Al-Mahrī's *Mirʾāt al-salāk li-kurāt al-aflāk*: A 16th-century Yemeni Navigator's Reflections on Astronomical Knowledge

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Abstract

The sixteenth-century Yemeni navigator Sulaymān al-Mahrī is one of the two main Arab authors writing on maritime navigation in the Indian Ocean in the early modern and pre-modern periods. While he is generally known to have written five treatises on various aspects of the navigational sciences, he is also in fact the author of a sixth work, entitled *Mirʾāt al-salāk li-kurāt al-aflāk* (Mirror of Travellers into the Heavenly Spheres). Unlike his other works, *Mirʾāt al-salāk* is an introduction to astronomical concepts and practices that has previously been largely ignored by scholars on the subject. This article provides an introductory discussion of this text, situating it within its broader literary context, both within previous astronomical literature as well as the corpus of al-Mahrī's other navigational works. It presents the ninth chapter of the work in particular in order to explore al-Mahrī's familiarity with historical mathematical astronomical practices. Collectively, the work is an interesting textual example of the connection between navigational and mathematical astronomical knowledge.

Résumé

La *Mirʾāt al-salāk li-kurāt al-aflāk* d'al-Mahrī : les réflexions sur le savoir astronomique d'un navigateur yéménite du xvi[e] s.

Le navigateur yéménite du xvi[e] s. Sulaymān al-Mahrī est l'un des deux auteurs arabes importants qui ont écrit sur la navigation dans l'océan Indien au début de la période moderne et prémoderne. Alors que cinq traités sur des aspects variés des sciences de la navigation sont généralement reconnus à son actif, il est l'auteur, en fait, d'une sixième oeuvre intitulée *Mirʾāt al-salāk li-kurāt al-aflāk* (Miroir des voyageurs dans les sphères célestes). À la différence de ses autres œuvres, *Mirʾāt al-salāk* est une introduction à des concepts et pratiques astronomiques qui n'ont pas été traités par les spécialistes du sujet. Cet article propose une première discussion de ce texte d'al-Mahrī en le situant dans les contextes plus larges de la littérature astronomique qui le précède et du corpus formé par les textes de navigation sous sa plume. Il en présente en particulier le chapitre 9, afin d'explorer la familiarité qu'al-Mahrī pouvait avoir à l'égard de l'histoire des pratiques de l'astronomie mathématique. Au total, on a là un exemple textuel notable de la connexion entre connaissance navigationelles et astronomie mathématique.

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الخلاصة

مرآة السّلاك لكراة الافلاك للمهري: أفكار تعاكس معرفة في علم الهيئة لملاح يمني من القرن السادس عشر ميلاديا

الملاح اليمني سليمان المهري من القرن السادس عشر يعتبر واحدا من إثنين من المؤلفين العرب الرئيسيين الذين كتبوا عن الملاحة البحرية في المحيط الهندي في أوائل العصر الحديث وما قبل الحديث. وفي حين أنه من المعروف أن له خمس مؤلفات حول جوانب مختلفة من العلوم البحرية، إلا أن له في الواقع مؤلف آخر مهم، وهو السادس في قائمة مؤلفاته، وعنوانه: *مرآة السّلاك لكراة الافلاك*. وهذا الكتاب على عكس أعماله الأخرى، فهو عبارة عن مقدمة في علم الفلك يشتمل على بعض المفاهيم والممارسات الفلكية التي تجاهلها الباحثين في السابق حول هذا الموضوع. هذا المقال (البحث) يبدأ النقاش على هذا النص، ويضعه في سياقه المصنفي الأوسع، سواء في الأدبيات الفلكية السابقة عليه أو ضمن مجموعة الكتب الملاحية الأخرى للمهري. ويقدم بالأخص على الفصل التاسع من هذا العمل، لنستكشف مدى معرفة المهري بالممارسات الفلكية الرياضية التاريخية. وبشكل عام، يزودنا هذا العمل بمثال حي عن العلاقة بين المعرفة الفلكية الملاحية والرياضية.

Keywords

Navigation — Islamic astronomy — Indian Ocean — Sulaymān al-Mahrī — Indian Circle — The Qibla — Mathematical astronomy — Folk astronomy — *ʿilm al-hayʾa*

Mots-clés

Navigation — astronomie islamique — océan Indien — Sulaymān al-Mahrī — cercle indien — *qibla* — astronomie mathématique — astronomie populaire — *ʿilm al-hayʾa*

الكلمات الرئيسية

علم الملاحة — علم الفلك الإسلامي — المحيط الهندي — سليمان المهري — الدائرة الهندية — القبلة — علم الفلك الرياضي — فنّ الملاحة المأثور — علم الهيئة

I. Introduction

The most important body of literature to date for better understanding pre-modern navigational knowledge and practices in the Indian Ocean has been a corpus of Arabian navigational texts written in the fifteenth and sixteenth centuries. The two authors that produced these works, Sulaymān al-Mahrī (d. ca 1550) and Aḥmad b. Māǧid (d. ca. 1500), were both practicing navigators originally from the Arabian Peninsula. Collectively, they composed a series of didactic poems and prose treatises that document the diverse methods navigators used to cross vast expanses of ocean. This literature unearths an incredibly rich and sophisticated body of knowledge that includes stellar compass rhumbs, star-altitude measurements, longitudinal distance measurements and much more.[2] Although Aḥmad b. Māǧid has received the majority of the focus in the relevant academic literature, the Yemeni navigator Sulaymān al-Mahrī also produced an important body of work in the first half of the sixteenth century. He is traditionally known to have written five treatises in total that varied from short theoretical works on calendar conversions and navigational theory to longer and more comprehensive rutters describing routes throughout the Indian Ocean. However, he is also the author of a sixth work that has been previously largely ignored by the main scholars working on Indian Ocean navigation. This work, entitled *Mirʾāt al-salāk li-kurāt al-aflāk* (Mirror of Travellers into the Heavenly Spheres), is extant in a manuscript in the Yale Library and focuses on a variety of astronomical topics. As such, it provides an invaluable connection between the often distinct fields of mathematical astronomy and maritime navigation.

II. Al-Mahrī: His Life and Works

Sulaymān b. Aḥmad b. Sulaymān al-Mahrī was a navigator and author of navigational treatises originally from Šiḥr, Yemen, in the Hadramawt. As his name indicates, al-Mahrī was a member of the Mehri or Mahra tribe that predominates in significant parts of Southern Arabia. The exact dates of his birth and death are not known. The Ottoman admiral Seydi ʿAlī Çelebī (also known as Seydi Ali Reis or Kātib-i Rūmī), when writing his navigational work *El-muḥīṭ fi ilm el-eflak ve'l-ebhur* (Book of the Ocean on the Science of the Spheres and the Seas) in 1554, provides a date of 917/1511 for one of al-Mahrī's treatises entitled *Al-ʿumda al-mahrīyya fī ḍabt al-ʿulūm al-baḥriyya*. The admiral makes it clear that al-Mahrī was no longer alive by the time Çelebī was writing his work, so it is assumed that the Yemeni navigator was born in the second half of the fifteenth century and passed away in the first half of the sixteenth century.[3] Unfortunately, we know almost nothing about the navigator's life other than the few concrete biographical details detailed above on his place of origin and an approximation of the time in which he lived. His true legacy was not his life story, but rather the navigational treatises that he left behind and which are still extant. He is the author of the following works:

1. *Al-ʿumda al-mahrīyya fī ḍabt al-ʿulūm al-baḥriyya* (The Reliable Mahrī Treatise on the Exactitude of Maritime Sciences; hereafter referred to as the *ʿUmda*). This is al-Mahrī's most well-known work. As mentioned previously, Çelebī stated that it was written in

[2] Ibn Māǧid's works are found in the following: G. Ferrand, *Instructions nautiques*, 1921–1928; A. Ibn Māǧid, *Ṯalāṯ rāhmanǧāt,* 1957; id, *Kitāb al-fawāʾid*,1971; A. Ibn Māǧid, *Aḥmad Ibn Māǧid,* 2010. English translations are found in G.R. Tibbetts, *Arab Navigation*, 1981 (a translation and extensive commentary of *Kitāb al-fawāʾid*), I. Khoury, *Al-sufaliyya*, 1983 (a translation of the poem of the same name). Al-Mahrī's works are published in the following printed editions: G. Ferrand, *Instructions nautiques*, 1921-1928; S. al-Mahrī, *Al-ʿumda al-mahriyya,* 1970a; id., *Al-minhaǧ al-fāḫir,* 1970b; id., *Risālat qilādat al-šumūs,* 1972. A Russian translation of *Al-ʿumda al-mahriyya* is found in T.A. Shumovsky, *Mahrian Base*, 2011. For a more detailed review of these sources, as well as the relevant secondary source literature, see J. Acevedo & I. Bénard, *Indian Ocean Arab Navigation Studies. Vol. 2: RUTTER Technical Notes*, 2020.

