A Universal Sundial Made for Sultan Mehmet II, in the Context of Astronomical Instrumentation in late-15th Century Istanbul

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Abstract: In this study we present a previously-unknown astronomical and mathematical instrument. This is a sundial for all latitudes made in 1477 and dedicated to the Ottoman Sultan Mehmet II who is known for his interest in astronomy. It is a unique example of a type of instrument previously known only from Arabic astronomical texts some two centuries earlier. This sundial, which enables the user to measure time from the solar altitude throughout the year, is conceived for all inhabited latitudes (as in classical geography, this would be from the equator to about 45°). By necessity, therefore, it is based on an approximate but practical formula for timekeeping.

In Islamic civilization sundials have a history of over 1,000 years, but this has yet to be documented on the basis of surviving sundials and texts – of these, universal sundials form a small but significant part. The immediate source of the design for this particular universal sundial can be identified as an Egyptian treatise on astronomical instruments from the late 13th century; however, the device itself was much earlier, maybe originating as far back as Baghdad *ca.* 900. The formula was known already to the earliest Muslim astronomer al-Fazārī in Baghdad *ca.* 750. This sundial is a mathematical device as well an astronomical one, in the sense that it was not really intended to be used as a *practical* time-telling device. It is so small that it would be difficult to measure time with it under any circumstances; the same is true of many hand-held astronomical instruments. It may

King, David A. & Charette, François (2024). «Astronomical instruments from late-15th-century Istanbul, introducing a universal sundial made for Sultan Mehmet II». *Suhayl. International Journal for the History of the Exact and Natural Sciences in Islamic Civilisation*, 21, December 2024, pp. 7–208. ISSN: 1576-9372. DOI: 10.1344/SUHAYL2024.21.1.

be «universal» but one could hardly travel about with it. Nevertheless, at some time it was brought from Istanbul to Bucharest, either whilst the latter was still under Ottoman control or even thereafter. In fact, it is simply an intriguing object embodying mathematical quantities associated with an elegant astronomical formula for timekeeping, and a testimony to part of the essence of the transmission of ideas from Antiquity to the early Muslim world, thence to Mamluk Egypt and on to the early Ottoman world. And similar devices appear in Renaissance Europe. This «new» sundial reveals how little we knew previously about the astronomical interests of Mehmet II and their level of sophistication; it invites a new look at the relevant sources. This study deals with materials not yet incorporated into the current history of Ottoman astronomy. It casts light on astronomy and dialling in 15th-century Istanbul and it adds substantially to our knowledge of Mehmet II's interest in astronomy.

Key words: Mehmet II; Istanbul; Ottoman; Aḥmar; universal sundial; latitudes; climates; al-Marrākushī; Najm al-Dīn al-Miṣrī; Habermel; Regiomontanus; Bessarion; Piero della Francesca; world-map; rectazimuthal; Ḥabash; Nasṭūlus; al-Bīrūnī; al-Ṣūfī; al-Khalīlī; universal auxiliary tables; astrolabe; alidade; sundial; Muslim prayer-times; Byzantine astronomy.

Resum: En aquest estudi presentem un instrument astronòmic i matemàtic fins ara desconegut. Es tracta d'un rellotge de sol per a totes les latituds fet el 1477 i dedicat al sultà otomà Mehmet II, conegut pel seu interès en l'astronomia. És un exemple únic d'un tipus d'instrument conegut prèviament només a partir de textos astronòmics àrabs uns dos segles anteriors. Aquest rellotge de sol, que permet a l'usuari mesurar el temps a partir de l'altura solar al llarg de l'any, està concebut per a totes les latituds habitades (en la geografia clàssica, des de l'equador fins a aproximadament 45°). Per necessitat, per tant, es basa en una fórmula aproximada però pràctica per a la mesura del temps.

A la civilització islàmica, els rellotges de sol tenen una història de més de 1.000 anys, però encara ha de documentar-se a partir dels rellotges de sol i els textos que han sobreviscut; d'aquests, els rellotges de sol universals formen una part petita però significativa. La font immediata del disseny d'aquest rellotge de sol universal en particular es pot identificar com un tractat egipci sobre instruments astronòmics de finals del segle xiii; no obstant això, el dispositiu en sí mateix era molt més antic, potser originari de Bagdad cap al 900. La fórmula ja era coneguda pel primer astrònom musulmà al-Fazārī a Bagdad cap al 750. Aquest rellotge de sol és un dispositiu matemàtic a més d'astronòmic, en el sentit que no es va concebre realment per a ser utilitzat com a dispositiu pràctic per a la mesura del temps. És tan petit que seria difícil mesurar el temps amb ell en qualsevol circumstància; el mateix passa amb molts instruments astronòmics manuals. Pot ser «universal», però difícilment es podria viatjar. No obstant això, en algun moment va ser portat d'Istanbul a Bucarest, ja sigui mentre aquesta última encara estava sota control otomà o després. De fet, és un objecte intrigant que encarna quantitats matemàtiques associades amb una fórmula astronòmica elegant per a la mesura del temps, i un testimoni de part de l'essència de la transmissió d'idees des de l'Antiguitat fins al món musulmà primerenc, després cap a l'Egipte mameluc i finalment cap al món otomà primerenc. Dispositius similars apareixen a l'Europa del Renaixement. Aquest «nou» rellotge de sol revela com de poc sabíem anteriorment sobre els interessos astronòmics de Mehmet II i el seu nivell de sofisticació; convida a una nova mirada a les fonts pertinents. Aquest estudi tracta de materials encara no incorporats a la història de l'astronomia otomana. Aporta llum a l'astronomia i la gnomònica a l'Istanbul del segle XV i incrementa substancialment el nostre coneixement de l'interès de Mehmet II en l'astronomia.

MOTS CLAU: Mehmet II; Istanbul; Otomà; Aḥmar; rellotge de sol universal; latituds; climes; al-Bīrūnī; al-Marrākushī; Najm al-Dīn al-Miṣrī; Habermel; Regiomontanus; Bessarion; Piero della Francesca; mapamundi; rectoazimutal; Ḥabash; Nasṭūlus; al-Bīrūnī; al-Ṣūfī; al-Khalīlī; astrolabi; alidada; rellotge de sol; hores de pregària.

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Part A. The instrument

1. Introductory remarks

We present here the first description of an instrument made for and dedicated to the Ottoman Sultan Mehmet II in 1477, almost 25 years after he had conquered the tired old city of Constantinople.[1] Fatih Mehmet, «The Conqueror», attracted scholars from all over the Muslim world to his Court, from al-Andalus to Central Asia, so that learning and science might flourish in a cosmopolitan milieu. It is known that the Sultan had an interest in astronomy, but until now scholars have not identified any written works or instruments specifically associated with him. This «new» instrument will take specialists of many disciplines by surprise, as it did the two authors.[2]

At the outset we stress that we shall be dealing only with the practical side of Ottoman astronomy in the 15th century and thereby do not discuss theoretical astronomy, which has been investigated by colleagues.[3] We shall only occasionally mention subjects such as astronomical handbooks with tables (*zīj*es); computation of annual ephemerides (*taqwīm*) with horoscopes (*ṭāliʿ*); and models to help understand the apparent motions of the imaginary spheres (*falak*, *hayaʾa*). Most of our discussion will be focused on علم الالات, *ʿilm al-ālāt*, the subject of astronomical instrumentation, serving علم الميقات, *ʿilm al-mīqāt*, the science of timekeeping by the sun and stars and the regulation of the prayer-times, which, one could argue, was the most significant branch of science as far as the majority of the population was concerned. It is the only aspect of the traditional rational/mathematical sciences that is still of importance to practising Muslims today.

1. In Ottoman Turkish, Arabic Muḥammad becomes Mehmet, and Bā (< Abū) Yazīd becomes Bayezid. In this paper, we have used the modern Turkish forms of the names of the Ottoman sultans and Muslim dynasties, and the transliterated forms for other Arabic names and terms, rendered according to the standard scholarly conventions. Some discrepancies are inevitable.

2. A brief, illustrated description of the instrument was presented to the International Congress «Channels of Transmission of Astronomical Knowledge in the Ottoman World (14th-18th centuries)» (https://ottomanastronomy.org/), held in Istanbul, 21-24 November 2023 (by video link). A summary of parts 1-5 of the present paper is to appear in the *Proceedings* of the Congress.

3. See, for example, numerous works by Jamil Ragep, Robert Morrison, Scott G. Trigg, Ahmet Tunç Şen, Hasan Umut, and others. For reliable popular surveys, see Salim Aydüz. On the recensions for Istanbul of astronomical tables (*zīj*es) from Cairo, Samarqand and Shirwan, see İhsanoğlu *et al*. and the forthcoming *zīj* survey by Benno van Dalen.

The instrument falls squarely within the disciplines of astronomical timekeeping and the regulation of the times of prayer on the one side, and astronomical instrumentation on the other. The first author has attempted to survey these two disciplines using primary sources.[4] In the present paper, we focus on astronomical treatises and tables and instruments from the early Ottoman period, especially the 15th century. The materials discussed provide a context for this instrument which cannot or should not be considered out of the context of the history of Ottoman astronomy.

The «new» instrument is made of brass, surrounded with a rim of silver inlay, of which part remains. It is rectangular in shape, measuring roughly 20 cm by 15 cm. The markings on the sundial are of a very special variety consisting of a series of snail-shell-shaped spirals. In medieval scientific Arabic, the device is called *ḥalazūn*, meaning snail or snail-shell. This appellation refers to the spiral markings for the hours. The original gnomon which fitted in the hole at the centre of the instrument is missing and has been replaced.

The instrument is a universal sundial, the sole known surviving example of a universal «spiral» sundial. Most sundials were designed for a specific latitude and the markings laid out according to a rather complicated procedure. This sundial is special because it is universal, serving the climates of classical geography, that is, all reasonable, inhabited latitudes, understood as being between the equator and about latitude 48 degrees. The markings are laid out according to a simple trigonometric formula for timekeeping by the sun (independent of terrestrial latitude) which was used for centuries alongside the accurate one.

The only Arabic source in which the *ḥalazūn* is clearly mentioned and illustrated is a substantial Egyptian work that was available in Istanbul in Mehmet II's times. We refer to the encyclopedia of al-Marrākushī (*ca.* 1280) containing an overview of the principal instruments known in his time. This provides the key to our understanding of the *ḥalazūn*.

Ottoman astronomers had no need to reinvent the wheel. They were happy to draw from the Central Asian astronomical tradition – mainly Samarqand, theoretical astronomy and planetary tables – and from the Egyptian and Syrian traditions – mainly spherical astronomy and astronomical timekeeping. Thus, for ex-

4. DAK, *Synchrony with the Heavens*, 2 vols., 2004-05. The first volume deals with astronomical timekeeping (*'ilm al-mīqāt*), and the second one with non-observational instruments. This work will be referred to simply as «*Synchrony*», and the two volumes by 'A' and 'B'.

ample, the astronomer ʿAlī Qūshjī came from Samarqand to the Court of Mehmet II in 1472,[5] and Taqī al-Dīn came from Nablus in Palestine a century later to direct the Istanbul Observatory.[6]

It is less well known that there was also a healthy tradition of practical astronomy in 14th- and early-15th-century Ottoman Anatolia and Thrace. This was certainly partly inspired by the visit to Sivas of the great late-13th-century Iranian scholar Quṭb al-Dīn al-Shīrāzī, who, although he only spent about 10 years there, authored three substantial books on theoretical astronomy, dedicating them to local dignitaries.[7] We also know of some serious timekeeping tables for 14th-century (?) Konya, of the same kind as those used in Cairo, Damascus and Jerusalem, and another very unusual set, apparently of Iranian inspiration, copied in Sivas in 1371 – see §6.5.

Already a dozen years after the conquest of Constantinople, the universal auxiliary tables for solving the problems of spherical astronomy for any latitude compiled by the mid-14th-century Damascus astronomer Shams al-Dīn al-Khalīlī[8] were copied in Edirne, the previous Ottoman capital. These represented the most remarkable achievement in spherical astronomy of any Muslim astronomer, and it is significant that they were available at least in Edirne, if not for widespread use. See again §6.5.

Furthermore, we present some other remarkable instruments, including the intriguing spherical astrolabe with a rete, signed enigmatically and simply by «Mūsà» at the end of the reign of Mehmet II, not dedicated to any ruler but clearly made by, or for, a court adherent. Then we have three astrolabes presented to Bayezid II. These were, until recently, mainly unknown to the scholarly community, in which there is still a tendency to favour historical texts over objects. Here we attempt to show how important a single instrument can be, and a group of instruments from the same milieu and timeframe even more so.

5. On ʿAlī Qūshjī, see the copiously documented book Umut, *Theoretical Astronomy in the Early Modern Ottoman Empire*.

6. See the article «Taḳī al-Dīn» in *Enc. Islam*, 2nd edn., and numerous articles by Sevim Tekeli (n. 151), and, more recently, the article «Taqī al-Dīn» by İhsan Fazlıoğlu in *BEA*. A new study is Avner Ben-Zaken, «The Revolving Universe and the Revolving Clocks» (2011).

7. On al-Shīrāzī see the article in *BEA* by Jamil Ragep.

8. On al-Khalīlī, see the article in *BEA*, and on his tables see *Synchrony*, A, pp. 359-401; also https://muslimheritage.com/al-khalili-astronomy/.

2. Description of the instrument

> Scientific instruments dating from antiquity and the middle ages are of unique historical value since they supply evidence quite different from that available in texts. In many cases as we know that the evidence of the artifacts directly contradicts that which had been presumed from written sources. With the exception of a few special classes such early instruments are also remarkably rare and, on the whole, badly published and inadequately indexed ... (Derek de Solla Price, «An International Catalogue of Scientific Instruments made before 1500» (1967), p. 41).

> Each medieval instrument can tell us something that contributes to the overall picture. The time is ripe for further study of related groups of instruments, with the aim of learning about the workshops in which they were constructed, why they were made, and how they were used. ... Medieval instruments constitute a veritable goldmine of historical sources still to be exploited. (DAK, «Making instruments talk – Some medieval astronomical instruments and their secrets» (1995), available at www.academia.edu/34695170/).

2.1 Provenance, form and size

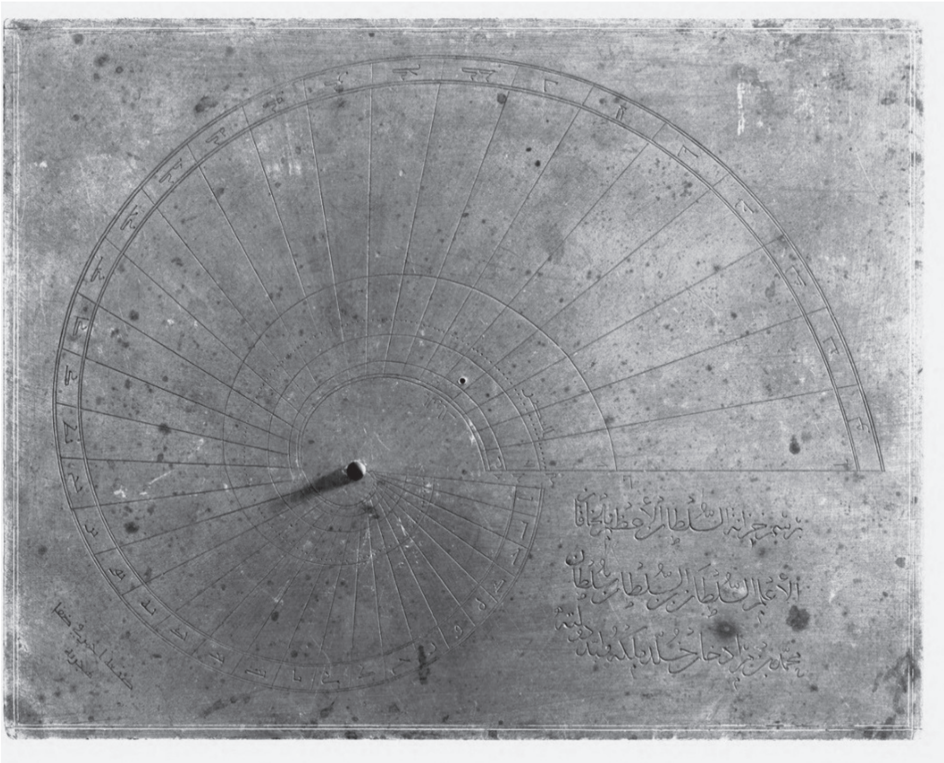
This is the only known scientific instrument made for and dedicated to the Ottoman Sultan Mehmet II, better known as Fatih Mehmet, «The Conqueror». It is also the sole surviving example of a universal «spiral» sundial in Islamic astronomy.

The instrument is now in a European private collection. According to the owner it was acquired at a pawn shop in Bucharest,[9] where it was deposited by a Romanian lady. It had been in her father's collection in the 1960s. The provinces of Moldavia and/or Wallachia (*Evlāk* / *Kara-Eflāk*) remained under Ottoman control until about 150 years ago,[10] but there remained a sizeable Turkish minority in Romania even during the 20th century.[11] A certificate issued by

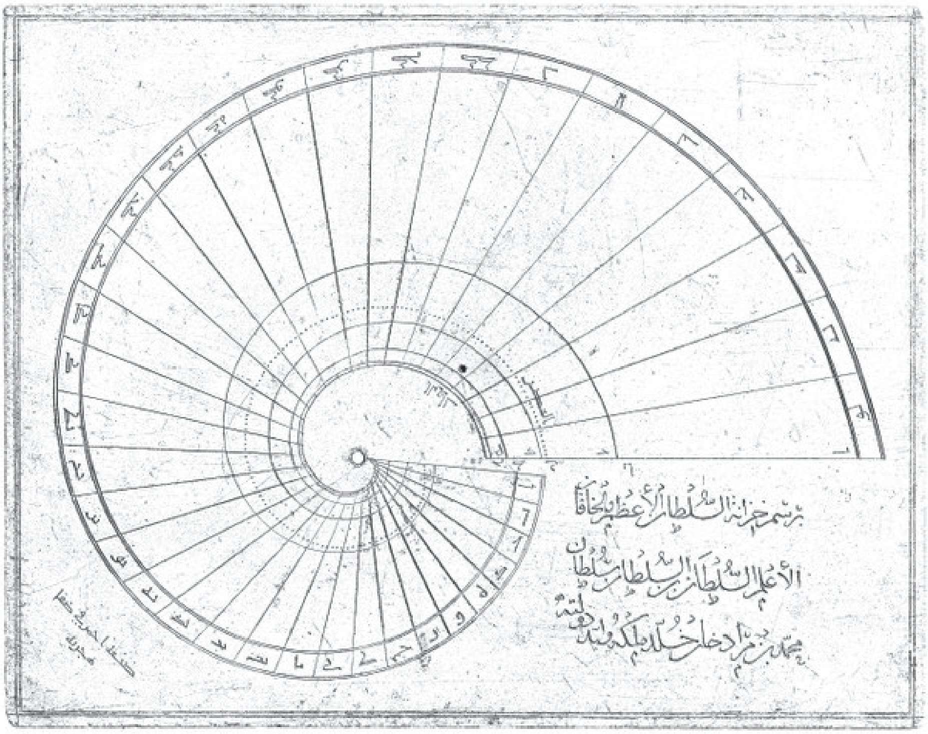
9. See https://bucharest-guide.ro/en/golden-falcon/ ... (under «jewelry»).

10. Article «Eflāk» in *Enc. Islam*, 2nd edn., by N. Beldiceanu.

11. «Islam in Romania», *Wikipedia*, https://en.wikipedia.org/w/index.php?title=Islam_in_Romania&oldid=1231770078 (accessed July 30, 2024); Kemal Kerpat, «Romania and the Ottoman Empire: A Historiographical Review», *Turkish Studies Association Bulletin* 24/1 (Spring 2000): 129-135, https://www.jstor.org/stable/43384752; Florin Anghel, «Romania Between Istanbul And Ankara: The Beginning of the Alliance in the first decade of the Kemalist Republic», *Ankara Üniversitesi Dil ve Tarih-Coğrafya*



Figures 1.1a-c: The front of the universal sundial, the dedication in the lower right of the spiral horary markings. All images courtesy of the owner.



the Art Loss Register attests that the object has never been declared lost or stolen.[12]

The sundial is made of brass. It is rectangular in shape, measuring 19.5 cm by 15.3 cm. Twin parallel lines just within the outer perimeter, are decorated with silver inlay, of which about one-third is still *in situ*.

The principal markings on the front consist of a series of snail-shell-shaped curves for the seasonal hours. The original gnomon which fitted in the hole at the centre of the spirals is missing and it now has a modern replacement conforming to the exacting description in the Arabic text (see §3.3).

Fakültesi Dergisi 54/1 (2014): 435-450, https://dergipark.org.tr/en/download/article-file/2153552; Steliu Lambru, «Romania and Turkey in the interwar period», *Radio România Internaţional, The History Show*, 5 February 2024, https://web.archive.org/web/20240205122034, https://www.rri.ro/en_gb/romania_and_turkey_in_the_interwar_period-2699018.

12. See www.artloss.com. The certificate is numbered 500203407 and dated 23.03.2022.

2.2 The dedication to Sultan Mehmet II

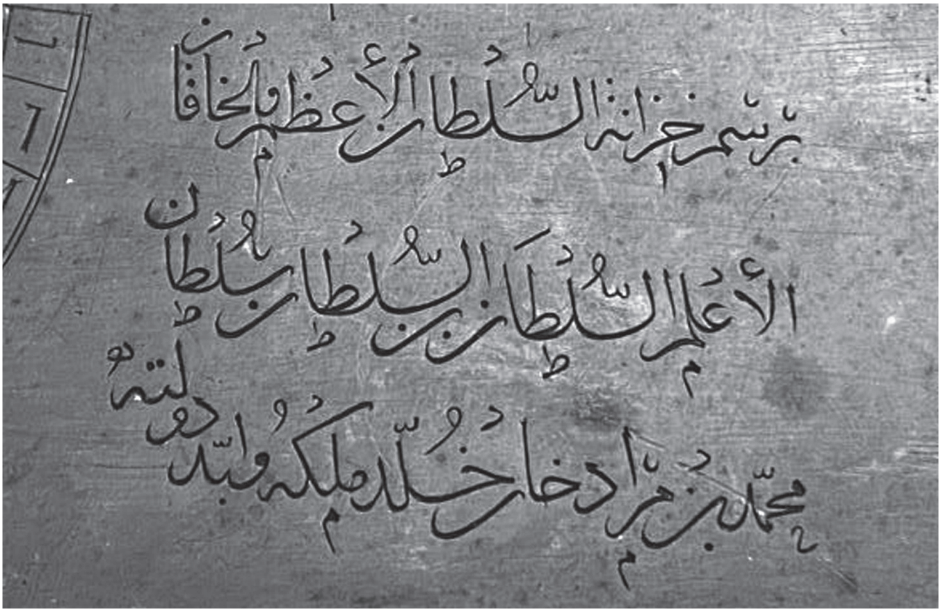


Figure 2.2a: The dedication to Sultan Mehmet II.

The dedicatory inscription in correct classical Arabic on the lower right side has been engraved in elegant *thuluth*, clearly by an educated hand. Above or below significant letters in the text, there are ample decorative miniature Arabic letters (particularly *mīm*s and *ṭā'*s). The Arabic and its transliteration, followed by a translation, are presented here:

برسم خزانة السلطان الأعظم الخاقان الأعلم
السلطان بن السلطان سلطان محمّد بن مراد خان
خلّد ملكه وأبّد دولته

Bi-rasm khizānat al-Sulṭān al-aʿẓam wa-'l-Khāqān al-aʿlam
al-Sulṭān ibn al-Sulṭān Sulṭān Meḥmed ibn Murād Khān
khallada (ʾllāhu) mulkahu wa-ʾabbada dawlatahu

By order of the Treasury of the Most Sublime Sulṭān and the Most Learned Khāqān,
the Sulṭān son of the Sulṭān, Sulṭān Meḥmet ibn Murād Khān,
may (Allah) make his sovereignty perpetual and his reign everlasting.

The formula presents the names and titles of Sultan Mehmet Khan II, son of Sultan Murad Khan II, who reigned as Sultan from 1444 to 1446 and again from 1451 until his death in 1481. He is of course known as Fatih Mehmet, that is, Mehmet the Conqueror, having successfully captured Constantinople from the Byzantines in 1453. His son, Bayezid II, succeeded him and ruled from 1481 to 1512.[13] The inscription does not imply that Mehmet II himself was involved in any serious astronomical activities. It simply associates the instrument with the Treasury of the Sultan, and thus particularly enhances its historical importance, inviting a closer look at astronomical activities under his patronage and raising them from the legendary to the seriously curious and even sophisticated.

FIGURE 2.2b: A portrait of Sultan Mehmet II by the Italian Bellini school. See Rodini, Gentile Bellini's Portrait of Sultan Mehmed II, 2020. Image from https://commons.wikimedia.org/wiki/File:Sultan_Mehmed_II_The_Conqueror.jpg.There is another, more subtle painting of Mehmet II by Piero della Francesca (see Figs. 7.5e-f).

2.3 The maker's signature and the date

In the lower left corner is an inscription in a modest *kūfī*, far less grand than the main inscription:

صنعه احمر في ضفا هجرية

ṣanaʿahu Aḥmar fī ḍ-f-a hijriyya

Aḥmar made it in 881 of the Hijra.

13. In the *Wikipedia* article on Mehmet II, quoting art historian Julian Raby, we read: «Mehmed's affinity towards the Renaissance arts, and his strong initiative in its creation and collection, did not have a large base of support within his own court. One of the many opponents to Mehmed's collection was his own son and future Sultan, Bayezid II, who was backed by powerful religious and Turkish factions in his opposition. Upon his accession, Bayezid II sold Mehmed's collection of portraits and disposed of his statuary».

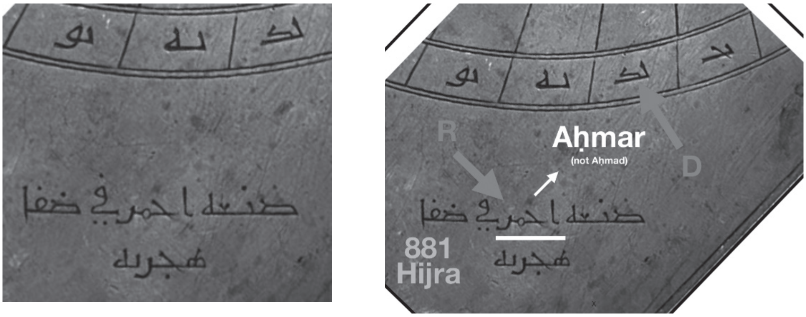


Figure 2.3: The name of the maker and the date of construction.

The year-number is written in the Arabic alphanumerical (*abjad*) system[14] as ا + ف + ض, that is, 800+80+1, along with the addition of the word *hijriyya*. This is the equivalent of May 1476 to April 1477.[15] The date of the instrument, 881 Hijra (= 1476~77), corresponds to the end of the latter part of Mehmet II's second reign, five years before he died. The instrument was manifestly made in Istanbul,

14. On the *abjad* notation in astronomical texts, the best source remains Irani, «Arabic Numeral Forms». All numbers in traditional Islamic astronomical tables are expressed sexagesimally, that is, to base 60. For a number «transliterated» 23 30 17, the notation now standard in the *history of science* is 23;30,17. In the sources this would be written in alphanumerical (*abjad*) notation as كجـ ل يز. (On the problems associated with interpreting astronomical tables and geographical data written in *abjad* notation, see Kennedy & Kennedy, *Islamic geographical coordinates*, p. x; Kunitzsch, *Sternkatalog des Almagest*, 1, pp. 19-21; King, *World-Maps for finding the direction to Mecca*, pp. 27-28 & 161-163; and idem & Samsó & Goldstein, «Islamic astronomical tables and handbooks», p. 10).

15. Approximate Christian era equivalents (C) of Muslim dates of the Hijra era (H) can be derived using C = 622 + H / 33. The range of Muslim dates which concerns us here is {800 / 850 / 900}, corresponding approximately to {1398 / 1446 / 1494}. Exact equivalents can be found on www.muslimphilosophy.com/ip/hijri.htm. Notation such as 1475~76 refers here to the two years in the Western calendar spanning a specific Hijra year 880. For convenience, we write this as «880H/1475~76».

In 1974 DAK acquired from an Istanbul second-hand bookshop a tattered little book published in Istanbul in 1943 with all the necessary equivalents of Islamic Hijra dates in the Western calendar from the beginning onward (reproduced from the *Wüstenfeld-Mahler'sche Vergleichungs-Tabellen*, 1854/61). The book was introduced by the educationalist Faik Reşit Unat. This constant companion is more useful than any of the sites on the internet he has seen, and is easier to consult. The original tables are available in their entirety at https://archive.org/details/vergleichungstab01wust/page/4/mode/2up.

although, as we shall see, the most recent known written sources for its construction originated in Cairo. This main source was available in Istanbul at that time. Another point in favour of Istanbul is that the maker signed himself simply «Aḥmar», with just his personal name, apparently following an early Ottoman tradition. On instruments, this custom is not attested elsewhere in the Muslim world.[16] If our maker had been named Aḥmad or Muḥammad, he might have included more of his full name. On the other hand, there is a contemporaneous spherical astrolabe by a maker who signed himself simply «Mūsà».

3. A closer look

3.1 More on the dedication

It is interesting to compare the very similar formulation of the dedication on the astrolabe dedicated to Mehmet II's son, Bayezid II, by al-Aḥmar (al-Nujūmī al-Rūmī), most probably the same instrument-maker, in 911H/1505~06.[17] On this instrument, see further §7.10b. The inscription reads:

لرسم خزانة السلطان الأعظم السلطان ابن السلطان
سلطان بايزيد بن محمد خان خلد ملكه

li-rasm khizānat al-sulṭān al-aʿẓam al-sulṭān ibn al-sulṭān
sulṭān Bāyezīt ibn Meḥmet Khān khallada ('llāhu) mulkahu

By order of the Treasury of the Most Sublime Sultan, the Sultan son of the Sultan, Sultan Bāyezīt ibn Meḥmet Khān, may (Allah) make his dominion be eternal.

The treatise on instruments and observations by al-Khiṭābī, astronomer to the court of Bayezid II, contains a similar dedication of several lines (p. 184) including the phrase:[18]

16. Compare the situation in Safavid Iran, where, following Shiʿite tradition, the majority of the instrument-makers have double names: see *World-Maps*, pp. 255-269.

17. See also *Synchrony*, B, pp. 717-718, for an enthusiastic dedication of a ceramic compass-bowl to Sultan Selim I *ca.* 1518 in Damascus.

18. Khiṭābī, *Risāla-yi Tashrīḥ al-ālāt fī sha'n al-imtiḥānāt* ..., p. 184. On Khiṭābī, see also §6.6.

السلطان ابن السلطان السلطان ابو المظفر با يزيد خان
ابن السلطان محمد خان

The Sultan son of the Sultan, the Sultan Abu 'l-Muẓaffar Bayezit Khān son of Mehmet Khān.

Several objects with the same mark of ownership by the Sultan are found in the Topkapı Palace Museum Archive:[19]

صاحبه السلطان بايزيد ابن محمد خان خلد ملكه. برسم السطان ...

Owned by the Sultan Bayezid, son of Mehmet Khan, may (Allah) make his dominion eternal. By order of the Sultan ...

Consider also the ornate mark of ownership of Mehmet II on a fine copy of al-Ṣūfī's treatise on the constellations in the University of Riyadh:[20]

برسم مطالعة السلطان الاعظم مالك رقاب الامم
السلطان محمد خان بن السلطان مراد خان
خلد الله تعالى خلافته واوضح على العالمين بره واحسانه

For the purpose of the study of the greatest Sultan, «possessor of the necks of the peoples», the Sultan Mehmet Khān son of Murād Khān, may Allāh Almighty make his caliphate eternal and may He manifest His kindness and His beneficence upon this world and the next.

Other examples of such extravagant imperial titles exist in Ottoman manuscripts, art and architecture and on luxury objects.[21] One such is the five-line dedi-

19. Markiewicz, «Topkapı Palace Museum Archive», nos. 28/29/30/36 = A3317/—3328/3355/3479.

20. Number 289 in the Collection, apparently uncatalogued and not yet studied. The manuscript belonged to the renowned Somali scholar Ḥasan al-Jabartī, who lived in Cairo (d. 1774).

21. For engraving on *Iranian metalwork we have Assadullah Souren Melikian-Chirvani's Islamic metalwork from the Iranian world – 8th-18th centuries*, albeit limited to objects in the Victoria and Albert Museum. More general is Sheila Blair's *Islamic Calligraphy*. It would be useful to have a survey of Islamic engraving on brassware. Whoever would undertake such an enormous task should not overlook the inscriptions on astronomical instruments which offer significant examples from

cation to the Sultan Selim I (reg. 1512-1520), son of Bayezid II, in a written work by the logician Ibn Arghūn al-Shīrāzī.[22]

3.2 Aḥmar, maker of the universal sundial

Who was Aḥmar, the craftsman who made the universal sundial? First, we claim to have read his name correctly. It ends in the letter rāʿ corresponding to r; this is confirmed by the identity of this *rāʿ* to the final form of *rāʿ* in the word *hijriyya*, and with the un-pointed letter *zāy* for '7' close by on the outer scale. The final dāl on the scale (as in 14 and 24) corresponding to d, is quite different. In other words, the name is definitely Aḥmar not Aḥmad. The latter is also used once in the Qur'ān (61:6) to refer to the Prophet Muḥammad; it became a common Muslim name, but it would not be used with the definitive article al- as a personal name. We note the second surviving astrolabe made for Bayezid II dated 911H/1505~06, on which the first name of the maker is al-Aḥmar. The definite article is sometimes used with the elative adjective form for handicaps and colours, and such a word can then form part of a name, for example al-Aḥwal for «cross-eyed»,[23] generally an epithet but sometimes even a first name. We strongly suspect, but cannot prove, that the Aḥmar who made the universal sundial for Mehmet II is the same al-Aḥmar al-Nujūmī al-Rūmī who made the astrolabe for his son Bayezid II.[24] This would

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the 8th up to the 19th century. Add to that, for example, a minuscule inscription on a 14th-century quadrant made of ivory, unpublished, or the illegible instructions on a 15th-century blue ceramic compass-bowl, or the various decorative scripts on ornate 17th-18th-century Safavid astrolabes.

22. From MS W.591 of the Walters Art Museum, Baltimore MD, available at https://art.thewalters.org/detail/82744/text-page-with-dedication-to-the-ottoman-sultan-selim-i/.

23. For example, the Imāmī theologian, Abū Jaʿfar al-Aḥwal, Muḥammad ibn al-Nuʿmān (d. 183H), featured in *The Biographical Encyclopaedia of Islamic Philosophy*.

24. No astronomer or mathematician with this name is recorded in İhsanoğlu *et al*., Osmanlı astronomi / matematik literatürü tarihi, which means that Aḥmar did not compose any known written texts, in spite of qualifying as a nujūmī, which is not the usual name for «astronomer». Indeed, in 50 years of research on Islamic astronomy, DAK has only seen the epithet *al-nujūmī* once previously, namely, in one of the volumes on Ottoman science by İhsanoğlu and his colleagues (reference pending). In the first analysis of the two astrolabes for Bayezid II (*Synchrony*, B, p. 796), the epithet *al-rūmī* was rendered as «a Turk from Anatolia», with a reference to the article «Rūm» in *Enc. Islam* by Halil Inalcik. Other personalities from the 15th century with this nisba are mentioned in https://islamansiklopedisi.org.tr/rumi. Gülrü Necipoğlu interprets the designation «al-Rūmī»

mean that of three instruments dedicated to Mehmet II or Bayezid II, two were made by Aḥmar / al-Aḥmar. The reason for our confidence is that, although both forms Aḥmar and al-Aḥmar («the red one») are unusual personal names, they are attested elsewhere.[25] Further, it would not have been unreasonable for an astrolabist to continue making instruments for more than 30 years.[26] Nevertheless, this «Aḥmar» is not otherwise known in the field of early Ottoman astronomy or mathematics.[27] He is not on the «list of astral experts at Bayezid's court, 1503-

more broadly as «an «Ottoman» regardless of ethnicity and from a wider geography than Anatolia» (Necipoğlu, «The Spatial Organization...», p. 68, 110). Bruno Halff, in Brieux & Maddison, *Répertoire*, p. 393, claims: «le nom n'est pas sûrement établi». Certainly the name and its two adjectives of origin and profession deserve further investigation. See also §7.9a.

25. See, for example:

(1) the philologist Abu 'l-Ḥasan al-Aḥmar, Basra, d. 810 (*Enc. Islam*, 2nd ed. xii, pp. 22-23).

(2) the astronomer ʿAlī ibn Khalaf ibn Aḥmar al-Shajjār in Toledo *ca.* 1050 (article by Roser Puig in *BEA*; Calvo, «ʿAlī Ibn Khalaf's Treatise on the Lámina Universal», p. 107, n. 1; King, *Islamic astronomical instruments*, vii, pp. 245-246; and Samsó, *On both sides of the Straights of Gibraltar*, p. 988, etc).

(3) the Naṣrid dynasty in al-Andalus, also called Banū 'l-Aḥmar, 1250-1500, named after the founder M. ... Ibn Aḥmar; cf. his successor the later M. VI, «El rey Bermejo», «the Red king» to the Castilians, *ca.* 1350 (*Enc. Islam*, 2nd ed., vii, p. 1020).

(4) the historian Abu 'l-Walīd ... Ibn al-Aḥmar in Fez d. *ca.* 1410 (Brockelmann, *Geschichte der arabischen Litteratur*, iii, p. 555 (the second reference is incorrect), leading to II, p. 241/340).

26. Brieux & Maddison, *Répertoire*, i, pp. 341-356, lists some 24 astrolabes made by the Maghribī astrolabist al-Baṭṭūṭī in Fez between 1703 and 1739 that have been preserved for us. (One sold recently in London for around £600,000, which suggests the buyer has more money than sense). Then ibid., i, pp. 187-216, details the surviving works of the prolific ʿAbd al-A'imma of Isfahan: some 40 astrolabes dated between 1700 and 1715. The number they actually made would have been substantially larger and the time span of their activities probably wider. In neither case did the vast output have a negative influence on the quality and accuracy of their oeuvre.

27. That is, we have not identified him from the volumes on Ottoman astronomy and mathematics by İhsanoğlu and colleagues, which were the first such bio-bibliographical works on the subject. The name or epithet *aḥmar / al-aḥmar* could conceivably have a Jewish connection. Jewish refugees from al-Andalus to Istanbul were common in the late 15th century, attracted by the scholarly interests of the Mehmet II, and the consonantal cluster ʻ-d-m in the Hebrew word for «man» and the name Ādām and the word adom for «red» was the same. But these instruments show no sign of Jewish influence. It may be that future research may identify our Aḥmar as a medic at the court, rather than specifically an astronomer. We shall mention another astrolabe somehow dedicated to a medic at the court of Mehmet II (§7.6), and a spherical astrolabe made about the time of the transfer of power from father to son by a member of the court, who was possibly as much a medic as an

1512», 19 in number, gathered by Ahmet Tunç Şen.[28] The epithet surely refers to the colour of his skin rather than his hair.[29] Indeed, the Prophetic expression *al-aswad wa 'l-aḥmar*, literally «the black and the white», meaning «all mankind», is found under *aḥmar* in Hans Wehr's excellent dictionary of standard modern Arabic.

The epithet *al-Rūmī* seems to indicate that he was from Central Anatolia, but it invites further discussion.[30] The rare epithet *al-nujūmī* indicates that he was an astronomer, and it is perhaps a title bestowed by the Sultan; the title is probably derived from the common phrase *aḥkām al-nujūm*, which might suggest he was particularly active in astrology. He is not mentioned in the new bio-bibliographical survey of Ottoman astronomers and their works, which means only that he is not the author of any treatises, or they have not survived. It is not possible to confirm that the Arabic signatures on the three instruments are from the same craftsman. The engraving of the signatures on the instruments is different. The individual letters occurring in each inscription have been compared. The engraving on the earliest instrument, the sundial, is more sophisticated. But, whereas on the later astrolabe Aḥmar himself appears to have engraved *both* his signature and the dedication, this is not the case with the «spiral» sundial, for there the dedication was a clear calligraphic success and was surely achieved by a professional, a *naqqāsh* or engraver. We have further noted that some of the other surviving instruments from this milieu bear only the first name of the maker. For example:

(a) The spherical astrolabe, complete with its rete, now in the Museum of the *History of Science* at Oxford University, was made in Istanbul not much later, in 885H/1480~81. As mentioned, it was not dedicated to a sultan, and is signed simply «Mūsà»: see §7.7. It is worth noting that Mehmet II died that year.

(b) Similarly, the glazed ceramic compass-bowl in the Archaeological Museum in Damascus, dedicated to the Ottoman Sultan Selim I in Damascus *ca.*

astronomer (§7.7). Recent works on Ottoman medicine tend to deal with a period beginning with 1500, a rough date for the institutionalization of medicine at the imperial court.

28. Şen, *Astrology in the Service of the Empire*, pp. 340-341.

29. When DAK was working in the Sudan in the early 1960s, his Sudanese colleagues would refer to his skin-colour as *aḥmar*, indicating «light-skinned», but this was always said with a smile.

30. Article «Rūmī» by Halil İnalçik in *Enc. Islam*, 2nd edn., also Kafadar, «A Rome of One's Own: Reflections on Cultural Geography and Identity in the Lands of Rum», also n. 24 above.

1518, is signed simply «Sayyid Thābit», although it does have an elaborate dedication: see §6.9.

(c) The compiler and copyist of an early Ottoman manuscript of astronomical texts, MS Istanbul Süleymaniye Hamidiye 1453, himself an astronomer of consequence, is referred to as «Sayyid ʿUmar»: see §6.8d.[31]

Particularly «Aḥmar» and «Mūsà», the makers of the Ottoman universal sundial and the Ottoman spherical astrolabe (§7.7), both of whom sign with their single name, must have been well-known at the Sublime Porte. On the other hand, as we shall see, the two astrolabes dedicated to Bayezid II were not signed in this way. A later Istanbul astrolabist signed himself simply ʿAbdī, probably a nickname shortened from a full name ʿAbd Allāh, «servant of God» or the equivalent using one of the 99 names of God,[32] and another as Muṣṭafà Ayyūbī, the first name being an epithet of the Prophet Muhammad and the second indicating only his association of the township on the Golden Horn called Eyüp after a Companion of the Prophet, Abū Ayyūb.[33] The practice of rendering makers' names with simply the personal name became popular in later Istanbul and beyond: witness the dozens of surviving wooden astrolabic quadrants from Istanbul and elsewhere in the Ottoman Empire in the 18th and 19th centuries, many of which are signed with the personal name of the maker, nothing more.[34]

3.3 The astronomical markings

The outer spiral of the sundial is surrounded by a scale of the midday shadow running clockwise from its innermost end at the left of the dedicatory inscription to its outermost end near the right-hand side of the plate, each section between the radial lines being labelled ا ب ج ... لو, that is, 1 2 3 ... 36. There is an angular separation of *ca*. 6° between the first and last lines for 0 and 36. The remaining radial

31. Arslan, «A Fifteenth-Century Mamluk Astronomer in the Ottoman Realm – ʿUmar al-Dimashqī and his *ʿilm al-mīqāt* corpus the Hamidiye 1453», p. 124.

32. On ʿAbdī and his surviving works, see Mayer, *Islamic Astrolabists and their Works*, p. 32, and Brieux & Maddison, *Répertoire des facteurs d'astrolabes*, I, pp. 407-408, also n. 159.

33. On Muṣṭafà Ayyūbī's works, see Mayer, *Islamic Astrolabists*, p. 79, and Brieux & Maddison, *Répertoire*, I, pp. 403-404, also n. 159.

34. See, for example, Brieux & Maddison, *Répertoire*, I, pp. 411, 416, 417-418, 418-419, 429, etc.

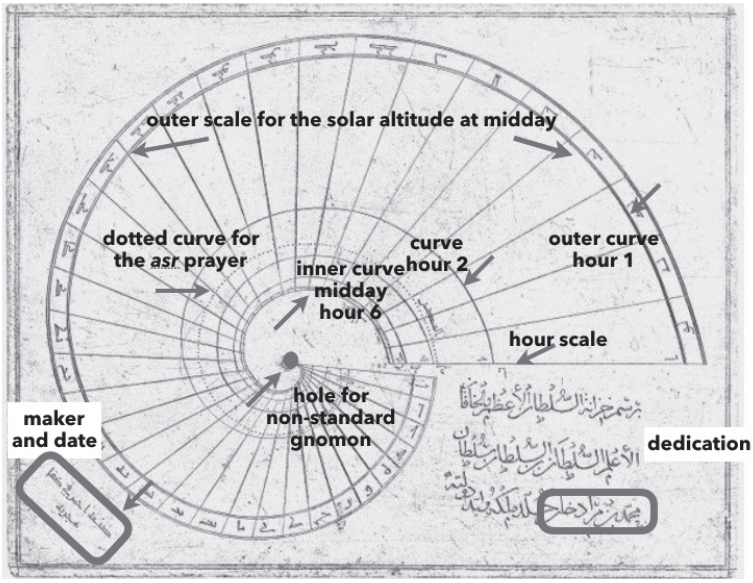


FIGURE 3.3: The various components of the universal sundial. Missing is only the gnomon, which has an unusual shape.

lines are *not* equally separated, the minimum separation being 8.5° and the maximum one 11°. In contrast to this, the instructions given by al-Marrākushī require the maker of the instrument to divide an imaginary circle into 37 equal parts. To a pure geometer, this might seem like a challenging requirement,[35] but the maker of this Ottoman instrument was obviously following a more pragmatic tradition, and for practical purposes, whether the radial lines are equally separated makes little difference.

The radial lines do not converge at the centre of the gnomon, but just to the right thereof. The original gnomon must have had a conical form, slightly inclined toward the right, so that the position of its tip is above the point where all radial lines converge. The replacement satisfies this condition.

Above the dedicatory inscription, along the radial line for the midday shadow of 36, the seasonal hours are labelled near the extremity of each corresponding spiral curve. Each seasonal hour is here understood as a temporal interval, each spiral curve denoting the beginning or end thereof. Counting from the centre, we

35. Even Archimedes might have baulked at this.

thus have the arguments ب ج د ه (5-4-3-2) on one side and ح ط ي يا (8-9-10-11) on the other. There is no argument for the innermost interval, which serves the seasonal hours before and after midday (marked *al-zawāl*). The outermost curve, adjacent to the scale for the midday shadow, corresponds to the end of the 1st and the beginning of the 11th hour.

3.4 The curves for the times of the daylight prayers

In Islam, the day starts at sunset with the sunset prayer (*maghrib*). The second prayer is at nightfall (*ʿishāʾ*), and the third is at daybreak (*fajr*). The fourth is shortly after midday (*ẓuhr*) and the last prayer is about mid-afternoon (*ʿaṣr*). Prayers should be performed as early as possible in the intervals beginning at these times.[36]

Two times of day are indicated on the universal sundial by textual labels: الزوال, *al-zawāl*, that is midday, along the innermost spiral which denotes the end of the 6th and beginning of the 7th hour, and العصر, «the *ʿaṣr*», or «the time of the *ʿaṣr* or mid-afternoon prayer» which is marked by a dotted spiral. The silver inlay is still visible inside some of the dots that run inside the area for the 10th hour. According to Islamic tradition, the *ʿaṣr* is the most sacred time of the day.[37] The time to begin the *ʿaṣr* is normally defined as the moment in the afternoon when the shadow of a vertical gnomon has increased over the minimum midday shadow by the length of the gnomon. There is, however, an issue (or rather an interesting peculiarity) with the *ʿaṣr* curve on this instrument. It does not match the usual definition: «the midday shadow plus the gnomon length» for the beginning of the prayer or the definition «the midday shadow plus twice the gnomon length» for the end of the prayer.[38] These have been shown to relate the shadow increase corresponding to the beginning of the 9th hour and the beginning of the 10th hour, as one can easily see by applying a simple arithmetical rule to which we shall return in §6.5.

36. For an overview see the article «Mīḳāt [= astronomical timekeeping]» in *Enc. Islam*, VII, 1990, pp. 27-32, repr. in *Astronomy in the Service of Islam*, V.

37. Goldziher, «Die Bedeutung der Nachmittagszeit im Islam». Of the many studies of the early history of the prayer-times, most ignore the times adopted for the daylight prayers.

38. This latter definition was particularly popular in the Ḥanafī legal school, which the Ottomans followed. See further the next note.

