Astronomical timekeeping in Mamlûk Jerusalem

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"Urbs Syon aurea, patria lactea, cive decora
omne cor obruis, omnibus obstruis et cor et ora ... "
"Jerusalem the golden, with milk and honey blest,
beneath thy contemplation sink heart and voice oppressed ... "
Bernard of Cluny (France, 12th C), first verses of his stinging satire
against corruption, translated by J. M. Neale (1851) as an English hymn

"Wherever in the medieval world there were tables, real astronomy was practiced;
where tables were lacking there were only dilettantes and dabblers."
James Evans, *Ancient Astronomy* (1998), p. viii

"And this is my message: That you think of these people, and
that the world finally becomes aware of them again."
Aeham Ahmad, Frankfurt, 2017

Summary

Various medieval Arabic manuscripts preserved in libraries around the world – Leipzig, Cairo, Princeton, and not least Jerusalem – attest to activity in astronomy in Mamlûk Jerusalem, mainly in the 14th century and thereafter into the Ottoman period, the most recent manuscript having been copied *ca*. 1900. The main figures in this activity are the Cairo astronomer al-Rashîdî and his Jerusalem contemporary al-Karakî. There can be no comparison with the established sophisticated astronomical traditions in Mamlûk Cairo and Damascus and Aleppo, but since the Jerusalem tradition is virtually unknown, it is surely worth documenting separately, and for this the time is ripe.

This study is concerned with an important branch of Islamic astronomy, namely, astronomical timekeeping and the regulation of the five daily prayers, as well as the determination of the *qibla* or sacred direction toward the Ka'ba in Mecca. Most of the astronomers associated with mosques who practiced such applied astronomy for religious purposes were called *muwaqqit*s, literally "those concerned with time-keeping", others simply *mîqâtî*s, specialists in the discipline *'ilm al-mîqât*, "the science of astronomical timekeeping". In the central lands of Islam this activity is attested in Cairo from the 13th century onwards, and in Damascus from the 14th. Prior to that similar tables were compiled all over the Islamic world (except al-Andalus) but on a less organized basis.

Our manuscripts present a corpus of tables, containing over 20,000 entries, for finding the time of day from the altitude of the sun throughout the year and for regulating the astronomically-defined times of Muslim prayer. Thus the *muwaqqit*s associated with mosques in Jerusalem were involved in the same colourful activities as their colleagues in the better-known astronomical centres as Cairo and Damascus. More modest tables are attested for Ramla and Nablus, and the most sophisticated treatise that we have come across was copied by in the early 14th century by a *muwaqqit* at the Sacred Mosque in Hebron who was clearly conversant with the finer points of the astronomical tradition in Cairo.

Dramatis personae

Note: The most useful references for Mamluk astronomers are Suter, *Cairo Survey*, and Rosenfeld & Ihsanoglu, *MAIC*.

Ibn al-Dahhân, Fakhr al-Dîn, born in Baghdad, worked in Mosul, Irbil and Damascus, author of a *zîj* of which only fragments survive – Suter #310; *MAIC* #506

al-Maqsî, Abu l-ʻAbbâs A.hmad ibn ʻUmar al-.Sûfî, from the suburb of Cairo called al-Maqs, an astronomer in Cairo in the late 13th century, author of tables for timekeeping and for sundial construction: Suter #383; *Cairo Survey* C15; *MAIC* #659

Ibn Sim'ûn, Na.sîr al-Dîn Mu.hammad, astronomer active in Cairo, d. 1337 – Suter #398; *Cairo Survey* C24; *MAIC* #695

Ibn al-Shâ.tir, 'Alâ' al-Dîn ʻAlî ibn Ibrâhîm, lived 1306-1375, head astronomer (*ra'îs al-muwaqqitîn*) at the Umayyad Mosque in Damascus, prolific author, primarily on *hay'a*, *zîj*es and instruments – Suter #416; *Cairo Survey* C30; King, article "Ibn al-Shâ.tir" in *DSB* & *BEA*; *MAIC* #750

al-Khalîlî, Shams al-Dîn Abî ʻAbdallâh Mu.hammad ibn Mu.hammad, formerly *muwaqqit* at the Yalbughâ Mosque in Damascus, later at the Umayyad Mosque, *ca*. 1360 – Suter #418; *Cairo Survey* C37; King, article "al-Khalîlî" in *DSB* & *BEA*; *MAIC* #764

Ibn al-Sarrâj, A.hmad ibn Abî Bakr, independent scholar in Aleppo *ca*. 1325, prolific author and the most important designer and constructor of instruments in the 14th century (and more) – Suter #508 (confused); *Cairo Survey* C26; *MAIC* #•••

al-Mizzî, Shams al-Dîn Mu.hammad ibn A.hmad ibn ʻAbd al-Ra.hîm , independent scholar at Damascus, lived 1291-1349 – Suter #406; *Cairo Survey* C34; François Charette, article "al-Mizzî" in *BEA*; *MAIC* #665=#715

al-Rashîdî, Shams al-Dîn Abû ʻAbdallâh Mu.hammad ibn Burhân al-Dîn Ibrâhîm, independent scholar in Cairo, *ca*. 1350, known for tables for timekeeping for the latitudes of Mecca and Jerusalem – *Cairo Survey* C39+C40; *MAIC* #743

al-Karakî, Zayn al-Dîn Abû Bakr Muhammad ibn Ayyûb al-.Sûfî, *muwaqqit* in Jerusalem, student of al-Mizzî – Brockelmann, *GAL*, SII, p. 156; *Cairo Survey* C35; *MAIC* ø

al-**Bakhâniqî**, Shihâb al-Dîn A.hmad ibn Mu.hammad, astronomer in Cairo, d. 1355 – *Cairo Survey* C28; *MAIC* #727

al-Wafâ'î, 'Izz al-Dîn 'And al-'Azîz ibn Mu.hammad, prolific author on astronomy in Cairo *ca*. 1450 – Suter #437+437N; *Cairo Survey* C61; *MAIC* #842

Ibn al-Hâ'im, Shihâb al-Dîn Abu l-'Abbâs A.hmad ibn Mu.hammad, leading authority on mathematics and algebra of inheritance, born in Cairo 1355, taught at the .Salâ.hiyya Madrasa in Jerusalem until his death in 1417 – Suter #423; *Cairo Survey* C58; *MAIC* #783

Introductory remarks

It is well documented that the astronomers of Mamlûk Cairo, Aleppo, and Damascus were the leading scholars of their day in theoretical astronomy, astronomical timekeeping and astronomical instrumentation.[1] The Cairo astronomers of the 13th and 14th centuries made remarkable contributions to their field. The Aleppo astronomer Ibn al-Sarrâj around 1325 was very innovative in instrumentation; he made the most sophisticated astrolabe ever made, universal in five different ways, and this is fortunately preserved in the Benaki Museum in Athens. The Damascus astronomer Ibn al-Shâ.tir *ca*. 1350 made sensible modifications to Ptolemy's solar, lunar and planetary models that were identical to those proposed by Copernicus some 200 years later. And his colleague al-Khalîlî compiled a set of universal auxiliary trigonometric tables for solving all of the problems of spherical astronomy and astronomical timekeeping that would have impressed any serious Western astronomer into the 20th century, had they known about them.