[3] G. Ferrand, *Instructions nautiques*, 1921–1928; G.R. Tibbetts, *Arab Navigation*, 1981, pp. 141–143; S. al-Mahrī/T.A. Shumovsky, *Mahrian Base*, 2011, pp. 255ff.; P. Lunde, "Sulaymān al-Mahrī", 2013a, pp. 61–62; E. Staples, "Navigation in Islamic Sources", 2017, p. 228.

917/1511. It is composed of seven chapters focused on different aspects of Indian Ocean navigation, including the fundamental principles, celestial bodies, courses, the stellar compass rhumbs (*al-aḫnān*), island navigation, astral height measurements, and the most well-known navigational routes. This is considered by most scholars on the subject to be his clearest and most important work. Versions of this text survive in five different manuscripts: Paris (Arabe 2559), Leiden (Or. 8660), Yale (Landberg ms. 401), Bahrain and Peshawar.[4] One critical edition has also been published, as well as a Russian translation of the text which includes the facsimile of the Paris manuscript and critical textual annotations of the manuscript variations.[5]

2. *Minhāǧ al-fāḫir fī ʿilm al-baḥr al-zāḫir* (The Precious Method on the Science of the Deep Sea). Similar to the *ʿUmda,* this work is also divided into seven chapters with a short conclusion. This appears to have been written after the *ʿUmda* and occasionally provides corrections and more accurate details regarding information originally found in the *ʿUmda*. Certain chapters also go into more depth on certain topics, such as east-west distance measurements (*masāfa*), the practice of *taraffa/tirfa* (latitude-azimuth-distance coefficient),[6] and the use of marine life for navigation. This work is found in six manuscripts located in Paris (Arabe 2559), Leiden (Or. 8660), Yale (Landberg ms. 401), Bahrain, Oman (3910) and Peshawar respectively, as well as one critical Arabic edition published in 1972.[7]

3. *Qilādat al-šumūs fī ʿilm al-tawāriḫ* (The Necklace of the Suns on the Science of Chronology). This is a short treatise, only three folios in length. It provides navigators with the mathematical formulas necessary to convert dates for the calendars used by navigators in the Indian Ocean at the time. These calendars include the solar Persian Nayruzi, Byzantine and Coptic calendars, as well as the lunar Islamic calendar, calendrical systems which were important for calculating the correct sailing dates for departure in relation to the monsoons. This text is only found in Paris manuscript Arabe 2559, and was published in Arabic in Ibrahim Khoury's series on al-Mahrī's works in 1972.[8]

4. *Tuḥfat al-fuḥūl fī tamhīd al-uṣūl* (The Worthy Men's Gift on the Introduction to Navigational Principles). This is another relatively short work, six to seven folios in length depending on the manuscript. It is primarily a theoretical text that succinctly explains the main principles of navigational science at the time. It is found in two manuscripts: Paris

[4] For more detail on the relevant manuscripts, see J. Acevedo & I. Bénard, *Indian Ocean Arab Navigation Studies. Vol. 2: RUTTER Technical Notes,* 2020. For more detail on the relevant manuscripts, see J. Acevedo & I. Bénard. *Indian Ocean Arab Navigation Studies Towards a Global Perspective: Annotated Bibliography and Research Roadmap. Vol. 2: RUTTER Technical Notes*, 2020, pp. 8–12.

[5] A facsimile copy of the Paris manuscript is available in G. Ferrand, *Instructions nautiques*, vol. 2, 1925. A printed critical Arabic edition is available in S. al-Mahrī, *Al-ʿumda al-mahrīyya*, 1970a. The Russian translation of the work is found in T.A. Shumovsky, *Mahrīan Base*, 2011.

[6] See F. Pimenta, "Astronomy and Navigation", 2015, p. 56.

[7] Facsimile copy of Paris manuscript: S. al-Mahrī/G. Ferrand, *Instructions nautiques*, vol. 2, 1925. Printed critical Arabic ed.: S. al-Mahrī/I. Khoury, *Minhāǧ al-fāḫir fī ʿilm al-baḥr al-zāḫir*, 1970b.

[8] Facsimile copy of Paris manuscript: G. Ferrand, *Instructions nautiques*, 1925, vol. 2. Printed critical Arabic ed.: S. al-Mahrī, *Risālat Qilādat al-šumūs*, 1972.

(Arabe 2559) and Yale (Landberg ms. 401), and was also published in Khoury's edition in 1972.[9]

5. *Šarḥ* Tuḥfat al-fuḥūl fī tamhīd al-uṣūl (A Commentary on the *Worthy Men's Gift on the Introduction to Navigational Principles*). As the name implies, this is a commentary on the short work, *Tuḥfat al-fuḥūl*, described above. Al-Mahrī apparently felt the need to expand this short work in order to better help navigators at the time. The general structure and format follow a popular literary genre of commentary particularly popular in the Islamic sciences. Although Gerald Randall Tibbetts was critical of this text,[10] it provides valuable information and explanations regarding key concepts and cultural influences in navigational knowledge at the time. Similar to the short text (*Tuḥfat al-fuḥūl*) it is commenting on, it is only found in the Paris (Arabe 2559) and Yale (Landberg ms. 401) manuscripts, as well as Khoury's 1972 edition.[11]

6. *Mirʾāt al-salāk li-kurāt al-aflāk* (Mirror of Travelers into the Heavenly Spheres). This treatise on astronomical topics is a little-known work only found in the Yale manuscript (Landberg ms. 401).

As can be seen in the list above, most works by Sulaymān al-Mahrī have been preserved in more than one of the extant collections, such as those in the Paris manuscript (Arabe 2559) or the Leiden manuscript (Or. 8660). There are only two works for which at the moment we only have one copy, and it is remarkable that these are precisely his two more astronomical works, namely the *Qilādat al-šumūs*, and the *Mirʾāt al-salāk*. The *Qilāda* is found in one of the Paris nautical codices (Arabe 2559) and, along with most of al-Mahrī's works, it was edited and published by Khoury in Damascus in 1971/1972.[12] The *Mirʾāt al-salāk*, however, has never been edited or published before. This text, which has been either ignored or not discussed in any serious depth in any of the previous literature, is the focus of the present article.

III. The Manuscript (Landberg ms. 401)

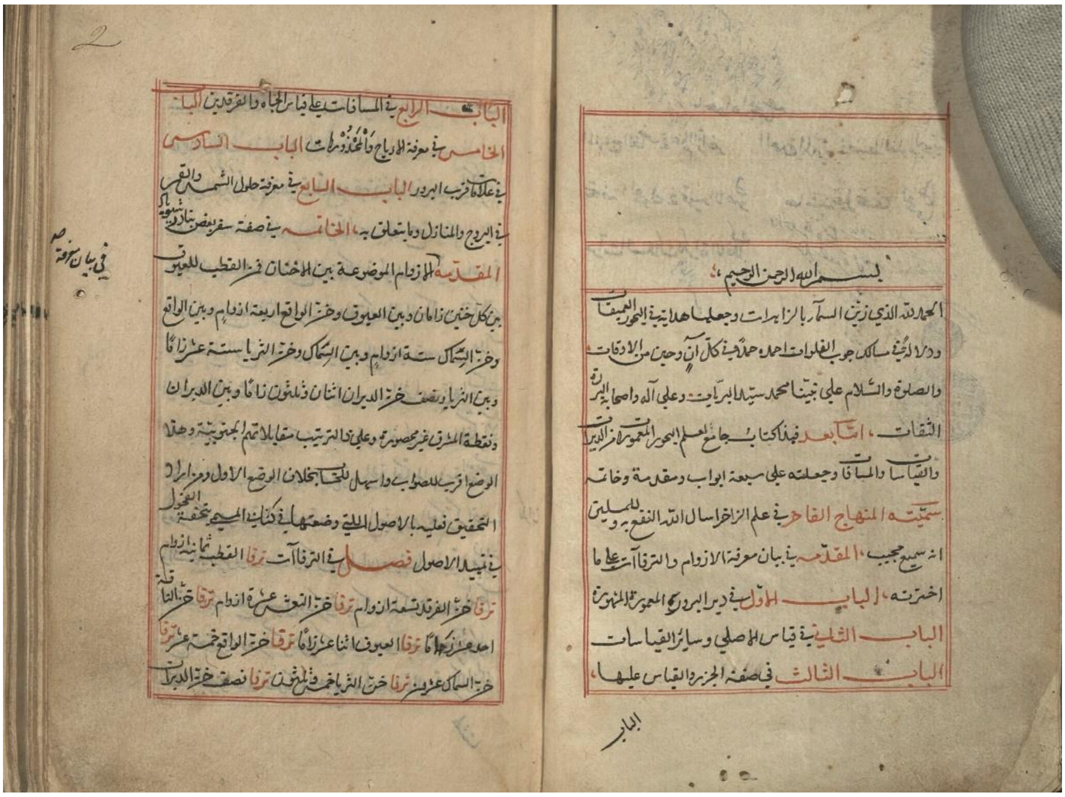
The source manuscript for *Mirʾāt al-salāk* is Yale's Landberg ms. 401, currently at the Beinecke Rare Book and Manuscript Library. It is a small (20 × 13 cm) manuscript in a fair slender *nasḫī* hand, with rubrication throughout, bound in red leather.