Now the convention underlying the «new» instrument seems to be midday shadow (*Z*) plus 1.5 times the gnomon length (*n*). This would correspond to the time roughly (not exactly) in the middle of the interval between the beginning (*Z*+*n*) and end (*Z*+2*n*) of the *ʿaṣr* prayer. This would be roughly halfway between the 9th and 10th hours. Such a definition is not attested in any text on the sacred law of Islam (*fiqh*) or in any *mīqāt* text known to us. Neither does it underlie markings on any other known instrument.[39]

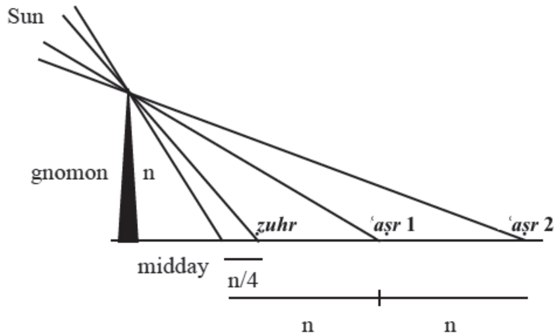


FIGURE 3.4: The standard definitions of the prayer-times in the historical Islamic sources are expressed in terms of the increase (Δz) of the shadow of a vertical object over its midday minimum. The ẓuhr prayer begins as soon as the sun has passed the meridian, in Andalusī practice when $\Delta z = n/4$. The ʿaṣr prayer begins when $\Delta z = n$, and ends in Ottoman practice when $\Delta z = 2n$. These practical definitions were originally intended to regulate the prayer in terms of the seasonal hours of daylight, and the names of the prayers correspond to the names of the hours in early Arabic.

3.5 Markings on the back

The hole for the gnomon is clearly visible on the back. A circle of radius *ca.* 23 mm, at the centre of the rectangular plate (and hence not centred around the gnomon hole) is engraved on the back of the instrument, but this seems to have nothing to do with the principal markings of the universal dial on the front. The ques-

39. On simple timekeeping using the standard approximate formula, see *Synchrony*, B, pp. 111-198, and Calvo, «Two Treatises on Mīqāt from the Maghrib», p. 189 (al-Jādarī).

On the origin of the definitions of the daylight prayer times in terms of shadow increases, see *Synchrony*, A, pp. 529-622.

tion remains: why is the circle fitted with silver inlay? There are various other lines and curves so lightly engraved as to be barely visible on the back; they do not constitute a relevant set of astronomical markings. The sundial may originally have been fitted in a frame of, say, wood.

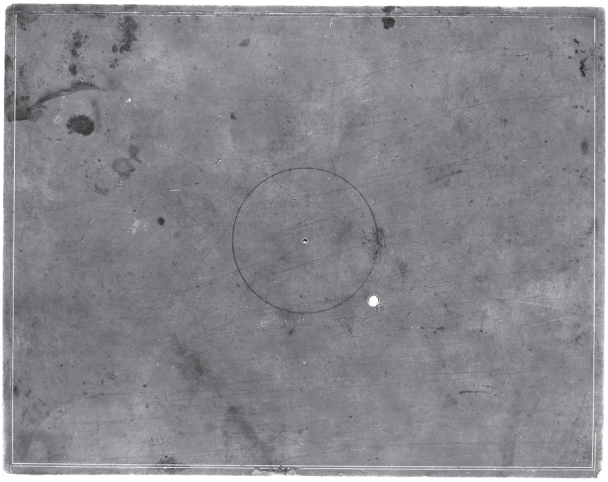


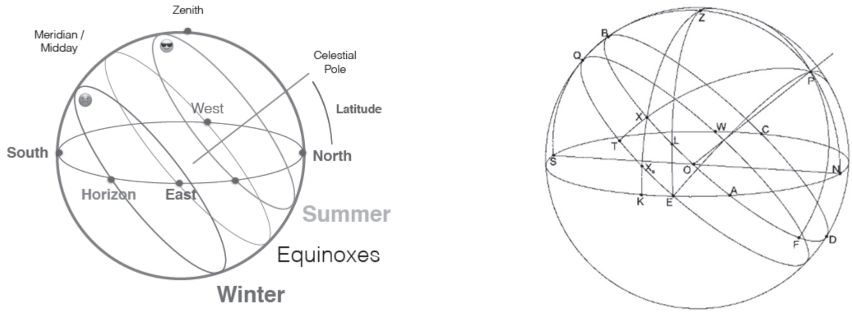
Figure 3.5: The back of the instrument. On this image, and on the instrument itself, the extraneous markings, which are barely visible, are not related to the sundial on the front. But why, then, is there an outer frame of silver inlay?

4. The inspiration

4.1 Excursus: Spherical astronomy at a glance

We shall be now dealing almost exclusively with spherical astronomy, that is, the study of the apparent daily rotation of the heavens about the observer. The first diagram below shows the sun's behaviour at the equinoxes and solstices, and the second prepares for a mathematical investigation of the three-dimensional problem starting from an instantaneous position of the sun. Various places in the secondary literature provide full discussions.

The local horizon is shown with the cardinal directions at NS & EW. The zenith is Z, and the meridian is NPZS. The celestial equator is EQW with pole at P. The sun rises at A, crosses the meridian (culminates) at B and sets at C. An



FIGURES 4.1: The basics of spherical astronomy, showing the apparent path of the sun at the eqiuinoxes and solstices (l.h.s). and a general position of the sun (X) on its apparent day-circle, ready for the determination of the time with respect to the horizon or the meridian.

arbitrary solar position is X. The solar declination is XT. The time since sunrise is measured by arc AX on the declination circle ABC. The prime vertical, perpendicular to the meridian, is ZE. The altitude circle of the sun is ZXK. The azimuth of the sun, measured on the horizon from the east point, is EK. The time since sunrise is measured by arc AX. The derivation of the time since sunrise (T) from solar altitude (h) for a particular solar declination (δ) at a given latitude (ϕ) is rather complicated, and a first approximation is to be welcomed. We cannot «prove» such an approximation, we can only show that it accords with common sense.

4.2 Excursus: Three Islamic formulae for timekeeping

Different procedures were used by those Muslim astronomers who favoured the simple procedures of folk astronomy and those who were undeterred by the complicated accurate formula. Three main formulae are attested, the first two being relevant to our study, and the third being the accurate formula.[40]

40. The Iranian historian of Islamic science, Pouyan Rezvani, is one of the very few scholars amongst «the next generation» to recognise the three formulae and their use, as well as to appreciate the various geographical traditions of *mīqāt*: see his «The Role of *ʿIlm al-Mīqāt* in the Progress of Making Sundials».

a) The arithmetical approximation

The first is arithmetical and makes no pretensions of being accurate. It reads:

$$T \approx \frac{6\,n}{\Delta s + n}$$

where n is the gnomon length, generally taken in Islamic astronomy (including folk astronomy) as 12 «fingers» but also as 7 «feet», and Δs is the increase of the shadow length over its midday minimum. This formula, probably of Indian origin, was known to the astronomer Yaʿqūb ibn Ṭāriq in Baghdad *ca*. 750, and is found here and there in later treatises on folk astronomy from al-Andalus to Iran and the Yemen.[41] Notice that when Δs equals n, the afternoon time is 3 hours after midday, and that when Δs is $2n$, the time is one hour later. This is the situation for the beginning and end of the *ʿaṣr* prayer. Furthermore, the seasonal hours were known in pre-Islamic Arabia, to the extent that the 24 hours had individual Arabic names; inevitably, the name of the 10th hour was named *ʿaṣr*.[42] This goes to show how important this simple approximate formula, albeit masked, has been in Islamic prayer ritual over 1400 years. As we have seen, such a definition underlies the curve for the afternoon prayer on the universal sundial.

b) The standard approximate formula

This trigonometric formula, used for a millennium in Islamic astronomy, and attested also already in Indian and Sasanian sources, as well as on Greek portable sundials, relates the time of day T in seasonal hours, measured from sunrise / sunset, to the solar altitude h and the solar meridian altitude H. The trigonometric functions used here are the ones used in Islamic astronomy, namely, to base R = 60 rather than unity as we use today, and they are denoted by capitals so that $\mathrm{Sin}_R\,\theta = R \times \sin\theta$. The formula is:

41. Pingree, «The astronomical works of al-Fazārī», pp. 121-122, and more recently the article «al-Fazārī» in *Enc. Islam*, 3rd edn., by Julio Samsó. For more information, see Kennedy, *al-Bīrūnī's* Shadows, II, pp. 116-122; and *Synchrony*, A, III: «A survey of arithmetical shadow-schemes for time-reckoning», pp. 456-527, esp. p. 478, and IV: «The times of prayer in Islam», pp. 529-622, esp. pp. 556-558, and the references there cited, also Rezvani, «The Role of *ʿIlm al-Mīqāt*», pp. 5-6.

42. *Synchrony*, A, pp. 588-596.

$$T \approx \frac{1}{15} \text{arcSin}\left(\frac{\text{R Sin}\,h}{\text{Sin}\,H}\right)\left[= \frac{1}{15} \text{arcsin}\left(\frac{\sin h}{\sin H}\right)\right]$$

The formula is accurate at the equator and at the equinoxes. Elsewhere and at other times of the year it is remarkably accurate for a wide range of latitudes because the undulating seasonal hours counteract the approximate nature of the formula.

The formula is probably of Indian origin and is attested already in the writings of the astronomer Yaʿqūb ibn Ṭāriq in 8th-century Baghdad.[43] It too is found here and there in Arabic treatises on folk astronomy.[44] However, it was also used by serious astronomers because it is reasonably accurate in reasonable latitudes. For quick calculations it gave an adequately accurate result. It was used sporadically in Islamic and Byzantine and Jewish astronomical texts. Occasionally, tables for astronomical timekeeping – tables of time in seasonal day-hours as a function of solar altitude and solar meridian altitude, or, perhaps less useful, tables of the altitude of the sun as a function of the solar meridian altitude and the seasonal hours of daylight, as well as tables for the duration of twilight throughout the year – were based on this formula.[45] This being said, such tables are not contained in the majority of medieval European sets of tables, where the emphasis is usually entirely on planetary (sun, moon, and five naked-eye planets) astronomy.

Although the occurrence of the formula, explicit and implicit, in the Islamic sources has been documented, it also underlies several classes of instrument that have been studied, but without any recognition of its efficacy or utility. One example is a type of portable universal sundials found in ancient Greek, Roman, and Byzantine astronomy: the horary markings on those instruments are based on our formula.[46] Another is the corpus of medieval English instruments known as *na-*

43. David Pingree, «The astronomical works of Yaʿqūb ibn Ṭāriq», p. 121; also King, *Synchrony*, A, p. 66. For just one example from medieval Europe, see Toomer, «A Survey of the Toledan Tables», p. 155: here Gerald Toomer presents adequate extracts from the table of $h(H,T)$ and analyses its structure.

44. See, for example, Calvo, «Two Treatises on Mīqāt from the Maghrib», pp. 184-185 (Ibn al-Bannā') and 188-189 (al-Jādarī), and *Synchrony*, A, pp. 471, 476, 484, etc., 557-558, etc.

45. Ibid., pp. 66-68, and VI: «Universal solutions in Islamic astronomy», *passim*.

46. We refer to those documented in Derek J. De Solla Price, «Portable Sundials in Antiquity», 1969; and Wright, «Greek and Roman Portable Sundials – An Ancient Essay in Approximation». Specialists in historical sundials still have problems identifying the formula on instruments

vicula de Venetiis: the principal markings provide a universal solution for time-keeping by the sun based on the accurate formula, and the horary quadrant on the back provides a quick approximate solution of the same problem, based on our formula.[47] In Europe from the 10th to the 16th century, our formula was used, if only implicitly, in the universal horary quadrants that grace the upper half of most astrolabes. For European latitudes the formula does not work satisfactorily, but we do not know of any discussion of its accuracy in any historical European text or suggesting that this kind of horary markings should be abandoned. Quite the contrary, for one medieval English instrument consists of nothing more nor less than a substantial quadrant of universal horary markings.[48] In these and other manifestations, the formula was popular in the Islamic and European worlds for over a thousand years until the 19th century.

An Abbasid (9th-century Baghdādī) treatise preserved in MS Cairo DM 969 (fols. 8v-9v, copied *ca.* 1800 in Meshed) describes three different sets of markings on a horary quadrant, to be used with or without a cursor (for entering the solar meridian altitude). One of these sets of markings without the cursor came to be so popular that it was to be found on the backs of most Islamic astrolabes until 1900 and most European astrolabes until about 1550.[49] The underlying formula is, as far as we are aware, not discussed in the contemporaneous astrolabe literature, and the associated error pattern, a function of latitude and solar longitude, are a modern addition. The use of seasonal day hours, dependent on latitude and solar longitude, tends to act as a counter to the simplified expression involving the solar altitude h and the solar meridian altitude H, the latter being also latitude-dependent. The range of latitudes for which the approximation works well is from 0° to about 40°, including Baghdad (*ca.* 33°).

based on it: see, most recently, Denis Savoie, «Three Examples of Ancient "Universal" Portable Sundials», 2020. It is necessary to start from the formulae which we know were used in Islamic astronomy, only to find that the one we want is also found in Indian, Greek, Byzantine Greek and medieval European sources.

47. On this class of instrument, see Catherine Eagleton, *Monks, Manuscripts and Sundials – The Navicula in Medieval England*, 2010, where, however, the underlying formulae are not mentioned, and DAK, «14th-century England or 9th-century Baghdad», in *Astrolabes from Medieval Europe*, IX.

48. For this remarkable single universal horary quadrant see *Synchrony*, B, pp. 224 & 226.

49. *Synchrony*, B, pp. 162-179.

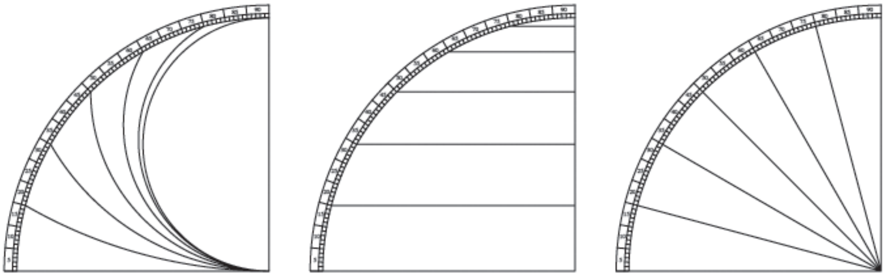


FIGURE 4.2a: The three sets of universal horary markings described in a 9th-century treatise from Baghdad (MS Cairo DM 969,4). These are all based on the standard approximate formula and are independent of latitude. They are to be used with or without the cursor for solar longitude or solar declination. Only the first one really caught on, being used for the next 1,000 years. The second one was popular in that it was developed into one form of a quadrant for trigonometric calculations. DAK, *Synchrony*, B, pp. 213-221, esp. fig. 2b.

Between them, al-Marrākushī and Najm al-Dīn present nine different types of universal sundial, and at least the former actually discusses the underlying formula.[50]

Already in 1927, the German scholar and instrument collector Joseph Drecker in his book on the theory of sundials established that underlying the markings on the universal horary quadrant was the approximate formula[51] which is of concern here, and which was used for a millennium in Islamic astronomy.[52] More recent attempts to penetrate the mystery of the universal horary quadrant have failed to identify the simple formula underlying it (because they started out from the hour-angle). In any case, this approximate formula underlies numerous Islamic tables and other instruments, as well as the markings on the universal sundial of Mehmet II.

c) The standard exact formula

Several exact methods are found in the astronomical handbooks known as *zīj*es, of which we know of over 200. These are essentially derived by projection methods

50. Ibid., pp. 148-161; and FC, *Mathematical Instrumentation*, pp. 145-165.

51. Drecker, *Theorie der Sonnenuhren*, pp. 86-87.

52. *Synchrony*, B, pp. 111-258.

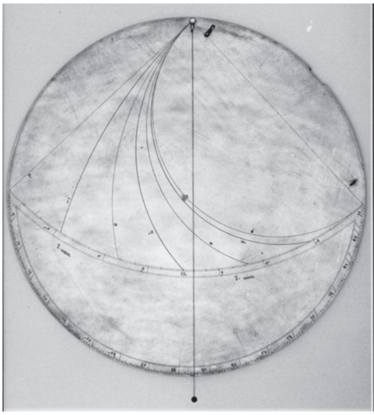


FIGURE 4.2b: A unique example of the markings of a universal horary quadrant on the back of an astrolabe from 14th-century England: the markings fill the entire surface. (Usually they occupy one-quarter or one-half of such a space). The procedures for simple timekeeping with this instrument would be rather inaccurate (for non-zero latitude and non-zero declination), since the underlying formula no longer yields reasonable results after about latitude 40°. Image from the History of Science Museum, Oxford. (This «other» side is apparently not shown on the website epact).

FIGURE 4.2c: A double universal horary quadrant as was standard on the backs of Islamic and European astrolabes. The device has been somewhat misunderstood in the modern literature. Its function is simply to provide a quick means of obtaining a rough estimate of the time of day for any latitude, whereas the astrolabe should give a reasonably accurate value for the latitudes represented by the plates, though more laboriously. It was not generally known that the markings of the universal horary quadrant were based on the standard approximate formula. This is the back of the «astrolabe of Berselius», a 14th-century Picard piece with all numbers in monastic ciphers. Image courtesy of Christie's of London.

(Indian origin), spherical geometry (Islamic), analemmas (Greek), and spherical trigonometry (Islamic), and are all ultimately equivalent, although this may not be obvious. The most compact formula for timekeeping is:

$$t = \text{arcvers}\left\{\frac{R^2\,(\text{Sin}\,H - \text{Sin}\,h)}{\text{Cos}\,\delta\ \text{Cos}\,\phi}\right\}\left[= \text{arcvers}\left(\frac{\sin H - \sin h}{\cos\delta\cos\phi}\right)\right]$$

where t is the time in equatorial degrees before/after midday, H is the solar meridian altitude, h is the instantaneous altitude, δ is the solar declination, ϕ is the local latitude, and the Versed Sine (سهم, *sahm*) is a useful trigonometric function that seems to have been abandoned.[53] This formula and other renditions of it in the form of textual references or geometrical constructions, or tables, as well as markings on instruments, notably sundials, were used from the 9th century onward, at least in the Islamic world.

4.3 Two instrument treatises from Mamluk Egypt

The vibrant and colorful tradition of astronomy in Mamluk Egypt was destined to influence the Ottoman tradition. This was a continuation of the Fatimid tradition, dominated by the works of the astronomer, Ibn Yūnus (d. 1009), one of the greatest Muslim astronomers who was particularly innovative in the field of spherical astronomy.[54] The entire tradition of astronomical timekeeping in Mamluk Egypt and Syria as well as the Ottoman world owes most of its inspiration, knowingly

53. In the *Enc. Islam*, 2nd edn., VII, pp. 841-842, taken over from the first edition, there is even an article «Sahm» by the celebrated Eilhard Wiedemann (1852-1928), who rediscovered Islamic physics and engineering – see his *Gesammelte Schriften zur arabisch-islamischen Wissenschafts-geschichte*, repr. 1984. More work could be done on spherical astronomy in the Islamic tradition. See already Kennedy & Davidian, «Al-Bīrūnī on the Time of Day from Shadow Lengths», and *Synchrony*, A, pp. 26-38, where an attempt is made to represent the standard medieval methods in modern notation. Excellent books have been devoted to spherical trigonometry in Islamic astronomy, notably by the Canadian historian of mathematics, Glen Van Brummelen, but there is nothing comprehensive on plane trigonometry and on the applications of analemmas, devices to represent three-dimensional problems in a plane, where they can be solved by plane trigonometry.

54. Articles «Ibn Yūnus» in *DSB* and *BEA*; DAK, «Fatimid astronomy» and «Mamluk astronomy». On instruments from Mamluk Syria, see *Paris IMA 1993 Catalogue*, pp. 386-395 and 432-443, with an English version in *Synchrony*, B, pp. 659-724.

or not, to him. In Egypt, a good two and a half centuries were to pass before another prolific astronomer of consequence was to appear.[55]

4.4 Abū 'l-Ḥasan ʿAlī al-Marrākushī

> L'auteur de cet ouvrage, Aboul-Hassan-Ali, de Maroc, ayant vu beaucoup de constructeurs d'instruments astronomiques, n'a pas tardé à reconnaitre que les plus habiles d'entre eux ne savent ni calcul, ni géométrie, ni cosmographie, choses dont ils sont en quelque sorte perpétuellement occupés et qu'ils ne connaissent néanmoins que de nom, quoique ce soient les seuls degrés qui puissent les conduire sûrement au but qu'ils se proposent d'atteindre. / The author of this work, Abu 'l-Ḥasan ʿAlī al-Marrākushī, having seen many makers of astronomical instruments, did not take long to recognize that (even) the most skilful among them know nothing about calculation, nor geometry, nor cosmography, subjects with which they are constantly concerned and which they nevertheless know only by name, even though these are the only means which could lead them surely to the goal which they set for themselves. (Jean-Jacques Sédillot (*père*), *Traité des instruments astronomiques des Arabes*, 1834, I, p. 57).

> Marrākushī is best known for his remarkable *summa* devoted to spherical astronomy and astronomical instrumentation, … which is intended as a comprehensive encyclopedia of practical astronomy. This work is the single most important source for the history of astronomical instrumentation in Islam. It was the standard reference work for Mamluk Egyptian and Syrian, Rasulid Yemeni, and Ottoman Turkish specialists of the subject. (FC, article «al-Marrākushī» in *Biographical Encyclopedia of Astronomers).*

The giant of the Mamluk scene, albeit not in the same class as Ibn Yūnus, was Abū 'l-Ḥasan ʿAlī al-Marrākushī, a Maghribī astronomer who had emigrated permanently to Cairo.[56] He paints a bleak picture of the scene of instrument-makers around him, but he is exaggerating, witness the fine instruments made there before his time. It is not surprising, given the turmoil affecting al-Andalus and the Maghrib

55. This apparent gap would be worth investigating. See the preliminary remarks in DAK, «Astronomy of the Mamluks», pp. 532-534.

56. On al-Marrākushī (Suter, *Mathematiker*, no. 363), see the articles in *BEA* by FC, replacing that in *Enc. Islam*, 2nd edn., by DAK. See also DAK, *Cairo Survey*, no. C17; «Astronomy of the Mamluks», pp. 539-540 & 553, no. 5; «Universal Solutions to Problems of Spherical Astronomy from Mamluk Egypt and Syria», p. 157; & Charette, *Mathematical Instrumentation*, pp. 9-13.

at that time, that a scholar from the westernmost part of the Islamic world would decide to move to Egypt, whose capital was already established as the major cultural center of the Arab-Islamic world. We know nothing about his background and training, and nothing about his activities in Cairo, except for the fact that *ca.* 1280 he authored the most comprehensive and extensive treatise on spherical astronomy and instrumentation ever produced in the Muslim world.[57] He wrote the celebrated *Summa* or «encyclopedia» of *mīqāt* entitled جامع المبادئ والغايات في علم الميقات, *Jāmiʿ al-mabādi' wa-'l-ghāyāt fī ʿilm al-mīqāt*, «An A to Z on astronomical timekeeping», in which he describes and illustrates several dozen different types of instruments.

It became the standard reference work for Mamluk Egyptian and Syrian, Rasulid Yemeni and Ottoman Turkish specialists on the subject. But it would not have been «an easy read». Most complete copies cover 250 to 350 folios of text, diagrams, and tables. A copy in two volumes purportedly made from a copy of an autograph manuscript[58] in the 14th century is preserved at the Bibliothèque nationale de France in Paris (MSS arabe 2507 & 2508, together 357 folios), which can now be viewed on the internet.[59] Most of the first half dealing with spherical astronomy and sundial theory with tables for sundial construction was partly translated into French – a truly monumental task – by the orientalist Jean-Jacques Sédillot in 1808, but published posthumously in 1834 by his son, Louis-Amélie Sédillot.[60] (An orientalist in this case means someone from the non-Muslim world who spends their lives contributing to our understanding of the Muslim world). The Paris manuscript has a variant title الشامل لجميع الرسائل والوضيعات, which, knowing what is in these weighty tomes, we can translate generously as «The comprehensive collection of texts (on spherical astronomy and the theory of instruments and sundials) and on their practical construction».

57. We do not even know the date of death, mention of which is standard in Muslim necrologies, see Brentjes, «al-Sakhāwī on muwaqqits». At least we know that his major work was compiled *ca.* 1280.

58. This is an old ruse which, whether true or not-so-true, would increase the scientific and material value of any manuscript. In this case, the three manuscripts consulted (in bits and pieces) give the impression of representing two versions of the original work. Certainly, there are at least two traditions of copying scientific instruments, represented, on the one hand, by the Khalili Collection copy and, on the other, by the Paris and Topkapı copies.

59. See https://gallica.bnf.fr/ark:/12148/btv1b10037489v.

60. Sédillot-*père*, *Traité des instruments astronomiques des Arabes composé au treizième siècle par Aboul Hhassan Ali de Maroc*.

TRAITÉ
DES
INSTRUMENTS ASTRONOMIQUES
DES ARABES
COMPOSÉ AU TREIZIÈME SIÈCLE
PAR ABOUL HHASSAN ALI, DE MAROC
INTITULÉ
جامع المبادى والغايات
(COLLECTION DES COMMENCEMENTS ET DES FINS
TRADUIT DE L'ARABE
SUR LE MANUSCRIT 1147 DE LA BIBLIOTHÈQUE ROYALE
PAR J.-J. SÉDILLOT

FIGURE 4.4a: The title folio of Sédillot-*père*'s translation of al-Marrākushī's treatise. This was a monumental achievement of 19th-century French orientalism. It has been mainly overlooked in more recent scholarship in the history of Islamic astronomy.

The same son in 1844 published a summary of the other half dealing with a variety of other instruments.[61] The manuscript is undated, but Sédillot-*père* dated it to the 14th century. On the title page of 2507, the copyist states it was the seventh copy he made from a copy of the autograph (!). The title-page of 2508 has an owner's mark from 813H/1410~11. The manuscript certainly came to Istanbul, for it entered the library of Taqī al-Dīn ibn Maʿrūf at the Istanbul Observatory in 981H/1573~74.[62]

Another copy is MS Istanbul Topkapı 3343, first documented by the German Arabist and historian of classical and Islamic mathematics, Max Krause (1909-1944) in 1936[63] and published in facsimile by Fuat Sezgin and his staff at the Institut für Geschichte der arabisch-islamischen Wissenschaften in Frankfurt in 1984. This manuscript was copied in the year 747H/1346~47, most probably in Cairo. In 774H/1372~73 it was in the possession of the Cairene astronomer al-Bakhāniqī, which suggests that it had been copied in Cairo. It bears undated notes of possession of Mehmet II and of Bayezid II, which proves that it was available to as-

61. Sédillot-*fils*, «*Mémoire* sur les instruments astronomiques des Arabes».

62. On Taqī al-Dīn, see n. 6 above.

63. Krause, «Stambuler Handschriften islamischer Mathematiker», pp. 492-493, ad Suter, *Mathematiker*, no. 363. Rosenfeld & İhsanoğlu, *Mathematicians, Astronomers ... of Islamic Civilisation*, no. 592, mention other Cairo and Istanbul manuscripts but give no dates of copying. Max Krause identified a very early copy of al-Marrākushī's treatise in MS 2902 belonging to the Nuruosmaniye Library in Istanbul, penned in 695H/1295~96, on which it would be interesting to have more information.

tronomers in Istanbul at the time of the former. So we can be fairly certain that instructions on how to make and use the *ḥalazūn* were available there in his time, or perhaps even an actual instrument, now long lost. However, the diagrams are of inferior quality, as in the Paris manuscript. It was however a standard strategy of medieval manuscripts to keep technical diagrams at a simple schematic level, to prevent corruption during the copying process. Instrument-makers would mainly follow the instructions and the main function of the diagrams is to confirm the generic idea conveyed by the technical instructions in the text.

A second Istanbul copy of the text, also dedicated to Bayezit II, is Ayasofya 2669, on which we have no further information.[64]

There is another manuscript, a beautifully-executed copy, in the Khalili Col-

FIGURE 4.4b: Part of the title-page of the first volume of al-Marrākushī's treatise with the two notices of possession of Sultans Mehmet II (right middle) and Bayezid II (top middle). On the lower left are two notices of possession by Egyptian astronomers, showing that in the late 14th century the manuscript was still in Cairo. From the Frankfurt facsimile, vol. 1, p. 1.

lection in London. To judge by the published illustrations of two double pages of the manuscript, it is of Ottoman origin, not Persian or Indian, as has been claimed. It can be dated to around 1500 and it is important not least because, from a technical point of view, the diagrams are accurately executed. However, part of each diagram is traced in gold-coloured ink, which fades with time and which does not

64. Mentioned in Arslan, «Qunawī on the Astrolabic Quadrant», p. 101.

photograph well. The manuscript has been labelled Persian or Indian because the copyist's *nisba* was al-Tabrīzī but it is clearly Ottoman Turkish. It purports to be a copy of a copy of a holograph, but the manuscript is shorter than the Paris and Topkapı ones, and the section-numbers appear to have disappeared. Much effort has been put into decorating the diagrams with coloured and gold ink. In its present environment, this scientific gem has mainly become a piece of wonderment for historians of Islamic art.

We have not compared the relevant section in these three manuscripts. A critical edition of the entire text would be a *desideratum*. The second author notes that 14 complete manuscript copies of this text exist today, along with three incomplete ones, numerous fragments, as well as extracts and quotations from it in other authors' works. This voluminous work has occasionally been qualified as a mere compilation of older sources without original content. While it is true that it depends heavily upon the works of mainly unnamed (and still unidentified) predecessors, it is definitively original and without precedent. In fact, no single part of the work can be proven to reproduce the words of any earlier author, except for the few sections where Marrākushī clearly states from whom he is quoting. In those occasional cases where an earlier source is mentioned, Marrākushī's text always turns out to be either a major rewriting of the original or an independent paraphrase.

Universal sundials are illustrated and described by al-Marrākushī. One of these instruments is the حلزون, «*ḥalazūn*». The Arabic name of the instrument means «snail» or «snail shell» and refers to the markings engraved on the instrument which are indeed shaped like a spiral or snail shell.[65] This is illustrated with a diagram in the texts of both al-Marrākushī and (to a lesser extent) Najm al-Dīn al-Miṣrī (see below) with a full explanation of the instrument and how to use it. Until the rediscovery of the Mehmet II dial, it had only been known from these texts and illustrations. No other Islamic example of this type of instrument, the *ḥalazūn*, is known.

The text of Sédillot-*père* provides a full French translation of al-Marrākushī's description of the universal spiral sundial and an explanation of its use. Follow-

65. The term *ḥalazūn* and/or the associated adjective *ḥalazūnī* are also used in Islamic zoology and fine engineering. See Eilhard Wiedemann, *Gesammelte Schriften zur arabisch-islamischen Wissenschaftsgeschichte*, I, p. 279, for the former, and ibid., pp. 1392, 1432, 1436, for the latter. The Hebrew equivalent is חלזון, *hillazon*, and both Arabic and Hebrew are related to Aramaic חלזונא, *ḥəlāzōnā*. The name in Persian is also حلزون.

ing his idiosyncratic transliteration system, he gives the name as *khalazoune*, providing the French translation «*hélice*» (English, helix). It is a universal sundial based on the midday shadow. The outermost curve represents the first hour. The innermost curve marks midday. This spiral for midday divides the circumference of an imaginary circle into 37 equal parts numbered from 0 (zero), 1 (one), ... to 36 (thirty-six), followed by a space to separate the two extremities of the family of hour-curves.

In the treatise there is a drawing of this instrument. An engraving of this illustration is provided in Sédillot's published translation.[66] The illustration in the Topkapı manuscript is similar in detail. Another computer-generated image by the second author of Najm al-Dīn al-Miṣrī's *ḥalazūn*[67] is also shown (Fig. 4.4g). The companion instrument is the *ḥāfir*, the vertical variety in which the hour-lines are not so crowded. The Arabic name means «hoof» and the outermost horary markings do indeed resemble the outline of the hoof of a camel or a horse. Just one example of an Islamic *ḥāfir* is known and it is datable to Baghdad, *ca.* 900 – see §5.2 below. The existence of this instrument implies that the various universal sundials described by al-Marrākushī were probably conceived in the 9th century.

The notion of a spiral (*lawlabī*) is also used in a variety of astrolabe rete design with the ecliptic as a spiral that is featured by both al-Marrākushī and Najm al-Dīn, but which goes back to al-Sijzī in the late 10th century.[68] The expression *khuṭūṭ lawlabiyya* is used for «spiral curves» in Arabic Archimedes translations.[69] In fact, only the midday and *ʿaṣr* curves on the «new» sundial are true Archimedean spirals; the other ones are much more complex: for i=6, the polar equation of the hour curve simplifies to the form $\varrho(\theta) = (37/2\pi) \cdot \theta - 1$ and likewise at the *ʿaṣr* it is of the form $(37/2\pi) \cdot \theta + n - 1$.[70]

Whilst there is no mention of Archimedes in the sources we consider here, there does not need to be: Archimedes was one of the leading Greek mathematicians, if not

66. Sédillot-*père*, *Traité sur les instruments*, Plate VIII, figure 70. The Arabic of the original can be consulted at I, pp. 450-452 of the Frankfurt facsimile of the Topkapı manuscript.

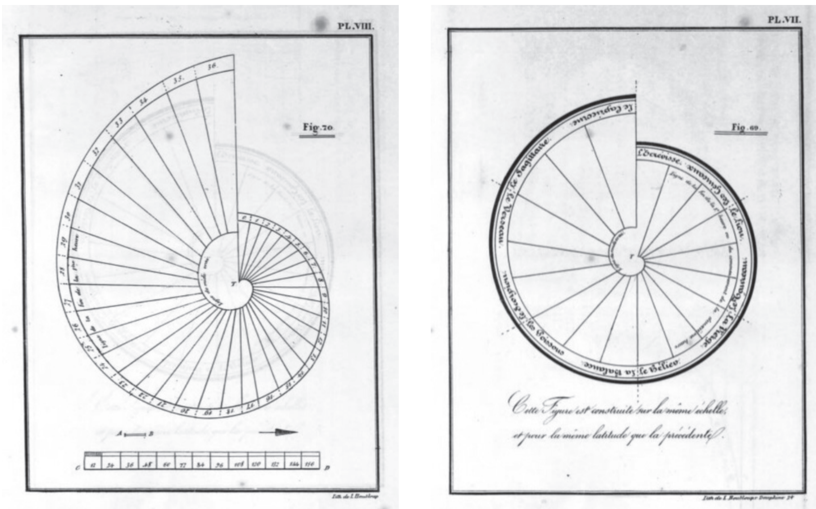
67. FC, *Mathematical Instrumentation*, as fig. 3.34 in chapter 3 on p. 162.

68. See Sédillot-*fils*, *Mémoire*, pl. 92, & FC, *Mathematical Instrumentation*, pp. 243-244 & 21-22 (Arabic).

69. Fazlıoğlu & Ragep, «Archimedes among the Ottomans: An Updated Survey», p. 243.

70. For details, see FC, *Mathematical Instrumentation*, pp. 161, 163.

FIGURE 4.4c: The section of al-Marrākushī's magnum opus dealing with the *ḥalazūn*, as it appears in MS Paris BnF arabe 2507. The copy is indeed early, probably 14th century. The names of owners are all Egyptian, and the Paris manuscript did not leave Egypt until *ca*. 1800. Image from https://gallica.bnf.fr/ark:/12148/btv1b10037489v/f129.ite



Figs. 4.4d-e: Sédillot's reconstruction of two *ḥalazūn* sundials, the first with the midday shadow as argument and the second the solar longitude as argument. Images from https://www.digitale-sammlungen.de/de/view/bsb10218885?page=285 and ?page=287.

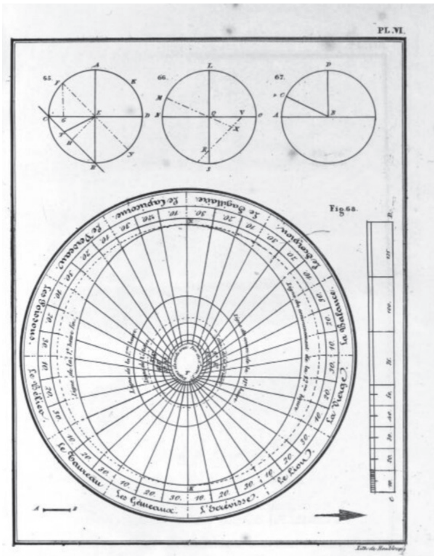


FIGURE 4.4f: The corresponding illustrations of the *ḥāfir* with the solar longitude as argument in the French edition of Sédillot-*père*, I, pl. VI. Image from https://www.digitale-sammlungen.de/de/view/bsb10218885?page=283.

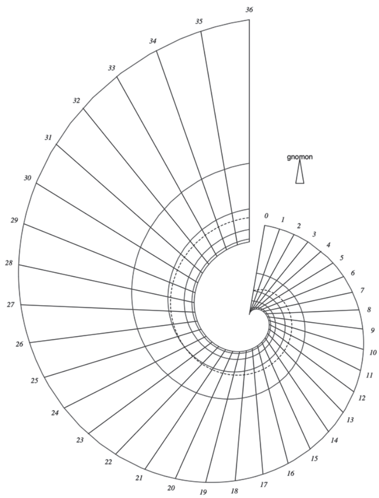


FIGURE 4.4g: A reconstruction of al-Marrākushi's *ḥalazūn*. From FC, *Mathematical Instrumentation*, p. 162.

the leading one. He was appreciated by Muslim scholars in the very early centuries,[71] and we know that some of his works were available to them, if not the *Spirals*, and at least to some Ottoman astronomers and mathematicians.[72] But first, the sundial for Mehmet II can be constructed without any knowledge of Archimedes' *Spirals*. Second, we have no proof of when and where this type of sundial was invented, but surely some location between 9th-century Baghdad and 12th-century al-Andalus is possible. Third, the most relevant sources for the Ottoman connection of this instrument are the Mamluk works that were circulating among the Ottomans in the 15th century, and not their hypothetical knowledge of the Archimedean corpus.

In the present study, we are concerned with the first actual example known of a particular instrument genre — a universal sundial with curves in the form of a spiral — to come to light. Indeed, it is the sole surviving Islamic example of this kind of universal horizontal sundial with hour-curves in the form of a spiral.[73] In fact, we stress, only the curves for the midday and the *ʿaṣr* are true Archimedean spirals; the other ones are more complex! (The principle is that of a curve generated uniformly from a fixed centre at a uniformly increasing ra-

71. Sezgin, *Geschichte des arabischen Schrifttums*, v, pp. 121-143. See two studies by our late colleague Richard Lorch on the transmission of some fragments of the Archimedean corpus through Islamic sources, reprinted in his *Arabic Mathematical Sciences – Instruments, Texts, Transmission*, I & II.

72. The history of the Archimedean corpus in the Ottoman world was investigated by J. Len Berggren in a 1987 study entitled «Archimedes among the Ottomans» on the basis of a remarkable text by Asʿad ibn ʿAlī ibn ʿUthmān al-Yāninawī *ca*. 1700, extant in a unique manuscript preserved in Cairo. This scholar (who has not fared well in the recent bio-bibliographical works on Ottoman science) came from Yannina in Epirus (now N.W. Greece). Although his mother-tongue was Greek, he studied in Istanbul and became professor (*müderris*) at Eyüp and judge (*cādī*) at Galata. Berggren was able to conclude from al-Yāninawī's treatise that the author is telling us that an Arabic version of *On Spirals* was available to him, and this he discusses. It would be interesting to learn more about the Ottoman Archimedes tradition than what the unique Cairo manuscript tells us, although the universal sundial is not related to this. Indeed, a remarkable study by İhsan Fazlıoğlu & Jamil Ragep has been published for the *Festschrift* for Len Berggren; it is aptly labelled «an updated survey» to Berggen's paper and it contains a wealth of new information to supplement that of Berggren. It treats of the contributions of such scholars as Dāwūd al-Qayṣarī and Muḥammad al-Fanārī, as well as the better-known Taqī al-Dīn al-Rāṣid, and, last but by no means least, Muṣṭafā Ṣidqī, who is proving increasingly important for historical studies – see n. 176.

73. For two basic introductions to the underlying mathematics of Archimedes' Spirals, see https://en.wikipedia.org/wiki/Archimedean_spiral and https://mathworld.wolfram.com/ArchimedeanSpiral.html.

dius – we are dealing with polar coordinates). The theoretical spirals of Archimedes perhaps influenced the astronomer who first devised the «spiral» markings on this new instrument, but we have no evidence that this was so. It is the experience of the authors that most innovations in astronomical instrumentation were made within that milieu. Yet what of the Archimedean connection in Ottoman Istanbul?

4.5 Najm al-Dīn al-Miṣrī

> The Muslim astronomers of the Middle Ages had a predilection for computing tables. Their output in this field of learning was astonishing in diversity, in quantity and in quality. Of all medieval calculators, the unrivalled champion was Najm al-Dīn al-Miṣrī (*fl. ca.* 1300 in Cairo), an astronomer whose main concern, like most of his contemporaries, at least in Egypt and Syria, was the science of astronomical timekeeping. Najm al-Dīn compiled a set of tables which, with nearly half a million entries, qualifies as the largest ever produced during the Middle Ages, and even until the 19th century. It is not the size of Najm al-Dīn's tables alone, however, that accounts for their interest to the history of the exact sciences. (FC, «A Monumental Table», p. 12).

Other than the treatise of al-Marrākushī, the only comparable and enormous Egyptian work on instrumentation is by the astronomer Najm al-Dīn al-Miṣrī, who flourished in Cairo *ca.* 1325. This remarkable compendium presents 100 instruments, some he invented himself and others he selected from earlier works. His treatise covers some 140 pages with carefully-drawn illustrations of each instrument and including numerous tables to facilitate their construction. It survives in two manuscripts, both early, say, *ca.* 1325, one in the Chester Beatty Library in Dublin (nearly complete but with disordered pagination, and unhappily numbered «Persian 102»). The other now in the Museum of Islamic Art in Doha is incomplete.[74]

74. On these two copies and their fates and fortunes, see FC, *Mathematical Instrumentation*, pp. 31-43. On the first, see the unpublished catalogue of the astronomical manuscripts in the Chester Beatty Library in Dublin by FC. The work is not mentioned on the website of the Library. On the second, see the detailed description by the present authors at www.christies.com/en/lot/lot-1749834. The work does not feature on the website of the Museum.

Some confusion arose when DAK discovered the anonymous Dublin manuscript. Since the tables in this previously-unknown Mamluk treatise were for latitude 36°, serving Aleppo, he as-

The second author was able to show that the Dublin manuscript was copied from which the original Doha manuscript was copied.

The second author has investigated all the known works of the Najm al-Dīn, and has also tried to find out exactly who he was.[75] The mysterious Egyptian astronomer compiled not only this treatise, but also a monumental table for solving all of the standard problems of spherical astronomy for any latitude, using an exact formula and containing some 440,000 entries.[76] The second author analyzed this enormous table, using the two halves of a unique manuscript preserved, one half in Oxford and the other half in Cairo.Given the obvious potential of his treatise, it is curious that we find barely a mention of the author in later sources, astronomical or biographical, and none whatsoever of his instrument treatise or his half-a-million entry table, neither in the Mamluk nor in the Ottoman world.

Najm al-Dīn erroneously calls the *ḥalazūn* a *ḥāfir*.[77] He does not use the word «*ḥalazūn*» a single time: the astrolabe with the spiral ecliptic on the rete is called «*lawlabī*». It is featured in Chapter 86 but with a significant variant, where the outer scale is the meridian altitude and not the midday shadow! Najm al-Dīn displays only three curves: *ẓuhr*, beginning of the *ʿaṣr*, and end of *ʿaṣr*.

The second author, who has published the most detailed description of these instruments, and has identified the existing Islamic and European texts thereon and examples thereof, introduces the genre with these words: «These sundials are circular horizontal plates on which the shadow length is represented in polar coordinates».

He also uses the expression «mathematical instrumentation» in the title of his detailed study of Mamluk instrumentation focused on the contents of a medieval description of some 100 instruments, which include a complicated horizontal

sumed that the author was the leading instrument-maker of Mamluk times, Ibn al-Sarrāj of Aleppo. In fact, the latitude 36° was a didactic choice for the middle of the 4th climate, that is, the middle of the oikumene. FC came to this treatise having published on the monumental universal auxiliary table of Najm al-Dīn – see next two notes – and was able to properly identify Najm al-Dīn of Cairo as the author of the instrument treatise. This immediately explained the presence in the treatise of blue-prints for the astronomically-oriented wind-catchers of Cairo.

75. See FC, *Mathematical Instrumentation in Fourteenth-Century Egypt and Syria – The illustrated treatise of Najm al-Dīn al-Miṣrī*, pp. 25-26.

76. *Idem*, «A monumental medieval table for solving all the problems of spherical astronomy for all latitudes».

77. *Idem*, *Mathematical Instrumentation*, p. 156; see also Fig. 3.30 on p. 157.

FIGURE 4.5: A typical page from the treatise by Najm al-Dīn. There are 100 such pages in the complete work, each page illustrating a particular instrument together with a short commentary in very technical Arabic. This image from the incomplete copy, auctioned at Christie's London on 11.04.2000, shows a universal plate of Najm al-Dīn's invention virtually identical to the better-known universal plate of the contemporaneous Andalusī astronomer Ibn Bāṣo, on which see various publications of Emilia Calvo. Image from https://www.christies.com/en/lot/lot-1749834, courtesy of Christie's London..

sundial with several sets of horary markings.[78] These are not necessarily observational, nor even computational instruments, rather they are devices to demonstrate the relationship between the principal functions of spherical astronomy which are dependent on the solar longitude such as solar declination, and those dependent on solar altitude such as time after sunrise or before sunset, the times of the five daily prayers, azimuth, and others beside; these relationships may be defined by exact or approximate trigonometric formulae.

Such instruments are the material counterparts of the voluminous astronomical tables of the same functions that were produced by Muslim astronomers for

78. FC, *Mathematical Instrumentation in 14th-century Egypt and Syria* (2003).

individual latitudes or for all latitudes during more than a millennium.[79] For these reasons, the second author prefers the expression «mathematical instrumentation» to «astronomical instrumentation». The first author, on the other hand, has published on numerous Islamic astronomical instruments, including some from Mamluk Damascus and Cairo and Ottoman Istanbul.[80] Mehmet II's universal *ḥalazūn* sundial, a mathematical instrument from Ottoman Istanbul, was inspired by an instrument, or, more probably, by an illustrated treatise from Mamluk Cairo, more likely that of al-Marrākushī than that of Najm al-Dīn.

4.6 How were the markings executed?

> Najm al-Dīn al-Miṣrī (Cairo, *ca.* 1300) proposed several universal sundials based on an approximate formula for timekeeping, but it seems doubtful that these were ever constructed. (DAK, *Synchrony*, A, pp. 705-706).

Muslim astronomers in all regions of the Muslim world and from the 9th to the 19th century compiled tables for timekeeping by the sun and stars. These might include tables of time and solar azimuth as function of solar altitude and either solar longitude or solar meridian altitude.[81] Now the construction of this instrument depends on the availability of a table of the horizontal shadow for each seasonal hour as a function of the shadow at noon, using the formula given in §4.2.[82] Indeed, we find tables of the function $z_i(T, H)$ in some treatises on sundials, in-

79. For analyses of these tables see *Synchrony*, A, I: «A survey of tables for timekeeping by the sun and stars» at pp. 1-190 and II: «A survey of tables for regulating the times of prayer» at pp. 191-456. A summary is in the article «Mīḳāt» in *Enc. Islam*, 2nd edn.

80. For descriptions of these instruments see *Synchrony*, *B*.

81. A survey of such tables from the 9th century to the 19th is in *Synchrony*, A, pp. 43-113, esp. pp. 84-101, for an individual latitude or for all latitudes during more than a millennium and B, pp. 135-137, for the tables of al-Marrākushī and Najm al-Dīn based on the standard approximate formula. See also ibid., A, pp. 457-527, for shadow tables based on formulae other than the accurate one and the standard approximate one.

82. The recent study Bir & Bütün & Kaçar & Akın, «The Guide for the Zarqaliyya (Universal Astrolabe) by al-Marrakushi», shows how al-Marrākushī's instructions could be used to construct a universal astrolabic plate. However, none of the 30-odd surviving Ottoman astrolabes contains such a plate (pp. 812-911 of the catalogue at https://www.academia.edu/35737806/).

cluding, of course, the extensive work by al-Marrākushī, which is reproduced below.[83] al-Marrākushī's instructions require:

(1) A gnomon of length 12 units
(2) A linear scale (at least) 13 times the length of the gnomon (*i.e.*, 156 units)
(3) An imaginary circle divided into 37 equal parts (*i.e.*, each part covering 9.73°),[84] for drawing radial lines from the centre (basis of the gnomon).

