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Astronomy at the service of the Islamic society

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Abstract. The Islamic society has great ties to astronomy. Its main religious customs (start of the Islamic month, direction of prayer, and the five daily prayers) are all related to two main celestial objects: the Sun and the Moon. First, the start of any Islamic month is related to the actual seeing of the young crescent after the new Moon. Second, the direction of prayer, i.e., praying towards Mecca, is related to the determination of the zenith point in Mecca. Third, the proper time for the five daily prayers is related to the motion of the Sun. Everyone in the society is directly concerned by these customs. This is to say that the major impetus for the growth of Islamic astronomy came from these three main religious observances which presented an assortment of problems in mathematical astronomy. To observe these three customs, a new set of astronomical observations were needed and this helped the development of the Islamic observatory. There is a claim that it was first in Islam that the astronomical observatory came into real existence. The Islamic observatory was a product of needs and values interwoven into the Islamic society and culture. It is also considered as a true representative and an integral par of the Islamic civilisation. Since astronomy interested not only men of science, but also the rulers of the Islamic empire, several observatories have flourished. The observatories of Baghdad, Cairo, Córdoba, Toledo, Maragha, Samarqand and Istanbul acquired a worldwide reputation throughout the centuries. This paper will discuss the two most important observatories (Maragha and Samarqand) in terms of their instruments and discoveries that contributed to the establishment of these scientific institutions.

Keywords. Islamic calendar, Qibla, prayers times, observatories

1. Introduction

The daily life of the Islamic society has great ties to astronomy. It can be said without any doubt that the major impetus of astronomy in Islam came from three main religious customs: (1) the determination of the beginning of the Islamic months, (2) the determination of the direction of *Qibla* (direction of prayers), and (3) the determination of the time for the five daily prayers. These three religious customs are all related to two celestial bodies: the Sun and the Moon.

The Moon regulates the start of the Islamic month. The observation of the new crescent after sunset is a religious requirement following the tradition of the Prophet. This observation may appear trivial, but it is much more complicated. Muslim astronomers like their predecessors have tackled this problem and came up with a new set of criteria.

The Sun has an important rôle in regulating the time for the five daily prayers. Simple schemes can be elaborated using the shadow of a stick to set these prayers times and to determine the rising and setting of the sun at the solstices and equinoxes, which will eventually help to find the direction of the *Qibla* (Mecca).

In this paper, Section 2 describes the different criteria used to determine the start of Islamic months. In Section 3, we discuss the determination of the direction of *Qibla*.

Section 4 defines the time for the five daily prayers. In Section 5, we discuss the two main observatories of Islam, i.e., the Maragha and the Samarqand observatories. Section 6 summarises the paper and presents a concluding remark regarding the rôle of the Islamic observatory.

2. Start of the Islamic month

The yearly cycle of the apparent solar motion provides an unaided time keeping in years. This leads to say that the division of the year into solar months and weeks is artificial. In contrast, the monthly cycle and the daily changing visible face of the Moon provide a realistic unaided time keeping in days and months. This explains why the lunar (or luni-solar) calendar practice is very old.

The Islamic calendar is principally a lunar calendar. The determination of the first day of any Islamic month is not a simple matter, but rather a complex one. The question is how soon after the new Moon can one spot the lunar crescent in the evening twilight? Several civilizations before the Muslims faced the same question, and several criteria were introduced for a possible sighting. The most common one is that the thin lunar crescent should be at least one day old at the time of sunset. Each succeeding day the Moon sets later, increasing the chance that it will be seen. Sightings of the Moon within 20 hours of its new phase are extremely rare. However, some records have been set such as the naked-eye visibility of a 15.4 hours crescent in 1871, a 14.9 hours visibility in 1972, and a 13.5 hours visibility in 1988.

The sighting of the thin lunar crescent depends on several factors such as the atmospheric clarity, the sky brightness, and the sensitivity of the eye during the evening twilight. The uncertainty in the weather adds more problems in the exact determination of the Islamic months. One general method used by earlier Muslim astronomers for possible sighting is the time lag between sunset and moonset. The thin crescent can be visible if the Moon sets at least 48 minutes after sunset. This limit, however, can be either shorter or longer depending on the location and the season. Another equivalent method is that the angle of separation of the Moon and the Sun should be at least 12 degrees at sunset.