[9] Facsimile copy of Paris manuscript: S. al-Mahrī, *Instructions nautiques*, vol. 2, 1925. Printed critical Arabic ed.: S. al-Mahrī, *Risālat Qilādat al-šumūs*, 1972.

[10] G.R. Tibbetts, *Arab Navigation in the Indian Ocean*, 1981, pp. 43–44.

[11] Facsimile copy of Paris manuscript: S. al-Mahrī, *Instructions nautiques*, vol. 2, 1925. Printed critical Arabic ed.: S. al-Mahrī, *Risālat Qilādat al-šumūs*, 1972.

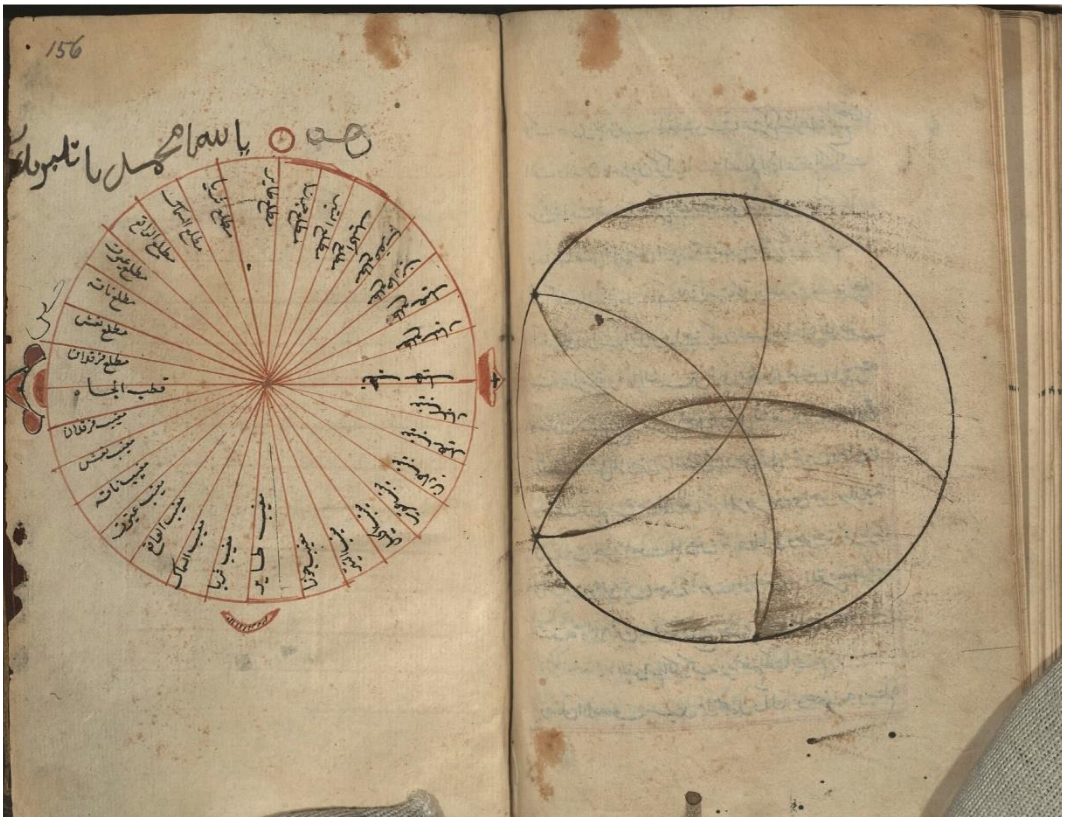
[12] S. al-Mahrī, *Risālat Qilādat al-šumūs*, 1972.



Landberg ms. 401-1v. Opening spread of the manuscript, beginning of the *ʿUmda al-mahriyya*.

It contains five works attributed to Sulaymān al-Mahrī:[13] *Al-minhāǧ al-fāḫir fī ʿilm al-zāḫir* (fols 1–34); *Al-ʿumda al-mahriyya fī ḍabṭ al-ʿulūm al-baḥriyya* (35–84); *Tuḥfat al-fuḥūl fī tamhīd al-uṣūl* (85–91) and *Šarḥ* (or *Ḥāšiya*) Tuḥfat al-fuḥūl (92–126); *Mirʾāt al-salāk li-kurāt al-aflāk* (127–156). The manuscript has a number of illustrations, including astronomical diagrams and, on the last folio, what may be one of the earliest preserved illustrations of the Arab stellar compass rose of thirty-two rhumbs.

[13] We are grateful to the staff at the Beinecke Library for providing digital images of the manuscript and generously answering our numerous queries.



Landberg ms. 401-155. Final spread: a geometric doodle and a stellar compass.

Marginal notes, present in around thirty pages, provide comment on details of the nautical instructions, and thus seem to indicate that the manuscript was actually used for sailing (e.g. fols 44r, 47v). No provenance of the manuscript can be ascertained, and there seems to be some confusion regarding its dating.

Dating of the manuscript

In his 1972 edition, Khoury dates the manuscript to 1097/1686. Tibbetts, in his article for the *Encyclopaedia of Islam*,[14] seems to draw directly from Khoury, referring to the manuscript as “Yale Arab ms. 1480, 1535, 1536–7”, but dates it to 1091/1680.

Now, we can find three dates in the manuscript itself which though not really dates of production, can give precious indicators. There is one in-text reference in the *Mirʾāt*, and there are two margin notes, namely one collation statement (“*balaġa muqābala*”) and one astronomical note. The collation note, like a certificate of verification of the text at the end of the *Minhāǧ*, is a marginal note on fol. 32v, dated 15 Raǧab AH 975 (approx. January, AD 1568). The other note, technically fascinating, is on fol. 26v, and it specifies that “nowadays”, “on the year AH 1100” (ca. AD 1688) the Nayrūz calendar

[14] G.R. Tibbetts, “Sulaymān al-Mahrī”, *EI*^{2}.

starting date corresponded with the sign of Libra.[15] The date in the text is in chapter 2 of the *Mirʾāt* (fol. 133v, 4), where al-Mahrī gives the degrees of specific astronomical phenomena for a particular date, the year AH 900 (approx. AD 1495). Given that the data in question, degrees of planetary apogees and perigees, are most likely to be derived from astronomical tables, our assumption is that AH 900 probably does not indicate the date of composition, but the date of the astronomical source used by al-Mahrī, which would be effectively our *terminus post quem*.

These three dates tell us that the manuscript was in use over a span of more than a hundred years, but they do not give us any indication as to the date of creation. Apart from these three, there is an ownership seal on the first folio, "from the library of al-Ḥāǧǧ Muṣṭafā Ṣidqī", dated 1179 (ca. AD 1765).[16]

The puzzling text of the *Minhāǧ* on fol. 26v, where the Nayrūz comment is found, speaks of "this year AH 1016" (ca. AD 1607). This complicates the date of creation of the work, since it is accepted that al-Mahrī was already dead by the middle of the sixteenth century (when Çelebī was writing his Turkish *Al-muḥīṭ*),[17] but it might be the closest we have to a creation date for the manuscript: AD 1607. This gives us a clear span of eighty-four years between the copying of the *Minhāǧ* and the addition of the note. We can therefore sum up with the hypothesis that al-Mahrī wrote the *Mirʾāt* at some point after AD 1495, and by suggesting that this particular manuscript was copied at the beginning of the seventeenth century, and that it was in use as a sailing manual for over a hundred and fifty years, when it became part of the library of Muṣṭafā Ṣidqī in AD 1765.

