Large Wooden Astrolabe from the State Hermitage Museum

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Most planispheric astrolabes known to have survived to modern times were made of brass. Sometimes the most valuable instruments have silver inlay. At the same time, in the 16th century, when the demand for astrolabes began to exceed the capacity of his workshop, the European maker Georg Hartman turned to laminated wooden boards (today known as 'plywood') and solid wood, and used those extensively. Wooden astrolabes were short-lived and very few of them have survived today. A much less known fact is that Persian makers also used wood to make their instruments. For instance, Greenwich Royal Museum displays an astrolabe IC 1047 made of wood in the 19th century. The author of its description writes, 'No wooden astrolabe or quadrant are known from Iran…'.[1] That is why the find of a well-preserved record-large astrolabe made of wood three hundred years ago in 1720, and probably manufactured in Persia, became a real discovery, or perhaps a rediscovery (Cover, Figs 1 and 2). The catalogue details are:

Astrolabe by Muhammad Karim
IC 1149
Maker: Muhammad Karim
Date: AH 1133 = 1720/21 AD
Diameter: 43.5 cm
Material: wood, brass, cardboard
Weight: 2.2 kg
Inventory number 856 VP

History of the Astrolabe

This astrolabe, currently displayed in one of the nation's finest museum, the State Hermitage Museum (St. Petersburg Dvortsovaya Square, 2), has survived turbulent years of revolutions in the beginning of the twentieth century and the 872-day siege of Leningrad during the Second World War, which cost the lives of an estimated 1,000,000 city residents. The astrolabe was transferred to the Hermitage in 1930 from the Asian Museum, and before that, it could have been kept in the Imperial Public Library. Information about this is found in the article of the Russian academician Bernhard Dorn written in German:

> 'Ein anderes Astrolabium wird in der öffentlichen Kaiserlicher Bibliothek aufbewahrt. Dasselbe ist von Holz; und eine eben daselbst befindliche Beschreibung in Französischer Sprache erklärt, dass es zum Gebrauche Türkischer Bombardiere verfertigt worden sei, und zwar nicht vor dem Jahre 1731, in welchem Belidor's Werk: *Le Bombardier français*[2]], zu Paris erschien, sofern die eine der beiden Tafeln des Astrolabiums Zahlen enthält, welche den Kugel und Bombenwurf nach der in dem erwähnten Werke angegebenen Methode bestimmen. Es ware sehr zu wünschen, dass die von sehr geschickter Handverfasste Beschreibung des Instrumentes der gelehrten Welt mitgetheilt würde…'.[3]

Judging by the opinion of Academician B. Dorn, 'the instrument was used by the Turkish bombardier-gunners,' we can assume that it was a trophy in one of the Russian-Turkish wars of the late 18th or early 19th century, for example, the naval battle in 1807 near Mount Athos, when one of the Ottoman flagships and commander, Kapudan Pasha Seyit-Ali were captured by Russians. In 1865, Dorn once again mentions the wooden astrolabe in his catalogue of European instruments.[4]

Thus, only in the 21st century has time come to follow Dorn's instructions and describe this astrolabe. Dorn himself informed European historians about its existence and the astrolabe got an international number of its own - IC 1149 (Fig. 3).[5]

The fact that the instrument was made in Persia, is evidenced not only by the abundance of inscriptions in Farsi, but also by the existence of its close 'relative'. This is an astrolabe made 8 years before, in 1712 for Shah Sultan Husayn, king of Persia, and now preserved in the British Museum, London. Its dimensions are no less impressive – the height is 53 cm (our astrolabe is 55.5 cm high) and the weight is huge (the exact amount is not known) as it is made not of wood but of brass and silver. Other similar parameters of the two astrolabes will be outlined below.

The inscription (Fig. 4 a and b) on the throne of our astrolabe is 'at the command of his excellency the powerful attendant of the Khaqan the reigning Aqa Qanbar Ali, may his high patronage endure, this astrolabe was finished. This was created by the sinful slave Muhammad Karim'. The second inscription (Fig. 4 c) is on the back of the instrument in a circle below the shadow square. It informs about the time the astrolabe was made – 1133 Hijra [1720/21 AD], which corresponds to the last year of the reign of the last Safavi - Shahanshah Sultan Husayn I, on the eve of the Afghan invasion. The text of this inscription is presented below.

حسب الفرمودهٔ عالیحضرت خدایگانی، مقرب الخاقانی آقائی، آقا قنبر علی، دام ظلّه العالی، این اسطرلاب صورت اتمام یافت.

صنعة العبد الاثیم، محمد کریم، سنهٔ 1133

Professor Bagheri from Iran kindly helped us to answer the question 'Who was Aqa Qanbar Ali who had ordered the astrolabe?' He informed us that the customer was 'a chief of the treasury in the Safavid dynasty. His name is mentioned in a manuscript #502077 extant in the Majlis library (Iran).' No information about the master Muhammad Karim has yet been found.

