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Possible Origins of the 14/15th-Century English Navicula Sundial in Islamic Civilization

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ABSTRACT

Prof. Dr. Fuat Sezgin was always very keen on tracing back the scientific interactions between the Islamic world and medieval Europe. Among the many scientific instruments he had reconstructed for the museum in the Institute for the History of Arabic-Islamic Science in Frankfurt there is one small peculiar sundial, called a navicula. Prof. Dr. Fuat Sezgin reconstructed this navicula in order to facilitate research into the possible origins of this sundial that was first manufactured and written about in 14th- and 15th-century England. After explaining the modus operandi of the navicula, we present new perspectives on possible historic relationships between this European sundial and the Islamic scientific tradition.

Keywords: Navicula sundial, universal horary dial, astronomy in 14/15th-century England, Islamic scientific tradition, second declination

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1. Introduction

Figure 1 displays a close-up picture of the navicula sundial that Prof. Dr. Fuat Sezgin had reconstructed for the museum in the Institute for the History of Arabic-Islamic Science in Frankfurt. This reconstructed navicula is not listed in the catalog of the museum (Sezgin, 2003).

The navicula sundial is a small portable instrument with which the local true solar time can be found by setting it according to the altitude and the declination of the sun, as well as the (geographical) latitude of the observer.[1] The navicula is universal in the sense that it can be used for a whole range of latitudes, roughly for between the Tropic of Cancer and the Arctic Circle (in the northern hemisphere).[2] The name navicula translates as “small ship” and refers to the shape of the instrument. Sometimes the navicula is referred to as “*navicula de Venetiis*,” meaning “navicula of Venice”, for example by (Kragten, 1997) and (King, 2003).

Figure 1: Close-up of the navicula sundial that Prof. Dr. Fuat Sezgin had reconstructed for the museum in the Institute for the History of Arabic-Islamic Science in Frankfurt.

In the present paper, we elucidate the possible origins of the navicula sundial, an instrument that was first manufactured and written about in 14th- and 15th-century England, and of which less than ten items survived which are now preserved in museums and private collections. We start by describing the navicula sundial in detail, both from a mathematical and morphological point of view. After explaining how the navicula can be used to tell the true local solar time, we conclude on the basis of historical resources that this peculiar instrument is far more precise -at least in theory- than has been realized before by modern historians of science.

In our research, we have reconstructed the navicula sundial following the construction instructions and diagrams in some of the few surviving Latin manuscripts in which the navicula was described. We have discovered in doing so that the declination scales on the instrument were drawn using relatively simple, but very ingenious, constructions. Jan Kragten (Kragten, 1997), an amateur scientist and member of the Dutch sundial society, was the first to realize the importance of these constructions for the precision of the instrument. In our PhD thesis in preparation (De Graaf, 2022), we will shed

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[1] The local true solar time is the time defined by the hour angle (i.e., the angle between the hour circle and the (noon) meridian circle, both of which pass through the celestial north pole). It can be computed for a given locality from the observed altitude of the sun. It differs from the local mean solar time, where a constant increase in the right ascension of the sun is assumed.

[2] The navicula can also be used for localities in the southern hemisphere, by appropriately rearranging the zodiacal signs depicted on the instrument.

new light on the astronomical background of the constructions and show that the constructions significantly increased the accuracy of the instrument, to a level that far exceeds the precision required for all its practical applications. In our view, this demonstrates that the makers of the navicula had a solid understanding of the mathematical and astronomical background of the instrument. We will argue in (De Graaf, 2022) that the deeper motivation for constructing the navicula was theoretical of nature, rather than practical.

In the present paper, we review the different views of modern historians of science on the origins of the navicula sundial and present new perspectives on possible historic relationships between this European navicula sundial and the Islamic scientific tradition. We do not explicitly intend to explain the navicula in connection with similar European dials, namely the later developed Regiomontanus sundial with which the time could be computed in an exact way, the Uhrtäfelchen of Regiomontanus, or the Organum Ptolemei. See the book by Catherine Eagleton (Eagleton, 2010) for descriptions and drawings of these dials. The Regiomontanus sundial is easier to construct and to use than the navicula, as it did not require modified declination scales. Modern authors have compared or tried to explain the navicula on the basis of the Regiomontanus sundial or other dials. This has often led to erroneous explanations and misconceptions.

