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The sciences in Islamic societies (750 1800)

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Introduction

The study of the non religious scholarly disciplines in Islamic societies has mostly focused on elite writings, instruments and, occasionally, images. A vertical historical approach that compares texts, tables or instruments pro duced at different places and times has prevailed over a horizontal approach that situates a scholar within the complex environment of his time and space. The vertical approach favoured the comparison between ancient Greek achievements and those of scientists in Islamic societies. During recent deca des a minority of historians of mathematics have focused on the comparison of achievements by scientists in Islamic societies with those of later Western scholars.

A corollary of the vertical approach is its preference for the study of outstanding achievements over more ordinary ones, the correct over the erroneous and the realistic over the symbolic. Historical questions such as whether mathematicians and astronomers in Islamic societies preferred Greek theories, models and methods over their Indian and Persian counterparts, and if so, why, have been answered primarily by pointing to cognitive superiority (better models, exact methods, more difficult subjects, axiomatic and deduc tive structure) to the neglect of other possible factors involved in such decisions. In contrast, the overarching theme of this chapter is the complex relationships between the work of scientists and physicians and the societies that they lived in.

The expressions *scholarly disciplines* and *science(s)* used in this chapter render the Arabic *ʿilm* (pl. *ʿulūm*). Although there is a strong religious connotation to *ʿilm* in particular, the reader of this chapter should note

1 The section entitled The Islamic aspects of cosmology, astronomy and astrology is written by Robert Morrison.

that this word and its plural were also used to denote other fields of know ledge such as mathematics or astronomy. It is hoped that using its modern equivalents as well as the less value laden term *scholarly disciplines* is a tolerable compromise.

The translation movement

The translation movement was the court sponsored process of massive trans lations of Pahlavi, Sanskrit, Syriac and Greek texts on philosophy, astro nomy, astrology, mathematics, theoretical music, alchemy, magic, divination, human and veterinary medicine, gnomology, princely ethics, agriculture, military science and some history that took place between the second half of the second/eighth and the late fourth/tenth centuries, primarily in Baghdad. Many historians consider this process either exclusively or primarily as the translation of Greek books from the late eighth to the late ninth or early tenth centuries. They see this process as focused upon writings by leading Greek and Hellenistic scholars such as Hippocrates, Plato, Aristotle, Archimedes, Euclid, Apollonius, Diophantus, Ptolemy, Galen and Dioscorides. The motives and objectives that caused this massive cross cultural transfer of knowledge under the first ʿAbbāsid caliphs and their courtiers are seen as answering the practical needs of the new dynasty, among them astrological and medical concerns. Ritual duties of the Muslim community such as praying at particular times and in specific directions are thought to have inspired an interest in various mathematical disciplines. Religious debates that brought together mem bers of various Christian Churches, Manichaean dualists, Mazdakites, Jews and adherents of various Muslim factions left Muslim disputants in an uncomfort able position, as they were unfamiliar with the various tools of pre Islamic philosophical and theological debates. It has been argued that a handful of ʿAbbāsid caliphs promoted enlightened, tolerant and rational values in a politics that was opposed to obscurantism and literalism. Professional and cultural aspirations and the needs of mostly Christian physicians are often seen as the most important single factor that stimulated the translation of Greek texts into Syriac and Arabic.

This concept of continuity, utilitarianism and enlightenment focuses pri marily on the scholarly aspects of the movement and exaggerates the impor tance of some of its contributors. It leaves unexplored the social and cultural factors that sustained two hundred years of heavily financed and highly visible efforts to acquire and transform knowledge of pre Islamic provenance. In 1998 Gutas offered a new perspective that tried to explain the translation movement as a social and cultural phenomenon.[2] The major points he raised seem to be well founded. The survival of Hellenic and Hellenistic philosophy, science and medicine was affected by the rupture between Orthodox Byzantium and Hellenism and by the schisms within the Christian Church.[3] As a result, Nestorian and Monophysite communities in Sasanian Iraq and Iran pursued a substantially truncated practice of Hellenism. Certain Coptic communities outside Alexandria continued to cultivate her metic medical and alchemical teachings. The so called Sabian communities of northern Iraq resisted pressures to abolish their adoration of the planets and taught a mixture of hermetic gnosticism and mathematical astrology. All these communities were freed from Byzantine Orthodox control after the Arab Muslim armies conquered Syria, Palestine, Egypt, Iraq and Iran. The abolition of Byzantium's oppressive control was a major factor behind the cultural possibilities open to the Umayyads and the ʿAbbāsids.

The second major factor was the material improvements that followed the conquests. A new Pax Islamica united territories formerly divided by crown, Church and war. Trade, crafts and agriculture profited from increased secu rity, stability, the repair of irrigation, new crops and the migration of people and husbandry.[4] But the end of Orthodox oppression and the material better ment of life did not bring about a substantial Umayyad translation movement. The locus of the Umayyad caliphate (41 132/661 750) in Byzantine Syria and Palestine with its Greek speaking Orthodox majority among the popula tion did not encourage such a cultural transformation. The few translations into Arabic that occurred under Umayyad rule were undertaken on the initiative of *mawālī* of possibly Persian descent, that is, newly converted clients of Arab tribes, who served as secretaries in the administration, as well as by Arabic speaking Nestorians in Iraq and by unidentified astrologers in the north west of the Indian subcontinent.[5] Some of these translations were already part of the cultural environment of the ʿAbbāsid revolt, which started around 102 3/719 20.[6]

2 Dimitri Gutas, *Greek thought, Arabic culture: The Graeco Arabic translation movement in Baghdad and early ʿAbbāsid society (2nd 4th/8th 10th centuries)* (New York and London, 1998).
3 Ibid., pp. 176 86.
4 Ibid., pp. 11 14, 17 20.
5 Ibid., pp. 25 7; David Pingree, 'Astronomy and astrology in India and Iran', *Isis*, 54 (1963); Mario Grignaschi, 'Un roman épistolaire gréco arabe: La correspondence entre Aristote et Alexandre', in M. Bridges and J. C. Bürgel (eds.), *The problematics of power: Eastern and Western representations of Alexander the Great*, Schweizer Asiatische Studien, Monograph 22 (Bern, Berlin, Frankfurt am Main etc., 1996).
6 See also Gutas, *Greek thought, Arabic culture*, p. 27.

The translation movement was primarily caused by forces that opposed the Umayyad dynasty and sought to restore pre Islamic Iranian rule and splendour. Iranian groups in Khurāsān were among those who fought for this. As part of these efforts and as a result of the slowly changing linguistic patterns in Iran, Iranian members of the anti Umayyad movement, including those who fought for a Sasanian and Zoroastrian revival and hence against any kind of Arab Islamic rule, established translating as one of their political and cultural tools, and drew on Sasanian precedent and anti Macedonian cultural and religious rhetoric.[7]

It has been argued that the Sasanian propaganda of re collecting Zoroastrian scripture, the Avesta, and re translating wisdom shattered by Alexander of Macedonia (d. 323 BCE) and his marauding troops after the defeat of Dara (Darius III, r. 336 331 BCE) did not lead to a broad and sustained cultural process of translating Greek works on philosophy and the sciences. While it is undisputed that such translations took place, their limited number and thematic scope has been seen as an argument against Gutas's view of the importance of the Sasanian model. This argument overlooks that the emphasis of the Sasanian propaganda was first and foremost on religious knowledge. Wisdom and practical secular knowledge came second. Although the disciplinary breadth was substantially smaller than in the later translation movement sponsored by the ʿAbbāsids, Sasanian pro translation propaganda was more than mere propaganda. It reflected historical events and managed to create a cultural climate favourable to translating scholarly writing. The importance of this sort of translation was accepted by Iranian scholars, nobles and priests for several centuries after the fall of the empire itself, including those who already had converted to Islam, as references to the Sasanian politics of translation in the *Denkard* and Abū Sahl ibn Nawbakht's (*fl.* second/eighth century) report in his *Kitāb al nahmūṭān fī l mawālīd* indicate.[8]

It is possible that the historical memory as described in eighth and ninth century Zoroastrian sources such as the *Denkard* might be a construction based on what happened during the ʿAbbāsid rebellion and under the two ʿAbbāsid caliphs, al Manṣūr (r. 136 58/754 75) and al Ma'mūn (r. 198 218/813 33), who were responsible for adopting and implementing the politics of patronising and commissioning translations of Middle and New Persian, Sanskrit, Syriac and Greek books into Arabic. Nevertheless, the fact that

7 Ibid., pp. 47 50.
8 Ibid., pp. 36 7, 39 40. See also Ibn al Nadīm, *The Fihrist of al Nadim*, trans. Bayard Dodge, 2 vols. (New York, 1970), vol. II, p. 651, note 67.

translating was represented as a major cultural tool of the anti Umayyad movement both by its ʿAbbāsid beneficiaries and their Iranian clients is indubitable. In this sense the translation movement owes its origins and cultural force to Zoroastrian imperial ideology. This imperial ideology saw all knowledge as ultimately derived from the Avesta. Knowledge was lost for the Iranians through Alexander's material destruction of the Holy Book. It was transferred to the Greeks because Alexander had ordered the translation into Greek of those parts of the Avesta that he saw fit. From this event, the story concludes, Greek philosophy, science and medicine had their beginnings. Rulers of the two subsequent Iranian dynasties, the Arsacids (284 BCE 226 CE) and the Sasanians (226 642 CE), are remembered with declarations, prescriptions and testaments that call for re collecting the scattered remnants of Zoroastrian wisdom including those parts that had in the mean time been translated into foreign languages.[9] By drawing on this complex pre Islamic propaganda, translating was legitimised and justified as an imperial cultural activity for the ʿAbbāsid movement and dynasty. It is only when the process of courtly sponsored and encouraged translations was well under way at the end of the eighth and the beginning of the ninth centuries that translations from Greek became important. It took at least several decades before Islamic scholars considered Greek philosophy and science as superior and neglected the other cultural components of the translation movement.

The decision by the caliph al Mahdī (r. 158 69/775 85) around 166/782 to order the Nestorian patriarch and caliphal counsellor Timothy I to translate Aristotle's *Topics* was an important step in extending the scope of translations and integrating the local Aramaic elite in that activity. Al Mahdī chose the book because it taught dialectics, the art of argumentation. It gave support to the use of demonstrative proofs and dialectic disputations as major tools among the early practitioners of *kalām*.[10] Al Mahdī's decision was part of a political strategy to maintain and consolidate ʿAbbāsid power against the resurgence of pre Islamic Iranian doctrinal debates and the emergence of strong non Islamic tendencies among members of the ʿAbbāsid administrative personnel. The memory of these conceptual clashes is preserved in later Arabic books on *uṣūl al dīn* with their standard references to the arguments raised by dualists, naturalists, natural philosophers, astrologers and geometers against positions held by Muʿtazilites, Qadarites and other religious factions of the first ʿAbbāsid century. It is also reflected in reports by Muslim historians

9 Ibid., pp. 41 5.
10 Ibid., p. 65.

such as al Masʿūdī (d. 345/956), who described al Mahdī's politics as directed against followers of religious doctrines by Marcion (*c.* 140 CE), Bardesanes (154 222 CE) and Mani (216 77 CE). Al Mahdakhbārī ordered the *mutakallimūn* to write books against these doctrines.

Al Mahdī's turn to Aristotle was not, however, the beginning of a process that would lead directly to his dream of Aristotle. (Al Maʾmūn is reported to have had a dream in which Aristotle appeared and the caliph interrogated him about what was good.) The following of Iranian cultural patterns con tinued under Hārūn al Rashīd (r. 170 93/786 809), who is credited with the establishment of the Bayt al Ḥikma, often hailed as a scientific academy and the centre of the Graeco Arabic translation movement. The data about this institu tion as reported in Arabic historical sources such as Abū Jaʿfar Muḥammad ibn Jarīr al Ṭabarī's (d. 311/923) *Taʾrīkh* (Annals), Ibn al Nadīm's *Kitāb al fihrist* (Catalogue) and later books does not, however, support such an interpretation.[11] These sources, enriched by poetry, suggest that the Bayt al Ḥikma was a library where rare books on history, poetry and strange alphabets were collected and which was established when al Manṣūr structured the administration of his court and empire along the lines of Sasanian tradition.[12]

A second institution little mentioned in the context of the ʿAbbāsid trans lation movement was the hospital funded by Hārūn al Rashīd's vizier, Yaḥyā ibn Khālid al Barmakī (d. 189/805). According to Ibn al Nadīm, Yaḥyā ibn Khālid paid several physicians from India to run the hospital, to translate books on medical subjects from Sanskrit into Arabic and to collect pharma ceutical plants and drugs in India and bring them to Baghdad.[13] As well as this transfer of mainly medical knowledge Yaḥyā ibn Khālid ordered that a book should be written about the doctrines various peoples in India believed in. Ibn al Nadīm claims to have had access to the Arabic report to Yaḥyā ibn Khālid in a manuscript owned and annotated by Abū Yūsuf Yaʿqūb ibn Isḥāq al Kindī (d. *c.* 256/870), the major philosopher of the third/ninth century.[14] These activities confirm that the influx of Indian scholarly knowledge in the later decades of the second/eighth century into Baghdad also was directly con nected with the ʿAbbāsid court and its cultural politics. The descent of the Barmakid family from Zoroastrian and Buddhist clergy apparently contri buted to the vizier's specific interest in and attention to knowledge and

11 Marie Génèvieve Balty Guesdon, 'Le Bayt al Ḥikma de Baghdad', *Arabica*, 39 (1992); Gutas, *Greek thought, Arabic culture*, pp. 54 60.
12 Gutas, *Greek thought, Arabic culture*, pp. 54 9.
13 Ibn al Nadīm, *Fihrist*, trans. Dodge, vol. II, pp. 590, 710, 826 7.
14 Ibid., pp. 826, 831 2.

goods from India. The larger relevance of such knowledge consisted in its contribution to 'an atmosphere of culture' as Ibn al Nadīm wrote about the entrance of the Jewish secretary, physician and convert to Islam ʿAlī ibn Sahl al Ṭabarī (d. 247/861) into the circle of boon companions of the caliph al Mutawakkil (r. 232 47/847 61).[15]

Adherence to Sasanian style imperial politics and the preference for political astrology and translations continued until the second half of the 810s. Things changed when al Maʾmūn decided to return to Baghdad. In 203/818 he left Marw after executing his mentor, general and vizier al Faḍl ibn Sahl (d. 203/818). Arriving in Baghdad, al Maʾmūn had to pacify the ravaged city, convince the local elites of his capability to effectively quell all opposition and gain loyalty from at least some of their factions. According to later Islamic historians he achieved these goals by turning to Muʿtazilite doctrines and by allegedly introducing Greek philosophy and science.[16] This representation of the caliph's politics reflects the success of al Maʾmūn's legitimising propaganda. He did not introduce Greek philosophy and science into ʿAbbāsid society; he merely showed favour to the translation movement that was already under way. The application of Muʿtazilite concepts as state doctrines also occurred relatively late in his life, after he had tested other possibilities in particular, cooperation with the Shīʿa. What unified al Maʾmūn's various efforts to solve his manifold problems was the adoption of an absolutist interpretation of Islam which defined the caliph as the sole arbiter of orthodoxy and the reinforcement of the politics of centralisation adopted by his great grandfather al Manṣūr. Coinage, military and fiscal reforms were part of this new politics, as was his new foreign policy. The major factor behind the enormous growth of the translation movement was al Maʾmūn's introduction of a philhellenic anti Byzantinism.[17]

As in the case of the earlier application of Zoroastrian imperial ideology, al Maʾmūn's new philhellenic imperial ideology brought with it new translations, new social elements and specific practices. Universalists such as al Kindī emerged. He was one of the most radical and comprehensive practitioners of the new intellectual programme. It was through his personal patronage, teaching and writing that many Aristotelian and pseudo Aristotelian as well as Neopythagorean and Neoplatonic writings on philosophy were translated into Arabic, commented upon and recast as a philosophy in a Muslim

15 Ibid., p. 697.
16 Gutas, *Greek thought, Arabic culture*, pp. 77 8.
17 Ibid., pp. 83 95.

community.[18] Professionally defined specialists such as Yūḥannā ibn Māsawayh (d. 243/857), a Nestorian physician from Gondeshapur and court physician to Hārūn al Rashīd and subsequent ʿAbbāsid caliphs, engaged in systematic trans lations of Greek medical works as translators and patrons. While most historians consider the translation of Greek medical books to be the result of professional exigencies rather than as a part of courtly patronage, the fact that before al Maʾmūn's new politics developed most medical translations apparently were made from languages other than Greek suggests that Ibn Māsawayh's activities as well as those of his students and collaborators were also closely connected to ʿAbbāsid cultural politics, rather than being merely an effort to bring ʿAbbāsid medical teaching in line with the late Alexandrian curriculum.[19] The stories of the translocation of Alexandrian medical and philosophical teaching via intermediary stops in Syria and northern Iraq to Baghdad should also be placed in the context of the stress on ʿAbbāsid superiority as the result of Muslim acceptance of ancient Greek knowledge. One of the most outspoken formulations of this connection is given by Ibn Jumayʿ (d. 594/1198), court physician of the first Ayyūbid sultan, Saladin (Ṣalāḥ al Dīn, r. 564 89/1169 93). He claims that if it had not been for al Maʾmūn, 'medicine and other disciplines of the Ancients would have been effaced and obliterated just as medicine is obliterated now from the lands of the Greeks, which had been most distin guished in this field'.[20] When compared to the variant told by the Christian scholar Job of Edessa (second third/eighth ninth centuries), it becomes obvious that the account of al Maʾmūn's involvement in the transfer of Greek and Hellenistic knowledge is an embellishment that does not describe simple, straightforward historical facts, but reflects values attached to al Maʾmūn's politics.[21]

When weighing the merits of these new views on the social history of the translation movement, it has to be taken into account that previous accounts overstressed the importance of ancient Greek, Byzantine and Christian com ponents. Well into the first half of the third/ninth century ʿAbbāsid scholars

18 Gerhard Endress, 'al Kindī über die Wiedererkennung der Seele: Arabischer Platonismus und die Legitimation der Wissenschaften im Islam', *Oriens*, 34 (1994), pp. 179 84.

