APPLICATIONS OF FOLK ASTRONOMY AND MATHEMATICAL ASTRONOMY TO ASPECTS OF MUSLIM RITUAL

David A. King

J. W. Goethe-Universität, Frankfurt am Main

1 *Introduction*

Modern accounts of Islamic astronomy, with their emphasis upon technical achievements, tend to ignore the simple, popular astronomy which flourished alongside mathematical astronomy in the Islamic world throughout the medieval period. This popular tradition was far more widely practised than mathematical astronomy but has not yet received the attention it deserves.

Some work has been done on the way folk astronomy was used to regulate the agricultural activities, in that several medieval almanacs have been studied. Arab navigational astronomy, which can be viewed as a branch of folk astronomy, is rather well documented in the modern literature; in this case, most of the available texts have been published and studied. But popular astronomy had other practical applications in the Islamic context, which have only recently been studied in a preliminary fashion for the first time.

None of the general surveys of Islamic science stresses the importance of the ways in which that science, either at the highest level or at the simplest, practical level, was applied to three aspects of daily life in the Muslim community, namely:

(1) the regulation of the lunar calendar by the sightings of the lunar crescent;

(2) the organization of the times of the five daily prayers which are defined in terms of astronomical phenomena; and

(3) the determination of the *qibla* or direction of Mecca which Muslims must face in prayer.

THE ARABIST. BUDAPEST STUDIES IN ARABIC 13-14 (1995)
https://doi.org/10.58513/ARABIST.1995.13-14.21

These particularly Islamic aspects of Islamic astronomy were of no interest to the medieval Christian West and so the distinctive Islamic flavour of the Islamic astronomical tradition is no longer discernible in early European astronomy. On the other hand, they are the only aspects of Islamic science that have remained important in the Muslim world until the present time. Since most of the extant sources have been studied only in this century, and in some cases only in the past few years, it is not surprising that these Islamic aspects of Islamic science are usually omitted in surveys of Islamic science. In this paper I shall discuss the two main trends in Islamic astronomy and then point to the areas of interaction and overlap of interest between them.

2 *Folk Astronomy*

In the *Qur'ān* it is written not only that God created the stars but also that men should be guided by them. Thus a general knowledge of the celestial phenomena visible by day and night without the trappings of any theory or computus was considered valuable in medieval Islamic society. Islamic folk astronomy, as I label this corpus of information and associated techniques, is recorded in a variety of different works, some published but very few translated, and most existing only in manuscript form.

One genre of Arabic literature on this subject consists of general treatises compiled in each of the different regions of the Islamic commonwealth extending from Andalusia to Central Asia. These describe the sun and its passage through the twelve signs of the zodiac; the resulting seasons and the associated agricultural activities and meteorological phenomena; the moon and its phases and its passage through the 28 lunar mansions; and also prominent star groups and their risings and settings. Such is the work of the ninth-century scholar Ibn Qutayba. It is essentially a compendium of pre-Islamic Arabian starlore and contains many references to the *Qur'ān* and pre- and early-Islamic poets. The basic notions of folk astronomy are also recorded in encyclopaedias and in references scattered throughout treatises on lexicography. The second genre consists of calendars or almanacs for the solar year, sometimes arranged for a given lunar year. Of the former variety is the celebrated tenth-century *Calendar of Cordova*, representative of a large class of such works often including local (in this case, Andalusian) scientific folklore.

Beyond this, the techniques of popular astronomy were applied to the three problems of Muslim daily life which were also so amply treated by the astronomers working in the strictly scientific tradition – see Section 3.2. Thus the third major genre consists of independent works dealing with these particular problems, as well as certain general treatises in which these problems are discussed in detail, and, last but not least, legal texts. In Islamic society, law is sacred law, based on the *Qur'ān* and the sayings and actions of the Prophet Muḥammad, as well as on the consensus of the religious scholars over the generations. As such it deals with each of the religious obligations such as prayer at the right times and in the right direction; thus in this corpus of literature we find discussions of the way to regulate the lunar calendar by sighting the crescent, the way to regulate the times of prayer using shadow lengths by day and the lunar mansions by night, and the way to find the *qibla* by means of the sun, the stars, and even the winds.

Before we consider each one of these applications in turn, we should mention the simple astronomical practices of the Arab navigators. Most of what we know about them is contained in the writings of two South Arabian professionals from the fifteenth and sixteenth centuries, Ibn Māǧid and Sulaymān al-Mahrī. Their major works have been published from the few surviving manuscripts, and a valuable study of them has been prepared by G. R. Tibbetts.

The tradition is characterized by the same central rôle of the lunar mansions as in the popular tradition of the Muslim landlubbers. But there are other independent features, such as the 32-division windrose, and simple techniques for measuring latitude and departure (*qiyās* and *masāfa*), which are, however, sufficiently sophisticated that they include a correction (*bāšī*) to latitude determinations using the Pole Star to account for the altitudinal variation of that star from the true celestial pole. The magnetic compass was well known to the Arab navigators of the Mediterranean in the early thirteenth century and is first mentioned in the known astronomical texts in a book on instruments by the late-thirteenth-century Yemeni Sultan al-Ašraf. The only "instrument" used by the Arab navigators besides the compass was the *kamāl*, a simple knotted rope for determining latitudes by means of the Pole Star.

Certain features of Islamic navigational astronomy were clearly adapted from Indian or Persian navigational practice. In addition to this simple astronomical lore they possessed an intimate knowledge of shorelines from the Red Sea to the East Indies, and of the seasonal weather conditions in these waters. The early navigators developed all that they required of this practical science and before the Ottoman period (beginning of the sixteenth century) borrowed nothing from the scientific tradition.