It is less well known that some of this activity extended to other cities in the realm, for example, to Jerusalem. Although the participants in this activity are perhaps not known from the medieval biographical sources or the modern bio-bibliographical ones, the manuscripts of their works preserved in libraries around the world speak for themselves. Unfortunately I have not visited the rich Khâlidiyya Library in Jerusalem itself, where some 70 Arabic astronomical manuscripts are preserved are preserved, but I have at least investigated the Arabic catalogue of that collection available on the internet. Alas I have not found any manuscripts directly relating to astronomical timekeeping using tables. However, I know from my own experience in cataloguing the 2,500 Arabic scientific manuscripts in the Egyptian National Library that

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[1] For an overview of their activities see King, "Astronomy of the Mamluks". On the general context see *idem*, "Islamic astronomy".

the jewels in the crown – usually anything from before 1500 – are often hard to spot and sometimes obscured by traditional cataloguing methods. A substantial proportion of the hundreds of manuscripts I used for my history of astronomical timekeeping in Islamic civilization were labelled *jadâwil falakiyya majhûlat al-mu'allif*, "anonymous astronomical tables" in library card-catalogues. Such manuscripts usually contain one of three main types of tables:[2]

(1) a *zîj* or astronomical handbook with tables and explanatory text, often consisting of hundreds of folios (over 200 such works are known);

(2) ephemerides displaying the positions of the sun, moon, and five naked-eye planets for each day for a given year (these were compiled for major centres from the 9th century to the 19th).

(3) tables for timekeeping by the sun and regulating the times of prayer (dozens of such tables are known for major localities).

We know of no zîjes for Jerusalem and no ephemerides have survived. It is the third category of tables that concerns us here.

The first notice of these astronomical works from Jerusalem was presented at the First International Symposium for the History of Arabic Science in Aleppo in 1976,[3] and the present survey is part of an overview of all available medieval Islamic tables for astronomical timekeeping which I published in 2004.[4]

These discoveries have remained more or less unknown ever since, not least because very few moderns are interested in medieval astronomical tables. However, such is also the fate of many Muslim achievements that have come to light only in the past sixty years or so, as more and more enthusiastic bloggers write about a glorious Islamic astronomy centred on the limited achievements of al-Khwârizmî, al-.Sûfî and their ilk. They tend to use secondary

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2 For more information see King & Samsó & Goldstein, "Islamic astronomical tables".

3 King, "Astronomical timekeeping in 14th-century Syria".

4 *Idem*, *Synchrony*, I-VI.

literature that is over half a century out of date, or modern authors who have never seen an Arabic scientific manuscript, and thereby ignore the discoveries of the past 200 years (by the Sédillots, Nallino, Suter, Schoy), and especially those of the past 60 years (Kennedy, King, Saliba, Samsó and numerous others of the following generations).

An introduction to medieval spherical astronomy

The position of localities on earth is defined in terms of longitude and latitude relative to the terrestrial equator. We call these "coordinates". Spherical astronomy, which concerns us here, is the study of the apparent rotation of the heavens – represented by a sphere – about the observer, which takes place about a celestial axis whose altitude above the horizon is equal to the latitude of the locality, or, in other words, parallel to the celestial equator. This branch of astronomy essentially involves the conversion of coordinates between three systems: the horizon-based coords of altitude and azimuth; the ecliptic-based coords of celestial longitude and latitude; and the celestial equator-based coords of ascension and declination. So, for example, the observer (at a specific latitude) can measure the altitude (above the horizon) of the sun (measured on the ecliptic) or a star, and convert this into a measure of time (measured on the celestial equator). He/She can achieve this either by calculation using trigonometric tables, or by using astronomical tables, or by means of an astrolabe together with a plate for his/her terrestrial latitude.

Muslim astronomers concerned themselves with these problems from the 8th to the 19th century. They excelled in producing trigonometric tables, tables for astronomical timekeeping, and varieties of instruments for facilitating the determination of time from celestial configurations. In particular, they produced tables and instruments that were universal, that is, serving all latitudes.

The determination of the qibla or local direction of Mecca is a problem of terrestrial geography. However, Muslim astronomers sometimes found it convenient to consider the qibla as a problem of spherical astronomy: the problem was then to determine the direction from the zenith of a locality to the zenith of Mecca. This they were able to solve using geometry or trigonometry or even special maps. Again, the most remarkable solutions to the qibla problem, dating from the 9th century onwards, are universal tables that display the qibla in degrees and minutes for each degree of longitude and each degree of latitude. Muslim astronomers in the 10th and 11th centuries even conceived of Mecca-centred world-maps with highly sophisticated cartographic grids that preserved direction and distance towards Mecca.

In this study we use the following notation:[5]

EDITOR - please change the following to the corresponding Greek letter: alpha / epsilon / phi / lambda / sigma throughout the text

a	azimuth (*samt*)
alpha	right ascensions measured from Aries 0° (*al-ma.tâli' fî l-falak al-mustaqîm*)
alpha'	right ascensions measured from Capricorn 0° (*al-ma.tâli' min awwal al-jady*)
$\text{alpha}_{\text{phi}}$	oblique ascension (*al-ma.tâli' al-baladiyya*)
_$_{a}$	functions relating to the *'a.sr* prayer
delta	(solar) declination (*mayl al-shams*)
d	excess of half-daylight over 90° (*ni.sf fa.dl al-nahâr*)
D	half-arc of daylight (*ni,sf qaws al-nahâr*)
epsilon	obliquity of the ecliptic (*al-mayl al-a'.zam*)
phi	terrestrial latitude (*'ar.d al-balad*)
h	altitude above the horizon (*al-irtifâ'*)

5 For a detailed introduction to Islamic spherical astronomy see *Synchrony*, pp. 15-42.

h_0	altitude in the prime vertical
$\_^{h}$	hours
H	meridian altitude (*irtifâ' ni.sf al-nahâr*)
lambda	ecliptic longitude (*al-.tûl*)
L	terrestrial longitude, measured according to medieval custom (*.tûl al-balad*)
n	the duration of darkness of night (*jawf al-layl*)
N	half-arc of night (*ni.sf qaws al-layl*)
q	the direction of Mecca (*al-qibla*, or *al-in.hirâf* when measured from the local meridian)
$\_{q}$	functions relating to the time when the sun is in the azimuth of Mecca
r	duration of morning twilight for a specific solar depression below the horizon (*.hi.s.sat al-fajr*)
$\_{r}$ / $\_{s}$	functions relating to morning / evening twilight
s	duration of evening twilight for a specific solar depression (*.hi.s.sat al-shafaq*)
$\_^{sdh}$	seasonal day-hours
sigma	functions relating to the *salâm*, a blessing on the Prophet announced by the muezzin a number of minutes before daybreak
t	hour-angle or time remaining until or passed since midday (*fa.dl al-dâ'ir*)
T	time since rising or remaining until setting (*al-dâ'ir*)

Medieval Islamic astronomy consisted of six main parts:

(1) Folk astronomy, derived from pre-Islamic Arabian star-lore, and folk Islamic cosmology, based on pronouncements of the Prophet and his Companions.

(2) Theories about the nature of the orbs of the sun, moon and planets (*'ilm al-hay'a*).

(3) Tables for the sun, moon and planets and the fixed stars, and tables for determining eclipses and visiblity (*'ilm al-zîjât*) and tables of positions of the sun, moon and planets for a specific year (*'ilm al-taqwîm*).

