Celestial Epistemology:

A Select Historical Exploration of Astronomical Knowledge in Islamicate Societies

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What kind of knowledge was astronomical knowledge in premodern Islamicate societies? It is generally well-known (and correctly so) that the astronomical tradition in Islam was both diverse and dynamic, informing the culture it belonged to while simultaneously being shaped by it. The intricate interplay between the role of astronomy as a practical tool for religious observance and its deep-seated connections with theological, philosophical, and scientific thought created a tapestry rich in significance and meaning. This paper explores this tradition, aiming to cast light on a few important historical nodes of change and continuity concerning the notion and nature of astronomical knowledge in the premodern Islamic milieu. The primary intention is to delve into some of the various threads that constitute this intellectual fabric, emphasizing the multifaceted nature of astronomy as a utilitarian discipline and a realm for profound contemplation and theoretical reflection, as well as examining its evolving relationships with rational theology (*kalām*), metaphysics, and natural philosophy.

The Utilitarian Nexus of Astronomy

From the early days of Islam, the practical utility of astronomy for the new religion was clear and cherished. Astronomical knowledge, in the form of extensive tables and techniques, was utilized to solve a set of interesting computational problems resulting from the practical requirements of the Islamic faith. The simple command to pray *ṣalāt al-ʿaṣr* (afternoon prayer), a command linked with knowing the shadows, meant it was tied to an astronomical phenomenon, and hence mathematical geometry. Similar utilitarian concerns such as the need to face Mecca every time one prays, ascertaining the visibility of the crescent moon (to verify the beginnings of the lunar month), or calculating the times of sunrise and sunset (to know the times of fasting) required solving some of the most sophisticated spherical trigonometric problems of its time, creating, in turn, a particularly fertile milieu for astronomy.

On one hand, these practical considerations allowed for significant refinements to the mathematical techniques appropriated from the Greeks, leading, for example, to the invention of several new trigonometric functions and laws; on the other, it enabled a space for astronomical knowledge in religious education and institutions, thereby lending such knowledge a formidable degree of social legitimacy and prestige. Eventually, it led to the introduction of astronomy in the curriculum of several *madāris* (Islamic seminaries) throughout the Muslim world and the establishment of the position of a *muwaqqit* or timekeeper in large mosques. One notable example is, of course, Ibn al-Shāṭir (d.

776/1375), who worked as a *muwwaqit* in the Umayyad mosque in Damascus in the eighth/fourteenth century and is credited with constructing a sundial for its minaret as well as devising innovative models for the motion of Mercury, which would later intriguingly appear in the works of Copernicus. Ultimately, this inclusion of astronomical knowledge within religious institutions allowed a more public and favorable image of astronomical knowledge in society.

Astronomy within the Web of Knowledge

Practical religious concerns were only one side of the story. Ptolemy (*fl*. 2nd c.)—arguably, the single most influential figure of ancient and medieval astronomy—is well-known today for composing the *Almagest*, a Greek-language astronomical treatise on the motion of the stars and planetary paths. It would prove to be one of the most significant scientific texts of its time, canonizing the geocentric model of the universe that would be accepted for more than twelve hundred years across the cultures of late antiquity, the Islamic world, and early modern Europe. Less well-known, though, is *Tetrabiblos*, a work Ptolemy wrote on the philosophy and practice of astrology, in which he had fully endorsed astrology. When Ptolemy and his legacy were appropriated within the Islamic milieu, many quickly developed an appreciation and respect for the mathematical-astronomical tradition of the *Almagest*, seeking diligently to refine it further; however, the astrological pursuits came under fateful criticisms from several quarters of society, the criticisms being motivated by a wide array of considerations, which were not always religious.