Several algorithms exist today to predict the first visibility of the crescent (Bruin 1977; Yallop 1998). Some of these algorithms use just the old criteria methods described above without taking into account the observing conditions. Other algorithms, however, include the brightness of the sky, the atmosphere of the observing site (Schaefer 1988) and even the characteristics of the human eye. The problem is to narrow the marginal error of such a prediction. An international lunar dateline can be worked out after every new Moon. Observers West of this line are those who have most chances to see the crescent on the first night, while observers to the East should wait one more day. This is due to the line which marks the sunset since it sweeps westward as the Earth rotates. The accuracy of such algorithms is based upon a good reliable sighting of the crescent. In any case, the algorithm is set to help, not to determine automatically the beginning of any Islamic month.

3. The direction of *Qibla*

The problem of determining the direction of prayers for the Muslims, *i.e.*, the *Qibla* (Mecca, Saudi Arabia) is a problem of spherical trigonometry or mathematical geography and is of big importance for the Muslim society. It formed an important problem for the

Muslim scientists in medieval time who usually treated it in an astronomical form. Most astronomical handbooks on time-keeping contain a chapter on the determination of the Qibla.

Mathematically speaking, the problem involves the solution of a spherical triangle formed by the place of interest (P), Mecca (M), and the geographical North (N). The determination of the angle formed between the meridian that crosses (P) and the arc (PM) marks the direction of the *Qibla*. Early Muslim astronomers dealt with the problem and came up with sophisticated formulas that give the direction of Qibla with great accuracy.

Using a less sophisticated approach, however, one can use basic astronomy knowledge to find the *Qibla* direction. First of all, one must find the four main directions (N, E, S, and W). This is easily accomplished by either following the Sun shadow (during daylight) or finding Polaris, the North Star (during night time). The shadow direction is towards the West in early morning hours, North-West before noontime, North at noontime, North-East in mid-afternoon, or East in late afternoon, just before sunset. Once these four main directions are set, one should locate himself with respect to Mecca: is oneself East, West, North, or South of Mecca? For example, Paris is North-West with respect to Mecca, the direction of the *Qibla* is then South-East.

4. Time for the five daily prayers

Compared to the other two religious customs, the determination of the times of prayers is relatively easy. This is due to the fact that prayers times have close correspondence to astronomical phenomena like sunrise, sunset, midday, and twilight. Astronomically speaking, it involves the determination of the times of specific positions of the Sun with respect to the local (Zenith, Azimuth) coordinate system. Sophisticated algorithms have been developed throughout the centuries to compute these prayers times for any location on Earth (Ilyas 1984). Our aim, however, is to show that a simple knowledge of the direction of shadows and twilight can be more than enough for the general person to figure out roughly the times of the five daily prayers. Otherwise, specific algorithms exist and can be used to compute these times with great accuracy.

The practical astronomical requirements for the period of the five compulsory prayers are as follows:

(*a*) *Fajr* (early morning prayer): It begins at day break, *i.e.*, at the beginning of the (indirect) sunlight (*i.e.*, starts at morning astronomical twilight, 18 degrees). It ends at sunrise (upper limb of the Sun).

(*b*) *Dhur* (midday prayer): It begins after the meridian crossing of the Sun (whole disk and not the center). This is also the time when the shadow is shortest. It ends at the beginning of *Asr* prayer.

(*c*) *Asr* (afternoon prayer): It begins when the shadow of a vertical rod is equal to the length (*Asr-Shafei*) or twice (*Asr-Hanafi*) of the rod plus its shadow at noontime. It ends slightly before sunset.

(*d*) *Maghrib* (sunset prayer): It begins at sunset and ends at the beginning of *Isha*.

(*e*) *Isha* (evening prayer): It begins at the end of the (indirect) sunlight (*i.e.*, starts at evening astronomical twilight, 18 degrees), and last until midnight or *Fajr* (depending on the different theological schools).

