Workshop on Reading an Early Astrolabe by Muḥammad ibn Aḥmad al-Baṭṭūṭī (1133 H/1720-21 CE)

Introduction. The aim of the workshop is to familiarize yourself with the astrolabe of Muḥammad ibn Aḥmad al-Baṭṭūṭī and its many purposes.
The workshop is based on the astrolabe no. A-76 made by Baṭṭūṭī, which is now in the collections of the Adler Planetarium in Chicago. Twenty excellent photos of the astrolabe are available online on the website of the Adler Planetarium. These photos can be found by searching in the Adler collections `https://www.adlerplanetarium.org/collections/` with the term A-76, or directly via the link

`https://adler-ais.axiellhosting.com/Details/collect/453`

The photos are numbered 1/20, 2/20 , . . . 20/20. For this workshop you will need the six photos 1/20, 4/20, 6/20, 7/20, 8/20 and 12/20. By clicking on each photo, the photo will appear in a separate screen with buttons for magnification and printing.
We hope you enjoy the workshop!

A. *Abjad*-numbers.
On the front side of the astrolabe (photo 4/20), read the *abjad*-numbers on the outer rim, starting at the top, in clockwise order. Make sure you understand all numbers.

B. Almucantars and azimuthal lines.
Photos 12/20 and 1/20 show the plates for localities with latitude $33°40'$ (Fès) and $28°30(?)'$ (Draa).

a) In Photo 12/20, for the city of Fès, locate the zenith, which is the point in the middle of the (almost) concentric circles. These circles are the *almucantars*, that is, circles of equal altitude. Find their abjad numbers (from 3 or 6 to 36 and from 39 to 78), and locate the Eastern horizon and the Western horizon. Find which almucantars are dotted. There is an irregularity here, which we will come back to later.

b) Locate the azimuthal lines, whose extensions pass through the zenith. Read their numbers from 90 in the North to 5 in the East and West, and again until 90 in the South.

c) Locate the celestial north pole (center of the hole in the middle), and use the almucantars to estimate the altitude of the north pole.

d) Below the horizon, find the numbers for the latitude of the plate, and read the inscription inside the semicircle. Find the three concentric circles: Tropic of Cancer (small), celestial equator (intermediate), Tropic of Capricorn (large).

e) Repeat the above exercises for Photo 1/20 (plate for the city of Draa) and notice the differences with Photo 12/20 (for the city of Fès).

C. Hour lines.
In civil life in the time of al-Baṭṭūṭī, every day (from sunrise to sunset) and every night (from sunset to sunrise) was divided into 12 hours. We call them *seasonal hours* because their length depends on the season: a seasonal day hour in summer is longer than a seasonal day hour in winter, a seasonal night hour in winter is longer than a seasonal night hour in summer. In Figures 2 and 3, locate the seasonal night hour lines and their abjad numbers.
Hint. Sunrise and sunset happen at the horizon. What is the hour line for midnight, that is the (beginning of the) seventh hour?
Note. Night hour lines can also be used to find the seasonal day hours, if we take the point in the ecliptic diametrically opposite to the sun.

D. Prayer lines (part 1).
Locate the lines for the *fajr* prayer below the Eastern horizon. Then locate the lines for the ^{c}*aṣr* prayer and the *ẓuhr* prayer. The latter prayer lines were used with the point diametrically opposite the sun.
Remark. For more exercises on prayer lines: Exercise **K**.

E. Spider. Dating the astrolabe.
Photo 8/20 shows the spider (*ankabūt*) which contains the star map and a metal circle with the 12 signs of the zodiac, divided into six-degree intervals. The path of the sun (the ecliptic) is the outer circumference of the metal circle.

a) Read the names and the signs of the zodiac on the spider. See the list on the attached reference sheet.

b) Identify as many star names as possible, using the list. The exact position of the star is at the tip of its pointer. Notice how al-Baṭṭūṭī shaped the metal star pointers to make the spider look symmetrical. Also locate the Tropic of Capricorn.