Indeed, a notable Hellenized philosopher and an early figure like al-Fārābī (d. ca. 339/950) could critique certain forms of astrology on scientific and philosophical grounds. Yet, while departing significantly from his Greek predecessors through his critical assessments, he did not go as far as fully separating astronomy from astrology. In his classification of the sciences, he used *ʿilm al-nujūm* (the science of the stars) to designate astronomy in its widest sense, subsuming both mathematical astronomy and astrology under this overarching discipline.[1] It would be al-Fārābī's influential successor, Ibn Sīnā (d. 428/1037), who would proceed to precisely articulate such a total and complete separation between astronomy and astrology, by replacing *ʿilm al-nujūm* with *ʿilm al-hayʾa* (the science of the configuration) as the general term for the discipline and discarding astrology entirely from what was beginning to take shape as the new, reformulated astronomy. *ʿIlm al-hayʾa*, this reformulated astronomy expunged from astrology, would eventually become the distinctive science *par excellence* for the later astronomers.[2]

Yet, while astronomy was successfully extricated from its connections with astrology, negotiating its broader relationship with metaphysics and natural philosophy seemed less clear. Indeed, the general issue of how to situate the mathematical sciences within the full spectrum and hierarchy of the philosophical sciences was an old one, with lively debates extending back to the early Greeks. Both Plato and Aristotle, in varying ways, had prized metaphysics and theology over and above mathematics. Later, Ptolemy, crucially, challenged the conventional hierarchy, placing mathematics at the summit of the philosophical edifice, above both metaphysics and physics. For Ptolemy, physics and metaphysics were closer to guesswork than to knowledge, for the objects of physics are always changing and hence unstable, while the objects of metaphysics are invisible and ungraspable. Only objects of mathematics, he held, enjoyed both constancy and accessibility and therefore qualified for certain knowledge.[3]

The debate continued in the Islamic context, generating several responses on determining the relative worth of mathematical knowledge compared to the knowledge found in other disciplines. For many, particularly the philosophically minded, metaphysics reigned supreme. The classical topos of mathematics as an "instructional" (*taʿlīmī*) and "training" (*rīyāḍī*) science appeared to reflect this image of mathematics as somewhat of a preparatory exercise for those intending to begin their pursuit of the presumably higher philosophical sciences. And yet there were others, particularly in the postclassical Central Asian circles, like the fourteenth century Samarqand astronomer and *mutakallim*, Sayyid Sharīf al-Jurjānī (d. ca. 816/1413), who could consider mathematical sciences (arithmetic and geometry) to be superior to metaphysics and natural philosophy, holding the former's conclusions to be more certain, its principles to be more primary, and its rules more universal, in turn, allowing it to formulate proofs that could be utilized in other sciences.[4]

Navigating Boundaries: Astronomy and the Natural Sciences

Astronomy's relationship with the natural sciences (Aristotelian natural philosophy or physics) came to be negotiated in the context of two distinct issues which apparently seemed to pull in opposing directions. Although Islamic astronomers made celestial objects a subject of astronomy, they did not thereby make astronomy a branch of natural philosophy (or physics). This is already evident in the early classificatory scheme of al-Fārābī, which, by situating astronomy among the mathematical sciences, clearly demarcated it from the physical and metaphysical sciences. In a move that would be followed by practically all succeeding Islamic astronomers, al-Fārābī, following his Greek predecessors, formally positioned astronomy as a science that studied the exterior aspects of the celestial bodies pertaining to their shapes, sizes, positions, and motions.[5] The largely qualitative features of the bodies pertaining to their substances, natures, and intrinsic properties were investigated under the discipline of natural philosophy, thus lying outside the purview of astronomy. In this way, astronomy and natural philosophy, though sharing a common subject, were differentiated in terms of the way each approached it. Already, there was a clear concern for the need to eschew unnecessary conflation between both disciplines and maintain a sense of disciplinary boundary and integrity.