(4) Tables for timekeeping by the sun and stars, and for regulating the astronomically-defined times of prayer, as well as the determination of the qibla (*'ilm al-mîqât / 'ilm al-mawâqît*).

(5) Instruments for observations (*'ilm al-ra.sad*) and for timekeeping and other practical purposes (*'ilm al-âlât*).

(6) Astrology (*'ilm a.hkâm al-nujûm*).

We can assume that ephemerides (*taqwîm*, pl. *taqâwîm*) were available in Mamlûk Jerusalem, that is, almanacs displaying the positions of the sun, moon and planets for each day of a given year, for these were prepared annually in different centres of the Muslim world from the 9th century at least to the 19th.

The tables of Ibn Yûnus and al-Maqsî for Cairo

Ibn Yûnus (d. 1002) was the greatest astronomer of medieval Egypt.[6] One of his achievements was a set of tables of the solar azimuth and the hour-angle for the latitude of Cairo (30°0′) for each degree of solar altitude and each degree of solar longitude, that is, a(h,lambda) and t(h,lambda). In the late 13th century al-Maqsî completed the tables with a set for the time since sunrise, T(h,lambda). Between the two of them they produced a corpus of tables for regulating the times of prayer. The corpus was used in Cairo throughout the Middle Ages and into the early modern period, and survives in numerous manuscripts.

The tables of al-Mizzî and al-Khalîlî for Damascus

The early-14th-century Damascus astronomer al-Mizzî is best known for his quadrants. However, he also compiled a set of tables for timekeeping for Damascus based on his own distinctive parameters (latitude 33°27′ and obliquity 23°33′) and some tables for the times of prayers. These survive in the unique MS Cairo MM 62, copied *ca*. 1400.[7]

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6 On Ibn Yûnus see the articles in *DSB* and *BEA*. On the Cairo corpus see *Synchrony*, II: 247-347.

7 On al-Mizzî 's tables see *Synchrony*, II: 351-352.

Without a doubt the mid-14th-century Damascus astronomer al-Khalîlî was the foremost Muslim scholar in astronomical timekeeping. His relationship with al-Mizzî is unknown, but he thought fit to recompute all of al-Mizzî's tables with his own parameters (latitude 33°30′ and obliquity 23°31′). In addition he compiled a spectacular set of universal auxiliary functions for solving problems of spherical astronomy for all latitudes without more calculation than interpolation, addition and subtraction.[8] His tables survive in several manuscripts, of which the most complete is MS Paris BnF ar. 2558, copied in 1411.

With this background the scene is set for a discussion of the corpus of tables for Jerusalem.

al-Karakî's timekeeping tables for Jerusalem

MS Leipzig University Library 808, fols. 3r-93r, penned in 805 Hijra [= 1402], is an apparently unique copy of a set of tables with about 20,000 entries for timekeeping by the sun compiled by Zayn al-Dîn Abû Bakr al-Karakî[9] for the latitude of Jerusalem.[10] al-Karakî, whose family surely stemmed from the citadel-town of Kerak now in S. Jordan, appears to have been a student of early-14th-century Damascus astronomer al-Mizzî[11] and can thus be dated to the mid 14th century.

In the introduction to his tables (fol. 2v) al-Karakî states that he wished to emulate the Egyptian astronomer al-Maqsî, who had computed T(h,lambda) for phi = 30°0′;[12] his own teacher al-Mizzî, who had computed t(h,lambda) for phi = 33°27′, and al-Rashîdî,

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8 On al-Khalîlî see the articles in *DSB* and *BEA* and on the main Damascus corpus see *Synchrony*, II: 359-401

9 The Leipzig manuscript of al-Karakî's tables is mentioned in Brockelmann, *GAL*, SII, p. 156, after *Leipzig Catalogue*, p. 261.

10 *Synchrony*, I-2.2.1 and II-9.4 •••••••••

11 *Synchrony*, II: 351-352.

12 *Synchrony*, II: 287-289.

who had computed t(h,lambda) for an unspecified latitude.[13] None of these scholars had prepared tables showing both T and t, and al-Karakî states that there he saw his opportunity to join their ranks by compiling tables of both functions for Jerusalem. With due respect to al-Karakî, it seems to me probable that al-Rashîdî's tables of t(h,lambda) were computed for Jerusalem and that al-Karakî simply changed the format and added the values of T(lambda,h). The entries for t(lambda,h) in the Leipzig manuscript are identical with the corresponding entries in the tables of t(h,lambda) for Jerusalem in MSS Cairo DM 45 and Cairo DM 153, which I suspect were computed by al-Rashîdî (see further below).

The introduction to al-Karakî's tables on fol. 2v is of considerable historical interest as the only medieval text known to me in which an astronomer explains what tables have inspired him, what tables he is presenting himself, and how he computed these. The following is a translation:

> "In the Name of God, the Merciful and Compassionate. The *shaykh* and *imâm* Zayn al-Dîn Abû Bakr ibn Mu.hammad ibn Ayyûb al-Tamîmî known as al-Karakî, *muwaqqit* in Sacred Jerusalem – may God have mercy on him – said the following in the first section (of his book), which concerned the compilation of tables of time since sunrise and the hour-angle for latitude 32° north. When I saw that the virtuous *shaykh*, scholar, and calculator Jamâl al-Din Abu 'l-'Abbâs A.hmad ibn 'Umar ibn Ismâ'îl ibn Mu.hammad ibn Abî Bakr al-.Sûfî al-Maqsî – may God have mercy on him – had compiled tables of the time since sunrise for latitude 30°, which require further calculation to find the hour-angle, and that our teacher the virtuous *shaykh* and meticulous scholar Shams al-Dîn Abû 'Abdallâh Mu.hammad ibn A.hmad ibn 'Abd al-Ra.hîm al-Mizzî – may God Almighty have mercy on him – had compiled tables of the hour-angle for latitude 33°27', which also require further calculation to find the time since sunrise, and that the *shaykh* Shams al-Dîn ibn al-Rashîdî – may God have mercy on him – had put the altitude at

13 *Synchrony*, II: 351-352.

> the head of each table and the hour-angle opposite the solar longitude, I wanted to participate with them in such compilations. So I put the significant (functions) together to facilitate the work of the observer, and tabulated the time since sunrise and the hour-angle opposite the altitude with the solar longitude at the head of the tables, beginning at the first point of the ascending zodiacal signs (*i.e.*, the winter solstice). The same tables can be used for the descending signs in the opposite direction (since the last table is for the summer solstice). I did this, asking help from God and placing my trust in Him ... ."

al-Karakî's tables do indeed display the functions:

T(lambda,h) and t(lambda,h)

for each degree of both arguments. The two sets of tables are in two different hands. Note that values are given for both solstices and the equinoxes. For each value of lambda, D(lambda) is also tabulated. The underlying parameters are:

phi = 32;0° and epsilon = 23;35° .

The entries, which are given to two digits, are rather accurately computed. Note that al-Karakî does not actually say that he computed both of the functions himself. Indeed, it may be that he only computed the time since sunrise from someone else's hour-angle tables since T(lambda,h) + t(lambda,h) = D(lambda).

