New archeoastronomical investigation of the complex Koy-Krylgan-kala

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Abstract. In this paper the ancient Khorezmian complex Koy-Kryilgan-kala was studied from the point of view of archaeoastronomy. Previously it was assumed that the main structure of the complex was oriented on an azimuth of 69 degrees, which is associated with the direction of the rising Sun in the middle of the period of time between the spring equinox and the summer solstice, and (or) in the direction of heliacal rising of Fomalhaut. A comparison of the archaeological plans of Khorezmian buildings with reliable satellite images from Google Earth, shows considerable difference in azimuth. In some cases the measured Magnetic North was not been recalculated to the True North, or the recalculation might have been done incorrectly. In particular, it is shown that the main axis of the complex Koy-Kryilgan-kala is oriented on an azimuth of 80 degrees. This conclusion refutes all previous results.
According to historical data, in ancient times the third flood of Amu Darya was called "flooding of the star" and in the pre-Islamic period the asterism Pleiades had the name "The Star". When the complex Koy-Kryilgan-kala was built, the heliacal rising of the Pleiades coincided with the moment of the third flood of Amu Darya, and the moment of visibility of the Pleiades occurred at an azimuth of $78 - 79$ degrees. Hence, we assume that the main axis of the complex Koy-Kryilgan-kala is directed to the azimuth of rising of the Pleiades, which had a special meaning in the culture of ancient Khorezm.

Key words: archaeoastronomy, an astronomical orientation, Koy-Krylgan-kala, Khorezm

1 Previous investigations of the complex Koy-Kryilgan-kala

The discovery. The complex Koy-Krylgan-kala (latitude: 41.76^0, longitude: 61.12^0) was discovered during the Khorezmian Archaeological and Ethnographic Expedition of the USSR Academy of Sciences, led by S.P. Tolstov in 1938. The complex was built between the fourth and third centuries BC and was used until the fourth century AD, with a break from second to first centuries BC. The complex is a circular two-storey building with a diameter of 44.5 meters and a height of approximately 9.5 meters, surrounded by a circular wall of thickness of about 7 meters. Between the central building and the wall, remains of industrial and residential buildings are present. The cultural layer contains a large amount of pottery, jewelry, weapons, religious figurines, ceramic vessels, bas-reliefs and murals. Probably the complex was at first a Zoroastrian temple for the burial of the kings of Khorezm.

Astronomy and Koy-Krylgan-kala. In 1967 the complex Koy-Krylgan-kala was studied from the standpoint of archaeoastronomy [THAEE 1967; Vorobjova 1969]. The authors investigated the astronomically significant azimuths corresponding to sunrise and sunset, and the brightest stars. Below are the most significant results of their study.

The main axis of the building (see Fig. 3), which passes through windows in the rooms I and V, was measured as 69^0 degrees (21^0 from the direction east-west). According to Vorobjova:

"Windows of Koy-Krylgan-kala did not look out to the points of sunrise and sunset at equinoxes. However, in archaeoastronomy it is known that any openings, including stairs may be used for such observations. The diagonal staircase 2 and the main axis of the building form an angle close to 21 *degrees, which is equal to the deflection value of the main axis from the east-west line. ... Taking into account the direction of the main axis of the building, then the spring and autumn equinox sunrises and sunsets could be observed from the stairs 2."*

"Thus, the calculations showed that the building could be targeted 1) to the azimuth of sunrise in the middle of the interval between the spring equinox and the summer solstice when the Sun's declination is about 15.5 *degrees, constituting with Fomalhaut [α PsA] angle of* 90 *degrees, 2) or in the direction of the rising of Fomalhaut. It is possible to assume that the building was oriented at the moment when both of these events occurred at the same time, i.e. at the time of the heliacal rising of Fomalhaut."*

Agriculture in ancient Khorezm was based on irrigation, so the ability to predict the beginning of the flood of the river was very important. According to Vorobjova, in the fourth century BC, the heliacal rising of Fomalhaut (at moment of sunrise) occurred at azimuth 69^0 around 4 May and coincided with the start of the third flood of the Amu Darya. The methodical shortcoming of this study is the fact that the authors did not properly investigate the processes corresponding to the Amu Darya flooding.

The concept of Vorobjova was later developed by M.S. Bulatov [1978]. Bulatov associated the heliacal rise of Fomalhaut with the third flood of the Amu Darya and the festival Ajghar. Bulatov told that, according to the study of Ya.G. Gulyamov, the Amu Darya flooding occurs in four stages:

Ya. G. Gulyamov wrote that the calendar in ancient times was based around the Khorezmian floods, in which certain omens were used to define changes in the mode of the river. The first flood was called "the flood of green reeds" (kok kamish tashuvi). It begins at the time when the first young reed grows in the islands and lakes. This time corresponds to the twentieth of March. The second one is called "the flood of inconnu" (ak-balik-tashuvi). It is correspond to mid-April, as at this time fish begins to swim from the Aral Sea up the Amu Darya. The third flood is called "the flood of a star" (yulduz-tashuvi) and it begins in the middle of May. The fourth one "flood of forty days of heat" (kirk chilgav-tashuvi) - starts during the second half of June and ends in early August. The duration of the fourth flood is 40 *days [p. 51]."*

The name of the third flood points to an association with a star. According to Veselovskiy's modern calculations, the heliacal rise of Fomalhaut occurred around May 4, and the third flooding of Amu Darya was in mid-May. The difference between these events is about one and a half week, therefore, Fomalhaut could be a forewarning for Amu Darya's flood. We have no direct cultural arguments to prove that the third flood was associated with Fomalhaut. However, Bulatov's hypothesis supports Vorobjova's study as an independent historical argument.