19 Manfred Ullmann, *Handbuch der Orientalistik*, division I, supplementary vol. VI, section 1 (Leiden, 1970); Felix Klein Franke, *Vorlesungen über die Medizin im Islam*, Sudhoff Archiv, supplement 23 (Wiesbaden, 1982).

20 Hartmut Fähndrich (ed.), *Ibn Jumayʿ: Treatise to Ṣalāḥ ad Dīn on the revival of the art of medicine*, Abhandlungen für die Kunde des Morgenlandes XLVI, 3 (Wiesbaden, 1983), p. 19.

21 Gutas, *Greek thought, Arabic culture*, pp. 92 4.

worked with concepts and methods from different pre Islamic cultures. Even with the preponderance of Greek and Hellenistic concepts and methods from the late third/ninth century onwards, scientific knowledge from other cul tures was never completely eradicated. Problems, methods, parameters, techniques and instruments of Indian, Iranian, Mesopotamian and Chinese origin either remained available as alternatives to Greek and Hellenistic knowledge or were merged with this knowledge. Moreover, the scholarly world of ʿAbbāsid Iraq and Iran was by no means homogeneous, for some of the scholars who worked on religious, historical and philological themes looked at the translations of Greek philosophical books and Indian arithmetic with scorn, disdain or condescension. Scholars who were primarily engaged in the sciences took different positions on such questions as whether algebra was inferior and number theory superior to geometry, whether astrology was the queen of all sciences or not a science at all and whether divination from the cooked shoulder blades of sheep was part of Greek philosophy.

Patronage and education

Court patronage was the major element that provided the necessary means to carry out the translations. Most of the ʿAbbāsid caliphs of the second/eighth and third/ninth centuries were involved in this patronage in various forms (receiving dedications; employing professionals as tutors and healers; inclu ding Muslim and non Muslim scholars in their cultural entourage; paying stipends and giving gifts). The caliphs alone, however, could not have main tained the depth and breadth of this process. Numerous viziers, starting in the second/eighth century with the Barmakids al Khālid and Yaḥyā and continu ing in the third/ninth century with al Faḍl ibn Sahl or Abū Ṣaqr Ismāʿīl ibn Bulbul, generals such as Ṭāhir ibn Ḥusayn (d. 207/822), administrators such as the Banū Nawbakht and courtiers such as al Kindī, the three Banū Mūsā Muḥammad, Aḥmad and al Ḥasan and the Banū al Munajjim contributed their own funds to the enterprise. In addition to the money they spent, the courtiers and administrators invested cultural capital. They shaped the trans lation movement and the kind of knowledge and practices that sustained it by composing scholarly works and by installing circles for teaching and discus sion. Such *majālis* were also held by caliphs. They were an important courtly institution that elicited the necessary interest for further patronage and sponsorship.

One major result of courtly patronage for the ancient sciences of the third/ninth century was the formulation of scientific programmes that were linked to different religious and political outlooks. Al Kindī, for instance, worked to create a scientific philosophy in Arabic for Muslims that harmonised pre Islamic Arabic, Neoplatonic, Aristotelian and hermetic knowledge as well as belief about all parts of the universe (the heavens, nature, the human body, fate, society and the afterlife) in the form of a systematic exposition, deductive structuring and demonstrative proofs.[22] The Banū Mūsā followed a different course by focusing primarily on the mathematical sciences such as geometry, astronomy, optics and mechanics. Al Kindī mainly worked with high ranking Christian clergy such as Ḥabīb ibn Bahrīz, the Nestorian metropolitan of Mosul, and descendants of Byzantine nobility such as Yaḥyā ibn Baṭrīq. The Banū Mūsā sided with leaders of the Shuʿūbiyya such as the Banū al Munajjim, funded Christian professionals such as Ḥunayn ibn Isḥāq (d. 260 or 264/870 or 873) and Isḥāq ibn Ḥunayn (d. 298/911) and trained gifted Sabians such as the money lender Thābit ibn Qurra (d. 288/901). The different religious, political and scientific goals of al Kindī and the Banū Mūsā turned them into bitter enemies.

A second important result of courtly patronage for the ancient sciences was the reliance on cross denominational cooperation. This included Nestorians, Jacobites, Sabians, Greek Orthodox, Sunnīs, Shīʿa, Zoroastrians and Jews. Only members of the medical profession expressed rivalries, tensions and enmities as religious difference. Religious difference was, however, only one factor that shaped the fortunes of a discipline at the ʿAbbāsid court. Galenism, for instance, emerged as the leading medical theory and practice during the third/ninth and fourth/tenth centuries because of the higher number of its practitioners compared to competing practitioners, their better local avail ability, more extensive networks, better literary skills and the greater political power of their patrons.[23]

In the fourth/tenth century the diversification of the ʿAbbāsid empire into a number of vassal as well as independent dynasties such as the Ṭāhirids (205 59/820 72), the Sāmānids (261 389/874 999) and the Ḥamdānids

22 al Kindī, *al Kindī's* Metaphysics*: A translation of Yaʿqūb ibn Isḥāq al Kindī's treatise 'On first philosophy' (*Fī al falsafah al ūlā*)*, trans. with introd. and commentary Alfred L. Ivry, Studies in Islamic Philosophy and Science (Albany, 1974); al Kindī, 'Kitāb fī 'ilm al katif': Textvs arabicvs et translatio anglica. Cvra et stvdio Gerrit Bos et Charles Burnett', in Gerrit Bos, Charles Burnett, Thérèse Charmasson, Paul Kunitzsch, Fabrizio Lelli and Paolo Lucentini (eds.), *Hermetis trismegisti astrologica et divinatoria* (Turnhout, 2001), pp. 290 3; Endress, 'al Kindī über die Wiedererkennung der Seele', p. 179.

23 Keren Abbou, 'Medicine and physicians in the 'Abbāsid court, from the reign of al Manṣūr until al Mutawakkil', MA thesis, Ben Gurion University (2000), pp. 69 91; al Jāḥiẓ, *The book of misers*, trans. R. B. Sergeant (London, 1996), pp. 86 7.

(317 94/929 1003) and the emergence of rivals such as the Andalusian Umayyads (138 422/756 1031) and the North African and Egyptian Fāṭimids (297 567/909 1171) broadened the opportunities for scholars as new courts, cultural centres and intellectual policies appeared. Decentralisation as well as anti ʿAbbāsid policies inside and outside the caliphate shaped the funding and sponsoring of philosophy, astronomy, medicine, geometry, optics, botany and alchemy. The Umayyads in Cordoba sought to emulate ʿAbbāsid cultural splendour, while at the same time cooperating with Byzantium and the Fāṭimids.[24] The Fāṭimids turned to Neoplatonic philosophy as a helpful tool for formulating their theory of the imamate and to back up their claims to genealogical legitimacy. The Būyids drew upon three major strands of cultural politics: pre Islamic Sasanian heritage; Arab culture; and Shīʿite belief. The ancient sciences constituted one aspect of Būyid princely education in Arab court culture. Their patronage flourished at the courts in Baghdad, Rayy, Shīrāz, Iṣfahān and Hamadhān. Competition with the ʿAbbāsid court probably provided an additional impetus. Similar motives led rulers in Central Asia, eastern Iran, Syria and northern Iraq to attract astrologers, philosophers, physicians and 'engineers' to their courts and to pay for the copying of treatises by ancient and Muslim authors.

The strong cultural role of Būyid viziers as tutors of princes, together with their own splendid sponsoring of the arts and sciences, suggests that the support for these two cultural domains at courts in subsequent Islamic societies, in particular in Iran and Central Asia, was partly the result of the cultural identity of the vizierate.[25] Family networks created by intermarriage diversified the patronage of the sciences below the level of rulers and princes. Several generations of physicians, geometers, astronomers and historians came from families linked with the ʿAbbāsid and Būyid courts such as the Bukhtīshūʿs, the Ibn Qurras and the al Ṣābiʾs. In later centuries such family networks formed around the *madrasa*, where they brought together jurists, *ḥadīth* scholars, astronomers and physicians.

Court patronage for the sciences continued to flourish after the end of the Būyid and Fāṭimid dynasties.[26] Several courts included physicians and

24 Marie Geneviève Balty Guesdon, 'Médecins et hommes de sciences en Espagne musulmane (IIe/VIIIe Ve/XIe)', Ph.D. thesis, Sorbonne (1988), pp. 106 25.

25 See R. N. Frye, 'The Samanids', in R. N. Frye (ed.), *The Cambridge history of Iran*, vol. IV: *From the Arab invasion to the Saljuqs* (Cambridge, New York, Melbourne and Madrid, 1975), pp. 142 3.

26 Heinz Halm, *The Fatimids and their traditions of learning* (London, 1997), p. 71, Yahya Michot, 'Variétés intellectuelles … L'impasse des rationalismes selon le Rejet de la Contradiction d'Ibn Taymiyyah', in Carmela Baffioni (ed.), *Religion versus science in Islam: A medieval and modern debate*, *Oriente Moderno* 19, 3 (2000), p. 602.

astrologers among those who had to be addressed by special honorific titles according to courtly protocol, and these professionals were treated as being of equal reputation and standing as the judges and the students of the Qurʾān and *ḥadīth*. The best known examples are the courts of the Ottomans, Ṣafavids and Mughals.[27] The Mamlūks (648 922/1250 1517) in Egypt are a rare exception. They acknowledged only physicians as worthy of such treatment.[28] This does not mean, however, that the Mamlūks did not seek astrological counselling. Their approach to this discipline took a different course. They regarded it as a minor element of the practice of a new class of astronomical professionals, which they sponsored through religious donations and by appointments to *madrasa*s and mosques. *Muwaqqit*s, as these new professional astronomers were called, came to be regarded as full members of the class of *ʿulamāʾ*, and hence received the same honorific titles as the judges and *imām*s. The change is illustrated in the shift of emphasis between Ibn Khallikān (d. 681/1282), who does not mention a single *muwaqqit* in his biographies, and Shams al Dīn al Sakhāwī (d. 902/1496) almost two centuries later, who included a good number of *muwaqqit*s in his dictionary.[29]

The courtly salon culture continued to be promoted by later dynasties too. Administrators, boon companions, jurists, poets, musicians, Sufis, gramma rians, transmitters of *ḥadīth*, astrologers, physicians and people with an inter est in metaphysics as well as natural philosophy populated its sessions and dominated its atmosphere. A specific kind of scientific literature emerged within this salon culture the genre of questions and answers.[30] Several later encyclopaedias such as the *Nawādir al tabādur* (Rarities of spontaneity) of Shams al Dīn al Dunayṣirī, compiled in 669/1270, and the *Nafāʾis al funūn fī ʿarāʾis al ʿuyūn* (The precious arts of the choice brides) by Shams al Dīn al Āmulī (d. 752/1352), dated around 741/1340, were created in this framework. Both literary genres indicate that courts played a major role for the dissem ination and preservation of scientific knowledge and its underlying philosoph ical concepts both after 500/1107 and outside the sphere of Arabic.

A major field of courtly patronage was the copying and illustrating of scientific treatises in courtly *kitābkhāne*s or *kārkhāne*s, workshops for the arts

27 See MS Paris, BNF, Supplement Persan 1838, Appendix.

28 Abu ʾl ʿAbbās Aḥmad ibn ʿAlī al Qalqashandī, *Ṣubḥ al aʿshā fī ṣināʿat al inshāʾ*, 14 vols. (Cairo, 1331 8/1913 20), vol. VI, pp. 168 70.

29 Ibn Khallikān, *Wafāyāt al aʿyān wa anbāʾ abnāʾ al zamān*, 8 vols. (Beirut, n.d.); Shams al Dīn al Sakhāwī, *al Ḍawʾ al lāmiʿ li ahl al qarn al tāsiʿ*, 10 vols. (Beirut, n.d.).

30 Živa Vesel, 'La science à la cour: Les questions et les réponses', in C. Balaÿ, C. Kappler and Ž. Vesel (eds.), *Pand o Sokhan: Mélanges offerts à Charles Henri de Fouchcour* (Tehran, 1995).

of the book. Almost no illustrated scientific manuscripts in Arabic or Persian survive from earlier than the sixth/twelfth century. But there is evidence that this process started in the fourth/tenth century, if not earlier. The iconogra phy of the extant illustrated scientific manuscripts points to cross cultural artistic exchange with Byzantium, Egypt, Khurāsān, Sogdiana, Balkh, China, non Muslim India and the nomadic steppes of Eurasia. With the exception of later courts in North Africa, dynasties in apparently all major cultural areas of the core Islamic territories contributed in this way to the spread and main tenance of scientific literature.

The connection between the arts and the sciences was not limited to the occult and the popular such as magical bowls or illustrations of the miracu lous. Neither was it stereotypical and conventional. Scientific works profited from the innovative changes in the arts that took place under various Islamic and non Islamic dynasties, from new views about which scholarly disciplines should be sponsored by princely and other courtly patrons and from an opening of disciplines to artistic illustration that previously had pursued rather austere modes of the visual. Examples include translations of Chinese medical and agricultural writings at the Ilkhānid court under the patronage of the vizier Rashīd al Dawla (d. 718/1318) and the Mongol military and diplomatic counsellor at the Ilkhānid court, Bolad Ch'eng Hsiang (d. 713/1313), or the illustration of Quṭb al Dīn al Shīrāzī's (d. 710/1311) theoretical work on planet ary movements *al Tuḥfa al shāhiyya* (The royal gift) in the style of one of the leading painters of the Ṣafavid court, Rezā ʿAbbāsī (d. 1045/1635).[31] The literary, religious and scientific anthologies of the Tīmūrid prince of Shīrāz and Iṣfahān Iskandar Sulṭān (r. 812 17/1409 14) represent another example of the relation ship between science and art. The scientific texts in these anthologies are illustrated by carefully constructed diagrams, colourful images of zodiacal signs, planetary houses and related subjects as well as a beautifully drawn map. A number of them are inscribed on the margins, thus serving themselves

31 Thomas T. Allsen, 'Biography of a cultural broker: Bolad Ch'eng Hsiang in China and Iran', in Julian Raby and Teresa Fitzherbert (eds.), *The court of the Il Khans 1290 1340* (Oxford, New York and Toronto, 1994); Nasrollah Pourjavady (gen. ed.), *The splendour of Iran*, 3 vols. (London, 2001), vol. III: C. Parham (ed.), *Islamic period*, pp. 282 7; Thomas W. Lentz and Glenn D. Lowry (eds.), *Timur and the princely vision: Persian art and culture in the fifteenth century* (Los Angeles, 1989), pp. 57 8, 79 103, 108 39; Zeren Akalay [Tanindi], 'An illustrated astrological work of the period of Iskandar Sultan', in *Akten des VII. Internationalen Kongresses für Iranische Kunst und Archäologie (Munich, 1976)*, Archäologische Mitteilungen aus Iran, n.s., supplementary vol. (Berlin, 1979), pp. 418 25; Priscilla P. Soucek, 'The manuscripts of Iskandar Sultan', in Lisa Golombek and Maria Subtelny (eds.), *Timurid art and culture: Iran and Central Asia in the fifteenth century* (Leiden, New York and Cologne, 1992).

as decorations. The only known miniature of astronomers studying and observing the sky in a domed building, dated before the late tenth/sixteenth century, comes from one of these manuscripts.

