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ANALYSIS OF FRAGMENTS OF ASTRONOMICAL INSTRUMENTS FROM TSAREVO SITE (VOLGOGRAD REGION)

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Abstract. Questions related to the level of astronomical knowledge in Volga Bulgaria and the Golden Horde in the 10th-16th centuries are presented. Fragments of astronomical instruments found during excavations at the Tsarevo site are analyzed. These are the remains of the mount of the celestial globe and the tympan – a part of the astrolabe. A reconstruction of the original appearance of the instruments was carried out, and their purpose was described briefly. Using the lines on the surface of the tympan, an attempt was made to restore the latitude of the place for which tympan was intended.

Keywords: astrolabe, tympan, celestial globe, Golden Horde, Volga Bulgaria, Tsarevo site, Akikula (Afkula), The State Hermitage Museum, Kunstkamera

There is very little information about the level of astronomical knowledge in Volga Bulgaria (10th-13th centuries) and in the Golden Horde (13th-16th centuries). Only a few writing sources containing astronomical information have survived until now [4, 5]. But we know about the early penetration of Islam here, accompanied by the appearance of mosques and appropriately educated people. This is confirmed by the stories of travelers who visited the cities of the Golden Horde, and by modern archaeological excavations. The correct schedule of divine services and correct orientation towards Mecca could not be ensured without knowledge of astronomy and the availability of appropriate instruments. Unfortunately, during archaeological excavations, not a single complete instrument has been found yet, but there are two finds of small fragments, which will be discussed further.

But, before going on to the main topic of the article, let's consider one important astronomical question. It was discussed in several sources [5, P. 71; 10, P. 238], but remained incomprehensible for the author.

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About shortest night at northern latitudes

This question was extremely important due to the fact that at northern latitudes near the summer solstice the nights are very short. We call them "white nights' season". Because of this, the night eating for Muslims overlapped with the time of morning prayer. Bukhara jurists even sent a special fatwa to Bulgar with an answer to this question, allowing them to first eating and postpone prayer [10, P. 238].

The Syrian scientist Ibn Fadlallah al-Umari (al-Omari) (1301-1349), who served as secretary to the Egyptian Sultan, collected a number of information about the Golden Horde. So, for example, he retells the words of a certain Hasan Elirbili:

> "One of the most famous cities of his (Kipchak) is Bulgar; his shortest night (lasts) *4½* hours. [Merchant] Hasan Errumi [ar-Rumi] says (the following): "then I asked Mas'udi, the determiner of the times (of prayers) in Bulgar, about this. "We calculated it," he said, "with the help of astronomical instruments and found that it (lasts) a little over *4½* hours. This is the extreme loss of night time there. As for the "kasaba" Akikula, we (and there) made observations on it and found that the shortest night there (lasts) *3½* hours, (hence) shorter than the Bulgarian night by one hour. Between Bulgar and Akikula, he says, the distance is 20 days of ordinary walking [about 730 km]. The word "kasaba" in Persian terminology means a small town" [10, P. 237-238].

This fragment needs comments. Firstly, astronomical instruments are mentioned here, and the most common instrument in those days was the astrolabe. With its help, it was possible to establish the exact time by observing the stars and the Sun. The oldest surviving Arab astrolabes date back to the 9th century [16]. Secondly, we need to understand what is night here. In modern understanding, this is the time from sunset to sunrise. Ancient Bulgar (the current city Bolgar in Tatarstan) was located at a latitude of 55 degrees. The shortest night here on the summer solstice, June 22, lasts 6 hours 37 minutes, or approximately 6.5 hours [6]. This is very different from the 4.5 hours mentioned in the above fragment. What's the matter? It should be noted that the last Isha prayer should be performed after dark, and the first Fajr prayer should begin at dawn. It's twilight time. In modern astronomy, three types of twilight are distinguished. The first are civilian ones, from sunset until it dives 6 degrees below the horizon. The second – navigation – the Sun goes down to 12 degrees. And the third – astronomical – up to 18 degrees. And only after the end of astronomical twilight comes complete darkness.