Title

The full title, *Mirʾāt al-salāk li-kurāt al-aflāk,* is to be found only in the heading of the book itself. There is unfortunately no internal reference to the title wording, and we have found no references to it in al-Mahrī's other works, though thematic and even stylistic parallels do exist and will be mentioned below. It is a typical rhyming title (*ʿunwān masǧūʿ*) which poses no particular question except for its second element, *al-salāk*. Indeed, the genre of "mirrors" is of ancient stock, and probably adopted by Arabic writers from Greek or Byzantine sources.[18] Equally, the second half, *Li-kurāt al-aflāk*, is part and parcel of the astronomical genre: this is a primer about the "cosmic sphere of the planetary orbits", or simply about the heavenly spheres. But the relation between the first two elements is rather unclear. It is not uncommon for analogous *iḍāfa*s to refer to the theme of the treatise, like the *Mirʾāt al-zamān* (*Mirror of time*, a chronicle), or the *Mirʾāt*

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[15] The Nowrūz or Nayrūz calendar, in one or other of its historical iterations, was of crucial importance to the Muslim navigators of the Indian Ocean, since it provided a calendrical reference for the monsoon dates which could not be obtained from the Hiǧrī calendar. For details, see A. Al Salimi & E. Staples, *A Maritime Lexicon*, 2019, p. 488.

[16] About this 18th-century library and its volumes now found around the world, see C. Bonmariage, "La Bibliothèque de Mustafa Sıdkı", 2016, pp. 533–356.

[17] See T.A. Shumovsky, "Sulaymān Al-Mahrī", 2009, pp. 133–154.

[18] R. Bradley, "Backgrounds of the Title Speculum in Mediaeval Literature", 1954, pp. 100–115.

al-ḥaramayn (Mirror of the Two Harams, a travel guide to Mecca and Medina); or also to refer to the addressees of the treatise, like *Mirʾāt al-ṭālibīn* (Mirror of Students, a manual for Sufi students) and the many European examples of "mirror of princes", i.e. for the education of those princes who will be reading it. But in this case there is the initial complication that the word *salāk* itself is hardly documented. A form *sallāk* (*faʿʿāl*), with *tašdīd* on the *lām*, would make good sense, like "the mirror that clarifies…", but there is no *šadda* in the manuscript, where they are generally marked. To cut the discussion short, we are inclined to think that *salāk* responds more to the rhyming need of the title; it is there for the sake of *saǧʿ*, with the root sense which is obvious in the context of a nautical manuscript, that of travel.[19] Accordingly, *salāk* would stand here for *sālikūn*, the travellers, or *sulūk* or *salk*, travelling. Hence our proposed translation: The Mirror of Travellers into the Heavenly Spheres.

The Contents of the *Mirʾāt al-salāk*

As mentioned above, it is quite remarkable that among the experts dealing with al-Mahrī's work, only Khoury mentions the *Mirʾāt al-salāk*, and this only briefly,[20] ignoring it later in other passages where a mention would have been expected. Some authors like Gabriel Ferrand were simply not acquainted with the Yale manuscript, but we may perhaps speculate that others, like Tibbetts, Paul Lunde and Khoury, considered the *Mirʾāt* such an atypical work that it did not warrant inclusion among the properly nautical works of al-Mahrī.

The following is the detailed table of contents:

[19] We are grateful to Prof. Abdellatif Charafi, formerly at Mohammed VI Polytechnic, Casablanca, who has kindly shared with us his expertise on this particular issue.

[20] S. al-Mahrī, *Al-ʿumda al-mahrīyya*, 1970a, p. 12.

Chapter Six (143v): On the knowledge of the mean motions (*awsāṭ*) of the planets, their distances, latitudes, altitudes, and the amplitude (*saʿa*) of their rising and setting points; and the knowledge of the mean motion of the sun, the moon and the nodes (*ǧawzahir*).

Chapter Seven (145r): On the knowledge of the explanation of the parallax (*iḫtilāf al-naẓar*).

Chapter Eight (145v): On the knowledge of what befalls the moon in relation to the sun, in terms of brightness, waning, plenitude, decrease, eclipsing, being eclipsed, and such.

Chapter Nine (147v): On knowing how to calculate the meridian line (*ḫaṭṭ niṣf al-nahār*) using the Indian Circle (*al-dāʾira al-hindiyya*),[21] as well as the longitude and latitude of a location; and how to obtain the azimuth of the *qibla*.

Chapter Ten (149v): On the knowledge of the meaning of dawn.

Chapter Eleven (149v): On the knowledge of the seven climes.

Chapter Twelve (152r): On the knowledge of the arc of day and night and the circles; and knowledge of the year, the month, the day and hour, which are the indicators of time.

Section 12.1 (153r): On the fixed stars and their positions.

The Literary Context of *Mirʾāt al-salāk*

As the table of contents indicates, the *Mirʾāt al-salāk* presents itself to the reader as an introduction to astronomy (*muqaddima fī ʿilm al-hayʾa*). In its literal meaning, *ʿilm al-hayʾa* is often translated as "the science of the configuration [of the world]", as it began to define a branch or tradition of astronomy which aimed at understanding the configuration of the universe in its entirety, dealing with both the terrestrial and the celestial realms. This paper is not a detailed discussion concerning *hayʾa*, given that scholars such as F. Jamil Ragep, Sally P. Ragep and George Saliba have discussed it in considerable depth over the last few decades.[22] However, it is important to mention here that *hayʾa* was an attempt to reform theoretical astronomy—primarily Ptolemaic astronomy—to make it coherent with Aristotelian principles of natural philosophy; in a way, to go beyond the "imaginary" circles and lines that Ptolemy presented in the Almagest and de-

[21] This practical method to determine with accuracy the cardinal points based on solar observation will be explained in detail below. Usage of similar devices seems to date back in India to Vedic times (see A. Mollerup, *Ancient Khmer Sites*, pp. 152–153); in Antiquity it is attested in Vitruvius (d. after c. 15 BC) (I.6, 6-7) and later in Proclus (d. 485 AD) (Hypot. 3.22–23; cf. Sédillot, *Mémoire*, pp. 17–18, 30, 76); the first Arabic mention, with the "Indian" added, seems to be by al-Bīrūnī (362/973–440/1048) (see *Al-tafhīm*, 25v–26v), after whom it became a fixture of Arabic astronomical texts.

[22] N. al-Ṭūsī, *Nasīr Al-Dīn al-Ṭūsī's Memoir on Astronomy*, 1993; G. Saliba, *Islamic Science*, 2007; S.P. Ragep, "Fifteenth-Century Astronomy in the Islamic World", 2017; Ibn al-Šāṭir, *L'achèvement de l'enquête et la correction des fondements*, 2021.

pict the physical objects that explained how celestial movements occur. One of the earliest astronomers to write about the need to solve the philosophical inconsistencies of Ptolemaic astronomy was Ibn al-Ḥayṯam (353/965–430/1039), in his work *Šukūk ʿalā Baṭlamyūs* (Doubts Concerning Ptolemy).[23] Over time, *hayʾa* as a topic of study expanded and by the 12th century, it has been argued that it had become the general term used for the field of astronomy.[24]

As with most disciplines, astronomy was approached from different perspectives with different degrees of technical detail. At the most complex level, there were astronomers such as Naṣīr al-Dīn al-Ṭūsī (597/1201–672/1274), or Ibn al-Šāṭir (699/1300–761/1360), who attempted to describe the terrestrial and celestial realms as a coherent system also through geometrical models and proofs that would be able to predict movements seen in the skies. These would not only have to be precise, as the Ptolemaic ones already were to a great extent, but also physically plausible. That is, in order for an astronomical theory to be valid, no mechanism employed could be inconsistent with the principles of Aristotelian natural philosophy—and thus al-Ṭūsī begins his famous treatise *Al-taḏkīra fī ʿilm al-hayʾa* (Memoir on Astronomy) with a chapter on "what needs to be known that pertains to geometry" and another on "what needs to be accepted from natural philosophy in this science".[25] To give but one example, every movement seen in the sky would have to be explained in terms of uniform circular motions, for any other kind of motion was considered impossible to exist in the heavens.

The attempt to integrate theoretical astronomy with natural philosophy was central in *hayʾa* generally, but not all astronomical works shared the same level of complexity. After his *Šukūk ʿalā Baṭlamyūs*, Ibn al-Ḥayṯam wrote a work called *Hayʾat al-ʿālam* (The Configuration of the World)[26] where he described an image of the heavens consisting of physical orbs with different centers and arrangements. The difference between his theories for the planetary movements and that of astronomers such as al-Ṭūsī is that in his *Hayʾat al-ʿālam*, the description is mainly qualitative. No mathematical proofs are presented, nor is much detail given regarding the distances and dimensions of the orbs. Ultimately, it is an astronomical work meant—as Ibn al-Ḥayṯam mentions in his introduction—to be accessible also to a non-specialist audience.

It is in this literary astronomical context that Sulaymān al-Mahrī is situated. With *Mirʾāt al-salāk*, he is composing an introduction to astronomy, most likely for a non-specialist audience. His approach to planetary models is not a highly technical treatment specifying in depth all of the parameters, distances and sizes of the individual planets, but rather a mainly qualitative description, focused on the arrangement of the orbs. However, al-Mahrī's work is still quite different from Ibn al-Haytham's, for *Hayʾat al-ʿālam* includes no diagram and is mainly focused on a description of the heavens.