On fols. 94v-123v of the Leipzig manuscript, in a different hand, there is another set of hour-angle tables arranged in the same way as al-Karakî's tables, and also showing D(lambda). The title and colophon state that they are for latitude 31°40′. In fact they are for 32′0° and the entries are the same as those in al-Karakî's set. A note in the incomplete introduction to this second set on fol. 94r mentions the completion of the minaret on a mosque in Ramla in 797 H [= 1395]. The value 31°40′ is used for Ramla in several medieval Islamic geographical tables.[14]

In brief, we have a set of tables for the latitude of Jerusalem displaying the time of day and the time remaining until midday

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14 Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 280-281.

for each degree of solar altitude and each degree of solar longitude, with about 20,000 entries. So far we have not mentioned a set of tables for determining the prayer-times in Jerusalem, but these too have been recovered: see below.

al-Rashîdî's tables for the latitude of Jerusalem

Two disordered copies of tables for timekeeping for Cairo, MSS Cairo DM 45 and DM 153, copied in the same hand *ca*. 1650, contain odd folios from one and the same set of tables of the function t(h,lambda) computed for:

phi = 32°0′ (Jerusalem) and epsilon = 23°35′ ,

with the same format as the Cairo tables. The altitude arguments 22°-23° (MS DM 153, fols. 11r-11v), 24°-25° (MS DM 45, fols. 27r-27v), and 34°-35° (MS DM 153, fols. 13r-13v) head the fragments of the tables which have found their way into these two manuscripts. The six pages of tables are copied in the same hand. There is no indication of the parameters underlying the tables, which were determined by inspection.

The entries in these fragments are reasonably accurately computed and are identical to the corresponding entries in al-Karakî's tables of t(lambda,h) – note the change in format – for Jerusalem. Since al-Karakî states in his introduction to his tables that (the 14th-century Egyptian astronomer) al-Rashîdî also compiled a set of tables of t(h,lambda) (latitude unspecified), I am inclined to think that these fragments are from al-Rashîdî's hour-angle tables. al-Rashîdî also made some corrections to Ibn Yûnus' azimuth tables where these had been incorrectly copied.[15]

A late set of tables for Jerusalem

In MS Cairo .TM 81,1, fols. 1r-84v, copied *ca*. 1900, there is a complete set of tables of the function t(lambda,h) with values in degrees and minutes, for the same parameters:

phi = 32;0° (Jerusalem) and epsilon = 23;35° .

15 *Synchrony*, II: 266-267.

These tables are copied without the solar longitude arguments, and without the degrees of the entries, except at the head of each column. I have not been able to check that the entries in various sub-tables are the same as those in the fragments mentioned above, but it seems unlikely that there would be two different sets in existence. See also below.[16]

Fig. 2.1.5: An extract for solar altitude 12° from an anonymous corpus of hour-angle tables for Jerusalem. The corpus was copied *ca*. 1900, possibly from a manuscript in the Khâlidiyya Library in Jerusalem. [From MS Cairo .TM 81,1, courtesy of the Egyptian National Library.]

Fig. 2.2.1a-b: The tables of the time since sunrise for solar longitude Aquarius 12° / Scorpio 18° (a) and the hour-angle for longitudes 4°-6° of a certain sign (b) in the Jerusalem corpus. [From MS Leipzig UB 808, fol. 23v and 119v, courtesy of the Universitätsbibliothek.]

Other medieval tables for Jerusalem

In MS Princeton Yahuda 861,1, copied *ca*. 1600, amidst a set of anonymous prayer-tables for latitude 32°, there is an odd table of T(h) and t(h) computed for the equinoxes, which apart from copyist's errors has the same entries as al-Karakî's tables of T(lambda,h) and t(lambda,h) for lambda = 0°. Likewise the entries in the twilight tables for latitude 32° in MS Princeton Yahuda 861,1 are related to the entries for solar altitudes 20° and 16° in al-Karakî's set.[17]

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16 *Synchrony*, II: 410.

17 *Synchrony*, II: 335, and 357-358.

A late set of tables for Jerusalem

MS Cairo .TM 81,1, copied *ca*. 1900, contains some very late tables displaying values of the function:

T(lambda,h)

now expressed in hours and minutes, with entries for altitude in both east and west. They are based on the parameter phi = 32°0′ (Jerusalem).[18]

Fig. 2.2.6: An extract from some tables for Jerusalem preserved in a late manuscript. These are probably based on those illustrated in Fig. 2.1.5. [From MS Cairo .TM 81,1, fols. 1v-2r, courtesy of the Egyptian National Library.]

al-Rashîdî's prayer-tables for Mecca

MS Cairo Sh (*lughât*) 89,4 (fols. 29v-32v), copied in 1025 H [= 1616], is the only known copy of the introduction to a set of prayer-tables for latitude 21°, that is, Mecca, by al-Rashîdî.[19] The tables are no longer contained in the manuscript but they are described in the text. The latitude 21° is specifically mentioned, as well as the parameters 19° and 17° for twilight. al-Rashîdî mentions ten tables of the following functions:

T(h) and t(h) for = 0°, H, D, h_a, t_a, h_b, T_a, s, r, and $alpha_{phi}$.

The first table has its counterpart in the tables for Jerusalem in MS Princeton Yahuda 861,1 which I suspect were also computed by al-Rashîdî (see above).

MS Leiden University Library Or. 2805, which I have not consulted, may contain these tables.

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18 *Synchrony*, II: 410..

19 *Synchrony*, II: 313.

Anonymous prayer-tables for all latitudes

MS Princeton Yahuda 861,1, penned ca. 1600, contains a set of some 150 prayer-tables computed for each integral degree of latitude between 21° (Mecca) and 41° (Istanbul).[20] The tables are appropriately entitled *al-Natîja al-kubrâ*, which may be rendered "Universal prayer-tables". (The term *natîja* means "calendar" or "prayer-tables" in late medieval scientific Arabic.) On the title-folio the tables are attributed to 'Izz al-Dîn al-Wafâ'î, a *muwaqqit* at the Mu'ayyad Mosque in Cairo who died about 1470. This attribution is highly doubtful, but at least some of the tables are due to him. The manuscript is carelessly copied in an untidy hand, and is bound in some disorder. According to the title folio al-Wafâ'î's •CR• tables also included a set of universal auxiliary tables, but these are those of al-Khalîlî and are described as such in their sub-title. al-Wafâ'î did compile some universal auxiliary tables of his own, which are extant in another source.

The manuscript begins with a short introduction on the use of the table displaying the solar longitude for each day of the Coptic year. This is stated to have been computed for longitude 55° by al-Wafâ'î (the entry for Tût 1 is Virgo 14°39'). A star catalogue showing the right ascensions of 72 stars is likewise attributed to al-Wafâ'î. Neither solar longitude table nor star catalogue is dated. There follow two sets of prayer-tables, the first for Cairo, and the second for all latitudes, including that of Cairo.

The first set of prayer-tables are for latitude 30°, Cairo.

In the second set most of the eight functions:

D, H, h_a, t_a, r, s, n and $alpha_{phi}$

are given for latitudes (no localities are mentioned):

21° (Mecca), 24° (Medina), 30° (Cairo), 31° (Alexandria),
32° (Jerusalem), 33°30' (Damascus and Bagdad),
34° (Tripoli and Homs) and 36° (Aleppo).

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20 *Synchrony*, II: 334-336.

These are ostensibly based on obliquity 23;35°. For other integral latitudes between 21° and 41° the functions D and H are given. The function D is also tabulated for latitude 15° (Yemen).