At a latitude of 55 degrees, on the shortest night in June, the Sun goes down to 11.5 degrees maximum. This leads to the fact that in the evening, after sunset and civil twilight, navigational twilight is coming. It last all night and falls into the morning twilight. There is neither astronomical twilight nor complete darkness in the summer. If we take the evening and morning boundaries of civil twilight beyond the night, then the night in Bulgar will last 4 hours 41 minutes. This meaning is already very close to the information of the ancient author.

The same is with the Akikula (Afkula) site. It is believed that it was located in the modern Perm region, near the village of Rozhdestvensk, on the banks of the river Obva. The latitude of this place is 58.5 degrees [1, P. 6]. During the shortest night, the sun goes down the horizon here by 8 degrees only. The night, if calculated by civil twilight, will last 2 hours 58 minutes, or approximately 3 hours. An

ancient author writes about 3.5 hours. But in the note to the text on page 238, Tiesenhausen twice mentions the value 3 hours also. So here the boundary of night coincides with the boundaries of civil twilight too.

The concept of twilight was well known to Muslim scholars. And we find confirmation of our conclusions about the boundaries of the night from the famous scientist Abu Rayhan al-Biruni (973-1048): "experts in Muslim jurisprudence count the day from dawn" [2, P. 56].

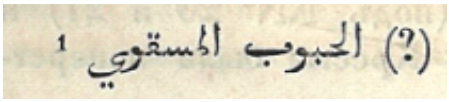
Next we move on to the study of material sources. It is known that during excavations of Golden Horde sites many coins were found. L. Galkin studied astronomical images of the zodiac signs on copper, bronze and silver coins, which were often minted at the beginning of the year according to the lunar calendar [3]. Two more objects found during excavations were described by their discoverers very sparingly. Let's look at them in more detail.

Fragments of the horizontal circle of the celestial globe

The first report of an astronomical discovery during the excavations of the Tsarevo site was made by archaeologist Alexander Tereshchenko (1806-1865), who was sent to carry out excavations by the Ministry of Internal Affairs. In a report for 1848, he writes:

> "Together with the crosses, two fragments of copper were found, with an Arabic inscription: el-maskawi el-habub, i.e. Moscow angle-meter. It is divided into degrees, which are marked with numerals and Arabic letters. Counting degrees visible from 10; it comes from the right hand, in the following order: 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and then from the left: 65, 70, 75, 80, 85 and 90; therefore, the ancient Russian angle-meter was divided into 145°" [9, P. 398].

Currently, these two fragments (Fig. 1) are in the State Hermitage. Thanks to the help of research fellow Anastasia Teplyakova, photographs of these fragments and their exact dimensions were obtained. We were able to read the inscriptions on their surface again. They turned out to be elementary and quite expected. According to information from Moscow State University professor Rustam Shukurov, on the large fragment at the top it is written "*al-janub*", i.e. "south", and on the small fragment – "*al-masharik*", i.e. "east" or rather "eastern lands" (the Arabic word is plural). So the "Moscow angle-meter" was debunked after 175 years. However, in a commentary to A. Tereshchenko's message, archaeologist and orientalist Pavel Savelyev (1814-1859) put a question mark, being unsure of the correct reading of the inscription [9, P. 398]:



When these two fragments are combined (Fig. 2), taking into account their sizes, it turns out that the circular scale has an internal diameter of 30 cm. It remains to determine what kind of instrument it was. Astrolabes, quadrants, armillary spheres, and celestial globes could have a graduated scale. The astrolabe disappears due to the shape of the cutout and the large thickness of the fragments – 1.1 cm. The quadrant scale was 90 degrees, but here we see at least 115. The armillary sphere was too rare an instrument. Most likely this is a horizontal circle in which the celestial globe should be installed. A rectangular slot is the point of intersection with a vertical circle aligned in the north-south direction.

An example of such an Arabic globe is a specimen (Fig. 3), which is stored in the Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera) (inventory number ML-02721).