The evolution of the Sunnī *madrasa* in Iran, Anatolia, Syria, Iraq, Egypt and North Africa created a new outlet for court patronage. Caliphs, sultans, *atabeg*s, royal wives and daughters, officers, merchants and scholars engaged in funding *madrasa*s, Sufi convents, hospitals, houses for the study of *ḥadīth* and the Qurʾān and tombs. The ancient sciences also benefited from these donations. ʿAbbāsid caliphs funded chairs for medicine in prominent *madra sa*s. Ilkhānid Buddhist and Muslim rulers sponsored the observatories of Marāgha and Tabrīz. They kept a travelling *madrasa* in their camps, where scholars taught literature, religion, philosophy and mathematical sciences. Mamlūk sultans sponsored a chair for *ʿilm al mīqāt* (science of timekeeping), appointed *muwaqqit*s as professors of *fiqh* and heads of Sufi convents, opened medical *madrasa*s and donated chairs for medicine at central mosques in Cairo. Ottoman, Ṣafavid and Mughal rulers likewise provided for other than religious and legal teaching at the *madrasa*s they gifted with funds. The impact of rulers, wives and court officials remained mostly limited to funding, the creation of positions, the appointment of professors and the settling of power struggles among the *ʿulamāʾ*. They rarely interfered in the subjects taught at the *madrasa*s, mosques and other teaching institutes. Neither did they set up administrative bodies that unified the teaching and controlled its results, with the exception of medicine. The Mamlūks, for instance, entrusted the control of medical qualification to the head physician, who was attached to the court. The Manṣūriyya *madrasa* in Cairo and its affiliated hospital was governed by a *dīwān* specifically created for this purpose.[32]

A third strand of patronage came from individuals who invested their own funds and labour. Marginalia and colophons in numerous extant manuscripts testify that they were copied and even illuminated by practitioners of one of the sciences or scientific professions. Physicians and students of medicine not only copied medical textbooks and astrological treatises, but were responsible for attractively illustrated copies of Zakariyyāʾ al Qazwīnī's work, Euclid's *Elements* and astronomical texts. Such activities indicate that Ibn Jumayʿ's demand that physicians should study *ʿilm al hayʾa* (mathematical cosmology), not *ʿilm al nujūm* (astrology) in order to become truly scientific experts of the art of medicine was not a mere topos of complaint, but was derived from

32 al Qalqashandī, *Ṣubḥ*, vol. VI, pp. 34, 38 9.

competing scientific practices.[33] Students of astronomical and astrological knowledge also copied treatises from related mathematical sciences such as arithmetic or algebra. The contribution of private sponsorship to the produc tion, reproduction and distribution of scientific manuscripts and objects has not yet received much attention.

Innovation in the mathematical sciences

The concepts of what the mathematical sciences were, the tools with which they should work, the purposes they should fulfil and the names that were thought appropriate for them differed substantially over time, space and culture. In part, divergent pre Islamic traditions lay behind the differences. Not only did Indian perceptions differ from those of classical Greece, those of classical Greece differed from those of Byzantine Late Antiquity, those of ancient Mesopotamia from those of ancient Egypt and those of Seleucid Iraq from those of Sasanian Iran, but there was more than one school of mathe matics taught in Byzantine Late Antiquity. There was also more than one local tradition by which tax collectors, merchants and constructors calculated their gains, the labourers' wages and the necessary hours of work and measured or weighed the harvest, the commodities, the building blocks and the fields. Hence, in the first centuries of Islam not only did a multitude of peoples, religions and lifestyles come together under a new central government with a different creed and concept of leadership, but the empire did not and could not operate with uniform standards of calculating, measuring, weighing, solving mathematical problems and proofs.

Our knowledge about the local mathematical practices during these early centuries is not very good. Egyptian papyri of the second/eighth century were long believed to contain the first record of Indian numerals in an Arabic document. But this reading has been contested.[34] The Qur'ān indicates that inheritance shares were determined before Muḥammad recited the verses with the new quota, but we don't know which mathematical rules were used for calculating the shares in a concrete case.[35] When Muḥammad ibn Mūsā al Khwārizmī wrote the first surviving Arabic handbook on algebra, which

33 Fähndrich (ed.), *Ibn Jumay'*, pp. 2, 16.

34 Paul Kunitzsch, 'The transmission of Hindu Arabic numerals reconsidered', in Jan P. Hogendijk and Abdelhamid I. Sabra (eds.), *The enterprise of science in Islam: New perspectives* (Cambridge, MA, and London, 2003).

35 *The Koran Interpreted: A translation*, trans. A. J. Arberry, 2 vols. (New York, 1996), vol. I, sura 4: Women, pp. 100 2.

also contained chapters on surveying, commercial transactions and inheri tance mathematics (*farāʾiḍ*), he presented the rules according to Abū Ḥanīfa (d. 150/767) in a fairly formalised manner. By doing so he may even have contributed to the process of standardising Abū Ḥanīfa's teaching. Moreover, Muḥammad al Khwārizmī used pre Islamic methods of geometrical arguing as well as proofs that were developed by Babylonian and Seleucid scribes.[36] Another Arabic text on algebra written by Ayyūb al Baṣrī may contain even earlier Islamic mathematical knowledge and techniques than al Khwārizmī's work.[37]

While we know very little about mathematics until the fall of the Umayyads, it is clear that a new level of mathematical interest and sophisti cation was reached under the early ʿAbbāsids. Arabic historical sources reported that the second ʿAbbāsid caliph, al Manṣūr, sent to Byzantium for a manuscript of Euclid's *Elements*. The manuscripts acquired as booty or tribute during the many clashes with Byzantine armies probably contained other texts by Euclid such as the *Data* and by other Greek scholars. A small but steady stream of translations of mathematical texts was produced during the first fifty years of ʿAbbāsid rule, sponsored by the caliphs, their viziers, commanders and administrators. Yaḥyā ibn Khālid al Barmakī, for instance, was patron of the translation of Euclid's *Elements* and Ptolemy's *Almagest*. The Nestorian metropolitan Ḥabīb ibn Bahrīz translated the *Introduction to arithmetic*, written by the Neopythagorean philosopher Nicomachus of Gerasa (second century CE), for the caliph al Maʾmūn's general Ṭāhir ibn Ḥusayn. Al Kindī gave seminars on this newly translated text.[38] The political, philosophical, religious and cultural differences between al Kindī and the Banū Mūsā included divergent views on mathematics. While al Kindī favoured Neoplatonic, Neopythagorean and hermetic texts and themes, the use of mathematical concepts and tools for proving major philosophical and religious tenets (the existence of God; *creatio ex nihilo*; the finiteness of the universe) as well as the application of Greek number theory to recreational mathematics of mixed origins (Mesopotamia, India, China), the Banū Mūsā supported the translation

36 Jens Høyrup, 'al Khwārizmī, Ibn Turk, and the *Liber mensurationum*: On the origins of Islamic algebra', *Erdem*, 5 (1986).

37 Barnabas Hughes, 'Problem solving by Ajjūb al Basrī, an early algebraist', *Journal for the History of Arabic Science*, 10 (1992 4).

38 Gad Freudenthal and Tony Lévy, 'De Gérase à Bagdad: Ibn Bahrīz, al Kindī, et leur recension arabe de *l'Introduction arithmétique* de Nicomaque, d'après la version hébraïque de Qalonymos ben Qalonymos d'Arles', in Régis Morelon and Ahmad Hasnawi (eds.), *De Zénon d'Élée à Poincaré: Recueil d'études en homage à Roshdi Rashed* (Louvain and Paris, 2004).

of Apollonius' *Conics*, favoured the creation of new mathematical results over the memorising of mathematical textbooks and recommended the study of Archimedean books and tools.[39] They agreed, on the other hand, in applying Greek theoretical mathematics to practical problems; and they studied not only Greek mathematical theory, but practice too, as much as it was codified in textual form. The fields of application comprised surveying, sundials, optics, burning mirrors, mechanics and medicine. The contribution of these groups of courtly patrons, scholars and translators to the development of a mathematical terminology in Arabic, the pursuit of different approaches to mathematics, the emergence of highly skilled and innovative mathematicians in the later third/ninth and throughout the fourth/tenth centuries and the spread of acceptance of mathematics as a well reputed set of disciplines and methods for finding truth among different groups of educated Muslims and members of the religious minorities cannot be overrated.

The relationship between algebra and arithmetic was shaped by the impact of the translations of Nicomachus' *Introduction to arithmetic*, books VII IX of Euclid's *Elements* and Diophantus' *Arithmetic*, on the one hand, and of the various local traditions of calculation for purposes of business, inheritance and surveying, on the other. The Neoplatonic and Neopythagorean classifications of the mathematical sciences identified arithmetic as number theory, ignored calculation, interpreted numbers and their properties as carriers of philosoph ical and religious meaning and ranked arithmetic above geometry, astronomy and theoretical music (theory of proportions). This approach was propagated by al Kindī in the first half of the third/ninth century and by Thābit ibn Qurra in the second. Fragments of an Arabic edition of Euclid's *Elements* indicate that it was also applied to interpreting book II and certain theorems in books I, III and VI of the *Elements*, which did not belong to number theory as taught in the framework of this work. It became the position taken by the author(s) of the *Rasā'il Ikhwān al Ṣafā'*, Ibn Sīnā in his *Kitāb al shifā'* (The book of healing) and other writers of encyclopaedic works of the fourth/tenth and fifth/eleventh centuries. While the philosophical attitudes of such writers may explain their preferences in number theory certain parts of Nicomachus' teaching were also privileged by writers who came from a different milieu *fuqahā'* and *mutakallimūn* such as Abū Manṣūr ʿAbd al Qāhir ibn Ṭāhir al Nīsābūrī al Baghdādī (d. 428/1037). Numerous later writers from this milieu such as Ismāʿīl ibn Ibrāhīm ibn al Fallūs (d. 637/1239), Abu 'l ʿAbbās Aḥmad ibn Muḥammad ibn al Bannā' al Marrākushī (d. 721/1321) or Shihāb al Dīn ibn

39 Ibn al Nadīm, *Fihrist*, trans. Dodge, vol. II, pp. 637 8.

al Majdī (d. 851/1447) continued along this line and taught this kind of number theory in their classes at *madrasas*, mosques and *khānqāhs*. In contrast to Greek traditions, algebra, number theory and calculation became classified in Arabic, Persian and Turkish treatises as parts of a comprehensive *ʿilm al ḥisāb* (the science of calculation), in which number theoretical knowledge in the Nicomachean tradition kept its position at the highest rank.

Muḥammad al Khwārizmī's books on algebra and Indian arithmetic had a significant impact on several scholarly milieus. When Qusṭā ibn Lūqā (d. *c.* 297/910) translated Diophantus' *Arithmetic* in the second half of the third/ninth century, he interpreted its contents according to the technical terminol ogy of al Khwārizmī's algebra.[40] Diophantine problems came to be seen as belonging to both algebra and arithmetic. The extension and reshaping of algebra by Abū Bakr al Karajī (d. *c.* 420/1029) and al Samawʾal ibn Yaḥyā al Maghribī (d. 570/1175) is shown by their treatment of algebraic themes with arithmetical concepts and methods. They extended the earlier limited concept of unknowns of higher than second order ($x^3 \ldots x^9$) to unknowns of finite but unlimited order, and applied this new view also to 'parts', i.e. fractions of the type $1/x^n$. These new objects became the focus of the new approach to algebra, above all the solution of polynomial equations of second and higher degree, as well as the development of a calculus for such equations.[41] As a result of these developments algebraic methods came to be seen as tools that also could be used in other mathematical areas. Several scholars such as Ibn Munʿim (sixth seventh/twelfth thirteenth centuries) or Kamāl al Dīn al Fārisī (d. 718/1318?) applied them to problems of combinatorics and found new methods or proofs for a number of theoretical problems such as the calcu lation of perfect or amicable numbers. A perfect number is a number the sum of whose parts equals the number such as $6 = 1 + 2 + 3$. Amicable numbers are a pair of numbers where the sum of the parts of one number equals the other number such as $220 = 1 + 2 + 4 + 5 + 10 + 11 + 20 + 22 + 44 + 55 + 110 = 284$, $284 = 1 + 2 + 4 + 72 + 142 = 220$.[42]

40 Jacques Sesiano, *Books IV to VII of Diophantus'* Arithmetica: *In the Arabic translation attributed to Qusṭā ibn Lūqā* (New York and Berlin, 1982).

41 Roshdi Rashed, *Entre arithmétique et algèbre: Recherches sur l'histoire des mathématiques arabes* (Paris, 1984); Roshdi Rashed, *The development of Arabic mathematics: Between arithmetic and algebra* (London, 1994).

42 Ahmed Djebbar, *L'analyse combinatoire au Maghreb: l'Exemple d'Ibn Munʿim (XIIe XIIIe siècles)*, Publications Mathématiques d'Orsay 85 01 (Paris, 1985); Roshdi Rashed, 'Materials for the study of the history of amicable numbers and combinatorial analysis', *Journal for the History of Arabic Science*, 6, 1 2 (1982); Roshdi Rashed, 'Nombres amiables, parties aliquotes et nombres figurés aux XIIIème et XIVème siècles', *Archive for History of Exact Sciences*, 28, 2 (1983).

The relationships between these two disciplines and geometry were similarly complex. Scholars such as Thābit ibn Qurra, Abū ʿAbd Allāh Muḥammad ibn ʿĪsā al Māhānī (d. *c.* 246/860), Thābit's grandson Ibrāhīm ibn Sinān (d. 335/946) and Abū ʿAlī al Ḥasan Ibn al Haytham (d. *c.* 432/1041) used number theory or algebra when dealing with geometrical problems such as the determination of the surface of a parabola and the volume of bodies of rotation or the discussion of an unproven lemma by Archimedes.[43] Thābit ibn Qurra also demonstrated that two theorems of book II of Euclid's *Elements* were a more rigorous tool for proofs than al Khwārizmī's own geometrical reasoning.[44] Despite his major contribution to the new algebra, Abū Bakr al Karajī believed that geometry was of a higher scientific value because of its demonstrative rigour and axiomatic structure.