Other standard functions are given for various latitudes, without any pattern: for example, s is given for latitude 22° but not r, and for latitude 27° t_a but not h_a. It is not difficult to show that virtually all the 150 tables were lifted from other sources.

For example, the 15 different functions for latitude 32° are taken from an independent source. There are tables of h_q and T_q for this latitude, based on a particular value of q: the only other tables for the qibla in the *Natîja* are those for latitude 30°. Also, the tables of r and s are based on parameters 20° and 16° rather than 19° and 17° as in the tables for other latitudes. I suspect that these tables were originally computed by al-Rashîdî or al-Karakî. See further below.

Anonymous prayer-tables for Jerusalem

The tables for latitude 32° in MS Princeton Yahuda 861,1 of the *Natîja al-kubrâ* attributed to al-Wafâ'î[21] differ from those for other latitudes in such a way that it is immediately obvious that they were lifted from various independent sources. Only by careful analysis can we begin top understand where they might come from. The following functions are tabulated for this latitude:

D, $2D_h$, 2N, H, h_a, t_a, h_q, T_q, r, s, n, alphaphi, $alpha_{sigma}$ and sigma .

The function sigma is the duration before sunrise for the performance of the *salâm*, a blessing on the Prophet a few minutes before dawn.

The entries in certain of the tables are reasonably accurately computed and in others are very carelessly computed. An investigation of the tables reveals the following.

(1) The table of D, which is carelessly computed, is the same as the corresponding table in MS Oxford Marsh 676 (Uri 944 = 995) due to Najm al-Dîn al-Mi.srî.

21 *Synchrony*, II: 357-358.

(2) The table of $2D^h$, the length of daylight in equinoctial hours, is a particularly wretched specimen. Some of the entries, which are badly garbled, are in hours and minutes and others are in hours and degrees.

(3) The table of 2N, which is rather accurately computed, is based on values of D other than those in (1). In fact it is based on the values of D used by al-Karakî to compile his tables of T(lambda,h) from (al-Rashîdî's ?) tables of T(h,lambda).

(4-6) The tables of H, h_a and t_a are likewise rather accurately computed.

(7-8) The tables of h_q and T_q are based on a value of q for some particular locality, although neither parameter nor locality is specified for either function. The latitude 32° is the only latitude other than 30° for which h_q and T_q are tabulated in the Princeton manuscript. However, in the title of the first function tabulated for latitude 32°, namely D(lambda), the cities of Gaza, Ramla and Jerusalem are specifically mentioned, and by inspection I find the underlying value of q to be 41°30′ (measured from the meridian). The two tables are reasonable accurately computed. Now in the geographical tables in MS Princeton Yahuda 861,1 the following entries for localities in Palestine are given:

	Long.	Lat.	q	q (acc.)	q (approx.)
Gaza	56°30′	32°0′	52°40′	42°59′	43°41′
Ramla	57°20′	32°20′	45°0′	39°37′	40°31′
Jerusalem	58°35′	32°10′	45°51′	35°58′	37°5′
Nablus	58°15′	32°20′	37°0′	36°41′	37°45′
(Mecca	67°0′	21°0′	-	-	-

In each of several earlier Egyptian and Syrian sources I have consulted,[22] the qibla values have been carelessly computed, and in some cases miscopied to boot. However, in none of these sources do we find the qibla value 41°30′. It was probably derived for Jerusalem. Indeed it was perhaps based on the value 33°0′ for the latitude of Jerusalem, as found, for example, in the tables of Ibn al-Dahhân.[23] Notice that if we take:

$L = 56°30'$ and $phi = 33°0'$ with $L_M = 67°0'$ and $phi_M = 21°30'$,

the accurate and approximate values of q are 41°37′ and 42°26′, and if we take:

$L = 57°0'$ and $phi = 33°0'$ with $L_M = 67°0'$ and $phi_M = 21°40'$,

then the accurate and approximate values of q are 40°31′ and 41°28′. Ibn al-Dahhân himself gives 41°21′ for the qibla at Jerusalem.

(9-11) The tables for twilight are based on parameters 20° and 16° for morning and evening and are reasonably accurately computed. The entries are the same as the corresponding ones in al-Karakî's tables of T(lambda,h) for h = 20° and 16°. All of the other twilight tables in the Princeton manuscript are based on parameters 19° and 17°.

(12) The table of $alpha_{phi}$ is carelessly computed, but is based on a different set of values of d than was used to compile the table of D (see (1) above).

(13) The table of $alpha_s$ is based on a more accurate set of values of than (12), using: $alpha_s(lambda) = alpha_{phi}(lambda+180°) + s(lambda)$.

(14) The table of •••(lambda), displaying the time from sunset to the *salâm*, that is, the time of the blessing of the name of the Prophet

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22 Namely, the geographical tables in MSS Paris BNF ar. 2513, fol. 89r, and Paris BNF ar. 2520, fol. 82v, of the *Mu.s.tala.h Zîj*; MS Oxford Seld. A30, fols. 155r-157v, of the *Zîj* of Ibn al-Shâ.tir; MSS Paris BNF ar. 5968, fols. 162v-163r, of the anonymous *Dastûr al-munajjimîn*; and Gotha A1403 of the derivative *zîj* of Ibn Zurayq. See further King, *Mecca-Centred World-Maps*, pp. 76-84, on the unhappy state of such tables.

23 *Synchrony*, II: 350-351.

by the muezzin, is ostensibly based on: sigma(lambda) = 2N(lamdba) - r(lambda), so that the *salâm* was to be performed precisely at daybreak rather than a few minutes before as was the case in Cairo.[24] However, the last four columns of entries are badly garbled.

(15) Finally, amongst the tables for latitude 31° in the Princeton manuscript there is one displaying the functions t(h) and T(h) for each degree of h at the equinoxes. The underlying latitude is 32° not 31° as stated, and the tables originally formed part of the more extensive set of tables compiled by al-Karakî. The entries are badly garbled.

From these investigations it is clear that there existed a set of carefully-computed prayer-tables for Jerusalem displaying at least the functions:

D, 2N, H, h_a, t_a, h_q, T_q, r, s, n and $alpha_{phi}$,

that is, the half-arc of daylight – the length of night – solar meridian altitude – solar altitude at the time of the *'a.sr* – time after midday of the *'a.sr* – the altitude of the sun when it is in the azimuth of the qibla – the time since sunrise until when the sun is in the qibla – duration of morning twilight – duration of evening twilight – the duration of darkness of night – the oblique ascensions

These tables complement al-Karakî's extensive set of tables for timekeeping.

Anonymous tables for Nablus

In MS Cairo .TM 81 at the end of some late timekeeping tables for Jerusalem (see above) there are three tables computed for latitude phi = 32;10° (Nablus). The functions tabulated are N(lambda), d(lambda) and h_0(lambda). ••K&K••

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24 *Synchrony*, II: 273.

The geographical table of al-Mizzî with qibla-values computed by al-Khalîlî

Some copies of the Damascus corpus of tables for timekeeping, for example, MS Paris ar. 2558, fol. 51v, copied 811 Hijra [= 1408], and the Egyptian copy MS Cairo MM 167, fol. 204r, copied 989 H [= 1581/82], contain a table of the geographical coordinates of close to 50 localities in Palestine, Syria and Iraq "copied from the handwriting of ... al-Mizzî" with associated qibla values "computed by Shams al-Dîn al-Khalîlî".[25]

Fig. 10.9: The geographical tables in al-Khalîlî's Damascus corpus. [From MS Paris BNF ar. 2558, fols. 51v-52r, courtesy of the Bibliothèque nationale de France.]