[23] Ḥ. Ibn al-Ḥayṯam, *Al-šukūk ʿalā Baṭlamyūs*, 1971.

[24] S.P. Ragep, "Fifteenth-Century Astronomy in the Islamic World", 2017, p. 150.

[25] N. al-Ṭūsī, *Al-taḏkīra fī ʿilm al-hayʾa*, in: *Nasīr Al-Dīn al-Ṭūsī's Memoir on Astronomy*, 1993, pp. 92–100.

[26] Ḥ. Ibn al-Ḥayṯam, *Ibn Al-Haytham's On The Configuration of the World*, 2018.

Rather, the structure and content of the *Mir'at* resemble much more closely the famous work *Mulaẖẖaṣ fī 'ilm al-hay'a al-basīṭa* (602/1205–603/1206), written by Maḥmūd b. Muḥammad b. 'Umar Ǧaġmīnī (d. 618/1221).[27] Ragep has described the *Mulaẖẖaṣ* as "one of the most popular textbooks on theoretical astronomy ever written in Islamic lands",[28] and it continued to be reproduced and copied into the nineteenth century.

The *Mulaẖẖaṣ* is divided in a preface, one introduction and two sections—one on the celestial and another on the terrestrial realms. The first section is formed by five chapters and the second by three—the third being a compilation of miscellaneous items. The *Mir'āt*, in contrast, has a four-line introduction immediately followed by twelve chapters dedicated to both the heavens and the earth. All of the chapters share some resemblance with those of the *Mulaẖẖaṣ*, though in different degrees. While some include sections that are nearly identical, others have several variations or are completely different. For example, in Chapter Eleven "on the knowledge of the seven climates", al-Mahrī adds more detail regarding the geographical spaces found in each climate. Al-Mahrī's diagrams are also different from those found in the *Mulaẖẖaṣ*, including the addition of the stellar compass rose which, although common in navigational texts, would not appear in a normal *hay'a* treatise.

Chapter Nine, which we translate further in this paper, corresponds to one of the sections that Ǧaġmīnī included under miscellaneous items and that was commonly added—though with variations—in *hay'a* treatises. Even though the diagrams are somewhat different in both works, the text itself is very similar. The first part on how to calculate the meridian line contains only minor variations, and the second is nearly identical, starting with definitions found in the fourth chapter of the first part of the *Mulaẖẖaṣ*.[29]

Putting the *Mir'āt* in comparison with European astronomy, the work would seem to resemble Georg Peuerbach (1423–1461)'s *Theoricae Novae Planetarum* (New Theory of the Planets)[30] rather than, for instance, Copernicus (1473–1543)' *De revolutionibus orbium coelestium* (On the Revolutions of the Heavenly Spheres).[31]

Textual Parallels

Thus, *Mir'āt al-salāk* was written as a general introduction for the non-specialist to astronomy. Although it is clearly different from al-Mahrī's more navigationally-focused treatises, there are textual connections between the *Mir'āt* and his navigational work *Šarḥ* Tuḥfat al-fuḥūl. Some of the ideas that are discussed more extensively in the former

[27] S.P. Ragep, *Jaghmīnī's* Mulakhkhaṣ: *An Islamic Introduction to Ptolemaic Astronomy*, 2016.

[28] S.P. Ragep, *Jaghmīnī's* Mulakhkhaṣ: *An Islamic Introduction to Ptolemaic Astronomy*, 2016, p. 26.

[29] S.P. Ragep, *Jaghmīnī's* Mulakhkhaṣ: *An Islamic Introduction to Ptolemaic Astronomy*, 2016, pp. 115; 123; 126.

[30] G. Peurbach, *Theoricae novae planetarum Georgii Peurbachii dans l'histoire de l'astronomie: sources, édition critique avec traduction française, commentaire technique, diffusion du XV^e au XVII^e siècle*, 2020.

[31] N. Copernicus, *Nicholas Copernicus: On the Revolutions*, 1985.

are briefly mentioned in the latter, especially in the chapter "On the description of the orbs and the celestial bodies in them" (*Fī ṣifat al-aflāk wa-al-kawākib fīhā*).[32] Both texts include sections with nearly the same titles, as well as passages that are nearly identical. For instance, the *Šarḥ* Tuḥfat al-fuḥūl has a heading that reads "The indication for their number [i.e., of the orbs] is that there exist nine different movements" (*al-dalīl ʿalā ʿadadihā wuǧdān tisʿ ḥarakāt mutaḫālifa*).[33] The first chapter of the *Mirʾāt* includes a similar passage: "Our indication that they are nine orbs is that there exist nine different movements" (*dalīlnā ʿalā kawnihā tisʿat aflāk li-wuǧdān tisʿ ḥarakāt mutaġāyira*).[34] Though the two sections are not exactly the same, the information provided in the *Šarḥ* Tuḥfat al-fuḥūl is found later in the third chapter of the *Mirʾāt*, almost verbatim.

Another example is the entry of the *Šarḥ* Tuḥfat al-fuḥūl that reads: "The indication for the already mentioned organization [of the orbs] is that the celestial bodies eclipse each other and the eclipsing bodies are under the eclipsed ones."[35] This is remarkably similar to the lines found in the *Mirʾāt*: "Our indication on the organization of the orbs according to the already mentioned way is that the planets eclipse each other."[36] Both of these sections begin with similar explanations, that is, that a planet eclipsing another one is known to be under it, but each is phrased differently. However, when both sections transition to discuss the Sun, and the fact that it is not seen to be eclipsed by another body except the Moon, both texts become identical, with only a few minor exceptions. Such textual echoes illustrate connections between al-Mahri's astronomical and navigational texts, and raise larger questions relating to the degree of interaction between the two fields.

Navigation and Astronomy

One of the more interesting aspects of this text relates to larger discussions regarding the relationship between maritime navigation and astronomy, in particular mathematical astronomy. There has often been a theoretical distinction in the secondary literature made between the fields of mathematical astronomy and maritime navigation in the Islamic world. These fields have been traditionally viewed as very different from each other, with little interaction between the two. Navigation is often seen as a "practical" science or art, based on observations made at sea, and largely relying on a maritime form of "folk astronomy", rather than the more abstract and sophisticated formulations proposed by mathematical astronomers in their technical treatises on astronomy.[37] Although they both studied the stars, the practitioners of these two different disciplines

[32] S. al-Mahrī, *Šarḥ tuḥfat al-fuḥūl*, 1972, vol. 3, pp. 42ff.

[33] S. al-Mahrī, *Šarḥ tuḥfat al-fuḥūl*, 1972, p. 49.

[34] Fol. 129r, l. 9–10.

[35] S. al-Mahrī, *Šarḥ tuḥfat al-fuḥūl*, p. 49.

[36] Fol. 128v, l. 13–14.

[37] There has been a distinction made in the study of pre-modern Islamic astronomy of two basic types of astronomy in this time period: mathematical astronomy and 'folk' astronomy. As the name implies, mathematical astronomical literature largely focuses on geometrical and trigonometrical understandings of

even used different units of measurement for recording star altitude heights. Mathematical astronomers referred to them in degrees, while the navigators referred to them in finger heights (*iṣbaʿ*). Such practices suggest that there seems to have been very little dialogue between these two.