Other scholars such as Abū Jaʿfar al Khāzin (d. between 349 and 360/961 and 971), Abu 'l Jūd ibn Layth (fourth/tenth century), Aḥmad ibn Muḥammad al Sijzī (d. *c.* 410/1020) and ʿUmar al Khayyām (d. 517/1123) pursued an oppo site approach and used Apollonius' *Conics* for tackling problems that led to cubic and bi quadratic equations. Several of these problems originated in a geometrical context, such as the debate about how to inscribe a regular heptagon into a circle. This and related problems came from discussions of works of Archimedes and classical mathematical problems such as the trisec tion of an angle, as well as certain mathematical tools that had already caused lively debates among ancient geometers such as the use of movements in geometrical constructions, for instance the device called *neusis* (verging construction).[45]

Due to the diversification of courts, patronage and cultural centres the fourth/tenth century saw a particularly productive and widespread discussion carried on by mathematicians, mainly in greater Iran, through the exchange of personal letters, evening discussions, competitive questioning and proud occasionally even boastful reports about apparently or truly successful new ideas and solutions. As a result, several treatises on constructing the side of

43 Aḥmad Salīm Saʿidān, *Rasā'il Ibn Sinān* (Kuwait, 1983).
44 Paul Luckey, 'Thabit b. Qurra über den geometrischen Richtigkeitsnachweis der Auflösung der quadratischen Gleichungen', in *Berichte über die Verhandlungen der Sächsischen Akademie der Wissenschaften zu Leipzig*, Mathematisch physikalische Klasse 93 (Heidelberg, 1941).
45 Ahmet Djebbar and Roshdi Rashed (eds., trans. and comm.), *L'oeuvre algébrique d'al Khayyām* (Aleppo, 1981), p. 11; Jan P. Hogendijk, 'How trisections of the angle were transmitted from Greek to Islamic geometry', *Historia Mathematica*, 8 (1981); Jan P. Hogendijk, 'Greek and Arabic constructions of the regular heptagon', *Archive for History of Exact Sciences*, 30 (1984); Jan P. Hogendijk, 'The geometrical works of Abū Saʿīd al Ḍarīr al Jurjānī', *SCIAMVS*, 2 (2001).

a regular heptagon, trisecting the angle and related problems were written and a systematic geometrical theory for solving cubic equations was established.[46]

Besides these cross disciplinary works and debates, much innovative work was done within the classical disciplines. The ancient methods of analysis and synthesis were at the centre of mathematical research and discussion. Several scholars of the third/ninth, fourth/tenth and fifth/eleventh centuries wrote manuals about these two methods, among them Ibrāhīm ibn Sinān and Ibn al Haytham. Others, such as al Sijzī and Abū Sahl Wījān ibn Rustam al Kūhī (fourth/tenth century), compiled collections of problems for which they proposed various kinds of synthesis and analysis. Their texts make clear that different opinions were held about how to work with these two methods, and disputes arose over violations of mathematical rigour.[47] The problems treated in these and related works were either derived from texts of ancient Greek authors or devised in a similar way. The works used in this context were in particular Euclid's *Data*, *Division of figures* and *Porisms*, Apollonius' *Conics*, *Cutting off a ratio*, *Plane loci* and *Determinate section*, Menelaus' *Introduction to geometry* and Archimedes' *Sphere and cylinder*, *Measuring the circle* and the spurious work on the heptagon.[48] The extant writings by al Sijzī, Abu 'l Jūd and others indicate that these problems, the two methods (analysis and syn thesis) and their results were studied, debated and challenged in the milieu of the private evening *majlis*, publicly shared letters and publicly held disputes as is documented, for instance, in the treatise *Jawāb Aḥmad b. Muḥammad b. ʿAbd al Jalīl li asʾila handasiyya suʾila ʿanhā bi 'l nās min Khurāsān* (Reply by Aḥmad ibn Muḥammad ibn ʿAbd al Jalīl to geometrical questions asked by people from Khurāsān).[49] Al Sijzī placed the art of finding new results in geometry in an epistemological context. He opposed the claim that 'discovery

46 Jan P. Hogendijk, 'Abū l Jūd's answer to a question of al Bīrūnī concerning the regular heptagon', in D. A. King and G. Saliba (eds.), *From deferent to equant: A volume of studies in the ancient and medieval Near East in honor of E. S. Kennedy* (New York, 1987).

47 J. Lennart Berggren and Glen van Brummelen, 'The role and development of geometric analysis and synthesis in ancient Greece and medieval Islam', in Patrick Suppes, Julius M. Moravcsik and Henry Mendell (eds.), *Ancient and medieval traditions in the exact sciences: Essays in memory of Wilbur Knorr* (Stanford, 2001).

48 See, for instance, Jan P. Hogendijk, 'Arabic traces of lost works of Apollonius', *Archive for History of Exact Sciences*, 35 (1986); Jan P. Hogendijk, 'On Euclid's lost *Porisms* and its Arabic traces', *Bolletino di Storia delle Science Matematiche*, 7 (1988); Jan P. Hogendijk, 'The Arabic version of Euclid's *On division*', in M. Folkerts and J. P. Hogendijk (eds.), *Vestigia Mathematica: Studies in medieval and early modern mathematics in honour of H. L. L. Busard* (Amsterdam, 1993); J. L. Berggren, J. P. Hogendijk, *The fragments of Abu Sahl al Kuhi's lost geometrical works in the writings of al Sijzī* (University of Utrecht, Department of Mathematics, Preprint no. 1226, February 2002), pp. 4 18.

49 See Fuat Sezgin, *Geschichte des arabischen Schrifttums*, 12 vols. (Leiden, 1974), vol. V, p. 333, no. 22.

in geometry proceeds only by means of innate ability and not by study'.[50] He then proceeded to enlist and discuss seven rules to find new results, mostly constructions. These rules included knowledge of the conditions of a problem; knowledge of common features and differences of a set of problems; mastery of the relevant theorems and preliminaries; familiarity with tricks used by experienced mathematicians; and specific mathematical methods (analysis, transformation).[51]

In a similar way, the branches of optics and mechanics, which ancient Greek scholars had mostly seen as parts of geometry, were modified, enlarged and in some of their parts revolutionised. Optics, for instance, merged the various strands of ancient mathematical, philosophical and medical theories about vision into a coherent whole that added the study of light to that of sight and also included parts of astronomy and surveying. On the methodological side, it abandoned the ancient preference for geometrical demonstrative theory and made room for experiments, practical concerns and technical constructions.[52] During the third/ninth and fourth/tenth centuries, optical themes were discussed in four main intellectual contexts: geometry (vision through air, vision through mediums other than air, burning mirrors and lenses); philo sophy (theories of light and perception, meteorology); astronomy (shadows, perception, visual errors); and medicine (anatomy and physiology of the eye). A decisive step towards a new disciplinary understanding took place in the fifth/eleventh century with the work of Ibn al Haytham, who aimed at combining the mathematical and physical aspects of vision, moved the focus of the discipline towards light and integrated into his approach topics from Ptolemy's *Optics* such as refraction. Ibn al Haytham's most important work on optics is his *Kitāb al manāẓir* (Book of optics), which gives an experimental and mathematical treatment of the properties of light and colour in relationship to vision.[53] A summary of its arguments and a fuller presentation of his exper imental results is the *Maqāla fī l ḍaw'* (Treatise on light).[54] He differentiated

50 Al Sijzī, *Treatise on geometrical problem solving:* Kitāb fī tashīl al subul li istikhrāj al ashkāl al handasīya, ed., trans. and comm. Jan P. Hogendijk, Arabic text and a Persian trans. Mohammad Bagheri (Tehran, 1996), p. 2.

51 Ibid., pp. x xiii.

52 Elaheh Kheirandish, 'Optics: Highlights from Islamic lands', in Ahmad Y. al Hassan, Maqbul Ahmed and Ahmad Z. Iskandar (eds.), *The different aspects of Islamic culture*, vol. IV: *Science and technology in Islam*, part 1, *The exact and natural sciences* ([Paris], 2001), pp. 337 8, 345; Abdelhamid I. Sabra, *The optics of Ibn al Haytham*, books 1 3, book 2: *On direct vision* (with introduction, commentary, glossaries, concordance, indices) (London, 1989).

53 Sabra, *On direct vision*, p. lv.

54 Ibid., p. li, fn 73.

between the approach of the natural philosopher, who studies the *māhiyya* (quiddity) of light, transparency or the ray, and that of the mathematician, who deals with the *kayfiyya* ('howness') of the ray's extension in transparent bodies and the shapes of rays.

Natural philosophers and mathematicians also differed in their basic belief about what light is. Ibn al Haytham set out to synthesise the two different disciplinary programmes, and did so by experimenting with 'dark chambers' and by criticising theories, methods and concepts of previous scholars of both approaches. Through experiments he discovered that the Euclidean theory of vision (visual rays extend from the eye to the object) was wrong. Through his critical analysis of previous writings he observed that the natural philoso phers and physicians, who correctly believed that vision took place by a *form* (light) that emerged from a shining object and was received by the eye, had no precise doctrine of the ray.[55] Following on from this, he applied the methods of the mathematicians to the doctrines of the natural philosophers and physicians.[56] He introduced new categories such as 'primary light' and 'secondary light', and posed new questions. Primary light is light that issues from self luminous bodies. Secondary light is light that emanates from acci dental light, i.e. light existing in bodies illuminated from the outside. One of Ibn al Haytham's new questions was: if vision resulted from the imprint of a form onto the eye, why does one see the object outside the eye?[57]

But while revolutionising the science of optics in many ways, Ibn al Haytham's *Kitāb al manāẓir* did not discuss all optical themes he had treated in previous writings and other disciplinary settings.[58] The major breakthrough in respect to a new disciplinary understanding of optics came with Kamāl al Dīn al Fārisī's *Tanqīḥ al manāẓir li dhawī al abṣār wa 'l baṣā'ir* (Revision of [The book of] optics for the possessors of insight and discern ment), a commentary on Ibn al Haytham's opus. He added three further treatises by Ibn al Haytham on shadows, perception and light together with his own analysis and exposition of the subjects. Kamāl al Dīn justified this collection by claiming these subjects as part of the science of optics. Except for burning mirrors, Kamāl al Dīn considered all other previously discon nected strands that dealt with themes related to light and vision as constitu ting optics.[59]

55 Ibid., p. liii.
56 Ibid., pp. liv lv.
57 Ibid., pp. lii, liv.
58 Ibid., p. liii.
59 Kheirandish, 'Optics', p. 349.

A similar process took place with regard to the ancient domains of statics, hydrostatics, dynamics and weights discussed in the contexts of geometry, medicine, natural philosophy and technology. Various works by or ascribed to Aristotle, Euclid, Apollonius, Archimedes, Heron, Pappus and Galen were translated into Arabic during the third/ninth century and taken up in a process that reshaped the various disciplines. The major figures who contributed to this process were the Banū Mūsā, Qusṭā ibn Lūqā, Thābit ibn Qurra, Abū Naṣr al Fārābī (d. 340/950), Wījān al Kūhī, Ibn al Haytham, Ibn Sīnā, al Karajī, Abū Ḥātim al Muẓaffar ibn Ismāʿīl al Isfizārī (d. *c.* 504/1110), ʿUmar al Khayyām, ʿAbd al Raḥmān al Khāzinī (d. after 515/1121) and Ibn Ismāʿīl ibn al Razzāz al Jazarī (*fl. c.* 603/1206). The result of this process was twofold. On one hand, al Fārābī, in his *Iḥṣāʾ al ʿulūm* (Enumeration of the sciences), testified to and justified philosophically the evolution of two separate mathematical disciplines of mechanics: *ʿilm al athqāl* (the science of weights) and *ʿilm al ḥiyal* (the science of machines). Neither of the two new disciplines unified all relevant ancient strands. The first focused on a relatively small range of subjects (the theory of the balance and practical problems of weighing).[60] Its conceptual core is the investigation and explan ation of mechanical questions through motion and force. The inspiration for this approach stems from the Pseudo Aristotelian *Problemata mechanica*. As a result, the new discipline was closely linked to natural philosophy, on the one hand, and to medical and commercial practices of weighing, on the other. The study of the centres of gravity of surfaces and solids was seen by al Kūhī, al Isfizārī and al Khāzinī as the theoretical nucleus of this new discipline, which is a new point of view when compared to Thābit ibn Qurra's *Kitāb al qarasṭūn*, which mainly dealt with the law of the lever for material beams and balances. The second new discipline also may be considered as formed by two different domains. One domain was part of natural philosophy and dealt with the so called five simple machines of Antiquity (the windlass, the lever, the pulley, the wedge and the screw). It studied, as al Fārābī explained, the ways in which mathematical knowledge could be brought from *quwwa* (potentiality) to *fiʿl* (actuality) by applying it to natural bodies by means of machines.[61] The other shared the mathemat ical methodology, but dealt with practical machines for time measuring, water lifting, entertainment, healing and other purposes.

60 Mohammed Abattouy, *The Arabic tradition of the science of weights and balances: A report on an ongoing research project* (Max Planck Institute for the History of Science, Preprint 227, 2002), pp. 7 11, 13.

61 Al Fārābī, *Iḥṣāʾ al ʿulūm*, ed. ʿUthmān Amīn, 2nd edn (Cairo, 1949), pp. 88 9.

The enormous attraction exercised by the axiomatic, deductive structure of geometry can be seen in al Karajī's treatise on water lifting, which is written in the style of Euclid's *Elements*. Al Jazarī, in his monumental book on machines, which he composed at the Artuqid court of Diyarbakr, also considered what he did as an application of geometry to machines, which he understood as a philosophical act.[62] In the title of his book *al Jāmiʿ bayna l ʿilm wa'l ʿamal al nāfiʿ fī ṣināʿat al ḥiyal* (The combination of theory and practice in the mechanical arts) al Jazarī formulated a second purpose, namely to bring together *ʿilm* (knowledge) and *ʿamal nāfiʿ* (useful practice).[63] This aim refers on one level to theory and practice in a scientific context. On another level the chosen title has a religious subtext. Every Muslim was called to acquire *ʿilm* and exercise it through *ʿamal* in order to do things useful for the community. Al Ghazālī made this point repeatedly in his influential writings when he discussed the sciences as well as the duties of a Muslim. The praise for the usefulness of books written by scholars of all disciplines, expressed time and again in the biographical dictionaries, underlines the social relevance of these terms for the scholarly world in medieval Islamic societies.

Innovations were not restricted to those disciplines that were already established before the advent of Islam. From the third/ninth century onwards mathematicians and astronomers created new mathematical branches by either building upon certain components inherited from Greek and Indian predecessors or by inventing completely new fields of mathematical knowl edge. Such new branches often did not receive a specific name, or if they did the names do not fit into modern divisions of mathematics. Examples are trigonometry, magic squares, combinatorics, multi entry astronomical tables with auxiliary functions and the use of mathematics in philosophy and *kalām*. While many of the above mentioned innovations developed within the context of the appropriated ancient sciences, the newly emerging fields of knowledge also had strong connections with particular needs and interests of Islamic societies, their religions, languages and everyday life. Combinatorics first appeared in the work of the Arabic grammarian Khalīl ibn Aḥmad (d. 170/786?) as he tried to arrange the three and four consonants of Arabic roots for a

62 al Jazarī, *The book of knowledge of ingenious mechanical devices:* Kitāb fī maʿrifat al ḥiyal al handasiyya, trans. Donald R. Hill with annotations (Dordrecht, London and New York, 1973). For a critique of Hill's interpretation of al Jazarī's work and title see George Saliba, 'The function of mechanical devices in medieval Islamic society', in P. Long (ed.), *Science and technology in medieval society*, Annals of the New York Academy of Sciences 441 (New York, 1985).

63 al Jazarī, *al Jāmiʿ bayna l ʿilm wa'l ʿamal al nāfiʿ fī ṣināʿat al ḥiyal*, ed. Ahmad Y. al Hassan (Aleppo, 1979).

dictionary. Magic squares and their development were part of the search for licit methods of protecting oneself from misfortune, disease and death and determining the best approaches to travelling, marriage, house building and other undertakings.[64] Mathematical themes and methods as applied in philo sophy and *kalām* were used for arguing about what separated *tawḥīd*, the specific Muslim notion of the oneness of God, from other forms of oneness as well as from multitude, for proving God's existence and for discussion about the material structure of the universe and its regularities, i.e. about atomism, continuity, infinity and causality. The most frequently borrowed mathemat ical themes in such contexts came from Euclid's *Elements* and from Nicomachus's *Introduction to arithmetic*, for instance the definition of *one* as the beginning and the root of integers, but no number itself; the question of whether the area between an arc and a tangent to one of its points was a geometrical quantity, i.e. a plane angle in the Euclidean sense; whether the ratio between the circumference and the diagonal of a circle was a rational number; and whether motion was a permissible geometrical concept.