In the Paris copy the first four entries (Mecca, Medina, Cairo and Alexandria) are doubtless later additions, because the qibla-values are carelessly computed.

The table displays longitudes, latitudes and qibla-values (L,phi,q). The qibla-values can be compared with values computed using interpolation in al-Khalîlî's splendid qibla-table, which gives remarkably accurate values of the qibla in degrees and minutes for each degree of latitude and each degree of longitude from the meridian of Mecca.[26]

The following list includes only localities in Palestine. Our sources are **A**: MS Paris BNF ar. 2558, and **B**: MS Cairo ENL MM 167. For convenience the sexagesimal notation used in the history of ancient and medieval astronomy is used here, so that n;m° stands for n°m'. The entries Δq are the errors in the minutes compared with computation using the accurate formula. The entries q* are those

25 *Synchrony*, II: 390-393.

26 *Synchrony*, II: 386-390.

derived by linear interpolation in al-Khalîlî's qibla-table and Δq* are the corresponding errors.

•EDITOR - PLEASE FIX FORMAT•

No.	Locality	L	phi	q	Δq	q*	Δq*
1	Shawbak	56°0′	31°0′	48°42′	[+3]	48°42′	[+3]
2	Gaza	57;0	32;0	42;46	[+1]	42;46	[+1]
3	Ramla	56;50	32;10	42;56[a]	[+8]	42;50	[+2]
4	Hebron	56;30	31;35	45;21	[-6]	45;29	[+2]
5	Jerusalem	56;30	32; 0	44;14	[-2]	44;16	[0]
6	Nablus	57;30	32;10	40;38	[-6]	40;44	[0]
7	Baysan	58; 0	32;50	37;[2]5[b]	[0]	37;26	[+1]
8	Tiberias	58;15	32;5	38;34	[+4]	38;30	[0]
9	Ajlun	58;10	32;10	38;35	[+1]	38;34	[0]
10	Salt	58;10	32;0	39;2	[+2]	39; 0	[0]
11	Adhraat	60;0	31;55	32;40	[+3]	32;39	[+2]
12	Bosra	60; 0	32;15[c]	31;52	[+4]	31;51	[+3]
13	Sarkhad	60;20	32;15[d]	30;31	[-1]	30;33	[+1]
14	Damascus	60;0	33;30[e]	29;4	[+1]	29; 7	[+4]
15	Safad	57;35	32;30[f]	39;35	[0]	39;36	[+1]
16	Shaqif Tayrun	57;40	33;5	37;53	[+1]	37;51	[-1]
17	Baniyas	59;0	33;0	33;40	[0]	33;40	[0]
....							
44	Shiraz	78;0	29;36	53;8	[-8]	53;20	[+4]
Additional entries in A only:							
45	Mecca	67;0	21;30	-			
46	Medina	65;20	24;40	??;40	[?]	26;23	[+13]
47	Cairo	54;40	30;0	55;58[k]	[+34]	55;24	[0]
48	Alexandria	51;54	31; 0	58;35	[+5]	58;30	[0]

Notes: [a] B: 42;36°; [b] A/B: 37;35°; [c] B: 32;55°; [d] B: 32;55°; [e] B: 32;55° (!), a value not attested in other known source; [f] B: 33;30°; [k] The standard approximate formula yields q*: 55;19°, and the 55;58° given here may be a copyist's error for 55;18°.

The values Δq* indicate that the values q were not derived by using linear interpolation in al-Khalîlî's qibla-table since the values of q* are slightly more accurate than those of q. Perhaps this table was compiled by al-Khalîlî before his universal qibla-table.

Opposite this geographical table in the first Paris manuscript (and also in MS Paris BNF ar. 2560,13, fol. 164v, *ca*. 1750) is a list of stations on the pilgrim road from Damascus to Mecca (*manâzil al-.Hijâz al-Sharîf 'ala 'l-darb al-Shâmî*) with their respective latitudes. It is unlikely that al-Khalîlî made these measurements himself, and the list should be compared with similar ones in other sources (e.g. MS Cairo MM 167, fol. 203v). In some sources (*e.g*., Cairo MM 167, fol. 203r), we find also a list of pilgrim stations on the road from Cairo to Mecca.[27]

Astrolabes with markings for Jerusalem

The astrolabe was the most popular instrument of the Islamic and Latin Middle Ages. Its main use was in timekeeping, but it was certainly not the only instrument or means to achieve that, especially in serious astronomical circles.[28] In particular, serious astronomers would have tables at their disposal, such as we have seen for Jerusalem. But the astrolabe was a universal instrument, in the sense that originally it served the seven climates of ancient geography, latitudinal bands dividing the ancient world. Later, these plates for the climates were replaced by plates for a series of latitudes or for a series of localities.[29] In Islamic astrolabes Jerusalem was often featured, as it was on Latin astrolabes. As far as we know, instruments were not made in Jerusalem at any time.

Here I mention just two examples of Islamic astrolabes featuring Jerusalem, the first from 11th-century al-Andalus and the second from 14th-century Damascus. First, the unsigned 11th-century

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27 *Synchrony*, II: 393.

28 On Islamic astrolabes see Synchrony, X: 339-402, and "What is an astrolabe, and what is an astrolabe not".

29 See "Geographical data on astrolabes", also in *Synchrony*, XVI: 915-962.

astrolabe made in Córdoba and preserved in the Jagiellonian University Museum in Cracow.[30] The plates relevant to cities in Palestine serve the following latitudes and associated localities:

21°40′ Mecca – 24° Medina – 27° Hejaz – 30° Cairo –
32° Jerusalem, Kairouan – 36°30′ Almería –
38,30′ Córdoba, Valencia – 40° Toledo, Santarem – 42° Saragossa.

Second, the astrolabe of an anonymous student of al-Mizzî is preserved in the Museum of Islamic Art in Cairo.[31] The plates serve the following latitudes:

21°, 30°, 32°, 33°27′, 36°,

which can be uniquely associated with the following localities of the Mamlûk realm:

Mecca, Cairo, **Jerusalem**,
Damascus (parameter specific to al-Mizzî), Aleppo.

For comparison, a 14th-century Catalan astrolabe (#416) with a V-shaped frame on the rete preserved in Greenwich[32] has plates for the following localities:

DAMIATA (= Damietta), **GERUZALEM**, AFRICA (= Tunisia),
TRIPOLI, CAPTA (= Ceuta), CECILIE (= Sicily), VALENCIA,
SEGOVIA, BARCELONA, PANPLONA (= Pamplona),
MACEDONIA (= Macedonia), GENOVA, MILA (= Milan)

As far as I am aware, none of the medieval European astrolabes with Hebrew inscriptions, few as they are, has markings specifically for Jerusalem, but these have not yet been published in their entirety. The Khalili Collection in London possesses a unique

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30 For a detailed description see Maier, "Islamisches Astrolabe aus Córdoba", and ••Azucena••

31 See *Synchrony*, XIVb: 705-709, for a detailed description of this piece.

32 •GREENWICH / AZUCENA•

Andalusî astrolabe from *ca*. 1300 with inscriptions in Judaeo-Arabic, that is Arabic in Hebrew script,[33] has markings specifically for:

Sijilmasa, Cairo, Marrakesh, **Jerusalem**, Tunis, Seville, Cordova.