In the Mediterranean during the Ottoman period, new techniques were adopted from Western navigational works. These are evident in the navigational atlas of the sixteenth-century Tunisian scholar aṣ-Ṣafāqusī, as well as an Ottoman navigational manual discovered a few years ago in Cairo (MS Dār al-Kutub *mīqāt* 570), which contains extensive tables for navigation that remain to be analyzed.

2.1 *The Lunar Calendar*

For the purpose of regulating the lunar calendar, and in particular, the religious festivals, the actual sighting of the lunar crescent was of prime importance. But the *Qur'ān* also implies that if the moon is for some reason obscured, one should estimate the beginning of the month. So a scheme of twelve lunar months of alternate 29 and 30 days was considered acceptable, with occasional local variations to take into account the first visibility of the crescent, especially for the beginning and end of Ramaḍān, the holy month of fasting.

A preliminary study of a few texts relevant to the regulation of the calendar in practice was published by H. P. J. Renaud in 1945, and nothing of consequence has been written on the subject since. I am currently gathering materials to undertake a new investigation of popular techniques for regulating the calendar.

2.2 *The Times of Prayer*

In Islam, the times of the five daily prayers are astronomically determined. Since they depend on the apparent position of the sun, they vary throughout the year and are dependant on terrestrial latitude. The day begins at sunset (because the calendar is lunar and the months begin with the sighting of the lunar crescent), and the first prayer begins at sunset. The second prayer begins at nightfall. The third prayer begins at daybreak (to be distinguished from the zodiacal light) and must be completed by sunrise. The fourth prayer begins shortly after midday (the definitions vary). The fifth prayer begins when the shadow of any object has increased beyond its midday minimum by the length of the object, and ends either when the shadow has increased again by the length of the object, or at sunset.

These definitions in terms of shadow increases result from an attempt to regulate the midday and afternoon prayers in terms of seasonal hours, the relationship being provided by a simple Indian formula which became known to the Muslims in the eighth century, connecting the time of day with shadow increases. In some circles there was also a prayer at midmorning. The three daytime prayers in Islam correspond to the prayers at the third, sixth and ninth seasonal hours of daylight practised by Syrian Christians, and evidence is not lacking to show that the Islamic institution of prayer at specific times owes its inspiration, in part at least, to Christian practice.

In their discussions of the prayer-times, the Muslim scholars working in the popular tradition often presented Hellenistic or Egyptian/Coptic arithmetical shadow schemes, with values of the midday shadow for each day of the solar (Syrian or Coptic) year. These shadow lengths served to regulate the midday prayer. Values for the beginning of the afternoon prayer could be easily found by adding the length of the gnomon to these midday shadows. Also advocated were simple arithmetical schemes of Indian and Hellenistic origin for reckoning the time of day in seasonal hours from shadow lengths. Discussions of the phenomena associated with evening and morning twilight, including the zodiacal light, also feature in the texts. None of the known legal books dealing with the subject of the prayer-times states that one should consult the tables prepared for this purpose by the astronomers – see Section 3.2.

2.3 *The Sacred Direction*

In Islam the direction of prayer is towards the sacred Kaᶜba in Mecca. But the *qibla*, as this direction is called in Arabic, is more than just the direction of prayer. Various ritual acts, such as recitation of the *Qur'ān*, pronouncing the call to prayer, and slaughter of animals for food, as well as burial of the dead, are to he performed facing in the *qibla*. In addition, various bodily functions are to he performed in a direction perpendicular to the *qibla*. Thus the *qibla* is of prime importance in the daily life of the pious Muslim, and I refer to it as the "sacred direction", a term not yet widely used amongst Islamicists, including even those with an anthropological bent.

The scholars working in the popular tradition presented ways to find the *qibla*, using the risings and settings of the sun and certain prominent fixed stars over the local horizon. The reason for the use of astronomical horizon phenomena for the *qibla* is easily explained: the Kaᶜba in Mecca is itself astronomically aligned, a fact which was already well-known to the Meccans in the seventh century. The rectangular base of the Kaᶜba has its major axis aligned with the rising of Canopus and its minor axis roughly with summer sunrise and winter sunset (and precisely with the southernmost setting point of the moon at midwinter!). Each sides and corners of the Kaᶜba were from an early date (probably before the advent of Islam in the seventh century) associated with different regions of the known world. When the first generation of Muslims built mosques in localities as far apart as Andalusia and Central Asia, they oriented them in the same direction as the particular walls of the Kaᶜba which they wanted their mosques to face. Some early mosques were, of course, converted from earlier religious edifices or built on their foundations, but only when the orientation of these was deemed acceptable as a *qibla*.

These early *qibla* directions were respected over the centuries and generally preferred to the *qibla*s computed by the astronomers. Inevitably there were differences of opinion, and in each main region of the Islamic world there was a variety of *qibla* directions (usually spanning a quadrant of the local horizon), each one at some time favoured by one group or another. Muslim scholars from the ninth to the sixteenth century produced a variety of schemes of sacred geography, in which the world was divided into sectors around the Kaᶜba. These are quite distinct from the Islamic tradition of mathematical geography and cartography. Such schemes represent visually the supreme significance of the Kaᶜba in Islamic belief as a pointer to the presence of God. Each sector of the world was associated with a particular segment of the perimeter of the Kaᶜba, and the *qibla* in each sector was defined in terms of an astronomical horizon phenomenon. The crudity of the geographical information incorporated into these schemes contributed to the variety of directions used for the *qibla* in each region of the Islamic world.

This situation is reflected in the apparent confusion prevailing in the orientation of medieval mosques, a phenomenon which has long bewildered historians of Islamic architecture but which can now be regarded as explained. Considerable light on this subject has been cast by various medieval treatises, recently investigated for the first time, which discuss the problems of mosque orientation in specific regions.