Astronomy and culture. Let's consider the other Bulatov's hypotheses, which combine the use of complex Koy-Krylgan-kala within the cultural traditions of the era. At first Bulatov [1978] associated the heliacal rise of Fomalhaut and the beginning of the third flood with the Ajghar festival, which, according to his opinion, corresponds to the beginning of certain agricultural work.

"Biruni reported about the calendar reform, which were made by Ahmed ibn Muhammad, the penultimate of an ancient dynasty Khorezmshakhs in 959 *CE. We learn that the date of celebrating of the festival Ajghar, which started the agricultural works, was completely lost. Biruni and other medieval scientist could not restore the date of this festival. [p. 50].*

This thesis creates an impression that people did not know when to celebrate the festival Ajghar in the Middle Ages. They were trying to establish the date of Ajghar but were unable to do that. However, in reality, the situation is quite different. Biruni argues that the date of celebration of Ajghar falls in the middle of the summer. Moreover, he writes that many agricultural events were counted from Ajghar tens of days ahead. As a matter of fact, the problem with the determination of the date of Ajghar was the duration of the year in Khorezmian calendar which differed with the duration of tropical year. As a result, an error accumulates over time and the civil calendar began to mismatch the weather events. To eliminate this inconsistency, a reform of the calendar was made.

"Thereupon he said: "this is a system which has become confused and forgotten. The people rely upon these days (i.e. certain feast-days, Ajghar, Nimkhab, ect.), and thereby they find the cardinal points of the four seasons, since they believe that they never change their places in the year; that Ajghar is always the middle of summer, Nimkhab the middle of winter; certain distance from these days they use the proper times for sowing and ploughing." [Biruni, 1957, p.229.]

"Now, the scholars told him that the best way in this matter would be to fix the beginnings of the Chorasmian month on certain days of the Greek and Syrian month - in the same way as Almu'tadid had done - and after that to intercalate them as the Greeks and Syrians do. This plan they carried out A.Alex. 1270 [Alexander The Great], and they arranged that the 1st of Nausarji should fall on the third of the Syrian Nisan, so that Ajghar would always fall in the middle of Tammuz. And accordingly they regulated the times of agricultural works." [Ibid., p. 230.]

Thus, in the Middle Ages, the festival Ajghar was celebrated in the middle of summer. The assertion that the date of celebration was lost is contradicting the assertion of Biruni. Therefore, the assumption that festival Ajghar was celebrated in early May is wrong.

The Bulatov's second assumption relates to the attempted dating of the complex Koy-Krylgan-kala by using a solar eclipse. Zoroastrianism, whose adherents worshiped fire and light, was the main Khorezmian religion in the era of construction of Koy-Krylgan-kala. Therefore, the author suggests that the entire complex combines the functions of the Temple of Mithras, the treasuries and the observatory. Referring to the canon of eclipses of Oppolzer, he suggested that the impetus for the construction of the works was the total solar eclipse on February 29, −356. Let's note that in the Oppolzer's canon the dates of eclipses are given in the astronomical years, which, for convenience of calculation contains a zero year. In calendars the zero year is not used, so the zero year of astronomical year corresponds to the first year BC of the calendar year. Therefore, the mentioned eclipse occurred on February 29, 357 BC.

According to our calculation made by using the program EmapWin [Takesako], this eclipse was partial in Khorezm. At the location of Koy-Krylgan-kala the maximum magnitude was 0.86. Between 450 BC and 250 BC one could witness in Khorezm about two dozen solar eclipses with the magnitude of more than 0.80. This means that solar eclipses with high magnitude occur often enough, so the eclipse 357 BC was not special. The eclipses of 31 May 436 BC and 2 April 303 BC were seen as total in the territory of Khorezm. The first one was total in vicinity of Koy-Krylgan-kala. The hypothesis that the construction of Koy-Krylgan-kala was caused by the observation of a partial solar eclipse, should have at least some more justification. At the moment there are no valid grounds to accept this assumption.

The third astronomical hypothesis, which was suggested by Bulatov, is the use of number 56 in the construction of structures of circular shape. Beside Koy-Krylgan-kala he considered two Bactrian facilities Dashly-3 (eighteenth to seventeenth centuries BC) and Kutlugh Tepe (fifth century BC). He allocated in different ways the number 56 (or close to it a fractional number), and associates it with the prediction of eclipses:

"This brings us to the question of the likelihood of the use the Saros Cycle $19+19+18$ *years by the ancient priests to determine the onset time of solar and lunar eclipses." [Bulatov, 1978, p. 46]*

Saros is a period equal to the interval of 223 synodic months or 6585.32 days, which is equal to 18 years and 11.32 days. If we know the date of the eclipse, it is possible to calculate the date of another eclipse, by adding to this date the Saros interval. Since the Saros number is not an integer, the "extra" time is 0.32 days which shift time of the eclipse with $\sim$ 8 hours ($0.32^d \cdot 24^{h/d}$). As a result, the Moon or the Sun could be below the horizon, and the eclipse will not be visible in a given geographic location. For a tripled Saros cycle, we get an integer number of 19756 days = 54 years and 32 days. Tripled Saros cycle is called Exeligmos. This cycle provides a very high probability of predicting eclipses even for solar eclipses, where the location mainly determines the visibility. A lunar eclipse is almost always predicted correctly with Exeligmos. The quasiperiod of 56 years is not suitable for predicting eclipses.