In drawing this methodological distinction, Islamic astronomers, though, were not breaking new ground, for the idea, in its main outlines, can be traced back at least to the commentarial tradition of late antiquity. Instead, their contribution lay in appropriating an existing position among a set of competing views, forging it more fully than their predecessors, and providing it a sense of stability by fully integrating it into the larger tapestry of knowledge itself. Indeed, this basic position of methodological distinction endured through successive generations, even as the details were being continuously refined, and eventually came to be canonized in the form of the Persian polymath and astronomer Nasīr al-Dīn al-Ṭūsī's (d. ca. 672/1274) astronomical masterpiece, *Tadhkira fī ʿilm al-hayʾa* (A Memoir on Astronomy), a treatise which became the mainstay for the later *haʾya* practitioners. Astronomy, in this presentation, was clearly and cleanly demarcated from natural philosophy both in its subject and method. Astronomy investigated the external appearances of simple bodies, utilizing proofs that were *inniyya*, a demonstration that gives "the fact that" (*inna*) something is the case based on observationally-related evidence and reasoning. Natural philosophy, conversely, studied the essential and intrinsic natures of the bodies, employing *limmiyya* proofs, a demonstration that gives "the reason why" (*lima*) something is the case by relying on a more *a priori* reasoning to furnish the real (physical or metaphysical) cause.[6]

It is important to note that although al-Ṭūsī conceived of a disciplinary separation between astronomy and natural philosophy, he crucially was not willing to dispense with natural philosophy altogether. Indeed, he regarded sense perceptions, empirical observations, experience, and mathematical techniques as important features of the astronomical method. Yet, he also held that, taken together, these tools alone would prove insufficient to solve all the problems of astronomy. Instead, astronomers must additionally borrow certain physical principles from natural philosophy to fully account for the celestial motions and their causes. Perhaps the most significant was the principle of the earth being stationary at the center of the universe—a principle, which, al-Ṭūsī held, had to be assumed by astronomy to launch its model-making enterprise, and which was ultimately taken to be proved in natural philosophy.[7] Overall, it meant that astronomy depended on another science for at least some of its key principles and was therefore not an entirely autonomous and self-contained discipline.

Al-Ṭūsī's position was again not something entirely novel but drew on the late antiquity discussions which extended back to Ptolemy and Aristotle himself. Interestingly, this position did not go unchallenged in the Islamic context. Key individuals such as al-Bīrūnī (d. ca. 442/1050) and later ʿAlī al-Qūshjī (d. 879/1474) argued that astronomy could, in principle, and even should, be completely divorced from natural philosophy and be established self-autonomously using its own principles.[8]

Meanwhile, in the Islamic West, a diametrically opposing view had emerged earlier associated with the Spanish Aristotelians of the sixth/twelfth century, which was a minority view by al-Ṭūṣī's time, that asserted the Ptolemaic system was fundamentally false, and a system based on the homocentric spheres which would fully satisfy the criteria of Aristotelian natural philosophy and metaphysics could be devised. Yet, despite all the diversity, al-Ṭūṣī's *Tadhkira* encapsulated what came to prevail as the dominant view, according to which, on one hand, a system fulfilling the rigorous criteria of homocentric spheres is unlikely to be attained in astronomy, so the astronomers are well-advised to use the Ptolemaic eccentrics and epicycles in their modeling, but should not tolerate any further compromises to the Aristotelian natural philosophy. On the other hand, astronomy's own tools would be unable to solve all problems, thus necessitating that it borrowed at least some principles from natural philosophy.[9]

Models, Virtues, and Interpretations

A related and important facet of premodern Islamic astronomy was the role of astronomical models and how the *hay'a* practitioners interpreted them. Model-making, of course, lies at the heart of astronomy, and arose from the need to harmonize the discrepancy between the requirements of physics—the key principle that all celestial bodies must possess uniform circular motion—and the facts given through observations—the apparent irregular motion of planets as witnessed in the sky (speeding up, slowing down, turning back). The task of astronomers was precisely to base the apparent irregular motions on such models that could bring about uniformity of the motion in itself and its irregularity with respect to the observer. I have shown elsewhere that Islamic astronomers, particularly since the seventh/thirteenth century, explicitly understood the models to meet two core conditions.[10] First, a model must be able to adequately account for the phenomena, that is, it should be accurate in systematizing and predicting the apparent positions and motions of the celestial bodies. In modern parlance, a model should be empirically adequate. Second, it should be consistent with an understanding of celestial bodies as physical objects that properly obey certain physical principles, most importantly, that of uniform circular motion. In other words, it should be physically consistent.