2. Description, anatomy and use of the navicula sundial

The navicula sundial consists of two solid parts that can be moved with respect to each other, the mast part and the ship part, and two additional parts: an axis and a string with a bead and a plummet to keep the string stretched (see Figure 2). The solid parts were often made of metal, but could also be wooden or made of ivory. The mast contains a latitude scale, typically running from latitude 20 or so to latitude 60 or even latitude 66.5, corresponding to the Arctic Circle. The ship part contains two different declination scales, one at the bottom and one on the right side, and hour lines. We call the lower bottom declination scale the mast declination scale, and the right-hand declination scale the bead declination scale. Both declination scales were divided according to the corresponding zodiacal signs, i.e., according to the corresponding ecliptical longitudes. Full details about the constructions of these two scales will be provided in the PhD thesis (De Graaf, 2022).

The ship part is the lower part of a circle with radius R typically between five and eight centimeters in the preserved instruments. According to the instructions for construction in one of the surviving manuscripts, i.e., MS Bodley 68 (see (Eagleton, 2010) for a translation from Latin into English), the manuscript we also use for our reconstruction, the maximum size would be half a foot divided by two, corresponding to approximately eight centimeters. We call the slightly smaller circle with radius $R \cos \varepsilon$, which has the same center as the *hour circle* (not drawn in Figure 2). Here, ε is the obliquity of the ecliptic, taken to be $\varepsilon = 24$ degrees, both in the instructions in MS Bodley 68 and in our reconstruction, and consequently in Figure 2 and 3 in this paper. See the appendix for a short description of the celestial sphere and its related terminology and concepts. The hour lines representing equinoctial (or equal) hours are drawn perpendicular to the horizontal diameter.[3] The hour circle is tangent to the noon hour line on the right side of the figure and to the midnight line on the left side of the figure.

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[3] Until the 15th century, seasonal hours were used in civil life, whereas equal hours were only used by astronomers. For an introduction to the history of timekeeping, and history of astronomy in general, see the book Cosmos by John North (North, 2008).

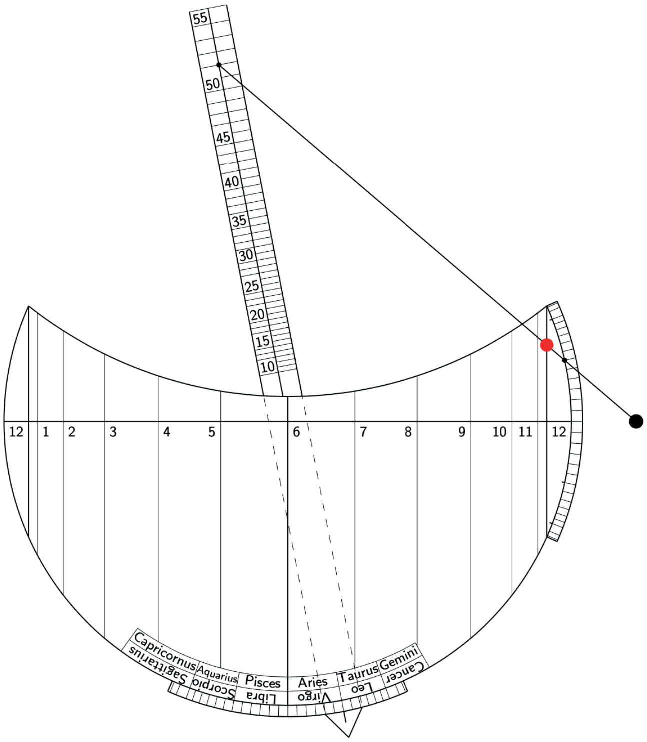

Figure 2: The navicula sundial is set for a location at latitude 52 degrees North and for a date in the year that corresponds to 0 Taurus (or 30 Aries), that is, for April 20.

The mast is connected to the ship at the center of the instrument by the axis, and can be rotated and set according to the declination of the sun at the mast declination scale. Along the mast, a small rider can be moved to set the latitude of the observer. At the rider, a string with a bead is attached. The bead can be moved along the string and set according to the declination of the sun at the bead declination scale. The bead itself has to be positioned at the noon hour line, so not at the declination scale itself. To find the time, the navicula can be set at the altitude of the sun by aligning the instrument with the sun using the two sights that are mounted atop of the noon and midnight hour lines, equidistant to the horizontal diameter. The rays of the sun pass through small holes in the sights. The time is subsequently indicated by the position of the bead on or between the hour lines when the string is suspended vertically. At night, the time can be found by aligning the instrument with a star, according to some further instructions we will not specify here.