As already mentioned, dividing an outer scale into 37 equal parts may seem unnatural. It would have been far easier to divide the circumference into 36 parts of 10° each. al-Marrākushī does not provide a justification for this, and we must assume it was for aesthetic reasons only. Once the outer scale is in place, one reads from the numerical table, for a particular hour, the values of the horizontal shadow for each argument of the midday shadow, sets the legs of a compass divider on the linear scale, with one leg at zero and the other one on the value for the argument of the midday shadow. Then one leg of compass is put at the centre (just at the right of the hole) and the other one on the appropriate radial line, and the position of the other leg is marked with a dot. At the end one connects each dot for a given seasonal hour as a curve that is as smooth as possible. The same operation is repeated for each hour, and for the *ʿaṣr*. For the latter no numerical table is needed, as one simply needs to add 12 to the values of the curve for midday. We suspect that the curves were first engraved freehand, as thin scratches connecting small dots, to be then engraved with a punch or another standard tool. In any further investigation, the hour plate of Nasṭūlus should be taken into consideration, even though it is some 500 years earlier than Mehmet II's *ḥalazūn*!

The second author has checked all values of the shadow lengths for hours 1 to 6 and midday shadows 0, 6, 12, ... to 36 on the sundial, using the measurement tool provided by the open source image processing software Gimp.[85] Comparison with the recomputed values show that all values are accurate to the nearest millimetre. Only the values for the curve corresponding to the 1st/11th hours appear to be slightly too large for values of the midday shadow between 18 and 36 (the largest

83. Sédillot-*père*, A, pp. 257–258.

84. Even Archimedes would have been challenged by this.

85. GIMP (GNU Image Manipulation Program) version 2.10.34 on macOS, https://www.gimp.org/. On the digital photograph available to us the instrument measures 4625 × 3597 pixels, where 24 pixels correspond to *ca.* 1 mm.

deviation being 1.8 mm). But such measurements are not to be taken too literally, as distortions due to the optical and digital processes of the photograph are inevitable. Given the size of the instrument and the challenges of engraving such complex curves on a small sheet of brass, we can say with confidence that the maker of this instrument was fully successful in applying the instructions of al-Marrākushī.

The instrument thus displays the horizontal shadow for each seasonal hour as a function of the midday shadow. al-Marrākushī used the following formula to calculate the table to construct various sundials: it is based on the approximate universal formula given above and basic trigonometric identities, that the horizontal shadow z_i at the ith seasonal hour (with) can be found as follows. (We use z for *ẓill*, Arabic for ʿshadow'). Again, n is the length of the gnomon, usually taken as 12 units or «fingers», and Z is the shadow length at noon.[86] Using the well-known trigonometric identities

$$\cot\ (\arcsin x) = \frac{\sqrt{1-x^2}}{x} \text{ and } \sin\ (\operatorname{arccot} x) = \frac{1}{\sqrt{1-x^2}}$$

and starting from the universal approximate formula for the altitude of the ith hour:

$$h = \arcsin\{\ \sin(\ 15\ i)\ \ \sin H\ \},$$

we can transform the expression for the midday shadow (with a gnomon of length n)

$$Z = n \cot H$$

into

$$\begin{aligned} h &= \arcsin\ \{\sin(\ 15\ i)\ \ \sin(\operatorname{arccot}(Z/n))\} \\ &= \arcsin\left\{\frac{\sin(15\ i)}{\sqrt{1+(Z/n)^2}}\right\} \end{aligned}$$

which means we can express the shadow of each hour i as:

$$z_i(Z) = n\ \cot h = n \cot\left(\arcsin\left\{\frac{\sin(15\ i)}{\sqrt{1+(Z/n)^2}}\right\}\right)$$

86. The mathematical derivation is also available in FC, *Mathematical Instrumentation*, p. 161.

from which we finally derive

$$= \frac{n}{\sin(15\,i)} \sqrt{1 - \frac{\sin^2(15\,i)}{1 + (Z/n)^2}}\ \sqrt{1 + (Z/n)^2}$$

al-Marrākushī's universal shadow table

> 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).

We now present al-Marrākushī's universal shadow table based on this formula, and we can be confident that Aḥmar used such a table to construct his universal sundial. al-Marrākushī's values of the horizontal shadows z_i for each seasonal hour, i from 1 to 5, are shown as a function of the midday shadow Z from 0 to 36, that is, $z_i(T, Z)$, assuming a gnomon of length 12.[87] The columns e_i provide the divergence or error in sexagesimal minutes from the recomputed values.

No such table is known from any other Islamic sources. Tables of the sine and cotangent (shadow) functions are found in virtually every *zīj*, in increasing accuracy over the centuries. Tables of more complex trigonometric functions for the construction of astrolabes and sundials are attested from the 9th century onward. Tables of $T(h, H)$ for a specific latitude or approximate for all latitudes are frequent.[88] We omit here the values of the vertical shadows, which are likewise provided by al-Marrākushī.

87. It is based on MS Paris BnF ar. 2407, fol. 61v, which corresponds to Sédillot-*père*, *Traité*, vol. 1, pp. 256-257.

88. The profusion and variety of the tables produced by the Muslim astronomers is illustrated in King & Samsó & Goldstein. «Astronomical Handbooks and Tables from the Islamic World» – see §6.1.

Z	z_1	e_1	z_2	e_2	z_3	e_3	z_4	e_4	z_5	e_5
0	44;46	[-1]	20;47		12;00		6;56		3;13	
1	44;57		20;53		12;05		7;01		3;22	[-1]
2	45;25	[-2]	21;10		12;20		7;18		3;50	[+1]
3	46;14	[-2]	21;38		12;43	[-1]	7;45		4;27	[-1]
4	47;22	[-1]	22;17	[+1]	13;16		8;19	[-1]	5;15	
5	48;47	[+1]	23;05	[+1]	13;55	[-1]	9;01		6;06	
6	50;26		24;00		14;43	[+1]	9;47	[-1]	7;00	
7	52;16	[-3]	25;03	[-1]	15;33		10;38	[-1]	7;56	
8	54;26	[+1]	26;13	[-1]	16;29	[-1]	11;33		8;53	
9	56;42		27;29	[-1]	17;29	[-1]	12;29		9;51	
10	59;10	[+1]	28;51		18;32	[-1]	13;29	[+1]	10;51	[+1]
11	61;45	[+1]	30;16		19;37	[-2]	14;29	[+1]	11;50	
12	64;27	[-1]	31;43	[-2]	20;47		15;28	[-2]	12;50	
13	67;15	[-3]	33;16	[-1]	21;57		16;32		13;50	
14	70;12	[-2]	34;53	[+1]	23;10	[+1]	17;35		14;50	[-1]
15	73;17	[+2]	36;30		24;23	[+1]	18;39		15;52	
16	76;20		38;11	[+3]	25;37		19;48	[+4]	16;53	[+1]
17	79;30		39;50	[-1]	26;52		20;49		17;53	
18	82;36	[-7]	41;34		28;09		21;56	[+1]	18;56	[+1]
19	86;07	[+7]	43;19		29;25	[-1]	23;02	[+2]	19;57	[+1]
20	89;20	[+1]	45;09	[+4]	30;45	[+2]	24;07		20;58	[+1]
21	92;37	[-4]	46;51	[-1]	32;01	[-1]	25;12	[-1]	22;00	[+1]
22	96;07	[+2]	48;40		33;22	[+1]	26;20		23;01	[+1]
23	99;24	[-7]	50;26	[-3]	34;41	[+1]	27;25	[-2]	24;01	[-1]
24	102;56	[-3]	52;20	[+2]	36;00		28;34		25;03	
25	106;20		54;08	[-1]	37;21	[+1]	29;42	[+1]	26;05	
26	110;28	[+29]	55;59	[-1]	38;44	[+3]	30;50	[+1]	27;08	[+1]
27	113;33	[+1]	57;52		40;00	[+1]	31;56		28;08	
28	117;08	[+3]	59;42	[-2]	41;21	[-2]	33;03	[+1]	29;10	
29	120;14	[-26]	61;38	[+1]	42;41	[-3]	34;12		30;12	

Z	z_1	e_1	z_2	e_2	z_3	e_3	z_4	e_4	z_5	e_5
30	124;02	[-14]	63;31	[+1]	44;04	[-1]	35;23	[+3]	31;14	[+1]
31	128;09	[+17]	65;28	[+5]	45;22	[-5]	36;32	[+4]	32;15	
32	131;26	[-4]	67;15	[-2]	46;44	[-5]	37;38	[+2]	33;15	[-2]
33	135;21	[-13]	69;14	[+2]	48;11		38;48	[+4]	34;21	[+3]
34	138;05	[+42]	70;57	[-9]	49;29	[-4]	39;50	[-2]	35;20	[-1]
35	141;55	[+32]	72;53	[-8]	50;50	[-6]	40;57	[-3]	36;19	[-4]
36	145;57	[-11]	74;55	[-1]	52;15	[-3]	42;05	[-4]	37;??	[?]

This is reproduced from the Paris manuscript only and should not be considered a critical edition. (*Nota bene*: the value for $z_5(36)$ is not visible in the Paris manuscript, and Sédillot's transliteration provides only the integer part 37. The recomputed value is 37;25).

4.7 How to use the universal sundial

The instrument serves to determine the seasonal hours and the time of the afternoon prayer (*ʿaṣr*). Since the shadow at sunrise and sunset is infinitely large, the outer curve is for the first and eleventh hour, while the innermost curve is for the 6th hour (midday).[89] The scale around the outer hour curve serves the length of the shadow at midday. The scale along the principal radial axes serves the seasonal hours.

With the plate set on a horizontal surface and the gnomon in position perpendicular to the plate, to use the markings for all latitudes, one enters the length of the midday shadow on the outer scale. The value of the midday shadow can be determined either empirically or based on a table for the appropriate latitude. If using the empirical method and the time of the day is before noon, one can conveniently use the value of the previous day or extrapolate by adding or subtracting to the value of the previous day the same increment as between the two previ-

89. A reminder: we are dealing with seasonal day-hours measured from sunrise, as used in both classical and medieval times. We are not dealing with the well-known late Ottoman convention in which the first hour begins at sunset, on which see, for example, Würschmidt, «Die Zeitrechnung im Osmanischen Reich», and a plethora of modern works on clocks in the Ottoman world.

ous ones (linear extrapolation). Given the size and accuracy of the sundial, this would not make much of a difference though. The instrument should then be rotated until the shadow of the sun falls on the radial line that corresponds to the midday shadow. The extremity of the gnomon's shadow will then fall within the area of the appropriate seasonal hour.

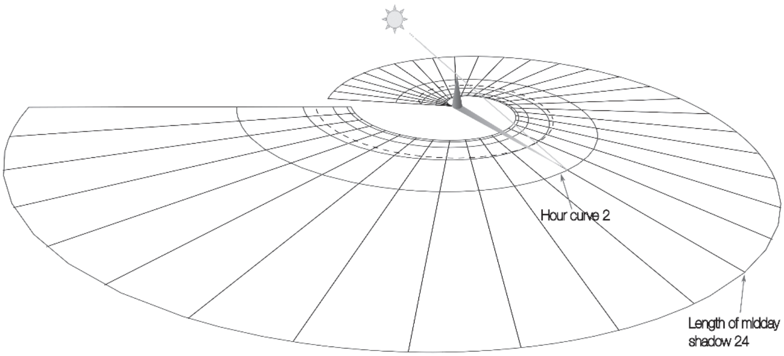


Figure 4.7: To use the sundial one simply turns the instrument so that the direction of the gnomon shadow corresponds to the reading for the midday shadow on the outer scale, here 24 units. Then the end of the shadow marks the time of day given by the appropriate hour curve, here for the second seasonal hour of daylight (or the second hour before sunset). Of course, interpolation may be required. Image by FC.

From a practical perspective, the main drawback of all such horizontal dials using polar coordinates is that the curves for hours 5 and 6 are extremely close to each other and are hardly distinguishable when reading the time from the position of the tip of the gnomon shadow.[90]

One should not think of the Mehmet II sundial, or any other small sundial, such as abound in late Islamic astronomy, as a practical device. For practical purposes, to be useful, and visible, in a mosque courtyard, or on a wall, a sundial should be about 1m×1m. A much smaller instrument that one can set down, turn so that it lies in the meridian, and use a component thereof as a sundial, can be at least 20×20cm. Such is the compendium or multi-function instrument of 14th-century Damascus astronomer Ibn al-Shāṭir.[91] And such are the many later *qibla*-indicators

90. See FC, *Mathematical Instrumentation*, figs. 3.27 to 3.34 on pp. 154-162.
91. On Ibn al-Shāṭir, see n. 141 below.

fitted with sundials, as is the universal sundial of Mehmet II. It certainly does qualify as a mathematical device.

4.8 The authenticity of the «spiral» sundial

> Our initial studies disclosed that the astrolabes carrying the name of ʿAbd al-A'imma fall into two categories. Although both are distinguished by rich calligraphy and elaborate metalworking, the instruments in the larger group are accurately designed from an astronomical point of view, whereas those of the second group can at best be called degenerate. (Owen Gingerich & David King & George Saliba, «The ʿAbd al-A'imma Astrolabe Forgeries», p. 188)

> By neglecting actual historical objects, and championing their reimagined counterparts, we efface the past. (Nir Shafir, «Forging Islamic science», p. 13).

> When speaking about the authenticity of a painting it is not so much whether it's a real painting or a fake but whether it's a good fake or a bad fake. (Orson Welles, *F for Fake*, 1973, though in the BBC documentary «Orson Welles: Stories of a Life in Film», Welles stated that «everything in that film was a trick». See https://en.wikipedia.org/wiki/F_for_Fake#Questions_of_truthfulness).

This instrument is, without any shadow of a doubt, genuine and precisely what it purports to be. Even though its reappearance took both the authors by surprise, as it will other specialists, it fits fully with the context of Mamluk astronomy transplanted on Ottoman soil. The serious faking of Islamic instruments appears to have begun in Iran in the 18th century, and it now flourishes in India, Egypt and especially the Maghrib.[92]

Fakes are mainly clumsy and incompetent. But not all ... The first author has examined hundreds of genuine Islamic instruments, but also dozens of fake instruments at Christie's and Sotheby's in London, stored in drawers marked «Fakes». The purpose was to look at every component of each piece, because

92. See Price, «Fake Antique Scientific Instruments» from 1956. Also, Gingerich & King & Saliba, «The ʿAbd al-A'imma astrolabe forgeries», in *Islamic Astronomical Instruments*, VI; *Synchrony*, B, pp. 106-110. On some fake spherical astrolabes, see the text to n. 97 below.

genuine maters can house fake plates and genuine plates can end up in fake maters, and a genuine rete might be found in a fake mater with fake plates. Fake instruments are those intended to deceive. For at least the past century, astrolabes and other kinds of instruments have been produced for the acquisition of gullible visitors to the Muslim world.[93] The reproductions of dozens of instruments for the original Frankfurt IGAIW museum collection «Science and Technology» and its offshoots in Istanbul, Riyadh, Sharja and elsewhere, specifically intended for educational purposes, led to the unhealthy situation where copies of some of the true facsimiles of actual instruments were being produced and hawked for sale as genuine instruments.[94]

Sometimes these copies or fakes then appear at the leading auction houses where they are dubbed «decorative astrolabes», and some are auctioned at an appropriate fraction of what the makers or their customers might have expected. Several fake copies of the al-Aḥmar made for Sultan Bayezid II (§7.9b) are in circulation and have been hawked to auction houses and museums.[95] They have their origin in genuine copies made from serious instruments for important exhibitions; nevertheless, they confuse even the specialists, and they clutter the market. Their inscriptions are particularly suspicious.

Errors can arise if inscriptions on copies are not properly legible. Thus in the description of a copy of the other astrolabe made for Bayezid II, actually the only Turkish astrolabe featured in the Frankfurt catalogue of instrument facsimiles,[96] we read:

> The instrument was made in the year 1091/1680 [*sic*] for a certain Sulṭān ibn Aʿẓam ibn Bāyezīd [*sic*], probably a descendant [!] of the Ottoman Sultan Bāyezīd II (d. 918/1512).

93. On schools of instrument-fakers (with an 'f') from India to Morocco see *Synchrony*, B, pp. 106-110, 489-494, 569-570.

94. Sezgin, ed., *Science and Technology in Islam*, vol. 2 on astronomical instruments. See the insightful reaction to the problems which can arise from the dissemination of genuine copies of historical instruments in Shafir, «How digitization has transformed manuscript research».

95. See for one example of such a copy the catalogue of an auction at Bonham's of London on 27.10.2015: www.bonhams.com/auction/22832/lot/100/. The piece sold for £1,250 incl. premium. See also www.christies.com/en/lot/lot-5360513 for one for £1,500.

96. Sezgin, ed., *Science and Technology in Islam*, vol. 2, p. 109.

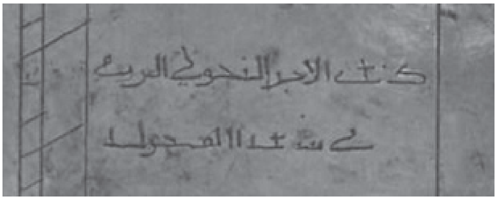


FIGURE 4.8a: The wretched dedication on a fake astrolabe copied from a copy of the one made for Bayezid II in 911H. On this piece, as on other fake copies, there are numerous orthographical mistakes. The piece was offered to several London dealers, one of whom kindly provided these images.

In fact, this is a facsimile of the astrolabe dedicated to Sultan Bayezid II himself, and the date is 910 Hijra (1504~05) but has been misrepresented on the Frankfurt copy – see §7.9a.

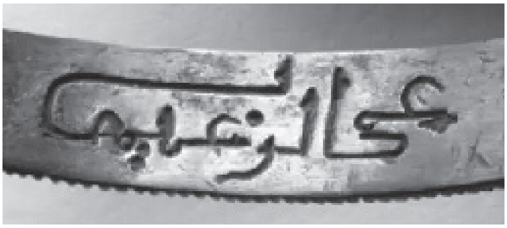


FIGURE 4.8b: The unevenly-spaced altitude circles on the fake spherical astrolabe signed by «al-Zaʿīm», a sure indication of an amateur instrument-maker or a modern faker. The «signature» is cute: the lām or final ‘l’ in the word ʿamal, «constructed by», is written backwards and suppresses the initial alif or ‘a’ in the name, in which the final mīm or ‘m’. Images courtesy of a dealer in London.

One of the most recent major faking actions produced a spherical astrolabe slightly different from the Oxford piece signed by Mūsà (in Istanbul), the fake being suspiciously signed «al-Zaʿīm», an Arabic term and an Ottoman title best rendered «The Boss». The piece was naïvely deemed genuine at first, and it took several weeks of research to establish that this was indeed a modern fake and not an early work of an inexperienced Mūsà, as well as to document this.[97] Its existence raises all sorts of questions about the fakers and the location of their *atelier*, their competence, their access to images of real instruments, their advisors and their motivations. In the meantime, some crude copies of copies, signed as if the maker was «Mūsà» by someone innocent of Arabic, are making the rounds of art dealers' in London.

Some ten years after the auction at which the horary dial of Nasṭūlus (§5.2) was sold,[98] another virtually identical instrument, this time a fake, appeared at an auction in Holland. Whereas on the original instrument there was a hole that had devoured the number لجـ, 33, for the degrees of the latitude of Baghdad, on the fake there was no hole and no latitude to complete the lengthy faked inscription. A total of four instruments by Nasṭūlus have been identified identified in the past 50 years, three of these in the past 20 years, and they are all genuine.

For the present piece, the astronomical milieu, the rarity of the genre, the awkward density of some of the markings, the clarity of the inscription, are all indications of its authenticity. How is it that we just now learn of an important 15th-century instrument made for an Ottoman sultan, indeed, a Turkish national treasure? The reader should keep in mind that only in the past 20 years have some 30 genuine Ottoman astrolabes been identified for what they are, even though most lack an indication of the place of construction and the name of a maker.[99]

Assessing historical instruments is a precarious field, and even experts can err. Several important genuine instruments have been unjustly treated. The oldest Islamic astrolabe, formerly preserved in the Archaeological Museum in Baghdad, was not recognized as such until the year 2000, and is still dubbed «Ottoman» in the literature because it bears the name of an owner in the Ottoman period. The most sophisticated (and most beautiful) astrolabe from 10th-century Baghdad, the masterpiece of the astronomer al-Khujandī, was first misdated by several centu-

97. DAK, «Spherical astrolabes», esp. pp. 119-141. For images of the real one and the fake one, see www.academia.edu/37947243 & 37957884, respectively. The workshop where this fake piece was produced appears to have been in Cairo, though some experts say Morocco. It seems clear that someone involved, probably a Westerner, is in control of the latest publications on instruments.

98. On the original instrument see n. 117.

99. On these, see n. 82. For the most historically-exciting find, at least from the point of view of the history of Islamic science, see DAK, «An Ottoman astrolabe full of surprises». Among a series of plates from an early Andalusī astrolabe, we find one for 16;30° south of the equator. See also n. 305.

ries and was for this reason not acquired by the Science History Museum in Oxford. Now, although it has been published in minute detail from both a scientific and an artistic point of view, all of its special features are ignored.

An important astrolabe in the Metropolitan Museum of Art in New York was pronounced a fake in the 1960s by a leading American historian of science. Although the piece was signed by the Yemeni sultan al-Ashraf in 1295, it was deemed suspicious because «there was no astronomy in the Yemen». In fact, there was continuous activity in astronomy there from the 9th century to the 20th, attested to by over 100 hundred surviving manuscripts. The Sultan al-Ashraf not only compiled an extensive treatise on the astrolabe, sundial and compass, and another on mathematical astrology, but his teachers left notes of approval on six astrolabes he made, one of which is the piece now back on proud display at the Met.

Not only Islamic instruments have suffered in this way or other. The earliest European astrolabe, now preserved in the Institut du Monde Arabe in Paris, was pronounced dubious or even a fake by French academics because they could not understand it within the context of the earliest Latin astrolabe texts. The oldest European astrolabe was omitted from the Paris IMA astrolabe catalogue because «Monsieur le Prof X ne l'aime pas». In fact, on the rete, the names of the signs of the zodiac are in Catalan Latin, and it has been established that the piece stems from 10th-century Catalonia, the place where eager Europeans first encountered the astrolabe. And indeed, it corresponds to no Latin text.[100]

Likewise, the most important Renaissance astrolabe, from a historical point of view, made by the German astronomer Regiomontanus in 1462 for his patron the Greek Cardinal Bessarion, and inspired by a Byzantine astrolabe dated 1062 (the 400-year difference is noted in the inscription), has been deemed a fake or at least highly suspicious by English experts. «So-and-so says the Latin is not right ...» «So-and-so says he's not happy by the leading astronomer in Europe engraving an angel on an astrolabe». The dedication, deemed by some as «kitchen Latin»,

100. Compare Samsó, *On Both Sides of the Straights of Gibraltar*, pp. 392-397, and DAK, *Astrolabes from medieval Europe*, II: «The earliest known European astrolabes in the light of other early astrolabes», pp. 359-404. On this important astrolabe, see further §7.5.

It should be mentioned that medieval astrolabes seldom correspond to what one finds in contemporaneous texts. In this case, the Carolingian astrolabe resembles in its details neither any earlier Eastern or Western Islamic astrolabes, nor any later but still early European astrolabes. Islamic astrolabes do not in general resemble the images in medieval Arabic and Persian texts. And so on, for Byzantine astrolabes...

turns out to be what is perhaps the most ingenious acrostic of the Renaissance. See further below §7.5. Once an object has been falsely designated as a fake, or even just «suspicious», the stigma never goes away.

5. On earlier and later universal dials of the «ḥalazūn» type

5.1 On Islamic universal horary dials

A sundial can be universal if it can be adjusted for latitude. Such are the 14th-century Islamic compendia with a plate which can be tilted in the plane of the celestial equator for any latitude by means of a latitude scale. A single complete example of the «jewel box» of the 14th-century Damascus astronomer Ibn al-Shāṭir survives as an example of such an instrument.[101]

The universal horary markings on astrolabe alidades

In various medieval Arabic and Latin sources, we find a device consisting of a series of markings representing the seasonal hours on the alidade of an astrolabe, one sight being used as a gnomon. A very limited number of early Islamic, medieval European, and later Islamic astrolabes bear alidades with these markings. Sometimes the purpose of these markings has been misunderstood by modern researchers.[102] The history of this device has not yet been written.[103]

101. Janin & King, «Ibn al-Shāṭir's *Ṣandūq al-Yawāqīt*: An astronomical compendium»; also *Synchrony*, B, pp. 95-98. On Ibn al-Shāṭir, see n. 141.

102. It was pointed out already in *Washington NMAH Catalogue*, p. 59, where, however, the authors mistakenly claim that the markings should be used in conjunction with an astrolabe plate. The supposed non-functionality of the markings on the alidade of the sole surviving astrolabe by the Yemeni Sultan al-Ashraf (see Fig. C1b) claimed in King, «Yemeni Astrolabe», p. 107, is nonsense. Since I did not understand the markings, it was thought that the alidade could not be used and therefore that it could not be original. Several parallels come to mind.

103. For a start, see also, for example, Stephen Johnston, «Rome revisited: the vertical disc dial»; *Synchrony*, B, pp. 253-255. and Josefina Rodríguez-Arribas, «A Treatise on the Construction of *Astrolabes* by al-Corsuno», esp. pp. 63-65 & 76-78.

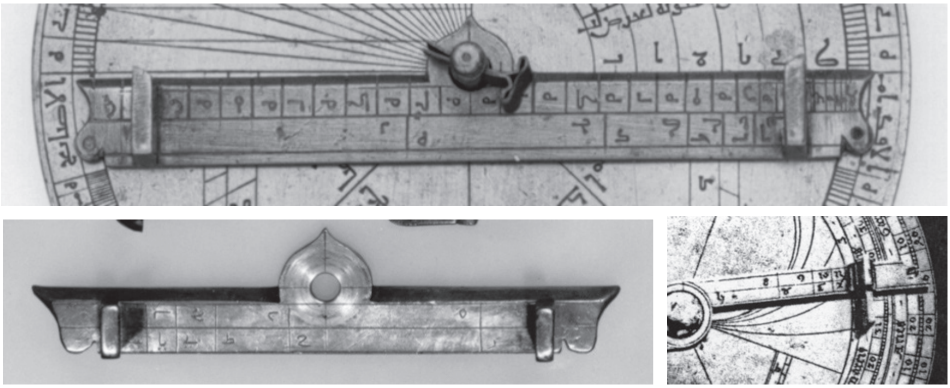


FIGURE 5.1: Three alidades with universal sundials, from Isfahan *ca.* 1100, the Yemen *ca.* 1290, and the workshop of Jean Fusoris in Paris *ca.* 1400. For more information, see *Synchrony*, B, pp. 253.

To use the device, one should suspend the astrolabe in the plane of the meridian and point the alidade towards the meridian position of the sun. Then, regardless of the local latitude, at each seasonal hour the shadow of the upper sight will fall on the appropriate mark on the alidade, except at midday when it falls on the other sight and at sunrise or sunset when there is no shadow. It is supposed that the «altitude» of the sun in the plane of the day-circle decreases from 90° by 15° each hour. Given its crudity the device is surprisingly accurate.[104] Clearly the underlying principle is not directly related to the standard approximate formula, although Abū ʿAlī al-Marrākushī does mention it as a special case. The great al-Bīrūnī (*fl.* Central Asia *ca.* 1025) reports that Ḥabash al-Ḥāsib, in some work of his now lost, had discussed such alidade markings, and that he had presented a table to facilitate engraving them, which simply displays values of $\mathrm{Tan}_{12}(15\,i^\circ)$ for $i = 1, 2, ..., 6$).[105] al-Bīrūnī called the device ساق الجرادة, *sāq al-jarāda*, «the locust's leg».[106]

104. Drecker, *Theorie der Sonnenuhren*, pp. 64-66.

105. On al-Bīrūnī, see the *DSB* article by E. S. Kennedy. For this passage see idem, *al-Bīrūnī on Shadows*, I, pp. 238-241, and II, pp. 149-151. Ḥabash also put a tangent scale for terrestrial latitude on his universal horary dial for the stars. The universal horary dial for the sun on the *navicula* also has a tangent scale for the latitude.

106. This name was also used in technical Arabic for latitude-specific and universal vertical sundials: see FC, *Mathematical Instrumentation*, II-3.2.1 and 3.5.3, pp. 40, 115, 139-141, 145-150,

The use of such markings is recorded, for example, already in the Latin treatise on the astrolabe falsely associated with Messahalla.[107] This «universal alidade sundial» is known from a very few medieval European astrolabes, including one from the atelier of Jean Fusoris in Paris *ca.* 1400. Since the alidade is usually the first component of an astrolabe to get broken and removed, sometimes to be replaced by an inferior substitute, and since it is often the last piece to get photographed, if at all, a survey of surviving alidades in quest of such markings would be fraught with difficulty.

The equatorial semicircles on the Safavid world-maps

And such are the dials – are they really inspired by European gnomonics? – which feature on the three brass world-maps apparently from late Safavid Iran, dating from *ca.* 1650, skilfully hiding all the information on the maps, and being next to useless for finding the times of the *ʿaṣr* prayer.[108]

If we derive the coordinates of the markings on the horizontal *ḥalazūn* and the horizontal *ḥāfir* using the exact formula, the instrument will serve a fixed latitude. If we use the standard approximate formula, we will produce a *ḥalazūn* and a *ḥāfir* which serve all reasonable latitudes.[109] The same reasoning holds for conical and cylindrical sundials. As we shall see in the next section, with the markings for Baghdad on the hour-plate by Nasṭūlus *ca.* 900, it is not possible to determine whether the horary curves were laid out according to the exact formula or the approximate formula.

The *ḥāfir* is based on the same principle as the *ḥalazūn*, namely, they are both horizontal dials where the shadow is represented in polar coordinates. The difference between al-Ṣūfī's «lemon dial» (*uṭrujja*) and the *ḥāfir* is that the former has a uniform solar longitude scale, while the latter, due to the underlying method

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163, 174-176, 292-293, 302-303, 324-326, 333.

107. For the text of Maslama al-Majrīṭī (shown by Paul Kunitzsch to be falsely attributed to Māshāʾallāh), see Gunther, *Early Science in Oxford*, v, pp. 220 and 174 (also mentioned in Morley, *Astrolabe of Shāh Ḥusayn*, p. 21, and quoted in *Washington NMAH Catalogue*, p. 59). See also Gunther, *op. cit.*, v, p. 146.

108. DAK, *World-Maps*, pp. 207-212.

109. For universal sundials in Islamic astronomy, see FC, *Mathematical Instrumentation*, pp. 145-166, and *Synchrony*, B, pp. 149-161.

of construction, has a non-uniform outer scale and its gnomon is not placed at the centre.

The first author believes that this type of universal sundial was probably first conceived, along with other numerous calculating and observational devices, in the formative period of Islamic science, that is, Baghdad in the 9th-10th centuries, Isfahan or Cairo in the 11th century, and elsewhere. There is the one remarkable example made by Nasṭūlus, the leading instrument-maker of Baghdad *ca.* 900 (see §5.2), but also part of a treatise by him survives attesting to a Greek origin for the device. And we have a diagram of another such dial in the astrolabe treatise of the well-known astronomer al-Ṣūfī of Shiraz *ca.* 950 (see §5.3) in his monumental work on the use of the astrolabe.[110] Later it is described and illustrated in the major medieval Egyptian work on instrumentation, namely, the treatise by al-Marrākushī in Cairo, *ca.* 1280.

The two instruments were not invented by, nor first described by al-Marrākushī, who barely gave a single source for any of his instruments. The first author has long maintained that the ideas behind most of the numerous instruments described by al-Marrākushī are of 9th- or 10th-century Baghdadi provenance, often without an identifiable intermediary. It has been shown, for example, that the universal horary quadrant in six variations stems from 9th-century Baghdad, one of which was transmitted on the backs of astrolabes.[111] Likewise, the idea behind the universal horary device (underlying the medieval European *navicula de Venetiis*) for timekeeping by the sun is the same as that in a parallel device for timekeeping by the stars invented by Ḥabash in Baghdad *ca.* 875 (neither featured by al-Marrākushī).[112]

This also proved to be true for the *ḥāfir*, for in 2006 a related instrument with horary curves of a similar form, made by Nasṭūlus in Baghdad for the latitude of *ca.* 900, came up for auction at Sotheby's of London.[113] An interesting realization was that the hour curves for the approximate formula were indistinguishable from those for the exact formula on an instrument of this size, diameter about 20 cm.

110. FC, *Mathematical Instrumentation*, pp. 153-154; and DAK, «Instrument by Nasṭūlus», pp. 114-115. (On the treatise of al-Ṣūfī, see now Vafea, «The Contribution of al-Ṣūfī to the Study of the Astrolabe» – see n. 119).

111. DAK, «A *vetustissimus* treatise on the *quadrans vetus*», and *Synchrony*, B, pp. 199-258.

112. Charette & Schmidl, «A Universal Plate for Timekeeping with the Stars by Ḥabash al-Ḥāsib», also *Synchrony*, B, pp. 308-311.

113. See n. 117.

Perhaps we were dealing with an adaptation of the simple approximate formula for a specific latitude, for which we have several other examples.[114] In any case, we can claim with some certainty that the universal approximate formula was well known in Baghdad between 800 and 900, and that several significant instruments including the *ḥāfir* and the *ḥalazūn* were first conceived in that milieu. This does not preclude a Greek origin for the formula and for the two instruments, but, as far as we know, the concept of universality in ancient astronomy has not been documented. The whole idea of universality in Islamic astronomy is not mentioned in a recent volume on universality in Islamic science, which even contains a chapter dealing with astronomy.[115]

In 1972 the American historian John Livingston, in an important study of a text on the مكحلة, *mukḥula*, or conical sundial by a 13th-century Sicilian (?) astronomer Ibn Yaḥyà al-Ṣiqillī, observed:[116]

> al-Marrākushī also believed that conical sundials could be designed for use at different latitudes, but recognized that there would be an error, which he wrongly [*sic*] considered negligible for places within the habitable part of the world.

It is not known where Ibn Yaḥyà worked, although Livingston derived a construction for the latitude of Alexandria, where Ptolemy developed the analemma.

5.2 The horary plate made by Nasṭūlus in Baghdad ca. 900

In 2006 a remarkable instrument came to auction at Sotheby's of London; it is now in the Museum of Islamic Art, Doha, Qatar. It merited immediate publication.[117] The

114. *Synchrony*, A, pp. 66-68.

115. Morony, ed., *Universality in Islamic Thought: Rationalism, Science and Religious Belief*.

116. Livingston, «The Mukḥula, an Islamic Conical Sundial». Another astronomer named al-Ṣiqillī, and thus also with an association with Sicily, is … (?) ibn Hārūn, author of some unusual tables for timekeeping by the stars. He worked in Cairo and, coincidentally, Alexandria – see Schmidl, «On timekeeping by the lunar mansions».

117. DAK, «An instrument by Nasṭūlus». On the auction catalogue entry see www.sothebys.com/en/auctions/ecatalogue/2006/arts-of-the-islamic-world-l06222/lot.87.html.

On the discovery of Nasṭūlus' instrument, see now Anthony Turner, «The Art Market and Discovery in Mathematical Instruments», p. 14.

maker was Nasṭūlus, who worked in Baghdad *ca.* 900. Three astrolabes signed by Nasṭūlus are known and they can all be classified as straightforward or classic. Not so this instrument! The unusual markings for the seasonal hours serve the latitude of Baghdad (33°), called «The City of Peace». There is a longitude and calendrical scale around the outer rim, and a radial ruler for the solar altitude. The curves show the altitude of the sun for each hour represented in polar coordinates. The instrument is therefore not a sundial, let alone a universal one. The signature indicates that the maker was Nasṭūlus, the leading instrument-maker in Baghdad *ca.* 900, who in addition was an author of consequence.[118] It proved impossible to determine whether horary markings were laid out according to the exact formula (as one would expect from Nasṭūlus) or the standard approximate formula adapted for a specific latitude (as is found in some early Islamic tables). In any case, one can only marvel at the execution of the markings and the smoothness of the curves. The existence of this instrument shows that the horizontal *ḥāfir* and presumably the horizontal *ḥalazūn*, for a fixed latitude and probably also for all latitudes, were known in the 9th century. A prime candidate for developing these simple but nevertheless effective instruments is surely Nasṭūlus himself. Obviously, sundials that were fixed and which served a single latitude would be more popular in future centuries.

FIGURE 5.2: The horary dial for the latitude of Baghdad by Nasṭūlus. Image courtesy of Christie's of London.

118. See already the article «Nasṭūlus» in *BEA* by Mònica Rius. and on his astrolabes and the problems of his name (he always left out the dot above or under the first letter), see *Synchrony*, B, pp. 470-484. The impossible rendering Basṭūlus is to be supressed!

FIGURE 5.3: The lemon dial of al-Ṣūfī's astrolabe treatise, a remarkable piece of evidence compiled in Shiraz *ca.* 950 which confirms that such dials were known three centuries before the time of al-Marrākushī. From al-Ṣūfī, *Kitāb al-Asṭurlāb*, (facsimile edition of MS Istanbul Topkapı Ahmet III 3509, copied in 1277), p. 469 (foliation removed for facsimile edition).

5.3 The «lemon» dial by al-Ṣūfī in Shiraz ca. 1000

This is a very unusual astrolabe plate, to be used with an appropriate pin gnomon at the centre, which is featured in chapter 361 (out of 400) of treatise on the use of the astrolabe (*Kitāb al-ʿAmal bi-'l-asṭurlāb*) by the well-known astronomer al-Ṣūfī.[119] It is called «the plate (*ṣafīḥa)* whose hour-lines are set up in the form of a lemon (*uṭrujja*)». It is in fact the natural ancestor of the *ḥāfir* of al-Marrākushī, and surely stems from the same Abbasid tradition as the instrument by Nasṭūlus. The only difference between the instruments of Nasṭūlus and Ṣūfī is that the former is displaying the altitude and the latter the horizontal shadow; they both feature polar coordinates for each seasonal hour, where the radial coordinate is h and Cot(h), respectively. While Nasṭūlus' plate features a uniform scale of the solar longitude (as the angular coordinate), that of al-Ṣūfī's, due to the underlying method of construction, has a non-uniform longitude scale and its gnomon is not lo-

119. On al-Ṣūfī see the article by Paul Kunitzsch in *BEA*. On this plate, see already DAK, «An instrument by Nasṭūlus», p. 20; *Spherical Astrolabes*, p. 140; and FC, *Mathematical Instrumentation*, pp. 153–154. A brief introduction to al-Ṣūfī's astrolabe treatise, without mention of this plate, is provided in Vafea, «The Contribution of al-Ṣūfī to the Study of the Astrolabe» – see n. 110.

cated at the centre. Presumably al-Ṣūfī's plate is for the latitude to have of Shiraz. Instructions on how to use the plate are provided by al-Ṣūfī but appear to have never been studied in the occasional modern references to his work.

5.4 Previous studies on the ḥāfir and ḥalazūn

After the monumental French translation of al-Marrākushī on spherical astronomy and sundial theory by Sédillot-*père* in the early 19th century, which made available descriptions of the two instruments, we have a series of studies by 20th-century European historians of Islamic astronomy and sundial enthusiasts. Some confusion has surrounded al-Marrākushī and his provenance, because his name has often led historians to associate him only with Marrakesh, whereas, in fact, at one point he moved from there and spent the rest of his life in Cairo. All his tables are for latitude 30°, serving Cairo. We have such little information on him partly due to the fact that he is unknown to the medieval Maghribī and Cairene biographical sources.[120] Modern writings on the *ḥalazūn* have partly been vitiated by the fact that the underlying formula was unknown to researchers. Some of these writings have sought to explore the underlying mathematics only to find that it worked only for latitude zero and/or declination zero. These writings deal mainly with *ḥāfir*, with the *ḥalazūn* as an afterthought. In his excellent survey of Islamic gnomonics published in 1923, the German historian of Islamic astronomy and mathematics, Carl Schoy, devoted two pages to the two instruments with a diagram of the *ḥāfir* for latitude 30°, serving Cairo.[121] Two important studies on the two kinds of universal sundials, both intensely mathematical, are by A. Wedemeyer (1916)[122] and by a triumvirate of very serious sundial enthusiasts, Fer De Vries & Mac Oglesby & William Maddux (1999).[123]

The Italian sundial specialist Gianni Ferrari (1997 & 2001) likewise devoted several pages of his books on Islamic sundials to the *ḥāfir* and *ḥalazūn*, and even a

120. Charette, *Mathematical Instrumentation*, pp. 9-10; Bir *et al.*, «The Zarqaliyya in the work of al-Marrakushi».

121. Carl / Karl Schoy, *Gnomonik der Araber*, pp. 37-38 (II, pp. 409-410 of the reprint).

122. Wedemeyer, «Der Mittagshafir und -halazun von Abul Hassan. Die älteste Meßkarte zur Bestimmung von Sonnenhöhen», with critical comments by Schoy.

123. Fer De Vries & Mac Oglesby & William Maddux, «Hāfir and Halazūn». De Fries has an earlier paper in Dutch from 1994 – see the Bibliography.

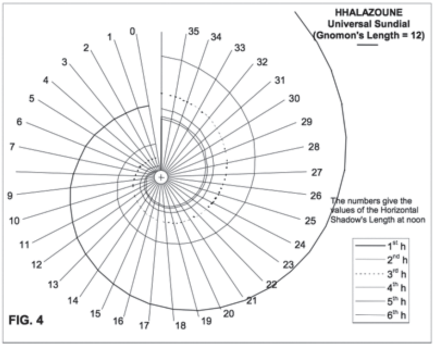

Fig. 5.4: A reconstruction of the universal *ḥalazūn*,
by Gianni Ferrari. (From his *Le meridiane dell'antico Islam*, p. 284).

separate article on the two instruments in which he explained their function in simple terms. He too investigated the error in using the *ḥalazūn* and wrote for sundial enthusiasts:[124] «All of these studies (lead to the result that) the hour that we find with a universal sundial using the described method is not always correct because the shadow's length (at midday) depends from the place's latitude ϕ and on the season of the year (that is, on the Sun's declination δ). From many calculations, summarized in the graphs, I have found that for latitudes inferior to 40°-45° (that is practically for all the places of the Islamic civilization, that is, for all the «habitable places») and for temporal hours, the method gives results with errors of only a few minutes».

We see that although these authors may have seen Sédillot's translation of al-Marrākushī, they could add little to the historical aspects of these instruments. They all made somewhat misguided attempts to determine the underlying formula, which is nothing other than the standard Islamic approximation for timekeeping, not documented until about the year 2000 – see §4.2. But certainly praiseworthy is the curiosity of these sundial specialists concerning the *ḥāfir* and *ḥalazūn* and their attention to these two remarkable instruments.

In 2003, the second author published the Arabic text with translation and commentary of the illustrated treatise of Najm al-Dīn al-Miṣrī dealing with 100 instrument types invented by himself or known to him. Amongst the detailed

124. Ferrari, *Le meridiane dell'antico Islam*, pp. 273-291, and *Appunti per uno studio delle meridiane islamiche*, pp. 119-120; also, for English-speaking gnomonics specialists, the same author's article «The universal sundials of ancient Islam».

descriptions of dozens of instruments are those for both the *ḥāfir* and the *ḥalazūn*. Simultaneously in Frankfurt in 2005, the first author published brief descriptions of nine universal sundials recorded in the two Mamluk texts, by Najm al-Dīn al-Miṣrī and al-Marrākushī, all based on the standard approximate formula, which is the subject of a lengthy historical analysis in the same work.[125] Unfortunately, he omitted the *ḥalazūn*, perhaps because he could not understand it! In any case, not long thereafter, there was published the newly-rediscovered *ḥāfir* made in Baghdad *ca*. 900 by the leading instrument-maker of the time, Nasṭūlus (§5.2).

5.5 The ḥalazūn in Iran and Europe

We are dealing here with a mathematical instrument which serves an astronomical function. It is a testimonial, first, to the appreciation of an astronomer at the Ottoman court for the finer points of Islamic spherical astronomy and instrumentation. Second, it is a tribute to the astronomical knowledge of Sultan Mehmet II that the maker thought the ruler might understand the principles underlying this instrument, at once simple and complex. In addition, while we probably could not have come to terms with the instrument were it not for the treatise of al-Marrākushī, Aḥmar, the maker, must also have been familiar with this work. This, at least, is our present understanding of the situation.

Later examples of this instrument-type from Iran

There is as yet no evidence that this type of instrument was known to later Ottoman astronomers, who in the practice of their profession concentrated mainly on tables, ephemerides and horoscopes, but also on astrolabes, quadrants and sundials, and mathematical instruments.[126] Thus, for example, it is not featured

125. *Synchrony*, B, pp. 153-161.

126. But there is more to relate: MSS Cairo Egyptian National Library Muṣṭafā Fāḍil *riyāḍa* 40 and 41, copied *ca*. 1747 by the important scholar Muṣṭafā Ṣidqī, are two volumes, of which the first contains illustrations of unusual instruments from Ottoman Cairo, both of Islamic and European origin (fols. 40-63). See *Cairo Survey*, p. 112 (no. D81), and pl. LXVII & LXLX. They have been studied (FC), but not published. MS Princeton University Library 373 contains another important

in the extensive treatise on astronomy and instrumentation by Ghāzī Aḥmad Mukhtār (1839-1919) entitled *Riyāḍ al-Mukhtār* and published simultaneously in Turkish and Arabic in 1885.[127] We do have one example of *ḥalazūn*-type markings from Ṣafavid Persia at the hand of the astronomer and instrument-maker, Qāsim ʿAlī al-Qāyinī (*fl.* Isfahan and Meshed, *ca.* 1685).[128] The markings are not found on the surviving astrolabes of his construction but they are illustrated in his Persian treatise on the times of prayer and *qibla* and length of daylight, مطلع در معرفه اوقات صلاة و سمت قبله و ساعات و دقایق زماني وغير ذلك, «A note on finding the times of prayer and the azimuth of the *qibla* and the hours and minutes of time and more besides», extant in MS Tehran Majlis 6266,5 (p. 61).[129] In this case, as in many others, it is the Arabic phrase وغير ذلك at the end of the title, meaning «*et cetera*» or «and so on», which can often lead modern researchers to important new material.[130] These markings merit further investigation.

set of instrument illustrations. There are no instruments with spiral horary markings included in the illustrations. but see Danışan, «Cylinder Dials in the History of Ottoman Astronomy», p. 3, for the markings of a (universal) cylindrical sundial in this historically very important manuscript comprising 20 treatises. On the many significant scientific manuscripts copied by Muṣṭafā Ṣidqī, see n. 176.

127. On this work see the bibliography under Mukhtar with a reference to a complete digital copy on the internet. On the author see the article «Aḥmad Mukhtār» by Salim Aydüz in *BEA*, and İhsanoğlu *et al.*, *Osmanlı Astronomi Literatürü Tarihi*, II, pp. 701–706.

128. On this device see FC, *Mathematical Instrumentation*, p. 160 and notes 100-101. These markings are alas not published. On Qāyinī and his best-known astrolabe, on which these markings are not to be found, see Gunther, *Astrolabes*, I, pp. 215-216 (no. 85); and Gibbs & Saliba, *Astrolabes from the NMAH*, pp. 124-12; also, Maddison & Brieux, *Répertoire*, I, pp. 162-164, (where four astrolabes are mentioned), and DAK, *World-Maps*, pp. 264, 266-268, 299. For another horary device of his, see ibid., p. 299. On the various writings of Qāyinī, see Marjan Akbari, «A little known astronomer in the late Islamic period. A study of Qāsim ʿAlī al-Qāyinī's manuscripts», 2011, where this treatise is not mentioned.

129. Not listed in Storey, *Persian Literature*, II:i, pp. 89-90 (no. 135).

130. The rediscovery of the first Ottoman list of cites with their *qibla*-values occurred by chance whilst looking through a Paris manuscript which had been catalogued section by section over a century ago. The list was spotted between the sections. It is doubly important from a historical point of view because there are those who claim that Ottoman mosques do not face the modern (!) direction of Mecca and that they were deliberately aligned to face other goals. Such nonsense is best countered by a knowledge of which directions the Ottomans actually took for the *qibla* in different places.