Its diameter is 18.3 cm [12, P. 56]. But there are also larger globes. Thus, in the vast catalog of the German researcher S. R. Sarma there is information about bronze globes with a diameter of 36 and 37 cm [14, P. 3025, 3011]. So the diameter of 30 cm we obtained is not something unique for globes. For an armillary sphere this is too small.

Fig. 1. Two fragments found during archaeological excavations in 1848. The horizontal size of the large fragment is 16.0 cm, the small one – 7.7 cm, thickness – 1.1 cm. The State Hermitage Museum, Inv. number CAP-809, CAP-810. Photograph © The State Hermitage Museum, St. Petersburg, 2023.

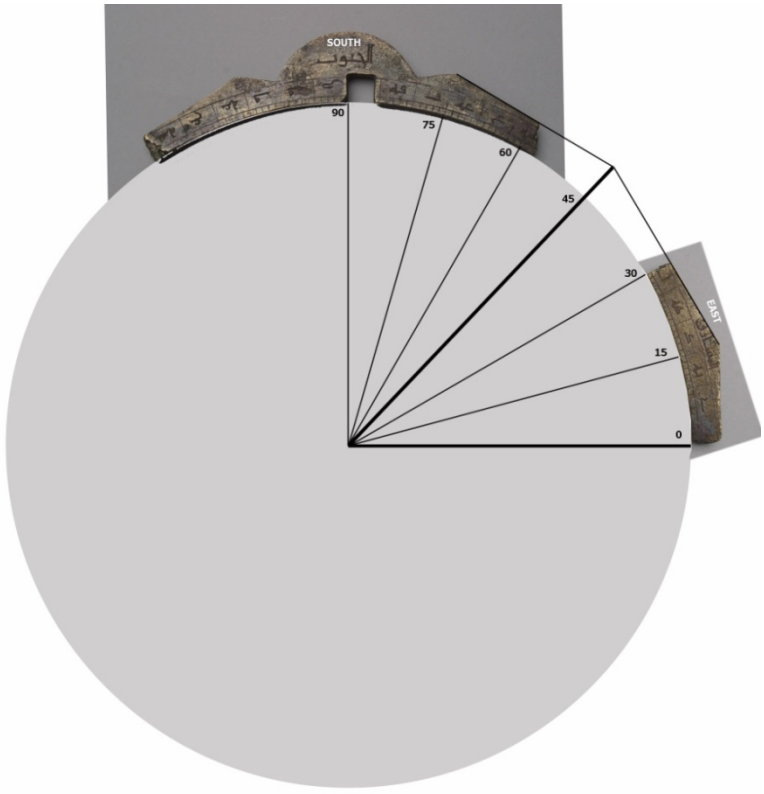


Fig. 2. The location of the fragments on the circle is restored according to the numbering of degrees. The numbering goes from east (right) to south (top), and from west (left) to south from zero to 90 degrees.

R.S. Sarma also confirms the principle of horizontal circle graduation (example in Fig. 4). Most often this is the numbering of each quadrant from 0 to 90 degrees, starting from the points of east and west in the direction of north and south [14, P. 2702]. This is exactly how our fragments are graded. This is another argument in favor of a globe rather than an armillary sphere. Since the globe was inside a horizontal circle, its diameter should be slightly less than 30 cm. The outer edge of our horizontal circle is made in an unusual way – in the form of 30-degree corner protrusions. Perhaps this is some feature of the master. Such globes were made primarily as teaching aids, but they could simply serve as decoration in the interior of a rich home.

Fig. 3. Celestial globe from the collection of the Kunstkamera. The outer edge of the horizontal circle is designed in the form of semicircular protrusions. Vertical circle of simple shape [13, P. 45].

Fig. 4. An example of a horizontal circle, inside of which a celestial globe was installed. All three grooves into which the vertical circle was placed are visible [14, P. 3067].

Tympan of the astrolabe

We learn about the next discovery of fragments of an astronomical instrument from an article by German Fedorov-Davydov (1931-2000). He reports:

> "in 1963, two fragments of a bronze quadrant were found - an astronomical instrument, well known in the Muslim East in the Middle Ages. <...> The found fragments of the bronze quadrant had such a grid of parabolic lines and Arabic letters denoting degrees. This is the first quadrant, discovered at the Tsarevo site, but not the first astronomical instrument" [11, P. 248].