3 *Mathematical astronomy*

In it earliest stages, the mathematical astronomy practised by the Muslim scientists was based on the Greek, Sasanian and Indian astronomical traditions. This activity began with translation and exegesis, but already by the ninth century it had acquired the distinctive Islamic feature by which it was characterized throughout the medieval period, and indeed until the nineteenth century. The sources for our knowledge of this scientific tradition are texts and instruments. Most of the texts exist only in manuscript form, preserved in the major libraries of Europe and the Near East. Of the instruments, some survive in various museums around the world, others are known only from descriptions of them in texts.

Muslim astronomers compiled books either on the theoretical or practical aspects of their science, or both. A series of observation programs was conducted from the ninth to the sixteenth century, but the greatest scientific achievements of the Muslim astronomers were in the development of geometric models to explain the apparent motions of the planets and of mathematical methods and tables for solving problems of planetary and spherical astronomy.

The interest of Muslim astronomers in Ptolemy's planetary models increased over the centuries, and these models were modified and improved by them. On the more practical side, the astronomical handbooks, known as *zīǧes* and consisting of tables and explanatory text, were the main tool of the medieval astronomer. The *zīǧes*, of which close to 200 were compiled in the millennium beginning in the eighth century, contained tables for calendar conversion; tables of solar, lunar and planetary mean motions and equations (corrections to find the true positions); tables of stellar coordinates; tables of trigonometric functions: tables of spherical astronomical functions; tables of geographical coordinates, and tables for astrological purposes. With these, the astronomer could compute planetary positions, generate ephemerides, predict eclipses and forecast the appearance of the lunar crescent at the beginning of a given month – see Section 3.1, solve problems of spherical astronomy – particularly timekeeping – by trigonometric method, calculate the *qibla* for different localities using trigonometric or geometric methods – see Section 3.3, and compute horoscopes. Muslim astronomers also compiled extensive tables for different latitudes for timekeeping by the sun and stars, including tables fur regulating the times of prayer, though these are not usually contained in *zīǧes* – see Section 3.2.

Muslim scientists inherited the instruments of their Greek predecessors, such as the meridian quadrant, the armillary sphere, the astrolabe and the sundial. They themselves developed the alt-azimuth quadrant, the torquetum, the universal astrolabe, the polar and equatorial sundials, and various kinds of quadrants.

In the later period of Islamic astronomy – that is, from the eleventh to the sixteenth century – regional schools developed with rather different interests and specializations. These regions included Andalusia and the Maghrib; Egypt and Syria; the Yemen; Iraq, Iran and Central Asia; and India. From the ninth to the fifteenth century, Muslim scholars were the leading scholars of their day, and they solved all of the major problems which concerned them to their entire satisfaction. Indeed, after the fifteenth century there were no new problems to be solved, and Muslim astronomers carried on their tasks in traditional ways until the nineteenth century. By this time the cultural level of the Western world had risen to such an extent relative to the Islamic world that it was left mainly to Western orientalists to recover the Islamic scientific heritage, an undertaking which began in earnest in the nineteenth century and which is still in progress.

To a considerable extent, Muslim astronomers were writing for themselves and for each other. Their discoveries and developments in this field were, with but few exceptions, not all widely disseminated outside their own circles. Already in the eighth and ninth centuries, the techniques of mathematical astronomy were applied to the practical problems of the calendar, the prayer-times and the *qibla*. Over the centuries the solutions to these problems were substantially improved, and these activities provided a distinctively Islamic flavour to Islamic astronomy.

3.1 *Lunar Crescent Visibility Theory*

Astronomers from the eighth century onwards discussed the prediction of the visibility of the lunar crescent. The first Muslim astronomers adopted an Indian condition for visibility, namely: if the time between sunset and moonset is greater than or equal to 12 equatorial degrees (or 48 minutes of time), then the crescent will be seen. In eighth-century Baghdad astronomers such as al-Fazārī and Yaʿqūb b. Ṭāriq introduced a modification to this condition to take account of the lunar latitude. In the early ninth century al-H̱wārizmī compiled a table displaying the minimum ecliptic elongation between the sun and moon to ensure visibility, with values for each 30° of solar longitude computed for the latitude of Baghdad.

In later centuries other Muslim astronomers devised more complicated conditions and more sophisticated tables for predicting visibility. Information about crescent visibility for each month was often contained in the ephemerides which were prepared annually in various urban centres. But the extent to which the computations of the astronomers were used in practice is not clear. Certainly it varied from one location to another and from one period to another, depending on the popularity of the astronomer with the authorities, political and religious. Today the astronomers are rarely consulted in the regulation of the religious festivals, a situation which accounts for the annual confusion in various parts of the Islamic world over the determination of the beginning of Ramadan.

3.2 *Astronomical Timekeeping*

Prescriptions for regulating the times of the five daily prayers by means of shadow lengths and twilight phenomena are recorded in the *ḥadīṯ* literature and earliest legal texts. In Damascus at the beginning of the eighth century the Caliph ᶜUmar II used a Graeco-Roman sundial to regulate the daytime prayers, clearly by means of the seasonal hours. The definitions of the times of prayer which are in use to this day appear to date from the mid eighth century. As noted above (Section 2.2), the times of the daytime prayers are defined in terms of shadow increases (as opposed to shadow lengths), the definition being derived from a simple Indian formula for timekeeping (see Section 2.2).

In the early ninth century, an astronomer in Baghdad, probably al-Ḫwārizmī, compiled a table displaying the lengths of the shadows at the midday prayer and at the beginning and end of the afternoon prayer. Values were given for each 6° of solar longitude and were computed specifically for Baghdad. In later centuries other Muslim astronomers compiled more sophisticated tables for regulating all of the prayer-times, as well as for finding the time of day from solar altitudes and the time of night from the altitudes of certain prominent stars, each of these tables being computed for a specific latitude. In several Islamic cities in the medieval period there existed corpuses of tables for timekeeping, often containing tens of thousands of entries. Such corpuses included tables for the duration of morning and evening twilight and occasionally even tables displaying the effect of refraction at the horizon.