Fig. 1 *The front of the wooden astrolabe. inv. no. VP-856, The State Hermitage Museum, St. Petersburg. Photograph © The State Hermitage Museum. Photo by Alexander Koksharov.*

Fig. 2 *The back of the wooden astrolabe, inv. no. VP-856, The State Hermitage Museum, St. Petersburg. Photograph © The State Hermitage Museum. Photo by Alexander Koksharov.*

Fig. 3 *The author with the astrolabe.*

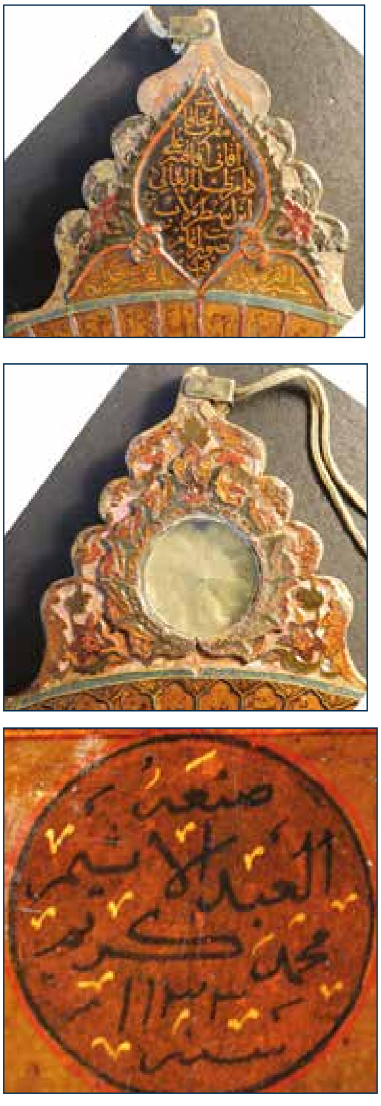

Fig. 4. *The front (a) and the back (b) of the throne of the astrolabe. The inscription in the circle (c) is on the back of the instrument.*

Mater

The diameter of the wooden mater is 43.5 cm, its height is 55.5 cm, and thickness is 2.3 cm. To the best of our knowledge, there are no other wooden astrolabes of such a generous size. Thus, the first feature of the astrolabe is its huge size. The calligraphic inscriptions are made with coloured ink. The hollow of the mater holds 8 cardboard tympanums, on top of which there is a rete and a narrow brass arrow head. The wooden alidade is attached to the back of the instrument. The surface of the wooden parts is varnished. Fastening elements – pin and wedge (‘horse’) – are made of brass, as well as a simple Pi-shaped suspension (handle) with a hole at the top. There is no ring or shackle (Lat., ‘armilla reflexa’). On the back of the throne there is a vacant recess for a magnetic compass but no compass itself. Persian masters adopted this element from Europe not before 1645 – the year of the earliest emergence of Iranian astrolabes with compasses.[6] All elements of the instrument are in good condition and only edges of the throne are slightly damaged.

The limb is divided into degrees, with every fifth degree bearing an unusual inscription in words: پنج / ده / پانزده / بیست (*panj / dah / pânzdah / bist*), i.e. five, ten, fifteen, twenty, and so on up to 360. Likewise, almost all numerical values on the astrolabe are written in words. This is the second characteristic feature of the studied astrolabe. Probably, this tradition is typical of the Persian masters of the early 18th century or, at least, of the astrolabists in the city where this instrument was made. The Hermitage collection includes another astrolabe of the same period – IC 3670 – dedicated to Shah Husain and bearing similar inscriptions.

Table I. Persian numerals, which are used in the inscriptions on the astrolabe

first	awwal	اول
second	dom	دوم
third	som	سوم
fourth	chehārem	چهارم
1	yek	یک
2	do	دو
3	se	سه
4	čahâr	چهار
5	panj	پنج
6	šeš	شش
7	haft	هفت
8	hašt	هشت
9	noh	نه
10	dah	ده
200	devist	دویست
300	sesad	سیصد
400	čahârsad	چهارصد

11	yâzdah	یازده
12	davâzdah	دوازده
13	sizdah	سیزده
14	čahârdah	چهارده
15	pânzdah	پانزده
16	šânzdah	شانزده
17	hafdah	هفده
18	hejdah	هجده
19	nuzdah	نوزده
20	bist	بیست
30	si	سی
40	čehel	چهل
50	panjâh	پنجاه
60	šast	شصت
70	haftâd	هفتاد
80	haštâd	هشتاد
90	navad	نود
100	sad	صد
200	devist	
300	sesad	
400	čahârsad	

Gazetteer

In a recess of the mater, there is an extensive gazetteer of 94 localities. As usual, data of one locality are arranged as a column along the radius of the instrument. For this purpose, the circle is divided into 48 sectors, one of which is intended for the heading. The data are in the inner and outer circles. The photograph (Fig. 5) shows a fragment containing localities from 1 to 3 (localities have been numbered by the author). The heading is on the right.

The heading includes the name of the city (*bilād*), longitude (*aṭwāl*), latitude (*^{c}urūḍ*), the qibla (*inḥirāf*), distance from Mecca (*masāfat*), and the side of the horizon where Mecca is located (*jihat*). The heading is repeated below for the lower circle. Angle values are measured in degrees (*daraja* - درجه) and minutes (*daqiqe* - دقیقه), and distances are measured in *farsakh* (فرسخ). As can be seen, all coordinates are written in words (excluding the distances in the inner circle, which are not visible in this fragment).

The comparison of coordinates from the gazetteer and modern geographical position of the localities has yielded some interesting data. Out of 94 cities, we selected those of which the position can be uniquely identified on the modern map. The gazetteer included 76 such localities. Furthermore, depending on the studied parameter, obviously erroneous values were discarded.

The longitudes had been reckoned from the Fortunate Isles so that the longitude of each city was on average by 34.6 degrees greater than modern longitudes reckoned from the meridian of Greenwich. The standard deviation of their latitude is ±0.7º. This accuracy is not very high but acceptable for determining the latitude using the astrolabe. The standard deviation of the longitudes is twice as large and equals ±1.4º.