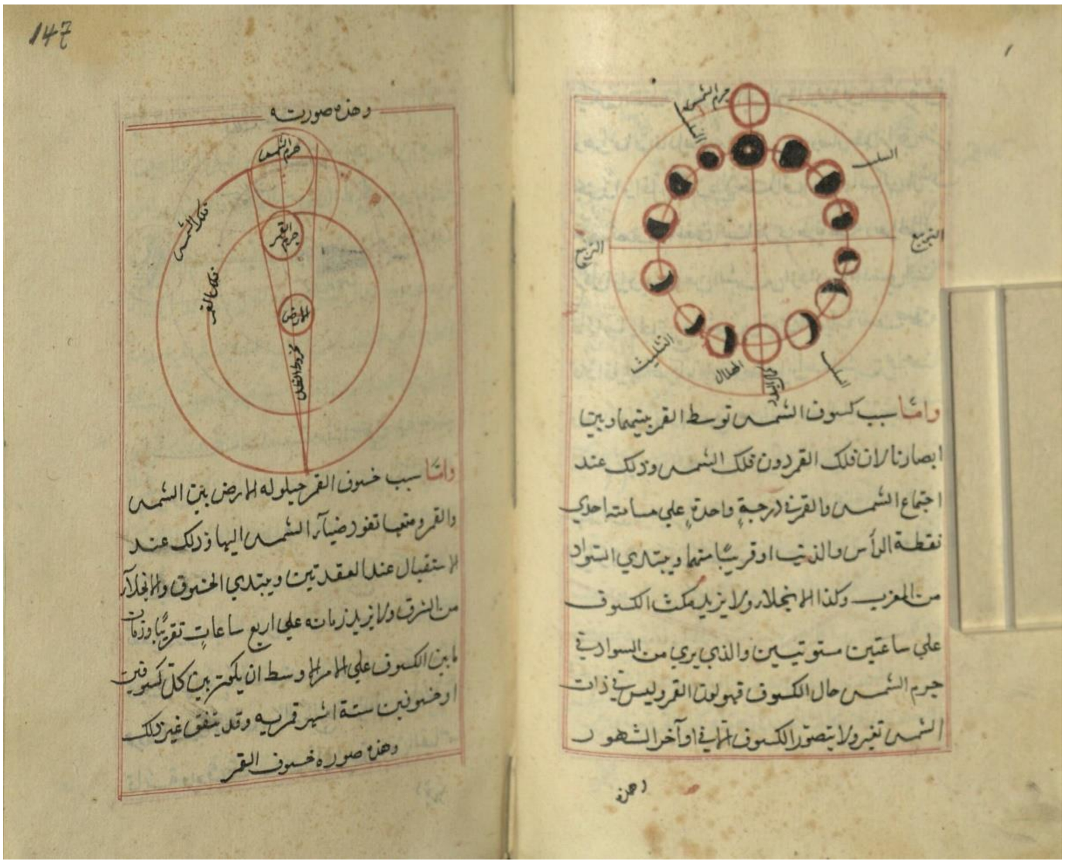
However, passages in this work clearly indicate that al-Mahrī, a sixteenth-century navigator, was engaging with certain texts found in the broader corpus of Islamic mathematical astronomical literature[38] and attempting to introduce the fundamental concepts embedded in these texts to a larger non-specialist audience. The inclusion of this work within a manuscript primarily composed of navigational treatises strongly suggests that navigators were an essential part of his intended audience.

IV. Chapter Nine of *Mirʾāt al-Salāk*

A prime example of al-Mahrī's incorporation of mathematical astronomical formulas within this introductory work is found in Chapter Nine of *Mirʾāt al-Salāk*, which focuses on the use of a particular astronomical instrument called 'the Indian Circle' (*al-dāʾira al-hindiyya*), to determine the meridian and the *qibla*, or direction to Mecca. Below is al-Mahrī's description of this process:

astronomical questions, whereas 'folk' astronomy relied primarily on direct observation on non-mathematical methods to understand astronomical questions. See D.A. King "Astronomy in the Service of Islam", 2015, pp. 182–184; P. Schmidl, "Islamic Folk Astronomy", 2015, pp. 1928–1933; and C. Montelle, "Islamic Mathematical Astronomy", 2015, pp. 1909–1915, for more discussion on this.

[38] This tendency in al-Mahrī had been noted, e.g., in H. Grosset-Grange, "Les traités arabes de navigation : De certaines difficultés particulières à leur étude", 1972, p. 240.



Landberg ms. 401-147. Part of the *Mirʾāt al-salāk*: lunar phases.

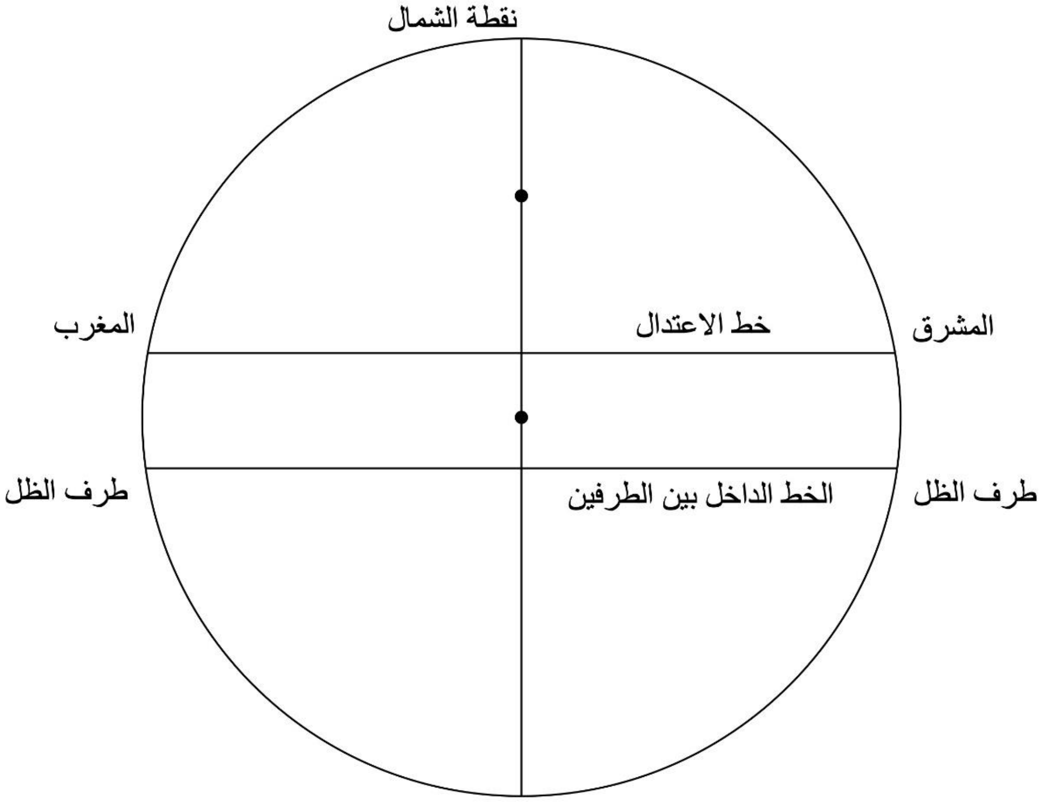
Text and Translation of Chapter Nine of *Mirʾāt al-Salāk*

الباب التاسع

في معرفة استخراج خطّ نصف النهار من الدائرة الهنديّة وطول البلد وعرضه واستخراج سمت القبلة.

أمّا استخراج خطّ نصف النهار وهو أن تستوي موضعا من الأرض بحيث لايقع فيه تحديب ولاتقعير ولو صبّ ماء لَجرى وسال من كلّ جانب ثمّ يدير عليه دائرة بأيّ بُعد كان ويُنصب على مركزها مقياسا مخروطا ممدّد الرأس مساويّا لربع قطر الدائرة على زاوية قائمة ويعرف قيامه عمودا بأن يقدّر ما بين المقياس ومحيط الدائرة من ثلاثة مواضع فإن تساوت الأبعاد فهي قائمة ثمّ يُرصد الظلّ أيّ ظلّ المقياس قبل الزوال حين يكون خارجا عن محيط الدائرة نحو الغرب فإذا انتهى رأس الظلّ إلى محيط الدائرة يريد الدخول فيه يُعلم عليه علامة ثمّ يُرصد بعد الزوال قبل خروج الظلّ من الدائرة فإذا انتهى الظلّ إلى محيط الدائرة يريد الخروج يُعلم عليه علامة ويصل بين العلامتين بخطّ مستقيم فيُنصف ذالك الخطّ ويصل بين مركز الدائرة ومنتصف

الخطّ بخطّ مستقيم وبخرجه في الجنبيين إلى محيط الدائرة فذالك الخطّ هو خطّ نصف النهار ثمّ تنصف أحد نصف الدائرة إمّا الشرقي أو الغربي وتصل بين المنتصف ومركز الدائرة بخطّ مستقيم فيخرجه إلى محيط الدائرة فذالك هو خطّ الاعتدال وهو خطّ المشرق والمغرب وتكتب على أطراف الخطّين النقط الأربع أعني نقطي الشمال والجنوب نقطي المشرق والمغرب وهذه صورة الدائرة