Astronomers in some urban centres, such as Cairo, Damascus and Taiz (Yemen), and later, Istanbul, specialized in astronomical timekeeping (*ʿilm al-mīqāt*) and the use of such tables. These astronomers were usually associated with the principal mosques and were known – at least in Egypt, Syria, and Turkey – as *muwaqqits* (professional timekeepers). Such scholars also made substantial advances in astronomical instrumentation, particularly in the development of sundials, quadrants and calculating devices.

In the modern Islamic world, the times of prayer for each day of the year for specific localities are displayed in newspapers, pocket diaries and wall calendars. As we now know, these tables have a history spanning more than a millennium.

3.3 *The Mathematical Determination of the Qibla*

Already in the eighth and early ninth centuries, Muslim astronomers turned their attention to the determination of the *qibla* by mathematical means using the geographical coordinates of Mecca and the locality in question. The earliest methods were approximate, but by the mid-ninth century a complicated solution equivalent to the accurate formula had been derived. Most Islamic astronomical treatises include a chapter on the determination of the *qibla*, either by accurate or approximate methods, and either by trigonometry or by geometric construction. Many sets of geographical tables, which were a feature of Islamic *zīǧes*, display the *qibla* of each locality alongside the latitude and longitude.

In the early ninth century, an astronomer in Baghdad, probably al-H̱wārizmī, compiled a table displaying the *qibla* as an angle to the local meridian, for each degree of latitude and longitude difference from Mecca (up to 20° for each argument). The table was based on an approximate formula. Several later Muslim astronomers compiled *qibla*-

tables, and in the mid-fourteenth century the Damascus astronomer al-Halīlī compiled a *qibla*-table based on an accurate formula; this table is without doubt one of the most sophisticated trigonometric tables computed in the Middle Ages.

There is little evidence to show that the astronomers were consulted on the matter of the *qibla*. Only a minority of medieval mosques are oriented in directions which correspond to those advocated by the astronomers. The prize examples are the mosques in the city of Tripoli (Ṭarābulus aš-Šām), founded by the Mamlūks in the fifteenth century. The religious architecture in this new city is oriented in a variety of different directions; none of these corresponds to the mathematically-determined *qibla* for Tripoli, which would have been known to any contemporary Syrian astronomer.

In the modern Islamic world mosques are usually oriented in directions computed by the local Survey Department and approved by the religious authorities. Calculation is deemed acceptable in this instance as in the case of tables for the times of prayer; only in the regulation of the calendar is it not trusted.

4 *Interaction between the Traditions*

Writers on popular astronomy and its applications are usually silent on the mathematical tradition. The "sciences of the ancients", especially astrology and it handmaiden mathematical astronomy, were anathema to the majority of pious Muslims. There is nothing in the *Qur'ān* to necessitate the pursuit of mathematical astronomy, and the Prophet Muḥammad himself had spoken out against astrology as an obvious contradiction of God's supreme power in the Universe. Thus, for example, legal scholars writing on the prayer-times never, to my knowledge, advocate the use of tables, or astrolabes or quadrants, or sundials, the standard tool of the *muwaqqits* who worked in the same establishments as the legal scholars in such cities as Cairo and Damascus.

In general, the Muslim astronomers had little interest in the popular tradition, although from the ninth century onwards it was well documented and readily available to them. Several Muslim astronomers deal with such topics as the lunar mansions, though without reference to ways of using them to regulate time of night. But they never even mention the astronomy of the navigators. No texts of navigational lore are known to have been compiled in the formative period of Islamic science before the eleventh century, and even the later texts do not seem to have circulated amongst the astronomers.

When Ibn Māǧid presents to his reader a list of the treatises on astronomy and geography known to him, the works mentioned are mainly *zīǧ*es (Ptolemy's *Almagest*, and several others down to the fifteenth-century *Zīǧ* of Uluġ Beg of Samarqand) and geographical works, in addition to aṣ-Ṣūfī's treatise on the fixed stars and a compendium on astronomical instruments by the thirteenth-century Cairo astronomer al-Marrākušī. The only treatise on popular astronomy which he mentions is the no-longer-extant work by the ninth-century scholar Abū Ḥanīfa ad-Dīnawarī, which appears to have been an important source for Ibn Qutayba. Yet Ibn Māǧid gives no indication in his writings of actually having used any of these works (with the possible exception of Abū Ḥanīfa's treatise).

The reader will have gained the impression that the two astronomical traditions were distinct and virtually independent, and this was indeed the case. A notable exception was in the astronomical activities of various scholars working in the Yemen, which was an active centre of astronomy from the tenth to the seventeenth century. There we find several authors compiling works on both mathematical astronomy and folk astronomy, and occasionally combining them. A particularly interesting example is the late-thirteenth-century Adeni scholar al-Fārisī, who compiled not only an extensive *zīǧ* with tables computed specifically for the Yemen but also a treatise on popular astronomy. Yet neither al-Fārisī nor any of the other Yemeni astronomers mentioned navigational astronomy. Likewise, neither Ibn Māǧid nor Sulaymān al-Mahrī, hailing from Oman and the Ḥadramawt, respectively, mentions any member of the Yemeni school of their works.

