copernicus's De Revolutionibus Orbium Coelestium. Although Copernicus does not explicitly cite Arabic sources, researchers suspect that he accessed translated manuscripts through a network of Italian and Greek scholars who had access to Byzantine library collections (Henry, 2017). Academic controversy exists as to whether these similarities represent direct transmission or independent reconstruction. Nevertheless, the kinematic structure proposed by Islamic astronomy provides an alternative cosmological model that would later become a pillar of the European scientific revolution (Blake, 2016).

Traces of the astronomical legacy can also be found in the work of Johannes Kepler, although he is better known for his reformulation of elliptical orbits. The high-precision observational data from al-Battānī's tables—particularly regarding the length of the tropical year and the shifts of the equinoxes—were critically used by 15th-century European astronomers as a standard correction before the Rudolphine Tables (Chabás & Goldstein, 2015). Otto Neugebauer (1975) and Noel Swerdlow (1973) note that although Kepler did not cite Muslim scholars directly, he worked within the computational tradition established by generations of Islamic astronomers through the compilation of the Toledan and Alfonsine Tables. A crucial point often overlooked is that Kepler's revolution would not have been possible without the observational discipline inherited from the entire astronomical tradition. In other words, European astronomers continued the relay of cosmological measurements and criticism that Muslim scientists had practiced in rearranging the order of the heavens (Americo, 2024).

The relevance of the astronomical heritage does not end in history but lives on in contemporary Islamic civilization through the application of precision astronomy-based technology. The principles of triangulation, azimuth coordinates, and spherical trigonometry—developed in classical astronomy—are now the core algorithms for GPS-based and satellite-based *Qibla* direction-finding applications (Abosekeen, Noureldin, & Korenberg, 2020). In compiling the global Hijri calendar, institutions such as the *Majma' al-Fiqh al-Islāmī* and the Muslim World League utilize modern astronomical ephemeris, essentially continuing the work of astronomical calculations (Royyani et al., 2023).

At the epistemological level, the legacy of astronomy offers important lessons about the dialogue between religion, mathematics, and empirical observation. Astronomy demonstrates that the Islamic intellectual tradition has never separated spiritual devotion from rational inquiry. However, modern challenges test whether astronomy can evolve into a branch of astrophysics and celestial mechanics or remain confined to ritual functions. In the digital age, as artificial intelligence begins to be used for crescent moon simulation and millisecond accuracy of the *Qibla* (Al-Rajab et al., 2023), astronomy is required to expand its ontological horizon, from determining the direction of prayer to participating in a global conversation about the nature of time and the universe. Thus, the legacy of astronomy is not merely a nostalgic legacy of glory, but an epistemological asset that provides direction for the future of science.

Conclusion

Astronomy during the Islamic Golden Age, from the 8th to the 14th centuries, played a crucial role in bridging the interests of worship and the development of science, with tangible contributions through the refinement of observational methods, the use of astrolabes, the measurement of sun shadows, and the compilation of astronomical tables to more accurately determine the direction of the *Qibla* and the Hijri calendar. Theoretically, this study confirms that the integration of religion and science not only enriches Islamic epistemology but also demonstrates that religious practices can drive astronomical progress and influence global scientific traditions. Practically, the relevance of astronomy remains evident in the determination of the global *Qibla*, the compilation of the international Hijri calendar, and its contribution to the development of modern cosmography and navigation. However, this study is limited by the restricted access to classical manuscripts and the uneven distribution of historical sources, which means the analysis does not fully encompass the variations in astronomical traditions across Islamic regions. Future research should expand the study of primary astronomical manuscripts, conduct methodological comparisons with contemporary astronomy, and explore the potential for further digitization to strengthen the integration of astronomy with modern scientific developments.

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