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Dating Historical Arabic Observations

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Abstract. The first visibility of the lunar crescent signals the start of a new month in the Islamic calendar. The eminent astronomer Ḥabash al-Ḥāsib developed a method of uncompromising complexity for predicting the visibility of the lunar crescent. He derived his threshold value from a moonwatch carried out at different places in Iraq on November 17th, 860 CE. We will allude to a few modern visibility criteria as well and highlight the uncertainties of today's calculations when converting historical Arabic into Julian or Gregorian dates. Tables of first visibility of the lunar crescent for different locations are provided for the purpose of date conversions. Since the Islamic calendar was based on the observation of the lunar crescent, historical dates imply information on positive and negative sightings of the lunar crescent. From such information estimations of cloudiness in different regions of the Islamic world can be extracted.

Keywords. lunar crescent visibility, moonwatch, Islamic calendar, Ḥabash al-Ḥāsib, cloudiness

1. Introduction

The first or last visibility of the lunar crescent is the decisive phenomenon for the start of a new month in various calendars, e.g. the Islamic, Jewish, Babylonian or lunar Egyptian calendar. In order to convert correctly the dates of astronomical observations documented by these cultures into Julian or Gregorian dates, it is necessary to compute the beginnings of the lunar months. The Babylonians were the first to formulate visibility criteria in order to predict whether or not the crescent would be visible. In Arabic times, special moonwatch programmes were organised. We will discuss one extended moonwatch programme from 860 CE in the Middle East and also modern attempts, and discuss the uncertainties of modern calculations.

2. A Lunar Crescent Visibility Criterion and a Moon Watch in 9th Century Iraq

Many criteria for the visibility of the lunar crescent were developed by astronomers in the Islamic world. In early Abbasid time Ya^{c}qūb ibn Ṭāriq (active 778 CE) predicted the visibility of the lunar crescent, based on a very rough approximation of the thickness of the crescent (Hogendijk 1988). Other criteria were based on the time difference of sunset and moonset, or on the sum of the Moon's elongation and its latitude, or on the negative altitude of the Sun. Ibn Yūnus (d. 1009) established a list of several necessary conditions for visibility based on the difference in setting times, the thickness of the crescent and the velocity of the Moon. A very simple criterion, a 10° threshold for the negative altitude of the Sun at the time of the setting of the Moon, is ascribed to Ḥabash al-Ḥāsib (d. after 869 CE), a fact frequently referred to in scholarship (Yazdi 2018). However, it has gone unnoticed until recently that Ḥabash also proposed the most complicated description for predicting the visibility of the lunar crescent in any premodern astronomical work (Thomann 2017). Ḥabash's chapter on crescent visibility consists of two parts. It begins with a general step by step description of his solution, which consists of more than sixty steps of calculation. It leads to a critical value which is compared to a threshold value of $14^\circ\ 29'$. If the critical value is smaller, the Moon is supposed to be invisible, and if greater, it should be visible. After the description of the method in general, a fully calculated numerical example for November 17th, 860 CE at Samarra follows. Ḥabash finds a value of $14^\circ\ 26'$, which is too small for visibility, and indeed the crescent did not appear in the sky on that evening. It was also not seen at Baghdad, but it became visible in Kufa and Anbar, which are west of Baghdad. Ḥabash did not give an explanation for his threshold value of $14^\circ\ 29'$, but obviously he chose it with the intention to receive a correct prediction for the sightings of November 17th, 860 CE. For that purpose, he must have organized a moon watch.

3. Modern visibility criteria and calculations

Computations of first and last visibility of the lunar crescent for the distant past are subject to several uncertainties. The most important uncertainty is the decreasing rotation rate of the Earth, which causes the length of the day to increase with time. The resulting time difference due to the slowing down of Earth's rotation is referred to as ΔT. For details about ΔT see the contribution of Stephenson *et al.* (page 160). In our computations we use the long-period DE406-ephemeris of the Jet Propulsion Laboratory (Standish 1998) and for ΔT the values of Morrison & Stephenson (2004) with a small correction that accounts for the different values of the Moon's secular acceleration used by them and by the DE406-ephemeris. Morrison & Stephenson stressed that their ΔT -values should not be extrapolated further to the past than about 700 BCE because there are no ancient observations earlier on that can be used to derive a value of ΔT. The uncertainty of these values was estimated with the formula of Huber (2006) that is based on the analysis of the stochastic behaviour of the length of day process and a model comprising a global Brownian motion process with infinite relaxation time. All our calculations were made for three different values of ΔT: a mean value, a lower ΔT value that is equal to the mean ΔT value minus the error of ΔT, and an upper ΔT value that is equal to the mean ΔT value plus the error of ΔT.