There were, however, some isolated cases of interaction in other parts of the Islamic world, of which the following are examples:
(1) The celebrated tenth-century astronomer of Shirāz, aṣ-Ṣūfī, compiled a book on the fixed stars and constellations. Although this work followed the Ptolemaic tradition of star catalogue and uranography, it also included a substantial amount of Arabian folklore on the stars. aṣ-Ṣūfī's book was widely disseminated in the Islamic Near East.
(2) In a twelfth(?)-century Egyptian (?) treatise on popular astronomy (MS Princeton Yahuda 4657 (4983), fols. 105v-106r), an anonymous author presents an orthogonal latitude-longitude grid with Mecca and various Islamic cities marked in the appropriate places. The grid is surrounded by a circle on which astronomical risings and settings are indicated. To find the *qibla* one should draw a line from one's own locality to Mecca on the grid, and see where that line produced cuts the circle to determine the appropriate astronomical direction for the *qibla*. Clearly the author realized that the *qibla* is a function of geographical coordinates, but he also wished to avoid any involvement in calculating it.
(3) In a thirteenth(?)-century Egyptian manual for muezzins and unsophisticated *muwaqqits* (MS Oxford Bodleian Or. 133,2), the anonymous author presents tables displaying the lunar mansions rising, culminating and setting at various times during the night. The compilation of tables was in general practised only by real astronomers. These Egyptian tables have their counterparts in contemporary Yemeni works.
(4) The fourteenth-century Damascene astronomer Ibn aš-Šāṭir made impressive contributions to the development of non-Ptolemaic planetary models, and was a master of spherical astronomy. Yet in a minor work on the times of prayer (MS Leiden Universiteitsbibliotheek 1111, fols. 108r-113r), he advocated the use of a simple approximate Indian formula for timekeeping. In his *zīǧ*, he proposed a series of only slightly accurate trigonometric procedures, and it is curious that a distinguished astronomer should have even considered mentioning such an approximate formula.
(5) In his major navigational manual, Ibn Māǧid complains that the early-fifteenth-century Egyptian scholar Pseudo-Ibn al-Wardī, author of

a treatise on cosmography, had presented a scheme of sacred geography in which the sector for Sind and India was near to the sector for Ethiopia. Indeed, in Ibn al-Wardī's scheme of twelve sectors of the world around the Ka^cba – and in the earlier schemes on which it is based – only the sector for the Yemen separates these two. As Ibn Māǧid remarked, Ibn al-Wardī had left out most of Arabia and the surrounding seas. In contrast, I know of no astronomers who even mentioned these schemes of sacred geography, let alone criticized them.

(6) In the navigational atlas of the sixteenth-century Tunisian scholar Aḥmad aš-Šarafī aṣ-Ṣafāqusī (preserved in MSS Paris B.N. ar. 2273 and Oxford Bodleian Marsh 294), there is a scheme of sacred geography in which the world is divided into 40 sectors about the Kaᶜba. This scheme is superimposed on a 32-division windrose, which, like aṣ-Ṣafāqusī's maps of the coastline of the Iberian peninsula, appears to have been inspired by eastern navigational science.

(7) On the fly-leaf of a recension of the *Zīǧ* of Ḥabaš, the leading astronomer of the ninth century, there is an unusual *qibla*-diagram (MS Berlin Ahlwardt 5750, fol. 169v). A semi-circle represents one-half of the world about the Kaᶜba, divided into 18 sectors. Full circular schemes with 36 and 72 sectors were fairly common in Ottoman texts and on Ottoman instruments, but some of them reflect rather poorly the distribution of the various localities about the Kaᶜba, even by the standards of medieval geography. However, in this half-diagram actual *qibla* values to the nearest degree have also been inserted, these highlighting the inconsistency of the distribution of the localities around the Kaᶜba.

(8) Finally, we should include the astronomical tables for navigation found in the Ottoman navigational manual mentioned above. These represent the application of techniques of mathematical astronomy to navigation, but they must be studied before we can assess their significance.

5 *Conclusion*

The procedures of Arab navigation by the stars represent simple applications of popular astronomy to the problems of navigation, and for many centuries these also were considered adequate for all practical purposes. In this paper I have shown that folk astronomy was also applied to the three religious needs of the calendar, prayer-times and *qibla*, to produce simple practical solutions. One reason why the astronomers were not generally consulted on these matters was that these simple solutions were considered adequate for practical purposes. Also, the solutions proposed by the astronomers were not comprehensible to the vast majority of the population, including the scholars of the sacred law. When the eleventh-century legal scholar al-H̠aṭīb al-Baġdādī listed those aspects of science which were acceptable, he mentioned those aspects of popular astronomy which we have discussed above and none of the other concerns of the astronomers:

> "The science of star nomenclature, the appearances of the stars, their risings and settings, their courses, finding one's way by them, the wanderings of the Bedouin from their watercourses and wells according to the times (of the stars), the selection of time for their young cattle, the fertilization by their male animals, the knowledge of the rain according to the changing stars, their method of telling the good from the bad, the determination of the direction of the *qibla* by the stars, the knowledge of the time of prayer and the hour of the night by the appearances and settings of the stars."

On the other hand, in his book on mathematical geography the celebrated eleventh-century scientist al-Bīrūnī complained about people who apparently understood the notions of terrestrial longitude and latitude but who could not determine the *qibla* properly:

> "They become perplexed and they start talking about completely irrelevant phenomena such as the directions from which the winds blow and the risings (and settings) of the lunar mansions."

In his book on timekeeping he again spoke out against such popular practices, this time targeting certain muezzins who "get goosepimples at the mere sight of computation or scientific instruments". Elsewhere he suggested that prospective muezzins should study Euclid and Ptolemy. He would have been impressed by the achievements of the later Damascus school of *muwaqqits*.

There is much more basic research to be conducted on the history of astronomy in the lands of Islam and its practical applications to aspects of daily life. This is true of both the popular and the scientific traditions. But the number of scholars working in all aspects of Islamic science is small indeed, and the number concerned with popular science even smaller*.