Bulatov appeals to Hawkins's study [Hawkins, White, 1965], where an algorithm for predicting eclipses by using the Aubrey holes was suggested.

The number of holes is equal to 56, and Hawkins's algorithm allows the prediction of an eclipse under certain rules of shifting, if at the initial time the pebbles lay in the necessary holes. However, there is no evidence that this algorithm actually was used in ancient times. In addition, we do not have any direct or indirect historical data, that the builders of Stonehenge could predict eclipses.

Bulatov uses Stonehenge's concept for buildings of Central Asia, which raises even more questions, because there are many other cultural links for this region. It is known that in the first millennium BC the Babylonian astronomers developed simple methods for prediction of lunar eclipses. According to the Bulatov's logic it turns out that there was an ancient eclipse prediction algorithm, which was not mentioned in any written source. Then this knowledge was lost, but a sacred number 56 remained in the architectural traditions. Thus, the astronomical concept of the Koy-Krylgan-kala offered by Bulatov is untenable.

2 Investigation of the accuracy of archaeological plans

Statement of the problem. The above mentioned hypothesis about the astronomical usage of Koy-Krylgan-kala is based on the analysis of this single azimuth. One can determine the spatial orientation of the structure based on an archaeological plan by using a ruler and protractor. Such method provides the accuracy of determination of the direction of about 1^0. This is acceptable way to determine angles; however, it is necessary to know the accuracy of drawing up of archaeological plans including its actual orientation.

To investigate the accuracy of drawing up of archaeological plans of the fortress and residential buildings of ancient and medieval Khorezm we scanned all available materials: Tolstov [1948 (1); 1948 (2); 1955; 1962], MHE [1959; 1960; 1963 (1), 1963 (2)], Vorobjova [1969], PDS [1998]. We considered schemes of architectural structures, which are based on regular geometric shape. Modern graphics software packages allow the measurement of the spatial orientation for each facility.

The method for determination of orientation using archaeological plan. To determine the angle that forms the walls of the buildings with the direction of the North arrow, we used tools of the program Adobe Photoshop and applied the following algorithm: 1. It is necessary to draw a replica of the original North arrow at the center of the picture. 2. We have to create a copy of the image in a second layer and make it semi-transparent. 3. By using the tool "Rotate" we have to turn this second layer and map it in such a way that a selected item (like the wall of the building) on the second layer coincides with a North arrow on the first layer. 4. The angle of rotation (A_r), which corresponds to the desired angle, will be displayed in a separate window.

The method for determination of orientation using Google Earth. To determine the angle of walls of a building (kala) that can be located in Google Earth, the following process is used: 1. Activate the Ruler tool. 2. Draw a line as parallel as possible through visible remnants of walls.

3. Read the azimuth of the wall: A_{GE}

Estimation of standard deviation value of measurements. Suppose we made a plan from some building and defined so called "control angle" A_r, which is the angle between chosen wall of the building and line of the North arrow. So we obtain angle A_r from the above procedure. Let's suppose that true value of this angle A_0 is known. Considering all possible sources of error, that lead to the deflection (error) $\Delta A = A_0 - A_r$.

The first type of error (standard deviation) A_1 is related to the accuracy of determination the North orientation which was made by archaeological expedition. It is assumed that they used compass or theodolite leading to a standard deviation in orientation of about 5^0 and 0.5^0. Given the time of the expedition, we can assume that both these instruments could have been used. However, there is no information what tool was used to measure each archaeological plan.

The second type of error (standard deviation) A_2 is related to accuracy of azimuth determination by using the topographic plan or Google Earth (GE) image. Firstly, a wall of a building is not always perfectly straight line, and therefore in some cases it is impossible to determine the orientation unambiguously. Secondly an error can be attributed to the evaluation of a photograph, where we define the azimuth by the most contrasting fragments which correspond to the walls of buildings or their shadows. Partially destroyed buildings cast uneven shadows that increase the error of azimuth.

To estimate the value of this error (standard deviation) due to processing of a GE - image, the following technique was used. At the first, we selected a set of GE-images of buildings for which we could find archaeological plans. After that, two researchers (NM and VR) processed the images independently from each other, and obtained the values of the azimuth for the same buildings. For each pair we calculated residuals. A frequency histogram for the entire set of residuals was made, which is approximated by a Gaussian distribution, Fig. 1.