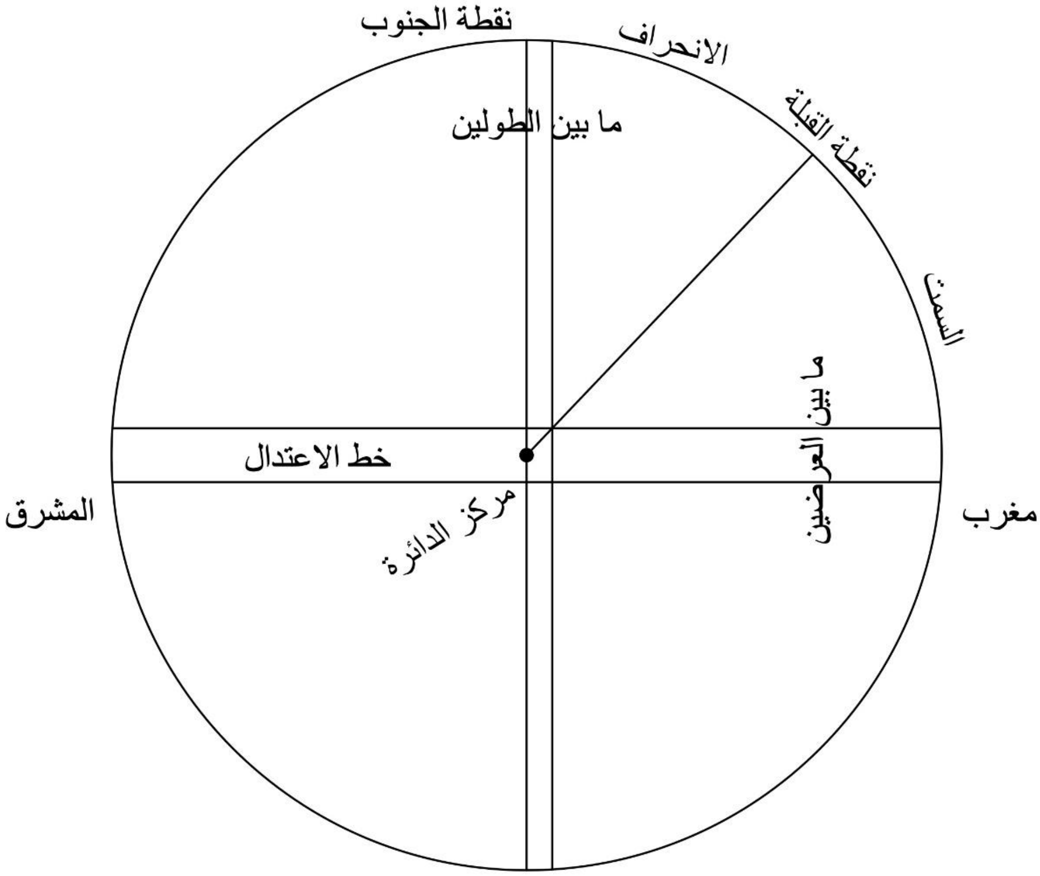


Indian Circle diagram, from Landberg ms. 401, 148v.

وأمّا طول البلد هو قوس من معدِّل النهار ما بين دائرة نصف النهار بآخر العمارة وبين دائرة نصف النهار فذلك البلد عرض البلد هو قوس من دائرة نصف النهار ما بين معدّل النهار وسمت الرأس وهو عبارة عن ارتفاع القطب سمت القبلة هي نقطة التقاطع بين دائرة الأفق وبين دائرة عظيمة تمرّ سمت الرأس أيّ رأس ذلك المكان وبرؤوس أهل مكّة وأمّا إذا أردت استخراج سمت القبلة لبلد مفروض فلابدّ من معرفة طول البلد وعرضه وطول مكّة وعروضها فإذا كانت مكّة أقلّ طولا وعرضا من البلد المفرض فمدّ من الدائرة من نقطة الجنوب بقدر فضل من ما بين الطولين إلى الغرب من نقطة الشمال مثله وتصل بين النهايتين بخطّ مستقيم وعدّ من نقطة المغرب بفضل ما بين العرضين إلى الجنوب ومن نقطة المشرق مثله وتصل بين النهايتين بخطّ مستقيم فيتقاطع الخطّان لا محالة فتخرج من مركاز دائرة خطّان إلى نقاطها وتنفذه إلى محيط على صوب

القبلة فالقوس إلى بين طرفه ونقطة الجنوب من الأفق هي قوس سمت القبلة وهي مقدار ما ينبغي إن ينحرف المصلّي على الجنوب وقِس على ذلك غيره

وهذه صورته



Azimuth of the *qibla*. Diagram from Landberg ms. 401, 149r.

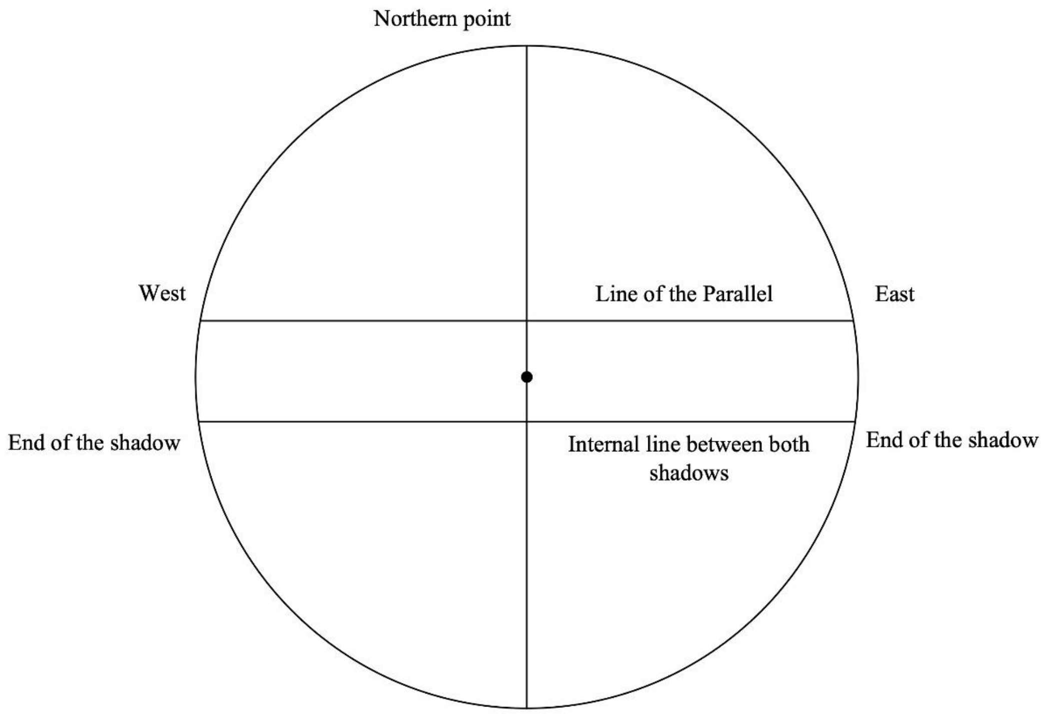
English Translation

Chapter Nine

[147v] Title: Knowledge on how to calculate the meridian line using the Indian Circle, as well as the longitude and latitude of a location; and how to obtain the azimuth of the *qibla*.

1. How to calculate the meridian line

In order to calculate the meridian, level a space on the ground without any raised areas or depressions in it, so that if water was poured on it, it would run down all sides. Then trace a circle of any diameter on it, and fix at its centre a conic gnomon[39] at an upright angle, the upper extremity of which is equal to a quarter of the diameter of the circle. Its vertical position will be confirmed when you measure between the gnomon [148r] and the circumference in three places; if the distances tally, then the gnomon really is perpendicular. Then let the shadow, i.e. the gnomon's shadow, be observed before noon when it moves towards the circumference on the western side. When the tip of the shadow reaches the edge of the circle, and is just about to enter it, this is known to be a marker. It should also be observed in the afternoon prior to the shadow exiting the circle. When the shadow reaches the circumference, and is just about to move beyond it, this is known as the other marker. Draw a straight line between these two markers, and then divide the line in half. The centre of the circle is connected to the centre of the line until it [reaches] the circumference. This line is the meridian line. Split one half of the circle, either the eastern or the western half, into two, and then join this midway point to the centre of the circle with a straight line extending beyond the circumference. This is the line of the parallel, which is the line of sunrise and sunset. Then mark the four points on the ends of the two lines, that is, two points for north and south, and two points for east and west, and this is the illustration of the circle.



Indian Circle diagram, after Landberg ms. 401, 148v.