Bibliographical notes:

Part 1

A bio-bibliographical survey of the sources for early (to *ca*. 1050) Islamic astronomy, including both the mathematical and the folk traditions, is contained in Sezgin, *GAS*, vols. V, VI and VII. For the later period the reader must have recourse to Suter, *MMA*; Brockelmann, *GAL*; Matvievskaya & Rosenfeld, *MAMS*; and *Cairo Survey*.

Part 2

Introductory: For information on Islamic folk astronomy see Nallino, *Scritti*, V, pp. 152-197, and also the articles "*anwāʾ*" (= pre-Islamic divi-

* Note added in proof:

In 1989 there was discovered a world-map centred on Mecca, with a highly sophisticated cartographical grid that enabled the user to find the direction and distance to Mecca from any locality between Andalusia and China. The map is engraved on an astronomical instrument made in Isfahan *ca.* 1710, and it is clearly a copy of an earlier map of the same kind. The coordinates of the 150 localities marked on the map are taken from the mysterious *Kitāb al-Aṭwāl wa-l-ʿurūḍ li-l-Furs*, a work of unknown authorship that was the source of geographical tables of Naṣīr ad-Dīn aṭ-Ṭūsī (Marāġa, *ca.* 1260) and Uluġ Beg (Samarqand, *ca.* 1425). A second tradition of such maps is attested by the geographical tables of Ibn aš-Šāṭir (Damascus, *ca.* 1350), Sanǧar al-Kamālī (Yazd, *ca.* 1310) and ʿAbdarraḥmān al-H̱āznī (Marw, *ca.* 1120), in which *qibla*-values are given alongside the longitudes and latitudes of 250 localities. The longitudes and latitudes, as well as the *qibla*-values, were read from a map based on the coordinates of al-Bīrūnī (Central Asia, *ca.* 1025). Since al-Bīrūnī authored at least a dozen treatises on mathematical geography, of which only two are extant, there can be little doubt that he prepared a world-map similar to the Isfahan world-map tradition, but using a different selection of localities and different geographical coordinates. This was used by al-H̱āzinī to prepare his geographical table, which was then copied by Sanǧar al-Kamālī, Ibn aš-Šāṭir and others. The available manuscripts allow a reconstruction of this map, which is currently in progress in Frankfurt.

sions of the year), "*manāzil*" (= lunar mansions), and "*maṭlaʿ*" (= rising points) in *EI*², and the articles "Ibn Qutayba" and "al-Ṣūfī" in *DSB*. On medieval almanacs see for example Pellat, *Calendar of Cordova* and *Calendars*. The major works on Islamic navigational astronomy are Ferrand, *Instructions nautiques*, and Tibbetts, *Arab Navigation*. The most important Arabic texts have been published in Damascus by I. Khoury.
The lunar calendar: For an overview of calendars in the Islamic world see A. Grohmann, *Arabische Chronologie* (Leiden, 1966). See also the article "*zamān*" (= time) in *EI*¹. On the regulation of the lunar calendar see the somewhat outdated article H. P. J. Renaud, "Sur les lunes du Ramadan", *Hespéris* 32 (1945), pp. 52-68.
The times of prayer: On the definitions of the times of prayer see the article "*mīḳāt*" (= timekeeping and the regulation of the prayers) in *EI*², and also J. Frank and E. Wiedemann, "Die Gebetszeiten im Islam", (1929), repr. in Wiedemann, *Aufsätze*, II, pp. 757-788. On the origin of the definitions of the prayers see D. A. King, "On the Times of Prayer in Islam", to appear (see already King, *IAI*, XVIII, pp. 193-196). On the use of shadow schemes for timekeeping see D. A. King, "A Survey of Medieval Islamic Shadow Schemes for Simple Timereckoning", *Oriens* 32 (1990), pp. 191-249.
The sacred direction: On the religious obligations associated with the sacred direction and for an overview of the popular methods used to determine it, see the articles "*ḳibla* (= sacred direction) (legal aspects)" and "Makka (as centre of the world)" in *EI*². See also G. S. Hawkins and D. A. King, "On the Orientation of the Kaʿba", *JHA* 13 (1982) pp. 102-109, D. A. King, "Astronomical Alignments in Medieval Islamic Religious Architecture", *Annals of the New York Academy of Sciences* 385 (1982), pp. 303-312, and *id.*, "The Sacred Geography of Islam", to appear.
Part 3
Introductory: A brief overview of Islamic mathematical astronomy is in D. Pingree's article "*ʿilm al-hay'a*" (= astronomy) in *EI*². For further information on the mathematical tradition and on instrumentation see the numerous articles in Goldstein, *Studies*; Hartner, *Studies*; Kennedy *et al.*, *Studies*; *Kennedy Festschrift*; King, *IAI* and *IMA*; Wiedemann, *Aufsätze*

and *Schriften*, as well as various other publications in Spanish and Russian. The overview of Islamic mathematical techniques in Berggren, *Episodes*, takes into consideration some of the astronomical material discussed in this paper.

On early Islamic astronomy see D. Pingree, "The Greek Influence on Early Islamic Astronomy", *JAOS* 93 (1973), pp. 32-43, and "Indian Influence on Sasanian and Early Islamic Astronomy and Astrology", *Journal of Oriental Research* (Madras) 34-35 (1964-66/1973), pp. 118-126; and A. I. Sabra, "Greek Science in Islam", *History of Science* 25 (1987), pp. 223-243. The astronomical activity in the later Muslim East is surveyed in E. S. Kennedy, "The Exact Sciences in Iran under the Seljuqs and Mongols", and "The Exact Sciences in Timurid Iran". in *CHI*, V, pp. 659-679, and VI, pp. 568-580, as well as H. Winter, "Persian Science in Safavid Times", *ibid.*, pp. 581-609. On astronomy in medieval Egypt and Syria, the Yemen, and the Maghrib see King, *IMA*, III, IV, and VIII, pp. 5-9, respectively. For Muslim Spain see now Samsó, *Cliencias en Al-Andalus*, and *idem, IAMS*.