The third recorded geographical parameter is the azimuth of the qibla. The azimuth is measured from the south point westward or eastward. The direction to qibla is specified by the fifth parameter – direction of the azimuth of the qibla (*jihat*). Since Mecca is the southernmost of the other cities, *jihat* can only assume two values. For most of the cities, Mecca is located on the southwest (*qharbi-janūb-*, غرب حنوب) and only for six cities – on the southeast (*sharq-janūb* - سرق حنوب).

To check the values of the qibla (q), this parameter was calculated based on coordinates of Mecca (φ_m, λ_m) and each city (φ, λ) from the list using the formula[7]:
tg q = $\sin(\lambda_m - \lambda) / [\cos\varphi \cdot \mathrm{tg}\,\varphi_m - \sin\varphi \cdot \cos(\lambda_м - \lambda)]$.

For 49 cities, the deviation of the values in the table from the calculated quantities was less than half-degree; and for many localities, these values fully coincided. Some deviations were caused by the errors that appeared when copying the coordinates. These errors are clearly visible when comparing our gazetteer with the already mentioned instrument from the British Museum.

The fourth parameter *masāfat* (ماسافات) is rather uncommon to gazetteers of astrolabes. For example, in the extensive Washington collection, there is only one late astrolabe (1801) with this coordinate.[8] We are most interested in the large astrolabe, which is stored in the British Museum, London. It was made in 1712 for Shah Husain Safawi, Shahanshah (king) of Persia and there are 103 localities on it. It has been found out that all 94 localities of the astrolabe considered here are also present in the list of Shah Husain's astrolabe. This may be indicative of the same source of information or even of direct copying. According to Morley[9] , the most likely source of the data could be the Geographical Table by Jamshīd al-Kāshī, compiled around 1420 in Kāshān and containing 516 localities.[10]

It can be assumed that the presence of the *masāfat* parameter is the third characteristic feature of the studied astrolabe. Furthermore, this feature prompts us to consider what linear measure was used by the compiler of the original tables. 76 localities (out of 94) were clearly identified on a modern map. In addition, seven obviously erroneous distances were discarded. The route between the specified point and Mecca was plotted along currently existing motorways using the service *Google-Maps* and website www.distance.to. The results obtained from the both sources were similar. It was assumed that modern roads in the countryside were close to the medieval caravan routes, or at least were not longer than those.

For example, according to the gazetteer, distance from Kūfah to Mecca is 223 farsakh. If we travel along the shortest path using modern highways, first across the territory of Iraq - road No. 28, then through Saudi Arabia - roads No.6262, No.70, No.60 (via Medina), No.15, the total length is 1722 km. This implies that 1 farsakh is equal to 7.7 km. Any other route implies a greater distance and thus a greater value of the farsakh.

The results of comparing data for the 69 localities yielded the average value 1 farsakh = 7.50 km with a standard deviation of about ±0.35 km. The result is at some variance with findings of other studies. For instance, A. Houtum-Schindler derives the value of one farsakh to be equal equal to 5.67 km[11], W. Hinz estimates it as about 6 km.[12] N. Hanykov, Russian orientalist of the 19th century, wrote that the farsakh was equal to about 9.4 km.[13] Our estimate of farsakh is between these two extremes. It should correspond to the period of the source (i.e. Kāshān, *c.* 1420).

The fact that the standard deviation of the farsakh length in the 15th century is less than 5% of the measured quantity raises a question about the means of measuring these distances. Could a camel's step *really* be so stable? This table can be a source of information for the further historical research. After all, it allows one to refine the data on the caravan routes of that time. For example, the distance from Mecca to the western cities - Misr and Damascus - show that at the time of the table's compilation the way along the Red Sea coast was not yet known and caravans took a roundabout way from Mecca through the desert to the north before reaching the main road.

Thus, the gazetteer of the studied astrolabe makes it possible for us to determine the following: 1. standard deviation of the latitudes for the localities (±0.7º); 2. standard deviation of the longitudes (±1.4º); 3. the difference between the antique and modern longitudes for the Iran cities (34.6º); 4. the value of the Arabic linear unit farsakh and its standard deviation (7.5 ± 0.35 km); 5. the analysis of qibla values has demonstrated to us the high precision of trigonometric computations performed six centuries ago.

Table II. Localities

	Localities		Longi-tudes	Latitudes	Qibla	*Masāfāt*	*Al-jihāt*
1	Makka Mu'azzamah	مكة معظمه	77º 10'	21º 40'	-	-	-
2	Masāfāt in farsakh	مدينة مشرفة	75 20	25 10	26º 2'	86	S.-E.*
3	Kūfah	كوفه	79 30	31 30	12 21	223	S.-W.
4	Basra	بصره	85	30	37 59	230	S.-W.