Sundials in Jerusalem and Acre

Muslim astronomers were extremely proficient in gnomonics, the science of sundial construction.[34] They inherited the Greek traditions of horizontal and vertical sundials and already in the 9th century the astronomer .Habash al-.Hâsib of Baghdad and Samarra, perhaps the most innovative astronomer anywhere at the time, prepared a set of tables for constructing horizontal sundials for each few degrees of latitude.[35] Within a century auxiliary tables were prepared by Ibn al-Âdamî for constructing vertical sundials for all latitudes and all orientations. The magnificent horizontal sundial made by Ibn al-Shâ.tir for the Umayyad Mosque in Damascus in 1371/72 is the most sophisticated sundial made between Antiquity and the early modern period. Not only does it perform all of the standard functions of the sundial in several different ways, it also shows the time remaining until each of the five daily prayers.[36] In the Mamlûk realm a sundial would have featured in every mosque of consequence.

As far as medieval sundials are concerned, we can draw attention to one standard vertical sundial in Jerusalem and another of a very rare kind in Acre. In Jerusalem, the Scottish architect and historian of Islamic architecture Archibald Walls alerted me to the vertical sundial from the late Mamlûk or early Ottoman period on the West Wall of the Madrasa of Sultan Qaytbay. This shows the time

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33 See Abu Zayed & King & Schmidl, "Astrolabe with Judaeo-Arabic inscriptions".

34 See the article "Mizwala (= sundial)" in *Enc. Islam*, 2nd edn., for an overview, also *Synchrony*, X: 81-91.

35 *Synchrony*, I: 84-88.

36 On this see Janin, "Le cadran solaire de la Mosquée Umayyade à Damas", and King, *Synchrony*, XIVb: 712-715.

remaining to the *'a.sr* prayer (close to mid-afternoon) for the particular orientation of the wall and for latitude of Jerusalem. We published a joint article on the sundial in 1979.[37] The markings on the sundial would probably have been laid out using tables for constructing vertical sundials. In the Khâlidiyya Library there is a manuscript of such tables for each degree of inclination from the meridian but these are for the latitude of Cairo, and the manuscript was copied at the al-Azhar Mosque in Cairo.

Of greater scientific interest is a polar sundial – the only surviving one from the Islamic world – in the courtyard of the al-Jazzâr Mosque in Acre. On this the plane of the sundial is perpendicular to the celestial equator. The sundial is elegantly constructed out of marble and there is a beautifully engraved Arabic inscription on the pedestal. [38] This sundial is fully within the medieval Islamic tradition, for coordinates for marking the parallel hour-lines on a polar sundial for different latitudes are found already in the treatise of .Habash, from 9th-century Baghdad. Also, the brass compendium or multi-functional instrument of Ibn al-Shâ.tir for 14th-century Damascus known as the *.sandûq al-yawâqît*, "jewel box", contains such a sundial on a much smaller scale.

The astronomical manuscripts in the Khâlidiyya library in Jerusalem

The following brief remarks are based on the 70 manuscripts catalogued under "Astronomy" in the library catalogue.[39] The reader should know that subject divisions and author attributions and contents assessments are particularly difficult for scientific manuscripts because only rarely does the cataloguer have any idea about the subject matter. This is especially the case for astronomical tables, where the cataloguer may be confronted with dozens, if not hundreds of pages of tables. Incipits and explicits and other

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37 King & Walls, "Jerusalem sundial".

38 Michel & Ben-Eli, "Un cadran solaire remarquable".

39 *Khâlidiyya Catalogue*, pp. 798-823.

cataloguers' musts are usually irrelevant and relate only to the accompanying text.

At first reading, the catalogue contains no works compiled in Jerusalem and very few manuscripts of consequence copied there. With very few exceptions other copies of the same texts are available in other more accessible libraries. The first item in the list below might contain some tables for timekeeping. The following list assumes familiarity with most of the authors.

- **Some anonymous tables (#1848, 30 fols., 17th C), might be worth investigating**.
- Treatises on astrology by al-Kindî, Sahl ibn Bishr, Abû Ma'shar, Ibn Abi l-Rijâl, Kûshyâr ibn Labbân, al-Sijzî and Ibn Abî Shukr al-Maghribî.
- A treatise on astrology falsely attributed to Ibn Yûnus (#1854, 30 fols., 18th C).
- A copy of the *Kitâb al-ulûf* of Abû Ma'shar (#1872, 44 fols., 17th C) – should be investigated.
- The usual late Syrian, Egyptian and Maghibi treatises on the determination of the prayer-times and the *qibla*, as well as operations with the astrolabe, and both astrolabic and trigonometric quadrants.
- The treatise on the construction of different types of quadrants by the 15th-century Egyptian astronomer Ibn al-'A.t.târ (#1852).
- Treatises on less common instruments such as the equatorial semi-circle and the universal plate (*shakkâziyya*).
- More significant historically, copies of the *Zîj* of Ibn al-Shâ.tir, his work on theoretical astronomy called the *Nihâyat al-su'l* (two copies) and his treatises on the astrolabe and *kâmil* quadrant.
- The *Zîj* of Ulugh Beg of Samarqand.
- A *ruznâme* or almanac / calendar.
- One manuscript that catches the eye is of an astrological treatise supposedly involving Sabian practices by Mâlik ibn 'Aqbûn (?) al-.Harrânî, copied in 832 H (#1860, 15 fols.).

- An astrological treatise (with the spurious title *Risâla fi l-.tâli'*) concerning events near Adana (#1868, 21 fols., cop. 896 H) – this important historical text should be compared with a similar one preserved in Cairo.[40]
- Treatises on the sun and moon by al-Wafâ'î.
- Sib.t al-Mâridînî's treatise on constructing vertical sundials.
- A short work (*madkhal*) by Ibn al-Bannâ'.
- An astrological treatise for Mu.s.tafâ ibn A.hmad Khân, 18th-century Ottoman sultan (#1874, 6 fols., 1204 H).
- Various simple works on folk astronomy by the Moroccan folk astronomer Abû Miqra'.
- Treatise on the circle of *mi.hrâb*s and the adjustable sundial, 'Abd al-Ra.hmân al-Wafâ'î, *muwaqqit* at the Ghawriyya Madrasa (in Cairo), copied *ca*. 1250 H

The following manuscripts were actually copied in Jerusalem or therabouts:

- al-Suyû.tî's treatise on Islamic cosmology (#1833, 1135 H in Jerusalem.
- *al-Hidâya mina l-.dalâla* on simple astronomy by al-Qalyûbî (#1836, 1322 H)
- A treatise (*al-Fat.hiyya*) on the sine quadrant by Sibt al-Mâridînî (#1843, cop. 1117 H in Qa.sabat Yarmûk).
- A treatise on the astrolabic quadrant by Ibn al-Majdî (#1846, 1171 H in Qa.sabat Yarmûk).
- *Shar.h Mukhta.sar al-Khattâb* on simple astronomy by 'Umar ibn A.hmad al-Jâlî (#1847, 1171 H in Qa.sabat Yarmûk)
- *al-Mughnî fî shar.h al-Muqni'* by al-Mirghîthî, on folk astronomy (#1880, cop. 1246 H in Jerusalem)
- Various treatises, each of a few folios, on the prayer times and *qibla* as well as the use of the astrolabic quadrant by Mu.hammad .Sâli.h al-Qudsî, *imâm* at the al-Aq.sâ Mosque, copied in 1236 H (for example, #1849)

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40 MS Cairo ENL Sh 74, on which see *Cairo Survey*, C91, item 5.3.16.