Example. Use of the navicula for timekeeping. Let us set the navicula sundial for the latitude 52 degrees North for 0 Taurus (or equivalently 30 Aries), that is for 20 April for the latitude of Utrecht, Netherlands. See Figure 2 for this configuration. The altitude of the sun in Figure 3 is taken to be 30 degrees, and the navicula is aligned with the sun in the diagram accordingly. The true local solar time can then be read off between the parallel hour lines to be approximately 08.15 in the morning or equivalently 15.45 in the afternoon. The correct true local solar time would be 08.17 or 15.43, giving an indication of the accuracy of the instrument.

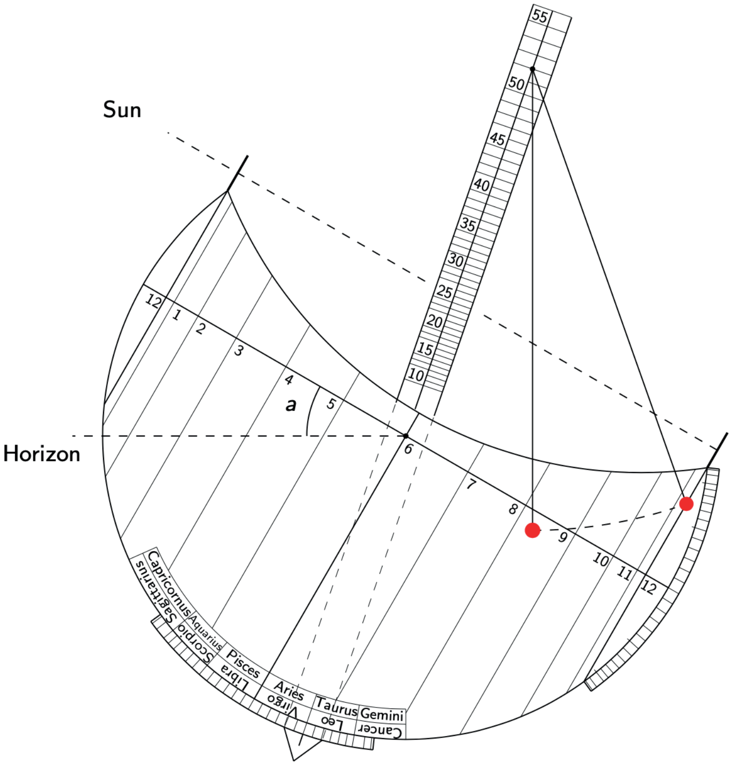

Figure 3: The navicula sundial is aligned with the sun, which is at *a* = 30 degrees above the horizon. The true local solar time in equal hours can then be read off by estimating the position of the bead (in red) on or between the hour lines, when the string with the bead is suspended vertically.

3. Different views on the origins of the navicular sundial

Modern historians of science have expressed different views regarding the possible origins of the navicula sundial. Whereas Catherine Eagleton (Eagleton, 2010, p.4) warns that suggestions about the origins of the navicula must be considered carefully and that the instrument could have been developed both from elements from the Islamic scientific tradition and medieval European influences and developments, David King (King, 2003, p.11) conjectured an origin in the ninth-century Eastern Islamic world. Other authors, such as Robert T. Gunther (Gunther, 1923, p.40) and Derek J. de Solla Price (De Solla Price, 1960, p.399), mention the *zawraqi* astrolabe as a possible predecessor to the navicula sundial from Islamic civilization. I think this suggestion is baseless, as the boat element in the *zawraqi* astrolabe reflects a horizon and not an hour circle.

King argues that astronomers in the Eastern Islamic world, most notably the ninth-century astronomer Ḥabash al-Ḥāsib, solved the same problem as the navicula, namely to determine the true local solar time from the altitude of the sun in a way which is valid for all geographical latitudes. Ḥabash al-Ḥāsib solved the same problem also from the altitude of stars at night. However, King has not shown that the solutions in the Islamic scientific tradition are similar to those produced by the navicula. Therefore, his evidence remains unconvincing to us. The solutions differ also from one another; whereas the navicula produces the time mechanically using one single instrument, Ḥabash al-Ḥāsib computed the true local solar time in equal hours by a series of sine quadrant computations. If competent authors in different cultures worked on the same mathematical problem, they might both have found a correct solution, even if there are no historical connections. We remind the reader that both the medieval European and the Islamic scientific tradition were ultimately based in part on the same fundamental Greek geometrical and astronomical works, such as Euclid's Elements, the Spherics of Theodosius, and the Almagest of Ptolemy. Thus, to prove a historical connection between the navicula and the Islamic scientific tradition, one would need to find similarities in detail. That is to say: one would have to identify texts, instruments, or concepts from the medieval Islamic tradition that can be directly related to aspects of the navicula or of the underlying mathematics.