The astronomers knew that these two conditions, undergirding the model-making endeavors, did not, however, always lead to a unique solution or a model. Indeed, Ptolemy had long before conceded the point that sun's irregular motion could be accounted for equally well by utilizing the epicycle (sun revolves on a circle the center of which revolves around the earth) or the eccentric model (sun revolves on a circle with a center not at the earth). Both were geometrically equivalent: one could be obtained from the other by a set of mathematical operations. They were also observationally equivalent: both produced the same observable motion of the sun with respect to the background of the fixed stars. Yet, interpreted realistically, they were inequivalent. In general, the Islamic astronomers were willing to entertain any of the multiple models provided it met both conditions, which meant that they were disposed towards viewing the models as mathematical tools, rather than actual descriptions of the world.

This, of course, leads to an immediate and pressing question: given two observationally equivalent but physically incongruous models, how (if at all) should one choose between them? Is there an epistemically responsible way of deciding between them? I have shown in another work that the *hay'a* practitioners did indeed choose between rival hypotheses, and on grounds of what we can call theoretical "virtues."[11] Considerations of simplicity, economy, elegance, and parallels with legal reasoning feature prominently in the discussions as the type of virtues which helped guide theory development and theory choice. One can say that the models, while observationally equivalent, were inequivalent with regard to virtue. I will draw on two examples from my study of al-Jurjānī's astronomy to briefly illustrate this point.

Commenting on al-Ṭūṣī's *Tadhkira*, al-Jurjānī asked how many initial orbs would be necessary to account for the motions of the heavens.[12] Al-Ṭūṣī had adhered to the traditional scheme by establishing nine orbs: two orbs for the primary (east toward west) and secondary (west toward east) motion respectively, and seven orbs for the two luminaries (sun and moon) and the five visible planets (Mercury, Venus, Mars, Jupiter, and Saturn). Since the stars did not have additional motion other than the first two, it would suffice to place them on one of the first two orbs (orb for the primary or secondary motion). Al-Ṭūṣī had chosen the orb of the secondary motion as the place of the fixed stars but admitted that their being on multiple orbs was possible. Explaining the reason why the astronomers have not established an excess of orbs for the stars, despite the possibility of it being so, al-Jurjānī said that "what is most appropriate for the noble bodies is that they be devoid of any excess."[13] He added that this reasoning is, of course, not certain, but only plausible. The criterion invoked here can be called the "principle of economy," according to which, when applied in this context, a hypothesis that utilizes the least number of orbs should be preferred.

The second example concerns the relative position of the sun in an earth-centered cosmology.[14] In his commentary, al-Jurjānī first explained that the evidence of parallax and occultation, two of astronomy's stock techniques, shows that the position of the sun is above the moon but below the orb of the fixed stars and the upper planets (Saturn, Jupiter, Mars). Beyond this, however, its position relative to Mercury and Venus remains unclear. Owing to the two planets' close proximity to the sun, the techniques of parallax and occultation, for various reasons, could not be applied here, so the astronomers had to content themselves with only a plausible, rather than a certain, solution. Ultimately, al-Jurjānī, following al-Ṭūṣī, positioned the sun in the middle orb below the upper three planets and above the lower three bodies (Venus, Mercury, moon). Considerations of appropriateness (*istiḥsān*) justified the move this time, according to which the sun's medial position was the most elegant, like a "pendant in the middle of the universe."[15] Unlike the principle of economy, which may appear to have a grounding in theology or metaphysics, *istiḥsān* (literally, viewing something good, preferable, and beautiful) was properly a technical term in Islamic legal theory (*uṣūl al-fiqh*), referring to the concept of juristic preference for one ruling over the other based on some recognized proof. Using arguments from elegance to place the sun in the middle was common enough since late antiquity. The key point is that these Islamic astronomers could draw parallels with legal reasoning to ground the elegance of the cosmos.