Numerical estimates of residuals show that the level of σ corresponds to the value of $\sigma = 1.5^0$. In addition, there is a small systematic residual $x_c = 0.8^0$, which is likely associated with different preferences when measuring the azimuths by researchers. Taking into account both errors, we estimate that the standard deviation of determining azimuth is about $\Delta A_2 = 1.7^0$. The total error will be:

$$\Delta A^{total} = \sqrt{\Delta A_1^2 + \Delta A_2^2}$$

As result, with an archaeological plan, the minimum orientation error $\Delta A_{min} = 2.0^0$ happens when the North arrow is determined by theodolite ΔA_{1min}, and the maximum orientation error is $\Delta A_{Max} = 5.3^0$ when determined by compass ΔA_{1Max}. If we compare the two archaeological plans which were measured by a similar instrument, the total standard deviation will increase by $\sqrt{2}$ times. The standard deviation will be $\Delta A_{min} = 2.8^0$ for theodolite and $\Delta A_{min} = 7.5^0$ for compass. If the plans were measured by using various tools (compass + theodolite or vice versa) then total error will be about $\Delta A_{min} = 5.7^0$.

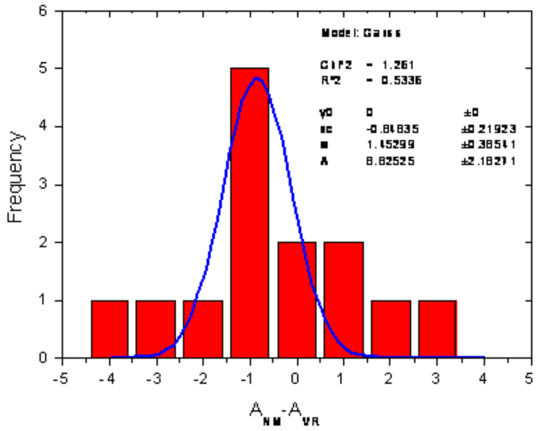

Fig. 1. Distribution of residuals of azimuths obtained by processing the same image by two different researchers.

Analysis of the distribution of azimuths. For further analysis, we selected only those buildings for which we have found an archaeological plan and a GE-image, (Appendix 1). For each building the A_r seen in archaeological plan was determined by using the algorithm which was described above. A_{GE} was defined by the most well-preserved wall. As a result, we have two estimates of the same "control angle" A_{GE} (image GE) and A_{map} (in archaeological plan). We can now calculate their residue $\Delta A = A_{GE} - A_{map}$ (Table 1).

If a building has more than one archaeological plan (e.g., Chirik-Rabat-kala, Toprak-kala), the residues were determined independently for each plan. Fig. 2 shows the frequency histogram of the residues.

Maximum frequency of the histogram $Mf = 0$ corresponds to the situation when the azimuths defined by the images of GE and archaeological plans coincide within error $\Delta A = |A_{GE} - A_{map}| < 1.25^0$.

The shape of the histogram has a distinct asymmetrical shape with a mean $M(f) \approx 3.8^0$. The expected event is to obtain a symmetrical histogram, the shape of which is close to a Gaussian distribution with mean $M(f) \approx 0$. Thus, the shape of the resulting distribution of residuals indicates the presence of unaccounted systematic errors.

The most likely reason might be an error in the calculation of true north. The value of magnetic declination for the epoch of Khorezm expedition is $\delta_m = 5^0 38'$. We can assume that in some cases the magnetic declination was not taken into account. If we add value of magnetic declination δ_m to the azimuths A_{map} which have positive residuals then the frequency distribution becomes more symmetrical. The $\Delta A = 10^0$ could be due to adding instead of subtracting the magnetic declination. In two cases, the value of the residuals reaches $\Delta A \sim 15^0$, which cannot be explained according to

	Building	A_{GE}	A_{map}	ΔA	Source
1	Angka-kala	45	35	10	Tolstov 1948 (1), p. 50
2	Ayaz-kala 1	-12	0	-12	Tolstov 1948 (1), p. 40
	Ayaz-kala 3	0	18	-18	Tolstov 1948 (1), p. 40
		0	9	-9	PDS 1998, p. 117
3	Babish-mulla 1	3	-12	15	MHE 1963 (1), p. 59
4	Bazar-kala	23	22	1	Tolstov 1948 (1), p. 47
5	Chirik-rabat-kala	57	51	6	Tolstov 1948 (2), p. 98
		57	56	1	MHE 1960, p.24
		57	41	16	Tolstov 1962, p. 141
6	Dzhanbas-kala	64	56	8	Tolstov 1948 (1), p. 29
7	Duman-kala	15	12	3	Tolstov 1948 (1), p. 57
8	Eres-kala	90	90	0	Tolstov 1948 (1), p. 58
9	Guldursun (east wall)	25	23	2	Tolstov 1948 (2), p. 95
	Guldursun (west wall)	34	29	5	Tolstov 1948 (2), p. 95
10	Hazarasp	0	-5	5	MHE 1963, p. 158
11	Koi-Krylgan-kala	80	73	7	Tolstov 1955, p. 202
		80	76	4	Vorobjova 1969
12	Kurgashin-kala	50	51	-1	Tolstov 1948 (1), p. 46
13	Pil-kala (citadel)	0	0	0	Tolstov 1948 (1), p. 67
14	Toprak-kala	70	70	0	Tolstov 1948 (2), p. 49
		70	60	10	Tolstov 1962, p. 208
		70	66	4	PDS 1998, p. 37
15	Yakke-Parsan	10	-1	11	MHE 1963 (2), p. 4

Table 1. Evaluation of the accuracy of the archaeological plans. Legend: A_{GE} - the "control" azimuth according GE image; A_{map} - the "control" azimuth according archaeological plan; ΔA is difference between A_{GE} and A_{map}: $\Delta A = A_{GE} - A_{map}$; Source - the investigation which contains given archaeological plan.