In the course of our research, we have found one such similarity, pointing to a historical relationship between the navicula and the Islamic scientific tradition. As will be more fully explained in the PhD thesis (De Graaf, 2022), one of the two declination scales is based on the concept of "second declination." This concept has not been found in Greek works but it is often used in medieval Islamic zijes, i.e. astronomical works (see: Kennedy, 1953, p.140). If there was indeed an influence from the Islamic scientific tradition, the details of course need further investigation. This investigation will be much facilitated by the publication program of the Institute for the History of Arabic-Islamic Science of Prof. Dr. Fuat Sezgin, putting reprints and facsimiles at the disposal of researchers.

Appendix. Trigonometry of the celestial sphere

In Figure 4, the point O represents the center of the Earth. Here, O is the center of a very large imaginary sphere that is called the celestial sphere. The points S and N represent the south pole and the north pole of the celestial sphere, respectively, i.e., the points of intersection with the axis of the earth. On the celestial sphere, the positions of the stars and the apparent one-year path of the sun around the Earth, i.e., the ecliptic, are projected from the center of the Earth. The celestial sphere is so large that the size of the Earth can be ignored. The position of an object along the ecliptic, e.g., the position of the sun ☉ in Figure 4, can be expressed by its ecliptical longitude λ, with $0 \leq \lambda \leq 360$, as measured from the vernal point P where the ecliptic intersects the celestial equator. The ecliptic can be divided into the 12 signs of the zodiac, with 30 degrees of ecliptical longitude for every sign. The position of the sun can also be expressed in terms of its declination δ, the perpendicular distance of the object to the celestial equator, and its right ascension α as measured along the celestial equator. The angle between the celestial equator and the ecliptic is denoted by ε, called the obliquity of the ecliptic, and is close to 23.5 degrees in modern times. The declination, right ascension, and declination of a celestial object are related to one another by the formula $\sin \delta = \sin \varepsilon \sin \lambda$. For full explanations, see the textbook on spherical astronomy by (Smart, 1977).

The position of the sun in the ecliptic can be estimated using the fact that the sun moves with nearly constant speed through the 12 zodiacal signs, into which the ecliptic is divided, in the course of one year. Consequently, the sun moves along the ecliptic with a velocity of approximately one degree per day. See the table below for the division of the ecliptic into the signs of the zodiac and the approximate calendar dates when the sun enters a particular sign. The dates can slightly differ from year to year because of the effect of leap years. In the table, we assume $\varepsilon = 24$.

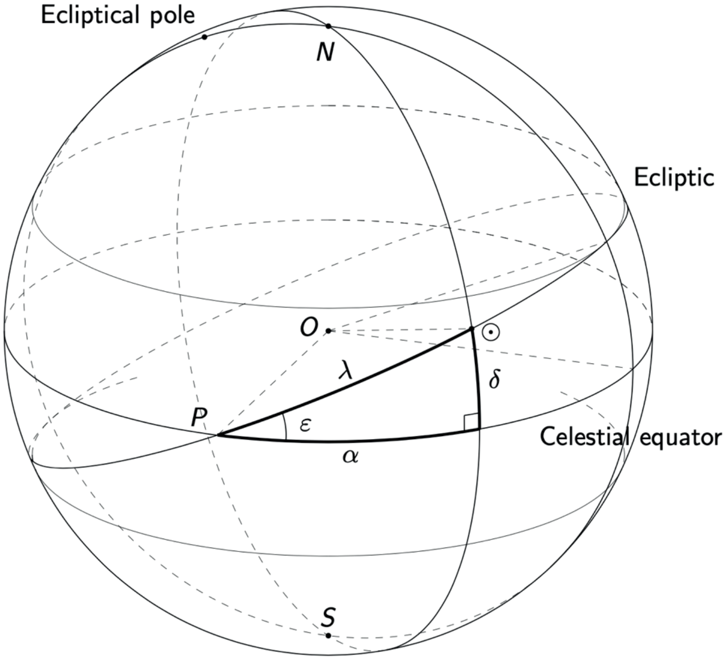

Figure 4: The celestial sphere, with the ecliptic, and the position of the sun on it.

Table 1:			
	λ	**δ**	
Aries	0	0	March 21
Taurus	30	11.7	April 20
Gemini	60	20.6	May 21
Cancer	90	24	June 21
Leo	120	20.6	July 23
Virgo	150	11.7	August 23
Libra	180	0	September 23
Scorpio	210	-11.7	October 23
Sagittarius	240	-20.6	November 22
Capricornus	270	-24	December 22
Aquarius	300	-20.6	January 20
Pisces	330	-11.7	February 19

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