Further, the author refers to the above-described find of 1848.

In the same article on page 245 there are photographs of two fragments taken from both sides. The photos are not very high quality. The size of the fragments and their thickness are not given.

We do not know why G. Fedorov-Davydov called these fragments the remains of a quadrant. But the astronomical quadrant was also a fairly common instrument in the Arab world. In addition, the term "quadrant" was used in translated literature when describing the reverse side of astrolabes. In this case, the full circle was conventionally divided by horizontal and vertical lines into four parts, i. e. quadrants [8, P. 187, 191].

It is not known whether G. Fedorov-Davydov tried to combine these two fragments; his article does not mention this. But we performed such a combination (Fig. 5), from which it became clear that these are most likely the remains of a tympan, one of the astrolabe's part, and not a quadrant. The fact is that a quadrant, in mathematical terms, is an astrolabe folded twice along two diameters. The lines on the surface of the quadrant run differently. In addition, our two fragments occupy more than a quarter of the full circle, as seen in Fig. 6. The conclusion could be confirmed by measuring the thickness of these fragments. The tympan is usually thin - from 0.5 to 1 mm thick. On its surface there are circular (not parabolic) lines, which represent circles of equal altitudes (almucantarates). The altitude values are signed next to each line according to the abjad system, i.e. Arabic letters. The most recognizable letter here is "lam", meaning 30. All neighboring values, going in increments of 6 degrees, are also restored from it. Biruni called such astrolabes "six-fold", because there are 15 circles (see Fig. 6), which is a sixth of the total number – 90 [2, P. 154]. A spider (rete) with stars was placed over the tympan. Each tympan (and there could be from 3 to 6-7 of them inside the astrolabe) was designed for a very specific latitude of the place where it could be used.

Fig. 5. Combination of two fragments of the tympan. Both sides are shown. The altitude lines are marked.

An interesting task arises: what latitudes correspond to the circles on each side of the tympan? The fact is that circles on the tympan are drawn according to strictly defined rules [7, P. 66-67]. The first step is to restore the circles and measure their diameters. After this, it is possible to calculate for which latitude a given tympan was intended (each of the two sides). The difficulty is that our fragments contain no more than one third of the full circle, and the quality of the photograph is not high.

It is unknown where the fragments are now stored. These fragments were not found in the collections of the State Hermitage, in the Volgograd Regional Museum of Local Lore, in the Museum of the Department of Archeology of the Faculty of History of Moscow State University [1]. The author carry out calculations using the available photographs from the article by G. Fedorov-Davydov (Fig. 6).

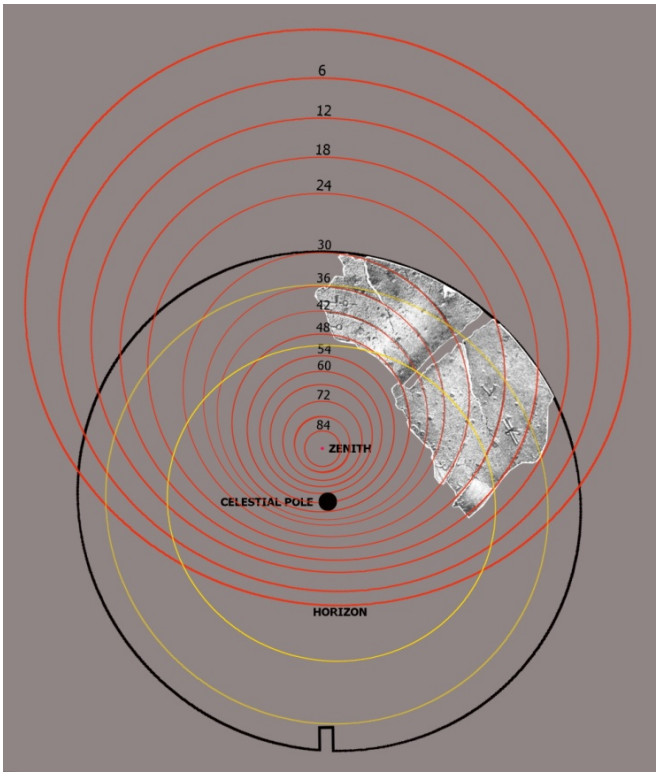


Fig. 6. The figure shows the location of the found fragments on the tympan.