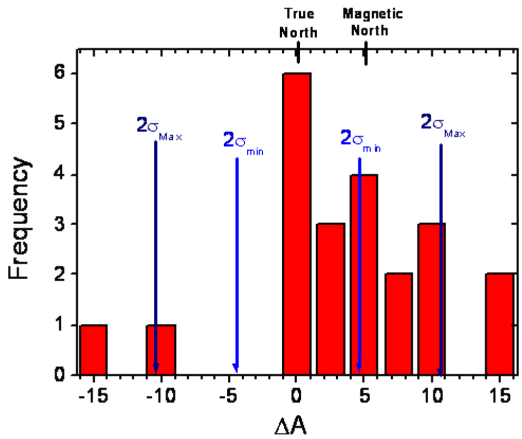

Fig. 2. Frequency histogram of residues.

the adopted model of errors. In the negative value range there are 2 unexplained cases with large residuals.

Analysis of the azimuths of chosen facilities. Let's consider the buildings for which there are more than one archaeological plans and image GE. These are Chirik-Rabat-kala, Toprak-kala and Koy-Krylgan-kala.

Chirik-Rabat-Kala. According to GE-image, western and eastern walls of the citadel have orientation to the azimuth $A_{GE} = 57^0$. Measurement of the same azimuth according to the plans [Tolstov 1948 (1)] gives the azimuth and the value of the residual value $A_{map} = 51^0$. Such residual value is close to the value of magnetic declination $\delta_m = 5.63^0$ and also to the error estimation $\varDelta A = 6^0$. As result we have relation $\varDelta A \approx \delta_m \approx \sigma_{Max}$. This makes it impossible to establish the exact origin of this error. The more recent study [MHE, 1960] provides value of azimuth $A_{map} = 56^0$ and the value of residual $\varDelta A_1 = 1^0$ which corresponds to a good approximation the direction of true north. In the previous study we could suppose that magnetic declination was not taken into account, but in the present investigation, probably, this error was fixed.

Finally, the value of azimuth $A_{map} = 41^0$ gives the highest value of the residual $\varDelta A_1 = 16^0$ for the last study [Tolstov, 1962]. This is very different from all previous measurements, although the description of the details of this plan is exactly the same [MHE, 1960]. The only difference is that the direction of the north has another orientation. As the study [Tolstov, 1962] has a general nature, there is every reason to believe that in this work all the archeological plans were borrowed from previous studies. So, the plan [Tolstov, 1962] is a consequence of the plan [MHE, 1960]. The error of the plan [Tolstov, 1962] can be explained in two ways. First, the author could have made accidental error when copying. The possibility of such an error is always there, but it should have a low probability.

Secondly, the researcher could not have taken into account the magnetic declination. Let suppose that the azimuth $A_{map} = 41^0$ is the magnetic azimuth obtained during field studies. Taking into account the correction for magnetic declination we obtain true azimuth of $A_{map} = 47^0$, which is different from the GE value by less than $2\sigma_{Max} : \Delta A \approx 10^0 < 2\sigma_{Max} \approx 11^0$.

Toprak-kala. For the building Toprak-kala we have found three archaeological plans. The study [Tolstov 1948 (1)] provides an azimuth, which corresponds exactly to the azimuth based on the processing of the GE images $A_{GE} = A_{map} = 70^0$. The next study [Tolstov, 1962] gives an lower azimuth $A_{map} = 60^0$. The discrepancy $\Delta A_1 = 10^0$ can be explained by large error of measurement around $2\sigma_{Max}$. In other case, the measurement error is around σ_{Max} and the magnetic north was picked for this plan. Finally, according to the last paper [PDS, 1998] the value of azimuth is $A_{map} = 66^0$. This value is within the errors of the previous results. On the other hand, the study [PDS, 1998] is a late publication, and it probably is based on the previous study [Tolstov, 1962], with recalculation of north direction.

Koy-Krylgan-kala. Unlike previous buildings, Koy-Krylgan-kala has a circular shape. The main axis of the building is the line passing through the rooms I and V [Vorobjova, 1969] (Fig. 3).

Let's consider the azimuth, which forms a straight line drawn through the centers of rooms I and V, with the line of the meridian. Processing of GE images gives azimuth $A_{GE} = 80^0$ (Fig. 4), and according to archaeological plans [Tolstov 1955] and [THAEE 1967], we have a couple of azimuths $A_{map} = 73^0$ and $A_{map} = 76^0$ respectively. M.G. Vorobjova and her coauthors assumed that this azimuth is equal $A_{map} = 69^0$, which makes contrast with our measurement based on GE $\Delta A \approx 11^0$. Such a large discrepancy has a simple explanation. During the translation of the magnetic direction of north to the true north a sign of the magnetic declination was incorrectly considered. The value of magnetic declination is about $\delta_m = 5.63^0$, therefore the total residual is equal to the doubled value of magnetic declination $\Delta A \approx 2\delta_m = 11^0$.