Later examples of this instrument-type from Renaissance Europe

This kind of sundial, albeit sometimes vertical and sometimes for a specific latitude, apparently became known in Europe: firstly from Nuremberg, the leading centre of instrumentation in Europe in the 16th century,[131] but mainly at the hands of the masterly Erasmus Habermel (d. 1606) at the imperial court of Prague.[132] Altogether, examples have been preserved in collections in Nuremberg, Frankfurt, Prague, Utrecht, Traunstein and Munich. These instruments, with scales different from the Islamic ones, could perfectly well be an independent European development, although the first author has shown that most Renaissance instruments, once thought by historians to be new European inventions, indeed had Islamic precedents of one sort or another.[133] But these different European instruments are the same as the variants of al-Marrākushī's *ḥāfir* and *ḥalazūn*, that is, vertical and horizontal sundials for a specific latitude, where the shadow is displayed as a function of the solar longitude, so it is quite different in shape from the universal version, despite the name. They were probably developed independently, for there is little evidence of transmission to Europe of most of the non-standard instruments from Abbasid Baghdad or Mamluk Cairo or Ottoman Istanbul. What evidence there is has only been uncovered during the past few decades, and continued research in the vast manuscript libraries and instrument collections of the world will surely further clarify the situation.[134]

131. *Nürnberg GNM Catalogue*, II, pp. 613-614 (no. I.97).

132. These examples are listed in FC, *Mathematical Instrumentation*, pp. 159-160, esp. notes 94-95. An illustration of a fine example of a *ḥāfir* by Erasmus Habermel of Prague dated 1586 and preserved in the Kunsthistorisches Museum in Vienna is at https://www.khm.atat/de/object/86925/. Another spectacular piece by him, also dated 1586, is an octogonal «mater» with four sets of markings including a *ḥāfir* and a *ḥalazūn*. This is preserved in the Museum of the History of Science in Oxford with inventory no. 35550: see https://www.mhsmhs.ox.ac.uk/epact/catalogue.php?ENumber=32778, where all four sets of markings have been spotted. Gianni Ferrari (*Le Meridiane dell'Antico Islam*, pp. 283-284) referred, with illustrations, to the examples in Oxford and Nuremberg.

133. See DAK, «Islamic astronomical instruments and some newly-discovered examples of transmission to Europe», and the illustrated lecture «Some astronomical instruments of the European Renaissance and some earlier Islamic examples of the same instruments», video of a lecture at the Al-Furqan Foundation, London, 2018, at www.youtube.com/watch?v==KmsixNDb7oo, starting at 51m30s. At least the forms of the *ḥāfir* and *ḥalazūn* could be added to the examples presented.

134. See the contributions to Calvo & Comes & Puig & Rius, eds., *A Shared Legacy – Islamic Science East and West*, dedicated to the memory of the Catalan scholar, J. Millàs Vallicrosa (1897-1970), who contributed so much to our knowledge of transmission to Europe from al-Andalus.

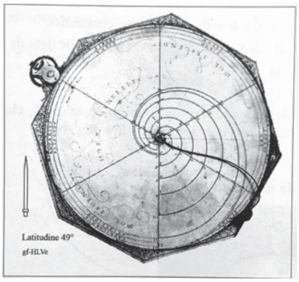

Figure 5.5: The spiral horary markings on the vertical dial by Habermel of Prague, dated 1586. Source: www.mhs.ox.ac.uk/epact/picturel.php?ENumber=32778, courtesy of the Science History Museum, Oxford.

Transmission of the various forms of these instruments or of these kinds of spiral markings from the Islamic world to Europe merits further investigation.[135]

Part B. The Context

6. The astronomical context

> We are not contained within a rigid infrastructure: we are immersed in a gigantic flexible snail-shell. (The physicist Carlo Rovelli on Albert Einstein's «Theory of Relativity»).

6.1 Islamic mathematical astronomy

> The most impressive aspect of the source material for the study of medieval oriental astronomy is its overwhelming quantity. Thousands of Byzantine Greek, Sanskrit, Hebrew, Arabic, Persian, and Turkish astronomical and astrological manuscripts exist, many in uncatalogued collections, and most of them untouched by modern scholarship. (E. S. Kennedy, «A Survey of Islamic Astronomical Tables» (1956), p. 123).

The situation today is not much changed, although the secondary literature on Islamic science has become substantial. Today we know of over 225 such works. It

135. FC, *Instrumentation*, p. 160, esp. nn. 96-99.

has been estimated that some 10,000 Islamic scientific manuscripts survive in libraries around the world. And not to forget the 1,000-odd Islamic astronomical instruments surviving in museums around the world. These sources reveal that the Muslims operated on two different and distinct levels in their astronomical pursuits, one «scientific» for specialists and the other «folksy» for «the person in the street». Informed enthusiasts and even historians of science are not generally aware of this dichotomy in Islamic astronomy, their curiosity inevitably limited to «what was transmitted to the West?» rather than «what did the Muslims do for themselves?» The manuscripts and instruments represent only a small fraction of those that were once in circulation, but with these we must try to assess what the Muslims were doing in astronomy centuries ago.[136]

We refer now to the planetary and spherical astronomy which were conducted with a mathematical basis. We know of over 200 astronomical handbooks with tables and instructions from all over the Muslim world between 800 and 1800. It was Ted Kennedy who first recognized the scope of these handbooks or *zīj*es, which constitute a treasure trove for astronomical theories and mathematical methods, not yet fully exploited by historians far. Already in 1956, he assembled a list of some 125 *zīj*es, and our colleague Benno van Dalen in his new survey counts over 225.[137] These are to some extent independent of a vast corpus of tables for timekeeping by the sun and stars and regulating the times of prayer, tables for determining lunar crescent visibility, and tables for finding the *qibla* as a function of longitude and latitude, which represented the practical side of Islamic astronomy in the service of religion.[138] The wealth of the Islamic sources for documenting the history of a particular concept or group of concepts is well displayed by the surveys by Josep Casulleras & Jan Hogendijk on mathematical astrology; by Sajjad Nikfahm-Khubravan on planetary latitudes; let alone, the first author's efforts

136. Overviews are particularly difficult to write. Compare the following: Nallino, «[Islamic astronomy]» (1921); DAK, «Islamic astronomy» (1996); and Morrison, «Islamic astronomy and astrology» (2010) and «Astronomy in Islam» (2013).

137. On the *zīj*es see Kennedy, «Islamic astronomical tables», and van Dalen, *Islamic Astronomical Tables*. See provisionally King & Samsó & Goldstein. «Astronomical Handbooks and Tables from the Islamic World», which was prepared simultaneously with the article «Zīdj» that appeared in the final pages of the second edition of the *Encyclopedia of Islam*.

138. On these other tables, see *Synchrony with the Heavens*, A., King & Samsó & Goldstein, «Astronomical Handbooks and Tables from the Islamic World».

to document historical tables for timekeeping and regulating the times of prayer from all over the Muslim world.[139]

To give just one example of the utility of these sources for the history of many aspects of Islamic science: Ted Kennedy and his wife, Mary Helen, compiled a data base for the geographical data in Islamic *zīj*es. This was published in 1987 by the IGAIW in Frankfurt. The book *Geographical Coordinates of Localities from Islamic Sources* lists the longitudes and latitudes given for some 2,500 localities in some 80 Islamic geographical and astronomical sources, with the data now rearranged according to source, place-name, increasing longitude and increasing latitude, altogether 14,000 entries, a monumental achievement.[140] This splendid reference work has proved of the greatest utility in any investigation of Islamic geography and astronomy. (The reader is reminded that ancient and medieval geographical coordinates were substantially different from modern ones).

In recent decades, indeed since the 1950s when Ted Kennedy and Otto Neugebauer discovered that the solar, lunar and planetary geometrical models of the 14th-century Damascus astronomer Ibn al-Shāṭir[141] were strikingly similar to those of the early 16th-century Polish astronomer Copernicus, some of our colleagues have concentrated on the possible transmission of solar, lunar and planetary models from Ibn al-Shāṭir in Damascus *ca.* 1350 to Copernicus in Poland *ca.* 1514.[142] Whilst this

139. Cassuleras & Hogendijk, «Progressions, Rays and Houses in Medieval Islamic Astrology: A Mathematical Classification»; Nikfahm-Khubravan, *The Reception of Ptolemy's Latitude Theories in Islamic Astronomy*, (doctoral thesis, McGill University, 2022); and *Synchrony*, A, based on over 500 manuscripts. The last-mentioned book is based on about 500 manuscripts, mainly previously unstudied. For DAK in the 1970s, it was a convenience that most of the mosque libraries in Turkey, but not all, had been gathered in the Süleymaniye Library in Istanbul. With the cooperation of the library staff, he was then able to inspect, for example, all the manuscripts labelled in the hand-lists in Osmanli as «*cedveller, mechul-e müellif*», that is, «tables, anonymous». Since most of the tables were previously undocumented, the reader can perhaps appreciate why he was keen to return to Istanbul from Cairo on a regular basis.

140. See Kennedy & Kennedy in the Bibliography and nn. 192, 220, 325 below.

141. On Ibn al-Shātir, see the groundbreaking studies in Kennedy *et al.*, *Studies in the Exact Islamic Sciences*, pp. 50-107, repr. in Kennedy & Ghanem, eds., *The Life and Work of Ibn al-Shāṭir*, and the articles in *DSB* and *BEA*. The treatise by Ibn al-Shāṭir on theoretical astronomy (*Nihāyat al-su'l*) has finally been edited with translation and commentary: see Erwan Penchèvre, ed., transl., *Ibn al-Šāṭir, L'achèvement de l'enquête et la correction des fondements, Nihāyat al-sūl fī taṣḥīḥ al-uṣūl*. *Édition critique et commentaire*, (Islamic Mathematics and Astronomy, 116), 2022.

142. The first investigations of this material are in Kennedy *et al.*, *Studies in the Islamic Exact Sciences*. A useful recent overview is in Jamil Ragep, «From Tūn to Toruń: The Twists and Turns

investigation of previously unstudied texts was extremely worthwhile, eventually new sources established the mysterious Jewish scholar Mūsà Jālīnūs of Istanbul *ca.* 1500 (?) as perhaps the most likely intermediary – see §7.8.

In all of this flurry of activity related to the «Copernicus Chase», not enough attention has been paid by scholars to the history of science in Near Eastern societies after *ca.* 1250, independently of what knowledge fragments, artefacts or practices might have hypothetically been transmitted to Renaissance Europe. In particular, they have neglected all aspects of timekeeping by the sun and stars.

Fortunately for the development of our subject, the orientalists and historians of science Jean-Jacques Sédillot (1777-1832) and his son, Louis-Pierre-Eugène Sédillot (1808-1875), as well as the German historian of Islamic mathematics and geography, Carl Schoy (1877-1925), did not. It is thanks to these scholars that we could be informed about tables of polar coordinates for marking the curves on sundials, complicated methods for determining the *qibla* or sacred direction, solutions to a multiplicity of astronomical problems for all terrestrial latitudes, astronomically-defined times of Muslim prayer, and a variety of instruments of mathematical interest way beyond the standard astrolabe and quadrant. These were not only impressive from a mathematical point of view but also essential for understanding Muslim activity in practical astronomy and the motivation behind it.

6.2 Folk astronomy

> The science of star nomenclature, the appearances of the stars, their risings and settings, ... the finding of the direction of the *qibla* by means of the stars, and the knowledge of the times of prayer and the hours of the night by the appearances and the settings of the stars. (al-Khaṭīb al-Baghdādī, the 11th-century religious scholar and historian, outlining the acceptable aspects of astronomy in his treatise against astrology. Slightly modified from Anton Heinen, *Islamic Cosmology*, p. 25).

> Every challenge calls for the right men. ... When (some people) were asked to determine the direction of the *qibla* they were perplexed, because the solution of this problem was beyond their scientific powers. You see that they have been discussing completely irrelevant phenomena, like the directions from which the winds blow, and the rising points of the lunar mansions. ... Of the majority of people (who write about the

of the Ṭūsī-Couple».

> *qibla* in non-mathematical terms) none are closer to the truth than those who use (*iʿtabarahu bi-*) the Pole Star known as al-Judayy. By means of its fixed position the direction of a person travelling can be specified approximately. (Al-Bīrūnī (Ghazna, *ca.* 1025), in his geographical work *Taḥdīd nihāyāt al-amākin*).[143]

> [...] Their hearts are disgusted by the mention of shadows, or altitude, or sines, and they get goose-pimples at the mere sight of computation or scientific instruments. (al-Bīrūnī, *Shadows*, pp. 35-37, writing of some muezzins).[144]

In addition to all this activity in the Muslim world, there was also a tradition which we label folk astronomy, or «astronomy for the person in the street», based on what one could see in the sky and without calculation or serious instruments; this could be said to be essentially naked-eye observational and arithmetical in nature. It involves timekeeping by day using shadow-lengths and by night using the lunar mansions; and finding the *qibla* by means of the risings and settings of the sun or selected stars. The many such works dealing with folk astronomy have not been taken seriously by most of our colleagues except those of the Barcelona and Frankfurt schools, and not a few would repay investigation.[145]

There is far more to this subject of Islamic folk astronomy than the celebrated *anwāʾ*, the acronychal risings and settings of a series of stars or constellations. Much of the additional material is found in the categories of books labelled *kutub al-mawāqīt* and the *kutub dalāʾil al-qibla*, dealing with simple timekeeping by day and night, and with non-mathematical approaches to finding the *qibla*; it is in such works that we find answers to the questions why the daylight prayers came

143. See the translation by Jamil Ali, p. 12, to Arabic text, pp. 35-37, and Kennedy's commentary, *passim*.

144. See also Kennedy, *al-Bīrūnī's* Shadows, I, pp. 75-76 & 226-230, and II, pp. 28-29 & 142-143; *Synchrony*, A, 635-636; also Kennedy, *al-Bīrūnī's* Shadows, I, pp. 75-76 & 226-230, and II, pp. 28-29 & 142-143; *Synchrony*, A, 635-636.

145. The detailed study by Emilia Calvo, «Two Treatises on Mīqāt from the Maghrib», shows the breadth of topics covered by medieval astronomers in the «folk» tradition. See also Schmidl, «On timekeeping by the lunar mansions». In addition, it was in such treatises on folk astronomy that we discovered that the Kaʿba was astronomically aligned, and that this was known in the medieval period. In addition, there was a substantial sacred geography in Islam, a notion of the world divided around the Kaʿba, with the *qibla* for each sector aligned towards the sun at the equinoxes or solstices or towards the rising or setting of a particular star. We have located 20 different schemes. See for a start the article «Kaʿba. iv», in *Enc. Islam*, 2nd edn., and DAK, «Sacred Geography of Islam».

to be determined in terms of shadow increases over the midday minimum, and how the rectangular base of the Kaʿba is astronomically aligned. Both phenomena featured in Islamic astronomy for over a millennium, the first in Islamic religious practice, and the second in Islamic sacred geography.

6.3 Universal solutions and approximate solutions

> I have completed this table for latitudes 1° to 45° since in higher latitudes there is hardly anybody who studies this sort of thing nor even thinks about it. (Abū Naṣr, *ca.* 1000, writing on his universal auxiliary table of functions helpful for spherical astronomy,[146] quoted in Claus Jensen, «Abū Nasr Manṣūr's Approach to Spherical Astronomy», p. 5).

> Early in the development of Islamic astronomy there were tabulated sets of functions that had no direct astronomical significance, but were of such a nature that ordered applications of them would lead to the solution of spherical astronomical problems... (and they) would work for all latitudes... (DAK, «al-Khalīlī's Auxiliary Tables ...», p. 99).

> What I mean by universal solutions are instruments, mathematical procedures and tables which aim at provided solutions for all terrestrial latitudes to those problems of spherical astronomy in which latitude is involved. I am fully aware that I am imposing a modern categorization on the medieval source material, but it seems to me useful to consider these solutions together and thereby to add a new dimension to our understanding of the achievements of the Muslim scientists. (DAK, «Universal Solutions in Islamic Astronomy», p. 122).

In both the tables and instruments, we can distinguish between those serving a specific latitude and those that are universal. In the present context, and generally in classical and medieval mathematical astronomy, the term «universal» means «serving all latitudes», and «all latitudes» means all latitudes of Ptolemy's «inhabited world» from the equator to about 50°. Over 30 examples of universal

146. These tables were the first of this genre to come to light. They were analyzed in 1972 by the Danish historian of science, Claus Jensen: see his «Abū Naṣr Manṣūr's Approach to Spherical Astronomy ...». See also the next note.

solutions, tables or instruments, were achieved by Muslim scholars from al-Andalus to Central Asia during the period 9th-15th centuries, many of these being from the Mamluk realms, that is, 13th- to 15th-century Egypt and Syria.[147]

For timekeeping, we can have exact solutions to problems of spherical astronomy solved in tabular form for a specific latitude and a certain interval of solar longitude degrees. For constructing sundials this might involve a set of tables of polar coordinates constructing the hour and declination lines, with sub-tables for each few degrees of latitude. But there are also procedures and instruments that are universal since they are based on an approximate formula that works for all «reasonable» latitudes.[148] This formula is little known amongst historians of science even though it was as popular as the exact formula amongst Muslim astronomers all over the Muslim world. They called this kind of solution *āfāqī* in Arabic, a technical adjective based on *āfāq*, the plural of *ufq* or *ufuq*, «horizon», and signifying «serving all horizons and latitudes». Thus, for example, the markings on the universal horary quadrant which often features on the backs of astrolabes may be labelled *āfāqī*, meaning «it works for all latitudes», in contradistinction to the plates of the instrument, which serve specific latitudes. Likewise, but at the other end of the scale of sophistication, the 14th-century Damascus astronomer al-Khalīlī called his spectacular auxiliary tables for solving all of the standard problems of spherical astronomy for any latitude *al-jadwal al-āfāqī*, «The Universal Table».

Neither the maker of Mehmet II's instrument nor the user needed to know the approximate formula, nor did the maker or the user need to know that the instrument was universal. The instrument served the latitude of Istanbul, but it could also have served the latitudes from Sanaa to the Crimea. It is, like most other historical instruments, a mathematical one rather than a practical one. Its appeal to

147. On such universal solutions see *Synchrony*, A, pp. 679-710 (VIa: «Universal solutions in Islamic astronomy»), and 711-740 (VIb: «Universal solutions to problems of spherical astronomy from Mamluk Syria and Egypt»); also, FC, *Mathematical Instrumentation*, pp. 21-22.

148. On this formula, its origins, and its fate and fortunes over the centuries, see *Synchrony*, B, pp. 111-197 (XI: «An approximate formula for timekeeping from 750 to 1900»), and 199-258 (XIa: «On the universal horary quadrant for timekeeping by the sun»). The first two attempts to come to terms with the formula and the universal horary quadrant are both from 1981, namely, North, «Astrolabes and the hour-line ritual», and Lorch, «A note on the horary quadrant». They both investigate the hour-angle or the time remaining until midday (complicated) rather than the approximate time since sunrise from the solar altitude (relatively simple).

savants in the Court would have been not least on account of the snail-like form of the horary markings.

6.4 Outline of the historiography of early Ottoman astronomy

> The history of early Ottoman astronomy in general (14th to early 16th century) has not yet been properly researched. ... The sources for Ottoman astronomy in general have recently been properly documented for the first time, and the amount of important research for the future is daunting. (DAK, «Two astrolabes for Sultan Bayezid II» (2006/2005), p. 440/783).

> General textbooks and specialised treatises on instruments and timekeeping make up much of the intellectual output of Ottoman astronomers. But the crucial part of their work was the preparation of astronomical tables based on observations, to serve as the basis for further calculation. (Gottfried Hagen, «Ottoman intellectual life», p. 418).

> The Ottomans flourished at the beginning of the 14th century in western Asia Minor. Scientific studies encouraged and supported by rulers and statesmen had peaked at the reign of Mehmed II (the Conqueror), who highly valued science and philosophy and championed scholars of the Islamic world. (Salim Aydüz, «Sultan Mehmed II, his contemporary Scholars and their respective roles in the advancement of Ottoman Science...», p. 1).

Just as there was a flourishing tradition of astronomy in the Ottoman world, so there is now a developed subject called «The History of Ottoman Science», albeit somewhat lacking in sources relating to Sultan Mehmet II. We are interested in Ottoman astronomy *per se*, and as part of Islamic astronomy *per se*. We are less concerned with what was borrowed from, and transmitted to, other cultures. We are interested in what the Ottoman astronomers did for themselves.

Many moons have passed since the Turkish scholar Adnan Adıvar (1882-1955) published *La science chez les Turcs Ottomans* (Paris, 1939).[149] Whilst this was a popular non-technical work, Adnan Beg also, for example, wrote an article «Ali Kuşci» for the nascent *İslām Ansiklopedisi*, begun as a Turkish version of the Euro-

149. Adıvar, *La science chez les Turcs Ottomans*.

pean *Encyclopaedia of Islam*. Thereby, perhaps, the history of Ottoman astronomy was born.

The Turkish historian of science, Aydın Sayılı (1913-1993), wrote the first histories of the observatory and the hospital in Islamic civilisation. Only the former was published, in 1960, and it, being based upon primary sources, is of such excellence that it has not been superseded. He wrote the first account in English of the late-16th-century observatory in Istanbul.[150]

The Turkish historian of Ottoman science, Sevim Tekeli (1924-2019), formerly a doctoral student of Aydın Sayılı, first investigated the works of Taqī al-Dīn, the director of the Istanbul Observatory *ca.* 1575, and his treatises on some unusual instruments.[151]

Thereafter, the subject of Ottoman instrumentation took backstage, but then in 1997-2000 it took a major step forward with the publication by Ekmeleddin İhsanoğlu and his colleagues at I.R.C.I.C.A. of monumental volumes listing hundreds of Ottoman scholars in the sciences and their works as well as the available manuscripts thereof. These volumes cover all conceivable topics, of which the ones dealing with astronomy, mathematics and geography are relevant to our subject here.[152]

In 1977 the first author published surveys of published details of the tables for astronomical timekeeping and regulating the times of prayer that were used in Istanbul and elsewhere in the 14th-19th centuries, that is, the tables that were used by the Ottoman *muvakkits* to find the time of day and night and to regulate the times of prayer.[153] (For some reason, these tables are overlooked in most modern writings on the *muvakkit*s, which give the impression that these men used only sundials, astrolabes and quadrants for timekeeping). In 1986 he published the first survey of Ottoman sacred geography, the notion of the world divided in sectors about the Kaʿba. In 2006, he published the two astrolabes dedicated to Bayezid II. In 2018, he presented a detailed analysis of the spherical astrolabe which was made in Istanbul in

150. Sayılı, *The Observatory in Islam*. His writings on the hospital in Islam are in his 1942 doctoral thesis at Harvard University.

151. See www.biyografya.com/biyografi/16723 for a tribute to Sevim Tekeli. On Taqī al-Dīn, see n. 6.

152. İhsanoğlu *et al.*, *Osmanlı astronomi / coğrafya / matematik literatürü tarihi* (= *History of Ottoman Literature on Astronomy / Mathematics / Geography*) in Turkish, 2 vols. each, 1997/1999/2000.

153. An effort has been made to ensure that the entries for each author in the Bibliography are in chronological order.

the year of the death of Mehmet II. Most recently, he has written on the orientation of Ottoman mosques, countering those who seek to show that they were not built to face Mecca. His response is simply that these mosques face the Kaʿba (not Mecca) in ways that we can learn from medieval texts, and that it is not at all helpful to compare their orientations with modern directions toward Mecca.

Over the past few years, the American-trained historians of science in the Near East, Tzvi Langermann and Robert Morrison, have investigated the writings of, or attributed to one Mūsà Jālīnūs associated with the courts of Mehmet II and Bayezid II. We are apparently dealing with a multilingual Jewish scholar well versed in astronomy and medicine, author of serious treatises on both subjects and also in mechanics, to the extent of designing a robot. If this were not enough, the enigmatic and charming spherical astrolabe in Oxford signed by one «Mūsà», of unknown provenance but of a date that corresponds to the end of the reign of Mehmet II, has now been shown to have been constructed for the latitude of Istanbul. Whilst there was always some confusion about the identity of the three Mūsàs, and still is, it does seem that we can now distinguish between two of them. As we write these lines, we read that Morrison has succeeded in distinguishing between an «astronomical» Mūsà active during the reign of Mehmet II and a «medical» Mūsà active during the reign of Bayezid II. We propose that the spherical astrolabe might have been made by the former Mūsà in 885H/1480~81 probably at the court of Mehmet II. But why is there no dedication? Possibly because Mehmet had recently died 4 Rabīʿ al-Awwal 886 Hijra / 3 May 1481 at age 49, and Bayezit II assumed power (a few days later?) that same year. More to come ... – see further §7.7-9.

Yet more recently, the Turkish historian and historian of science Ahmet Tunç Şen has produced a brilliant and eloquent study specifically devoted to astrology at the Court of Sultan Bayezid II.[154] Inevitably he considers the available evidence for the Court of Mehmet II, but there are far fewer sources. Together with the late American Ottoman historian, Cornell Fleischer, he has published a survey of the titles represented by the astronomical manuscripts in the Library of Bayezid II listed in the inventory of the library of the Sultan.[155]

154. Şen, «Reading the Stars at the Ottoman Court».

155. Şen, pp. 342-352; and Şen & Fleischer, «Books on Astrology, Astronomical Tables, and Almanacs in the Library Inventory of Bayezid II». On Cornell Fleischer see https://themaydan.com/2023/06/in-memoriam-cornell-fleischer-1950-2023/. The manuscript of the inventory, preserved in the Hungarian National Museum Library in Budapest, is published in facsimile in the same volume.

A Turkish journal for the history of science is *Nazariyat – Journal for the History of Islamic Philosophy and Sciences*, serving authors who look inside the manuscripts and can thus contribute new insights or even new material.

Of the many writers on Ottoman history, few are those who venture to mention intellectual life as opposed to military campaigns. We can single out the Ottoman historian, Gottfried Hagen, who authored a chapter on Ottoman intellectual life for the new, four-volume *History of Turkey*.[156] He has written a short but insightful account of Ottoman astronomy which includes more serious information on the subject than most other writings on the subject. Whilst he makes no pretension of covering the field, he does mention that some 30 astronomical treatises are known to have been dedicated to Bayezid II and that six astronomers/astrologers received salaries from the imperial palace. These tidbits of information would be worth pursuing. The sources for astronomy in the reign of Mehmet II are, in comparison, few and far between.

The study of Ottoman instruments took off after several decades of neglect. The studies of Sevim Tekeli were all that was available for non-observational instruments. Three British researchers in Manchester, William Brice, Colin Imber and Richard Lorch, published in 1976 a treatise on the equatorial semi-circle, a device on which a graduated ring can be folded into the plane of the celestial equator.[157] The first author published in 2006 two astrolabes associated with Bayezid II[158] and a preliminary catalogue of some 30 Ottoman astrolabes.[159] Alas, there are no parallels to our subject specifically at the Court of Mehmet II, mainly because it has been thought that there were no sources, that is, no manuscripts and no instruments, with the exception of the cartographical manuscripts associated with him, now the subject of a definitive study by Karen Pinto.[160]

Numerous overviews of early Ottoman astronomy have been published, of which those by the prolific Selim Aydüz are recommended. New insights were provided by Gottfried Hagen in his essay on Ottoman intellectual life mentioned

156. Hagen, «Ottoman intellectual life».

157. Brice & Imber & Lorch, «The Dā'ira-ye Muʿaddal of Seydī Alī Re'is». This article was authored by an Ottoman historian, a historian of geography, and a historian of Islamic science!

158. DAK, «Two astrolabes for the Ottoman Sultan Bayezid II» – see now §7.9.

159. *A Catalogue of Medieval Islamic Astronomical Instruments*, Parts 1.1 to 2.3, §2.3 on Ottoman astrolabes, at https://davidaking.academia.edu/research#catalogueofmedievalastronomicalinstruments.

160. Pinto, «The Maps are the Message: Mehmet II's Patronage of an "Ottoman Cluster"».

above. A wider look at Ottoman scientific life is by Miri Shefer-Mossensohn, *Science among the Ottomans*.[161]

The ground was thus laid for the study of Islamic astronomical timekeeping and instrumentation and the incorporation of these aspects into the history of Islamic science generally. Recent studies have been conducted mainly in Frankfurt in recent years by the present authors using yet more previously unknown sources, and now two Turkish scholars, Yasin Taha Arslan and Gaye Danışan, have devoted themselves to the topic of instruments in Ottoman astronomy, again using primary sources and being fortunate enough to have the libraries of Istanbul close at hand.[162]

Better known for his exploits at sea, the Ottoman Admiral Sayyid ʿAlī ibn Ḥusayn, also known as Sidi Ali Re'is, authored a treatise on instruments in Turkish entitled *Mirāt-i kā'ināt*, dealing with the astrolabe, sine quadrant, astrolabic quadrant, armillary sphere, and equatorial semi-circle. This has recently been investigated from an Istanbul manuscript (Ayasofya 2674) by Gaye Danışan.[163]

A recent overview of Ottoman instruments up to the modern period has been provided by Turkish historian of science Irem Aslan Seyhan, albeit based mainly on Turkish secondary sources.[164] It nevertheless provides a useful introduction to the instrumental side of our subject, taking it up to Modern Period. Again, a history of timekeeping in the Ottoman world by Kaan Üçsu is valuable.[165]

A popular notion exists that Ottoman «astronomers» were interested only in astrology and precious little else. They certainly produced elaborately calculated horoscopes (*ṭāliʿ*) for dignitaries and annual ephemerides or almanacs (*taqwīm*s). But it is more appropriate to consider all the others and to distinguish between those who calculated planetary tables (*zīj*es) and thought about planetary models

161. Salim Aydüz, «Sultan Mehmed II, his contemporary scholars and their respective roles in the advancement of Ottoman Science» (2019), pp. 1-3. Hagen, «Ottoman intellectual life», pp. 415-420.

See also Shefer-Mossensohn, *Science among the Ottomans – The Cultural Creation & Exchange of Knowledge*, esp. pp. 32, 61-63, 76 & 135-138.The *Wikipedia* article «Mehmet II» offers a summary that is somewhat exaggerated and confused. The Turkish *Wikipedia* page is more reasonable but still not very informative.

162. Arslan, «A 15th-Century Mamluk Astronomer in the Ottoman Realm – ʿUmar al-Dimashqī and his *ʿilm al-mīqāt* corpus the Hamidiye 1453».

163. Danışan, «A 16th-Century Ottoman Compendium of Astronomical Instruments».

164. Seyhan, «Mathematical instruments commonly used among the Ottomans».

165. Üçsu, «Witnesses of the Time».

(real *munajjim*s), those who churned out ephemerides (*taqwīm*) each year (also *munajjim*s), and those who used the materials of the astronomers to make predictions and draw up horoscopes for individuals or events (also *munajjim*s!). Then there are the professional mosque timekeepers (*muwaqqitīn*), who used tables and instruments. Then there are the specialists in, and makers of instruments (*ālātīs* or *ṣannāʿīn*). Last but not least, for it was they who had the most influence in/on society, the legal scholars who advocated the methods of folk astronomy (*fuqahāʾ*). When writing the history of Ottoman astronomy, it is advisable to keep this in mind.

Ahmet Tunç Şen has identified three horoscopes (mislabelled *taqwīm*s) dedicated to Mehmet II which would surely repay further investigation:[166]

— MS Istanbul Topkapı Bağdatli 309, anonymous, for a date in 856 H / 1452.
— MS Istanbul Nuruosmaniye 3080, anonymous, for a date in 858 H / 1454.
— MS Oxford Bodleian Arch. Seld. 31, anonymous, based on *al-Zīj al-Shāmil*, for a date in 872 H / 1468. (The *Zīj al-Shāmil* is a rather mysterious but popular anonymous work from Northern al-ʿIrāq. Future researchers will be able to rely on a new edition by Benno van Dalen of the geographical table and the first investigation of any table of this genre with the specific aim of establishing its multiple sources).[167]

6.5 Aspects of early Ottoman astronomy

> The history of astronomy in Ottoman Turkey is a much neglected area of the history of science. [...] The above examples do not exhaust the known tables compiled by Ottoman astronomers for the purposes of timekeeping and preserved in manuscript form, but they must suffice for this brief survey. (DAK, «Astronomical Timekeeping in Ottoman Turkey» (1977), pp. 245 & 252).

> The history of early Ottoman astronomy in general (14th to early 16th century) has not yet been properly researched. [...] The sources for Islamic astronomy in general have recently been properly documented for the first time, and the amount of important re-

166. Şen, *Astrology in the Service of the Empire*.
167. Van Dalen, «The Geographical Table in the *Shāmil Zīj*».

search for the future is daunting. […] . (DAK, «Two astrolabes for Sultan Bayezit II» (2006/2005), p. 440/783).

Clearly, there were relatively few barriers to scientific exchange and the level of astronomy at Mehmet and Bayezid II's courts was high. (Robert Morrison, «Selective Appropriation: Jewish Scholars and Lunar Crescent Visibility Prediction in the Ottoman Empire», p. 154).

Individual studies of particular astronomical themes are rare. We have already mentioned them, but they seem to have been forgotten because they are seldom cited. It was the Turkish historian of Ottoman science, Sevim Tekeli (1924-2019), who first investigated the works of Taqī al-Dīn, the director of the Istanbul Observatory *ca.* 1575, and some unusual instruments.[168] The first author has written on two of the astrolabes associated with Bayezid II[169] and has published details on the tables for astronomical timekeeping and regulating the times of prayer that were used in Istanbul and elsewhere in the 14th-19th centuries.[170] We shall not repeat the materials on Ottoman astrology masterfully gathered by Ahmet Tunç Şen in his 2016 doctoral dissertation. The *takvīm*s or ephemerides necessary for astrological pursuits would be calculated from a *zīj* or astronomical handbook with tables, usually the *Zīj* of Ulugh Beg of Samarqand with solar, lunar and planetary tables modified for the longitude of Istanbul.[171] Now two Turkish scholars, Yasin Taha Arslan and Gaye Danışan, have devoted themselves to the topic of instruments in Ottoman astronomy, again using primary sources.[172]

Alas, there are no parallels to our subject specifically at the Court of Mehmet II, mainly because it has been thought that there were no sources, that is, no manuscripts and no instruments, apart from the cartography associated with him, now subject of a definitive study Karen Pinto.[173]

168. See www.biyografya.com/biyografi/16723 for a tribute to Sevim Tekeli; also, the articles «Taḳī al-Dīn» in *Enc. Islam*, 2nd edn., and in *BEA* by İhsan Fazlıoğlu. See also n. 6 above.

169. DAK, «Two astrolabes for the Ottoman Sultan Bayezid II», and below, §7.10.

170. DAK, «Astronomical timekeeping in Ottoman Turkey», also *Synchrony*, A, pp. 437-456.

171. Şen, «*Astrology in the Service of the Empire*», pp. 123-126.

172. Arslan, *op. cit.* (n. 162). Recent increased interest in Ottoman instruments is shown by Danışan, «A Sixteenth-Century Ottoman Compendium of Astronomical Instruments», and other papers by the same author mentioned in this study.

173. Pinto, «The Maps are the Message: Mehmet II's Patronage of an "Ottoman Cluster"»,

A recent overview of Ottoman instruments up to the modern period has been provided by Turkish historian of science Irem Aslan Seyhan, albeit based mainly on Turkish secondary sources.[174] It nevertheless provides a useful introduction to the instrumental side of our subject, taking it up to Modern Period. Again, a history of timekeeping in the Ottoman world by Kaan Üçsu is valuable.[175]

In our opinion, certain individual written works or instruments, when they are studied for the first time, could drastically expand and enrich our knowledge. Such was the situation in the history of Ottoman astronomy with the spherical astrolabe for the latitude of Istanbul, the little-known Ottoman scholar, Mūsà Jālīnūs, and his remarkable activities and productions. The enormous table for timekeeping by the stars, with some 240,000 entries, by Muḥammad ibn Kātib Sinān, dedicated to Ottoman Suleiman I in 1520 is another. The library of the scholar Muṣṭafā Ṣidqī (*fl. ca.* 1750), whose precious library is still to be exploited, has already attracted researchers.[176] To this list we can add the present very unusual instrument, dedicated to Mehmet II.

The history of Ottoman astronomy has only recently been studied using the vast manuscript sources available. And there is a lot more to be done. It is one thing to scan a list of manuscripts on a particular topic or of works by a specific author. It is another thing to begin to look at the texts in question and to know how to begin to handle them optimally.

We may draw a parallel with Mamluk astronomy, a tradition that lasted in Cairo, Jerusalem, Damascus & Aleppo from the mid 13th to the early 16th century. We think of the imposing treatise on instruments by al-Marrākushī; the fabulous universal astrolabe of Ibn al-Sarrāj; the taunting astronomical models of Ibn al-Shāṭir; the spectacular sundial (2m×1m) he constructed for the Umayyad Mosque in Damascus; the ingenious corpus of universal tables for solving all the problems of spherical astronomy for any latitude by al-Khalīlī; the enigmatic monumental table with 440,000 entries for timekeeping by day and night by Najm al-Dīn al-Miṣrī, and the treatise on 100 instruments which he compiled; as well as various monumental astrolabes.

174. Seyhan, «Mathematical instruments commonly used among the Ottomans».

175. Üçsu, «Witnesses of the Time».

176. On Muṣṭafā Ṣidqī, see the articles of ʿAbd al-Jawād and Bonmariage, also nn. 72 & 126 and 277 below. Most recently, Cécile Bonmariage has provided an inventory of some 90 manuscripts bearing the mark of ownership.

That said, the social history of astronomers cannot be written if the works of the astronomers are not known and assessed for their importance, alleged or real, and influence, legendary or actual. In the case of the Mamluk scene, we progressed from a famous art historian writing in the 1970s that the Mamluks had no science at all to the present situation where we first gained some control over their astronomical works (mainly by inspecting manuscripts in Cairo, Istanbul and Dublin), and then over the lives and careers of these men (mainly from published biographical dictionaries).[177]

*6.6 Khiṭābī on observations to improve astronomical handbooks (*zīj*es)*

The Islamic tradition of mathematical astronomy, compiling *zīj*es, that is, extensive sets of solar, lunar and planetary tables with commentary for miscellaneous purposes, continued after a fashion under Bayezid II's patronage. Khiṭābī Munajjim al-Ḥusaynī al-Lāhijānī, one of the Iranian astronomers at the Ottoman Sultan's court, seems to have conducted some observations in Istanbul using some instruments he constructed.[178] His *Tashrīḥ ālāt fī sha'n al-imtiḥānāt* (*Description of Instruments Pertaining to Testing*), written in 1483 and dedicated to Bayezid II, survives in several copies. Khiṭābī refers to criticisms directed at the *Zīj-i Īlkhānī* of Naṣīr al-Dīn al-Ṭūsī. He states that there were inconsistencies between this *zīj* and others; hence, he intended to examine these differences with the help of his own observations. He is perhaps quoting a Persian *zīj* entitled *Zīj-i Jāmiʿ-i Saʿīdī*, by Rukn al-Āmulī, who was a contemporary of Jamshīd al-Kāshī and Ulugh Beg.[179] According to al-Khiṭābī, such an examination had not been possible until the time of Bayezid II, under whose patronage he finally managed to construct instruments and perform observations. His treatise as it has come down to us mainly concerns determining a new set of coordinates for Istanbul, including a latitude of 41;15° (which is incorrect by +0;15° but was an improvement over the 41;30° of earlier works) and was widely used used in later Ottoman timekeeping, and concludes with a few remarks about various *zīj*es. The treatise bears further examination and

177. On this see Brentjes, «al-Sakhāwī on muwaqqits».

178. Şen & Fleischer, «Books on Astrology, Astronomical Tables, and Almanacs in the Library Inventory of Bayezid II». On the author, see Ragep, «Ṭūsī and Copernicus», p. 159, n. 32 (repr. *Islamic Astronomy and Copernicus*, 293); *Cairo Survey*, no. G43, n. 32.

179. Kennedy, «A Survey of *Islamic Astronomical Tables*», p. 3, no. 10.

his modern editors, Murzeda Sumi and Mohammad Bagheri, are to be thanked for making it available.[180] They identify other extant works by Khiṭābī, which deal with the astrolabe and with horoscopes and include a treatise on general astrology.

Ahmet Tunç Şen has identified in MS Topkapı Bağdatli 310 a horoscope computed by Khiṭābī for a date in 894H/1489, based on the *Zīj-i Jāmiʿ* of Rukn al-Āmulī mentioned above.[181]

6.7 Astronomy during the reign of Mehmet II

Mehmet II is reputed to have amassed a library of some 8,000 books. Alone the scientific holdings in the library of his son, Sultan Bayezid II, comprised some 600 manuscripts. We are hardly equipped to write the history of astronomy or even of instruments during the reign of Mehmet II. This is mainly because of the paucity of sources. This topic is desperately in need of revived input. Even the new book by Abdurrahman Atçıl entitled *Scholars and Sultans in the Early Modern Ottoman Empire*, does not mention astronomy, let alone Mehmet II's interest in the subject. Likewise, a review by Yasemin Beyazit with the same title does not mention astronomy. Therefore, perhaps, we may be forgiven for any deficiencies in the present work, in spite of the fact that it omits solar, lunar and planetary astronomy and also astrology, and even though it is restricted to spherical astronomy and instrumentation.

We therefore lack the ability to extol over these few sources leading «towards the Ottoman scientific zenith ... under the rule of Suleiman the Magnificent in the 16th century».[182] Rather, we can present here only notes on this subject identifying some astronomers of consequence and their works, mainly treatises and instruments, as well as some relevant works by a Byzantine Greek and a Jewish craftsman, each of which have a connection with Mehmet II. We do not provide full bibliographies for each subject, but rather references that will lead the reader to the others.

180. Sumi & Bagheri, 2014. Their edition, based on Tehran Majlis 6376, is listed under «Khiṭābī» in the Bibliography.

181. Şen, *Astrology in the Service of the Empire*.

182. Ammalina Dalillah Mohd Isa & Roziah Sidik Mat Sidek, «Impact of Ottoman Scientific Advancement in the Era of Sultan Muhammad al-Fatih ... towards the Ottoman Scientific Zenith», p. 85.

We have deliberately not included the abundant treatises that are commentaries and super-commentaries on works by ʿAlī Qūshjī, who spent only two or three years in Istanbul but nevertheless became so famous in Ottoman astronomical history and who dominates the modern historiography of the subject. Anyone who starts to gather information on him can eventually be the author of a book.

Now Jamil Ragep has recently discovered discussions of the possibility of a heliocentric universe in the writings of ʿAlī Qūshjī (d. 1474), namely, in his Persian *Risāla dar ʿilm-i hayʾa* and its Arabic translation *al-Risāla al-Fatḥiyya*, prepared for Fatih Mehmet.[183] This is an important treatise which merits further investigation.

So, the history of astronomy in the first decades after the Ottoman conquest of Constantinople remains somewhat obscure. Some names of players have been documented, some of their writings investigated, and some of the instruments they used have been identified and studied. It is certainly known that Sultan Mehmet II was interested in astronomy and astrology. Better known, thanks to abundant sources, are the scientific interests of his son, Bayezid II.

Jewish scholars overlapping the reigns of the two Sultans, father and son, were involved in some significant activity relating to the calculation of conjunctions and the prediction of the lunar crescent visibility. For example, the American specialist on Islamic and Jewish astronomy, Robert Morrison, has studied the tables by Elijah Bashyatchi (d. 1490, who moved to Istanbul from Edirne), with the text being completed by Bashyatchi's student and brother-in-law, Caleb Afendopolo (d. 1525). The tables are independent of the Islamic tradition of determining the appearance of the lunar crescent.[184]

The summary of Ptolemaic astronomy entitled الملخص في الهيئة, *al-Mulakhkhaṣ fi 'l-hay'a*, by al-Jaghmīnī (Khwarizm, *ca.* 1220) was an extremely popular work in the central lands of Islam. It was, in the words of its modern editor and translator, Sally Ragep, «a beginner's text, but not for the untutored».[185] It was nevertheless considered a good book for a student to begin to fathom astronomy, and it is a good book for a modern student to learn about medieval Islamic astronomy. Thousands of copies survive, of the text and of commentaries and super-commentaries. There are over 20 Arabic commentaries and 10 Persian ones, together with a single late

183. Rosenfeld & İhsanoğlu, *MAIC*, nos. 845-A1-2: see Ragep, «Ṭūsī and Copernicus».

184. Morrison, «Selective Appropriation: Jewish Scholars and Lunar Crescent Visibility Prediction in the Ottoman Empire», & «Tables for Computing Lunar Crescent Visibility in Adderet Eliyahu».

185. S. Ragep, ed., *Jaghmīnī's Mulakhkhaṣ*, p. 63.

Turkish version. What will interest us later is a Hebrew version written by Moses b. Elijah Galeano during the reign of Mehmet II.[186] This Hebrew version awaits study.

More important for our understanding of the transmission of astronomy within communities in Istanbul and on to Renaissance Europe, was the announcement already in the then-new *Journal for the History of Arabic Science* by the American historian of astronomy, Bernard R. Goldstein, that the *Zīj* of Ibn al-Shāṭir had been transcribed in Hebrew characters. (The reader should be aware that in the medieval period, Jewish scholars often wrote Arabic in Hebrew letters – the two Semitic languages are ideally suited for such an operation).[187]

The main source for spherical astronomy and sundial theory was the substantial treatise on instrumentation from Cairo by al-Marrākushī (*fl. ca.* 1280), discussed in §4.4. At least one manuscript of this enormous work was available in Istanbul during the reign of Mehmet II. (Amongst European orientalists in the 19th century who were uncovering the main works of Islamic astronomy, this work was considered so important that a substantial part of it was published in Paris in French translation). Now none of the astronomers at the Court of Mehmet II is accredited with a treatise on sundial theory, but some think a later, unsigned sundial, still *in situ* on the Fatih Mosque is by the celebrated guest of the Sultan, ʿAlī Qūshjī – see §7.2.

It is said that the Sultan Mehmet II was interested in the theory and construction of sundials, which surely belongs to the realm of fact rather than legend. For guidance, so the legend, he sent for an expert from Aleppo. Even if the latter did not leave Istanbul for this purpose, the Sultan was clearly interested in this subject. Apparently, the Ottoman admiral Seydī ʿAlī Re'īs, whose grandfather served Mehmet II as commander of the fleet and who also wrote on instruments, spent the winter in Aleppo *ca.* 1550, but there is no record of his pursuing astronomy there. On the other hand, he is said to have found at least one scholar there who was conversant with the classic works of mathematics.

The pinnacle of the development of spherical astronomy in Aleppo was not around 1550, but around 1325 with the brilliant astronomer and instrument-mak-

186. Ibid., p. 291.

187. Goldstein, «The Survival of Arabic Science in Hebrew», p. 38. See also the article «Judaeo-Arabic» in *Enc. Islam*, 2nd ed., by the world's expert on the subject, Joshua Blau (1919-2020). A study of the only surviving astrolabe with Judaeo-Arabic inscriptions by DAK's former graduate students Mohamed Abuzayed and Petra Schmidl is «From a heavenly Arabic poem to an enigmatic Judaeo-Arabic astrolabe», 2011, at http://www.academia.edu/34693250/.

er, Ibn al-Sarrāj, who had apparently dedicated one of his treatises on an unusual trigonometric instrument of his invention to Sultan Bayezid I (*reg.* 1389-1402), although the dates speak against this. There was no need for anybody to go from Istanbul to Aleppo around 1550 for assistance in constructing sundials: the substantial encyclopedia on spherical astronomy and instrumentation by al-Marrākushī, compiled in 1280 in Cairo, was already available in the new Ottoman capital. His work was influential in Egypt, Syria, and Anatolia (but not Iran or the Maghrib). Amongst modern historians of Islamic astronomy, it has certainly not yet aroused the interest it deserves.

There were surely other astronomical works in circulation during the reign of Mehmet II, but to document them will not be easy. The basic bibliography on Ottoman astronomers, their work and manuscripts / editions thereof, is to be found in İhsanoğlu *et al.*, *Osmanlı astronomi literatürü tarihi* (= *History of Ottoman Literature on Astronomy*). This is organized chronologically, as far as this is possible. It is the best source for the present subject. A quote by American writer and editor, Julia Fiore, identifies some of the problems arising at the end of Mehmet's reign:[188]

> By the end of his reign, Mehmet's ambitious rebuilding program had changed Istanbul into a thriving capital. However, he was succeeded by his son Bayezid II, a religious puritan who disapproved of his father's international tastes. Bayezid dumped Bellini's paintings and drawings at the bazaar, where Venetian merchants picked them up at cut-rate prices.