From the beginning algebra and Indian arithmetic were deeply linked to the needs and interests of an Islamic society. Muḥammad al Khwārizmī had argued for the relevance of these two fields by pointing in clear terms to merchants, surveyors and jurists as the three major groups in society who were in need of them. By applying his methods to positions and prescriptions taken from the not yet fully codified teachings of Abū Ḥanīfa rather than from the Qurʾān, or in general from all legal schools that were emerging during the second/eighth and early third/ninth centuries, al Khwārizmī made a clear point about the truly practical orientation of the two new fields in contrast to a merely illustrative function of potential fields of application for mathematical knowledge. When comparing the impact different treatises on algebra and Indian arithmetic had in later Arabic, Persian and Ottoman Turkish writings about commercial and legal calculations as composed and taught in the context of the *madrasa*, al Khwārizmī's *al Kitāb al mukhtaṣar fī ḥisāb al jabr wa 'l muqābala* (Abbreviated book on algebra) without doubt was the most successful one. Its elementary mathematical content, the visual accessibility

64 See Jacques Sesiano, *Un traité médiéval sur les carrés magiques: De l'arrangement harmo nieux des nombres* (Lausanne, 1996); Jacques Sesiano, 'Herstellungsverfahren magischer Quadrate aus islamischer Zeit', (I, II, II', III) *Sudhoffs Archiv*, 64 (1980), 65 (1981), 71 (1987), 79 (1995); Jacques Sesiano, 'Une compilation arabe du XIIe siècle sur quelques propriétés des nombres naturels', *SCIAMVS*, 4 (2003); Francis Maddison and Emilie Savage Smith, *Science, tools and magic*, part 1: *Body and spirit: Mapping the universe*, Nasser D. Khalili Collection of Islamic Art 12 (London, 1997).

of its arguments and its practical relevance may all have contributed to this preference given to al Khwārizmī's work over those by Abū Kāmil al Miṣrī (d. *c.* 235/850), al Karajī or al Samaw'al.

The Islamic aspects of cosmology, astronomy and astrology

Throughout the history of Islamic civilisation, as had been the case in the ancient world, astronomy was a sophisticated science that enjoyed much prestige. Astronomy, though at first closely connected to astrology, became, by the fourth/tenth century (or possibly the third/ninth), a more purely theoretical science of the heavens.[65] This increased distance between astron omy and astrology affected both fields, so this chapter places important developments in astronomy within the context of its relationship to astrology and to other applications and areas of religious scholarship.

The decision about whether to describe the astronomy and astrology of this chapter as 'Islamic' or as 'Arabic' deserves explanation. The appellation 'Arabic science' calls attention to the language in which many, but not all, important scientific texts were written. Arabic, too, remains the most impor tant (but not the only) language of Islamic scholarship. The term 'Islamic science' recalls the dominant religion of the science's broader context, but the participation of non Muslims in this science begs the question of the centrality of Islam to Islamic science. One leading journal in the field, *Zeitschrift für Geschichte der Arabisch Islamischen Wissenschaften*, acknowledges both terms.[66] Because users of this book are more likely to be students of Islamic civilisation than historians of science I have emphasised the intellectual and social contexts of astronomy and astrology in Islamic civilisation over the technical details.

Origins

The pre Islamic Arabs had a folk astronomy based on omens, but not lunar mansions, and perhaps a lunar calendar that they intercalated to keep pace with the solar year.[67] Isolated translations of scientific texts from Greek into

65 George Saliba, 'Astronomy and astrology in medieval Arabic thought', in Roshdi Rashed and Joël Biard (eds.), *Les doctrines de la science de l'antiquité à l'âge classique* (Leuven, 1999), pp. 137, 163.
66 Ahmad Dallal, 'Science, medicine, and technology', in John L. Esposito (ed.), *The Oxford history of Islam* (Oxford and New York, 1999), p. 158.
67 Daniel M. Varisco, 'The origin of the *anwā'* in Arab tradition', *SI*, 64 (1991).

Syriac and Pahlavi occurred in more settled regions of the pre Islamic Near East. But the explosion of scientific activity during the ʿAbbāsid caliphate was neither coincidental nor simply a continuation of translation activities in the pre Islamic Near East.[68] Social, economic and political conditions in the ʿAbbāsid caliphate, and in the earlier Umayyad caliphate, created a demand for top notch scholars and translators. The Umayyads had initially preserved the pre existing administrative apparatus of the lands they conquered. Then the caliph ʿAbd al Malik (d. 86/705), or perhaps Hishām (d. 125/743), decided to translate the administrative records of the caliphate into Arabic, which led to an influx of Arab administrators, ministers who were not proficient in Greek or Persian.[69] Information about administrative activities, such as sur veying and calendar calculation, would also have to be in Arabic for the benefit of these Arab ministers and scribes. Such practical considerations are one of the reasons why the Islamic empire would pay attention to the heritage of the civilisations that it vanquished. The ʿAbbāsid caliphs, after coming to power in 132/750, saw an additional value in the translation of scientific texts. One factor that brought the ʿAbbāsids to power was solidarity among Iranian converts to Islam. Translation, then, lent political prestige to the ʿAbbāsids by fostering a link to the Sasanian empire and thus to its real and mythical contacts with the rest of the ancient world. The acquisition of paper making technology in 132/751 from Chinese prisoners of war helped the translation movement flourish, and scientific knowledge became an asset in the socio economic competition among viziers for the caliph's favour. Literature about the education of scribes and ministers enjoined a rudimentary knowledge of scientific and technical subjects.

The earliest translations that we know of were of handbooks of astronomy with tables (Ar. *zīj*, pl. *azyāj*) in Sanskrit and Pahlavi.[70] Though the astron omers of Islamic civilisation have attained great renown for their responses to Hellenistic astronomy, Sanskrit and Pahlavi texts attracted their attention initially. The types of tables included varied slightly from *zīj* to *zīj*, but one

68 Gutas, *Greek thought, Arabic culture*, pp. 28 60.

69 Ibn al Nadīm, *Kitāb al fihrist*, ed. Gustav Flügel, 2 vols. (Cairo, 1929 30), p. 242; trans. in Franz Rosenthal, *The classical heritage in Islam*, trans. Emile and Jenny Marmorstein (Berkeley and Los Angeles, 1975), p. 48. See now George Saliba, *Islamic science and the making of the European Renaissance* (Cambridge and London, 2007), pp. 15 19 and 45 72. My account of the translation movement draws on both Saliba and Gutas's accounts.

70 The classic work on these handbooks with tables is E. S. Kennedy, 'A survey of Islamic astronomical tables', *Transactions of the American Philosophical Society*, n.s., 46, 2 (1956), p. 151. See now David King (with Julio Samsó), 'Astronomical handbook and tables from the Islamic world (750 1900), an interim report', *Suhayl*, 2 (2001).

would expect to find chronological tables, tables of trigonometric functions, the equation of time (which accounts for variations in the Sun's speed), planetary positions and positions of the fixed stars. Stars other than the Sun, Moon and five known planets (Venus, Mercury, Mars, Jupiter and Saturn) were the fixed stars.

The earliest Arabic *zīj* was *Zīj al Arkand*, composed in 117/734f. but no longer extant, based on the seventh century Sanskrit *Khaṇḍakhadyaka* of Brahmagupta.[71] In the early 150s/770s, at the court of the caliph al Manṣūr (d. 158/775), Ibrāhīm al Fazārī and Ya'qūb ibn Ṭāriq (*fl. c.* 143/760) produced translations that resulted in the *Zīj al Sindhind*.[72] This *zīj* would prove to be quite influential in al Andalus. Al Khwārizmī's (*fl.* 215/830) *Zīj al Sindhind* (no relation to the first) was the first complete, original text of astronomy from the Islamic period to survive, although not in Arabic.[73] Contemporary scholars have worked hard to determine the origin of the contents of *zīj*es. While most of the parameters in *Zīj al Sindhind* were of Indian origin, for example, some of the *zīj*'s contents derived from Ptolemy's (*fl.* 125 50) *Handy tables*. Yaḥyā ibn Abī Manṣūr's (d. 215/830) *al Zīj al Mumtaḥan* (Verified astronomical handbook with tables) contained more Ptolemaic parameters,[74] and then al Battānī's (d. 317/929) *al Zīj al Ṣābi'* (Sabian astronomical handbook with tables) indicated the ascendance of Ptolemaic planetary theory in the astronomy of Islamic civilisation.[75]

Another application to which the *zīj*es were well suited was astrological forecasting. Al Khwārizmī's *zīj* included tables with explicitly astrological applications such as the 'Table of the projections of the rays', and al Manṣūr consulted astrologers to great public effect when he commenced the construction of the new 'Abbāsid capital at Baghdad in 145/762.[76] Astronomy's contributions to astrological forecasts were an interest of those connected with the rise of astronomy in al Andalus. The caliphs of al Andalus would eventually declare their independence from the 'Abbāsids; when the *amīr*

71 David Pingree, 'The Greek influence on early Islamic mathematical astronomy', *JAOS*, 103 (1973), p. 37.

72 Ibid, p. 38.

73 'Alī ibn Sulaymān Hāshimī, *The book of the reasons behind astronomical tables:* Kitāb fī 'ilal al zījāt, trans. Fu'ād Ḥaddād and E. S. Kennedy with commentary by David Pingree and E. S. Kennedy (Delmar, NY, 1981), p. 224.

74 Ibid., p. 225.

75 Willy Hartner, 'al Battānī', in Charles Gillispie (ed.), *Complete dictionary of scientific biography*, 28 vols. (New York, 2008), vol. I.

76 Bernard Goldstein, *Ibn al Muthannā's commentary on the astronomical tables of al Khwārizmī* (New Haven, 1967); and Otto Neugebauer, *The astronomical tables of al Khwārizmī* (Copenhagen, 1962). On al Manṣūr see Gutas, *Greek thought, Arabic culture*.

Hishām (d. 180/796) gained the throne he summoned the astrologer al Ḍabbī (d. *c.* 184/800), who predicted the length of his reign.[77] Al Ḍabbī's writings, however, have no trace of the influence of the Indian, Persian or Greek texts that spurred the translation and development of astronomy and astrology under the ʿAbbāsids. After the Islamic conquest of al Andalus in 92/711 the earliest literature on astrology and astronomy in al Andalus, such as the *Libro de las cruces*, was of a Latin and Visigothic cast.[78] But during the reign of ʿAbd al Raḥmān II (r. 206 38/822 52) handbooks of astronomy with tables from the ʿAbbāsids began to appear. For example, ʿAbbās ibn Firnās (d. 274/887) or ʿAbbās ibn Nāṣiḥ (d. after 230/844) introduced al Khwārizmī's *Zīj* to al Andalus.[79] Astrology was entrenched at the royal court.[80] The late fourth/tenth century *Calendar of Córdoba* reflected not just the astronomy of the Muslim east but also the application of astronomy to religious time keeping (*mīqāt*).[81]

Applications: astrology

A key theme of the rise of astronomy in the Islamic world was astrology's place as astronomy's most significant application. Some details about several types of forecasts in astrology are in order. Omens for example, shooting stars or conjunctions of major planets such as Jupiter and Saturn were the basis for predictions about nature and nations. With horoscopic astrology the astrologer used celestial positions at the moment of a child's conception or birth to determine, for example, financial success in life. An interrogation was a type of prediction where an astrologer would be consulted to determine the optimal time for a battle or another major undertaking. Technical precision in astrology depended on accurate tables of planetary positions and some under standing of theories of planetary motion so as to predict future planetary positions. Astrology's lofty goals led its foremost defender in Islamic civilisa tion, Abū Maʿshar (d. 272/886), to present astrology as the highest natural science and to legitimise astrology with Aristotelian philosophy.[82] Astrology's

77 Julio Samsó, 'La primitiva version árabe del Libro de las Cruces', in Juan Vernet (ed.), *Nuevos estudios sobre astronomía española en el siglo de Alfonso X* (Barcelona, 1983).
78 Roser Puig, 'La astronomía en al Andalus: Aproximacíon historiográfica', *Arbor*, 142 (1992), pp. 170 1.
79 Juan Vernet and Julio Samsó, 'Development of Arabic science in Andalusia', in Roshdi Rashed and Régis Morelon (eds.), *Encyclopedia of the history of Arabic science*, 3 vols. (London and New York, 1996), vol. I, p. 248.
80 Monica Rius, 'La Actitud de los emires hacia los astrólogos: Entre la adicción y el rechazo', *Identidades marginales (Serie Estudios Onomástico Bibliográficos de al Andalus)*, 13 (2003).
81 Puig, 'La astronomía', p. 171.
82 Abū Maʿshar, *al Madkhal al kabīr ilā ʿilm al nujūm*, ed. Richard Lemay (Naples, 1995).

inability to live up to its ambitious claims elicited critiques that would widen the gap between astrology and astronomy.

Applications: service of Islam

Astronomy's ability to provide answers to practical problems in Islam was an excellent justification for pursuit of that science.[83] Such religious applications justified astronomy in the face of its most dogged sceptics. After the revelation of verse Q 2:144 ('Turn your face towards the sacred mosque') the sacred direction of prayer, the *qibla*, became the direction of Mecca, specifically the Kaʿba.[84] Outside Mecca, *qibla* determination was more difficult and very important, both for marking the *qibla* in mosque construction and for individuals praying away from a mosque. Inexact methods of *qibla* determi nation pre dated the technical. Islamic literature mentions methods of approx imating the *qibla* based on wind directions and the rising and setting of certain stars (*anwāʾ*). The Kaʿba itself, a structure that antedates Islam, was oriented with respect to certain astronomical phenomena and to wind directions. Because Muḥammad's sayings were a source of revealed knowledge, a saying of Muḥammad to the effect that the *qibla* was to the south was sufficiently influential so that mosques constructed through the early second/eighth century in locales to the north west of Mecca nevertheless faced due south. The research of David King has shown that even after mathematical solutions of the *qibla* problem appeared, there endured a parallel popular literature that answered the same questions in a less exacting manner. How, when and where different techniques of *qibla* computation were employed remain open questions.

Technical solutions to the *qibla* problem appeared perhaps by the end of the second/eighth century and certainly by the third/ninth.[85] The *qibla* problem was akin to the construction of a great circle arc, measured on the local meridian either from the north or from the south, between the given locale and Mecca. The angle between that great circle arc and the local meridian, measured from the south, is the *qibla* angle. Because this arc is on the surface of a sphere, and not a plane, one's intuition of the *qibla* direction is imprecise. A precise solution requires knowledge of the differences in

83 David King, 'The sacred direction in Islam: A study of the interaction of religion and science in the Middle Ages', *Interdisciplinary Science Reviews*, 10 (1985), p. 319.

84 David King, 'Astronomy and Islamic society: Qibla, gnomonics, and timekeeping', in Rashed and Morelon (eds.), *Encyclopedia of the history of Arabic science*, vol. I. I draw on this article for the rest of the paragraph.

85 David King, 'Ḳibla', *EI2*, vol. V, pp. 83 8.

longitude and latitude between Mecca and the given locale. Although rudimentary spherical trigonometry, in the form of the Menelaus theorem, was available from Hellenistic texts, other solutions to the *qibla* problem elicited the most elegant formulae of spherical trigonometry that scientists had ever developed.

Of importance too were analemmas, solutions in which one projects the celestial sphere and its arcs onto a plane. The simplest analemmas were serviceable approximations: the Earth was at the centre of a circle and diameters passed from the cardinal points through the centre of the circle. Then, the difference in longitude was an arc on the circumference from the north south diameter; the difference in latitude was an arc on the circum ference from the east west diameter. The endpoint of the arc of the difference in longitude became the endpoint for a chord parallel to the north south diameter, and the same for the difference in latitude and the east west diameter. The approximate *qibla* was the line from the circle's centre through the intersection of the chords. Other analemmas, such as Ḥabash al Ḥāsib's (*fl. c.* 236/850), were more complex, but accurate because they transformed a spherical problem, through fully accurate geometrical constructions, into a planar problem.[86] Ibn al Haytham (d. *c.* 432/1041) devised a universal solution to the *qibla* problem.[87] Ultimately, al Khalīlī (*fl.* 767/1365) computed *qibla* tables for all longitudes and latitudes. David King has uncovered two world maps for determining the *qibla*.[88] The efforts necessary to develop the precise solutions served double duty because the *qibla* problem was analogous to other prob lems in timekeeping.