It is possible to assume that many archaeological plans contain this error. In the case of Koy-Krylgan-kala, it can be confirmed. Architect, M.S. Lapirov-Skoblo [THAEE 1967], which made the archeological plan of the building, reports:

In well-preserved ground floor survived eight rooms, two of which (I and V) are elongated along the main axis of the monument (it has azimuth $74^0 30'$ *what is correspond the value of true North* 69^0*), the remaining six rooms (II and III, IV and VIII, VI and VII) are symmetrically distributed relative to the main axis. [p. 23]*

Thus, the magnetic azimuth is shown on the plans from studies [Tolstov

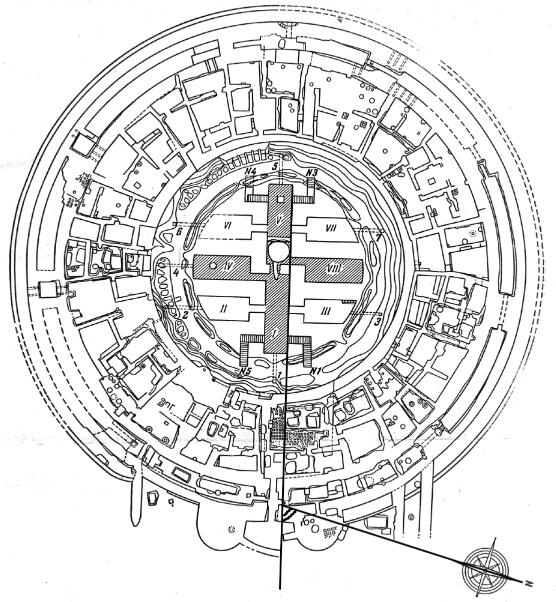

Fig. 3. Plan of ancient Khorezmian monument Koy-Krylgan-kala. The angle formed by the line of the meridian and the central axis of the building is shown. M.G. Vorobjova [Vorobjova et al., 1969] considered that this angle is close to 69^0.

1955] and [THAEE 1967]. Our evaluation of azimuth based on archaeological plans is in a good agreement with Lapirov-Skoblo measurements. To get the value of the true azimuth it is necessary to add the magnetic azimuth and magnetic declination: $A = 74.5^0 + 5.6^0 = 80.1^0$. This value we obtained using the GE-image processing of the monument.

Conclusion. Statistical analysis shows that different North arrow on archaeological plans of Khorezmian expedition are present. The true North, which indicates the direction of the celestial pole, is used the most often. In some studies, the magnetic North, which is offset to the east on 5.63^0 relative to the true North, was shown. The example of the building Koy-Krylgan-kala demonstrated that sometimes recalculation from magnetic North to the true North was done incorrectly. The reason for the error is that the magnetic variation was taken into account with the wrong sign. Perhaps to assume that the presence of three large residuals $\mid \Delta A \mid = 15^0$ on the Fig. 2 can be explained by wrong recalculation from magnetic north to true north.

We do not know what coordinate system (what kind of north) is used for each specific archaeological plan. This factor makes impossible using plans of Khorezmian expedition in astronomical applications.

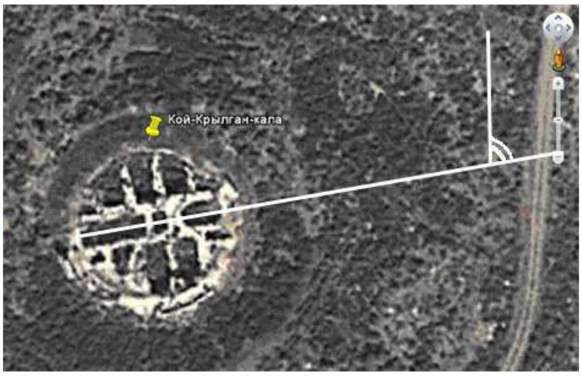

Fig. 4. This is satellite image of building Koy-Krylgan-kala which was got by using the program Google Earth. The angle formed by the line of the meridian and the central axis of the building is shown. This angle is close to 80^0.

3 Verification of azimuth 80 degrees

Thus, the major axis of the central building Koy-Krylgan-kala has the value of true azimuth of 80^0, but not 69^0 as previously thought. We can calculate the dates of civil calendar, which correspond to sunrise at the azimuth 80^0. Azimuth of sunrise slightly varies over time, so it can be applied to any era of observation. Also it is necessary to consider some bright stars which rise at this azimuth on the epoch of the proposed construction.

The Sun passes this azimuth twice per year about 12 April and 10 September. The first date coincides with the date of the second flood of Amu Darya (the flood of white fish), which took place in mid-April. The second date is near festival Ajgharminik, which is a precursor of Ajghar. According to Biruni, in antiquity festival Ajghar celebrated in autumn.

Ciri. The 15^{th} *is called Ajghar, which means: the firewood and the flame. In bygone times it was the beginning of that season when people felt the need of warming themselves at the fire, because the air was changing in autumn. In our time it coincides with the middle of summer. From this day they count 70 days, and then commence sowing the autumn wheat. [Biruni, 1957, p.224]*

The beginning of the first month of khorezmian year coincides to the summer solstice, therefore the fourth month of the year corresponds to the autumnal equinox. Subtracting 15 days from the date of the equinox, we get to the neighbourhood of the date September 10, when Ajgharminik was celebrated in ancient times. But in the case of solar azimuth it would be more expected to direct the main axis of the building to the azimuth of sunrise, which corresponds to the date of celebration of Ajghar.