As far as Mehmet II's interest in geography and cartography is concerned, we quote the historian Mohamed Benabbes, who in 2020 published a new study on the Ottoman translation of the world-map of Ptolemy:[189]

> In 1465, George Amirutzes and his son, two Greek scholars who had entered the service of the Ottoman Sultan Mehemet II, produced an Arabic translation of Ptolemy's Geography, certainly based on one of the Greek manuscripts preserved in Constantinople. This translation does not seem to have attracted much attention from researchers for many reasons. Although it was made in Arabic, it does not seem to have been of great interest to specialists in medieval Arabic geography, who have difficulties in deciphering its «classical» content. Despite the ancient character of this translated

188. Fiore, «The Renaissance Portrait That Helped End a War», penultimate paragraph.
189. Benabbes, «An Ottoman Translation of Ptolemy's Geography made in the 15th Century».

> work, its usefulness was also not recognized by the specialists of Classical studies, often little was initiated into Arabic manuscripts. However, must this 15th Century translation be known, firstly, as a modern work which should be studied by modernists, particularly those who specialize in Ottoman studies? In this paper, we [Benabbes] examine first the «scientific» context in which this translation took place. One wonders about the reasons for this translation and who sponsored it. One also wonders about the value of this Arabic translation for our knowledge of the original text of Ptolemy's Geography. Can it help us to better understand the source text? And finally, what is its interest for linguists?

Fuat Sezgin, in his *Geschichte des arabischen Schrifttums* (vols. x-xiv), provides a mine of information mainly in German but also in English on Muslim geographers and cartographers and their works. The reader will do well to consult these rich volumes, bearing in mind that the «world-map of al-Ma'mūn» has nothing to do with the Caliph al-Ma'mūn.

6.8 Notes on Ottoman astronomical timekeeping

> The history of astronomy in Ottoman Turkey is a much-neglected area of the history of science. [...] The above examples do not exhaust the known tables compiled by Ottoman astronomers for the purposes of timekeeping that are preserved in manuscript form, but they must suffice for this brief survey. (DAK, «Astronomical Timekeeping in Ottoman Turkey» (1977), pp. 245 & 252).

This section is long, but the information in it has never been published within the context of the history of Ottoman astronomy. In surveys of the works of Ottoman *muwaqqit*s these tables are very rarely mentioned because there is a general (false) belief that these astronomers measured time with sundials, astrolabes and quadrants, and nothing more. But the tables for the prayer-times for different localities which Muslims used extensively have history going back to 9th-century Baghdad.[190] Further details on the Ottoman scene are given in the references cited below.

190. See n. 4 above.

a) The latitude of Byzantium / Constantinople / Istanbul

The seven climates of Antiquity were the latitudinal bands whose midpoints and borders were defined in terms of increasing length of maximum daylight.[191] Thus, the first climate has lower limit at $12^1/_2$ h, midpoint at 13h, upper limit at $13^1/_2$h, and the second climate is at $13^1/_2$h – 14h – $14^1/_2$h, and so on. The latitudes of the climates depended on the value taken for the obliquity of the ecliptic. The latitudes of the mid-points of the climates are approximately:

16° — 24° — 30° — 36° — 41° — 45° — 48°.

(Would-be exact values depend on the changing values accepted for the obliquity of the ecliptic). The modern latitude of the Byzantine / Ottoman capital is a few seconds over 41°, and, as such, could reasonably have been associated with the midpoint of the fifth of the seven climates. But it was not, or not always.[192]

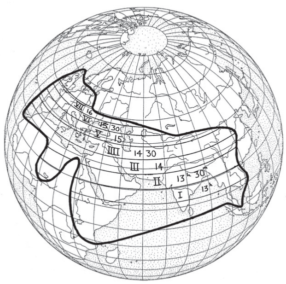

FIGURE 6.8a: The climates of Antiquity (I-VII) bounded by the limits of the *oikumene* or inhabited world as known to Ptolemy. These were of prime importance in astronomical timekeeping and instrumentation in the Islamic world.

The value available in 15th-century Istanbul, in the geographical tables of Ptolemy (*ca.* 150), as they were transmitted along with his maps is 43°. This is 2° too

191. On the climates in the Islamic tradition and their use in instrumentation, see *Synchrony*, B, pp. 925-927, and *World-Maps*, pp. 230-234, etc.

192. The information in this section is taken from DAK's review of two important studies: David Pingree, *The Astronomical Works of Gregory Chioniades. I: Zīj al-ʿAlāʾī by Gregory Chioniades* & Alexander Jones, *An Eleventh-Century Manual of Arabo-Byzantine Astronomy*, in *Isis* 82:1 (1991): 116-118. See also Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 93-94, for Constantinople, pp. 93-94, and for Shirwan, p. 319.

high, but is better than what else was available. The 13th-century Byzantine astronomer Gregory Chionades, author of what was perhaps the only independent Byzantine «*zīj*», used 45° for the latitude of the Byzantine capital (6th climate rather than 5th) and probably contributed to perpetuating this error. Curiously, one of his sources, a *zīj* of the 12th-century astronomer from Shirwan, al-Fahhād, was popular in the Byzantine world (if not at home, even though he compiled six *zīj*es, all now lost in their original form, and partly surviving only in Byzantine sources): this apparently had 41;0° for Shirwan in the Caucasus and was popular in Byzantine astronomy. (Islamic values for Shirwan are not happy either and go down to 36°, the 4th climate!) Islamic *zīj*es had mainly 45° for Constantinople, a city inaccessible to their authors for measuring it properly. As we shall see, Ottoman astronomers from the 15th century onward used better values 41°, 41;15° and 41;30°. This is a topic worthy of further investigation.

b) Anonymous tables of prayer-times (Konya)

Some serious tables for timekeeping for 14th-century Konya, based on the format of the corpuses of Cairo, Damascus and Jerusalem, are preserved in MS Istanbul Süleymaniye 1037,32 (fols. 282v-285v).[193] The tables are bound amidst a collection of later astronomical works for Istanbul. The following functions are tabulated side by side for each degree of solar longitude (from 271° to 90°) to two digits and the underlying parameters are latitude 38;30° and obliquity 23;35°:

— the meridian altitude of the sun
— the half-length of daylight
— number of degrees in one seasonal hour
— the altitude of the sun at the ʿaṣr
— the time from midday to the ʿaṣr
— the time from the ʿaṣr to sunset
— the solar altitude at the end of the ʿaṣr
— solar altitude at the beginning of the ʿaṣr
— the time from the end of the ʿaṣr to sunset

193. *Synchrony*, A, pp. 438-439. On the format of the tables see ibid., pp. 40-41, and the illustrations mentioned there.

— duration of evening twilight
— length of darkness of night
— duration of morning twilight

These tables would repay further analysis.

c) Zayn al-Munajjim, unusual prayer-tables

Another very unusual set of prayer-tables[194] was copied in Sivas in 773H/1371~72 by Zayn al-Munajjim («the astronomer») ibn Sulaymān al-Qūnawī, who was close to the court of the Uighur ruler Eretna in Central Anatolia (his capital was successively Sivas then Kayseri).[195] These are preserved in MS Istanbul Nuruosmaniye 2782, which consists mainly of calendrical and astronomical tables of a non-numerical character. The accompanying text, which is in Persian, makes mention of al-Khwārizmī, Kūshyār and al-Bīrūnī. Amongst the tables is one displaying the solar longitude for each day of the Syrian year (fol. 39v, the entry for Ādhār I is 11s 20°), followed by a set of tables for timekeeping (fols. 53v-54r), here labelled in Persian جدول طالع اوقات, *jadwal-i ṭāli'-i awqāt*, which means «table showing the horoscopus (that is, the ascendant, the point of the ecliptic simultaneously rising over the eastern horizon) at different times of day». It is stated that the entries were derived using a sextile astrolabe (*asṭurlāb sudsī*), that is, an astrolabe with altitude circles on the plates for each 6°.

Another copy of this table came to light after the first one had been evaluated. It is contained in the unique MS Cambridge Browne O.1, fol. 179r, of the Persian Zīj-i Mufrad of the 11th(?)-century astronomer Muḥammad ibn Ayyūb al-Ṭabarī. However, this table is not necessarily original to the *Zīj*, since it is appended to the main tables in a different hand. It is not certain whether the Persian or the Arabic terminology is original to this table, and the precise significance of the *chāsht* or *ḍaḥwa* is uncertain. The names of the functions tabulated, that is, the ten times of morning twilight through the day to the end of evening twilight, are given in the two sources (Persian and Arabic) as follows:

194. On these tables, see ibid., pp. 439-440, and 573-575 (illustrated).

195. On these tables, see *Synchrony*, A, pp, 438-439, and Şen, «Reading the Stars», p. 571, n. 37, where only a *taqwīm* or ephemeris is mentioned.

1	*ṣubḥ-i kādhib*	*al-fajr al-kādhib*	false dawn
2	*ṣubḥ-i-ṣādiq*	*al-fajr al-ṣādiq*	true dawn
3	*chāsht-i kūchak*	*al-ḍaḥwa 'l-ṣughrā*	small *chāsht* / *ḍaḥwa*
4	*chāsht-i-miyān*	*al-ḍaḥwa 'l-wusṭā*	middle *chāsht* / *daḥwa*
5	*chāsht-i-buzurg*	*al-ḍaḥwa 'l-kubrā*	large *chāsht* / *ḍaḥwa*
6	*nīm-i-rūz*	*anṣāf al-nahār*	midday
7	*mīyān-i-dūnamāz*	*mā bayna 'l-ṣalātayn*	(time) between two prayers
8	*awwal-i-namāz-i-dīgar*	*awwal al-ʿaṣr*	beginning of afternoon prayer
9	*ākhir-i-namāz-i-dīgar*	*ākhir al-ʿaṣr*	end of afternoon prayer
10	*maghīb i shafaq*	*maghīb al-shafaq*	end of evening twilight

The underlying latitude is found by inspection to be about 38°, and it is not possible to determine the value used for the obliquity. This latitude corresponds to Konya, although the possibility that the table was lifted from an earlier Iranian source cannot be excluded. The three sub-tables for twilight (1, 2, and 10) are based on parameters 23°, 18°, and 18°, respectively. The remaining seven sub-tables correspond to the division of the interval from the crack of dawn to the beginning of the night, into eight equal parts, i.*e*.: 1/8, 1/4, 3/8, 1/2, 5/8, 3/4 and 7/8. It is the only source in which such a division of the day is attested. No other known manuscripts contain these tables or anything similar.
This is a very strange table which demands further attention. Checking the values with an astrolabe would add to the challenge. Such was the case in 1970 when we found a medieval table for orienting air-catchers (!) in Cairo. It was just the beginning of our investigation of over 1,000 years of sustainable energy use, which had essentially been forgotten.[196]

d) ʿUmar ibn ʿUthmān al-Dimashqī

MS Istanbul Hamidiye 1453, copied in Edirne at different times during the period 1450-75, is a manuscript of mixed content, mainly *mīqāt*, but offering a variety of authors and their works. The unifying force is the copyist, ʿUmar ibn ʿUthmān

196. On this see *Synchrony* A, pp. 773-823, and www.academia.edu/43996180 (text) and www.academia.edu/43996333 (illustrations).

ibn ʿUmar al-Ḥusaynī al-Dimashqī al-Asṭurlābī, obviously an astronomer of consequence himself and close to ʿAlī Qūshjī. One of the treatises is an anonymous work on the spherical astrolabe (§6.8d & 7.7). The Turkish historian of science Taha Yasin Arslan has published a detailed description of the manuscript, identifying in it 20 treatises, the vast majority dealing with rules or tables or instruments for *mīqāt* from Mamluk Egyptian and Syrian sources.[197] The manuscript is a rich source of information on early Ottoman astronomical interests, and Arslan's study of it is to be regarded as a sequel to the present undertaking. We refer to some of the tables in this manuscript below.

e) Ottoman versions of al-Khalīlī's corpus of tables for Damascus

Already a dozen years after the conquest of Constantinople, al-Khalīlī's universal auxiliary tables were copied in Edirne, the previous Ottoman capital.[198] These tables represent the summit of the Islamic achievement in spherical astronomy: using them one can find the solution to any problem of spherical astronomy for any latitude without any calculation. (With close to 20,000 entries, they are more practical and less cumbersome than the enormous table of Najm al-Dīn al-Miṣrī with 440,000 entries).

First, a few words about al-Khalīlī. He was an astronomer associated with the Umayyad Mosque in the center of Damascus. A colleague of the astronomer Ibn al-Shāṭir, he was also a *muwaqqit*, an astronomer concerned with *ʿilm al-mīqāt,* the science of timekeeping by the sun and stars and regulating the astronomically defined times of Muslim prayer. al-Khalīlī's major work, which represents the culmination of the medieval Islamic achievement in the mathematical solution of the problems of spherical astronomy, was a corpus of tables for astronomical timekeeping. Some of these tables were used in Damascus until the 19th century, and they were also used in Cairo and Istanbul for several centuries. The main sets of tables survive in numerous manuscripts, but they were not investigated until the

197. Arslan, «A 15th-Century Mamluk Astronomer in the Ottoman Realm – ʿUmar al-Dimashqī and his *ʿilm al-mīqāt* corpus the Hamidiye 1453». (In the 1970s DAK had analyzed the principal tables in this manuscript without recognizing the importance of the ensemble and of the copyist – see *Synchrony*, A, p. 925).

198. Ibid., I: 173 & 446.

1970s. They have yet to be mentioned in the many surveys of Islamic astronomy. al-Khalīlī's tables can be categorized as follows:

(1) tables for reckoning time by the Sun, for the latitude of Damascus;
(2) tables for regulating the times of Muslim prayer, for the latitude of Damascus;
(3) tables of auxiliary mathematical functions for timekeeping by the Sun for all latitudes;
(4) tables of auxiliary functions for finding the solar azimuth from the solar altitude for any latitude;
(5) tables of auxiliary functions for solving the problems of spherical astronomy for all latitudes;
(6) a table displaying the *qibla*, *i. e.*, the direction of Mecca, as a function of terrestrial latitude and longitude for each degree of both arguments; and
(7) tables for converting lunar ecliptic coordinates to equatorial coordinates.

MS Paris Bibliothèque Nationale ar. 2558, copied in 1408, contains all of the tables in Khalīlī's major set (1, 2, 5 and 6). Some less complete copies are MSS Berlin Wetzstein 1138 (Ahlwardt 5754-6), Cairo MM 43, and Cairo ṬM 228,5. MSS Dublin Chester Beatty 4091, and Bursa Haraççioğlu 1177, 4, both copied *ca.* 1450, are the only known copies of the minor auxiliary tables (3) and (4), respectively). The first two sets of tables correspond to those in the large corpus of spherical astronomical tables computed for Cairo that are generally attributed to the 10th-century Egyptian astronomer, Ibn Yūnus, although they were actually compiled between the 10th and 13th centuries.[199] They differ only in format, the Damascus tables beginning with the winter solstice at solar longitude 271° rather than with the vernal equinox longitude 1° as in the Cairene tables.

The Damascus prayer-tables display the following functions in degrees and minutes for each degree of solar longitude from 271° through 360° = 0° to 270°:

the solar meridian altitude (غاية الارتفاع, *ghāyat al-irtifā'*);
half the diurnal arc (نصف قوس النهار, *niṣf qaws al-nahār*);
the number of hours of daylight (ساعات النهار, *sā'āt al-nahār*);
the solar altitude at the beginning of the *'aṣr* (ارتفاع العصر, *irtifā' al-'aṣr*);

199. See DAK, «Ibn Yūnus' *Very Useful Tables* for finding time by the sun» (1972), repr. in *Islamic Mathematical Astronomy*, II, with a much more detailed analysis in *Synchrony*, A, pp. 247-298.

the hour-angle at the beginning of the ʿ*aṣr* (دائر العصر, *dā'ir al-ʿaṣr*);
the time between the beginning of the ʿaṣr and sunset (ما بين العصر والغروب, *mā bayn al-ʿaṣr wa-'l-ghurūb*);
the time between midday and the end of the ʿaṣr (ما بين الظهر وآخر وقت العصر, *mā bayn al-ẓuhr wa-ākhir waqt al-ʿaṣr*);
the duration of night (قوس الليل بكماله, *qaws al-layl bi-kamālihi*);
the duration of evening twilight (حصة الشفق, *ḥiṣṣat al-shafaq*);
the duration of darkness (ما بين الشفق والفجر, *mā bayn al-shafaq wa-'l-fajr*);
the duration of morning twilight (حصة الفجر, *ḥiṣṣat al-fajr*);
the time remaining until midday when the sun is in the azimuth of the *qibla* (الباقي للزوال حين تساميت الشمس القبلة, *al-bāqī li-'l-zawāl ḥīna tusāmit al-shams al-qibla*)

Al-Khalīlī's fifth set of tables was designed to solve all the standard problems of spherical astronomy, and they are particularly useful for those problems that, in modern terms, involve the use of the cosine rule for spherical triangles. Al-Khalīlī tabulated three functions and gave detailed instructions for their application. The functions are the following:

$$f_{\phi}(\theta) = \sin\theta / \cos\phi \text{ and } g_{\phi}(\theta) = \sin\theta \tan\phi,$$
$$K(x, y) = \arccos\{\, x / \cos y \,\},$$

computed for appropriate domains, where ϕ is the local latitude, and θ is an independent variable and x and y depend on the calculation being performed. The entries in these tables, which number over 13,000, were computed to two sexagesimal digits and are invariably accurate. An example of the use of these functions is the rule outlined by al-Khalīlī for finding the hour angle t for given solar or stellar altitude h, declination δ, and terrestrial latitude ϕ. This may be represented as:

$$t(h, \delta, \phi) = K\{[\, f_{\phi}(h) - g_{\phi}(\delta)], \delta\},$$

and it is not difficult to show the equivalence of Khalīlī's rule to the modern formula

$$t = \text{arc cos}\{[\sin h - \sin\delta \sin\phi] / [\cos\delta \cos\phi]\}.$$

Similarly, the azimuth a of the sun is given by

$$a(h, \delta, \phi) = K\{[\, g_{\phi}(h) - f_{\phi}(\delta)], h\}.$$

These auxiliary tables were used for several centuries in Damascus, Cairo, and Istanbul, the three main centers of astronomical timekeeping in the Muslim world. They were first described in 1973, and they are not yet mentioned in overviews of Islamic astronomy. Several centuries, nay, half a millennium was to pass before any tables of comparable sophistication and scope were devised in Europe.

Khalīlī's phenomenal computational ability is best revealed by his *qibla*-table. The determination of the *qibla* for a given locality is one of the most complicated problems of medieval Islamic trigonometry. If (L, ϕ) and (L_M, ϕM) represent the longitude and latitude of a given locality and of Mecca, respectively, and $\Delta L = |L - L_M|$, then the modern formula for $q(L, \phi)$, the direction of Mecca for the locality, measured from the south, is:

$$q = \text{arc cot } \{[\sin \phi \cos \Delta L - \cos \phi \tan \phi_M] / \sin \Delta L\}.$$

al-Khalīlī computed $q(L,\phi)$ to two sexagesimal digits for the domains $\phi = 10°$, 11°, ..., 56° and $\Delta L = 1°, 2°, ..., 60°$; the vast majority of the 2,880 entries are either accurately computed or in error by a mere ±1′ or ± 2′. Several other *qibla*-tables based on approximate formulas are known from the medieval period. al-Khalīlī's splendid *qibla* table does not appear to have been widely used by later Muslim astronomers.

There is a sense that by the 14th century, al-Khalīlī's *qibla*-table and his universal auxiliary tables were too late for the Muslim world, insofar as all the major mosques had already been built. His tables were rediscovered in the late 20th century, by which time the world knew the names of al-Khwārizmī and al-Battānī, both of whose works had become known in medieval Europe, but not of al-Khalīlī. Recently, important scientific materials have passed through the auction houses for a pittance because nobody knows what they are or has any cognisance of the relevant literature. Imagine two fine copies, one of the universal *qibla* table by al-Khalīlī and the other of all of his tables that were recently sold for a fraction of their value because the auctioneers and the catalogue just described them as «anonymous astronomical tables».[200]

200. A «new» copy of al-Khalīlī's *qibla* table, also from Damascus and datable *ca*. 1400, was auctioned at Christie's of London in 2012 as «Astronomical tables of ... al-Khalīlī». See www.christies.com/lot/lot-astronomical-tables-of-shams-al-din-abu-abdullah-5604502/. For a complete manuscript of all of al-Khalīlī's tables dated 840 H (1436/37), in the catalogue falsely attributed to Ibn al-Shāṭir, see www.

f) Adaptations of the prayer-tables for Istanbul

MS Cairo Ṭalʿat *mīqāt* 255,6, copied about 1650, is the only known copy of al-Khalīlī's introduction to his corpus followed by some anonymous prayer-tables, with his format, for latitudes: 36° (Aleppo) and 41;15° (Istanbul).

Similar sets for the latter are in MSS Istanbul University Library T1824,1, Paris BnF ar. 2544,14, Istanbul Hamidiye 842 and Cairo MM 100.[201] This does not exhaust the list of tables suitable for Istanbul. MS Princeton 861,1, penned about 1600, is the only known copy of a set of prayer-tables, with Ibn Yūnus' format, for each degree of latitude from 21° (Mecca) to 41° (Istanbul).[202] The 17th-century astronomer al-Manāshīrī compiled a collection of prayer-tables for Damascus, Cairo, Mecca and Istanbul, of which MS Cairo DM 184 is a garbled copy. It is stated that the tables for Istanbul are based on latitude 41;15°, but in fact they are based on 41;0°.[203]

g) Ottoman copies of al-Khalīlī's universal auxiliary tables

MS Istanbul Hamidiye 1453,3 (fols. 232v-266v) contains al-Khalīlī's universal auxiliary tables and was copied in Edirne in 869H/1464~65 by ʿUmar ibn ʿUthmān al-Ḥusayn – see above. The tables follow a number of treatises on timekeeping and quadrants and are preceded by al-Khalīlī's instructions written in Arabic.[204] The functions f_ϕ and g_ϕ are tabulated only for latitudes: 20°, 21°,..., 49°, as well as 21;30° (Mecca) and 33;30° (Damascus).

The main tables are preceded by a small table (fols. 233v-234r) displaying the *qibla* as a function of local latitude and longitude difference from Mecca, ultimately of Abbasid origin – see below.

MS Istanbul Ayasofya 2590 is a second Ottoman copy of al-Khalilī's universal auxiliary tables in a recension prepared by the *muwaqqit* Muḥammad ibn Kātib Sinān) for Sultan Bayezid II, and dated 897H/1491. Ibn Kātib Sinān translated al-

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lotsearch.net/lot/attributed-to-ala-al-din-abul-hasan-ibn-ali-ibn-ibrahim-ibn-muhammad-45591850?perPage=80.

201. *Synchrony*, A, pp. 405-406, 447-448.

202. Ibid., pp. 334-336.

203. Ibid., pp. 408-409.

204. Ibid., p. 446.

Khalīlī's introduction into Turkish and then copied the tables in their entirety.[205] He also copied al-Khalīlī's parameters 19° and 17° for twilight in the introduction, although elsewhere (as in his treatise on the astrolabe preserved in MS Istanbul Ayasofya 2708) he advocated 20° and 16°.

In a late Ottoman miscellany of astronomical treatises preserved in an unnumbered manuscript formerly (*ca.* 1970) in the collection of the late Professor Buhairi of the American University of Beirut, there are tables of f_ϕ and g_ϕ for $\phi = 41°$ (Istanbul) and a single table of $K(x, y)$ for $x = 41°$. There are no accompanying instructions, and the unfortunate individual who thought fit to copy these three tables together was unaware that the argument x is unrelated to the local latitude.[206]

h) Muḥammad ibn Kātib al-Qūnawī

Muḥammad ibn Kātib al-Qūnawī, who died *ca.* 1524, was a prolific astronomer whose family came from Konya. He was not only able to translate into Turkish al-Khalīlī's instructions for his universal auxiliary tables (see above), but he also himself compiled an enormous table for timekeeping by the stars. This table was dedicated to Bayezid II. It is extant in MSS Istanbul Ayasofya 2710 and Topkapı T3046 (A3515) and was studied for the first time around 1975.[207]

The main tables themselves occupy about 500 pages in each of the manuscripts and indeed contain about 240,000 entries. The horizontal argument is intended to be the normed right ascension, and the vertical argument is the solar longitude; the argument increments are 1° for both. Several dozen consecutive pages serve each 30° of solar longitude. Four functions are tabulated side by side for each pair of arguments:

t_1 the time since sunset,
t_2 the time remaining until sunrise,
t_3 the time remaining until daybreak,
t_4 the time remaining until midday.

205. Ibid., pp. 171-173, 373-386, 446.

206. Ibid., p. 446.

207. On the author see İhsanoğlu *et al.*, *Osmanlı Astronomi Literatürü Tarihi*, II, pp. 84-90 & *eidem*, *Ottoman Scientific Heritage*, I, pp. 123-130, and the article in *BEA* by İhsan Fazlıoğlu, in none of which the tables are specifically mentioned. On his tables, see *Synchrony*, A, pp. 446.

Entries are given in equatorial degrees to one digit only. To use the table, one simply feeds in the normed right ascensions of the star culminating instantaneously and the solar longitude and can read off the appropriate time.

i) Shaykh Vefa

In the world of astronomy, Muṣṭafā ibn Aḥmad ibn al-Ṣīrawī (?) al-ʿĪsawī, known as Shaykh Vefa, was a significant figure, contemporary with Mehmet II and dying in 896H/1490~91 during the reign of Bayezid II. He prepared a *ruznāme*, a special kind of almanac, a document with tables for calendar conversion and regulating times of prayer. The *Ruznāme-yi Vefā'ī* survives in numerous copies, including MSS Istanbul Hamidiye 842 & Nuruosmaniye 2914,1, Paris BnF turc 186-118, 194, turc supp. 537, and Cairo Khalīl Āghā *mīqāt turkī* 3, and many more in Istanbul and Cairo and elsewhere. The almanac was published for the first time by the German Georg Hieronymus Welsch (Velschius, 1624-77), a polymath medic competent in Turkish.[208] All copies contain the calendrical tables but only a few contain the prayer-tables for Istanbul – are they really from Shaykh Vefa? (They are not contained in any other known work). They display, for each day of the year:

نهار, *nahār*, the length of daylight,
ليل, *layl*, the length of night,
ظهر, *ẓuhr*, the time from sunrise to midday,
عصر, *ʿaṣr*, the time from midday to the afternoon prayer,
مغرب, *maghrib*, the time from the afternoon to sunset, and
عشاء, *ʿishāʿ*, the duration of evening twilight.

The tabulated functions are expressed in equinoctial hours (*sāʿāt*), with fractions thereof in equatorial degrees (*daraja*), which is by no means the case with other early Ottoman tables. The underlying latitude is 41;30°, which is not well chosen.[209] A thorough examination of some of the many available manuscripts

208. On the author see İhsanoğlu *et al.*, *Osmanlı Astronomi Literatürü Tarihi*, II, pp. 51-54, and *Synchrony*, A, 440-443. A copy of his *Ruznāme* is currently on sale for €25,000 (as the earliest European printed version of an Oriental text). This printed version does not contain the prayer-tables. On the later and less popular *Ruznāme* of Darendeli, see ibid., A, pp. 444-445.

209. The first analysis of the tables is ibid., A, pp. 440-443.

would be worthwhile. For over 500 years we have not known what the *Ruznāme-yi Vefā'iye* really contained.

6.9 Ottoman works on the qibla

This section is severely lacking because the major sources have not yet been identified. This is one of those situations in which we can say the Ottoman astronomers must have produced some substantial works relating to the *qibla*, but these we have not yet found. (Compare the analogous situation with Iran in the 1980s and '90s, when three Safavid world-maps for finding the *qibla* exactly for the whole world were discovered, a genre unique in the history of Islamic cartography. At the time, no relevant textual materials were documented. Since then, dozens of Iranian works on the *qibla* have come to light but none mention the world-maps). Thus far we know of no Ottoman copies of al-Khalīlī's *qibla*-table (the only known copies are all from Mamluk Damascus). Here are three Ottoman works dealing with the sacred direction.

First, there is a blue ceramic compass bowl dedicated to the Ottoman Sultan Selim I, son of Bayezid II, and made by a mysterious «Sayyid Thābit» in Damascus *ca*. 1518, just after the Sultan had conquered the city. The bowl was to serve as a «wet» compass, that is, with a needle floating on water and indicating direction rather precariously on the circumferential scale. This charming piece has attracted the attention of art historians, but these have not confronted the names of 40 localities with their longitudes, latitudes and *qibla*s engraved inside the bowl, or the difficult inscription. These are, however, quite garbled and useless for any practical purpose. They are corrupted from the same 15th-century Samarqand geographical table which provided the data for the Safavid world-maps.[210]

210. On this bowl and the geographical data on it, see *Paris IMA 1993 Exhibition Catalogue*, pp. 440-441; DAK, *World-Maps*, pp. 110-114, 168-170, & 478-480, and *Synchrony*, B, pp. 715-720. Art-historical studies of limited scientific value are listed under Zamani and al-Moadin, also *Discover Islamic Art - Virtual Museum* - object_ISL_sy_Mus01_38_en («alphabets corresponding to numbers that indicate degrees of angles», which may be a misrepresentation of the Arabic original). On the magnetic compass in Islam, mentioning the wet compass, see Schmidl, «Two early Arabic sources on the magnetic compass». See also Brieux & Maddison, *Répertoire des facteurs d'astrolabes*, 1, pp. 393-394.

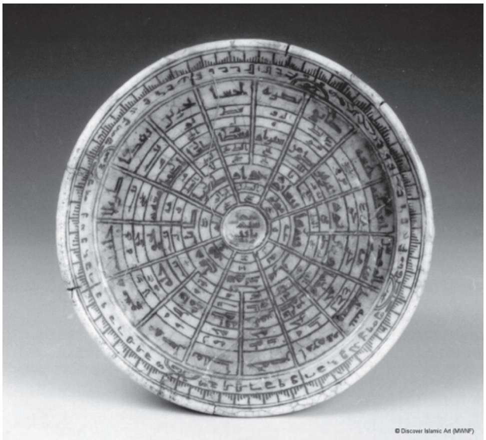

FIGURE 6.9: The Damascus *qibla*-bowl seen from above, and one side of the rim. Images courtesy of the Institut du monde Arabe, Paris.

The *qibla* values are hopelessly garbled. This is the more curious in light of the fact that the list of very accurate *qibla* values by al-Khalīlī (*ca.* 1360) for Syria and Palestine would have been available.[211] Nevertheless, the values on the bowl can be shown to be copied and miscopied from an enormous anonymous list of 250 sets of coordinates and very accurate *qibla*s for «the whole world» from early-15th-century Central Asia.[212]

Then we find smaller *qibla*-tables, such as the 20×20 one (*al-jadwal al-ʿishrīnī*) that is found in MS Istanbul Hamidiye 1453, copied in Edirne in 869H/1464~65. The same table is found in MS Istanbul Esat Efendi 3769, fol. 62r, amidst various Turkish treatises on astronomy. This table is of Abbasid origin and is based neither on the exact formula nor the standard approximate formula. At least nine copies are known.[213]

Anonymous Ottoman table of qibla-values

Source: MS Paris BnF ar. 2544, fol. 106v (see King, *World-maps*, p. 622, for critical apparatus). *Qibla*s are measured from the meridian or north-south line.

211. *World-Maps*, pp. 84-86 & 620-621.

212. First published ibid., pp. 86-87 & 622.

213. On these manuscripts containing these tables, see *Astronomy in the Service of Islam*, XIV, pp. 118-124, and *World-Maps*, pp. 64-65.

Qibla south-east		Qibla north-east		Qibla south-west		Qibla north-west	
1 Medina	9°	47 Zabid	21				
2 Azerbaijan	9	48 Jedda	63				
3 Mardin	10	49 Sus	78				
4 Ayntab	5	50 Jarmi	87				
5 Alepp	17			51 Mosul	0		
6 Malaty	18			52 Khuy	10		
7 Siva	18			53 Kufa	14		
8 Amasya	20			54 Baghdad	14		
9 Hama	20			55 Nakhchevan	16		
10 Kayseri	24			56 Maragha	17		
11 Homs	[8]			57 Bardaa	17		
12 Antakya	28			58 Tabriz	18		
13 Aksaray	28			59 Ardebil	18		
14 Baalbek	28			60 Wasit	20		
15 Damascus	29			61 Bulghar	20		
16 Tripoli (Syria)	29			62 Bāb al-abwāb	20		
17 Ankara	31			63 Shamakha	20		
18 Konya	36			64 Madayin	22		
19 Akshehir	37			65 Nihawand	24		
20 Karahisar	38			66 Hamadan	25		
21 Larnaca	38			67 Sawa	30		
22 Belgrade	40			68 Kashan	35		
23 Iznik	41			69 Basra	38		
24 Mt Sinai	41			70 Jurjan	39		
25 Qustantiniyya	42			71 Isfahan	42		
26 Sofia	42			72 Shirwan	45		
27 Edirne	45			73 Bukhara	49		
28 Gallipoli	45			74 Samarqand	51		
29 Bursa	45			75 Kazerun	52		
30 Manisa	45			76 Shiraz	53		
31 Jerusalem	45			77 Khujand	55		
32 Plovdiv	46			78 Balkh	95		
33 Rhodes	47			79 Kashmir	27		
34 Skopje	49			80 Qandahar	47		
35 S-r-z (?)	51			81 Hurmuz	97		
36 Cairo	53			82 Mansura	38		
37 Athens	56					83 Aden	5
38 Rosetta	∅					84 Najran	10

Qibla south-east		Qibla north-east	Qibla south-west	Qibla north-west	
39 Salonica	58			85 Saba	2
40 Alexandria	58			86 Hadramawt	∅
41 Rome	63			87 Oman	25
42 Barqa	68			88 Kang	50
43 Tripoli (Libya)	77			89 Sarandib	80
44 Tunis	78			90? place?	84
45 Cordova	79				
46 Marrakesh	89				

What we do find are Ottoman lists of *qibla*s to the nearest degree for cities in the Empire from Belgrade to Sri Lanka, such as the one above.[214] (Such lists are found already in al-Khalīlī's corpus of tables for Damascus: he tabulated latitudes and longitudes and *qibla*s of numerous localities in Syria and Palestine, as well as the *qibla*s of stations on the pilgrim-route from Syria to Mecca). This list includes Belgrade, which was conquered by the Ottomans in 1521, which serves as a *terminus post quem* for the table. No longitudes and latitudes are given, so these need to be identified before any investigation of the accuracy of the values in the Ottoman table can be conducted,[215] and that is only of mathematical interest. This is the kind of list which would have been useful to architects for laying out the foundation of a mosque and travellers to correctly lay out a prayer-carpet whilst away from home. Most significant Ottoman mosques had been built before this kind of useful information was available in this form.[216]

214. DAK, «An Ottoman list of *qibla*-values for localities in the Ottoman Empire», *Zeitschrift für Geschichte der arabischen-islamischen Wissenschaften* 22 (2020): 155-161, at www.academia.edu/37894108/.

215. On the orientation of Ottoman mosques, see Ibrahim Tiryakioglu & Mustafa Yilmaz, «The astronomical orientation of the historical Grand mosques in Anatolia». See also the next note.

216. We mention a perverse, non-scientific, non-historical interpretation of Ottoman mosque orientations (in which actual historical orientations are judged by comparison with modern *qibla* values for the location in question, and modern knowledge of historical *qibla* determinations is ignored). This is found in *Monuments of Jihad*, (2018), by Canadian economist A. J. Deus. For a response, see DAK, «The Ottoman mosques fallacy – Places of worship facing the Kaaba or «Monuments of Jihad?», at www.academia.edu/37957500/. Deus claims, for example, that: «Turkish architects were not smart enough to read an angle off a table and draw a corresponding line on the ground [*sic*]» (p. 7). «Builders were able to orient structured precisely to a distant target long before the

One might have expected that some Ottoman astronomer would have made useful adaptations of al-Khalīlī's *qibla*-table. The fact that we have not found any probably means only that we have not looked far enough. There are thousands of manuscripts still awaiting study, many in Istanbul, many more in Iran and elsewhere.

6.10 Ottoman tables for sexagesimal multiplication & division

Every Muslim astronomer would have had a table of products $m \times n$ where both m and n are integers from 1 to 59. Such tables were called *jadwal sittīnī*, literally «60×60 table».[217] The first such table to be identified was in the Aḥmadiyya Libary in Aleppo in 1970: a sexagesimal multiplication table with 3,600 entries $m \times n$ for $m,n = 1, 2, \ldots, 60$. Some 20-odd examples were located thereafter. Only later did a 60×60×60 table with 216,000 entries come to light, namely, in Ottoman MS Paris BnF ar. 2552, 180 folios (!), copied *ca.* 1600. Then another one dated *ca.* 1475 showed up in MS Cairo Taymūr *riyāḍa* 119, as well as some extensive tables of sexagesimal quotients covering 120 folios in MS Istanbul Ayasofya 2698 and Istanbul Bayezid Umumi 4645, but also Cairo ENL Muṣṭafā Fāḍil *mīqāt fārisī* M 8,1, copied *ca.* 1300.

Of course, Ottoman astronomers had access to the remarkable trigonometric tables of Ulugh Beg which displayed the sine and cotangent functions to five sexagesimal places (!) for each minute of arc, with differences.[218] A survey of other tables of the Sine and Cotangent functions which they actually used is a task for the future, but an overview of all significant Islamic trigonometric tables is perhaps more pressing.

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advent of Islam ... [*sic*]» (p. 10). «None of the mosques by Mimar Sinan point to Mecca ... [*sic*]» (p. 19).

217. DAK, *Islamic Mathematical Astronomy*, XIV-XIV, on tables for sexagesimal multiplication and division.

218. Kennedy, «Survey of Islamic astronomical tables», p. 44. The tables were published in part in Carl Schoy's survey of the contents of the *zīj* of the great scholar, al-Bīrūnī (Ghazna, *ca.* 1025): *Gesammelte Schriften*, II, pp. 690-691 & 740-746), long before their accuracy could be checked by comparison with a computer output.

7. The instrumental context

> Since in the manufacture of measuring instruments it is not possible to achieve the desired precision, be it with the evenness of the surfaces or with the marking of the divisions or holes at the right place, it is but natural that errors occur, as with the adjustment of the instruments. In almost every construction, inaccuracies exist, whether visible or hidden. If the instrument is made of wood, then it will warp, particularly when it stands at a place exposed to Sun and humidity. The errors are larger or smaller, according to the theoretical knowledge, craftsmanship and experience. Added to this, there is the expertise of the observer in setting up and measuring, the precision of the adjusting apparatus and much more. Whosoever believes that anybody can execute measurements on order and without previous practice, and that each measuring instrument delivers correct results, is in error. Whosoever wishes to achieve this must, first of all, spend a long time on the study of the instruments and on the practice in measuring, until finally his measurement rests on the knowledge of the precision of his instrument and on his experience in measuring. (The Egyptian astronomer, Ibn Yūnus, *ca.* 1000, translation taken from Sezgin, ed., *Science and Technology in Islam*, v, p. 78).

We do not try to write the history of astronomical instruments in Ottoman science in the 15th century. Rather we simply discuss the most prominent surviving examples. The most significant instruments from Mamluk Syria were catalogued in 1993 for the exhibition on Syria at the Institut du Monde Arabe in Paris.[219] Those from Mamluk Egypt and the Ottoman Empire have not been so fortunate.

Note that from the Ayyubid period we have preserved for us first of all four monumental astrolabes, two made by ʿAbd al-Karīm al-Miṣrī for the Ayyubid Sultan al-Ashraf, one in the British Museum in London and the other in the *History of Science* Museum in Oxford.[220] Then we have the two astrolabes made in Da-

219. *Paris IMA 1993 Exhibition Catalogue*, pp. 432-443 & 480, with a new English version in *Synchrony*, B, pp. 659-744.

220. The instruments occur together for the first and last time in Gunther, *Astrolabes of the World*, I, nos. 103 on pp. 233-236 and 104 on pp. 236-237. The British Museum piece has been discussed in Ward, «Inscription on ʿAbd al-Karīm Astrolabe». Nothing else serious has been written on these splendid pieces. It is important to check the latitudes used for the plates, using Kennedy & Kennedy, *Islamic Geographical Coordinates* (n. 140). (Medieval latitudes should not necessarily be interpreted by using modern values). Also, al-Miṣrī here means «coming from the old Fatimid/Mamluk city kernel» of Cairo.

mascus for the Ayyubid Sultan al-Muʿaẓẓam, one in a private collection[221] and the other now in Istanbul Maritime Museum.[222] Since only one of even this group of precious, very large astrolabes has been adequately published, there is still work to be done. Each and every one gives an idea not only of what historical gems we have but also what we are missing from the Mamluk and Ottoman scenes. And we recall that Ottoman metalworkers at the foundries of Istanbul in 1464 were even capable of producing a monumental cannon that was over 5m long and ⅔m wide![223]

7.1 On Ottoman sundials and dialling treatises

Sundials in the Islamic world have a purpose which is at once scientific, artistic and architectural, communal and religious. Nowhere is this clearer than in the survey of historical sundials in the Muslim areas of the subcontinent by Indian cultural historian and commentator, Debasish Das.[224] Fixed sundials – horizontal, vertical and hemispherical – were widespread in Greek and Roman civilization, and different types of universal sundials also existed. Most of the surviving examples have been surveyed, if not published in detail.[225] Small sundials one could hold in one's hand were also popular. In a recent graphical analysis of the markings on some 10 Greek portable sundials, no attempt is made to derive the approximate formula connecting time and solar altitude, which is in fact the same as the one underlying the *ḥāfir* and the *ḥalazūn*.[226]

221. No further information available.

222. *Paris IMA 1993 Exhibition Catalogue*, pp. 480, and *Synchrony*, B, pp. 725-744.

223. Aydüz, «The Cannon of Mehmed II», at https://muslimheritage.com/the-cannon-of-mehmed-ii/. It was apparently last used against the British fleet in the Dardanelles War in 1915-16 and then the Sultan was soft-talked out of it by Queen Victoria, so that it is now in the Fort Nelson Museum near Portsmouth.

224. Das, «Sundials to tell the times of prayers in the mosques of India», at https://lighteddream.wordpress.com/2018/01/01/sundials-to-tell-the-times-of-prayers-in-the-mosques-of-india/.

225. See Gibbs, *Greek and Roman sundials*, now superceded by Schaldach, *Die antiken Sonnenuhren Griechenlands. Festland und Peloponnes*, and *Die antiken Sonnenuhren Griechenlands: Die Funde in historischer Sicht & Kataloge – Analysen – Texte*, an optimal treatment of a substantial amount of widely-scattered primary sources.

226. On portable dials see, for example, Wright, «Greek and Roman Portable Sundials – An Ancient Essay in Approximation», also n. 46 above.

We mention here just one unique but little-known hemispherical dial found near Mada'in Salih in the Hejaz. It bears an inscription in Nabataean script with Jewish influence and is obviously pre-Islamic.[227] It is of a type that is not found in later Islamic gnomonics, but its existence does confirm a story about Caliph ʿUmar II (Damascus, *reg*. 717-720) who «set up sundials» (*naṣaba sāʿāt*) for regulating his prayers. In all probability, he would have been using a Graeco-Roman sundial, hemispherical or even horizontal. What is clear is that he was regulating the times of prayer in terms of the seasonal hours.[228]

The principal sundials featuring in this study display markings for the seasonal hours (الساعات الزمانية), a concept known from Antiquity. These are 12th divisions of the length of daylight and vary throughout the year between a maximum at the summer solstice and a minimum at the winter solstice. (The concept of hours *alla turca* – that is, hours measured from sunset – does not occur in 15th-century Ottoman astronomy or gnomonics).[229]

Although no sundials are known from Baghdad *ca*. 830, we do have in MS Istanbul Ayasofya 4830, copied in Damascus in 626H/1228~29, a set of tables for the construction of horizontal sundials for each 3° of latitude as well for a universal polar sundial.[230] Whence the inspiration came for these remarkable tables we do not know. The author was probably Ḥabash al-Ḥāsib, the leading astronomer of 9th-century Baghdad, who included a table for Samarra, where he spent time.[231]

227. Healey, «A Nabataean Sundial from Mada'in Salih».

228. DAK, *Synchrony*, A, pp. 581-582.

229. Georgeon & Hitzel, eds., *Les Ottomans et le temps*, and Wishnitzer, *Reading Clocks,* Alla Turca – *Time and Society in the late Ottoman Empire*. On the practical implication for tables in that system, see *Synchrony*, A, pp. 444ff. On the situation in Cairo, see Stolz, «Positioning the watch hand: ʿUlamāʾ and the practice of mechanical timekeeping in Cairo, 1737-1874», and *The Lighthouse and the Observatory: Islam, Science, and Empire in Late Ottoman Egypt*. The 78 volumes of the Brill publication *The Ottoman Empire and its Heritage: Politics, Society and Economy*, 1994-2023, contain nothing of consequence on the Ottoman heritage of science or astronomical timekeeping. Historians are always fascinated by Ottomans measuring time *alla turca*, but not by the instruments and tables that were used for reckoning time before the introduction of the clock, or by sundials. Likewise, there is a common tendency to render *takvīm* as «calendar» when it stands for «ephemeris».

230. See further n. 252.

231. Brief overviews of tables for sundial construction are in *Synchrony*, A, pp. 84-88, and FC, *Mathematical Instrumentation*, pp. 181-184.

A slightly later treatise by Ibrāhīm ibn Sinān is geometrical in nature and contains no tables.[232]

Already in 10th-century Baghdad, Ibn al-Ādamī produced some auxiliary tables for finding the radial coordinates to construct the hour-lines on any vertical sundial inclined at any angle to the meridian for any latitude; extant in the 15th-century MS Paris BnF *arab* 2506,1, these have, as far as we know, never been studied.[233] In late-13th-century Cairo, the astronomer al-Maqsī compiled a set of tables for marking a vertical sundial at each degree of inclination to the Cairo meridian; extant in several manuscripts, these too have never been studied.[234]

In the period 900–1500 most major mosques would have a sundial. These would display the time in seasonal hours and the times of prayer, sometimes more besides. The surviving Islamic sundials, horizontal or vertical, mainly now found in mosques or museums, are few and are perhaps the least documented objects of the Islamic scientific (and architectural) heritage.[235] The yet rarer portable sundials have suffered likewise. Nevertheless, sundial enthusiasts and specialists, who are legion, have been more active in preserving and publishing them than historians of science. Several important examples have been studied in detail. Others are not featured at all in the literature on Islamic science.

The context and sources of the two enormous treatises dealing with several classes of instruments by al-Marrākushī and Najm al-Dīn in Cairo *ca.* 1300 are not fully understood but is important for the present study. There are no known serious Andalusī treatises on sundials, yet we do have at least eight surviving examples of fragmentary sundials from different parts of al-Andalus. Likewise, solitary sundials survive from all over the Islamic world from the Maghrib to India.

232. See the review by Sonja Brentjes of a new edition by Jan Hogendijk of Paul Luckey's 1941 doctoral thesis on this treatise.

233. Sezgin, *Geschichte des arabischen Schrifttums*, VI, pp. 179-180; *Synchrony,* A, pp. 89-90.

234. Suter, *Mathematiker*, no. 383; *Cairo Survey*, no. C15; and «Astronomy of the Mamluks», p. 548.

235. The only vertical sundials known to us have been published by a historian of Islamic architecture are Witkowski, «Vertical sundial from the Madrasa of Al-Ashraf Inal» (on the maker, the astronomer, Aḥmad al-Karādīsī, see Suter, *Mathematiker*, no. 180; Mayer, *Islamic astrolabists*, p. 47, and *Cairo Survey*, no. C90), and Walls & King, «The sundial of the Madrasa of Sultan Qaytbay in Jerusalem». The imposing illustrated manual for constructing such vertical sundials for the latitude of Cairo, on walls at any inclination to the meridian, is by the Cairo astronomer Shihāb al-Dīn al-Maqsī *ca.* 1300 (Suter, *Mathematiker*, no. 383; *Cairo Survey*, no. C15), but this remains unpublished.

These surviving sundials should always be considered in the light of contemporaneous texts on sundials. Several groups or families of sundials have indeed been studied, notably those in Turkey, Morocco and Tunisia. Few modern instrument specialists have known of the treatises of al-Marrākushī and Najm al-Dīn. Although al-Marrākushī treats different kinds of sundials in detail, at least his work is known, whereas several important treatises on sundial theory, presenting many tables, by Ḥabash, Ibn al-Ādamī, al-Maqsī, and Taqī al-Dīn, remain to be studied properly. We also know that the Jewish scholar Mordecai Comtino (Constantinople, mid 15th century) wrote a treatise in Hebrew on three types of sundials.[236] These are:

First, the universal horary quadrant with solar scale on a radius; invented in 9th-century Baghdad, this was to have a history of almost 1,000 years.