5	Miṣr	مصر	63 20	30 20	58 38	335	S.-E.
6	Madain	مداين	80	33 10	13 2	261	S.-W.
7	Wasit	واسط	81 30	32 20	20 54	251	S.-W.
8	Mûṣil	موصل	77	34 30	42	285	S.-E.
9	Dimashq	دمشق	70	33 15	30 31	293	S.-E.
10	Mashhad	مشهد	92 30	37	45 6	451	S.-W.
11	Neyšâbur	نيشابور	92 30	36 21	46 25	440	S.-W.
12	Sabzevar	سبزوار	91 30	36 5	44 12	422	S.-W.
13	Dāmghān	دامغان	88 55	36 20	38 5	382	S.-W.
14	Semnān	سمنان	88	36	36 17	382	S.-W.
15	Mazinan	مازنيان	90 30	37	40 41	426	S.-W.
16	Bastam	بسطام	83 10	38 10	39 53	400	S.-W.
17	Amul	آمل	88 20	36 15	36 45	389	S.-W.
18	Kahūr	كجور	86 50	36 25	32 25	377	S.-W.
19	Bait al-Mukaddas	بيت المقادس	66 30	31 50	45 43	309	S.-E.
20	Surra man Raa	سر من راي	79	34	7 56	286	S.-W.
21	Khuwar	خوار	87 15	35 40	34 38	366	S.-W.
22	Rayy	ري	86 20	35	37 23	356	S.-W.
23	Esfarain	اسفراين	91 50	36 25	44 50	433	S.-W.
24	Qum	قم	85 40	34 45	34 1	373	S.-W.
25	Rudsar	رودسر	85 10	37	26 32	394	S.-W.
26	Barfurush	بارفروش	87 50	36 50	34 17	375	S.-W.
27	Sārī	ساري	88	37	34 28	399	S.-W.
28	Lahijan	لاهيجان	84	37 15	22 40	370	S.-W.
29	Astarābād	استراباد	89 35	36 50	38 48	416	S.-W.
30	Gorgan	جرجان	90	36 50	39 48	418	S.-W.
31	Torshiz	تورشز	92	35	48 15	416	S.-W.
32	Herāt	هرات	94 20	34 30	54 5	439	S.-W.
33	Tūn	تون	92 30	34 30	50 20	414	S.-W.
34	Ṭabas	طبس	92	33	52 52	385	S.-W.
35	Sarakhs	سرخس	94 30	37	49 12	476	S.-W.
36	Marw	مرو	97	37 40	52 30	520	S.-W.
37	Kain	قاين	93 20	33 40	54 1	414	S.-W.
38	Qazwīn	قزوين	85	37	27 34	352	S.-W.
39	Alamut	الموت	85 37	36 21	28 53	364	S.-W.
40	Taleqan	طالقان	85 45	36 21	29 33	362	S.-W.
41	Abhar	ابهر	84 30	36 40	24 53	363	S.-W.
42	Zanjān	زنجان	83 40	36 30	22 37	352	S.-W.
43	Sāwa	ساوه	85	35	29 16	333	S.-W.
44	Hamadān	همدان	83	35 10	22 10	320	S.-W.
45	Nahāvand	نهاوند	83 15	34	24 29	305	S.-W.
46	Shahrazur	شهرزور	83 20	32 30	24 14	261	S.-W.
47	Ganja	گنجه	83	41 20	15 45	450	S.-W.
48	Barda	بردع	83	40 30	16 10	432	S.-W.
49	Darband	دربند	85	43	19 29	495	S.-W.
50	Tabriz	تبريز	82	38	15 40	465	S.-W.
51	Salamās	سلماس	79	37	7	357	S.-W.
52	Nakhjawan	نحجوان	85 9	38	12	375	S.-W.
53	Khuwai	خوي	79 40	37	8 30	357	S.-W.
54	Marand	مرند	82 40	37 50	11 50	365	S.-W.
55	Marāgha	مراغه	82	37 20	16	360	S.-W.
56	Dinawar	دينور	83	35	22	317	S.-W.
57	Damdam	دمدم	79 40	37	9 1	344	S.-W.
58	Kirman	كرمان	92 30	29 50	63	356	S.-W.
59	Sīrjan	سيرجاز	90 8	29	60	315	S.-W.
60	Hurmūz	هرموز	92	25	72	274	S.-W.
61	Qandahār	قندهار	107 40	33	75	356	S.-W.
62	Kabul	كابل	104 10	34 7	69	604	S.-W.
63	Multan	ملتن	107 35	29	81	632	S.-W.

64	Lahur	لاهور	119	31	77	674	S.-W.
65	Daibul	ديبل	102 30	25	86	521	S.-W.
66	Kashmir	كشمر	108	24	69	605	S.-W.
67	Haiderabad	حيدر آباد	119 8	28	89 4	757	S.-W.
68	Iṣfahān	اصفهان	86 40	31 50	40 25	330	S.-W.
69	Yazd	يزد	89	32	47 1	331	S.-W.
70	Kāshān	كاشان	84	34	35	324	S.-W.
71	Golpayegan	گلپايگان	85	35	39	323	S.-W.
72	Sumairam	سميرم	86	32 20	32 20	288	S.-W.
73	Kirmanshah	كرمانشاه	89	34	23	307	S.-W.
74	Kurdistan	كردستان	85	34	30	311	S.-W.
75	Shīraz	شيراز	88	29	50	279	S.-W.
76	Estakhr	اصطخر	88	30	53 20	292	S.-W.
77	Shabur	شابور	89	30	48	268	S.-W.
78	Fīrūzābād	فيروزآباد	88	28	57	253	S.-W.
79	Shustar	سوشتر	84	31	35	262	S.-W.
80	Arzangan	ارزنگان	87	38	38	362	S.-W.
81	Amud	امد	73	28	28	367	S.-E.
82	Badghis	بادغيس	94	25	50	452	S.-W.
83	Maruchak	ماروجاق	97	36	54	505	S.-W.
84	Sulṭāniya	سلطانيه	84	37…	37	376	S.-W.
85	Shamākhī	شماخي	84 30	40 50	20	447	S.-W.
86	Ardabil	اردبيل	82 20	28	28	377	S.-W.
87	Tiflis	تفليس	83	43	43	486	S.-W.
88	Urganj	اركنع	93 45	42 40	42 40	557	S.-W.
89	Baghdad	بغداد	80	28	28	266	S.-W.
90	Bahrain	بحرين	83	25	57	143	S.-W.
91	Fas, Tanjan	فاس طنجه	17	22 …	78	1212	S.-W.
92	Dihli	دهلى	114	28 …	87	763	S.-W.
93	Ujjain	اجين	102	24	25	515	S.-W.
94	Amurija	عموره	64	45	45	533	S.-E.