The positions of the stars on an astrolabe change slowly in the course of time, as a result of *precession* (which, in modern astronomy, is related to a motion of the axis of the earth). The effect is most visible for stars far away from the center of the spider. In the following exercises you will use precession to date the spider.

c) Find the stars Regulus (*qalb al-asad*), Spica (*a^{c}zal*) and Antares (*qalb al-^{c}aqrab*). Mark the point on the ecliptic which is closest to Spica. This position was called the 'longitude' of Spica in Islamic astronomy. Also find the longitudes of Antares and Regulus and mark these as points on the ecliptic (but note the inaccuracy for Regulus).

According to the authorative work *Kitāb ṣuwar al-kawākib* of Abdurraḥmān al-Ṣūfī, the ecliptical longitudes of the fixed stars increase by one degree in 66 solar years. Al-Ṣūfī gives the following longitudes for 964 CE: Spica 9 degrees 22 minutes Libra, Antares 25 degrees 22 minutes Scorpio, Regulus 15 degrees 12 minutes Leo.

d) Find an approximate date for the spider of the astrolabe from each of these three stars.

F. Geographical coordinates.
Photo 6/20 is the front of the astrolabe from which all the plates have been removed. Here we find names of cities with their geographical longitude (*al-ṭūl*), latitude (*al-ᶜarḍ*), and the number of their 'climate'. The climates were parallel areas into which the inhabited world was divided. Climate 1 was close to the equator, climate 7 in the far north.

Try to read the names of as many cities as possible, and read their coordinates. How can the values be compared to modern coordinates?

Back side of the astrolabe. Photo 7/20 shows the back side of the astrolabe. The alidade (see the figure on the next page) was mounted on top of it. The side of the alidade through the center (upper side of the figure on the next page) was used to read the scales of the four quadrants of Figure 6. These quadrants had different purposes.

G. Shadow quadrants.
In the lower right and lower left quadrant, the object which throws the shadow is divided into 12 units, called 'fingers' (*aṣābiᶜ*), and shadows are measured in fingers. The number 12 is derived from the human body: the span of the hand is approximately 12 finger breadths.

The 'horizontal shadow' (*al-ẓill al-mabsūṭ*) is cast on a horizontal plane and the 'vertical shadow' (*al-ẓill al-qā'im*) on a vertical plane. The two scales for horizontal and vertical shadows form a 'shadow ladder' (*ẓill salam*).

a) Use the quadrants to find the horizontal and vertical shadows of an altitude of 45 degrees in 'fingers'.[1]

b) Use the shadow ladder and a ruler or the side of a sheet of paper (to serve as an alidade) to find for which altitude the horizontal shadow of an object is half the object? Confirm your answer with a modern calculator.

c) *Extra.* For any altitude, 'the horizontal shadow' times 'the vertical shadow' is 144 square fingers.[2] Find the altitude such that the horizontal shadow of the object is twice the object. *Remark.* Computations like this were relevant for determining the time of the *aṣr*-prayer.

H. Upper quadrants.
The two upper quadrants on the back of the astrolabe (Photo 7/20) contain six circular arcs which could be used to (approximately) tell the time if the maximum (noon) altitude of the sun is known.

> *Instructions.* First set the altitude on the altitude at noon (for example, 60 degrees). Make a mark on the alidade where it intersects the inner circle (indicated by the abjad number و). If you want to know the time, hold the astrolabe vertically and measure the altitude of the sun by having the rays of the sun fallen through the sights of both vanes of the alidade (see the figure on the previous page). Look at the position of the mark between the hour curves. This will tell the time in (seasonal) hours. The result is a good approximation, but not exact.

Find the time if the maximum (noon) altitude of the sun is 60 degrees, and the altitude at the moment is 30 degrees. Use the side of a sheet of paper as alidade.

[1] You can confirm this using modern trigonometry by computing tan(45) and cot(45).

[2] Check by modern trigonometry: The horizontal shadow in case of altitude a is $12 \cot a$, and the vertical shadow is $12 \tan a$. We have $12 \tan(a) \cdot 12 \cot(a) = 144$.