Second, the cylindrical sundial. This became quite common in Ottoman practice. The origins are, of course, also in 9th-century Baghdad.

Third, a vertical south-facing sundial with radial markings for the seasonal hours. Presumably, the gnomon is to be perpendicular to the plane of the sundial. This can only offer an approximate solution. (One thinks of the dials common on English churches, but these were also known in Antiquity.[237]) See §7.3a for a contemporaneous example still extant in Konya.

In his partial translation of al-Marrākushī's *summa*, Sédillot-*père* provided an extensive overview of Islamic gnomonics, or sundial theory. This was followed about a century later by overviews by two specialists, one on Islamic mathematics and the other on Islamic sundials. Carl Schoy authored a very academic book *Die Gnomonik der Araber*, dealing with Arabic texts on sundial theory, but alas, the exigencies of his time and his ill-health meant that he had not actually seen any Islamic sundials *in situ*.[238] Sundials can be approached at different levels, and it helps to understand the markings and be able to read the inscriptions.[239] The

236. See Bernard Goldstein in «Descriptions of Astronomical Instruments in Hebrew», p. 123.

237. Gibbs, *Greek and Roman Sundials*, pp. 45-46.

238. Schoy, *Gnomonik der Araber*.

239. On Islamic sundial theory, see Schoy, *Gnomonik der Araber*. The survey article, Berggren, «Sundials in Medieval Islamic Science», is useful. Turner, «A Mingling of Traditions: Aspects of Dialling in Islam», contains new insights. Samsó, «Ibn al-Raqqām's Treatise on Sundials», offers an informed glimpse into the manuscript of a medieval text. A book on historical Islamic sundials is a *desideratum*. So would be a study for the Muslim world equivalent to Sarah Schechner's «The material culture of astronomy in daily life: Sundials, science, and social change», 2001. Regional

first serious study of a historical Islamic sundial was by the French sundial enthusiast, Louis Janin.[240] His publication appropriately dealt with the most sophisticated of all Islamic sundials, namely, the horizontal sundial which the celebrated astronomer, Ibn al-Shāṭir, constructed in 1371 for the main minaret of the Umayyad Mosque in Damascus. Janin and the first author then studied a compendium (multi-functional instrument) by Ibn al-Shāṭir: the instrument was at the time preserved in Aleppo and a treatise thereon in Berlin.[241] Janin and DAK collaborated on the 13th-century sundial from the Mosque of Ibn Ṭūlūn in Cairo, known only from an illustration in the Napoleonic *Description de l'Égypte*.[242] DAK then ventured on his own to publish a 14th-century sundial for Tunis, which revealed the reason behind the curious standard definitions of the daytime prayers in terms of shadow increases, outlined neither in the *Qur'ān* nor in the *ḥadīth*.[243] He also published the article «Mizwala» on sundials for *the Encyclopaedia of Islam*.[244]

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or national surveys of surviving historical sundials are a *desideratum* – model examples are Jarray, *Mesurer le temps en Tunisie*, and Przypkowski, «The art of sundials in Poland from the 13th to the 19th century». Another very useful form of presentation is to study all of the productions of one prolific individual, as in Fathi Jarray & Eric Mercier & Denis Savoie, «Islamic sundials signed by al-Mansur carrying dates in the late 17th century». Modern mathematical approaches to Islamic sundials and Ottoman sundials in general are in Ferrari, *Le meridiane dell'antico Islam*, and Bir, «Principle and Use of Ottoman Sundials».

240. Janin, «Le cadran solaire de la Mosquée Umayyade à Damas»; and *Synchrony*, B, pp. 712-715. See also Bailey, «Ibn al-Shatir Sundial – Great Mosque Damascus». On Ibn al-Shāṭir, see n. 141.

241. Janin & King, «Ibn al-Shāṭir's *Ṣandūq al-Yawāqīt*» (see n. 101).

242. Janin & King, «Le cadran solaire de la Mosquée d'Ibn Ṭūlūn au Caire». Almost 50 years after the publication of this sundial, using the image in the *Description de l'Égypte,* neither the sundial nor this publication is mentioned on the *Wikipedia* nor ArchNet.com sites for the Mosque.

243. DAK, «A 14th-century Tunisian sundial for regulating the times of Muslim prayer», in *Islamic astronomical instruments*, XVIII; also *Synchrony*, A, pp. 571-573. At the time, no other sundials from Tunisia were documented in the literature – see n. 246.

244. The most usual medieval Arabic word for a horizontal sundial was رخامة, *rukhāma*, meaning simply «marble (slab)». The word for a vertical sundial was منحرفة, *munḥarifa*, literally «inclined». The expression آلة الاظلال, *ālat al-aẓlāl*, «instrument of shadows», was also used by serious writers. Shadows were particularly important in Islam because they are mentioned in the Prophetic ḥadīth and came to be used to define the times of the daylight prayers (*Synchrony*, A, IV: 529-622. The leading scientist of historical Islam, al-Bīrūnī, wrote an entire book about shadows, but, alas, he did not write about sundials in his extant works: see E. S. Kennedy, *The Exhaustive Treatise on Shadows by ... al-Bīrūnī*. The term مزولة, *mizwala*, is a modern Arabic word for sundial, no

A remarkable number of Islamic sundials in Tunisia, a few very early, have been published thanks to the labours of the Tunisian specialist, Fathi Jarray. His is the first serious survey of historical sundials in a particular Islamic country and lists over 100 examples.[245]

Some of the far fewer historical sundials in Turkey have been briefly identified and illustrated by art historian Süheyl Ünver and sundial specialist Wolfgang Meyer, respectively.[246] In 1990 sundials in the Ottoman realm were documented in a very brief fashion by the Turkish scholar Nusret Çam.[247] The most detailed overview of Ottoman sundials is by the enthusiastic Italian sundial specialist Gianni Ferrari.[248] As is the case with astrolabes, such overviews have been conducted by amateur enthusiasts innocent of Arabic and without knowledge of the associated literature, historical and modern. Thanks to Ferrari, we have one informative book on Islamic sundials, which, however, omits many important contributions, such as those of Carl Schoy, Louis Janin, and L. A. Mayer, who in his book on astrolabe-makers, documented all known Muslim sundial-makers.

The internet is a useful tool for locating a sundial here or there. An astounding number of websites, including those by sundial enthusiasts, deal with this sundial or that sundial, or groups thereof, with little idea about Islamic astronomy or Islamic gnomonics or the Arabic language. Thus, the purpose of the sundial can be misunderstood and its inscriptions misinterpreted.

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doubt influenced by the inappropriate French «méridien». Nowadays we also find ساعة شمسية, *sāʿa shamsiyya*, literally «solar, or sun-related clock», resulting from an effort to render the English term «sundial». The term *«mizwala»* was used in the *Encyclopedia of Islam* (unfortunately mainly arranged alphabetically by the Arabic names of the subjects) because production had reached the letter 'M'. The article «Mizwala» is comfortably close to the article «Mīḳāt», on astronomical timekeeping and the regulation of the times of prayer.

245. Jarray, *Mesurer le temps en Tunisie*, lists – we repeat – over 100 historical sundials.

246. See Ünver, «Les cadrans solaires en Turquie» (very brief overview) and Wolfgang Meyer's *İstanbul'Synchronyi güneş saatleri (Istanbul sundials), in Sandöz kültür yayınları (Istanbul)* 7 (1985), and «Sundials of the Osmanic Era in Istanbul», 1977. See https://www.meyerobjects.com/about.html on Meyer's family's clock business in Istanbul over several generations.

247. We have been unable to access Nusret Çam's book(let) on Turkish sundials. A German translation by Serkan Ince is available at https://www.ta-dip.de/fileadmin/user_upload/bilder3/Der_geschichtliche_Werdegang_der_osmanischen_Sonnenuhr.pdf (only 3 dense pages).

248. Ferrari, *Le meridiane dell'antico Islam*, pp. 435-488, also the overview in idem, «Ottoman sundials».

Ottoman treatises on sundial theory and construction are rather few in number. Tables for constructing horizontal sundials for latitude 40° had been available in earlier works. A complete set for all latitudes in the classical world was available (see below). Tables for constructing vertical sundials at any angle to the meridian for the latitude of Istanbul had to be computed afresh. We presume that the horizontal sundial which ʿAlī Qūshjī constructed for the Fatih Mosque has disappeared without physical trace and that the vertical sundial there now, with no inscription, is not by him (§7.2). Surely, tables were available in Istanbul to facilitate the construction of that vertical sundial. Tables to construct all sorts of sundials, even those skew to both the horizontal and to the meridian, first appear a century later in the treatise by Taqī al-Dīn.

The Turkish historians of science Atilla Bir, Şinasi Acar and Mustafa Kaçar, have attempted to show that a short anonymous treatise from the 16th century, with no tables, was the earliest Ottoman work on sundial theory.[249] We suspect that there were works already from the 15th century, but we have not come across any. This begs the question: when were the known manuscripts of earlier works on sundials available in Istanbul? The work of Thābit ibn Qurra on horizontal sundials is to be found in a precious unique manuscript, Istanbul Köprülü 984/1, pp. 1-89, copied in 370H/980~981 (!).[250] Thābit's book is strictly theoretical, and in the time of Mehmet II, astronomers were surely also in need of something more practical. For that, there is a manuscript preserved in Istanbul of a treatise attributed to the renowned al-Khwārizmī on tables of polar coordinates – gnomon shadow and azimuth – for the construction of sundials from 9th-century Baghdad, which had been copied in Damascus in 1228/29.[251]

249. Bir & Acar & Kaçar, «A Mathematical Analysis of the Theory of Horizontal Sundials in the Ottoman Period: The Case of *Risālah of Ruhāma*».

250. Krause, «Stambuler Handschriften», p. 456, item 18; Sezgin, *Geschichte des arabischen Schrifttums*, VI, p. 168, no. 9; *Cairo Survey*, no. B30/4.7.1. The title is كتاب في الات الساعات التي تسمى رخامات, *Kitāb fī ālāt al-sāʿāt allatī tusammà rukhāmāt*, «The Book on the hour-instruments called *rukhāma*s»: see n. 245. The work has been published in German translation by Karl Garbers (1936), with critical notes by Paul Luckey (1937-38). The latter's dissertation on the treatise on sundial theory by Thābit's grandson Ibrāhīm (1944) has been republished by Jan Hogendijk (1999).

251. Not mentioned in Krause. On the manuscript, see Sezgin, *Geschichte des arabischen Schrifttums*, VI, p. 143. On the tables of al-Khwārizmī and al-Sijzī, see DAK, «al-Khwārizmī and practical astronomy in 9th-century Baghdad», pp. 7-11, and a more detailed study in *Synchrony*, A, pp. 84-88, and B, pp. 51-52. We do not cite the other bio-bibliographical sources because they give no information on what the treatises contain. The former were published with a Russian translation

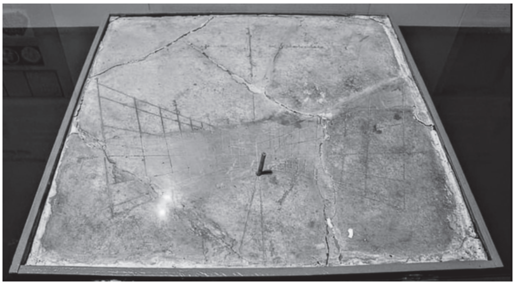


FIGURE 7.1: Parts of a horizontal sundial on a marble slab apparently found in Samarra, which would probably mean that it dates from the second half of the 9th century. It is precisely this kind of sundial that could be constructed using al-Khwārizmī's tables: for latitude 34° alone there are coordinates for each 20 seasonal minutes, as we find here. Apparently first published by Khalid Khalil Hamoudy in the Iraqi archaeological journal *Sumer* 45/1-2 (1987-88): 302, and found in the article «Samarra sundial (ساعة سماراء الشمسية)» in Arabic *Wikipedia* at https://ar.wikipedia.org/wiki/ ساعة سماراء الشمسية . This piece is new to the scholarly literature on the history of Islamic science. Not the least important aspect is that it is apparently signed by the astronomer, ʿAlī ibn ʿĪsà.

It was this kind of work that would have inspired the Ottomans' interest in horizontal sundials for it already contained a table for latitude 40° presenting the polar coordinates – shadow and azimuth – needed to plot the points of the hyperbolae corresponding to the solstices with the hour-lines. (The latitudes served were 12 values between 0° and 40°, with emphasis on 33° for Baghdad and 34° for Samarra). It remains unknown whether this manuscript was already in Istanbul in the 15th century. A similar range of latitudes is served by the tables of the 10th-century scholar al-Sijzī, extant in MS Istanbul Topkapı A3342 (fols. 114r-122v), copied in Damascus in 1236/37. These may well have been available in Istanbul at the time of Mehmet II. Otherwise such a table needed to be compiled afresh for latitude 41° or thereabouts. Or the sundial could be drawn using the kind of geometry laid out in the work of Thābit and others.

of the introduction and all the tables in Boris A. Rosenfeld *et al*., eds., *Al-Khorezmi* (in Russian), Moscow: Nauk, 1983, pp. 221-234. A new edition and an analysis of both sets of tables would be worthwhile. The fact that additional tables for [Samarra] with latitude 34° are included in the former might be indicative of the authorship of someone more innovative like Ḥabash al-Ḥāsib, who compiled other tables for the new Abbasid capital. In any case, it seems that fragments remain of a sundial for Samarra based on these coordinates – see Fig. 7.1.

7.2 The sundial by ʿAlī Qūshjī for Mehmet II

The 17th-century historian and tireless traveller, Evliyā Çelebī, with his «seemingly endless curiosity», records in his *Siyāḥetnāme* or travelogue that the highly influential astronomer to Mehmet II, ʿAlī Qūshjī, in 878H/1473~74 constructed a sundial for Fatih Mehmet in the courtyard of the Fatih Mosque.[252] This edifice, built between 867H/1463 and 875H/1470, was, as its name suggests, dedicated to Sultan Mehmet II. If the sundial was indeed in the courtyard, it would have been of the horizontal variety.

Now the same astronomer, who came from Samarqand to Istanbul only in 877H/1472, died in the Ottoman capital in 879H/1474. The recorded association of Qūshjī with the construction of a sundial for the Fatih Mosque in Istanbul is perfectly credible. Certainly, however, no horizontal sundial of consequence is to be found in the mosque today, possibly the result of damage to the Mosque complex itself; no image of one has ever been published.

The present sundial, which is unsigned, is an early modern replacement, a vertical one, very modern looking, with Arabic numerals for the hour-curves, whereas if there had been an original, it would probably have had numerals in the *abjad* notation.[253] In any case, the numerals here, like the sundial itself, look suspiciously modern. How and when the present sundial was put up, is perhaps explained in the copious explanations on the wall-plaques beneath it. The sundial serves only to indicate the time remaining until the beginning of the time of the *ʿaṣr* prayer and its end.

A certain amount of confusion surrounds this sundial. Some writers have even claimed that the splendid sundial in the Topkapı Palace was by Qūshjī.[254] What

252. *Evliya Chelebi's Book of Travels: Land and People of the Ottoman Empire in the Seventeenth Century*, recorded in Mayer, *Islamic astrolabists and their works*, p. 47; Brieux & Maddison, *Répertoire*, p. 391.

253. But see the Arabic numerals used for dates on two astrolabes made for Bayezid II – see §7.10a-b.

We have not seen the Turkish article on the reconstruction of the sundial by A. Bir and colleagues on the renovation of this sundial, mentioned in Umut, *Theoretical Astronomy in the Early Modern Ottoman Empire*, p. 44.

254. On the Topkapı sundial see the brief account in Atilla Bir, «The principle and use of Ottoman sundials». The sundial deserves a more detailed study and a critical look at the inscription. This maintains that it is a renovated 15th-century sundial.

perhaps happened here is that the existing historical vertical sundial on the wall of the Fatih Mosque has been thought to be that of Qūshjī, and several modern writers have stated this. Various reliable earlier sources mention this and add the date 878H/1473~74. For example:[255]

> Le premier cadran solaire d'Istambul fut construit dans la cour de l'Université en 1473 (878 de l'Hégire) et de nombreux autres lui succédèrent.

> The first sundial in Istanbul was constructed in the courtyard of the university in 1473 (878H) and numerous others succeeded it.

Yet this vertical sundial is unsigned and undated and less finely worked than one would expect from the Master. Qūshjī apparently did write words to the effect:[256] «Whoever contemplates the shadows on the surfaces of sundials will bear witness that this is due to something wondrous and will praise the astronomers with the most laudatory praise». So, although his sundial for the Fatih Mosque may be lost, his words can be said to remain true.

The Fatih Mosque was built by the greatest Ottoman architect, Sinān Pāshā. It is aligned in the *qibla*, that is, the direction toward Mecca that was accepted in Istanbul at the time (historical *qibla*s were not identical with modern ones, for obvious reasons). That *qibla* was 48° E of S (§6.9). The vertical sundial we have described is therefore on the south-western wall of the mosque, where the sun is shining during the afternoon. The major markings show the time in the afternoon and the smaller ones show the time remaining until the *ʿaṣr*, that is, the afternoon prayer.

7.3 Two sundials from Konya and Diyarbekir

It is also interesting to look at two Anatolian sundials, at least one of which seems to predate the time of Sultan Mehmet II. An early Islamic sundial is to be found in Konya, at the Ḥasan Pāshā Mosque. It is signed but apparently undated. Brief no-

255. Ünver, «Cadrans solaires en Turquie», pp. 257, 259, fig. 1), L. A. Mayer, *Islamic Astrolabists*, p. 43, and Maddison & Brieux, *Répertoire des facteurs d'astrolabes*, I, pp. 391-392, mention this and add the date 878H/1473~74.

256. From *Sharḥ Tajrīd al-ʿaqā'id*, Tehran edn., 1890, p. 187, cited in Ragep, «Ṭūsī and Copernicus», n. 32 on p. 159 (repr. in *Islamic Astronomy and Copernicus*, p. 293).

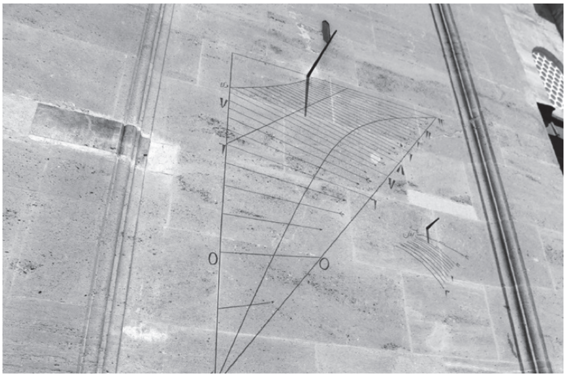


Figure 7.2: The vertical sundial on the wall of the Fatih Mosque, probably 16th or 17th century, though the numbers look 20th century. It is often confused with the horizontal sundial which ʿAlī Qūshjī made for the Mosque, which is lost. The construction of the markings on sundials was usually achieved by means of tables of coordinates. Image from www.imtilak.net/en/turkey/articles/fatih-mosque.

tices have appeared[257] but the piece has apparently never been published. It consists of an equatorial semi-circle marked with a horizontal diameter and ten equally-spaced radii defining 12 equal sectors. The gnomon may well originally have been horizontal, perpendicular to the wall. This is a very simple and inaccurate sundial on a south-facing wall, of which we know no other example from the Islamic world. Such hapless dials, lacking any scientific function, were a feature of early churches in England, where the surviving ones number over 5,000 and are called Mass dials or scratch dials.[258] On the Konya dial, there is still a gnomon, probably once horizontal, now appearing bent upward (but not for 38°), perhaps by a well-wisher trying to help improve it (?) for the latitude of Konya. The south wall is most likely facing neither the south nor the medieval *qibla* for Konya.[259]

Below the ensemble is the inscription اوقات الصلات, «times of the prayers». The vertical radius is labelled وقت الظهر, «time of the *ẓuhr* or midday prayer». The 9th radius is labelled as وقت العصر, «time of the *ʿaṣr* or afternoon prayer». It is surely to be understood that the two prayers begin at those times, the onsets of the 6th and 9th

257. Ünver, «Cadrans solaires en Turquie», p. 258, & Maddison & Brieux, *Répertoire*, I, p. 391.

258. See, for example, Peter T. J. Rumley, «Medieval Mass Dials Decoded», at www.building-conservation.com/articles/mass-dials/mass-dials.htm.

259. Compare *Historical Mosque Orientations*, pp. 706-708. On a historical *qibla* for Konya, see §6.9.

seasonal hours; however, the additional dotted radial lines associated with the two prayer-times are actually about 6h5m and 9h20m seasonal hours. For this we have no explanation. At the outer end of the extended dotted radial line for the *aṣr* is an asterism which seems to emphasize the importance of the prayer-time.

On the various available images of this Konya sundial, all of the inscription is legible. The maker is named but is otherwise unknown to us. It reads:

عمل هذه الرخامة العبد المحتاج الى رحمة الله الحسن الصائغ

This sundial was made by al-Ḥasan al-Ṣā'igh,
the servant needy of the mercy of God.

FIGURE 7.3a: The Konya sundial. Image from https://anadoludabugun.com.tr/foto-galeri/anadolunun-bilinen-en-eskisi-konyada-ama-cok-az-kisi-biliyor-124.

Although there is no date on the available image, some secondary sources give it as 812H/1409~10. The above website gives it as «the time of Karamanoglu», that is, late 14th to the end of the 15th century. This cannot as yet be countered.

The second sundial of interest is in the courtyard of the composite Ulu Cami (Great Mosque) in Diyarbekir, which part of the Mosque apparently dates from the 11th century.[260] The sundial is much later and is probably a replacement. It is

260. Since it is not signed, it is not featured in the standard repertories of L. A. Mayer or Brieux & Maddison. We have not located any worthwhile information on the sundial and have relied on images found on the internet.

horizontal, raised on a column, and the markings show the equatorial hours since sunrise (*ab ortu*).[261] It is unsigned and undated, but the choice of a Classical system for the hour-markings is a remnant of Byzantine practice also adopted by the Muslims, if only rarely on sundials. The gnomon is aligned with the celestial pole, as on the sundial of Ibn al-Shāṭir. The middle of the right side of the markings, for the afternoon, have been gouged out so that nothing remains of the curve for the *ʿaṣr*. No effort has apparently been taken to repair this. Likewise, the left side is damaged. An inscription, within an ellipse, is in Ottoman Turkish with considerable Arabic influence, but because of damage, only the initial word, غروبی (*ab ortu*), is legible. The sundial deserves further investigation. Judging by the Ottoman Turkish inscription, the sundial is perhaps from the 17th or 18th century. A metal railing around the sundial successfully prohibits anyone who would wish to read the hour from approaching the sundial. This has recently been painted bright blue, as has the gnomon.

Figure 7.3b: One of several images of the Diyarbekir sundial on the internet. It is encased in a metal band, and the column is surrounded by a tall metal railing. The railing and the metal band and also the gnomon have been painted bright blue. Image from https://www.mucadelegazetesi.com.tr/gunes-saati-850-yildir-zamani-gosteriyor.

261. Other satisfactory images are one by Tom Bresnaha at www.pinterest.com/pin/turkish-history-timeline--131871095315276781/, and another at https://www.alamy.com/view-of-old-ancient-stone-sundial-in-courtyard-of-ulu-grand-mosque-in-diyarbakirturkey-image214341627.html. There is even a 3D model at https://www.artstation.com/marketplace/p/qVVva/karamanoglu-sundial. Another image with a creative commons license, but on which the inscription is barely legible, is at: https://commons.wikimedia.org/wiki/File:Diyarbakır:_Ulu_Cami_Güneş_Saati1.jpg. Yet another is at https://foursquare.com/v/eb%C3%BBl-iz-el-cezeri-g%C3%BCne%C5%9F-saati/5dc12d92aff6dc0007b9f306.

Of interest here is a feature of the marble sundial from 696H/1296~97 which once adorned the spectacular Mosque of Ibn Ṭūlūn in Cairo.[262] On this, the *ʿaṣr* curve was carved erroneously so a second, correct one was carved alongside. Obviously, somebody was unhappy about this because the sundial was smashed to smithereens. Only good fortune led Napoleon's scholars to recover the pieces inside a column in the Mosque. They reassembled them and made a copy on paper, which is preserved in the *Description de l'Égypte*. (This inspired the French sundial specialist Louis Janin to suggest a publication). Perhaps there was a problem with the *ʿaṣr* curve of the Diyarbekir sundial and an equally destructive solution was pursued?

7.3c: Part of a historical sundial in the courtyard of the Grand Mosque at Şanlıurfa, that is, Urfa (Edessa), in South central Turkey. The formidable gnomon is unusual, and at least it is still in situ. The curve for the summer solstice has been drawn as two line segments meeting by the gnomon. From https://depositphotos.com/photo/view-old-ancient-stone-sundial-courtyard-ulu-grand-mosque-sanliurfa-212489530.html.

The sundial in the Ulu Cami of Şanlıurfa (Edessa) is apparently previously unknown to the history of science. It is mentioned in neither of the extensive articles «Şanlıurfa» nor «Grand Mosque of Urfa» on *Wikipedia* nor anywhere else. The massive gnomon is curious: to the angle of inclination of the plane of the sundial appears to be adjustable but this is unnecessary, and its upper edge is perhaps less straight than it should be. It is more important that we should see the scope of the markings on the sundial.

262. Janin & King, «Le cadran solaire de la Mosquée d'Ibn Ṭūlūn au Caire».

We can now take advantage of the appearance on the internet of the first acceptable image of a later Ottoman sundial, namely, that in the Mosque of Aḥmad Pāshā al-Jazzār, Governor of Acre during 1775-1805, who built the Mosque in 1781. The sundial was made by Ibrāhīm al-Faraḍī al-Kurdī in 1201H/1786~87 for the Governor al-Jazzār. It was the subject of an article by Arie Ben-Eli, curator of the Maritime Museum in Haifa, and Henri Michel, the Belgian engineer who was the author of one of the best books on the astrolabe ever written.[263] Otherwise, the significance of this «provincial» polar sundial for the history of Ottoman astronomy has been completely overlooked. Unique of its genre, it bears markings for a polar sundial, that is, parallel hour-lines across a surface parallel to the celestial equator with the gnomon perpendicular to this, that is, in the direction of the celestial pole (elevated above the north point by the amount of the local latitude). On the right side, notice the curve for the *ʿaṣr* at 2h 40m at the winter solstice to 3h 45m at the summer solstice.

The coordinates for marking such curves on a polar sundial are to be found already in the 9th-century treatise on sundial construction attributed to al-Khwārizmī mentioned above. The disadvantage of this kind of sundial is that it cannot be used when the sun has a southern declination, which is a good part of the year. This splendid device can serve as a reminder that Islamic astronomy lasted around a thousand years. The beautiful inscription could challenge any student of Arabic.

Beside the frequent early Ottoman treatises on the construction and use of the astrolabe and the astrolabic quadrant, we find rarer instruments mentioned in the manuscript sources. Thus, for example, the Turkish astronomer and historian of astronomy, Gaye Danışan, has published extracts from some Ottoman Arabic treatises on the linear astrolabe (*ʿaṣā Mūsà*) and cylindrical sundial (*al-usṭuwāna*). The relevant manuscripts were preserved in Kandilli Observatory Library, now catalogued; the cylindrical sundial is universal, but is too late in date for consideration here.[264] The universal function of the sundial is established by the fact that no latitude is indicated; the markings on the instrument should be compared with the relevant table in the treatise of al-Marrākushī. Later Ottoman instrument design can be of such sophistication that it defies classification within both the traditions of

263. Ben-Eli & Michel, «Un cadran solaire remarquable». The sundial is overlooked in the otherwise informative article https://en.wikipedia.org/wiki/El-JazzarMosque.

264. Danişan, «Cylinder Dials in the History of Ottoman Astronomy».

FIGURE 7.3d: The remarkable polar sundial in Acre. This fine image is by Benjamín Núñez González, and it is the best we have seen which includes both the sundial and the full inscription in all their glory. From https://commons.wikimedia.org/wiki/File:Mezquita_de_Al_Jazar,_San_Juan_de_Acre,_Israel,_2017_08.jpg.

Islamic and Renaissance European instrumentation.[265] Gaye Danışan has recently written on the instrument called *dā'irat al-muʿaddil*, the equatorial semicircle.[266] It was invented in Cairo by the Mamluk astronomer al-Wafā'ī, who was probably inspired by the compendium (*ṣandūq al-yawāqīt*) of Ibn al-Shāṭir, of which he owned an example.[267] The instrument became known in Istanbul, and various Ottoman treatises and examples survive. It was a device singularly limited in its application. Nevertheless, around 1450, al-Wafā'ī was the first to measure magnetic declination, and his value – true north is 7° east of magnetic north – is mentioned in his treatise. In this way, magnetic declination became known in the Ottoman world, but only centuries later was it realized that it depended on location and epoch.

7.4 On Ottoman astrolabes and treatises

The astrolabe is an instrument with which one can achieve the solution of many astronomical problems, for practical and didactic purposes, not including those relating to

265. Such is the universal horary plate illustrated in MS Cairo Egyptian National Library *riyāḍa* 40,2, fol. 45v, dated 1747, which is discussed in *Synchrony*, B, pp. 306-308.

266. Danişan, «A Sixteenth-Century Ottoman Compendium of Astronomical Instruments», pp. 10-11. For the first study, see Brice & Imber & Lorch, «The Dā'ira-ye Muʿaddal of Seydī Alī Re'is», and DAK, *Islamic Astronomical instruments*, XIII, and the literature there cited.

267. Janin & DAK, «Ibn al-Shāṭir's *Ṣandūq al-yawāqīt*», pp. 213-215 & pls. 8-9.

the (moon and) five planets, by the easiest procedures and simplest methods. (The Andalusī astronomer Abu ʿl-Ṣalt, *ca.* 1000, his treatise on the use of the astrolabe: see DAK, *Synchrony*, B, xiiie, pp. 603).

Ptolemy was riding on a donkey with an armillary sphere in his hand; it fell and the donkey trod on it and squashed it: the result was an astrolabe. (Imaginative anecdote recorded (not proposed) in a 13th-century Arabic historical text: see *Synchrony*, B, pp. 594-595. [Out of many medieval suggestions as to the origin of the astrolabe, this is the only one that is ever cited in the modern non-academic literature because it is cute, and false]).

The astrolabe is a working model of the heavens, a kind of analog(ue) computer. *It enables the user to represent the heavens with respect to the sky of an observer.* In the astrolabe, the celestial sphere has been projected onto a plane surface*, actually the plane of the celestial equator*. Thus, the astrolabe can be considered a two-dimensional version of a celestial globe or armillary sphere. The basic principle of the astrolabe was a discovery of the ancient Greeks, but the oldest surviving astrolabes are medieval. Throughout the Middle Ages, first in Islam and later in Christian Europe, the astrolabe was the most common astronomical instrument. When precise results were called for, the astronomer had recourse to specialized instruments and to tedious trigonometric computation *or to extensive tables for timekeeping (Islam only). Since the astrolabe is based on exact mathematical procedures, the accuracy of its various functions is limited mainly by the size of the instrument*. The beauty of the astrolabe was that approximate solutions (good to the nearest degree or so) to astronomical problems could be found by a mere glance at the instrument. (James Evans, *The History and Practice of Ancient Astronomy*, (1998), p. 141 (with authors' additions in italics)).

(The astrolabe) is not simply one object, it is many objects in one: an astronomical measuring device; a timepiece; an analogue computer; a two-dimensional representation of the three-dimensional celestial sphere; a work of art and a status symbol. (The British historian of science Tony Christie, in «The astrolabe – an object of desire» (2016)).

The astrolabe is a symbol of astronomy in late Antiquity, the Islamic Middle Ages, the European Middle Ages, and the Renaissance. You can set it to show the instantaneous configuration of the heavens as they appear in your own sky. It is a veritable model of the universe that you can hold in your hand. The rete or star-map bears pointers for a selection of bright stars and a ring for the apparent path of the sun against the background of stars. This can rotate over the plates for different latitudes, showing the horizon and meridian and altitude circles up to the zenith of the observer. The astrolabe is primarily an instrument for reckoning time of day or night because one rotation of the celestial part over the terrestrial part corresponds to one rotation of the heavens about the observer, that is, 24 hours.

There is an imposing amount of excellent modern literature on the astrolabe and its history,[268] as well as numerous reliable catalogues of the major and minor museum collections, from which one can make regional surveys.[269] Anyone can tap into this at any level in libraries or on the internet. Yet much of this modern literature is based only on medieval treatises on the astrolabe, without reference to surviving instruments, and these texts tell only part of the story. The instruments themselves can speak to us, if we understand their language, and they tell a very different story from what we can learn from texts, one that is far more interesting.

In a 2018 study, the first author attempted to explain anew what an astrolabe is by means of some of the many surviving examples, and to convey some of its potential and its usefulness and its magic, also to introduce the available reliable literature on it, popular as well as academic.[270] Some remarkable discoveries have been made in the past few decades by scholars who know the language of instruments and who afford them the same importance as textual sources, if not more, for many instruments tell us things that are not recorded in any texts. And there are still plenty of surviving astrolabes deserving of detailed study. The

268. For reliable introductions see Willy Hartner's article «Asṭurlāb» in *Enc. Islam*, 2nd edn., and David Pingree's article «Asṭorlāb» in *Enc. Iranica*. Henri Michel's excellent book *Traité de l'astrolabe*, 1947, has been replaced by Jim Morrison's book, *The Astrolabe*, 2007. See also DAK, «The neglected astrolabe», in *Synchrony*, B, pp. 339-402, and n. 271 below.

269. All Eastern Islamic astrolabes to *ca.* 1100, some 20 altogether, are catalogued in *Synchrony,* B, pp. 403-544. All Andalusī and Spanish astrolabes to *ca.* 1500, some 50 altogether, are catalogued in Azucena Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 2018. We are far from having a catalogue of all surviving examples, such as Raja Sarma's monumental catalogue of Indian astrolabes (https://srsarma.in/catalogue.php). For the time being, we still do not have surveys of astrolabes from Safavid Iran or from medieval France or Germany or England, or anywhere else.

270. This is discussed in DAK, *The Astrolabe*, 2018, available at www.academia.edu/92556795/, which was intended as a supplement to the standard sources.

plethora of inaccurate literature currently appearing on the astrolabe prompted the first author to survey it.[271]

Islamic astrolabes were originally (8th century) derived from and inspired by Byzantine ones, and production and development of serious instruments continued for over a millennium (19th century). Different regional schools produced different designs and modifications. The major centres of production were Baghdad, Isfahan, Cairo, Rayy, Tunis, Marrakesh, al-Andalus, Samarqand, Yemen, and Istanbul. Astrolabe-making in Morocco and Iran and Muslim India continued longer but also more prolifically. Here we treat some astrolabes with a connection to 15th-century Istanbul, one of which is spherical as opposed to the standard planispherical (flat) ones. Quadrants were of three types, sometimes two on a single piece.[272] There were latitude-specific and universal horary quadrants (*rubʿ al-sāʿāt*, also *āfāqī*) in a tradition dating from 9th-century Baghdad. There were trigonometric quadrants (*rubʿ mujayyab*) with a grid for performing calculations, dating back to the same epoch; we have a magnificent example by Hibat Allāh al-Baghdādī in 1120.[273] And there were astrolabic quadrants for a specific latitude (*rubʿ al-muqanṭarāt*), apparently first developed in Cairo in the 12th century.[274]

The only surviving 15th-century Ottoman astrolabes are the three pieces dedicated to Bayezit II discussed in §7.9. No quadrants are known from this milieu, and no celestial globes or armillary spheres. There are, however, treatises on all such instruments dedicated to him, besides the treatise of al-Marrākushī, surely more than we are able to list here. All such treatises are in the same vein as those compiled in Mamluk Egypt and Syria, except that they can now be in Arabic, Persian, or the new language of Ottoman science, Turkish.

271. We are currently witnessing an unprecedented amount of unnecessary wordage, fake news, if you like, on the astrolabe by moderns who have never held an astrolabe in their hands or who have no idea about the literature available on the instrument or who have no idea about the history of astronomy. They are quite happy to write about the history of the instrument as they see it, the theory behind it as they discover it, the ways in which it was used in navigation (it was not), and the ways it constituted a kind of smart phone for ancients and medievals (who knew more about spherical astronomy than most folk nowadays and who did not need smart phones). One result of this is the 2024 fiasco mentioned in n. 296.

272. For an overview see the article «Rubʿ [= quadrant]» in *Enc. Islam*, 2nd edn.

273. See *Synchrony*, B, p. 73.

274. Ibid., p. 79.

First, there is perhaps a copy of one of the most significant Arabic treatises on the astrolabe, the *Istīʿāb fī wujūh ṣinaʿat al-asṭurlāb* of al-Bīrūnī in an Istanbul manuscript.[275] Then there is a treatise in Persian on the construction and use of the sphere in 7 chapters dedicated to Sultan Bayezid (II) in MS Paris BnF pers. 793, in 20 folios, copied in Mecca in 999H/1590 by the calligrapher Sulṭān al-Harawī and later owned by Muṣṭafà Ṣidqī.[276] Qāḍī Zāde dedicated to Bayezid II a Persian treatise on the astrolabic (almucantar) quadrant, extant in MS Paris BnF 792, a late-16th-century copy in 20 chapters.[277] The Arabic treatise by the prolific Muḥammad ibn Kātib Sinān Qunawī on the astrolabic quadrant dedicated to Bayezid II is extant in several manuscripts, and the contents have been surveyed by Taha Yasin Arslan.[278] Of the many surviving Ottoman quadrants none is so early as the 15th or 16th centuries.

Finally, there is an anonymous treatise in Persian dedicated to Bayezid II on an instrument similar to the *ṭabaq al-manāṭiq* of the great Samarqand astronomer Jamshīd al-Kāshī, extant in MS Princeton 75, with 37 folios, an early-16th-century copy. That instrument is a planetary equatorium for demonstrating the relative motions of the sun, moon and planets.[279] Alas, no Islamic equatoria have survived intact.

7.5 A Byzantine astrolabe from Constantinople reinstated

> The large astrolabe in the Museo dell'Età Cristiana at Brescia is remarkable not only because its Byzantine origin makes it an object of great rarity, but also on account of the inscriptions which it bears. One of these, in five iambic verses, declares the general uses of the instrument, ending with the name and nationality of the person who had it constructed. (O. M. Dalton, «Byzantine Astrolabe», p. 133).

275. Arslan, «Qunawī on the Astrolabic Quadrant», p. 101, states that MS Ayasofya 2576 is a copy of *al-Bīrūnī's* treatise bearing Bayezid II's mark of ownership, but Krause, «Stambuler Handschriften», p. 479, no. 218/2, states that it is late, and the other two Istanbul manuscripts are from the 13th and 17th centuries.

276. In Blochet, *Catalogue des manuscrits persans*, II, no. 793, this is stated to be a treatise on the astrolabe. On Muṣṭafà Ṣidqī, see n. 176.

277. Blochet, *Catalogue des manuscrits persans*, II, no. 792.

278. Arslan, «Qunawī on the astrolabic quadrant».

279. Storey, *Persian Literature*, IIi, p. 79, no. 117. On al-Kāshī's treatise on the instrument, see E. S. Kennedy, *The Planetary Equatorium of Jamshīd Ghiyāth al-Dīn al-Kāshī*. Princeton: Princeton University Press, 1960. On al-Kāshī, see the article in *BEA* by Petra Schmidl.

Those who are familiar with fine oriental or western instruments will observe that the workmanship of this Byzantine example is by comparison rude and unattractive throughout, the whole producing an impression of relative clumsiness. The detailed examination of this astrolabe has shown that it is wholly Byzantine. Except for the incidental mention by Sergios of his Persian descent, we find nothing in the object itself or its inscriptions at all suggestive of oriental influence. (Ibid., p. 135 + p. 143).

L'unique astrolabe byzantin que nous possédions est signé par un certain «Sergios le Persan, de rang consulaire»; au moins une des étoiles de (l'araignée de l'astrolabe de 1062) montrent clairement une influence arabe [*sic*] ; enfin, la disposition générale de l'instrument rappelle fortement [*sic*] des instruments analogues mais d'origine islamique, du xe siècle. Autrement dit, cet astrolabe est un bon témoin des échanges islamo-byzantins au xie siècle, et ne peut passer, en rigueur de termes, pour un astrolabe byzantin [*sic*] : c'est plutôt un astrolabe produit à Byzance. Et sans doute cela est-il dû au fait qu'il n'y avait pas d'autre artisan capable de produire des astrolabes à Byzance [!!]. / Summary:This astrolabe cannot pass for a Byzantine astrolabe; rather, it is an astrolabe made in Constantinople. And that is doubtless due to the fact that there was no other artisan capable of making astrolabes at Constantinople [!]. (The French historian of science Alain-Philippe Segonds (1942-2011), in the notes to his 1981 edition and translation of the Greek astrolabe text of *Philopon sur l'astrolabe*, pp. 87-88).

C'est du xe siècle, aussi, que date le seul astrolabe byzantin conservé, l'astrolabe de Brescia, exécuté pour un certain Sergios, d'origine persane, et qui semble marqué d'une influence orientale. (Anne Tihon, «Les sciences exactes à Byzance», 2009, p. 18).

«[...] only one Byzantine astrolabe, the so-called Brescia astrolabe, survives today: it dates from 1062 and manifests [!] Persian [!] influence» (Lazaris, ed., *Companion to Byzantine Science*, p. 100, n. 223); «[...] an astrolabe from 1062 showing Arab influence [!]» (ibid., p. 100); «Although made for the latitude of Constantinople, the instrument was influenced by Arabic instruments [!]» (ibid., p. 214).

A substantial Byzantine astrolabe, diameter 37.5 cm, made in Constantinople in 1062, has been preserved for us in the Santa Giulia Museo della Città in Brescia.[280] Its presence in Brescia is attested since 1844. It is (or, rather, should be) important

280. Dalton, «The Byzantine Astrolabe at Brescia»; and Gunther, *Astrolabes of the World*, i, pp, 104-108. See more recently DAK, «The Byzantine astrolabe of 1062», also *Astrolabes and Angels*, pp. 27-31 & 221-233; and Brieux & Maddison, *Répertoire des facteurs d'astrolabes*, i, pp. 315-316. See also the next note.

for Byzantine Studies and in the history of Byzantine astronomy but it has been largely overlooked in those disciplines because it was commissioned by Sergios, a government official (*protospatherios*) with Persian ancestry and because the instrument was wrongly thought to display Islamic influence, considered to be not a good thing. (Also, some of our colleagues are more interested in texts than instruments, and the latter invariably do not correspond to the former). The first description, in 1926, was one of the first proper descriptions of an astrolabe made in the West. It appears that no Byzantinist has written anything accurate about the Byzantine astrolabe since then.

Ormonde Maddock Dalton (1866-1945) was a British museum curator and archaeologist. Though very much an all-rounder, his main expertise was in medieval art. In 1911 he published a monumental 727-page volume on *Byzantine Art and Archaeology*, a handbook of art and artefacts, including several objects from Brescia but not the astrolabe. From 1921 to 1928, he was Keeper of the British and Medieval Antiquities Department at the British Museum, and it was in 1926 that he published a brilliant study of the Brescia astrolabe, as sound technically as it was philologically. Dalton was a little condescending about the workmanship of the piece, probably comparing it in his mind with the spectacular Sloane instruments in the Museum, Islamic and Medieval European, both several centuries later. Robert Gunther, author of the two-volume *Astrolabes of the World*, 1932, and the 14-volume *Early Science at Oxford*, 1923-45, accepted Dalton's assessment of the piece.

The piece is simply the sole surviving Byzantine astrolabe, with a bird most probably symbolizing the Holy Spirit — a common Byzantine motif[281] — on the central pointer for (α) Lyra(e) on the rete. (A bird on any other Byzantine decorative object would be considered to have had this association. The problem that we have

281. DAK, *Astrolabes and Angels*, pp. 227-228. See Dorothy Resig Willette, «The Enduring Symbolism of Doves – From ancient icon to biblical mainstay», at https://www.biblicalarchaeology.org/daily/ancient-cultures/daily-life-and-practice/the-enduring-symbolism-of-doves/, also also https://www.christianity.com/wiki/holy-spirit/why-is-the-dove-often-a-symbol-for-the-holy-spirit.html. For Byzantine examples, see articles «Birds» and «Holy Spirit» in *The Oxford Dictionary of Byzantium*, or google «byzantine bird». On the charming Attarouti dove, fashioned in Syria 500 years before our astrolabe, see https://www.metmuseum.org/art/collection/search/466135.

The bird on the Byzantine astrolabe is certainly not the eagle sent by Zeus to rescue the lyre of Orpheus from the river (https://www.constellation-guide.com/constellation-list/lyra-constellation/. Nor is it the goose in the jaws of the fox of the nearby constellation Vulpecula (Gloria Vallese,« Possible representations of Vulpecula in some Italian medieval monuments», 2021, at www.academia.edu/66079152/).

Figure 7.5a: The front of the Byzantine astrolabe of 1062. This instrument shows not one iota of external Islamic influence! Image courtesy of the Santa Giulia Museo della Città in Brescia.

Figure 7.5b: Three birds surrounding a man – John the Baptist (?) – carrying a cross on a Byzantine pottery bowl dated to the 5th century, found in Chersonesus (presumably Crimea not Thrace) in 1904. Image from Banck, *Byzantine Art in the Collections of the USSR*, no. 24 and p. 336 («three doves»).

is: the bird on the Brescia astrolabe has been falsely pronounced as mimicking the bird on early Islamic astrolabes; in fact, the earliest Islamic astrolabes mimicked the bird on Byzantine astrolabes). The 14 stars on the rete are from the 17 of the earliest Greek texts on the astrolabe. The plates serve the latitudes of Rhodes 36°, Constantinople 41° and Hellespont 40°, with altitude circles for each 6°. In addition, we are here witness to the form in which the astrolabe was adopted by the Muslims from the Byzantines, bearing in mind that the Brescia astrolabe is a *Prachtstück*, surely much larger and more richly decorated that more typical Byzantine astrolabes (none of which exist).

There is no need to repeat here the names of scholars who, in all innocence, have stated that the piece is not genuinely Byzantine or who have thought the bird was Islamic. There is, in fact, not a single external aspect of the Brescia astrolabe that is «Islamic», at first sight (the pointless squares on the back are a later addition). Elsewhere we have documented decades of neglect, nay, abuse, of the Brescia astrolabe. We give here just one example: some colleagues have been misled by the bird for the star constellation Lyra on the rete, which the Muslims adopted for the star Vega, from النسر الواقع, the falling eagle. In fact, it is the Islamic astrolabes that copied the Byzantine motif. Sadly, this kind of misinformation, and more besides, has accumulated over the years,[282] and, as a result, the Byzantine astrolabe has not fared well in modern writings on the history of Byzantium, the history of Greek astronomy, or the history of Byzantine astronomy. It is even ignored in works on Byzantine astrolabe texts! There is not a single sentence about it in the new 650-page *Companion to Byzantine Science* that is accurate. The Brescia astrolabe is mentioned in passing in one sentence in a footnote in a recent article on traditions of Byzantine astrolabes in Renaissance Europe; the author is apparently oblivious to the fate and fortunes of the piece in Renaissance Italy.[283]

We trust that henceforth the Brescia astrolabe will be treated with the respect that it deserves, not least now that we have (1) re-established its Byzantine credentials, and (2) established its tentative connection with Bessarion and Regiomontanus. Scholars of the history of Byzantine science should know that this is surely a very fine example of a Byzantine astrolabe. Smaller and less ornate examples have not survived: these would have been the earliest models that the Muslims had at their disposal to copy. The earliest known Islamic astrolabes are indeed very simple, much simpler than those known to Dalton and Gunther.[284] A real standard Byzantine astrolabe surely looked like the very earliest Islamic astrolabes we have from the 8th and 9th centuries.

This having been said, our colleague Burkhard Stautz, in his 1997 investigation of star-positions on historically-significant astrolabes, has shown that the star-positions on the Brescia astrolabe correspond to a date of around 1062 only if one assumes an Islamic value for precession added to the Ptolemaic positions of the selected stars, not the incorrect Greek value.[285] This calls for further investigation of the Byzantine sources.

Worth mentioning also is the fact that the 1062 Byzantine astrolabe is the earliest dated non-Islamic astrolabe to have survived. In other words, there are ear-

282. DAK, *Astrolabes and Angels*, pp. 220-233. See also Field & Wright, «Gears from the Byzantines» (1985), pp. 114-115, where it is compared with a contemporaneous Islamic astrolabe (published in *Synchrony, B*. pp. 517-528), to which it actually bears no resemblance whatsoever.