5. Islamic observatories

In modern times, it is usually said that bigger is better in terms of astronomical observatories. A bigger telescope is better when it comes to collect the maximum amount of light from such far away and dim celestial objects. The use of large instruments is synonym to our present day modern facilities and to the new research trend of using large scopes to better understand the fate of our universe.

A question then arises here: is this modern trend of using larger and larger instruments a really modern one, or did it exist in medieval times? The answer is straightforward: the need to use large instruments for better observing results goes back to as far as the 8th century. The period in between the 8th and 15th century is considered as the period where Islamic astronomy flourished the most. It is generally conceived that the growth of this astronomy was due to the geographic proximity to the world of ancient Greek and to the Islamic religious observances bearing with it a host of problem in mathematical astronomy related to the start of the Islamic month, the direction of the *Qibla*, and to the proper time for the five daily prayers. This specific set of astronomical problems along others requires a long observing program and the establishment of a long term Islamic observatory was an absolute necessity.

Several large Islamic observatories were established over all Islamic lands. Some of these observatories were short lived, and several were demolished either due to astrological or political reasons, but some had their observing programs ran over more than 30 years. A large number of these observatories were private, while the others were fully financed by the state.

In this work, we will emphasize on two main observatories: the Maragha observatory (13th c.) and the Samarqand observatory (15th c.) for three main reasons. The first one is that these two observatories have stayed, unlike any other observatory, active over more than two decades. The second one is that these observatories were not only centres of observing the sky, but also centres of instruction and learning. The third reason is that these observatories have used large observing instruments to get better accuracy and subsequently better results.

5.1. *Maragha Observatory*

The Maragha observatory is considered as the first truly astronomical observatory in modern science. It was founded in 1259 under the order of Hulagu (1217-1265), the first Mongol ruler of Iran from 1251 to 1265, and its foundations are still extant. The observatory was built under the supervision of Nasir al-Din Al-Ṭūsī (1201-1274) who used his influence to have the observatory built in Maragha, a city of Adharbayjan to the South of Tabriz. It was a center of instruction in science and philosophy and saw the collaboration of many scientists in its activities.

The financial support of the Maragha observatory was based upon private endowment funds and is considered as the first Islamic observatory to benefit from *waqf* revenues (Sayili 1960). This was of great importance because the observatory had secured funds to operate and this explains its quite long life compared especially to earlier observatories in Islam. After Hulagu's death in 1265, the observatory continued to function during the reigns of not less than seven rulers until 1316. This year would seem to be of importance since it does coincide with the year of Asil al-Din's death, the last person known to have directed the observatory.

As described by Sayili (1960), the whole building was located on the top of a hill having its length along the meridian. The hill was flattened at the top forming a rectangular shape of 400 meters in length and 150 meters in width. A mosque and a special building for Hulagu's residence were part of the construction. The observatory had an impressive tall dome which makes it visible at large distances as described by several scholars like al-Safadi (1931) and al-Kutubi (1951). The observatory building was described as a marvel and a treat to the eye. Its library was huge and consisted of more than 400,000 volumes in all branches of science. These books are said to have been collected from Baghdad, Syria, and Al-Jazira. This is the first case wherein the existence of an observatory library is mentioned. It undoubtedly facilitated the literary productivity of the scientists gathered at Maragha.

Sayili (1960) reported that there was a hole on the top of the tall dome through whic h the rays of the Sun entered. The image was used to measure the mean motion of the Sun in degrees and in minutes. The elevation angle of the Sun in different seasons and various times of the day were also determined with the help of this device. The arrangement was such that the solar rays fell upon the threshold on the first day of spring. Inside the building, there were representations of the celestial sphere, of the different epicycles and deferents, and illustrations of the phases of the Moon and the signs of the Zodiac. There were also terrestrial and celestial globes, maps of the seven climes, and illustrations concerning the length of days and nights.

The observatory also consisted of an elaborate network of caves, starting with a comparatively roomy entrance section, on the south side of the hill neat the flattened top. These cases may have served as place of work for the astronomers. The southerly exposure of the opening of the caves would make possible minor observations with portable instruments.