We assume that the main axis of Koy-Krylgan-kala corresponds to a stellar azimuth. First, we could not find solar azimuth, the presence of which would not cause any doubts. Second, it is necessary to remember that the third flood of the Amu Darya was called "the flood of star". Vorobjova with her co-authors and Bulatov thought that this star is Fomalhaut, but they used incorrect spatial orientation of the building based on wrong direction of the true north. Therefore Fomalhaut cannot be associated with orientation of main axis of Koy-Krylgan-kala.

Among other bright stars Aldebaran (α Tau) and Procyon (α CMi) have azimuths close to $A = 80^0$ on the era of construction. Aldebaran raised around June 9 at azimuth $A \approx 81^0$, and Procyon raised about 23 July at azimuth $A \approx 82^0$. However, these days are not associated with known Khorezmian festivals and they do not correspond to the time of the third flood of the Amu Darya.

Well-known Uzbek archaeologist Ja.G. Gulyamov [1957] relates flood "Julduz-tashuvi" with Pleiades.

The third [flood - auth.] - "Julduz-tashuvi" (the flood of constellation Pleiades) - falls in the middle of May. Khorezmians associated this flood to the appearance of the constellation Pleiades. [p. 237-238].

In the Biruni's manuscript "The book of admonition the rudiments of the science of the stars" [Biruni, 1973] [The English version is called The Book of Instruction in the Elements of the Art of Astrology] there is a special chapter in the astronomical section. Its name is "are known these fixed stars by other names?" The author tells about the old pre-Islamic names of stars.

The third lunar mansion [or lunar station - auth.] is the Pleiades. This six stars gathered like bunches of grapes. This is hump of Taurus. The people, especially the poets believed that there are seven stars, but they're wrong. The Pleiades, as separate from them is called The Star. [p. 74].

The fourth lunar mansion is Aldebaran. This beautiful bright star in the east eye of Taurus; the shape of Taurus's head is like a bowl, muzzle is directed towards the north. Aldebaran is called following behind the Star, that is, behind the Pleiades [Ibid].

Biruni two times calls the Pleiades as the Star. He use the meaning of word "the Star" as own name. During description of the fourth lunar mansion he clarifies this meaning. Similar information can be found in the comments A.A. Akhmedov to Ulugbeige's Zidzh [Ulugbeige, 1994].

Pleiades - daughters of Pleione, according to Ulugbek - Surayya - is the third lunar mansion. Muslim name "Surayya" is diminutive of Arab "Zeruiah" - "wealth," "abundance." Arabs associated with it an abundance of rain, food, livestock feed. It was called as well and Najm, i.e. "The Star." [p. 413].

Aldebaran - (from the Ad-dabiran) - is the fourth lunar mansion, Alpha Tauri, the Arabic name is derived from word combination "following behind" [following behind the Pleiades - auth.] Arabs believed that it located behind the Pleiades, and it forms the Arab letter "Dal" with several nearby stars; it is located at one end of the letter, above the right eyebrow of Taurus. It [i.e. the star Aldebaran] called "belonging to Najm", "First Najm" *and "Eye of the Bull" [Ibid].*

Let's note that A.A. Akhmedov is a modern author. He does not mention sources of his information, which is the basis of comments. Perhaps he uses data from the above-mentioned Biruni's book. However, it is possible that Akhmedov knows another source. The book [Kurtik, 2007] contains the following information about the Pleiades.

Sumerian "Stars", Akkadian "bristles" [p. 338].

... (5) Intervals between dates of heliacal rising: 20 days passes from rising of Stars till heliacal rising of Heaven Bull (i.e. Aldebaran - auth.) [Ibid, p. 340].

Thus, in ancient Mesopotamia, the Pleiades were called "Stars", Biruni reports old khorezmian name of the Pleiades - "The Star" and A.A. Akhmedov confirms it. Therefore, we can assume with high probability that in the pre-Islamic Khorezm Pleiades were called "The Star". Consequently, the third flood of the Amu Darya, which was called the flood of star, may be associated with the rising of the Pleiades. The name of the Pleiades "Urkur" which is characteristic of the languages of the Mongolian group was assimilated later.

In this case, we have a specific astronomical problem. It is necessary to calculate the date of the first morning visibility of the Pleiades and to determine the azimuth, which corresponds to the moment of heliacal rising. If the date of heliacal rising will correspond to the date of the third flood of the river, and the azimuth of rising will match the astronomical orientation of the main axis of the building $A = 80^0$ then orientation of Koy-Krylgan-kala may be associated with the Pleiades.

However, there are several uncertainties. The first, we have to know what is meant by the visibility of the Pleiades? The brightest of the Pleiades Alciona (η Tau) has a visible magnitude $m = 2.9^m$. Observer could fix the date of appearance of the brightest star, or the appearance characteristic the bucket which is formed by other stars of the Pleiades. To observe the bucket, it is necessary to detect the fainter stars with magnitude $m = 3.8^m$. The second, there is a dependence the date of heliacal rising from the atmospheric absorption coefficient (extinction coefficient). Since the Pleiades consist of faint stars, they become visible at higher altitudes compared with bright planets and stars. Therefore, value of the extinction coefficient has smaller influence on the date of heliacal rising of the Pleiades in comparison with bright objects.