* S.-E. – Southeast, S.-W. – southwest.

Rete

The rete is made of brass; its diameter is 358 mm and thickness is 1.4–1.7 mm. The floral pattern with lots of stems and leaves masks 22 star pointers. These pointers are also shaped as leaves, which bear the written names of stars (Fig. 6). The background is hammered. Since every leave is pronged, the star position is punched on one of the prongs. The calligraphic inscriptions of names of stars and constellations of the zodiac are weakly raised and of low-contrast, and therefore, not clearly legible. This makes it difficult to use the rete at night in low light. The ecliptic is divided into degrees and every third degree is inscribed.

Table III. Stars on the rete

#	Arabic name as engraved	Transliteration	English translation	Identification
1	بطن الحوت	baṭn al-ḥūt	the belly of the fish	β And
2	كف الخضيب	kaff al-khāḍīb	the hand tinted [with henna]	δ Cas
3	راس الغول	ra’s al-ghūl	head of Ghoul	β Per
4	عين الثور	ᶜayn al-thawr	eye of the bull	α Tau
5	عيوق	ᶜayyūq	(swaggerer?)	α Aur
6	رجل الحوزا اليسرى	rijl al-jawzā’ al-yusrā	the left foot of al-Jawzā’	β Ori
7	منكب الحوزا	mankib al-jawzā’	the shoulder of al-Jawzā’	α Ori

8	شعرى يماني	shi^c^rā yamānī[yyah]	the southern Sirius	α CMa
9	ارس اتوم	al-ras al-taum	the head of the foremost twin	α Gem
10	شعرى شامي	shi^c^rā sha'āmī[yyah]	the northern Sirius	α CMi
11	فرد الشجاع	fard al-shujā^c^	the isolated one of the hydra	α Hya
12	ظهر الأسد	ẓahr al-asad	the lion's back	δ Leo
13	صرفة	ṣarfa	the change [of weather]	β Leo
14	سمك اعزل	simāk a^c^zal	the unarmed simāk	α Vir
15	نير الفكة	nayyir al-fakka	the bright one of the broken vessel	α CrB
16	قلب العقرب	qalb al-^c^aqrab	the scorpion's heart	α Sco
17	نسر واقع	nasr wāqi^c^	the falling eagle	α Lyr
18	نسر طائر	nasr ṭā'ir	the flying eagle	α Aql
19	ردف الدجاجة	ridf al-dajāja	back of the hen	α Cyg
20	ذنب الجدي	dhanab al-jady	the tail of Capricornus	δ Cap
21	ذنب قيطس	dhanab qayṭus [janūbī]	the southern tail of Cetus	β Cet
22	سرة الفرس	ṣirrat al-faras	the navel of the horse	α And

To determine the date of star positions, the coordinates of the stars were measured. For each star, its distance to the centre of the instrument (celestial pole) was measured and the angular position corresponding to the right ascension α. The measured radius r made it possible to calculate the declination δ from the formula $r = R_{eq} \cdot \mathrm{tg}\,[(90 - \delta) / 2]$ where R_{eq} is the radius of the equator. Then we obtained the mediation of the star m by the formula $\mathrm{tg}\, m = \mathrm{tg}\, \alpha / \cos \varepsilon$ and then the ecliptic coordinates – longitude λ and latitude β. This allowed us to compare the coordinates of the stars on the astrolabe to the original list of stars. In this study, Ulugh Beg's Catalogue of Stars drawn up in 1438 was adopted as the original list.[14] Now we will skip the intermediate data and present the main results:

1. The comparison of the stars on the astrolabe and the values from Ulugh Beg's Catalogue of Stars allowed us to verify the accuracy of the stars' interpretation; basically, all coordinates correspond to Ulugh Beg's coordinates; large variations in longitude and declination are observed for the stars no. 1 (β And), no.12 (δ Leo), no. 14 (α Vir), and no.21 (β Cet);
2. The analysis of the longitudes revealed two groups of stars. The first group included the longitudes of the stars of the astrolabe, which coincided with the longitudes of the stars in Ulugh Beg's Catalogue (within one degree). Those are stars nos. 1, 4, 6, 7, 8, 10, 11, 14, 16 (the total of 9 stars). In the second group, the astrolabe longitudes are increased by 3–5 degrees. Those are nos. 2, 3, 5, 9, 13, 15, 17, 18, 19, 20, 22 (the total of 11 stars) – almost all within the circle of the ecliptic. Since between the epoch of Ulugh Beg's Catalogue of Stars (1438) and the astrolabe production date (1720) 282 years had passed, the astrolabist tried to consider the effect of precession. The precession adopted in the Arab world was equal to 1 degree for every 66 years. Accordingly, in 282 years the longitude of the stars should have risen by 4.3 degrees, which is in a very good agreement with the longitudes of the second group of stars. Thus, the master introduced precession correction, but only for stars within the circle of the ecliptic. It is unclear why he failed to do the same for all the stars.