There is a sixteenth century record (Wilson 1895; Sayili 1953) that there was a well which formed part of the observatory and that day-time observations of stars were made from it.

In terms of the observatory staff, several astronomers worked at the observatory among which we can mention Nasir al-Din Al-Ṭūsī (main supervisor), Qutb al-Din al-Shirazi, Muhyi'l Din al-Maghribi, Fakhr al-Din al-Maraghi, Fakhr al-Din al-Akhlati, Mu'ayyad al-Din al-Urdi (instrument maker), Ali Ibn Umar al-Kazwini, Najm al-Din al-Abahri, al-Tusi's sons Asil al-Din and Sadr al-Din, Fao Mun-Ji (a Chinese scholar), Kamal al-Din al-Ayki, and Abd al-razzaq ibn al-Fuwati (librarian). The life and works of these scholars are reported in Fernini (1998).

It is reported that Hulagu had a number of Chinese astronomers brought to the Maragha Observatory (Sayili 1960), among whom was Fao Mun-Ji. Through them a knowledge of Chinese astronomy and of Chinese calendar is said to have been obtained. The Maragha observatory had then an international status as reported by Sarton (1931). The *Ilkhani Tables* are said to have been popular not only in Islam, but also in China.

With its large scientific staff and its huge library, the Maragha observatory was thus not only an institution for research in astronomy, but it also had the characteristics of a scientific academy with excellent opportunities for scientific contact and exchange of ideas. In addition to the above-mentioned astronomers, its staff undoubtedly contained technicians and personnel connected with administrative work (Sayili 1960).

The main instrument maker of the Maragha observatory was Mu'ayyad al-Din al-Urdi (d. 1266). A detailed description of the instruments constructed is presented in al-Urdi's works. Most of the instruments described by al-Urdi were generally placed out in the open air. al-Safadi (1931) and al-Kutubi (1951) mentioned that the armillary sphere of the observatory was fixed on the ground. The site of the observatory contains t races of the places occupied by the instruments. The trace of a wall placed in line with the meridian is discernable. The mural quadrant too must therefore have been placed on the ground. After twelve years of observations by Al-Ṭūsī and his collaborators, the

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Maragha observatory published the *Ilkhani Zij* in 1271. Hulagu was anxious to have the tables completed in his own lifetime, and since he was told that the observations needed for the tables take about thirty years (*i.e.*, Saturn's period), he adopted a new observation program of twelve years, but he died in 1265 before seeing the end product. This Zij contained a set of astronomical tables regarding the motion of planets, stars, as well as some other astronomical information related to the daily life such as prayer tables. Later on, Muhyi'l Din al-Maghribi added a supplement to this Zij.

5.2. *Samarqand Observatory*

The Samarqand observatory was founded in 1424 by the illustrated ruler and scientist Ulugh Bey (Fernini 1998), whose grandfather was the celebrated Tamerlane. It was fully supported by the state with the consent of all the notable people. The observatory enjoyed about thirty years of active life under and exceptionally enlightened patron who was at the same time its founder. This observatory represented the high-water mark of Islamic astronomical achievements, and it is also probable that it constituted the most important link between Islam and Europe in the transmission of the tradition of founding observatories (Sayili 1960).

The observatory was a monumental building with a huge meridian. It was built from masonry to symbolise the idea of a long-lasting institution. The site of the Samarqand observatory was found following J.L. Vjatkin's 1908 excavations. Vjatkin unearthed the underground remains of a gigantic meridian arc which was the major instrument of the observatory. The building grounds are located on a hill of about 21 meters height made up of a bed of rocks. The top surface of this hill is about 85 meters from east to west and about 170 meters from north to south. The main observatory was surrounded by a garden or parc and lodges serving as dwelling places. The building was cylindrical in shape and had an intricate and elaborate inner plan. The radius of its horizontal cross section is about 23 meters, excluding the marble facings. The height of the building above ground level is estimated to be about 30 meters.

In terms of the observatory staff, several astronomers worked at the Samarqand observatory among which we can mention Ulugh Bey (main supervisor), al-Kashi (1st director), Kadi Zada (2nd director), and al-Kushdji (3rd director). More scholarly information on these scholars can be found in Fernini (1998).