283. Darin Hayton, «Traditions of Byzantine astrolabes in Renaissance Europe», p. 190, n. 23.

284. Described in *Synchrony*, B, pp. 403-437, and «Two newly-discovered astrolabes from Abbasid Baghdad», *Suhayl* 11 (2012): 103-116, at https://raco.cat/index.php/Suhayl/article/view/267221.

285. See Stautz, «Die früheste bekannte Formgebung der Astrolabien», and idem, *Untersuchungen von mathematisch-astronomischen Darstellungen auf mittelalterlichen Instrumenten*, pp. 40-43, 180-181.

lier dated Islamic astrolabes, and there are earlier European astrolabes that are not dated. The piece is also unique in that it led to an encounter of three of the greatest minds of the European Renaissance — see below.

Standard Byzantine astrolabes would have had plates for the seven climates, as we learn from astrolabe treatises. This is also true for the earliest Eastern astrolabes, copied from Byzantine ones, and for one set of manuscript illustrations of an early Western Islamic astrolabe, inspired by an Eastern Islamic one. Some of the earliest European astrolabes gave plates for the climates. In all four traditions, an effort was made to make the plates more user-friendly, namely, to serve specific localities. As we shall see, Andalusī astrolabists went overboard in their efforts in this direction: one plate is even marked for a locality in China! Remnants of the climates or their latitudes continued to be used. We include here some remarks about the transmission of astrolabes from one cultural region to another. A more detailed account is in preparation.

Excursus significans: On the transregional transmission of astrolabes

a) Byzantine astrolabes inspire the earliest Eastern Islamic astrolabes

It is generally accepted that the Muslims, probably in the 8th century, first encountered the astrolabe in the city of Harran. The 10th-century Baghdad bibliographer, Ibn al-Nadīm, in his *Fihrist* or *List of Books*, cites al-Fazārī as the first Muslim to make an astrolabe.[286] He also lists the names of some 25 makers of astrolabes, mainly in Baghdad.[287] Only since about the year 2000, we have one complete Eastern Islamic astrolabe and one incomplete piece datable at least to the early 9th century, if not the late 8th.

We are now in a position to witness the nature of the transmission of the astrolabe from Byzantium to the Muslim world. The earliest surviving complete Islamic astrolabe is small and somewhat crudely fashioned, and it has astrolabic markings for each of the seven climates — see Fig. 6.8a.[288] Otherwise, it bears some of the distinctive features of the Brescia Byzantine astrolabe: there are no

286. On al-Fazārī, see n. 41 above.

287. See the Arabic text with annotated translation and commentary in *Synchrony*, B, pp. 453-455.

288. A full description is ibid., pp. 403-408.

markings on the back; the bird on the rete is now purely decorative and surely inspired by the traditional Arabic name for α Lyrae, namely, النسر الطائر, *al-nasr al-ṭā'ir*, «the flying eagle». The positions of the stars are for *ca.* 500, indicating that it was copied from a very old Byzantine astrolabe, and the bird is actually on the pointer for *al-hawwā'*, «the snake charmer»; this invites further discussion.[289] The precious instrument was in the Archaeological Museum in Baghdad, at least until the illegal US/UK invasion of 2003; nobody knew that it was of prime importance. The other fragment, damaged by water corrosion, was clearly originally the same size and format.[290]

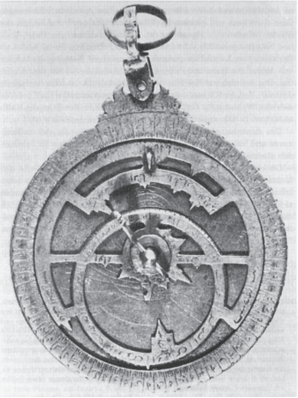


FIGURE 7.5c: The front of the earliest known Islamic astrolabe, datable to the 8th century. See also Figure 7.5f for the rete. The original kufic engraving has suffered partial reworking at a later date, purporting to identify a maker with an Ottoman- type name. Images from *Synchrony*, B, pp. 412, 413, 435.

Within decades, a distinctive style rete, which we call Abbasid, had developed. Some 20 Eastern astrolabes from the period 800-1100 bear witness to this development, and they have been published in detail with ample illustrations.[291]

289. See already Stautz, ibid., pp. 39-43 & 179; and *Synchrony*, A, pp. 403-437.

290. *Synchrony*, B, p. 432.

291. *Synchrony*, B, pp. 403-438, on the earliest piece and the fragment of a second, and pp. 439–544, on the others.

b) Byzantine & early Eastern Islamic astrolabes inspire the earliest known Western Islamic (Andalusī) astrolabes

For some time, we have known of two Latin manuscript illustrations of early Andalusī astrolabes[292] and one actual astrolabe,[293] of which we can say it precedes in type and detail the 35-odd later Andalusī astrolabes that have survived, and that it is moderately but significantly different from them. These instruments are all published in minute detail — altogether 35 Andalusī and 15 Christian Spanish pieces – by the Spanish art and science historian Azucena Hernández Pérez.[294]

Just this year, 2024, we have been introduced to a second Andalusī astrolabe which likewise precedes the majority, namely, one discovered in a private library in Verona by Italian art historian *cum* astrolabe *aficionada* Federica Gigante.[295] The

292. We refer to the illustrations in MSS Paris BnF lat. 7412, fol. 19v, and Vatican Reg. lat. 598, fol. 120r, which are not directly of concern here. For investigations of both of these, see, for example, Kunitzsch & Dekker, «The stars on the rete of the so-called "Carolingian Astrolabe"». For the former, see Kunitzsch, «Traces of a Tenth-Century Spanish-Arabic Astrolabe»; *Synchrony,* B, pp. 383, 928, 951, and idem, «The Astrolabe», fig. 5. On early Latin astrolabe texts, see Borrelli, «Aspects of the astrolabe in 10th- and 11th-century Europe».

293. DAK, «Earliest European Astrolabe», figs. 3 & 4a; *Synchrony*, B, pp. 350 & 352; Kunitzsch & Dekker, *op. cit*., pp. 657, 671; Hernández, *Astrolabios en España*, II, pp. 35-42, and Gigante, «Verona Astrolabe», p. 173.

294. Hernández, *Astrolabios en la España medieval*, 2018, introduced in n. 270.

295. Gigante, «Verona Astrolabe». This new study contains superb illustrations and a detailed description, but the commentary is wanting or incorrect. For example, the information on the plates could easily have been exploited and compared with that on other early Andalusī instruments, and the two persons with Muslim names mentioned in the later Arabic inscription, Isḥāq and Yūnus, are most certainly not Jewish. One original plate is missing; the inclusion of a spurious plate for Cairo from another Andalusī or Maghribī astrolabe does not mean the piece was ever taken to Cairo — see n. 303.

These problems notwithstanding, the «discovery» was greeted with much hype and yet more exaggeration in the press worldwide and the internet news agencies. See, for example, Sam Jones, «Extraordinary»: Islamic and Jewish science merge [*sic*] in 11th-century astrolabe — Instrument was adapted [*sic*], translated [*sic*] and corrected [*sic*] by Muslim and Jewish users in Spain, north Africa [*sic*] and Italy», *The Guardian*, 05.03.2024, at https://www.theguardian.com/world/2024/mar/05/extraordinary-islamic-and-jewish-science-merge-in-11th-century-astrolabe. To be precise, the only intervention of an astronomical nature by a Jew was to scratch the Hebrew names of some of the zodiacal signs and the incorrect latitudes on the plates. See DAK, «Elusive Astrolabes» (2024), Appendix G, for more details.

FIGURE 7.5d: The hitherto earliest known Andalusī astrolabe, with an Abbasid-type rete (bearing later Italian inscriptions), astronomical markings featuring several localities (including Medinaceli), and a single shadow square and non-concentric solar scale (cf. Nasṭūlus' horary instrument, §5.2) on the back. Images courtesy the British Museum, London.

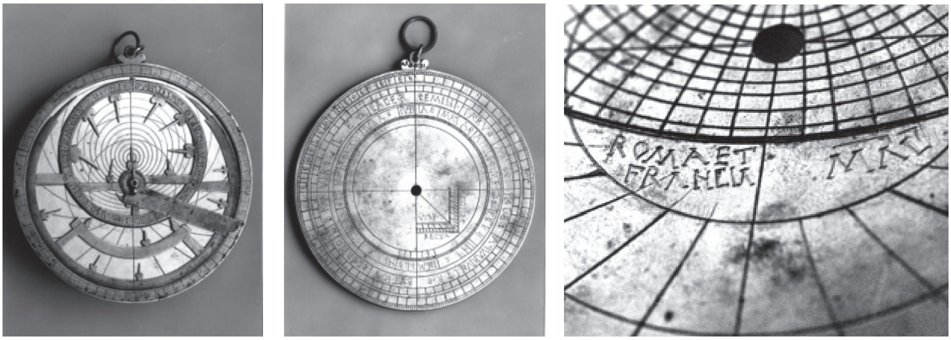
two astrolabes are both dateable to the 10th century, or, at least, they clearly precede in design and detail those of the 11th. These four early Andalusī examples have retes which resemble those on contemporaneous Eastern Islamic (Abbasid) ones. The two astrolabes have, in addition to their Abbasid-type retes, just one shadow square on the back (introduced in Baghdad *ca.* 850[296]), and astrolabic markings for various latitudes mentioning various associated localities. The Paris BnF illustration of an early early Andalusī astrolabe shows a series of astrolabic markings for the seven climates, thereby continuing the tradition of the Byzantine and earliest Abbasid astrolabes. We note that the astronomical markings for latitude 41;30° or 42°, only on these two surviving instruments, specifically feature the town of Medinaceli, halfway between Madrid and Saragossa — see further below. Within decades, Andalusī astrolabe retes developed their own distinctive style.[297]

Numerous other Andalusī astrolabes have Hebrew scratchings, mainly inconsequential like these, and not a few have later inscriptions in Latin, generally of no scientific merit but of considerable linguistic and historical interest.

296. On the origin of the shadow scales on astrolabes, see *Synchrony*, B, pp. 247-252, also Charette & Schmidl, «al-Khwārizmī on the astrolabe», esp. pp. 114, 139, 165-166, for the humble but promising precursor of the standard shadow scale.

297. The newly-published long-awaited *Répertoire des facteurs d'astrolabes* of the late Alan Brieux and Francis Maddison is now published, thanks to the intervention of a team at C.N.R.S., Paris. The second volume consists entirely of images of Islamic astrolabes and quadrants, grouped

c) Early Andalusī astrolabes inspire the earliest known European astrolabes.



Figures 7.5e: The Destombes astrolabe with its rete and unusually-shaped, unlabelled and incorrectly-placed star-pointers, together with a concentric solar scale and single shadow-scale on the back. The enigmatic inscription roma et francia on the plate for latitude 41;30° is also shown. Even the simple throne is significant in searching for the inspiration for this instrument. Images courtesy of the Institut du monde arabe, Paris.

The earliest known European astrolabe with Latin inscriptions was copied from an early Andalusī instrument, now with inscriptions in Latin. It was brought to the attention of scholars in 1962 by its new owner, the French naval officer and cartography historian, Marcel Destombes. Alas, French medievalists were trained only in astrolabe texts rather than instruments and declared the new piece suspicious or even a fake. In 1995 in Saragossa, a group of international scholars attempted to investigate the instrument anew and reinstate it to its proper place as the most precious physical symbol of the transmission of science to the West.[298] More recently,

chronologically by region. The first volume contains the information on the makers, arranged in the same way, and is more complete than L. A. Mayer's *Islamic Astrolabists* (1956).

298. Stevens *et al*., eds., *The Oldest Latin Astrolabe* — see especially the contributions of Samsó and King, and the paper by Anscari Mundó showing that the original inscriptions correspond to 10th-century Latin engravings from Catalonia. The proposal by DAK of a possible Roman connection to the astrolabe is to be abandoned, now that the relevant Arabic geographical data from early astrolabes has been evaluated. Also, Kurt Maier (p. 379) showed that the later inscriptions on the rete featured Catalan Latin, so that the piece remained in Catalonia. Some Parisian colleagues remained unconvinced of the genuineness of the piece. A more recent study is Kunitzsch & Dekker, «The stars on the rete of the so-called «Carolingian Astrolabe»», and an overview of the piece as one of 14 «landmark astrolabes» is in DAK, *Astrolabes and Angels*, pp. 209-211.

Paul Kunitzsch and Elly Dekker have established that the star-positions on the Destombes astrolabe are inaccurate, which is hardly surprising.[299] Numerous questions remained unresolved, only one of which we can address here.

Why, on one of the plates was there an inscription «ROMA ET FRANCIA 41 30», and *what* was it supposed to signify? *What* this meant was proposed already by Marcel Destombes and clarified by Julio Samsó, who pointed out that «Francia is a translation of what the Muslims (10th-12th centuries) called the افرنجة, *Ifranja*, «(land of the) Franks», referring to the Marca Hispanica, the lands of the Christian kingdoms in the north-east of the Iberian peninsula.[300] We here seek only the inspiration for the enigmatic inscription on that plate.

We note that the two earliest Andalusī astrolabes have astrolabic markings for latitude 41;30° serving the town of Medinaceli, halfway between Madrid and Saragossa, and they are the only ones which feature this town. Surviving Andalusī astrolabes of the late 10th and 11th centuries have a cluster of localities featured on the plates for 41;30° and 42°,[301] namely:

Barbastro (41;30°x2) — Calatayud (41;30x4) — Daroca (41;30x1) — Huesca (41;30x3) — Lérida (41;30x4) — Medinaceli (41;30x1, 42x1) — Santarém (40x1, 41;30x1, 42x1) — Saragossa (41;30x7, 42x7) — Toledo* (41;30x1) — Tortosa (42x1) — also Khwarizm (41;30x2) — Rome (41;30x2, 42x1)

[* Toledo is out of place here]

These Andalusī localities correspond to FRANCIA on the Destombes astrolabe. The later Andalusī astrolabes also have some Eastern cities rather arbitrarily featured, such as Cairo and Khwarazm and Mansura (in India, but stated to be in China). The latitudes associated with these localities are mainly taken from an anonymous adaptation of the geographical tables of al-Khwārizmī (Baghdad, *ca.* 830), extant in the unique copy MS Istanbul Aya Sofia 4830 (fols. 194v-196r, cop. Damascus in 626H/1228~29; see §7.1 — Kennedy & Kennedy's KHZ).[302]

299. Kunitzsch & Dekker, *op. cit.* (n. 299).

300. Samsó, «*ROMA ET FRANCIA* (= Ifranja)»,

301. Taken from DAK, «The geographical data on early *Islamic astronomical instruments*», in *Synchrony,* pp. 915-962. This surveys the latitudes and associated localities on 45 of the earliest astrolabes.

302. For this source, KHZ, see Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. xxiv and 410-412.

One of the «Eastern» localities on the plates for latitude 41;30° or 42° on three later (11th-century) Andalusī astrolabes is Rome. We also note that the table KHZ has 42;10° for Khwarazm and 41;50° for Rome. We propose that ROMA was included on the Destombes astrolabe not because anyone wanted to go there but simply because it was included in the Eastern geographical source that the astrolabists in al-Andalus favoured.[303] Further investigation of these untapped sources of geographical data would be worthwhile.[304]

The bird on the Byzantine pointer for the star α Lyrae had a chequered fate on later astrolabes. First, it reappears on the earliest Islamic astrolabe and various later Eastern Islamic astrolabes; see, for example, the fine astrolabe from Isfahan dated 1223.[305] Now we have a bird on the pointer for Vega on the very early Verona astrolabe rete from al-Andalus.[306] And, last but not least, we have a cockerel on the pointer for CAENT (Vega) on a Catalan astrolabe from *ca.* 1300.[307] The distinctive rete on the Judaeo-Arabic astrolabe[308] is related to this last, but now the bird is no more; the bird is gone, as are the *miḥrāb*-shaped niches (introduced on 11th-century astrolabes) are gone, and the quatrefoil[309] has degenerated (even though this originally Byzantine feature is widespread on astrolabes with Hebrew inscriptions by Jewish craftsmen).[310] A more detailed study would be in order. In this, it

303. It is necessary to distinguish between astrolabes which really did travel — see Schmidl, «Knowledge in Motion: An early European astrolabe and its possible medieval itinerary» — and those which did not. Thus, the astrolabe described by Gigante travelled from al-Andalus to Italy, but it did not necessarily travel to the Maghrib and to Cairo, as she claims. Now Thomas Freudenhammer in a 2023 paper «The Destombes Astrolabe and Early Medieval Travel between Al-Andalus and Francia», attempts to show that the piece was made for a trip to (the real) Francia, that is, Germania, with an optional trip to Rome. In fact, the Destombes astrolabe was in Catalonia for several centuries, as we know from the later inscriptions on the rete (see n. 299).

304. See already DAK, «An Ottoman astrolabe full of surprises», which describes an Andalusī set of plates including one for the Ptolemaic latitude of «Anti-Meroë» at 16;30° south of the Equator (see already n. 97).

305. Gunther, *Astrolabes*, pl. XXIV, opp. p. 118.

306. Gigante, «Verona astrolabe», pp. 174 & 185.

307. Gunther, *Astrolabes*, II, p. 307, and Maier & King, «Society of Antiquaries Astrolabe», pp. 682-683 & 713.

308. On the Judaeo-Arabic astrolabe, see n. 187.

309. On the quatrefoil as decoration on Islamic, Jewish and early Christian astrolabes, see *Synchrony,* XVII, pp. 963-991.

310. Some 10 astrolabes with Hebrew inscriptions have been known since the 1980s (*Astrolabes from Medieval Europe*, XII, pp. 6-7) but no overview of these has been unpublished. On the

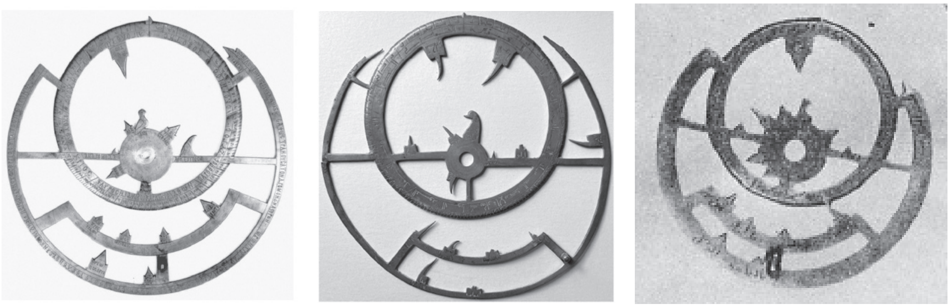


Figure 7.5f: The retes of the Byzantine and earliest Islamic astrolabes can be compared, bearing in mind that the former postdates the latter by some three centuries. Note the horizontal bar is rectilinear. These can now be compared with one of the two earliest Andalusī retes, namely, that of the Verona astrolabe. The horizontal bar on the latter is now counterchanged at the centre. We are seeking to compare types, not specific instruments.

should be borne in mind that in Italy, the earliest treatises on the astrolabe, namely, those by the Jewish scholar Ibn Ezra *ca.* 1125, appeared about one century after the treatise by Hermannus Contractus in Germany, and that the earliest surviving astrolabes from Italy have not yet been systematically studied.

d) The Byzantine astrolabe in Italy

Somehow the sole surviving Byzantine astrolabe came into the possession of the young Greek monk Basileios Bessarion from Trebizond, who had studied in the Byzantine capital of Constantinople and who apparently took it with him when he joined a diplomatic mission to Italy and arrived there as cardinal in 1438-1440. (We have no proof that he brought the astrolabe to Italy, but certainly Bessarion went in 1460 to Vienna, the centre of instrument-making in Europe,[311] and certainly Regio-

context, see Josefina Rodríguez-Arribas, «Medieval Jews and medieval astrolabes: Where, why, how, and what for?» (2013).

311. For a list of some 40 known instruments from the Vienna school of the 15th century, see DAK, «Astronomical instruments between East and West» (1994), pp. 183-188. On the astrolabes of this group, see DAK & Gerard L'E. Turner, «The Astrolabe Presented by Regiomontanus to Cardinal Bessarion in 1462», also Anthony Turner, «The Art Market and Discovery in Mathematical Instruments», p. 20.

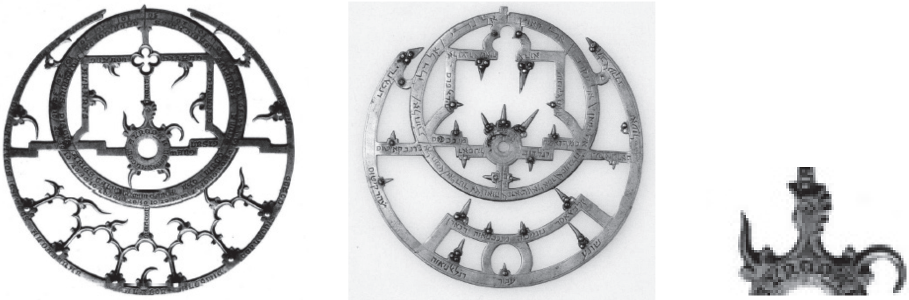


Figure 7.5g: The distinctive design of a Catalan rete with Latin inscriptions from *ca.* 1300: a cockerel's head graces the pointer for Vega. Compare this with the rete on a contemporaneous astrolabe with Judaeo-Arabic inscriptions on the right. Here we see convivencia in action! Images courtesy of The Society of Antiquaries in London and Christie's of Amsterdam. Images from *Synchrony*, p. 982.

montanus had seen the piece before he made — or commissioned — the 1462 astrolabe displayed in Fig. 7.5). In other words, a fine Byzantine astrolabe from 1062 was still in Constantinople *ca.* 1440, and Bessarion may have showed it to Regiomontanus in Vienna around 1460. We can now begin to see how it now happens to be preserved in a museum in Italy. Its presence in Brescia is documented since 1844.

Elsewhere, the first author has shown how this astrolabe with its Greek iambic verses might have inspired Regiomontanus to engrave a Latin dedication on the new 1462 astrolabe.[312] This means that Regiomontanus had seen the piece in Vienna on the occasion of Bessarion's visit there in 1460. The Latin verses constitute an acrostic in which there are vertical axes to read letters downwards as well as from left to right. Indeed, there are «hidden» messages about Bessarion and his 1062 astrolabe, Sergios, and Regiomontanus.

Later, presumably together with the mathematician Piero della Francesca, the Cardinal and his brilliant young astronomer-companion espied more names in the eight sectors of the dedication, all in the form of Greek or Latin monograms (*e.g.*, INRI for Christ, SRGIO for Sergio, IOANNIS for the Byzantine Emperor. The magic of the epigram produced IOs for four different individuals called Ioannis and

312. The whole story is related in DAK, *Astrolabes and Angels, Epigrams and Enigmas*. The connection between two astrolabes and a painting, as expected, did not appeal to certain colleagues in art history who had already formulated their own interpretation of the genesis of the painting without any textual leads. This is most obvious in Jo Marchant's article «A Leap of Faith», in *Nature* 446 (2007): 488-492, at https://www.nature.com/articles/446488a.

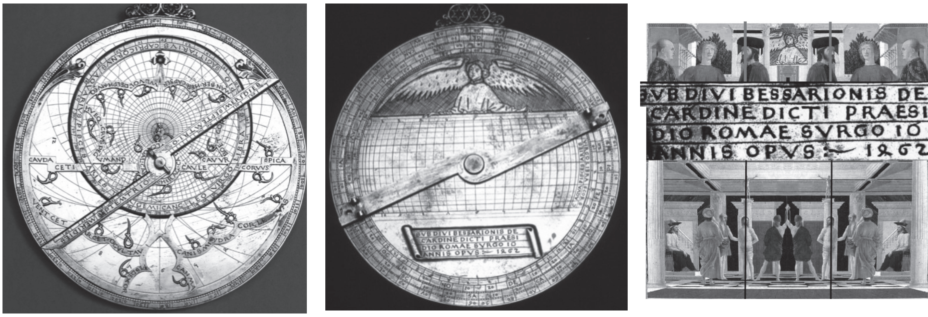


FIGURE 7.5i: The front and back of Regiomontanus' gift to Bessarion. Whilst the instrument is obviously from the same Vienna workshop as some ten other astrolabes of similar design, it is the only one that is signed and which bears the image of an angel on the back. The dedication is a bi-directional acrostic in which combinations of letters in the eight vertical columns correspond to clusters or even monograms of the eight persons features in Piero's most famous painting. Images courtesy of Christie's of S. Kensington.

CRD for Ottaviano dalla Carda, wearing a gown decorated with embroidered thistles, Italian *cardo*. All this, and much more, could have provided the inspiration for Piero's most famous painting, now known as «The Flagellation of Christ», but previously entitled *Convenerunt in unum*, in which each of eight persons has a multiple identity and they all «come together in one» (*convenerunt in unum*, a phrase in the Latin Bible). The key word is «polysemous», «having multiple meanings».

The principal figures on the right are to be identified with Bessarion and Regiomontanus, but not only them, because their images are polysemous. One of the figures on the left is Sultan Mehmet II, corresponding to the monogram OSMAN, which refers to ʿUthmān, the founder of the Ottoman dynasty. Even the surprising and superfluous roses stuck on a wall between Bessarion and Regiomontanus in Piero's painting are in the same relative position as the letters ROSAE in the inscription; they were surely also inspired by the Marian rosettes on the throne of Regiomontanus' astrolabe.

The Italian artist, Bellini, was, therefore, not the only one to paint the Sultan Mehmet II (Fig. 2.2b), although his «compatriot» Piero had no model with which to work and chose for the Sultan to behold the agony of Byzantium, implicit in the flagellation of Christ. The Sultan is standing next to the Byzantine Emperor Ioannis VIII (BA IOANNIS), who is seated on the throne (SEDES) of King Herod (ERODES) and who was also blamed for the fate of Byzantium. The interpretation of the painting is as complex as the painting itself. We do not know of any other painting based on, or inspired by an epigram, let alone an epigram on a scientific instrument. More than 50 interpretations have been proposed over the past 200 years for the three figures on the right. Art historians have never been able to fathom a unique and magnificent painting which is itself polysemous and featuring unreal images of persons each of which is polysemous. The sole surviving Byzantine astrolabe and the first astrolabe of the European Renaissance provide the clues to the composition and meaning of this magnificent painting.

FIGURE 7.5i: The front and back of Regiomontanus' gift to Bessarion. Whilst the instrument is obviously from the same Vienna workshop as some ten other astrolabes of similar design, it is the only one that is signed and which bears the image of an angel on the back. The dedication is a bi-directional acrostic in which combinations of letters in the eight vertical columns correspond to clusters or even monograms of the eight persons features in Piero's most famous painting. Images courtesy of Christie's of S. Kensington.

Note added after the completion of this paper. The astrolabe of Regiomontanus is to be auctioned on 20.04.2024 at Bonham's of London.[313] The catalogue entry has been prepared by Anthony J. Turner and cautiously reflects some of the progress that was made since the instrument was declared suspicious or even a fake by «experts» in Oxford in 1990. At the time, no related instruments were known to the Oxford team; in the 1990s DAK identified some ten other astrolabes from the same Vienna workshop with similar basic features, though none were signed. A list of 40 surviving instrument from 15th-century Vienna was made available to the Austrian Academy of Sciences, providing for the first time a context for the masterpiece.[314] The description for Bonhams ignores much of the research that has been conducted

313. https://www.bonhams.com/auction/29884/.

314. DAK, «Astronomical Instruments between East and West», pp. 183-188. See also a list of medieval instruments in Austrian collections on pp. 189-191.

since then but still feels the need to address questions raised in the 1990 report which have long been resolved. Just one example: the angelic image on the back of the instrument — now identified as «a clothed winged figure (? an archangel)» — ignores the fact that St Bessarion, whose name was adopted by the young Greek monk who later became a cardinal, was venerated as an angel in the Byzantine liturgy. We can assume that Bessarion told this to Regiomontanus, as the two were very close. Remarkably, the starting price for the astrolabe is £250,000, which is the same amount that was reached in 1989 before the buyer returned the item to Christie's a few weeks later on account of the Oxford report and got his money back. It has languished in a private collection ever since, but was made available for various exhibitions in Florence, Nuremberg and Schweinfurt.

Note added in proof: The Regiomontanus astrolabe sold for about £450,000, substantially less than the amount realised recently for a 17th-century Maghribī astrolabe! Once an unusual historical instrument has been declared suspicious by would-be experts, it is usually impossible to reinstate it.

7.6 An astrolabe for a medic at Mehmet II's Court

Information about an astrolabe dated 928 in the Armenian calendar, that is, 1479, is currently circulating in the art world.[315] The piece is unsigned and contains a plate for latitude 41° (which would serve Istanbul) and latitude 42° (which would serve Edirne). It apparently also bears an Armenian inscription «in memory of the medic Amirdovlat», but he died in 1496. There seems to be a problem with these dates. *Astrolabes* with Armenian inscriptions are extremely rare — only three are known to us — on the other two see below.

There is no mention on the astrolabe of Mehmet II, whose latter reign was from 1451 to 1481. The Armenian Amirdovlat Amasiatsi (b. Amasya *ca*. 1420-25, d. Bursa, 1496),[316] an encyclopedic polyglot fluent in six languages, was chief of the

315. *Paris Drouot* 19.12.1997 *Catalogue*; also *Synchrony*, B, p. 400, n. 107; and Brieux & Maddison, *Répertoire des facteurs d'astrolabes,* p. 471.The Paris auction catalogue, in which the piece was mentioned for the first time, had the maker as Zilmaspout or Zilmanfous. These cute terms are corrupt renderings of the technical terms on the shadow scales: *ẓill mabsūṭ* and *ẓill maʿkūs*, meaning «horizontal shadow» and «vertical shadow», respectively.

316. See the article «Amirdovlat Amasiatsi» by Avedis K. Sanjian in *Encyclopedia Iranica*, online edition, 2012, at www.iranicaonline.org/articles/amirdovlat-amasiatsi.

medics attending the Sultan, and author of *Angitats Anpet*, a substantial dictionary of natural drugs. This astrolabe was surely known to Mehmet II for it was somehow associated with his chief medic.

Another astrolabe with Armenian inscriptions has for many decades been preserved in the Byurukan Observatory in Armenia. It was mentioned and illustrated in a 1967 article by the Armenian astronomer Benik Tumanyan (1917-1980) on the history of astronomy in Armenia.[317] Though mentioned in Armenian literature, it has never been properly described in a Western source. Most recently it has appeared — front only, of course — on the internet, where it is sometimes correctly described as «made by an Armenian merchant named Vanandetsi in the 18th century».[318] To the uninitiated this instrument could be thought to come from any century from the 16th to the 20th century. In fact, the rete design reflects European, more exactly Dutch, influence and indeed its maker did spend time in Holland. This notwithstanding, two internet sites misdate the piece to the 17th century[319] and the 15th century,[320] respectively.

7.7 A spherical astrolabe by «Mūsà» relocated

> This spherical astrolabe is the only complete example of its kind to survive. It was used to make astronomical calculations and is of Eastern Islamic origin. All the inscriptions are in Eastern Kufic Arabic and it is signed «Work of Musa», Musa standing for an unknown instrument maker. (Anonymous, «Art Funded: Spherical astrolabe»,

317. See Tumanyan, *A History of Armenian Astronomy* (in Armenian, with summaries in Russian and English), published in Erivan, 1964. (A copy is in Utrecht Observatory Library, numbered II Ab 494). The astrolabe is also featured in idem, «A History of Armenian Astronomy» (1967). A fine image of the front appeared in *Synchrony*, B, fig. 10.8 on p. 397. For more references, see Brieux & Maddison, *Répertoire des facteurs d'astrolabes*, pp. 472-474.

318.www.dreamstime.com/brass-astrolabe-display-antique-brass-astrolabe-made-armenian-merchant-named-vanandetsi-xviii-century-image128516647.

319. This Facebook page from 2017 states that this is a 17th-century astrolabe which belonged to Petrus Uscan (1680-1751), an Armenian merchant and leader of the Armenian community of Madras: see Anonymous, «17th-century Armenian astrolabe», at www.facebook.com/ArtofArmenia/photos/a.355824704511128/1439070612853193/, accessed 05.07.2017.

320. This astrolabe of Vanandetsi is now featured on an authoritative-looking website «People of Ar» as being from the 15th century: see Anonymous, «Armenian astrolabe 15th century», 13.12.2012, at www.peopleofar.com/2012/12/13/armenian-astrolabe/. (View of front, no text).

at https://www.artfund.org/supporting-museums/art-weve-helped-buy/artwork/3600/spherical-astrolabe).

From (my) research, I can confidently say that the (Oxford spherical) astrolabe was made with only artistic intentions, most likely as a demonstration tool to show what a spherical astrolabe looks like and how it operates. The small size of the instrument, the choice of not-so-bright stars to form a symmetry on the rete, and lack of an alidade that can be used for stars makes the instrument visually appealing but impractical for observations. The instrument that is described in the (MS Istanbul) Hamidiye (1453) text, (copied in Istanbul or Edirne during 1450-75 and perhaps even compiled by the astronomer-copyist), however, is much more accurate and functional for both observations and calculations. It is hard to imagine that the author of this text constructed or commissioned a much less accurate instrument such as the (Oxford) astrolabe». Taha Yasin Arslan, «Rethinking the Spherical Astrolabe» (n.d., at https://scientificinstrumentsociety.org/rethinking-the-spherical-astrolabe/).

The Museum of the History of Science at Oxford University acquired an Islamic spherical astrolabe at a Sotheby's auction on 26 February 1962. The instrument was unique of its kind, though the theory and use of the species are discussed in several Arabic treatises. It is signed simply: عمل موسى, *ʿamal Mūsà*, «made by Mūsà», and dated 885H/1480~81. Its historical importance was immediately recognized and it was published the same year by Francis Maddison, then Curator of the Museum.[321] In his ground-breaking paper on this important instrument, Maddison left no stone unturned. He not unreasonably assumed that the horary markings would serve all the latitudes on the latitude scale; to have such markings for a single latitude partly defeats the purpose of having such an elaborate instrument. In particular, on the basis of the engraving, he quite reasonably posited «Persia or the Syro-Egyptian region» for the origin for the piece. After his time,

321. On the spherical astrolabe see Mayer, *Islamic Astrolabists*, p. 47; Maddison, «15th-Century Spherical Astrolabe» (1962); and DAK, «Spherical astrolabes in circulation — From Baghdad to Toledo and to Tunis & Istanbul» (2018), where the connection with latitude 41°, Istanbul, and the imperial court is established. The official Museum webpage is https://www.hsm.ox.ac.uk/spherical-astrolabe. See also, most recently, Brieux & Maddison, *Répertoire des facteurs d'astrolabes*, I, pp. 391-392 & 556 («facteur non classé»), with associations long out-of-date. On the spherical astrolabe in the Islamic West see the next note. A facsimile is described in Sezgin *et al.*, eds., *Science and Technology in Islam*, V. See also www.hsm.ox.ac.uk/spherical-astrolabe & www.mhs.ox.ac.uk/astrolabe/exhibition/spherical.htm & www.academia.edu/37947243/ (images).

various absurd suggestions were made for the provenance, from the Maghrib to India. If it came from the Maghrib, it would look different: witness the sphere from a 14th-century (?) spherical astrolabe from Tunis, which came to light in 1976 in the collection of Ernesto Cannobio.[322] If the Oxford piece came from, say, Shirwan, it might have the same latitude, but it would certainly look Persian, which it does not.

Figure 7.7a-c: The spherical astrolabe signed by the elusive «Mūsà» dated 885H/1480~81 and its complicated rete. The problems associated with positioning the star-pointers on the tentacles of the rete are manifold, and it is hardly surprising that one or two of the pointers end up in the wrong place. The lower half of the sphere shows the seasonal hours for latitude [41°]. Of all the available images, none shows the inscription properly. Part of the inscription is just visible to the left of the lower half-sphere shown here. Images courtesy of the Museum of History of Science, Oxford.

The Oxford spherical astrolabe is not a functional instrument. First, there is no alidade. Second, there is no latitude scale. Indeed, it serves only a single latitude. Further, some of the star-pointers are incorrectly placed. It is more a «representational» piece.

The Cannobio instrument has no rete and has horary markings for latitude 36;40°, a well-attested value for Tunis which was popular during the period,

322. Cannobio, «An important fragment of a West Islamic spherical astrolabe»; DAK, «*Spherical Astrolabes*», pp. 13-16. On astronomy in Tunis, see ibid., pp. 40-49; Samsó, «Spherical Astrolabe», in *On Both Sides of the Straits of Gibraltar*, pp. 341-352; also Réda & Aissani & Chadou, «Mesure du temps au Maghreb à l'époque médievale».

mainly the 13th and 14th centuries when there was considerable astronomical activity in the city.[323]

One stone, however, was still left unturned by Maddison. The horary markings have been found not to be universal but to serve a specific latitude, namely 41°, which, within the context of Islamic instrumentation, is only to be associated with Istanbul.[324] The spherical astrolabe of «Mūsà» comes, then, from the milieu of Mehmet II, though it may have «fallen through the woodwork» because it was made in the year in which Mehmet II died. It is not specifically mentioned in the Palace inventory of 1505. Nor has it been recognized as coming from Istanbul in any recent publication nor on the Oxford Museum website. If, as some have surmised, the maker was the prolific scholar and medic Mūsà Jālīnūs, it is remarkable that there is not a trace of Western Islamic or Jewish influence, neither in the engraving nor in the choice of stars and their names.

A detailed description of this instrument is available on the internet.[325] The identity of the maker, Mūsà, is still under discussion, and now, with Mehmet II's

323. *Synchrony*, A, pp. 427-436, on several sets of tables for timekeeping compiled in Tunis; also Samsó, *On Both Sides of the Straights of Gibraltar*, pp. 764-795, on the *Zīj* of Ibn Isḥāq al-Tūnisī, the most important astronomical work compiled in the Maghrib. The piece has an additional set of pairs of diametrically-opposed holes which could with considerable stretching of the imagination be used for some astronomical activity with a straight hollow cylindrical rule.

324. Kennedy & Kennedy, *Geographical Coordinates of Localities from Islamic Sources* (n. 140), pp. 93-94. See also *Synchrony,* B, pp. 915-962, for an investigation of latitudes on early Islamic instruments. An important new study is van Dalen, «The Geographical Table in the *Shāmil Zīj*» (n. 167), which shows what careful analysis of such a table can reveal. In fact, Shirvan has latitude 41° in the medieval sources, and we have a Shirvānī making an astrolabe for Mehmet II (§7.9a), but we seem to have no instruments made in Shirvan. However, the *zīj*es of the late-12th-century astronomer Ibn al-Fahhād were compiled in Shirvan and at least one became popular in Istanbul, possibly as a result of this identity of latitudes — see DAK, «Spherical astrolabes», p. 51, for references.

325. See the access to text and images indicated under DAK, «Spherical astrolabes in circulation». Judith Pfeiffer (p. 163, n. 75) remarks that this unpublished paper «has yet to undergo peer review». We should perhaps explain the rather unusual way in which that paper came into existence. In 2017, DAK was commissioned to write a description of a spherical astrolabe which had appeared on the market in London: it bore strong resemblance to the Oxford piece but was more crudely fashioned; it could easily have been an early work of Mūsà. An incomplete sphere with seasonal hour markings for the latitude of Tunis was also available. In the course of studying the new piece it was necessary to describe the «old» piece: the first thing that came to light was the fact the seasonal hour curves were for 41°; the second was that there were problems with the positions of the star-pointers. On the «new» piece the problems were worse: the name of the maker was frankly absurd; the hour

universal sundial, there is another «new» instrument in Ottoman astronomy. It may take some time for these instruments to be incorporated into the mainstream history of Ottoman astronomy. Meanwhile, as already noted (§4.8), poor quality copies are being produced and sold to gullible and uninformed collectors. There are numerous sites on the internet relating to spherical astrolabes, mainly uninformed. Some confusion has arisen because an instrument invented by the 17th-century Maghribi astronomer al-Rūdānī in Medina was auctioned at Christie's of London in 08.10.2015 as a spherical astrolabe, when in reality it has nothing to do with a spherical astrolabe except that it too is spherical.[326]

Mūsà may well have come into contact with two treatises on the spherical astrolabe that were in the library of Sultan Bāyezīt II and are now in the Topkapı Palace Library. One was supposedly authored by Ḥabash al-Ḥāsib, one of the leading astronomers of 9th-century Baghdad, but research has established that the first treatise has nothing to do with Ḥabash.[327] The other was by Ḥāmid ibn ʿAlī al-Wāsiṭī, one of the leading astronomers and instrument-makers there also *ca.* 950.[328] Or he may have known of the anonymous (Syrian?) treatise on the spherical astrolabe in the Istanbul Hamidiye 1453 manuscript, copied in Edirne or Istanbul in the period 1460-7 (§6.8d). Or if he was working in the Hebrew tradition, the treatise by Jacob ben Makhir (ben Tibbon, *ca.* 1236 – *ca.* 1305) might have been available.[329] In the precious manuscript Paris hébr. 1030 of a group of Hebrew treatises on instrumentation, we find a copy of the Hebrew version (22 folios) by the treatise by Ben Tibbon on the construction of the spherical astrolabe

curves were for the latitude of Tunis; and the star-positions and names of the stars were awry. DAK insisted on a metal analysis, but an X-ray procedure established that the sphere on the new piece was «made in China». The «new» piece was a poor composite copy of the Oxford and Cannobio pieces, a fake destined to deceive. DAK proceeded to try to liberate the descriptions of the genuine pieces and to try to relegate the description of the «new» piece to an appendix. Such was the genesis of the paper; it awaits review by a peer who knows about spherical astrolabes.

326. https://www.christies.com/en/lot/lot-5930901.

327. DAK, «Spherical astrolabes», pp. 16-17. The fact that the treatise in the manuscript is «anonymous, late, and singularly uninformative» does not mean that other copies might not be the treatise which Ḥabash is known to have authored.

328. Published by Ornella Marra as *L'astrolabio sferico ed il suo uso*, which contains treatises of al-Nayrīzī and al-Wāsiṭī.

329. On Ben Profeit Tibbon, as he is better known, see the article by Raymond Mercier in *BEA* at https://islamsci.mcgill.ca/RASI/BEA/Jacob_ben_Makhir_ibn_Tibbon_BEA.htm.

by Qusṭā ibn Lūqā (*ca.* 820 – *ca.* 912).[330] Around 1510 we find Abraham ben Yom Ṭov Yerushalmi writing in Istanbul on calendrics and associated aspects of astronomy (mentioning Ulugh Beg).[331]

Finally, the identity of Mūsà is not yet established. He is as elusive as Mūsà Jālīnūs/Galeano in Istanbul, whose remarkable contributions have only recently become known. There was a Jewish immigrant from al-Andalus, with the name of Moses ben Avraham, who wrote in Istanbul *ca.* 1495 a serious treatise on the use of the astrolabe in Hebrew.[332] He too might be a contender for the honour of being «our» Mūsà.

Excursus: The end of the *dābid*

The thoughtfulness of Ekmeleddin İhsanoğlu and his former colleagues at I.R.C.I.C.A. in Istanbul enables us to say a few words about an Andalusī instrument apparently first described in Jewish sources in al-Andalus (and not known to the history of Andalusī astronomy or Jewish astronomy elsewhere). The Jewish astronomer Hoca Iliyā (ben Avraham) al-Yahūdī, who converted to Islam in Istanbul as ʿAbd al-Salām al-Muhtadī, is the author of an Arabic treatise on an instrument perhaps called *al-dā'ir*, consisting of rings after the fashion of Ptolemy's armillary sphere and supposedly superior to that, compiled in 908H/1502~03. This is extant in MS Istanbul Topkapı A3495 (88 fols)..[333] The author says he translated the work from Hebrew to Arabic at the direction of (*bi-talqīn*) the Sultan (unspecified). A note in the manuscript says that the author, Iliyā' al-Yahūdī was one of the Jews of Constantinople and that he was «a man complete and

330. See Josefina Rodríguez-Arribas, «From Castile to Istanbul: Moses ben Abraham de Çivdat and his *Explanation of the Astrolabe with Clear Explanations*», p. 10. On Qusṭā see the article by Elaheh Kheirandish in *BEA* at https://islamsci.mcgill.ca/RASI/BEA/Qusta_ibn_Luqa_al-Balabakki_BEA.htm.

331. Bernard R. Goldstein, «Astronomy in Hebrew in Istanbul: Abraham ben Yom Ṭov Yerushalmi (*fl.* 1510)».

332. See Josefina Rodríguez-Arribas, «From Castile to Istanbul», p. 10.

333. İhsanoğlu *et al.*, *Osmanli Astronomi Literatürü Tarihi*, I, pp. 72-73 (pages muddled; this extract not in later version); also Morrison, «Scholarly Intermediary», p. 36, and DAK, «Spherical astrolabes», pp. 102-103. See n. 267 for the likewise clumsy but apt name of the instrument called *dā'irat al-muʿaddil*. See also Bernard Goldstein «Descriptions of Astronomical Instruments in Hebrew», p. 123, for a Hebrew misreading of the word *al-dā'ira* as *adayyina*.

perfect in knowledge of the *Almagest*, and the astrolabe, and arithmetic and geometry». The name of the instrument given by İhsanoğlu *et al.* is *al-dābid*, which makes no sense. The correct reading is in all probability *al-dā'ir*, a rather unfortunate name for an instrument because the word is an Arabic technical term meaning «(the amount which) is turning» and «time (since sunrise)». The treatise merits a closer look.[334]

7.8 The elusive Mūsà

> Less studied but fascinating episodes of exchange between Muslim and Jewish scholars occurred in the Ottoman Empire during the reigns of Mehmet the Conqueror and his son and successor Bayezit II. During the reign of Mehmet, Moses b. Elijah Galeano produced a Hebrew version of *Jaghmīnī's al-Mulakhkhaṣ fī al-hay'a al-basīṭa*. During the reign of Bayezit, Moses b. Judah Galeano (a.k.a. Mūsà Jālīnūs) learned of the theoretical astronomy of Ibn al-Shāṭir. But there were times when Jewish scholars in Ottoman lands did not appropriate methods from available Islamic texts. (Robert Morrison, «Jewish Scholars and Lunar Crescent Visibility Prediction»).

> Galeano's special interest in astronomical instruments would have served him well at the court of Bayazid II. The sultan himself studied astronomy with Mīram Chelebī, grandson of the famous Qādīzādeh, and several astronomers dedicated treatises, mostly on instruments, to Bayazid II. (Y. Tzvi Langermann, «Compendium of Renaissance Science», p. 288).

> We have no trace of (Mūsà Jālīnūs) in al-Andalus, and no information of how or when he came to Istanbul. (Ekmeleddin İhsanoğlu, «Scholars of Andalusian Origin», p. 17).

In the year 885H/1480~81, one Mūsà made a spherical astrolabe. Though not functional, it is the only more or less complete instrument of its kind. It consists of a sphere with horizon and altitude circles and horary markings, together with an encompassing rete with ecliptic and star-pointers. It is the «jewel in the crown» of the History of Science Museum in Oxford. Only recently has it been shown

334. An art historian (the first?) looks at early Andalusī instruments, each one already catalogued by specialists, in Glaire D. Anderson, «Mind and Hand: Early Scientific Instruments from al-Andalus». There is, inevitably, no trace of a *dābid*.

that the latitude underlying the horary markings is 41°, which can only have served Istanbul — see §7.7.

Since our last investigations of this scenario in 2018, we have the advantage of the new overview of the Zacuto corpus in the Eastern and Western Islamic worlds by our colleague, Julio Samsó. His new book *On Both Sides of the Straight of Gibraltar: Studies in the History of Medieval Astronomy in the Iberian Peninsula and the Maghrib* (2020) covers all aspects of mathematical astronomy, folk astronomy, and astrology which are currently deemed worth covering. This includes the spherical astrolabe in general and the Oxford and Cannobio examples in particular, and the Arabic traditions of Zacuto's *Almanach* in both the Maghrib and in Ottoman Turkey.

A question that has concerned leading scholars in our field is whether the multilingual polymath medic, Mūsà Gālīānū (or Galeano), is the same person as Mūsà Jālīnūs (Arabic for Galen). Their «surnames» and «nicknames» are quite different in Hebrew and Arabic, although they contain the same consonants *j-l-n-s* and the same selection of long vowels ā-ī-ū. Galeano is written גאליאנו, *g-'-l-y-'-n-w*, *Gālīānū*, in Hebrew. Galeano appears to be a Jewish name from the Iberian Peninsula originally derived from Latin «Gallianus» and meaning «of Gaulish/French origin»; the name is still in circulation as a surname, with the single 'l' much more frequent than the double 'l'. Galen in Arabic is written جالينوس, *j-'-l-y-n-w-s*, Jālīnūs, in Arabic. It was not presumptuous of the «second» Mūsà to bear the name of the greatest medic of Antiquity; rather, it was probably a sobriquet or title conferred upon him by the Sultan for his skills in medicine. The current consensus is that the names refer to one and the same individual. This is clear from the fact that Mūsà Jālīnūs in his treatise «Puzzles of Wisdom» mentions his grandfather Rabbi Eliyah Galeano in connection with a purported cure for leprosy common amongst the Christians (putting a gold coin on the forehead of the afflicted).[335] This means, *inter alia*, that our subject is a man called Moshe Galeano who was at some time accorded the honorific title Jālīnūs.