Plates

In the hollow of the mater there are 8 plates with the diameter of 358 mm made of cardboard 1.0 – 1.2 mm thick (Fig. 7). Lines and inscriptions are applied in ink of different colours. Almucantar (lines of equal height) are drawn for each degree and inscribed by the Persian version of the Indo-Arabic numerals – ١ ٢ ٣ ۴ ۵ ۶ ٧ ٨ ٩ ٠ – this is one of the few exceptions to the general rule. Equal azimuth lines are drawn through 10°. Words are also used to write the value of the latitude '^c^urūḍ' and the maximum duration of the day 'sā^c^at'. The values of longest daylight are based on an obliquity of 23° 35'.[15]

One plate is different from the others. On one of its sides there are lines of half-horizons (8b), and on the other there is a standard set of lines specially made for the city of Kūfah (8a) although this city is included in the list on the plate of 32º (4a). Inscriptions on this plate are in different handwriting. The value of the latitude 31º 30' on this plate is additionally presented in abjad numerals لا ل. Moreover, this plate is made of thinner cardboard, which is about 0,8 mm thick. This may indicate that one of the astrolabe owners lived in Kūfah and a different master made a personal plate for him.

On the special plate 6b there are 90 red and blue circles numbered from the center from 0 to 90. The 69th circle is drawn in black. The function of this plate is not clear. It resembles the plate for 90º, but it is not so.

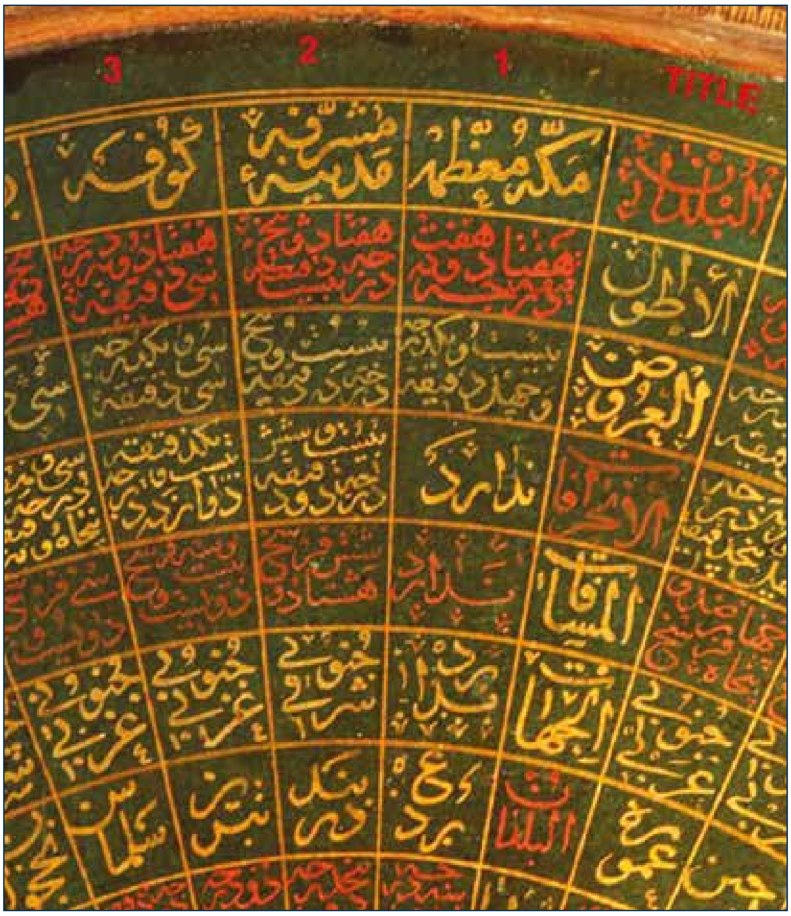

Fig. 5 *A portion of the gazetteer:*
1. Makka Mu’azzamah: مكه مكرمه */ 77º10 / 21 40 / - / - / -*
2. Masāfāt in farsakh: 75 / مدينة*º 20’ / 25º 10’ / 26º 2’ / 86 f/S.-E.*
3. Kūfah: 79 / كوفه*º 30’ / 31º 30’ / 12º 21’ / 223 f/ S.-W.*

Fig. 6 *A detail of the rete and pointers No. 12 (bottom) and No. 13 (top). There is a visible mark near the top prong of the pointer No. 12.*