I. Circular scales.
The following exercises refer to the back of the astrolabe (Photo 7/20). The innermost (circular) scale shows the four seasons. The second scale the moon houses (see Exercise **J**), the third and fourth scale the months and days.

a) Read the innermost scale and the third scale with the names of the months. Check the number of days of each month in the fourth scale.

The next two scales (so the fifth and sixth) show, for the date in the third and fourth scale, the position of the sun in the signs of the ecliptic in signs and degrees.

b) Check this with the list of solar positions on the workshop of the first day. What is the difference? Can you explain the difference?
Hint. Look at the date on which the sun enters the sign Aries.

c) According to most Islamic astronomers, the four seasons (spring, summer, fall, winter) correspond to three zodiacal signs: spring to Aries/Taurus/Gemini, summer to Cancer/Leo/Virgo, etc. Find from the astrolabe the length of each of the seasons. (Ignore the seasons on the innermost scale.) Are they equal? What do you conclude for the theory of the motion of the sun used by al-Baṭṭūṭī?

J. Moon houses.
The second (circular) scale contains the names of the 'lunar mansions' or 'moon houses': 28 parts of the ecliptic, usually indicated by one or more stars. The moon houses find their origin in pre-Islamic astronomy. For example, the third house is called Pleiades, the fourth house Aldebaran, and so on. Because the sidereal month is about 27.3 days, it takes the moon on average nearly one day to move from one house to the next.

a) Locate the third and fourth moon house, and read the names of the other moon houses. Use and compare with the list on the reference sheet.

b) Compare the lunar mansions Spica and Antares with their positions on the spider of the astrolabe. Can you draw any historical conclusion from this?

c) *Extra (not related to moon houses).* Finally, read the name of the maker of the astrolabe and the date in the interior of the circle for the sixth (seasonal) hour.

K. Prayer times (part 2).
Use the plates for Fès and Draa (Figures 2 and 3) again.
The lines for the prayer times were defined according to strict mathematical criteria.

a) To find this criterum for the *fajr* prayer, locate the intersection point F_1 of the *fajr* line with the celestial equator, and find the position P of the pole. Then find the point Q_1 on the celestial equator on the straight line F_1P. We have $F_1P = PQ_1$. Find the almucantar through the point Q_1. What is its number?
Note. In the sky, Q_1 and F_1 are diametrically opposite points.

b) Repeat this procedure for the point of intersection F_2 of the *fajr* line with the Tropic of Capricorn. Supposing that F_2 and Q_2 are projections of diametrically opposite points in the sky, Q_2 is located on the Tropic of Cancer. Although F_2, P and Q_2 are on a straight line, in this case $Q_2P \neq PF_2$. Find the almucantar through Q_2. What is its number?

c) Finally, do the same thing for the point of intersection F_3 of the *fajr* line with the Tropic of Cancer. Now the point Q_3 is on the Tropic of Capricorn. What do you conclude? Can you now explain the 'irregularity' mentioned in Exercise **B**, part a), of this workshop?

d) *Extra.* Find the mathematical criterium according to which the lines for the *ᶜaṣr* and *ẓuhr*-prayers were constructed. You need a calculator and a piece of paper to make some computations on here. Base your research (only) at the intersection points of these prayer lines with the celestial equator and with the Tropics of Cancer and Capricorn.

Bonus material.
We have a few copies of the spider and the back side of a larger astrolabe, which was made by al-Baṭṭūṭī in 1146 AH/1733-34 CE. If you are finished you can repeat the exercises **E**, **I** and **K** for a larger astrolabe made by al-Baṭṭūṭī in 1146 AH/1733-34 CE. This astrolabe is now no. 51459 in the History of Science Museum in Oxford:

`https://www.mhs.ox.ac.uk/astrolabe/catalogue/browseReport/Astrolabe_ID=137.html`
Spider `https://www.mhs.ox.ac.uk/astrolabe/images/51459/51459_rete_front.jpg`
Back side: `https://www.mhs.ox.ac.uk/astrolabe/images/51459/51459_mater_back.jpg`
(Note the underscore symbols _ in the links)
Investigate the differences between the two astrolabes.