Many of the problems relating to Moshe Galeano who went under the name Mūsà Jālīnūs — let us call him MGJ — is that all who have worked on him in the past 50 years come from different directions, and some thought the *nisba*s referred to different persons. Our main interest was to identify Mūsà, the maker of the spherical astrolabe, and not least to reinstate MGJ to his rightful place in Ot-

335. Langermann, «Medicine, mechanics and magic», p. 376.

toman science history. None of those scholars who have tried to do that merits any criticism, given the paucity of available personal details such as identity, association and date, and no less the fact that this man has two alternate first names, uses different compound names in his treatises, and spans two sultanates, two religious groups and three language communities.

Robert Morrison has to a large extent clarified the mystery of the identity of MGJ. But he has also laid bare one way in which certain significant aspects of Islamic astronomy might have reached Copernicus, marking a remarkable, unexpected, but perfectly credible means of transmission from one culture to another by means of a multilingual and multitalented person straddling both.[336] It goes beyond the scope of this paper to summarize the research of our colleagues, Tzvi Langermann and Robert Morrison, to whom goes all credit for their astounding findings relating to MGJ, save to question whether there might have been more than one Mūsà involved in astronomical activities in Istanbul during the reigns of Mehmet II and Bayezid II. Robert Morrison has informed the first author (email of 20.02.2024) that he has found yet another treatise by MGJ and that he has a book on Galeano/Jālīnūs, now one person, and his milieu, to appear in January, 2025: this will surely confirm, clarify or nullify the conclusions here.

The Mūsàs mentioned in the primary sources

It behoves us to check what the manuscripts tell us about the authors of the treatises, rather than what modern investigators, be it a century or a decade ago, have written about the authors, occasionally confusing them with others or with each other. Let us step back a little and look at what the primary sources tell us. The following table identifies the treatise, the name of the author as given in the text, and the language involved. S stands for the page in Steinschneider, *Hebr. Übers.*, 1893; A, H, T stand for Arabic, Hebrew and Turkish, Sp for Castillian; and X > Z means translated from language X to language Z:

336. Morrison, «An Astronomical treatise by Musa Calınus alias Moses Galeano», «Scholarly Intermediary between the Ottoman Empire and Renaissance Europe», and «Jews as scientific intermediaries in the European Renaissance»; DAK, «Spherical astrolabes from Baghdad to Istanbul», pp. 77-83 & 116-118; and Şen, «Reading the stars», pp. 598-599.

1.	Spherical astrolabe	
	Mūsà (not necessarily MGJ), 1480	A
2.	Theoretical astronomy	
	Mūsà Jālīnūs al-Ṭabīb, n.d.	A
	Zacuto Almanac, Mūsà Jālīnūs 1506	H/Sp > A
3.	Medical treatise	
	Mūsà Jālīnūs al-Isrā'īlī 1510	T
4.	Puzzles of wisdom	
	Moshe ben Judah Galeano, n.d.	H
5.	Sine quadrant by Muḥammad ibn Muḥammad	
	Moshe Galeano ben Yehuda S575-7	A > H
6.	Hebrew Jaghmīnī	
	Moshe ben Eliya היווני «the Greek» S578	A > H
7.	Physiognomy	
	Moshe Galena ben Eliya S253	A > H
	Printed version 1505, «Eliya ben Moshe» [sic] for «Moshe ben Eliya»	H
8.	Astrology fragment	
	Moshe Galeano ben Eliya S595	A > H
9.	Zarqāliyya extract	
	Moshe Galeano S577-8	A > H

Notes:

- Nowhere are the epithets Jālīnūs and Gālīānū (or Galeano) interchanged or used together. Nowhere is any Mūsà referred to as al-Andalusī.
- Pfeiffer («Mü'eyyedzade's Library», pp. 162, n. 70) accepts as possible DAK's reading of the *nisba* of Mūsà Jālīnūs in the Escorial manuscript (*al-x-x-w-y*) as al-Tīrawī, but cannot accept that al-Tīrawī might just be a corruption of al-Yahūdī. Julio Samsó (*Gibraltar*, p. 895) reminds us that his teacher Juan Vernet was not disturbed by the *nisba* al-Yatrawī, suggesting it was derived from Greek ἰατρός, *yathrós*, for «physician», but we are not aware of any such usage in the medical profession.
- Morrison renders the teacher of the translator of Jaghmīnī as «Mawlānā Aḥmaṭ» in the Hebrew, which name must surely be a corruption of Aḥmad. Who was this Aḥmad? We have had problems enough trying to identify the Aḥmar who made at least one universal sundial and two astrolabes for Mehmet II.

- Morrison has established that Mūsà Jālīnūs/Galeano lived at least until 1543 or thereabouts. It is unlikely that anybody, say at age 30, made a complicated instrument in 1480 and then lived till 1543. But it is possible (DAK, Pfeiffer).
- In the unique Escorial manuscript of Mūsà Jālīnūs' version of Zacuto's corpus (and in the *zīj* of Ibn al-Raqqām), there is a severely corrupted early Andalusī (?) Jewish (?) table for lunar crescent visibility (l.c.v). for each of the seven climates.[337] This is independent of the highly sophisticated tables for l.c.v. that were contained in Jewish sources available in Istanbul during the reign of Mehmet II, namely, those in the *Adderet Eliyahu* (*The Mantle of Elijah*), a significant treatise in Hebrew on Jewish law by Elijah Bashyatchi of Istanbul (d. 1490), which tables have been published by Robert Morrison.[338] This «universal» table for l.c.v. is also contained in the Maghribi version of Zacuto's tables, at least in the Milan Ambrosiana C82 copy.[339]
- Clearly, someone in Istanbul preferred to have a Jewish set of tables to an Egyptian set with the same purpose, such as had been prepared by the leading Cairene astronomer Ibn al-Majdī,[340] of which there is no apparent trace in 15th-century Istanbul. Zacuto's tables were also redacted by the author himself and arranged for the Jewish calendar for the use of Jewish astronomers in Jerusalem, whither he retired in 1513 and where he died around 1515.
- Mūsà Jālīnūs/Galeano has not fared well in the bio-bibliographical sources for the history of Islamic astronomy. Neither Suter nor Brockelmann was aware of him; Krause identifies the astronomy treatise; *Cairo Survey*, no. H3, urges research on the astronomy treatise; Rosenfeld & İhsanoğlu, *Mathematicians & Astronomers*, p. 319, mentions also the Zacuto edition; İhsanoğlu *et al.*, *Osmanli Astronomi Literatürü Tarihi*, II, pp. 224-225, has the astronomical treatise; but İhsanoğlu *et al.*, *Ottoman Scientific Heritage*, overlooks him altogether and attributes two of his works to another author (see below). He was not considered important enough to be included in *the Biographical Encyclopedia of Astronomers* (*BEA*).
- «Moshe Galliano called Galen» has been wrongly identified with the 16th-century Ottoman Jewish physician and astronomer Moshe ben Hāmūn (d. 961H/1554), son

337. DAK, «Some early Islamic tables for determining lunar crescent visibility», pp. 202-203.

338. Morrison, «Tables for Computing Lunar Crescent Visibility in Adderet Eliyahu», and idem, «Selective Appropriation: Jewish Scholars and Lunar Crescent Visibility Prediction in the Ottoman Empire».

339. This Milan copy was inadvertently attributed to Mūsà Jālīnūs/Galeano because at the time the Maghribī tradition of Zacuto's tables had not yet been researched.

340. On these, see E. S. Kennedy & DAK, «Ibn al-Majdī's tables for calculating ephemerides».

> of an emigré from Granada who rose to the position of position of palace physician to Suleyman the Magnificent, and the astronomical treatise and the medical treatise are attributed to this Moshe.[341]

Until now only DAK has investigated the identity of the Mūsà who made the spherical astrolabe. At least this enigmatic figure is now localized to Istanbul, in the year in which Mehmet II was succeeded by his son, Bayezid II.

The known written works of Mūsà Galeano/Jālīnūs

Here we propose to summarize the information on the various treatises of the Mūsà that was presented in the first author's 2018 paper on spherical astrolabes, available on the internet.[342] This was based largely on the writings of Langermann, Morrison and Parra. It is worthy of note that each work survives in a unique manuscript. What we need now is to discover another manuscript containing an autobiography! The writings of Mūsà Jālīnūs have been studied for the first time in the past 25 years by Juan Vernet, Julio Samsó and María José Parra (the almanac), Tzvi Langermann (the Hebrew treatise on «puzzles»), and Robert Morrison (the Arabic treatise on theoretical astronomy and the Ottoman Turkish treatise on compound medicines). The first author was pleased to have been involved at least in the first undertaking, which also involved identifying manuscripts relating to the tradition of Zacuto's tables in the Maghrib. Julio Samsó and his former doctoral students have been concerned with the tradition of Zacuto's tables in the Maghrib and he has also made an overview of the whole scene of Zacuto in the East and West which adds some colour to the in-depth analysis of Zacuto's tables themselves by José Chabás and Bernard Goldstein. The time is therefore ripe to enquire whether any instruments by him survive.

341. İhsanoğlu *et al.*, *Ottoman Scientific Heritage*, II, pp. 194 & 198-199 (no. 62: Mūsà b. Hāmūn), where the astronomical treatise in MS Topkapı 3302/2 is mentioned. The Zacuto tables have been inadvertently omitted from this work.

342. Taken from «Spherical astrolabes», pp. 106-118.

Theoretical astronomy (geometrical models for the sun, moon and planets)

In Istanbul *ca.* 1500 Mūsà Jālīnūs al-Ṭabīb (the medic) wrote a short but highly significant work on theoretical astronomy in Arabic which is extant in MS Istanbul Topkapi AIII 3302/2 (fols. 101-107, copied *ca.* 1500),[343] and has been investigated in an exemplary fashion by Robert Morrison. The author was *au fait* with developments in this topic that had influenced Islamic theoretical astronomy, not least with the astronomical models of the 14th-century Damascus astronomer Ibn al-Shāṭir.[344] He was also familiar with the tradition usually associated with certain Andalusī astronomers with a philosophical bent who opposed Ptolemaic theoretical astronomy and favoured an approach that rejected epicycles and eccentrics. Morrison has shown how Mūsà's description of his solar model is lifted from the astronomical treatise in Judaeo-Arabic by the Jewish scholar Joseph ben Nahmias, compiled somewhere in the Iberian Peninsula *ca.* 1400, a work which probably became known in Istanbul *ca.* 1500 as a result of the Sephardic diaspora. Mūsà travelled from Istanbul to Venice between 1497 and 1502, and was familiar with the planetary astronomy of Ibn al-Shāṭir and the contemporaneous Amico and Fracastoro of Padua. Copernicus spent time at Padua (1501-03). Since the 1950s, scholars have been searching for a supposed link between the geometric models proposed by Muslim scholars such as Naṣīr al-Dīn al-Ṭūsī and Ibn al-Shāṭir and those of Copernicus. Research on the Arabic and Persian manuscripts in the Vatican Library and elsewhere failed to find a «missing link». Now, the American historian of Islamic and Jewish science, Robert Morrison, has found a possible link through a Jewish astronomer familiar with Ibn al-Shāṭir's work who travelled from Istanbul to Venice and Padua.

Explanatory text (canons) to solar, lunar and planetary tables of Zacuto

Mūsà Jālīnūs [al-Tīrawī (?)] prepared an Arabic version of the *Canons* of the *Almanac Perpetuum* of Zacuto of Salamanca. The original had been in Hebrew and Mūsà says he also used a Castillian or Latin version (? *ifranjiyya*). Mūsà was commissioned to prepare the Arabic version, achieved in 912 H (= 1506/07), by

343. Krause, «Stambuler Handscriften», p. 520, no. 22, recorded the first few lines of the treatise.
344. On Ibn al-Shāṭir, see n. 141 below.

ʿAbd al-Rahmān Mu'ayyadzāde (§7.10), a judge with the Ottoman military who died in 922H/1516. The author states that some of the tables can only be used at latitude of 41;30°: this was one of the values used by serious astronomers for Istanbul and which had perhaps recently been measured again after the Ottoman conquest.[345] This work has been studied by three generations of Barcelona Arabists and historians of Islamic science: Juan Vernet, Julio Samsó, and María José Parra. Their work intermeshes with the studies of José Chabás and Bernard Goldstein on the *Almanach* of Zacuto itself.

A treatise on compound medicines

Mūsà Jālīnūs al-Isrā'īlī was the author of a medical treatise in Ottoman Turkish commissioned by Bāyezīd II's chief medic (*ra'īs al-hukamā'*) Ahi Çelebi, who assumed office in 1507 and was also interested in astronomy. The title reads *Risāla fī Ṭabā'iʿ al-adviya va-istiʿmālihā* , «Treatise on the nature of medicines and their use», and the only known copy is MS Istanbul University Yıldız Tip 352. This remarkable treatise was published with an English translation by Robert Morrison in 2016.

Puzzles of wisdom

The work in Hebrew entitled *Ta'alumot hokmah*, «Puzzles of wisdom», by Moshê ben Judah Galeano was apparently composed *ca.* 1500. Mūsà himself added comments to the unique MS Cambridge University Library Add 511, 1 in Candia, «the place of wandering», in 1536. The main text was copied by his student, Abraham Algazi, and sections have been added and others annotated, and one crossed out by the author. Parts of this work have been studied in depth and in a exemplary fashion by Tzvi Langermann, who regarded it as: «one of the most idiosyncratic and historically interesting specimens of Hebrew scientific literature». Even judging by the extracts presented and analyzed by Langermann, this is a most unusual document,

345. It should be borne in mind that some hapless Byzantine astronomers had taken the latitude as 45°, presumably situating their capital in the 6th climate rather than the 5th. (On the climates, see n. 191).

with a strong philosophical and ethical bent. To quote our colleague further: «the work is organized in ten sections, which the author labels *ḥadarim* («chambers»), each section groups together examples of similar errors of reasoning from different fields of knowledge: religion (including law, interpretations of scripture, and polemics), mechanics (or «machinations»), medicine, astronomy, and astrology. Generally, Galeano begins each «chamber» with an explanation in logical terms of the error involved; this «fallacy» is then the organizing principle of the chapter». Langermann's second study of Moshe's treatise presents materials which frankly blow the mind. His section headings on medical matters includes: two cases of medical intrigue at Court; a dentist's sleight of hand; bloodletting controversy; two applications of medical astrology; pure and simple medical fraud; a tragic case of amateur treatment. Then on magical matters: weather forecasting and exposing spell-casters. And Moshe, who was very interested in mechanical devices, built a robot, made of wood and in the form of a human, with a gown reaching the ground, which could move across a room at the whim of a trickster! The last event is the more surprising because Jews in Islamic society were not otherwise involved in mechanical devices.

Hebrew translations of Arabic treatises on instruments

Thanks to the painstaking and groundbreaking researches of Moritz Steinschneider (1816-1907) on the role of the Jews as translators in the Middle Ages, it has long been known that Moshe Galeano was interested in instruments. In particular, he translated from Arabic into Hebrew a work on a special kind of trigonometric quadrant (*bi-lā murī*) by one Muḥammad ibn Muḥammad, who is surely the Damascus astronomer Shams al-Dīn al-Khalīlī (*fl. ca.* 1360), author of a treatise on that very same kind of quadrant,[346] rather than the far more prolific but far less impressive Cairo astronomer Sibṭ al-Māridīnī (d. 1506/07), author of a plethora of treatises on quadrants and sundials, who has also been proposed.

Moshe Galeano also translated a commentary by one Aḥmad ibn Aḥmad al-Sunbāṭī (d. 1582 or 1589)[347] on a treatise (*al-Fatḥiyya*) on the standard trigonometric quadrant by the prolific Egyptian astronomer Sibṭ al-Māridīnī. This commentary must have been written when al-Sunbāṭī was quite young, and the

346. *Cairo Survey,* pp. 64-65, no. C37, item 4.5.2.

347. Ibid., p. 90, no. C126.

translation by Mūsà must have been written when he was quite advanced in years. Having seen several copies of al-Sunbāṭī's commentary, the first author cannot image why Mūsà thought it was worth translating.

Another work documented by Steinschneider was a Hebrew translation of an anonymous 6-page Arabic treatise on the *ṣafīḥa* (either the universal plate or the celestial coordinate converter?) of Ibn al-Zarqālluh (Toledo and Cordoba, *ca.* 1100). The Hebrew (or Judaeo-Arabic) treatises listed by Steinschneider are extant in manuscripts preserved in Berlin which apparently have not been studied since his time.

Other works

Moshe wrote some treatises on logic, also in Hebrew, which still await study.

The sale of manuscripts to the Fuggers

Moshe Galeano was active in a network of Jewish scholars who transmitted texts between Crete, the Ottoman Empire and Europe. They were based in Candia, with connections to Istanbul, and in the early 1540s they sold Hebrew manuscripts to the Fuggers of Augsburg.

We have previously suggested that the «Mūsà» who made the Oxford spherical astrolabe might be identical with this Mūsà Galeano/Jālīnūs. Now we mention again the mechanical devices of his own invention, including a humanoid robot, that he described alongside his medical anecdotes, and lo and behold, one is of especial interest to us. Langermann comments: «Another example from mechanics: a ball made of wood or some other material that moves easily on a level surface. A snail (חלזון, *hillazon*) is placed inside, and it is the cause of the ball's motion. However, people think that the ball moves by itself, rolling on the level surface». Our colleague was tempted to suspect the creature inside the ball might be a lizard, but apparently the Court had a propensity for snails. The slower the ball moved, the more spectators might be impressed. Now not one of Langermann or Morrison or Şen has made a statement yet about Mūsà as the maker of a spherical astrolabe in Istanbul in 1480. It does not help that Mūsà did not dedicate this piece to Mehmet II, nor anyone else, but this was the very same year in which Mehmet II died. If the Mūsà of the spherical astrolabe is not Moshe/Mūsà Galeano/Jālīnūs, the most versatile and colorful scholar in Istanbul during the reigns of Mehmet II and Bayezit

II, then we have more than one Mūsà involved in serious astronomy in Istanbul between, say, 1475 and 1540. This seems rather unlikely, unless they were both/all Jewish. We know that Moshe Galeano and Mūsà Jālīnūs were Jewish, and so was Mūsà Jālīnūs [al-Tīrawī?] or [al-Yahūdī], whose forefathers hailed from Anatolia (?). And what of our Mūsà, the maker of the spherical astrolabe? To repeat, we accept that this is a topic for further investigation. In particular, identifying these men properly — a task which escapes us for the time being — would mark a major step forward for the history of Ottoman astronomy in general and instrumentation in particular. We repeat that our Mūsà must have been so well known that he did not need to identify himself further. But since our Mūsà, the maker of the Oxford spherical astrolabe, may not be Galeano/Jālīnūs, we must leave the definitive identification of him to the next generation of scholars.

7.9 Three astrolabes dedicated to Bayezit II

Two standard astrolabes and the mater of a third dedicated to Bayezid II are preserved for us. We know that in the Sultan's treasury there were 16 astrolabes — see §7.11; this gives an indication of what we are missing. Since these three pieces are described in detail elsewhere,[348] we present here only the basic details and concentrate on the inscriptions.

a) An astrolabe by Shukrallāh Shirwānī

This is an elegant instrument with *kūfī* inscriptions, made of brass, with some silver and gold inlay. Its diameter is 18.3 cm. Clearly in the early Persian tradition, it was made by an individual from Shirwan in the Caucasus for Sultan Bāyezīt II in the year 910H/1504~05. Some details of the decoration of the rete are attested in later Ottoman astrolabes. The piece is preserved in the Museum of

348. On the two astrolabes see *Synchrony*, B, xive: «Two astrolabes for the Ottoman Sultan Bayezid II», first published in the *Festschrift* for Ekmeleddin İhsanoğlu. See also FC, «The locales of Islamic astronomical instrumentation», p. 133, where these two pieces are put into the context of other known instruments dedicated to rulers. On the latter see Necipoğlu, «The Spatial Organization of Knowledge in the Ottoman Palace Library», p. 68, n. 110. On the former see also Brieux & Maddison, *Répertoire des facteurs d'astrolabes*, i, p. 392, and on the latter, p. 393.

Islamic Art, Cairo (inventory number 15360); it was formerly in the Harari Collection, but its earlier provenance is unknown. It was featured by Robert Gunther in his *Astrolabes of the World* (1932), but it has otherwise attracted no serious attention in 90 years, except as a work of art. It was published in detail by the first author in the *Festschrift* for Ekmeleddin İhsanoğlu.[349]

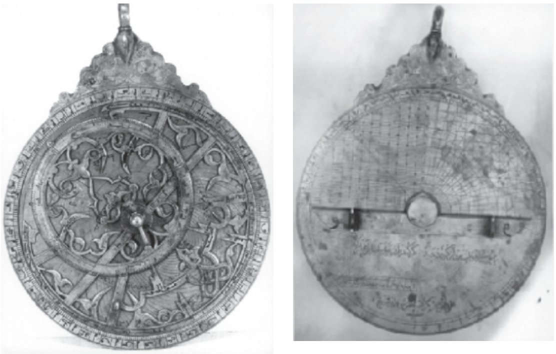


FIGURE 7.9a-b: The front and back of Shukr Allāh Shirwānī's astrolabe. Photos from the L. A. Mayer Memorial Collection in Jerusalem *ca.* 1950, latterly from the collection of the late Alain Brieux of Paris, courtesy of Dominique Brieux.

The throne is elegantly and ornately decorated with foliate patterns in inlaid silver and gold. The rete is highly ornate; in fact, it is over-decorated and the actual positions of some of the 26 stars are consequently not completely clear. The plates serve latitudes 30°, 33°, 36°, 38°, 40°, 41° and bear altitude circles for each 3° and no azimuth circles, except for the plate for latitude 41° (serving Istanbul), which is singled out to have azimuths for each 10° below the horizon. Additional markings are often found on plates for the latitude of the locality where or for which the astrolabe was made, in this case Istanbul. The back displays a two trigonometric quadrants and two shadow squares.

Shukr Allāh Shirwānī is a known scholar. In 1489 he presented Bayezit II with a compendium of sciences entitled *Riyāḍ al-qulūb*, in which he catalogued eight disciplines ranging from Sufism and theoretical astronomy to physiognomy and

349. On this instrument see already Gunther, *Astrolabes*, I, p. 126 (no. 12); Pope, ed., *Survey of Persian Art*, III, p. 2518, and VI, pl. 1399; illustrations also in Hartner, «Astrolabe», in *Enc. Islam*, pls. [3]A-B (front and back); Mayer, *Islamic Astrolabists*, p. 83 (under «Shukrallāh Mukhliṣ ... »); and Muṣaylaḥī, *Al-Asṭurlāb*, p. 61, and pls. 20-22 (front, back and inscriptions).

astrology, praising the last-mentioned as noblest of the sciences aside from the religious ones.[350] It is therefore not surprising that we find mystic tendencies in the inscription on his astrolabe for Bayezid II.

In a case such as this, where a scholar puts his name to a scientific instrument, one may well ask: did he actually make the instrument himself, or just oversee its fabrication? We can hardly answer this question because over many centuries we have encountered instruments signed by kings, astronomers, and craftsmen. The answer is probably yes, he made it.[351]

There are two inscriptions across the lower half of the back of the instrument. The upper one consists of two rhymed strophes in Persian, and it reads:

رفعت سياره و ثابت روان كرداد بديد
كر كند طرف نظر سلطان اعظم بايزيد

Rifʿat-i sayyāra vu thābit ravān gardad badīd gar kunad ṭarf-i naẓar sultan-i aʿẓam Bāyazīd

which translates roughly, with some difficulty:

> If the greatest (of all) sultan(s) Bayezid casts a glance (at the sky with this astrolabe), the elevation of the planet(s) and the motion of the fixed star(s) will become manifest.[352]

This inscription displays some poetic licence and reflects a rather limited understanding of what one can do with an astrolabe. But it deserves to be investigated by a specialist, not least because it may be from some known poem.

Below this is the other inscription in what is rather curious, even awkward, Arabic:

علمى وعملى شكر الله مخلص شرواني في تاريخ ٩١٠

350. Şen, «Reading the Stars at the Ottoman Court», p. 559.

351. The only instance when we have insight into the skills and practices of an instrument-maker is in the *ijāza*s or notes of approval by the maker's teachers. These notes relate to six astrolabes made by al-Ashraf, Rasulid Sultan of Yemen around 1295. See further *Synchrony*, B, xiva: «An astrolabe made by the Yemeni Sultan al-Ashraf», pp. 615-658, esp. pp. 645-646. The medieval Arabic is alas so technical that the details of some of the procedures are obscured.

352. *Cf. Synchrony*, B, xive, p. 789.

ʿilmī wa-ʿamalī Shukr Allāh Mukhliṣ Shirwānī fī taʾrīkh 910

Taking the first two words as adjectives with an adverbial function, an unhappy usage, and rendering them as verbs to achieve a sensible translation, this could mean something like:

> Devised and constructed by Shukrallāh Mukhliṣ Shirwānī in the year dated 910 (Hijra) [= 1504~05].

It is possible that these first two words were intended to convey some mystical significance.[353, 354]

The name Shukrallāh or Shukr Allāh is indeed attested in both Safavid Iran and Ottoman Turkey.[355] Contributing to the complexity of the problem is the possibility that there may have been two Shukr Allāh Shirwānīs active at the Ottoman Court at the same time.[356] The date is written in Hindu-Arabic numerals, which is unusual: alphanumerical (*abjad*) notation would be more usual in the medieval tradition. The dot for zero is written lower than normal, that is, awkwardly «on the line». See §4.8 for a misinterpretation of the inscriptions on a facsimile of this piece.

353. See the articles «Shukr» and «Ṣabr» in *Enc. Islam*, 2nd edn. We summarize the former by Alma Giese:

> Shukr, «gratitude», and its pre-requisite ṣabr, «patience or endurance», are here characterized as two halves of īmān, «faith». There are three parts to shukr. The first is ʿilm, «knowledge», characterized as «the real understanding that nothing except God has existence in itself, that the whole universe exists through Him and that everything that happens to a person (including afflictions) is a benefaction from Him». The second is ḥāl, «(the right) state», a state of joy in this benefaction with the associated conditions of humility and modesty (and sincerity — see below). The third is ʿamal, «action», in sense of «action in accordance with the state of joy deriving from complete knowledge of the benefactor», which has three aspects: the (hidden) action of the heart which is intending the good; the (manifest) action of the tongue which is praise of God; and the action of the members of the body, which is using them in obedience for Him». The opposite of shukr is kufr, «ingratitude for God's mercy, which is counted as disbelief».

354. Compare *Synchrony*, B, pp. 791-792, for a lengthy discussion lost in theological speculations, & Şen, «Reading the Stars at the Ottoman court», pp. 600-601. Şen writes: «The inscription on the astrolabe, idiosyncratically in Persian, clearly reads as «devised and constructed by Shukr Allāh, the sincere one from Shirwan» (*mukhliṣ-i Shirvānī*)». There is a lot more to the inscription than is indicated in Brieux & Maddison, *Répertoire*, 1, p. 392.

355. See the index of names in *Enc. Islam*. Note also the more recent names *Shukrī* and *Ṣabrī*, attested in Turkey and Egypt.

356. Suggested by Şen, *op. cit.*, p. 599, n. 1.

b) An astrolabe by al-Aḥmar al-Nujūmī al-Rūmī

This instrument, previously unrecorded, became available for study in 1998, when it was auctioned at Sotheby's in London, but was not sold. It was auctioned again in July, 2014, and it is now in the Museum of Islamic Art in Doha, Qatar. It was published by the first author in the *Festschrift* for Ekmeleddin İhsanoğlu.[357] The diameter is 9.5 cm. The workmanship is competent but not first-rate. This is an astrolabe to be used, not merely looked at. The engraving, in Kufic, is elegant and distinctive. The Arabic alphanumerical (*abjad*) notation is used throughout,[358] except for the date, which is written in Hindu-Arabic numerals. It was dedicated to the Sultan one year after Shukr Allāh Shirwānī presented his astrolabe. The rete is of unusual design but is simple and barely decorated. The vertical axis incorporates some decorative features: above the centre there is a heart-shaped frame in the upper half of the ecliptic (not known on any other astrolabe). Above this is a flower-shaped design with six petals, at the centre of which is a silver knob, which serves, along with three others, two at either end of the horizontal diameter and another below the centre, to facilitate turning the rete over the appropriate plate. The earlier development of these designs can be traced to the quatrefoil found on some early Islamic astrolabes, notably that of al-Khujandī (Baghdad, 984), which is surely of Byzantine origin. [359] The star-pointers are shaped like jesters' hats, developed — as if by lack of starching — from the dagger-shaped pointers on early Eastern Islamic astrolabes. They serve 15 named stars. There are three plates with five sides engraved with altitude-circles for each 3°, labelled for each 6°. The astrolabic markings serve latitudes: 33°, 36°, 39°, 40°, 41;30°. There is also a set of half-horizons. The back is simply executed. In the upper left quadrant is a sexagesimal trigonometric grid. In the upper right quadrant is the dedication engraved within a double circle. In the lower left quadrant the name of the maker is engraved on a single line. In the lower right quadrant is shadow square to base 12.

357. See «A royal brass astrolabe ... », at *Sotheby's London 15.10.1998 Catalogue*, pp. 68-71 (lot 94), also www.sothebys.com/en/auctions/ecatalogue/2014/arts-islamic-world-l14223/lot.135.html (the piece did not sell in the first auction!), sold for about £1M; and DAK, «Two astrolabes for the Ottoman Sultan Bayezid II», pp. 451-455/792-796.

358. See Irani, «Arabic Numeral Forms», cited in n. 14.

359. *Synchrony,* B, xvii: «The quatrefoil as decoration on astrolabe retes», pp. 963-991,

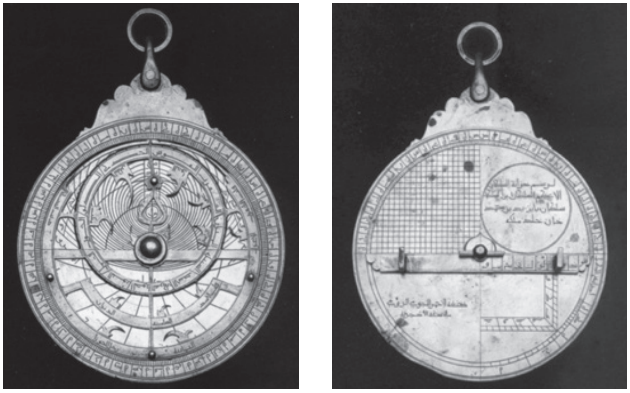


Figure 7.9c-d: The front and back of the second surviving astrolabe dedicated to Sultan Bayezid II. It The maker is surely the same artisan who made the universal sundial for Sultan Mehmet II. This connection is less obvious from the engraving than from the similarity of their names. Image courtesy of Sotheby's of London (Arts of the Islamic World, L14223, London 10.08.2014, lot 135). Object now in the Museum of Islamic Art, Doha.

Figure 7.9e-f: The dedication to Sultan Bayezit II, not carefully planned ahead (note the mess on the upper left), and the signature of the maker. The maker of the universal sundial for Mehmet II has the same very rare name Aḥmar (here al-Aḥmar) and is probably identical with the maker of this astrolabe.

The dedication reads:

لرسم خزانة السلطان الاعظم السلطان بن السلطان سلطان بايزيد بن محمد خان خلد ملكه

li-rasm khizānati 'l-sulṭāni 'l-aʿẓam al-sulṭān ibn al-sulṭān sulṭān Bāyazīd ibn Muḥammad Khān khallada ('llāhu) mulkahu

By order of the Treasury of the Greatest Sultan, sultan son of sultan, Sultan Bayezit son of Mehmet Khan — may (Allah) make his dominion last for ever.

The inscription naming the maker reads:

صنعه الاحمر النجومِي الرومِي في سنة ٩١١ هجرية

ṣanaʿahu ʾl-Aḥmar al-Nujūmī al-Rūmī fī sanati 911 Hijriyya

Constructed by al-Aḥmar al-Nujūmī al-Rūmī in the year 911 Hijra (1505~06)

The date is written in Hindu-Arabic numerals. There are three plates with five sides engraved with altitude circles for each 6°. The plate for 33° could serve Damascus and Baghdad; 36°, Aleppo and Mosul; 39°, Kayseri, Konya (?) and Ankara; 40°, Bursa and Sivas. The plate for 41;30° was clearly intended for Istanbul, although the latitude of that city is close to 41°. There were severe problems with medieval values for the latitude of Constantinople, which was often taken by Byzantine astronomers as 45°,[360] and Ottoman astronomers were apparently the first to measure it properly. This seems to have escaped our al-Aḥmar — see §6.5. It is beyond doubt that al-Aḥmar is the maker of the universal spiral sundial that we have described in Part A. Several facsimiles of this astrolabe have been produced, some being sold for modest sums at leading auction houses.[361]

c) The mater of a second astrolabe by Aḥmar al-Rūmī

At the 2023 Istanbul Congress, the Russian historian of science, Sergei Maslikov, of the Institute for the *History of Science*, Russian Academy of Sciences, in Novosibirsk, made an important announcement about the rediscovery of the mater of another astrolabe dedicated to the Sultan Bayezid II.[362] It was made by Aḥmar al-Rūmī in 906H/1500~01, some 5 years earlier than the astrolabe now in Doha. The

360. See further Kennedy & Kennedy, *Islamic Geographical Coordinates*, pp. 93-94; DAK, «Notes on Byzantine Astronomy»; and idem, «Geography of *Astrolabes*», at *Synchrony*, B, p. 921-962.

361. For one modern copy of this instrument, see «A small brass copy of a 16th century Ottoman astrolabe», at https://www.bonhams.com/auction/22832/lot/100/, sold for £1,250.

362. Sergei Maslikov, «Sultan Bayezid II's discovered in St Petersburg», paper delivered at the Congress «Channels of Transmission of Astronomical Knowledge in the Ottoman World (14th-18th

instrument is preserved in the National Library in St Petersburg, and would previously have been housed in the Imperial Public Library in the same city. The «new» instrument is missing the rete and plates. At some stage, the rete might have been considered out-of-date. The plates could have been used in another, new astrolabe mater, and fitted with a new rete. This actually happened with several Ottoman astrolabes,[363] but Aḥmar's plates are not known to have been recycled in this way. For details of the new instrument, the reader must consult the paper by Sergei Maslikov, who has kindly shared images of the mater with us.

7.10 Astronomical instruments in the Treasury inventory of 1505

Neither the «new» instrument nor any rectangular instrument (*lawḥ*) is mentioned in a short list of instruments in an inventory of the Treasury of the Sultan's Palace conducted in 1505.[364] For that matter, we can only tentatively identify two out of 16 astrolabes from that source. Around the same time, an unidentified astronomer asked the Sultan for access to four items of astronomical importance, one of which was a large astrolabe labelled *tāmm*, «complete», a technical term meaning it had markings on the plates for each degree. The other items sought by the astronomer were textual and do not concern us here.[365] The following items are relevant to our study:

centuries)» in Istanbul, 21-24 November 2023 (to appear in Archives internationales d'histoire des sciences, 2025).

363. See notes 32 & 33 on the makers of some astrolabes of this kind. Also DAK, «An Ottoman astrolabe full of surprises», 2014, esp. pp. 8-11, for the most remarkable one, in which an Ottoman astrolabe contains a set of plates from an Andalusī astrolabe some five centuries older, amongst which is a plate for 16;30° below the equator: an unexpected recurrence of a notion from ancient Greek mathematical geography.

364. Şen, *Astrology in the service of the Empire*, pp. 210-211»; idem. «Reading the Stars at the Ottoman Court», (inventory not mentioned), and DAK, «Spherical astrolabes in circulation», pp. 101-102. See also Necipoğlu, «The spatial organization of knowledge in the Ottoman Palace Library», p. 77, n. 187, where the information in the last-mentioned on these two astrolabes and on the Oxford spherical astrolabe is summarized.

365. Şen, «Reading the Stars at the Ottoman Court», pp. 600-601; also DAK, «Spherical astrolabes in circulation», p. 101, n. 209.

1. Reign of Sultan Mehmet II (1444-46 & 1451-81):
Toward end of his reign, an unidentified astronomer requests permission to see: one astrolabe with full altitude circles (this is not known to exist).[366]

2. Surviving from this milieu, dedicated to Bayezid II but not specifically mentioned in the inventory of 1505 or in any known texts:

1 astrolabe	Shukrallāh al-Shirwānī, 1504~05
1 astrolabe	al-Aḥmar al-Nujūmī al-Rūmī, 1505~06
1 astrolabe mater	Aḥmar al-Rūmī, 1500~01

No other instruments from the Palace are known to survive.

3.

Treasury inventory 1505	present or not:
numerous quadrants	not
several celestial globes	not
16 astrolabes	not
1 European clock	not
1 equatorium	?

4. Some relevant manuscripts now/still in Istanbul
MS Topkapı Ahmet III 3509,2, copied 676H/1278~79): treatise on the spherical astrolabe by Ḥāmid al-Wāsiṭī (ca. 950) and Nasṭūlus (ca. 925), both active in Baghdad.
MS Topkapı Ahmed III 3343, copied 747H/1346~47, presumably in Cairo: treatise on astronomical timekeeping and instrumentation by al-Marrākushī, compiled Cairo *ca*. 1280.

We refrain from listing the numerous astronomical and instrument treatises compiled, or manuscripts copied, in Istanbul during the reign of Bayezid II. On these, see the valuable listing by Tunç Şen & Fleischer, which aims at identifying the various authors and titles of treatises in each of more than 600 manuscripts, albeit without giving information on copyists, dates and dedications, because they set out only to identify the manuscripts from the Ottoman inventory. Thus, we are

366. It could be that the astrolabe in question was the magnificent one of radius 56 cm made in Damascus in 619H/1222~23 and dedicated to the Ayyubid Sultan al-Muʿaẓẓam, long before the establishment of the Ottomans in Istanbul. This piece, now in the Deniz Müzesi (Naval Museum) in the city, is one of the rare historical astrolabes of consequence which has altitude circles on the plates for each degree. For a description see DAK, «A monumental astrolabe for the Sultan al-Muʿaẓẓam», in *Synchrony*, B, pp. 725-744. How this enormous piece, so heavy that it requires two men to lift it, came to the Museum, we do not know. Perhaps it was originally in the Palace treasury.

barely able to identify manuscripts of treatises dedicated to Bayezid II (supposedly there are some 30 such treatises), let alone those dedicated to Mehmet II.

The library of Müeyyedzade

The published paper delivered by the Oxford Arabist Judith Pfeiffer at the First International Symposium in honour of our former colleague, Prof. Fuat Sezgin, held in Istanbul in 2019, deals with an exciting new find.[367] We quote from her summary, reminding the reader that it was Müeyyedzāde who commissioned Mūsà Jālīnūs to prepare an Arabic version of the Almanach of Zacuto for Istanbul:

> The Amasya-born scholar, qāḍī and bibliophile Mu'ayyad Zāde ʿAbd al-Raḥmān Efendī (d. 922/1516) was famed for his library collection which comprised between 2,000 and 7,000 books. One of the areas in which he had a special interest was the sciences of the stars, both astronomy and astrology. A key part of Müeyyedzade's education took place during his extended sojourn in Shīraz during the late 1470s and early 1480s, where he studied in the vicinity of such luminaries as Jalāl al-Dīn Dawwānī, Sadr al-Dīn and Ghiyāth al-Dīn Dashtakī, Mīr Ḥusayn Maybūdī and the young Shams al-Dīn Khafrī. From the extant *ijāza* of Dawwānī to Müeyyedzade we know that he studied astronomical texts while in Shiraz. Based on the surviving inventory of Müeyyedzade's extensive private library, this paper provides a survey of the works in the areas of astronomy and astrology that he once owned, shedding light on the question which texts were available to Ottoman intellectual circles at the turn of the sixteenth century.

In the version of her paper recently published, Pfeiffer presents a list of several hundred astronomical manuscripts in the list of Müeyyedzade's books, a small fraction of the whole. Apart from some treatises on the astrolabe and some important *zīj*es, the books represented are a healthy selection of Euclid, Ptolemy, Ibn al-Haytham, al-Kharaqī, Naṣīr al-Dīn al-Ṭūsī, al-Jaghmīnī, Qāḍī Zāde, and others. There is apparently nothing on astronomical timekeeping or instrumentation, a reminder that these practical subjects were not deemed so important by astronomers as those

367. Pfeiffer, «Deciphering the Stars: The Celestial Sciences in Müeyyedzade ʿAbdurrahman Efendi's Private Library Collection (*ca.* 1480-1516)»; and Şen, *Astrology in the Service of the Empire*, pp. 94-91.

on theory and cosmology (*hay'a*). And not even one manuscript of the Mūsà Jālīnūs' Arabic version of the *Almanach* of Zacuto is to be found in the library! Nevertheless, the list is of great historical interest. Would that the manuscripts themselves were available to us. As any manuscript cataloguer knows, and as Pfeiffer expounds, such lists generally record only the first work featured in a given manuscript. Not least we see here the value of surveying for the first time a large collection of manuscripts, even just by first title alone, paving the way to the study of individual works of historical consequence. The same can be said of instruments.

8. Conclusion

> In the study of European science it has become increasingly recognized that old instruments give information that complements and amplifies manuscript and printed sources. The study of extant Islamic instruments has not hitherto been a very happy field. In spite of several good monographs on single instruments or small groups of instruments, it has been very difficult for the student to obtain any wide picture of the range of material available. Undoubtedly the chief obstacle to progress has been the difficulty of correctly reading and interpreting the Arabic inscriptions containing the signature of the author of each instrument. The variant readings of almost any signature have been as numerous as the Arabists who have made the attempt. It has become well known that the munificently illustrated work of R. T. Gunther, *Astrolabes of the World* (Oxford, 1932), contains more incorrect readings of names and dates than correct ones. The situation has since been relieved by Henri Michel's *Traité de l'Astrolabe* (Paris, 1947), which has a careful analysis of the scientific features of this instrument and a biographical index. Much of the difficulty of reading the signatures of Islamic instrument-makers has now been dispelled by Professor Mayer ... (Derek de Solla Price, review of L. A. Mayer's *Islamic Astrolabists and their Works* (1956), col. 491b. [Much of this is still true today, save that Henri Michel's book was replaced by Jim Morrison's recent book on the workings of the astrolabe. L. A Mayer's book has almost been replaced by the new *Répertoire* of Alain Brieux and Francis Maddison]).

Thus ends our adventure, for such it was, with this «new» unique instrument for Sultan Fatih Mehmet. We hope to have done justice to this remarkable find, to have tried to identify its maker, and to have opened new doors to the subject of the astronomy of late-15th-century Istanbul. We also aim to have clearly demonstrated that some of the historically most important astronomical instruments have not yet been published. Furthermore, we hope that some interesting topics have emerged for future graduate students and researchers:

- an investigation of the sources available for the history of astronomy in Anatolia before and during the reign of Mehmet II;
- an investigation of all available Arabic writings on the *ḥalazūn* and *ḥāfir*, within the context of universal sundials;
- an analysis of the stars featured on the spherical astrolabe made in the year in which Mehmet II died, and on the two planispherical astrolabes made for Bayezid II;
- a survey of the available primary and secondary sources on the one, two or three men called Mūsà;
- an investigation of the various (30!) astronomical treatises dedicated to Bayezid II and the astronomers in his service (as has been done for his medics); and much more besides.[368]

Any researcher will have to learn the language of instruments, which is different from the language of texts. All instruments can speak to us if we are prepared to listen. One instrument will suffice for a beginning because enthusiasm for scientific instruments is incurable, and also — we hope — contagious.

Acknowledgements

A *ḥalazūn* in a dream means that one will move away from one's home. (Ibn Sīrīn, ca. 700, on dream interpretation).

Our description of this remarkable «new» instrument is based mainly on images kindly provided by the current owner, to whom our sincere thanks. Alas, we have currently no access to the manuscript libraries of Istanbul, Cairo and Dublin, but we are grateful for the extraordinary facilities we enjoyed in the rich manuscript collections there during the period 1970-2000. DAK in the 1970s was able to

368. See n. 126.

analyze all of the astronomical tables in the Topkapı Library and other collections in Istanbul, and catalogued the 2,500 scientific manuscripts in the Egyptian National Library. FC in 2006-08 catalogued some 150 scientific manuscripts, mainly Mamluk and Ottoman, in the Chester Beatty Library in Dublin. We remember with gratitude for their knowledge of manuscripts and for their encouragement at different times: the Turkish scholar Nuri H. Arlasez; the Egyptian scholar of Arabic literature and manuscripts thereof, Rashad Abdel Muttalib; and the English scholar of Islamic art and Qur'ān specialist, David James.

Help has come from all quarters to these French Canadian and Anglo-German authors and made it a truly international adventure. Our gratitude to our late Turkish colleague, Fuat Sezgin, for publishing reprints of the writings of the European orientalists and historians of science, including the French Sédillots and the German Carl Schoy. In the 1970s, our late American colleague, the Ottoman historian, Cornell Fleischer, copied extracts from the Persian and Turkish scientific manuscripts in the Egyptian National Library for the new catalogue. Our Turkish colleague Ekmeleddin İhsanoğlu and his colleagues at IRCICA provided the first comprehensive bio-bibliographical key to Ottoman scientists and their works. Our Russian friend Sergei Tourkin helped clarify some Persian poetry, and our colleague from Siberia, Sergei Maslikov, shared with us images of the newly-discovered mater for Sultan Mehmet II. Our Dutch colleague Benno van Dalen (Bayerische Akademie der Wissenschaften, Munich) provided us with a Persian treatise from Istanbul edited by our Iranian/Friulian colleague Mohammad Bagheri. The Anglo-American Adrian King, resident in Indonesia, made some useful bibliographical suggestions.

Libraries and museums around the world provided most of the images illustrating this article. The Süleymaniye and Topkapı Libraries in Istanbul, the Egyptian National Library in Cairo, the Bibliothèque nationale de France in Paris, and the History of Science Museum in Oxford deserve special mention. Other repositories of primary sources are mentioned *ad loc*. Particular credit must be given to art dealers in London astute enough to realize that instruments are scientific works of art. Also Christie's of London provided many high-quality images in the 1980s. Digital images were available only more recently.

Other friends and colleagues who deserve mention are Rachel Ward, Hans Frey, Eckhard Neubauer and Sonja Brentjes. We also thank colleagues Miquel Forcada and Cristian Tolsa of the editorial staff of *Suhayl* for their patience and two anonymous referees for their very useful suggestions and corrections. Especial thanks are due to our friend Shefayet Chowdhury for assistance in acquiring copies of relevant literature; without his help, this study could never have been written.

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Books are full of the voices of the wise, full of lessons from antiquity, full of moral and legal wisdom, full of religion. Books live, they discourse and speak directly to us, they teach and instruct us, they bring us consolation. They show us things far remote from our times, and, as it were, place them before our eyes as if they were present today. So great is the power of books, so great their dignity, their grandeur, even their divinity, that without them we should all be rude and ignorant. Without books, we should have almost no memory of the past, no examples to follow, no knowledge of either human or divine affairs. Were it not for books, the same tombs that consume men's bodies would likewise bury their very names in oblivion. (From Cardinal Bessarion's act of donation of his books in 1468 to the Doge and Senate of Venice, translated in David Englander *et al.*, *Anthology of Medieval Sources on Culture and Belief*, p. 149).

Notes:

For this study we have consulted mainly Western literature, and here aim to list as many modern books and articles dealing with early Ottoman astronomy as we have been able to consult. There is no shortage of available literature in Turkish, for which interested readers can first consult *İslām Ansiklopedisi*, online at *islamansiklopedisi.org.tr/*, and İhsanoğlu *et al.*, *Osmanlı astronomi literatürü tarihi* and *Osmanlı matematik literatürü tarihi*. Most German articles on historical Islamic topics, but also materials in European languages, have been reprinted by the IGAIW in Frankfurt — see the catalogue online at www.igaiw.de. Some of the items listed below are available on the internet sites www.researchgate.net and www.academia.edu. The fact that no internet reference is given for a given work does not mean that the work cannot be found on the internet. All websites mentioned in this paper were consulted and confirmed on 30.03.2024. An asterisk indicates that the work contains information on the astronomical instrument called *ḥalazūn* or on the standard approximate formula.

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