The second important point is the visibility criterion. Various criteria for the first visibility of the lunar crescent have been proposed based on ancient as well as on modern observational data. The first modern attempts to formulate a crescent visibility criterion by Fotheringham (1910), Maunder (1911), Schoch (1927) and Neugebauer (1929) incorporated two parameters: the true lunar altitude and the azimuthal difference between Sun and Moon at sunset. The most commonly used criterion of this kind is the one of Carl Schoch published posthumously by Neugebauer (1929). Frans Bruin chose a different ansatz in 1977, which was later modified by Bradley Schaefer (Bruin 1977; Schaefer 1988). Bruin calculated the necessary minimal brightness of the Moon in order to be observable at a certain sky brightness. He provided a purely graphic solution of the problem. One has to know the width of the Moon and its altitude above the horizon at sunset to determine whether or not the Moon will be visible. In addition, Bruin gives the time for a best possible sighting.

Bernard Yallop tried to merge the Frans Bruin's approach with the criterion of Carl Schoch, from whom he adopted the values for the minimal altitude of the Moon at a certain difference in azimuth (Yallop 1997). At the same time he resorted to the moment of the best possible sighting – the so-called "best time" – and the width of the lunar crescent defined by Bruin. Yallop accounted for the lunar parallax and the topocentric width of the lunar crescent and introduced a parameter q that describes the threshold for a possible successful sighting. He distinguished in total six zones for q. For historical purposes, only the first three zones are relevant. For the computations, we use the criterion of Yallop which was adapted slightly for our topocentric calculations. This criterion makes use of the so-called "best time" of observation when the Moon is still some degrees above the horizon – hence, effects of the local horizon can be neglected as long as the horizon is not higher than about 3°. In the calculations standard values of refraction are accounted for.

A successful sighting of the lunar crescent is highly dependent on the prevailing seeing conditions: dust in the air or slight fog can easily cause delayed first sightings. But especially in cases where the visibility parameter is close to the critical threshold, a lunar crescent may be missed even if the seeing is good.

4. Tables of first and last visibility

According to the tables of Wüstenfeld *et al.* (1961) the Arabic era began on July 16th in 622 CE. These tables are widely used, and starting from the mentioned zero point a regular calendar scheme is usually applied. However, modern calculations for Medina show that the lunar crescent should easily have been visible on July 15th. It is well known that the calendar dates of Wüstenfeld *et al.* (1961) may be in error by 1–2 days in comparison to the calendar that was actually used. Additionally, there are two more points of concern: first, Sura 9, 36-37 of the Koran suggests that a lunar calendar without intercalation was applied only from year 10 of the Hijra onwards. Earlier, a lunisolar calendar was used. Secondly, in many countries the first actual sighting of the lunar crescent was decisive for the beginning of a new month until quite recent times and not a regular scheme.

While we follow Wüstenfeld *et al.* (1961) in extrapolating a pure lunar calendar backwards to the beginning of the Hijra and earlier, our tables of first and last visibility of the lunar crescent take into account the fact that actual observations were decisive for the beginning of a new lunar month (Gautschy 2018). First and last visibility of the lunar crescent and the corresponding Islamic calendar date between 600 and 2000 CE were calculated for the following locations: Medina, Damaskus, Baghdad, Samarra, Cairo, Cordoba, Aleppo, Isfahan, Bursa and Istanbul. The Islamic calendar date is given on one hand according to the scheme following the tables of Wüstenfeld *et al.* (1961), but also according to observation for the desired location. In addition, the day of the week is specified. If an observational report mentions the day of the week in addition to the Islamic calendar date, then – and only then – an unambiguous conversion into a Julian or Gregorian calendar date can be achieved.

5. Historical Dates in the Islamic Calendar as Documents of Astronomical Observations

If a "calendar" is defined as a set of rules for organizing time, one can speak of a single Islamic calendar. But if a "calendar" is defined as a certain nomenclature giving an individual name for each natural day, month or year, one must speak of a multitude of local calendars in the Islamic world that differed from town to town. Furthermore, it has to be considered that even in the same town calendars could differ according to the religious parties and legal schools living side by side in the same community. All these calendars (except that of the Isma'ilis) are based on observations of the lunar crescent, usually performed in the evening of the 29th day of the month. Therefore, a month of 29 days documents a positive sighting of the lunar crescent, and suggests favourable atmospheric conditions at that day. If modern calculations indicate that on the 29th of a month the lunar crescent must have been visible, but nevertheless the next month started after the 30th day of that month, on can conclude that it was cloudy in the evening of the 29th of that month. The historical records of the Islamic wold – an immense corpus of writings – therefore contain records of atmospheric data that are precise in space and time. They enable estimates to be made of cloudiness in a vast area and over a time period of more than a millennium. All that has yet to be explored. A data collection is about to be built, and a selection has already been published (Thomann 2017). Methods for estimating seasonal cloudiness values from the binary data (positive/negative sightings) have been successfully tested. The significance of the data referred to is due to the fact that on one hand historical cloudiness data are otherwise not available in great quantity, and on the other hand that cloudiness has become a major issue in climatology, which previously concentrated, rather on temperature and precipitation (Lehmann *et al.* 2016).

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