The edge of the tympan is outlined in black, circles of equal heights are outlined in red. Their centers must lie on the same straight line passing through the center of the tympan, where the celestial pole is located. In this case, perfect alignment did not work out. The outer yellow circle marks the Tropic of Capricorn, the inner one the equator.

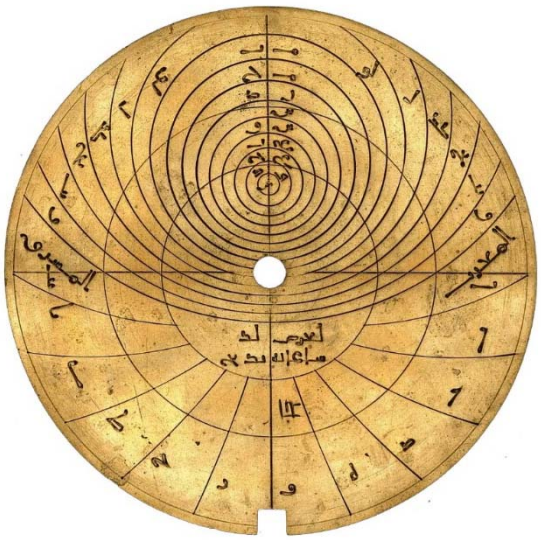


Fig. 7. Example of a tympan from a 9th century astrolabe for latitude 34 degrees [16].

A characteristic feature of early Arab astrolabes is the absence of lines of equal azimuths. They should diverge from a zenith point located above the center of the tympan.

Since the dimensions are unknown, it was necessary to express the diameters of the circles in fractions of the outer circle (edge of the tympan), i.e., take relative sizes. The latitude value can be calculated

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for each of the altitude circles (or rather, a small part of it). And this value, in theory, should be the same for each of the two sides of the tympan. Due to errors, this, of course, did not work out. On one side of the tympan the latitude values ranged from 27 to 32 degrees, on the other – from 29 to 37 degrees. Typically, the tympans of Arab astrolabes made in Persia were located in this range (Fig. 7). From the calculations, it only became clear that these were not tympans specially made for the capital of the Golden Horde, since the latitude of the Tsarevo site is about 48.5 degrees.

But astrolabes with tympanums specially designed for high latitudes could well have been preserved. In 2022, an astrolabe called Persian and approximately dating from the 17th century was sold at auction in Germany. It had tympanums designed for latitudes of 48, 52, 53, 54, 55, 56, 57 degrees! For Persian astrolabes these are exotic meanings. The author had not met them before. But these values cover latitudes from the capital of the Golden Horde to Bulgar and even almost to Akikula. It is possible that this astrolabe could have been manufactured much earlier than the stated date for use in these territories. This is also supported by the absence of lines of equal azimuths on its tympanums [15].

Conclusion

This article analyzes the question of the night's length, which is very important in Islam, as well as two archaeological finds made in 1848 and 1963. Both finds are fragments of astronomical instruments. The first two fragments once formed the frame of a celestial globe, the second two fragments were part of an astrolabe. The relative position of these fragments and their position in the original details have been restored. The diameter of the missing globe has been calculated. The latitudes for the fragments of the astrolabe – were calculated. Now, based on the material source found, we know for sure that astrolabes were used in the Golden Horde. The paucity of finds is due to the fact that these instruments were very highly valued and carefully stored. Even when they failed, the brass remained valuable and was melted down. The author was studying archaeological finds for the first time, so he is ready to listen to comments and additions.

This article could not have taken place without the help of many specialists, whose names are listed in the text of the article. The author is very grateful to them.

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