As a result, we have four variants, which describes the beginning of the visibility of the Pleiades. The first variant corresponds to the clear atmosphere and visibility of faint stars (the bucket of Pleiades); the second variant corresponds to the average transparence of the atmosphere and visibility of stars of the bucket; the third one corresponds to the clear atmosphere and visibility of the brightest star of Pleiades (Alciona); and fourth possibility - the average atmospheric transparency and visibility of the brightest star of the Pleiades. The results of calculations implemented by the model [Belokrylov and all, 2011] are shown in Table 2.

According to various embodiments of the calculation we got the date

	Extinction coefficient	Extremely visible stellar magnitude	Arc of visibility [degrees]	Date of heliacal rising	Rising azimuth [degrees]
1	0.20	$m = 3.8^m$	21.5	June 05	78
2	0.25	$m = 3.8^m$	22.5	June 07	78.5
3	0.20	$m = 2.9^m$	16	May 22	78
4	0.25	$m = 2.9^m$	17.5	May 25	78.5

Table 2. Calculating the date and azimuth rising of the Pleiades, depending on the extinction coefficient and the apparent magnitude.

range of May 22 till June 7. As expected, the extinction coefficient has a small influence on the date of heliacal rising of the Pleiades. Basically date of heliacal rising is determined by whether we observe whole bucket of the Pleiades, or the only one brightest star.

Let's use the latest excerpt from [Kurtik, 2007], which states that the heliacal rising of the Pleiades becomes 20 days before the heliacal rising of Aldebaran. Central Asia and Mesopotamia culturally related, and if Kwarezmians borrowed Sumerian name of the Pleiades, it is reasonable to assume that the techniques of observations were also borrowed. According to our calculations, Aldebaran rises on June 9, with an average transparency of the atmosphere. Subtracting from that date to 20 days, we get a date rising of the Pleiades - 20 May. According to our calculation the heliacal rising of the Pleiades occurs 5 days later at the same value of the extinction coefficient.

Given the number of uncertainties associated with atmospheric models, the error of model of stellar visibility and accuracy of Babylonian data and calendars translation, it is a good match. Thus, if we rely on the Mesopotamian tradition of observation of the Pleiades, it's necessary to select the 3^{rd} and 4^{th} variant in the Table 2. Thus, the ancient observers registred the heliacal rising of Alciona (the brightest star of the Pleiades), which took place on May 22-25 (depending on the model of the atmosphere), or a week later after beginning of the third flood of the Amu Darya.

Heliacal rising of the Pleiades occurred at the azimuth $A = 79^0$ and this value is in the good agreement with orientation of the main axis of the central building of Koy-Krylgan-kala. From this we can propose the following hypothesis. The main axis of Koy-Krylgan-kala is directed to the azimuth of the heliacal rising of the Pleiades. In the era of construction of the monument, heliacal rising of the Pleiades occurred in the twentieth of May, during the third flood of the Amu Darya. Because of the coincidence of these two events the third flood of the Amu Darya was called "yulduz tashuvi" or "the flood of the Star."

The Pleiades could be used as a marker of the third flood of Amu Darya during several hundred years after construction of the monument. In the future, due to the phenomenon of precession, the heliacal rising of the Pleiades began to lag from the May flood. Despite this, the May flood of Amu Darya has retained its original name, which, judging by modern ethnographic research has survived to our time.

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Appendix. List of khorezmian buildings which were used for the statistical analysis.

	Building	Google Earth coordinates
1	Angka-kala	$41^0 45' 31$" $61^0 09' 04$"
2	Ayaz-kala-1	$42^0 00' 51$" $61^0 01' 45$"
3	Ayaz-kala-2	$42^0 00' 38$" $61^0 01' 32$"
4	Ayaz-kala-3	$42^0 00' 19$" $61^0 01' 50$"
5	Babish-mulla-1	$44^0 25' 10$" $63^0 06' 49$"
6	Bazar-kala	$41^0 49' 31$" $61^0 11' 23$"
7	Chirik-Rabat-kala	$44^0 05' 06$" $62^0 54' 44$"
8	Dzhanbas-kala	$41^0 51' 30$" $61^0 18' 13$"
9	Duman-kala	$41^0 44' 17$" $60^0 52' 30$"
10	Eres-kala	$41^0 40' 03$" $61^0 05' 28$"
11	Guldursun (Large)	$41^0 41' 36$" $60^0 58' 54$"
12	Hazarasp	$41^0 18' 52$" $61^0 05' 32$"
13	Koi-Krilgan-kala	$41^0 45' 19$" $61^0 07' 01$"
14	Kurgashin	$42^0 02' 03$" $61^0 19' 19$"
15	Toprak-kala	$41^0 55' 60$" $60^0 49' 12$"
16	Pil-kala	$41^0 42' 18$" $60^0 44' 55$"
17	Yakke-Parsan	$41^0 55' 16$" $61^0 01' 06$"