Theological Undercurrents and Contingent Principles

The possibility of multiple models was but one aspect that highlighted the contingency of astronomical conclusions. Another equally important, and intriguing, facet involved understanding the status of some of the physical principles that needed to be assumed in astronomy to launch the model-making enterprise. I have shown in another work that some astronomers, especially those who were also *kalām* (rational theology) practitioners and had Ashʿarī leanings, could use a discourse about divine omnipotence to question the necessity of some physical principles.[16] In the *Sharḥ al-Mawāqif*, viewed as a key work of postclassical Ashʿarī *kalām*, al-Jurjānī, writing as a *mutakallim*, had argued that all existents are attributed to God without any necessity or necessitating. Thus, it is possible, for example, that the sun could move gradually around its orbit, while the shadows on the earth remain stationary, for both the motion of the sun and the shadows are attributed to God, who is a free agent. Yet, it is God's *ʿāda* (habit), he said, that ensures otherwise, and functions as the ground for regularity in daily events.[17] The concept of God's *ʿāda,* of course, famously traced back to al-Ghazāli (d. 505/1111) (and even earlier), who had utilized it as a bulwark against the necessitarianism embedded in the Avicennian notion of causality, in a move to preserve the religious tenets of divine omnipotence and the possibility of miracles.

In his commentary on al-Ṭūṣī's astronomical treatise, *Tadhkira*, al-Jurjānī appears to display these theological sensitivities in subtler ways. Examining the physical principles required in the astronomy of his time (such as the perpetuity of the motion of the orbs, the impossibility to produce a rectilinear motion in celestial bodies, the impossibility of void, and the simplicity of the orbs), he takes care to highlight that these are affirmed as principles "according to the philosophers."[18] As physical considerations (as opposed to mathematical), these principles appear to posit a certain necessity about the real world, precluding that God can, for example, produce a rectilinear motion in celestial bodies, if He so desires. Accordingly, al-Jurjānī may have felt compelled to point out that they are principles specifically for the philosophers; that they are not universal, first principles, the kind of which are evident and accepted by all without any debate. The intention appears to be to target the implicit assumption that the principles are necessary and instead to highlight some contingency about them. It is important to note, however, that al-Jurjānī does not explicitly reject or implicitly deny them, nor does he attempt to provide an alternative, opposing view. In other words, he remains faithful to the main text, interested in providing a commentary (*sharḥ*), not a calumny (*jarḥ*).

If this interpretation is correct, it brings clarity to how theologically minded astronomers like al-Jurjānī could negotiate two different traditions: on one hand, al-Jurjānī remains largely faithful to the commentary tradition of al-Ṭūṣī's astronomy by *granting* the principles, which he would have seen as required (and rightly so) to proceed with the task of cosmography. On the other hand, he reflects the Ashʿarī view of science by pointing to the contingency of the principles, thereby preserving the possibility that on these issues (physical considerations of astronomy) reality can be otherwise, if God so desires. Accordingly, the principles should be viewed in a deflationary sense, not as necessary or intrinsic facts of reality, but as regulative in nature, whose cessation at some time is not impossible, but whose acceptance is a condition for the possibility of successful astronomical research.