ʿ*Ilm al mīqāt* (religious timekeeping) computed times for the five daily prayers (daybreak, midday, afternoon, sunset and nightfall).[89] Of the five, the timing of the afternoon prayer was in especial need of analysis.[90] Early Islamic sources had defined the time of that prayer to be when the length of a shadow was equal to the height of a gnomon casting a shadow. This phenom enon could not occur at certain latitudes at certain times of the year. So, by the

86 Yūsuf ʿĪd and E. S. Kennedy, 'Ḥabash al Ḥāsib's analemma for the qibla', *Historia Mathematica*, 1 (1974).
87 Ahmad S. Dallal, 'Ibn al Haytham's universal solution for finding the direction of the *qibla* by calculation', *Arabic Sciences and Philosophy*, 5 (1995).
88 David King, *World maps for finding the direction and distance to Mecca: Innovation and tradition in Islamic science* (London, Leiden, Boston and Cologne, 1999), p. xiii.
89 David King, 'Mīḳāt', *EI2*, vol. VII, pp. 27 32. See now David King, *In synchrony with the heavens: Studies in astronomical timekeeping and instrumentation in medieval Islamic civilization*, 2 vols. (Leiden, 2004 5).
90 E. S. Kennedy, 'al Bīrūnī on the Muslim times of prayer', in Peter Chelkowski (ed.), *The scholar and the saint* (New York, 1975).

third/ninth century, legal scholars had to redefine the time of the afternoon prayer to be when the shadow was equal to the length of the shadow at midday plus the length of the gnomon. The definition of midday was when the Sun was at its highest altitude for the day, and at that time the shadow was at its shortest. Al Khwārizmī's development of prayer tables served the causes of both convenience and accuracy.[91] *Mīqāt* served astronomers by providing an institutional foothold in the seventh/thirteenth century with the develop ment of the office of *muwaqqit*.[92]

A final example of a religious application of astronomy is lunar crescent observation. The Islamic calendar is lunar, and the beginning of a new month depends on the observation of the new crescent Moon on the evening of the twenty ninth day of the old month; the precise length of a lunar month is 29.54 days. The visibility of the lunar crescent, a problem which astron omers of Islamic civilisation treated with greater energy than Hellenistic astronomers, was especially complex because multiple variables were involved. Yaʿqūb ibn Ṭāriq was one of the early scientists to work on this problem, and Ḥabash al Ḥāsib's *zīj* included a table of lunar crescent visibil ities.[93] Another solution, one that considered four variables, comes from Thābit ibn Qurra (d. 288/901).[94] Thābit calculated the four variables for the evening of the twenty ninth day of a month: the angular distance between the Sun and the Moon; the arc of the Sun's depression under the horizon; the Moon's angular distance on the horizon from the horizon's brightest spot; and the Moon's motion on its epicycle. Then he computed the crescent's arc of visibility from all but the second. If the arc of depression was greater than the arc of visibility, then the Moon was visible. Thābit's contributions are notable not only for their sophistication, but also for how they show that a non Muslim could participate fully in science in Islamic civilisation. Though scholars disagree over the contribution of astronomy's applications to the rise of that science in Islamic civilisation, certain applications did pose interesting theoretical questions.

91 E. S. Kennedy and Mardiros Janjanian, 'The crescent visibility table in al Khwārizmī's *Zīj*', *Centaurus*, 20 (1965 7).

92 David King, 'On the role of the muezzin and *muwaqqit* in medieval Islamic society', in F. Jamil Ragep and Sally P. Ragep (eds.), with Steven Livesey, *Tradition, transmission, transformation: Proceedings of two conferences on pre modern science held at the University of Oklahoma* (Leiden, 1996).

93 Kennedy, 'A survey', p. 152; Marie Thérèse Debarnot, 'The zīj of Ḥabash al Ḥāsib: A survey of MS Istanbul Yeni Cami 784/2', in David King and George Saliba (eds.), *From deferent to equant* (New York, 1987).

94 Régis Morelon, 'T̲ābit b. Qurra and Arabic astronomy in the ninth century', *Arabic Sciences and Philosophy*, 4 (1994), pp. 118 22.

The astrolabe

All of these applications, whether religious or astrological, involved time keeping in some way. The best *zīj* would be of no use without knowledge of one's location and the time of day or night. Among the instruments available to Islamic astronomers were sundials, armillary spheres and magnetic com passes (by the seventh/thirteenth century); the most popular and versatile instrument was the astrolabe (see plate 22.1).[95] The astrolabe was an analogue computer perfect for timekeeping, a variety of mathematical computations, astrological predictions and even sighting stars. The plate of an astrolabe is a projection onto the plane of the equator of the celestial longitude (azimuth) lines for a given latitude. Over this plate rested a see through grid, known as the spider (Ar. *al ʿankabūt*) or rete, which was a planar map of chosen constellations. One would use the alidade, similar to a rotating ruler with sights on it, to sight an object in the heavens. One then rotated the rete so that the sighted object, and thus all other objects, was in its appropriate location on the map of the heavens engraved on the astrolabe plate. While specific features of astrolabes might differ, material frequently engraved on astrolabes would often include curves to determine trigonometric functions, sundials and astrological diagrams.

Significant developments in astrolabe design occurred in al Andalus. In the fifth/eleventh century ʿAlī ibn Khalaf and Ibn al Zarqālluh designed a univer sal plate that could solve problems of spherical astronomy for all latitudes, although universal astrolabes could not provide a picture of the heavens on the plate.[96] Emilia Calvo's research has brought to light the improved univer sal plate of Ibn Bāṣo (d. 716/1316), who became chief *muwaqqit* in Granada.[97] Ibn Bāṣo's plate was reproduced throughout Europe.[98]

The significance of Ptolemy's Almagest

Further developments in astronomy and its applications, astrological and religious, cannot be understood outside the context of the implications of

95 Willy Hartner, 'Aṣṭurlāb', *EI2*, vol. I, pp. 722 8.
96 These scientists were aware of research in the Islamic east (al Mashriq). See Roser Puig, 'On the eastern sources of Ibn al Zarqālluh's orthographic projection', in Josep Casulleras and Julio Samsó (eds.), *From Baghdad to Barcelona: Studies in the Islamic exact sciences in honour of Prof. Juan Vernet* (Barcelona, 1996). See also Ibn al Zarqālluh, *al Shakkāziyya*, ed., trans. and comm. Roser Puig (Barcelona, 1986).
97 Emilia Calvo, 'Ibn Bāṣo's astrolabe in the Maghrib and the east', in Casulleras and Samsó (eds.), *From Baghdad to Barcelona*.
98 Emilia Calvo, 'Ibn Bāṣo's universal plate and its influence on European astronomy', *Scientiarum Historia*, 18 (1992).

22.1 Astrolabe. Courtesy of the Whipple Museum, Cambridge.

the reception of Ptolemy's planetary theory. Ptolemy was the single most influential astronomer, Hellenistic or otherwise, for Islamic astronomy and astrology. Islamic astronomers' introduction to him came, as I have men tioned, via the growing presence of Ptolemaic parameters in the *zījes*. Little time elapsed before the surviving third/ninth century translations of Ptolemy's *magnum opus*, the *Almagest*.[99] The *Almagest*'s significance was that

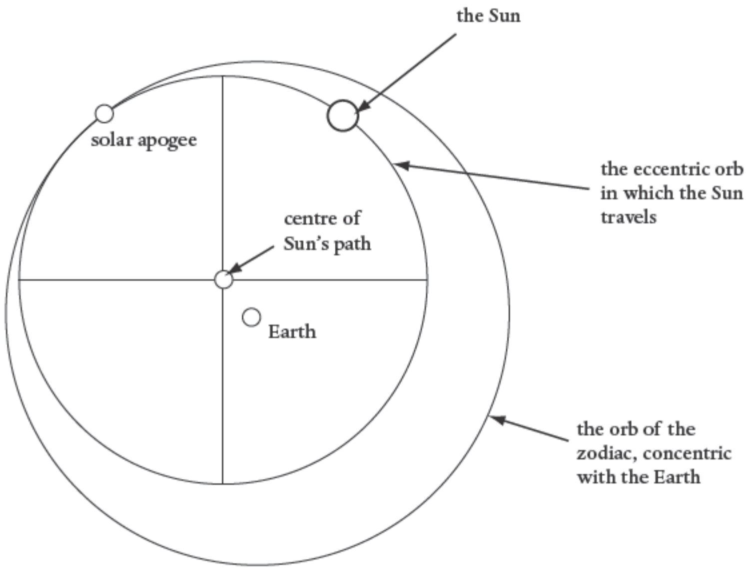
99 Paul Kunitzsch, *Der* Almagest: *Die Syntaxis mathematica des Claudius Ptolemäus in arab. latein. Überlieferung* (Wiesbaden, 1974), pp. 60 71.

it used a wealth of observational data to derive geometrical abstractions of a physical model of the heavens. The *Almagest* allows one to compute, on the basis of the geometrical models, tables of planetary positions. A popular (judging by the number of surviving manuscripts) recension of the *Almagest* translations by Naṣīr al Dīn al Ṭūsī (d. 672/1273f.) appeared in the seventh/thirteenth century. Al Ṭūsī's recension spawned, through the tenth/sixteenth century, the composition of a host of commentaries. Even the commentators' complaints about astronomers' unfamiliarity with the original *Almagest* evince its enduring relevance.

Astronomers must have reassessed important parameters as the transla tions of the *Almagest* were occurring, because the later translations of the *Almagest* have parameters different from those in the original. Indeed, astron omers under the caliph al Ma'mūn (d. 218/833) started a programme of observation, mostly in the vicinities of Baghdad and Damascus, that addressed observational questions raised by the early *Almagest* translations.[100] These astronomers produced new values for important parameters such as the length of a solar year and the dimensions of the solar model. These observa tions resulted in *al Zīj al Mumtaḥan*.[101] Just as translations created more possi bilities for research, research (which could include translation) sparked more translations because a surviving *Almagest* translation was produced after al Ma'mūn's death. Massive instruments were involved, such as a mural quadrant with a radius of five metres. Through these observations Islamic astronomers found, notably, that the solar apogee (the point of the Sun's greatest distance from the Earth) moved independently (see fig. 22.1).[102] Mathematical analyses of the solar apogee's motion ensued.

Astronomers took an interest in Ptolemy's other texts, and by the end of the third/ninth century Thābit ibn Qurra and others produced a trans lation of the *Planetary hypotheses*.[103] In that text Ptolemy summarised his model of the heavens in wholly physical terms. Ptolemy's physical princi ples, which he sometimes compromised for the purpose of predictive

100 Aydin Sayılı, *The observatory in Islam and its place in the general history of the observatory* (Ankara, 1960), pp. 56 63.
101 Benno van Dalen, 'A second manuscript of the *Mumtaḥan Zīj*', *Suhayl*, 4 (2004), pp. 28 30.
102 Régis Morelon, 'Eastern Arabic astronomy', in Rashed and Morelon (eds.), *Encyclopedia of the history of Arabic science*, vol. I, p. 26.
103 Bernard R. Goldstein, *The Arabic version of Ptolemy's* Planetary hypotheses (Philadelphia, 1967). For an edition and French translation of the first book see Régis Morelon, 'La version arabe du *Livre des hypothèses* de Ptolémée', *Mélanges de l'Institut Dominicain des Études Orientales du Caire*, 21 (1993).



22.1 The solar apogee, the Sun's greatest distance from the Earth

accuracy, assumed, supposedly, that the motions of the heavens resulted from combinations of orbs that rotated uniformly in place about an axis passing through their centre. And just as al Ma'mūn's astronomers revised Ptolemy's parameters, Ptolemy's views about how concentric orbs could move each other came into question.[104] The attention to the physical consistency of astronomical theories that would lead to the outstanding innovations of the seventh/thirteenth century and beyond had already emerged.

The astronomy of the ninth, tenth and eleventh centuries

The general impression scholarship has provided of the astronomy of the third/ninth, fourth/tenth and fifth/eleventh centuries is that topics of math ematical and observational astronomy were paramount. ʿAbd al Raḥmān al Ṣūfī (d. 376/986) focused on observations and instrumentation and pro duced a book on fixed stars that was best known in al Andalus, Iran and

104 George Saliba, 'Early Arabic critique of Ptolemaic cosmology: A ninth century text on the motion of the celestial spheres', *Journal for the History of Astronomy*, 25 (1994).

Europe.[105] Thābit ibn Qurra's involvement with the translation of the *Almagest* led to mathematical studies of important problems from the *Almagest*. Thābit was the first to ask the question of a mobile's speed at a particular point.[106] A host of theoretical questions arose from the construction of instruments such as sundials, an instrument necessary for the determination of prayer times.[107] Most sundials have to be recalibrated for different latitudes. Thābit produced mathematical analyses of a sundial valid for all latitudes, and his interest in that instrument led him to purely theoretical examinations of conic sections. Thābit's grandson Ibrāhīm ibn Sīnān (d. 335/946) extended Thābit's analysis of sundials and conic sections. Ibrāhīm was particularly interested in the application of the geometry of conic sections to lenses and burning mirrors.

While much of al Bīrūnī's (d. *c.* 442/1050) output is probably lost, what has survived is prodigious by any standard. He too was a gifted ethnographer (to wit his *India*) and historian of insatiable curiosity, upon whom we rely for much of our history of observations in Islamic civilisation. A native speaker of Khwārazmian, al Bīrūnī had to depend on the study of foreign languages, and composed works in Arabic and Persian. He also translated several texts from Sanskrit into Arabic, and knew something of Greek, Hebrew and Syriac. In astronomy, his most important work was an enormous *zīj* entitled *al Qānūn al Masʿūdī*.[108] His study of Greek, Hebrew and particularly Sanskrit, among other languages, meant that the section of *al Qānūn al Masʿūdī* on calendars was a few hundred pages long. He treated topics of descriptive and mathe matical geography in exhaustive detail, too. Al Bīrūnī's knowledge of the history of his subject allowed him to present the range of available approaches to solving a problem, from the common to the elegant and refined. His mathematical analysis of the motion of the solar apogee stands out.[109] Al Bīrūnī's *Kitāb maqālīd ʿilm al hayʾa* (Book of the keys of astronomy) was an important work on spherical trigonometry that also had a section on *hayʾa*'s astrological applications.[110] Abū al Wafāʾ al Būzajānī (d. *c.* 387/997f.), whose

105 Julio Samsó and Mercè Comes, 'al Ṣūfī and Alfonso X', *Archives Internationales d'Histoire des Sciences*, 38 (1988).
106 Morelon, 'T̄ābit b. Qurra'.
107 Roshdi Rashed and Hélène Bellosta, *Ibrāhīm ibn Sīnān: Logique et géométrie au Xe siècle* (Leiden, Boston and Cologne, 2000).
108 al Bīrūnī, *Kitāb al qānūn al masʿūdī*, 3 vols. (Hyderabad, 1954 6).
109 W. Hartner and M. Schramm, 'al Biruni and the theory of the solar apogee: An example of originality in Arabic science', in A. C. Crombie (ed.), *Scientific change* (London, 1963).
110 al Bīrūnī, *Kitāb maqālīd ʿilm al hayʾa: La trigonométrie sphérique chez les Arabes de l'est à la fin du Xe siècle*, ed. and trans. Marie Thérèse Debarnot (Damascus, 1985), pp. 276 90.

work was a foundation for al Bīrūnī's research, co operated with him on simultaneous lunar eclipse observations in two different cities.[111] By comparing local time at the time of the eclipse they could obtain the difference in longitude between the cities. In addition to his observational work, Abū al Wafā' al Būzajānī wrote a book, entitled *al Majisṭī* (The almagest), on spherical trigonometry.