Lunar crescent visibility theory: For some examples of the earliest Muslim activity with lunar crescent visibility see Kennedy *et al.*, pp. 140-163, *Kennedy Festschrift*, pp 185-225, and also F. Bruin, "The First Visibility of the Lunar Crescent", *Vistas in Astronomy* 21 (1977), pp. 331-358.

Astronomical timekeeping: The major Islamic text on timekeeping is al-Bīrūnī's *Shadows*: translation and commentary in Kennedy, *Shadows*. A survey of all known Islamic tables for timekeeping is in King, *SATMI*. On the corpuses of tables used in Cairo, Damascus and Jerusalem, and Istanbul, see already King, *IMA*, IX, X and XIl, respectively. On universal solutions see my contributions to the *Aaboe Festschrift* (general) and *Winder Festschrift* (Mamluk).

The mathematical determination of the qibla: A brief survey of Islamic mathematical methods for finding the *qibla* is in the article "*ḳibla* (astronomical aspects)" in *EI*[2]. For some individual methods and tables see Kennedy *et al.*, *Studies*, pp. 621-629; King, *IMA*, XIII; D. A. King, "The Earliest Mathematical Methods and Tables for Finding the Direction of Mecca", *ZGAIW* 3 (1986), pp. 82-149, and corrigenda *ibid.*, 4 (1987/88),

p. 270; and J. L. Berggren, "A Comparison of Four Analemmas for Determining the Azimuth of the Qibla", *JHAS* 4 (1980), pp. 69-80.
Modern treatment: For a modern approach to these three problems see M. Ilyas, *A Modern Guide to the Astronomical Calculations of Islamic Calendar, Times & Qibla*, Kuala Lumpur: Berita, 1984. Universal tables for the prayer-times and the *qibla* have been published in Cairo (n.d.) by H. Kamāl ad-Dīn.
Part 5
The quotations are adapted from Heinen, *Cosmology*, p. 25, *Ali*, p. 12, and Kennedy, *Shadows*, I, pp. 75-76.

Bibliographical abbreviations:

Ali = J. Ali, trans., *The Determination of the Coordinates of Cities: al-Bīrūnī's Taḥdīd [nihāyāt] al-amākin.* Beirut: American University of Beirut Press, 1966.
Berggren, *Episodes* = J. L. Berggren, *Episodes in the Mathematics of Medieval Islam*. New York: Springer, 1986.
*al-B*īrūnī, *Shadows* = Abū r-Rayḥān al-Bīrūnī, *Idrād al-maqāl fī amr aẓ-ẓilāl*, no. 2. in *Rasā'il al-Bīrūnī*. Hyderabad-Deccan: Osmania Oriental Publications, 1948.
al-Bīrūnī, *Taḥdīd* = Abū r-Rayḥān al-Bīrūnī, *Kitāb taḥdīd nihāyāt al-amākin.* Ed. P. Bulgakov, *Mağallat Maʿhad al-Maḫṭūṭāt al-ʿArabiyya* 8 (1962).
Brockelmann, *GAL* = C. Brockelmann, *Geschichte der arabischen Litteratur*, 2 vols. 2nd ed. Leiden: E. J. Brill, 1943-49, and Supplementbände, 3 vols. Leiden: E. J. Brill, 1937-42.
Cairo Survey = D. A. King, *A Survey of the Scientific Manuscripts in the Egyptian National Library. (Publications of the American Research Center in Egypt).* Winona Lake, Indiana: Eisenbrauns, 1987.
CHI = *The Cambridge History of Iran.*
DSB = *Dictionary of Scientific Biography.* New York: Charles Scribner's Sons, 16 vols., 1970-80.

EI[1] = *Encyclopaedia of Islam*, 1st ed., 4 vols. Leiden: E. J. Brill, 1913-1934.

EI[2] = *Encyclopaedia of Islam*, 2nd ed., 7 vols. to date, Leiden: E. J. Brill, 1960 to present.

Ferrand, *Instructions nautiques* = G. Ferrand, *Instructions nautiques et routiers arabes et portugais*, vol. III: *Introduction à l'astronomie nautique arabe* (Paris, 1928). Repr. Frankfurt: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1986.

Goldstein, *Studies* = B. R. Goldstein, *Theory and Observation in Ancient and Medieval Astronomy*. London: Variorum Reprints, 1985.

Hartner, *Studies* = W. Hartner, *Oriens-Occidens. Ausgewählte Schriften zur Wissenschafts- und Kulturgeschichte*, and *Oriens-Occidens* II, (ed. by Y. Maeyama). Hildesheim: Georg Olms, 1968 and 1984.

Heinen, *Cosmology* = A. Heinen, *Islamic Cosmology. A Study of as-Suyūṭī's al-Hay'a as-saniyya fī l-hay'a as-sunniyya*. Beirut: commissioned by Franz Steiner Verlag, Wiesbaden, 1982.

JHA = *Journal for the History of Astronomy.*

JHAS = *Journal for the History of Arabic Science.*

Kennedy *et al.*, *Studies* = E. S. Kennedy, Colleagues and Former Students, *Studies in the Islamic Exact Sciences*. Beirut: American University of Beirut, 1983.

Kennedy, *Shadows* = E. S. Kennedy, *The Exhaustive Treatise on Shadows by Abū r-Rayḥān Muḥammad b. Aḥmad al-Bīrūnī. Translation and Commentary.* 2 vols. Aleppo: Institute for the History of Arabic Science, 1976.