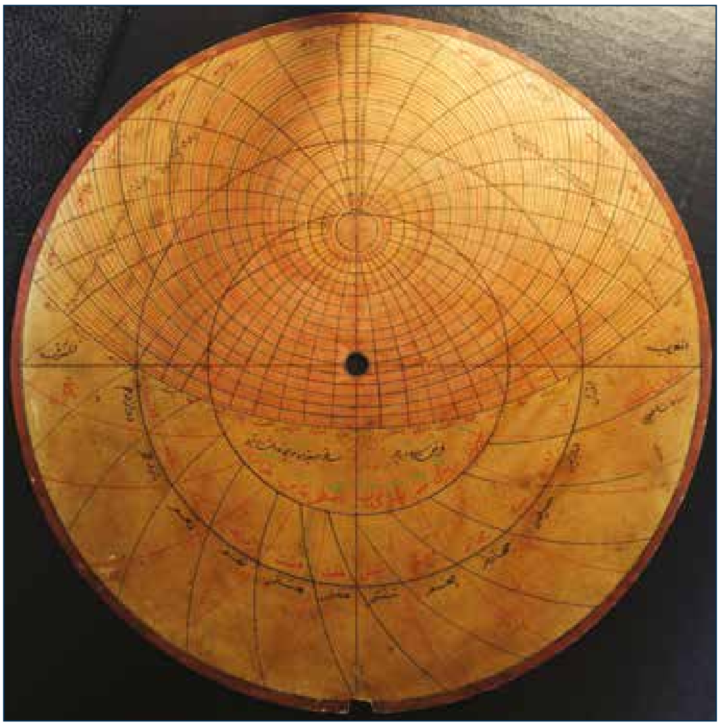

Fig. 7 *One of the plates. The names of cities (from the left: Multan, Fars, Estakhr, Kirman, Basra, Misr, Sirjan) and the latitude value (30 degrees) and the longest daylight (13 hours 57 minutes) are indicated by the author in green).*

Fig. 8 *The shadow square with table of triplicities.*

Each side bears curves for the temporal hours as well as for the equal hours calculated from sunrise. The equal hours are inscribed in black in words ‘first’, ‘second’, ‘third’, ‘fourth’ etc., starting from the western horizon designated by the word ‘maghrib’ (المعرب). Temporal hours are inscribed in words: ‘beginning’ (بن), ‘two’, ‘three’, ‘four’ etc.

Table IV. The plates

Side	Lati-tude	Longest daylight, hrs min	Localities, names of which are listed on this side
1a	22º	13 31	Makka, Fas Tanjan Maghreb;
1b	25º	13 34	Madīna, Bahrain, Hurmūz, Katif *, Daibul, Ujjain;
2b	28º	13 47	Jiroft *, Fīrūzābād, Haiderabad, Dihli, Kich Makran*, Mansurah*, Send (?)*;
2a	38º	14 40	Tabriz, Arzangan, Nakhjawan, Marw, Salamās, Khuwai, Marand, Sulṭāniya, Amul;
3a	30º	13 57	Shīraz, Sīrjan, Miṣr, Basra, Kirman, Estakhr, Fars *, Multan;
3b	36º	14 28	Qazwīn, Alamut, Talaqan, Neyšâbur, Sabzevar, Dāmghān, Samnān, Bastam, Khuwar;
4a	32º	14 07	Iṣfahān, Yazd, Sumairam, Shustar, Wasit, Kūfah, Lahur, Bait Al-Mukaddas;
4b	34º	14 17	Kāshān, Golpayegan, Kurdistan, Nahāvand, Kain, Surra man Raa, Kabul, Sham*, Hulwan *;
5a	33º	14 12	Qandahār, Shustar, Shahrazur, Ṭabas, Baghdad, Madain, Dimashq, Wasit
5b	35º	14 22	Hamadān, Sāwa, Rayy, Qum, Torshiz, Tūn, Herāt, Kirmanshah, Badghis, Kashmir, Mûṣil;
6a	37º	14 34	Mashhad, Mazinan, Sarakhs, Astarābād, Gorgan, Faručag (?)*, Barfurush, Sarija, Abhar;
6b	90º	-	Curves of Almucantar;
7a	41º	14 57	Ganja, Barda, Shamākhī, Kvant thuzum (?)*;
7b	43º	15 12	Tiflis, Darband, Nurkan *, Urganj, Amurija;
8a	31º 30’	14 7	Kūfah;
8b	-	-	Curves of Half-horizons.

* - is absent in the gazetteer.

The total list on the plates includes 93 cities and it is close to the list of cities in the gazetteer but there are certain differences between the lists. Some names are absent in our gazetteer while present in the gazetteer of the astrolabe from the British Museum. For instance, Jiroft, Kich Makran и Mansurah on the plate for 28º, Katif – for 25º, Hulwan – for 34º. This suggests possible copying of the 1712 astrolabe should, however, be noted that some cities are absent on the both gazetteers, those are Sham, Fars, and three more unidentified names.

Back

The upper half bears two altitude scales (0º – 90º) along the rim, with divisions every 5º and 1º, numbered 5º each. Inside the circular scale, there is a standard set of lines. In the upper left quadrant, there is a scale of sines (cosines). It is designed so that the lines are multiples of every 1º (there are always 77 lines). Accordingly, the lines are arranged unevenly and are thicker on top (see Fig. 2).

The quadrant in the upper right presents three sets of curves. The first one gives the declination arcs – one division for each 1/6 sign of the zodiac. These arcs serve primarily as the context for other graphed scales. The second set gives the meridian altitude as a function of the solar longitude for the range of terrestrial latitude from 28º to 42º, with increments every 2º. The third set represents the solar altitude when the sun is in the azimuth of Mecca for five different localities - Shīrāz, Baghdād, [Baṣrah is not inscribed], Iṣfahān, Tūs. The usual instructions for the use of the *qibla* curves are written in the innermost portion of the quadrant: “*Lines of the azimuth of the qibla in the localities marked at their extremities, in terms of westerly altitude*”. This inscription is hardly legible against the dark background.

The shadow square (Fig. 8) with the table of triplicities inside is in its usual place – below the centre of the instrument. On the right-hand side of the shadow square, there are twelve subdivisions for the shadow in fingers (*ẓill-i aṣābi*ᶜ). On the left-hand side, there are seven subdivisions for the shadow in feet (*ẓill-i aqdām*). The corresponding shadow scales along the rim are similarly labeled.