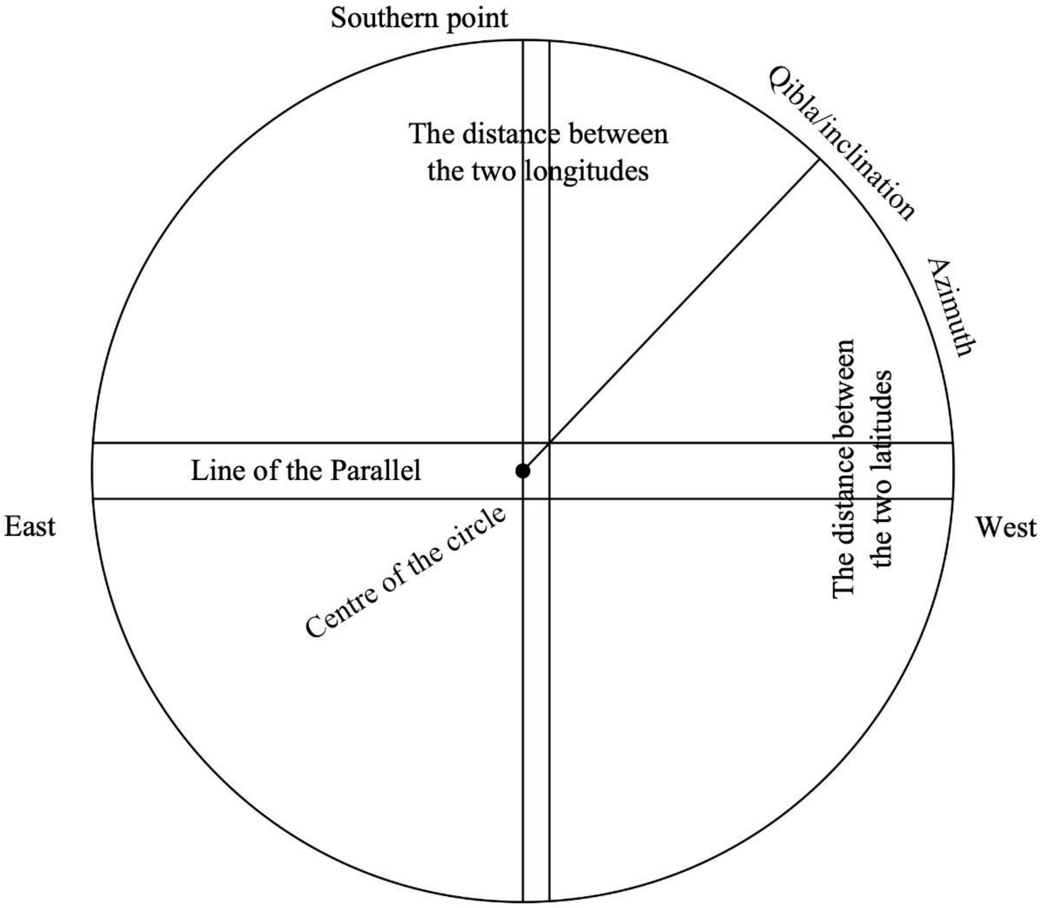
[39] Reading *maḫrūṭ* for *maḥrūṭ*. We are grateful to Prof. Henrique Leitão, University of Lisbon, for kindly sharing his expertise on the astronomical details of this passage.

2. The longitude of a location

The longitude of a location is the arc on the celestial equator that is between the meridian at the end of the civilized lands to the west and the meridian of that location.

The latitude of a place is the arc of the meridian line that is between the equator and the zenith, and it corresponds to the altitude of the pole. The azimuth of the *qibla* is the point of intersection between the circle of the horizon and the great circle that passes through the zenith, meaning the zenith of this place, and the zenith of the people of Mecca. If you want to calculate the azimuth of the *qibla* in a particular location, you need to know the longitude of the place and its latitude. It is also necessary to know the latitude and the longitude of Mecca.

If the longitude and latitude of Mecca are lower than those of the particular location, [149r] then measure the amount of the difference between the two longitudes from the southern point of the circle to the west. Do the same from the northern point, and join the two ends with a straight line. Then measure the difference between the two latitudes from the western point towards the south, and do the same from the eastern point. Join the two ends in a straight line, and the two lines will definitely intersect. Two lines will extend outwards from the centre of the circle through their point of intersection, and pass through to the circumference in the direction of the *qibla*. The arc between its end and the southern point from the horizon is the arc of the azimuth of the *qibla* and this is the measure which is needed if the person who prays is facing south. So calculate other cases according to this. This is the illustration:



Azimuth of the *qibla*. After diagram from Landberg ms. 401, 149r.

[End of the translation]

This chapter is effectively describing an intuitive geometrical method, used since at least the early Islamic period, to determine the direction of Mecca in order to pray in the right direction. A central part of this method requires the use of the Indian Circle to determine the meridian and the cardinal points. As the text indicates, the Indian Circle is an instrument in the shape of a circular disc with a pointed gnomon attached in the center. The shadow of the tip of the gnomon is marked when it enters and exits the circle, and a line is drawn between these two points to determine a true east-west line, whence the direction of the meridian.[40] Once the meridian is established, it is also necessary to have tables that have the necessary longitudes and latitudes for the places that the direction is being determined from. Al-Mahrī's passage above describes the necessary calculations, which are based on the following formula provided by King, where q is the angle of the *qibla*, ΔL is the longitude difference, and $\Delta\varphi$ the latitude difference:

[40] For a photograph of a reconstructed Indian Circle, see F. Sezgin, *Astronomy, Geography and Navigation in Islamic Civilization*, 2010, p. 140.

$$tanq = \frac{sin\Delta L}{sin\Delta\varphi}$$

King mentions that this was the most direct and basic mathematical method used to calculate the direction, and that "more sophisticated accurate procedures were derived by plane or solid geometry, or by spherical trigonometry."[41] In spite of its less "sophisticated" nature, it is nonetheless a form of mathematical astronomy reliant on mathematical tables to calculate the direction of the *qibla* from a variety of locations.

It is interesting to note that the first part of this chapter shows a truly remarkable historical consistency through languages and cultures, with some details found almost verbatim in Greek and Latin works, and presumably in Sanskrit (see our note 21 above for details). More particularly, the whole chapter echoes the description found in the *Kitāb al-zīǧ*, written in the late ninth-early tenth century by astronomer and mathematician Abū ʿAbd Allāh Muḥammad b. Ǧābir al-Battānī (240/858–317/929). Although it shares certain similarities with al-Battānī's description of the same practice, the text is not an exact imitation. Both texts describe the method of drawing the Indian Circle in the same manner, with a similar order of steps, but the specific phrasing and terminology are not quite the same. For example, al-Mahrī uses the word *zawāl* to refer to *noon*, whereas Battānī uses *awwal al-nahār*. There are some terms that also have slightly different shades of meaning, such as al-Mahrī's use of the term "the line of the parallel" in comparison with al-Battānī's "line of the azimuth" in the *Kitāb al-zīǧ* passage. Small additions are also found in each text, such as al-Mahrī's inclusion of the following passage relating to the gnomon, "through which can be determined what is between the centre and the circumference from three places". All of this firmly suggests that al-Mahrī was familiar from certain historical texts found with the Islamic mathematical astronomical tradition and attempting to simplify them for a non-specialist audience.

V. Conclusion

Mir'āt al-salāk is a unique work in the corpus of Sulaymān al-Mahrī, and even more within the larger corpus of Arabic navigational literature, which has been largely ignored in the predominant secondary literature. As a primer on astronomy written for non-specialists, it illustrates the fundamental astronomical concepts that al-Mahrī considered essential for the non-astronomer, and in particular the navigator, to know. The integration of several of these concepts in sections of his other more navigationally focused work shows that he was attempting to incorporate these astronomical ideas and practices within the field of navigation. With this work, al-Mahrī as an historical author provides us with an explicit connection between Arabic maritime navigational and mathematical astronomical literature, two distinct fields which have largely been considered to have little interaction.

[41] D.A. King, "Astronomy and Islamic Society: Qibla, Gnomonics and Timekeeping", 1996, pp. 142–143.

Figures such as al-Mahrī also complicate paradigms found in the predominant secondary literature of astronomy in the Islamic world being divided into two distinct spheres: that of mathematical astronomy and that of folk astronomy (and by association, navigation). Putting aside the problematic nature of the term “folk astronomy” being used to describe a wide variety of complex observational practices, this bipolar paradigm has the potential to create false dichotomies. Rather, these idealized theoretical sub-disciplines should be considered to be poles on a non-linear spectrum that overlap and intertwine with one another in a complex variety of ways depending on the specific contexts and interests of the individuals involved. Many scholars and practitioners such as al-Mahrī relied to varying degrees on both mathematical and observation-based knowledge and practices in order to understand the complex movements of the night sky.

Interestingly enough, a fascinating parallel to this rapprochement between learned astronomy and navigation was taking place in Europe at about the same time, where Portuguese and Spanish navigation treatises—such as Francisco Faleiro (1494–c.1575)'s *Tratado del Esphera y del arte del marear* (Treatise of the Sphere and the Art of Seafaring) in 1535, or Pedro Nunes (1502–1578)'s *De arte atque ratione navigandi* (Art and Reason of Navigation) in 1573—started incorporating elements of astronomy, enabling the fleets to venture deeper into the ocean. Although this parallel is beyond the scope of this article, and needs to be investigated in much more depth in order to fully understand the connections, it does suggest that this Arabic manuscript is reflective of a larger, more global trend in navigation to incorporate astronomical practices within its folds that extended far beyond the shores of the western Indian Ocean.

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