Before building his observatory, Ulugh Bey first founded a madrasa, a sort of school, in 1420. He himself selected the scientists who taught there, first interviewing them to determine their qualifications. His madrasa differed from others of that time in both the content and in the level of the subjects taught there. Besides Ulugh Bey, the lecturers included Salah al-Din Musa Ibn Mahmud (Kadi Zada) and Ghiyath al-Din Jamshid al-Kashi.

The main instrument of the observatory proved to be, not a quadrant as Vyatkin thought, but a Fakhri sextant. A trench about two meters wide was dug in a hill, along the line of the meridian, and in it was placed a segment of the arc of the instrument. The part that is preserved, which was in the trench, consists of two parallel walls faced with marble, fifty-one centimetres apart. The radius of the Fakhri sextant in Ulugh Bey's observatory was 40.04 meters, which made it the largest astronomical instrument in the world of that type. On the arc of the sextant are divisions in which 70.2 centimeters corresponds to one degree; 11.7 millimeteres represents one minute; 1 millimeter is five seconds; and 0.4 millimeters is two seconds. It has been experimentally established that with unrestricted time of observation and sufficient training of the observer, the value of the threshold of angular discrimination can be considered as two to five seconds. Thus

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the choice of the scale of main instrument, and its smallest divisions, was made with consideration for the limits of angular discrimination.

The main use of the Fakhri sextant was in determining the basic constants of astronomy: the inclination of the ecliptic to the equator, the point of the vernal equinox, the length of the tropical year, and other constants arising from observation of the Sun. Thus, it was built chiefly for solar observations in general, and for observations of the Moon and the planets in particular (an arc of 60 degrees is sufficient).

With the aid of the sextant, one could determine at noon every day the meridianal height of the Sun, its distance from the zenith, and its declination; and from this information one can deduce the latitude and the inclination of the ecliptic. The value obtained by Ulugh Bey for the inclination of the ecliptic, $23^\circ\ 30'\ 17''$, differs by only $32''$ from the true value (for his time). According to Ulugh Bey, the latitude of Samarqand was $39^\circ\ 37'\ 33''$.

Besides the Fakhri sextant, others instruments include a parallactic ruler, an armillary sphere, an equinoctial armilla, a two rings instrument (*halaqatan*), an azimuthal quadrant, a sine and versed sine instrument, a small armillary sphere with four rings, and a triquetrum, an astrolabe, and a *shamila* (an instrument serving as astrolabe and quadrant).

An important result of the scientific work of Ulugh Bey and his observatory was the astronomical tables called the Zij of Ulugh Bey or Zij-i Gurgani (Guragon, the title of Genghis Khan's son-in-law, was also used by Ulugh Bey) completed about 1437. This work, originally written in the Tadzhik language, consists of a theoretical section and the results of the observations made in the Samarqand observatory; the latter include actual tables of calendar calculations, of trigonometry, and of the planets, as well as a star catalogue.

6. Summary

The use of astronomy is essential in setting the three main requirements of the Muslim society: start of the Islamic month, the direction of the *Qibla*, and the time determination of the five daily prayers. Simple knowledge of the motion of the Sun and Moon has been used by the society throughout the centuries to help set these three religious duties. Astronomy has greatly benefited from these three interests by the emergence of great Muslim astronomers and large observatories. It can be said without any doubt that the present day modern definition of an observatory existed well back in the Maragha and Samarqand observatories. The foundation of these Islamic observatories was the result of cooperation among a diverse group of astronomers, specialized instrument makers, engineers, architects, and mechanics. Besides the large number of scientists in all fields, these large observatories also contained an impressive array of instruments of large and small sizes as in modern observatories. These medieval observatories were also equipped with libraries of their own supplied with appropriate books. Islamic observatories were also places of contact and exchange of ideas for scientists. They were not only research institutions, but also academic institutions where students came from as far as Europe to study not only astronomy and mathematics, but also all other sciences. It is to say, however, that the instruction in astronomy and in the mathematical sciences, were usual features associated with the observatories of Maragha and Samarqand as well as other Islamic observatories.

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