Finally, recent research has shown that theoretical questions did not escape the attention of these astronomers. For example, when Thābit critiqued the assumptions underlying the physical operation of Ptolemy's lunar model, he did not assume a qualitative difference between celestial and terrestrial physics; when Ptolemy spoke of the heavens as unchanging, he had implied such a distinction. There are seeds of an important transformation of astronomy from a branch of natural philosophy in the Hellenistic tradition to a science that could and should stand on its own. For instance, al Bīrūnī rejected the necessity of any relationship between astronomy and physics, specifically Ptolemy's recourse to the findings of physics to prove the sphericity of the heavens.[112] By doing so, Ptolemy, in al Bīrūnī's view, added nothing to astronomy's prestige. Conversely, when Ptolemy insinuated that observations could prove that the Earth was at rest, i.e. not rotating in place, al Bīrūnī agreed. Later, in the ninth/fifteenth century, al Qūshjī (d. 879/1474) would argue that since observations could not prove that the Earth was not rotating, there was no impediment to considering the Earth's rotation.[113] We have seen that critiques of Ptolemy's attention to physical principles emerged relatively early in the history of astronomy in Islamic civilisation. These critiques broadly resembled attacks on astrology's claims about physical causes.

The eleventh and twelfth centuries in Andalusia

Abu 'l Qāsim Maslama al Majrīṭī's (d. *c.* 398/1007) adaptation of al Khwārizmī's *Zīj* to al Andalus was a harbinger of a productive period of astronomy in al Andalus.[114] The best known figure of the period was Ibn al Zarqālluh (d. 493/1100). A contributor to the *Toledan tables* of Ṣā'id al Andalusī, Ibn al Zarqālluh was also the first known Islamic astronomer to write that the

111 al Bīrūnī, *Kitāb taḥdīd nihāyāt al amākin li taṣḥīḥ masāfāt al masākin*, ed. P. Bulgakov (Cairo, 1964), p. 250.
112 F. Jamil Ragep, 'Ṭūsī and Copernicus: The Earth's motion in context', *Science in Context*, 14 (2001).
113 F. Jamil Ragep, 'Freeing astronomy from philosophy: An aspect of Islamic influence on science', *Osiris*, n.s. 16 (2001).
114 Juan Vernet, 'al Madjrīṭī', *EI2*, vol. V, pp. 1109 10.

motion of the solar apogee was not equal to the motion in precession, and thus not equal to the motion of the ecliptic.[115] Ibn al Kammād's (*fl.* sixth/twelfth century) *zīj* tells us about Ibn al Zarqālluh's solar theory, and Ibn al Hā'im (*fl.* 602/1205) relied on Ibn al Zarqālluh's solar theory.[116] Connected to Ibn al Zarqālluh's work on the universal astrolabe was his instrument that deter mined the Earth Moon distance graphically.[117]

During the fifth/eleventh and sixth/twelfth centuries astronomers in al Andalus devoted more attention than their counterparts in the Islamic east to the development of theories to explain trepidation and variations in the obliquity of the ecliptic. The obliquity of the ecliptic is the angle, in the vicinity of 23.5°, between the celestial equator and the zodiac. Astronomers had also believed that they detected trepidation, variations in the Sun's position in the zodiac at the time of the equinoxes. Theories to explain one or both of these phenomena depended on accurate measurements of these parameters. Observations throughout the history of astronomy in Islamic civilisation, at the seventh/thirteenth century observatory at Marāgha for example, pro duced new values for the rate of precession. Although the existence of both trepidation and variations in the obliquity was always open to question, astronomers nevertheless did develop models first for trepidation, and then for both phenomena in combination. Such models had originated in the work of eastern astronomers such as Thābit ibn Qurra and al Battānī.[118]

The first combined theories showed only how one model could account for both phenomena. Andalusians such as Ibn al Zarqālluh and Ibn al Hā'im proposed more sophisticated models that considered the precise parameters of both the changes in the obliquity and trepidation, and acknowledged that the ranges of their variation were different.[119] The models that explain both phenomena in combination are of historical importance due to their structural similarities with the models that Andalusian astronomers would develop to try to reform Ptolemy. Astrologers, for their part, were quite interested in

115 G. J. Toomer, 'The solar theory of al Zarqāl: A history of errors', *Centaurus*, 14 (1969).

116 José Chabás and Bernard Goldstein, 'Andalusian astronomy: *al Zīj al muqtabis* of Ibn al Kammād', *Archive for the History of the Exact Sciences*, 48 (1994); see also Emilia Calvo, 'Astronomical theories related to the Sun in Ibn al Hā'im's *al Zīj al kāmil fi'l ta'ālīm*', *ZGAIW*, 12 (1998).

117 Roser Puig, 'al Zarqālluh's graphical method for finding lunar distances', *Centaurus*, 32 (1989).

118 F. Jamil Ragep, 'al Battānī, cosmology, and the early history of trepidation in Islam', in Casulleras and Samsó (eds.), *From Baghdad to Barcelona*, pp. 353 4.

119 Mercè Comes, 'Ibn al Hā'im's trepidation model', *Suhayl*, 2 (2001).

the impact of trepidation and variations in the obliquity of the ecliptic on forecasts.

Changes in the discipline of astronomy

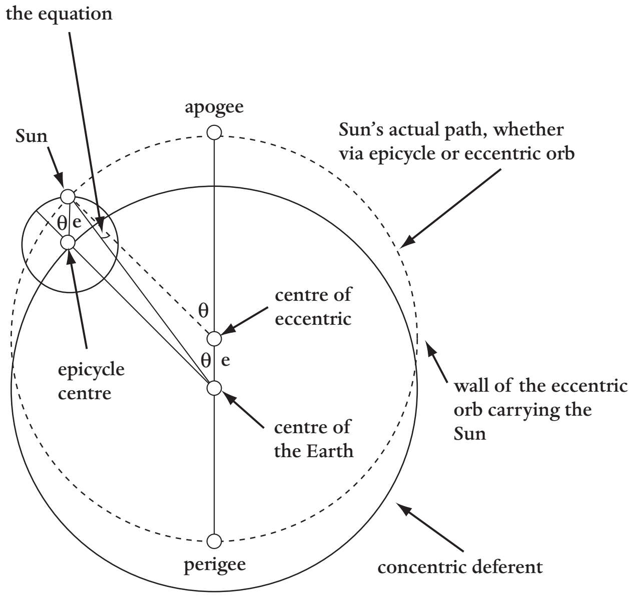
By the fourth/tenth century critiques of astrology had come to a head in the Islamic east. These critiques would force astronomy to become more independent not only of astrology but also of the natural philosophy upon which astrology depended. Al Bīrūnī wrote against astrology in his *al Qānūn al Masʿūdī*; and his handbook of astrology, *Kitāb al tafhīm* (Book of instruc tion), was composed for a royal patron and adopted a distanced position. Astrology's prestige relative to astronomy's other applications had declined. Why did astrology's position decline? Writers in the ancient world such as Cicero, in *De divinatione*, and Augustine, in *City of God*, formulated cogent critiques of astrology that resurfaced after the rise of Islam. Astrology threatened God's absolute unity and omnipotence. Astrologers were also often wrong, and had difficulty explaining why, for example, identical twins could lead lives that were not at all identical. More important, as even Hellenistic texts had distinguished between astronomy and astrology, the most serious arguments against astrology attacked its foundations in Hellenistic philosophy.[120] Astronomy shared with astrology many of those foundations.

Ibn Sīnā (d. 428/1037), who refuted many of astrology's claims himself, produced a text on the classification of the sciences in which astrology (*ʿilm aḥ kām al nujūm*) and astronomy (*ʿilm al hayʾa*) were no longer grouped together in the same category.[121] Ibn al Akfānī's (d. 749/1348) classification of the sciences presented an *ʿilm al hayʾa* that concentrated on holistic qualitative and quantitative descriptions of the orbs.[122] This new type of *ʿilm al hayʾa* had become the locus for most of Islamic astronomy's outstanding achievements.

Considerations of physical consistency

ʿIlm al hayʾa texts maintained an overt distance from questions of metaphysics. Instead, writers on *ʿilm al hayʾa* asked descriptive questions. Ibn al Haytham

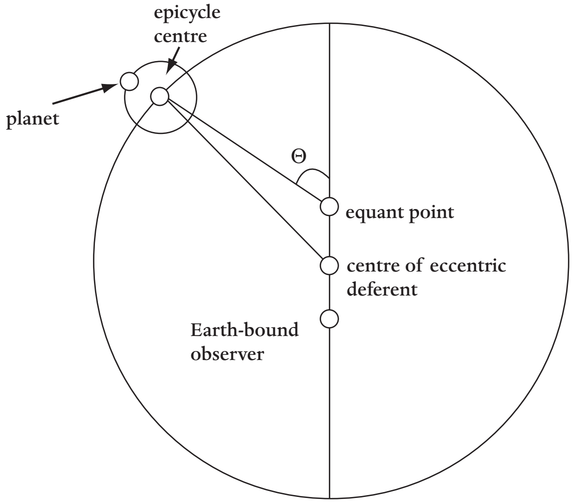
120 Saliba, 'Astronomy and astrology', p. 152.
121 Ibn Sīnā, 'Fī aqsām al ʿulūm al ʿaqliyya', in *Tisʿ rasāʾil fī al ḥikma wa ʾl ṭabīʿiyyāt* (Constantinople, 1880), pp. 71 81.
122 Ibn al Akfānī, *Irshād al qāṣid ilā asnā al maqāṣid*, ed. ʿAbd al Laṭīf Muḥammad al ʿAbd (Cairo, 1978), p. 144.



22.2 Eccentric and epicyclic orbs, two hypotheses for celestial motions

(d. *c.* 432/1041) asked whether Ptolemy's configurations of orbs could move as described, and found that they could not. Ibn al Haytham's *al Shukūk ʿalā Baṭlamyūs* (Doubts against Ptolemy) catalogued the physical inconsistencies of Ptolemy's *Almagest* and *Planetary hypotheses*.[123] On one level Ptolemy transgressed Aristotle's principle that the observed celestial motions result from combinations of uniformly rotating orbs; on another, Ibn al Haytham's critiques arose from a consideration of how orbs must rotate. An orb could not rotate uniformly about an axis that did not pass through the orb's centre.[124] The model for the Sun's motions is an excellent introduction to the foundation of all Ptolemaic (and Islamic) planetary theory. The simplest model would be to suppose that the Sun moves embedded in the wall of an orb (see fig. 22.2); the Earth would be at the centre of that orb. Babylonian astronomers, however, had observed variations in the Sun's motion, and Ptolemy used,

123 Ibn al Haytham, *al Shukūk ʿalā Baṭlamyūs*, ed. A. I. Sabra and Nabil Shehaby (Cairo, 1971).
124 See A. I. Sabra, 'Configuring the universe: Aporetic, problem solving, and kinematic modeling as themes of Arabic astronomy', *Perspectives in Science*, 6 (1998); George Saliba, 'Arabic versus Greek astronomy: A debate over the foundations of science', *Perspectives in Science*, 8 (2000); A. I. Sabra, 'Reply to Saliba', *Perspectives in Science*, 8 (2000).



22.3 The equant point, the centre of the planet's mean motion, but not the centre of any orb

as Hipparchus had, these variations to refine a solar model.[125] If the centre of the Sun's orb were removed from the centre of the Earth, the resulting model would account for the observed anomalies. In addition, Ptolemy noted that if the Sun were moving on a small circle known as an epicycle, which was carried in turn on a large circle at whose centre was the Earth, an equivalent motion would result.

In the models for the outer planets (Mars, Jupiter and Saturn) Ptolemy employed the principle of an orb eccentric to the centre of the Earth to account for the planet's mean motion in longitude. An analogy with the solar model would suggest that the centre of the planet's motion on the eccentric orb is at the centre of that orb, from which the centre of the Earth was removed by a given amount. Ptolemy's careful analysis found that the centre of the planet's mean motion in longitude was not the centre of the eccentric deferent orb. Nor was that motion uniform about the centre of the Earth. The motion was uniform about another point called the equant (see fig. 22.3), which was removed from the centre of the orb on the opposite side from the Earth. Indeed, the fact that the eccentric orb, according to Ptolemy, would have to rotate uniformly about a point other than its centre

125 Otto Neugebauer, *History of ancient mathematical astronomy*, 3 vols. (New York, Heidelberg and Berlin, 1975), vol. I, p. 56.

contradicted the Aristotelian principle of the heavens' uniform circular motion. Moreover, one could not conceive of an orb moving in place about an axis that did not pass through its centre. So Ptolemy's innovative mathe matical approach to determining the centre of the planet's motion on the eccentric orb led to the problem of the equant that Ibn al Haytham noted.

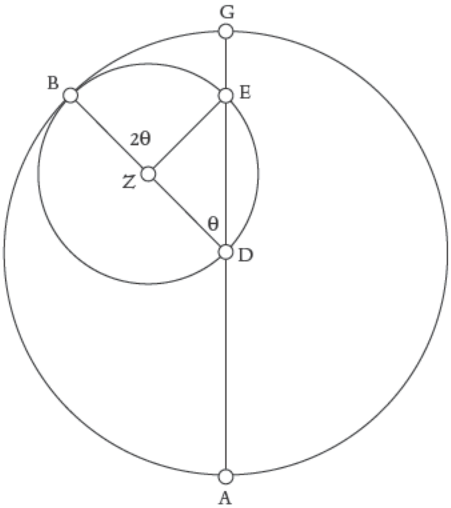
Related to the problem of the equant were other cases where Ptolemy had failed to propose a conceivable physical mover for observed motions of the celestial bodies. Ibn al Haytham's doubts were not restricted to matters of physical consistency; he noted the discrepancy between the apparent and predicted size of the Sun. Indeed, the ensuing programme to reform Ptolemy was comprehensive.

The reforms of the Maragha astronomers

Beginning in the mid seventh/thirteenth century, Islamic astronomers pro posed new models that preserved, and in some cases improved, Ptolemy's models' correspondence with observations. These models did not suffer from the physical inconsistencies arising from the equant point. In other words, these new, non Ptolemaic models no longer posited that the axis of any orb's uniform motion should pass through the equant. Many figures in that line of research who wrote *ʿilm al hayʾa* texts with these new models, such as Muʾayyad al Dīn al ʿUrḍī (d. 664/1266), Naṣīr al Dīn al Ṭūsī (d. 672/1273f.), and Quṭb al Dīn al Shīrāzī (d. 711/1311), were associated with the Marāgha Observatory in Azerbaijan.[126] Later figures, such as Ṣadr al Dīn al Sharīʿa (d. 747/1347) and Ibn al Shāṭir (d. 777/1375), composed works in the intellectual tradition of the astronomers at Marāgha.[127] Al ʿUrḍī was, in addition, respon sible for the engineering of the Marāgha Observatory's instruments that were a part of the observational programme there. These instruments' design was influential, and would later be mirrored, for example, by the instruments at the Jai Singh Observatory in Jaipur, India. Though Ibn al Shāṭir's theories

126 On al ʿUrḍī's astronomy see George Saliba, *The astronomical work of Muʾayyad al Dīn al ʿUrḍī (*Kitāb al hayʾa*): A thirteenth century reform of Ptolemaic astronomy* (Beirut, 1990). On al Ṭūsī's astronomy see F. J. Ragep (ed., trans. and comm.), *Naṣīr al Dīn al Ṭūsī's memoir on astronomy (*al Tadhkira fī ʿilm al hayʾa*)*, 2 vols. (New York and Berlin, 1993). On al Shīrāzī's astronomy see George Saliba, 'Arabic planetary theories after the eleventh century AD', in Rashed and Morelon (eds.), *Encyclopedia of the history of Arabic science*. See now Robert Morrison, 'Quṭb al Dīn al Shīrāzī's hypotheses for celestial motions', *Journal for the History of Arabic Science*, 13 (2005).

127 Ahmad Dallal, *An Islamic response to Greek astronomy:* Kitāb taʿdīl al aflāk *of Ṣadr al Sharīʿa* (Leiden, Cologne and Boston, 1995). See also George Saliba, 'Theory and observation in Islamic astronomy: The work of Ibn al Shatir of Damascus (d. 1375)', *Journal for the History of Astronomy*, 18 (1987).