Kennedy, *Taḥdīd* = E. S. Kennedy, *A Commentary upon al-Bīrūnī's Kitāb taḥdīd [nihāyāt] al-amākin*. Beirut: American University of Beirut Press, 1973.

Kennedy Festschrift = D. A. King and G. Saliba, eds., *From Deferent to Equant: Studies in the History of Science in the Ancient and Medieval Near East in Honor of E. S. Kennedy, Annals of the New York Academy of Sciences* 500 (1983).

King, *IAI* = D. A. King, *Islamic Astronomical Instruments*. London: Variorum Reprints, 1987.

King, *IMA* = D. A. King, *Islamic Mathematical Astronomy*. London: Variorum Reprints, 1986.

King, *Muwaqqits* = D. A. King, "On the Role of the Muezzin and *Muwaqqit* in Medieval Islamic Society", to appear in Stephen Livesey and Jamil Ragep, eds., *Proceedings of the Conference "Science and Cultural Exchange in the Premodern World" in Honor of A. I. Sabra, University of Oklahoma, Norman, Oklahoma, Feb. 25-27, 1993*, Leiden: E. J. Brill, 1995.

King, *SATMI* = D. A. King, *Studies in Astronomical Timekeeping in Medieval Islam*, I: A Survey of Tables for Reckoning Times by the Sun and Stars, and II: A Survey of Tables for Regulation of Time by the Times of Prayer, to appear.

Matvievskaya & Rosenfeld, *MAMS* = G. P. Matvievskaya and B. A. Rosenfeld, *Matematiki i Astronomi Musulmanskogo Srednevekovya i ikh Trudy (VIII-XVIII vv.).* 3 vols. Moscow: Nauka, 1983.

Nallino, *Scritti* = C. A. Nallino, *Raccolta di scritti editi e inediti*, vol. V: Astrologia – Astronomia – Geografia. Rome: Istituto per l'Oriente, 1944.

Pellat, *Calendar of Cordova* = Ch. Pellat, trans., *Le Calendrier de Cordoue publié par R. Dozy.* Leiden: E. J. Brill, 1961.

Pellat, *Calendars* = Ch. Pellat, *Cinq calendriers Egyptiens*. Cairo: Institut Français d'Archéologie Orientale du Caire, 1986.

Samsó, *Ciencias el Al-Andalus* = Julio Samsó, *Las ciencias de los antiguos en Al-Andalus*, Madrid: Mapfre, 1992.

Samsó, *IAMS* = Julio Samsó, *Islamic Astronomy in Medieval Spain*, Aldershot: Variorum, 1994.

Sezgin, *GAS* = F. Sezgin, *Geschichte des arabischen Schrifttums*. Band V: Mathematik. Band VI: Astronomie. Band VII: Astrologie, Meteorologie und Verwandtes. Leiden: E. J. Brill, 1974, 1978 and 1979.

Suter, *MMA* = H. Suter, "Die Mathematiker und Astronomen der Araber und ihre Werke", *Abhandlungen zur Geschichte der mathematischen Wissenschaften*, 10 (1900), and "Nachträge und Berichtigungen", *ibid.*, 14 (1902), pp. 157-185, repr. Amsterdam: The Oriental Press, 1982, and again in *idem, Beiträge zu Geschichte der Mathematik* *und Astronomie im Islam*, 2 vols. Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1986.

Tibbetts, *Navigation* = G. R. Tibbetts, *Arab Navigation in the Indian Ocean before the Coming of the Portuguese*. (London: The Royal Asiatic Society of Great Britain and Ireland, 1972), repr. 1981.

Wiedemann, *Aufsätze*: E. Wiedemann, *Aufsätze zur arabischen Wissenschaftsgeschichte*. 2 vols. Hildesheim: Georg Olms, 1970 ed. (originally published in the *Sitzungsberichte der physikalisch-medizinischen Sozietät zu Erlangen*, 1902-1928).

Wiedemann, *Schriften* = E. Wiedemann, *Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte*, 3 vols. Frankfurt am Main: Institut für Geschichte der Arabisch-Islamischen Wissenschaften, 1984.

Winder Festschrift = F. Kazemi and R. B. McChesney, eds., *The Way Prepared: Essays on Islamic Culture in Honor of Richard Bayly Winder*. New York: New York University Press, 1988.

ZGAIW = *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften.*

Additional bibliography:

Articles "Makka: as centre of the world" (on sacred geography based on the folk astronomical tradition) and "samt" (on world-maps centred on Mecca), "*nudjūm*" (on stars) and "*ru'yat al-hilāl*" (on lunar crescent visibility), as well as "*mizwala*" (on sundials) and "*rub*ᶜ" (on quadrants), in *EI*².

Donald R. Hill, *Islamic Science and Engineering*, Edinburgh: Edinburgh University Press, 1993. [A useful survey.]

David A. King, *Astronomy in the Service of Islam*, Aldershot: Variorum, 1993. [Contains reprints of several of the articles listed in the main bibliography.]

David A. King, "Strumentazione astronomica nel mondo medievale islamico", in Gerald L'E. Turner, ed., *Gli strumenti*, Turin: Giulio Einaudi, 1991, pp. 154-189 and 581-585, with a summary "Some Remarks on Islamic Astronomical Instruments", *Scientiarum Historia*

18:1 (Brussels, 1992), pp. 5-23. [The first surveys of Islamic instrumentation.]

David A. King, "World-Maps for Finding the Direction and Distance of Mecca: A Brief Account of Recent Research", paper presented at the Symposium on Science and Technology in the Turkish and Islamic World, Istanbul, Research Centre for Islamic History, Art and Culture, 3-5 June, 1994.

Daniel M. Varisco, *The Almanac of the Yemeni Sultan al-Ashraf*, Seattle, Wash.: University of Washington Press, 1994. [A valuable contribution to our knowledge of medieval folk astronomy.]