The triplicities, also known in Arabic as *muthallathāt,* consist of four groups of tree signs of the zodiac, each of which is separated from the others by an angle of 120º. Each of the four groups is given a characteristic, such as fiery, airy, earthy, or watery. Each of the groups also has a planetary ruler by day and a different one by night.[16] The vells of the table sized 4x10 are painted red and green, and resemble a chessboard. The peculiarity of this table is that some of the terms are given in Farsi. Thus, the far right column lists the names“Natures” (al-ṭabācic–الطبايع): Fiery (āteš –آتش), Earthy (hak – خاك), Airy (bad - باد), Watery (āb – آب). And the upper heading presents "their (of the respective signs) night rulers” (arbāb shabhāye īshān – ارباب شبهاى ايشان) and “their day rulers” (arbāb rūzhāye īshān - ارباب روزهاى ايشان). The remaining terms - names of the zodiac signs and the planets - are given in full and in Arabic.

At the bottom of the back side of the astrolabe five astrological scales are located arranged from left to right in a counterclockwise direction in the following order:length of terms (darajat hudūd–حدوددرجات), the planetary lords of the terms (arbab hudūd–حدودارباب), the zodiacal signs (al-burūj –البروج), length of decans (darajat wujūh–وجوهدرجات), the lords of the decans (arbab wujūh –وجوهارباب). Each item is labelled in words at both extremities.

The terms, also known in Arabic as *ḥudūd*, consist of five intervals of unequal size for each sign of the zodiac, each of which falls under the influence of one of the five planets (but not the Sun or the Moon). On our instrument the so-called 'Egyptian' arrangement is used, as given by Ptolemy in his Tetrabiblos (alongside the 'Chaldaean' or Babylonian system, also given by Ptolemy). The names of the planets are written in Arabic, while the length of each term is written in word in Farsi. There are slight differences from the canonical form.[17]

The faces, also known in Arabic as *wujūh*, are divided into three segments 10^{o} each indicating the sign of the zodiac. Each has a planetary ruler which governs one of the seven 'planets', including the Sun and the Moon. The typical arrangement follows the so-called 'Star of the Magi': Mars, Sun, Venus (in Aries), Mercury, Moon, Saturn (in Taurus), Jupiter, and then is cyclically repeated in the subsequent signs of the zodiac.[18]

Alidade and Horse

The alidade (Fig. 9) is used to measure the angles of altitudes of celestial and terrestrial objects. It is also made of wood and is 408 mm long. There are two holes in each sight, about 2 mm in diameter. In addition to its direct application, the alidade of this instrument performed three other essential functions. First, one half of the alidade is divided into 60 equal divisions (see top right of Fig. 6) to use with the sine scale (see above). The graduation here is uniform unlike the sine scale on the instrument itself. This scale is one of the few inscribed with traditional abjad numerals– 5, 10, 15, … 60.

The second half of the right part of the alidade (bottom right) could be used as a sundial, the sighting plate on the right functions as the gnomon.[19] Before noon, the scale marks inscribed 'seven' to 'eleven' are used (inscription under the scale mark): in the afternoon, the scale marks inscribed 'two' to 'six' (inscription over the scale mark). The third scale, the scale of the zodiac signs, it is on the left side of the photograph. It duplicates the scale of the zodiacal signs in the upper right quadrant. The zodiac signs are inscribed.

We should also mention the skillfully made wedge (Fig. 10), which fixes the axis of the instrument. This is the so-called 'horse'. The astrolabist carefully drew the horse's eyes, ears, and even the mane.

Fig. 9 *The alidade, 408mm.*

Fig. 10 *The horse.*

Conclusions

The study of the large wooden astrolabe has revealed some interesting facts, i.e.

1. the huge size, which confirms the high rank of the astrolabe customer - chief of the treasury in the Safavid dynasty;

2. the manufacturing quality of the wooden mater is very high as after three hundred years there are no visible cracks or deformation of the mater and the lacquer paintwork is still well-preserved;

3. almost all numbers are written in word in Persian - a feature that may help to locate the place of the instrument production;

4. the extensive table of localities made it possible to perform statistical analysis of the geographic data and to derive the value of the linear unit used in the source;

5. the presence of localities from the gazetteer of the London astrolabe on the plates of our astrolabe confirm the close relationship of these two instruments;

6. high precision of the rete production has helped to reveal a strange fact: for some reason the master had only partially allowed for the precession and took it into account only for stars, inside the circle of the ecliptic;

7. the analysis of the gazetteer and rete data has confirmed the possible source of the information, i.e. Khaqani Zij by Jamshīd al-Kāshī, 1420.

8. the presence of the individual sets of lines for Kūfah may indicate the place residence of one of the astrolabe owners;

9. the presence of such non-traditional elements of the instrument as compass and arrow head demonstrating the process of reverse transfer of knowledge - from the west to the east.

Altogether, these facts confirm that among all the scientific tools the astrolabe is the instrument providing the greatest wealth of scientific information, covering such fields as astronomy, geography, mathematics, technology, astrology, and art. In this survey, we were not able to answer all relevant questions. Fortunately, the time we live in is opening increasing amounts of digitized historical documents. They become available to researchers from remote places who are far away from big museums and libraries. It is, therefore, quite possible that over time we will be able to learn more about Master Muhammad Karim and establish his place of residence and work, and the relationship with other astrolabists and instruments made in the beginning of the 18th century.

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