Cultivating Awe Through Astronomical Inquiry

In conclusion, it is worth highlighting that knowledge as a means of glorification of God is a recurrent theme that runs throughout Islamic culture. Yet perhaps only a few disciplines could claim to surpass astronomy in terms of serving as a catalyst for contemplation and awe and providing its practitioners the ability to meaningfully glorify God through His creation. The closing reflection of al-Jurjānī resonates with the ethos of the pursuit—a bridge between scientific inquiry and spiritual reverence, reinforcing the intrinsic connection between knowledge, wonder, and the glorification of God:

> "Indeed, rational demonstrations and transmitted reports prove that the highest level a person can aspire to, in their quest for reaching the pinnacle of perfection and the loftiest rank of felicity, involves attaining knowledge (*mʿarifa*) of the Creator—exalted is He—in terms of the exaltedness of His Being and the purity of His attributes. This attainment is realized through contemplation of creation and its mysteries, as well as through reflection upon the objects within it and their [intricate] ways. Astronomy delves into the study of celestial orbs and their shapes, revealing the elements and their states. It serves as an excellent pathway to achieve this goal for those who pursue it by reflecting upon the creation of the skies and the earth. [Ultimately,] this pursuit leads one to exclaim, 'O my Lord, You have not created this in vain.'"[19]

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[2] On al-Fārābī's and Ibn Sīnā's critical assessments of astrology, see Damien Janos, "Al-Fārābī on the Method of Astronomy," *Early Science and Medicine* 15, no. 3 (2010): 237-265, and Jamil Ragep, introduction to *Naṣīr al-Dīn al-Ṭūsī's Memoir on Astronomy (al-Tadhkira fī ʿilm al-hayʾa)*, trans. Jamil Ragep (New York: Springer-Verlag, 1993), vol. 1, 33-36.

[3] Claudius Ptolemy, *Ptolemy's Almagest,* trans. G. J. Toomer (London: Duckworth, 1984), 35-37.

[4] For a detailed discussion of al-Jurjānī's understanding of the mathematical sciences, see Moiz Hasan, "Foundations of Science in the Post-Classical Islamic Era: The Philosophical, Historical, and Historiographical Significance of Sayyid al-Sharīf al-Jurjānī*'s* (d. 1413) Project," (PhD dissertation, University of Notre Dame, 2017), 246-276.

[5] Al-Fārābī, *Kitāb iḥṣāʾ al-ʿulūm*, 58-59.

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[7] Al-Ṭūsī, Naṣīr al-Dīn. *Naṣīr al-Dīn al-Ṭūsī ʾ s Memoir on Astronomy (al-Tadhkira fī ʿilm al-hayʾa)*. Edited, introduced, and translated by Jamil Ragep. 2 vols. (New York: Springer-Verlag, 1993), 106-107.

[8] Jamil Ragep, "Freeing Astronomy from Philosophy: An Aspect of Islamic Influence on Science," *Osiris* 16 (2001): 49-71.

[9] Hasan, "Foundations of Science," 313-316.

[10] Ibid., 348-352.

[11] Ibid.

[12] Ibid., 352-358.

[13] Al-Sayyid al-Sharīf al-Jurjānī, *Sharḥ al-tadhkira*, Damascus, Ẓāhiriyya, MS. 3117, fol. 23a.

[14] Ibid., 363-368.

[15] Al-Jurjānī, *Sharḥ al-tadhkira*, fol. 24b.

[16] Hasan, "Foundations of Science," 380-387.

[17] Al-Sayyid al-Sharīf al-Jurjānī, *Kitāb al-mawāqif bi sharḥ al-sayyid al-sharīf al-jurjānī,* ed. ʿAbd al-Raḥmān ʿUmayra (Beirut: Dār al-Jīl, 1417/1997), vol. 2, 279-280.

[18] Al-Jurjānī, *Sharḥ al-tadhkira*, fol. 3a; for a list of such instances in the treatise by al-Jurjānī and its significance, see Hasan, "Foundations of Science," 380-387.

[19] Al-Sayyid al-Sharīf al-Jurjānī, *Sharḥ al-mulakhkhaṣ,* Istanbul, Ayasofya, MS. 2649, fol. 1b.