These are hardly representative of the vast output of sophisticated treatises produced by Muslim astronomers over the centuries. More historically significant than most of the above sources is a manuscript in the Egyptian National Library in Cairo (QM 2) of a treatise probably compiled by the early-14th-century Cairo astronomer Ibn Sim'ûn. It deals with a special kind of sundial and astronomical scales from the 8th century called *mîzân al-Fazârî*. This ingenious instrument has not yet received due attention from historians. What concerns us here is the fact that the manuscript was copied in the year 706 H [= 1306/07] by **Ibrâhîm ibn A.hmad ibn Khalîl, *muwaqqit* at the Sacred Mosque (*al-.haram al-Khalîl*) in Hebron**.[41] This is important evidence that the office of *muwaqqit*, first documented in mid-13th-century Cairo, was attested in Hebron, and surely also in Jerusalem, even before its culmination in mid-14th-century Damascus.[42]

The Jewish connection

There was considerable activity in astronomy amongst Jewish scholars in al-Andalus from the 12th century to the 15th. This was inspired not only by the activities of Andalusî scholars but also by those of European astronomers from Poland to England. The Jewish tradition departed in different directions, namely, the preparation of long-term longitude-dependent almanacs for the sun, moon and planets, with additional tables for syzygy and eclipse determinations, and for the Jewish calendar, together with a modicum of latitude-dependent tables for spherical astronomy.

The Jewish astronomer of Salamanca Abraham Zacuto (b. Salamanca 1452, died Damascus 1515) was the most influential of

41 On the Ibn Sim'ûn and this manuscript see *Cairo Survey*, no. C24, and pl. CIIIb and the caption on p. 215.

42 On muezzins and *muwaqqit*s see *Synchrony*, V: 623-677, esp. p. 643.

these scholars.[43] He is best known for his perpetual almanac, a work which obviated the need to prepare ephemerides for each year. He left Portugal in 1496 and lived in Fez, Tlemcen and Tunis till at least 1505. In one of these cities he compiled a new set of tables (1501) and his perpetual Almanac in the printed Castilian version of 1496 was translated into Arabic by A.hmad ibn Qâsim al-.Hajarî. It was used in the Maghrib – along with several other Maghribî sets of tables (*zîj*es) – until the 19th century. In 1512 Zacuto arrived in Jerusalem where he composed a *zîj* using the Hebrew calendar, rather than the Christian one that he had used in his 1478 *zîj* composed in Salamanca. His works continued to be consulted by Jews in Syria and Iraq until the 16th and 17th centuries.

We note also that a Hebrew version of the *Zîj* of Ibn al-Shâ.tir survives in a unique manuscript copied in the mid 19th century in Aleppo.

Concluding remarks

Cairo and Damascus and Aleppo were the leading centres of astronomy in the Mamlûk realm, but the modest astronomical activity in various other cities also merits our attention. I think first of Jerusalem, for which this modest contribution that may well surprise a few people, but also Damietta, Alexandria, Assiut, Hama, Homs, Tripoli, ...[44]

As is the case with all medieval tables for time-keeping we can surmise how they were calculated but we can only speculate how they were used, or perhaps even wonder whether they were used at all. Of course they were used. We may have only a unique manuscript of a particular corpus of tables, but we can be sure that there existed dozens of copies in the medieval period and every

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43 For this section I have relied on my teacher Prof. Bernard Goldstein in King & Samsó & Goldstein, "Astronomical handbooks and tables from the Islamic World (750-1900)", pp. 64-69, and Chabás & Goldstein, "Astronomy in the Iberian Peninsula".

44 Astronomers and tables from these locations are mentioned in *Cairo Survey* and *Synchrony*.

self-respecting astronomer and *muwaqqit* would make sure that he had his own copy. At least for Jerusalem, we now know the main players and their principal productions.

Bibliography

Note: For bio-bibliographical information on Muslim astronomers (and mathematicians), excluding Iran and points eastward, the principal sources are Suter; Brockelmann; Sezgin; *DSB; Cairo Survey*; *MAIC*; and *BEA*, the last available on the internet. For an overview of Islamic mathematical and folk astronomy see King, "Islamic astronomy". On astronomical timekeeping see King, *Synchrony*, I-IX. On instrumentation see King, *Synchrony*, X-XVIII, and Charette, *Instrumentation in 14th-century Egypt*.

Mohamed Abu Zayed & David A. King & Petra Schmidl, "From a heavenly Arabic poem to an enigmatic Judaeo-Arabic astrolabe", *Suhayl – International Journal for the History of the Exact and Natural Sciences in Islamic Civilisation* 10 (2011): 1-58

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Glossary

ascensions: the rising time of an arc of the ecliptic over the horizon at the equator or at the observer's locality (see article "Ma.tâli'" in *Enc. Islam*).

astrolabe: a 2-dimensional model of the 3-dimensional celestial sphere, with a movable part (rete) featuring the ecliptic and various bright stars and a fixed part (plates for individual latitudes) showing the horizon and meridian as well as altitude and azimuth circles for a specific latitude. The combination can be used to represent the instantaneous configuration of the heavens about the observer.

astronomy, spherical: the study of the mathematics underlying the celestial sphere and of timekeeping by the sun and stars

axis, celestial: the imaginary axis about which the heavens appears to rotate

azimuth: the direction of a celestial body measured along the horizon (from Arabic *al-sumût* < *samt*, "direction")

azimuth of Mecca: translation of *samt Makka*, also called *in.hirâf al-qibla* in medieval Arabic, literally "inclination of the *qibla* from the local meridian"

coordinates: here, the definition of the position of any point on the terrestrial sphere or celestial sphere by means of one measurement along the principal circumference and another perpendicular to it - compare terrestrial longitude and latitude, and ecliptic longitude (sun, moon and planets) and latitude (moon and planets)

ecliptic: the apparent path of the sun against the background of the stars, conveniently all on the celestial sphere - see also zodiac

equator, celestial: the great circle of the celestial sphere perpendicular to the celestial axis, coordinates of any celestial body with respect to the equator are are ascension and declination

longitude and latitude, celestial: the coordinates of a celestial body with respect to the ecliptic

longitude and latitude, terrestrial: the coordinates of a locality with respect to the equator

qibla: the sacred direction of prayer and various other ritual acts towards the Kaaba in Mecca

sphere, celestial: an imaginary sphere of arbitrary radius encircling the observer at the centre, on which all celestial bodies appear to be fixed (stars) or moving (sun, moon and planets)

trigonometry, plane / spherical: the mathematics of angles / arcs, involving functions such as the sine and cotangent (labelled here Sine and Cotangent since the functions used in medieval times were to base 60 rather than unity, as we use today)

zenith: the point on the celestial sphere directly above the observer (*samt al-ra's* in Arabic)

zodiac: the belt of the heavens straddling the ecliptic within which the moon and planets appear to move, divided historically according to 12 constellation figures

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