22.4 The Ṭusı Couple, the basis of a model that solved the equant problem

improved on those of the astronomers at Marāgha, his revised solar model relied on observational considerations. The Marāgha Observatory was nota ble, too, because it drew its financial support from the revenues of a *waqf*, an endowment to serve religious purposes. The construction of non Ptolemaic models continued at least into the tenth/sixteenth century, as Shams al Dīn al Khafrī (d. 957/1550) proposed multiple mathematically equivalent models for the complicated motions of the planet Mercury.[128] In addition, a circum stantial link has appeared between the Marāgha astronomers and Renaissance astronomers such as Copernicus.[129]

Al Shīrāzī, al Ṭūsī's student, enumerated in his writings four hypotheses or principles (*uṣūl*) common to these post Ptolemaic models. One of these hypo theses was the Ṭūsī Couple, so named by contemporary scholars because it first appeared in the work of al Ṭūsī. It was based on the following lemma: we assume a small circle inside a large circle, with the radius of one the diameter of the other, and their circumferences are tangent at a given point (see fig. 22.4).

128 George Saliba, 'A redeployment of mathematics in a sixteenth century Arabic critique of Ptolemaic astronomy', in A. Hasnawi, A. Elamrani Jamal and M. Aouad (eds.), *Perspectives arabes et médiévales sur la tradition scientifique et philosophique grecque* (Leuven and Paris, 1997).
129 Saliba, *Islamic science*, pp. 193 232 and F. Jamil Ragep, ''Alī Qushjī and Regiomontanus: Eccentric transformations and Copernican revolutions', *Journal for the History of Astronomy*, 36 (2005).

If the large circle moves in one direction with a given angular velocity, and the small circle moves in the opposite direction at twice that angular velocity, then a given point oscillates on the diameter of the large circle. If these circles become the belts of orbs, one has the foundation of a physically consistent model in which the planet's mean motion is uniform about the equant point. Al Shīrāzī used the Ṭūsī Couple to rebut Aristotle's statement in the *Physics* (262a) that there must be rest between two contradictory motions; al Shīrāzī in addition mentioned an experiment one could perform to disprove Aristotle's contention that there must be rest between two contradictory motions.[130] Al Shīrāzī's challenge to Aristotle demonstrates that the astronomers of Islamic civilisation, perhaps because of criticisms of astrology and Hellenistic philosophy, came to be less interested in defending particular principles of Aristotle than in physically coherent models.

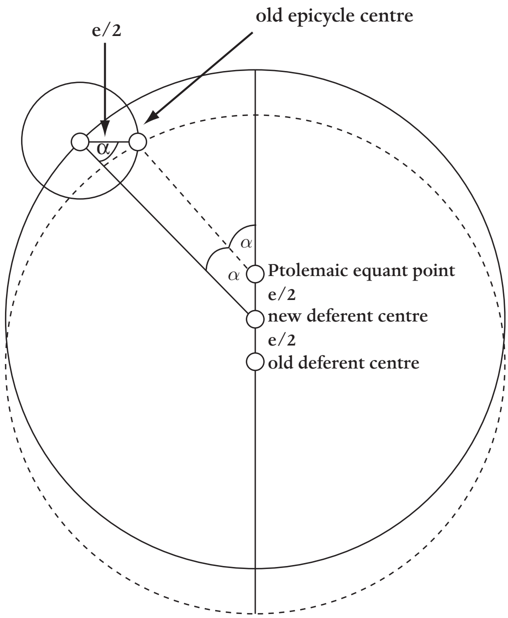
A second important hypothesis or principle of the post Ptolemaic models drew on the equivalence between the eccentric and epicyclic hypotheses present in the two versions of Ptolemy's solar model. If we think of the distance between the equant point and the centre of the deferent orb as an additional eccentricity, then one could attempt to account for the equant point with an additional epicycle to carry the original epicycle centre. That solution, however, proposed by Ibn Sīnā's student Abū ʿUbayd al Jūzjānī, distorted planetary distances.[131] Al ʿUrḍī made the theory conform with observations by proposing a second epicycle (see fig. 22.5) whose radius was half the distance between the centre of the Ptolemaic deferent and the equant centre.[132] That new epicycle would rotate in the same direction and with the same angular velocity as the new deferent, whose centre was halfway between the centre of the old deferent and the equant point. The result was that the motion of a point on the new epicycle would be uniform about the equant point and would almost (but not quite) trace the path of the epicycle centre in the Ptolemaic model. Rather than explain away that remaining discrepancy with the Ptolemaic model, al ʿUrḍī contested Ptolemy's assumption of a perfectly circular path for the epicycle centre.[133] After all, conclusive observa tional proof to support a circular path for the epicycle centre did not exist.

130 The experiment that al Shīrāzī proposed might be due, originally, to Ibn Buṭlān. See Roshdi Rashed, 'al Qūhī versus Aristotle on motion', *Arabic Sciences and Philosophy*, 9 (1999), pp. 17 18.

131 George Saliba, 'Ibn Sīnā and Abū ʿUbayd al Jūzjānī: The problem of the Ptolemaic equant', *Journal for the History of Arabic Science*, 4 (1980).

132 George Saliba, 'The original source of Quṭb al Dīn al Shīrāzī's planetary model', *Journal for the History of Arabic Science*, 3 (1979).

133 Saliba, *Astronomical work*, p. 223.



22.5 al ʿUrḍı's model for planetary motions, based on the equivalence of angles at the base of a parallelogram

Philosophers and earlier astronomers had posited such a circular path based on empirical evidence.

Reforms of Ptolemaic astronomy in al Andalus

In al Andalus the critique of Ptolemy began at a different starting point. In the sixth/twelfth century philosophers such as Ibn Bājja (d. 533/1138) and Ibn Rushd (d. 594/1198) advocated a reading of Aristotle's *Physics* that precluded epicyclic and eccentric orbs.[134] Neither an epicycle nor an eccentric rotated uniformly about the centre of the Earth. Drawing on these Andalusian philosophers, one astronomer, al Biṭrūjī (*fl. c.* 600/1200), proposed models incorporating only homocentric orbs.[135] This elimination of epicyclic and eccentric orbs meant that al Biṭrūjī's models could not approach the predictive

134 A. I. Sabra, 'The Andalusian revolt against Ptolemaic astronomy: Averroes and al Biṭrūjī', in Everett Mendelsohn (ed.), *Transformation and tradition in the sciences* (Cambridge and New York, 1984; repr. 2003).

135 Al Biṭrūjī, *On the principles of astronomy*, ed., trans. and comm. Bernard R. Goldstein, 2 vols. (New Haven and London, 1971).

accuracy of the Marāgha astronomers' models or of those of Ptolemy. In al Biṭrūjī's model for the Sun's motion, the Sun ventured from its observed path through the signs of the zodiac by as much as 1.5°! Only at four points, the equinoxes and the solstices, did the Sun's predicted position in al Biṭrūjī's model match observations. Still, al Biṭrūjī's work, besides being interesting in its own right, provides a useful contrast to understand better the essence of the work of the Marāgha astronomers. Whereas al Biṭrūjī privileged a certain reading of Aristotle, the work of the Marāgha astronomers valued consistency, conceivability and fidelity to observations.

An attempt to improve on al Biṭrūjī has come to light. Ibn Naḥmias' (*fl. c.* 800/1400) *Nūr al ʿālam* (The light of the world) noted al Biṭrūjī's theories' lack of agreement with observations.[136] Ibn Naḥmias devised improvements that addressed such discrepancies to some extent. In order to do so he had to introduce epicycles that rotated on the equator of the orb, but which were not moved by a pole rotating about the pole of the orb. Ibn Naḥmias' solar model included a double circle hypothesis similar, but not identical, to the Ṭūsī Couple. Ibn Naḥmias' increased attention to predictive accuracy and decreased obsession with Aristotle's philosophy, along with his models' greater resem blance to the astronomy of the East, distinguished him from the figures of the sixth/twelfth century Andalusian response to Ptolemy that Sabra noted.[137] Diverse regional research agendas coexisted with connections between astron omers and astronomies from different parts of the Islamic world.

Relations between astronomy and religious scholarship

This sketch of the history of astronomy in Islamic civilisation so far has chronicled astronomy's increasing independence from its applications in astrology, and from its foundations in Hellenistic philosophy. For religious scholars astronomy was transformed from a science within the Aristotelian scheme of natural philosophy into an independent science that could demon strate God's glory. Famous statements of al Ghazālī (d. 505/1111) encapsulated the relationship of astronomy, and to a lesser extent astrology, to traditions of religious scholarship. In a work entitled *al Munqidh min al ḍalāl* (Deliverance from error) al Ghazālī noted that most of the errors of the philosophers were in the areas of metaphysics and philosophical theology.[138]

136 Robert Morrison, 'The solar model in Joseph ibn Naḥmias' *Light of the world*', *Arabic Sciences and Philosophy*, 15 (2005).
137 Sabra, 'The Andalusian revolt'.
138 W. Montgomery Watt, *The faith and practice of al Ghazālī* (London, 1953), pp. 37 8.

Astronomy did not depend directly on the three questionable positions of the philosophers that he singled out in *al Munqidh min al ḍalāl* (denial of resur rection, the eternity of the world and God's inability to know particulars). Al Ghazālī's criticisms of Hellenistic philosophy, inasmuch as it pertained to astronomy, were more acute in his famous *Tahāfut al falāsifa* (Incoherence of the philosophers). In Discussion Seventeen of the *Tahāfut* he disagreed with the philosophers' position that fire causes burning in cotton: 'Observation, however, [only] shows the occurrence [of burning] at [the time of the contact with the fire] but does not show the occurrence [of burning] by [the fire] and [the fact] that there is no other cause for it.'[139] This statement questioned whether astronomers could in fact view the orbs as the proximate movers of the planets, or whether the orbs' causal role was only apparent. If astronomy distanced itself from Hellenistic philosophy, then could astronomers make any statement about the structure of the universe that was not purely contingent? Though authors of *'ilm al hay'a* texts would eventually take subtle positions in favour of the reality of their models, they would do so without explicit recourse to Hellenistic philosophy.

Al Shīrāzī, in his *al Tuḥfa al shāhiyya* (The royal gift), made an effort to establish the principles of *'ilm al hay'a* directly from observation.[140] 'Alā' al Dīn al Qūshjī (d. 879/1474), who produced an innovative model for Mercury's motions, argued in a *kalām* (rational speculation about God) text that *'ilm al hay'a* could stand on its own without relying on philosophical metaphysics. Such awareness of critiques of Hellenistic philosophy explains reports of astronomy being studied as late as the nineteenth and early twentieth centuries within a *madrasa*, a foundation for the study of Islamic subjects, most notably Islamic law.[141] Texts of astronomy abounded in the libraries attached to *madrasa*s.

At the beginning of the *Tahāfut* al Ghazālī made another statement that limited the implications of his own critique of causality. He mentioned a scientific explanation of a lunar eclipse which 'consists in the obliteration of the Moon's light due to the interposition of the Earth between it and the Sun, the Earth being a sphere surrounded by the sky on all sides. Thus, when the

139 al Ghazālī, *The incoherence of the philosophers*/Tahāfut al falāsifa, *a parallel English Arabic text*, ed., trans. and intro. Michael E. Marmura (Provo, UT, 1997), p. 167.

140 See Ragep, 'Freeing astronomy' on al Shīrāzī and al Qūshjī. See also Robert Morrison, *Islam and science: The intellectual career of Niẓām al Dīn al Nīsābūrī* (London and New York, 2007), chap. 5.

141 Robert Morrison, 'The response of Ottoman religious scholars to European science', *Archivum Ottomanicum*, 21 (2003).

Moon falls in the Earth's shadow, the Sun's light is severed from it.'[142] Al Ghazālī rebuked those who would dispute, out of a sense of religious duty, such indubitable arithmetical and geometrical demonstrations. *ʿIlm al hayʾa*'s success within a tradition of religious scholarship was due in part to the fact that criticisms of astronomy emphasised the weaknesses of its foundations in Hellenistic philosophy and not the value of its findings. Inasmuch as *ʿilm al hayʾa* texts ceased to situate themselves within a Hellenistic taxonomy of the sciences, in which astronomy was connected to Hellenistic philosophy, *ʿilm al hayʾa* became an Islamic science.

The oeuvres of some of Islamic civilisation's outstanding astronomers attest to the coexistence of scientific and religious scholarship. Al Ṭūsī, al Shīrāzī, Ṣadr al Sharīʿa and al Khafrī were all religious scholars of note. In addition, Ibn al Shāṭir served as the timekeeper in the Grand Mosque in Damascus. Scientific and religious arguments coincided in certain texts. Fakhr al Dīn al Rāzī's (d. 606/1209) Qurʾān commentary brought a great deal of astronomy and natural philosophy to bear on the Qurʾān's portrayal of nature.[143] To be sure, there were debates over the reality and validity of certain explanations for celestial phenomena, but the existence of those debates along with their religious subtexts is proof of the relevance of astronomy to themes of *kalām* and Qurʾān commentary. A famous statement of ʿAḍud al Dīn al Ījī (d. 756/1355) asserted the fictionality and contingency of the astronomers' theories and sparked debate in super commentaries for centuries.[144]

Most of the religious scholar/astronomers whom I have just cited were not Arab, and while some of them did write on astrology, they did not write such texts in Arabic, the pre eminent language of Islamic scholarship. Despite astrology's loss of intellectual prestige, it endured in Islamic societies as a craft for which there was always a steady demand. Astrology retained some support among physicians as a foundation of disease aetiology. Even al Ghazālī had pointed out in his *Iḥyāʾ ʿulūm al dīn* (Revival of the religious sciences) that astrology was similar to medicine in that both sciences depended on induction.[145] Niẓām al Dīn al Nīsābūrī (d. *c.* 730/1329 30), an astronomer and Qurʾān commentator, wrote in his Persian commentary on al Ṭūsī's *Zīj i Īlkhānī*, and in his Qurʾān commentary, that quotes in the Qurʾān could be interpreted to mean that the heavens were an instrument for God's control

142 al Ghazālī, *Incoherence of the philosophers*, p. 6.
143 Morrison, *Islam and science*, chap. 6.
144 A. I. Sabra, 'Science and philosophy in medieval Islamic theology: The evidence of the fourteenth century', *ZGAIW*, 9 (1994).
145 al Ghazālī, *Iḥyāʾ ʿulūm al dīn*, 5 vols. (Cairo, 1955), vol. I, p. 29.

over terrestrial events.[146] So while an author such as al Shīrāzī wrote on astronomy, astrology and philosophy, these fields no longer depended directly on each other.

To be sure, each astronomer was but a point on a broad spectrum of opinions about astronomy's value, its applications and its relation to astrology. Nevertheless, astronomers' sensitivity to such questions and their achievement in relating a theoretically sophisticated astronomy to religious scholarship are key characteristics of Islamic astronomy. The development of astronomy within Islamic civilisation can be fully understood only with attention to astronomy's applications and its connection to religious scholarship.

The cultures of cartography

Cartography in Islamic societies shares common ground with geography without being part of it. Many texts on geography do not contain a single map. Numerous maps are not connected to a text. The world of those that are intimately linked to a verbal narrative covers a broad range of disciplines, among them political history, creational history, pilgrimage and mathematical cosmography. Maps were drawn or painted on paper, papier mâché or cotton, embroidered on precious silks, woven into carpets or incised into metal. They were illustrations of manuscripts, single sheet pictures or parts of atlases, elements of mural decoration, instruments or parts thereof and symbolic components of miniature paintings. One set of items that could be considered maps was tables and diagrams.[147] The other set consists of landscape paintings and town views in miniatures adorning texts on history, military campaigns or romances.[148] Maps served as mnemonic devices, objects of art and entertain ment, symbols of authority and power, diplomatic gifts, instruments of war and faith as well as organisers of order and knowledge. Maps depicted the Earth, the stars or the universe.[149] The most vivacious and multifaceted map culture evolved in the Ottoman empire from the ninth/fifteenth century.

146 Morrison, *Islam and science*, chaps 4 and 6.

147 A tabular world map can be found in Ibn Faḍl Allāh al ʿUmarī's encyclopaedic work *Masālik al abṣār*. A tabular map for determining the *qibla* for Bursa and a number of other towns in Anatolia, Egypt, Syria and Azerbaijan is enclosed in an eighteenth century Ottoman Egyptian manuscript. See King, *World maps*, pp. 92 3.

148 Examples are maps of Mecca in Niẓāmī's *Iskandarnāme*, Mughal town views and landscape paintings with routes passed through by Ottoman sultans and their armies.

149 This section discusses only terrestrial maps.