3.10 THE ANCIENTS' CRITERION OF EARLIEST VISIBILITY OF THE LUNAR CRESCENT: HOW GOOD IS IT?

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Abstract. Earliest visibility of the lunar crescent is an important calendrical element. It was needed in all early calendars and remains in use in some lunar calendars today. An astronomical criterion of earliest lunar visibility was therefore evolved quite early, using observations, right from the Babylonian era. In subsequent periods the Babylonian single factor 'moonset lag' criterion was used extensively, although gradually it was realized that it was rather simple. Recently, an improved and comprehensive global criterion of earliest visibility, developed by the author, has been used to generate an extensive inverted moonset lag data set. These data, as a function of latitude and season, all for the first time provide a useful comparison with the simple ancient criterion. It is found that the simple criterion is remarkably good for the latitude region where the Ancients collected their observational data, illustrating the care with which their data was gathered. At other latitudes, there are significant differences, as may be expected. Although the simple criterion may now be replaced by an accurate season and latitude dependent criterion, the former will continue to provide a useful basis. The paper discusses various related historical developments.

Introduction

The easily observable monthly lunar cycle and the rapidly changing lunar phases make the moon an obvious choice for an unaided, simple, yet accurate natural timekeeping system. It is not surprising then that lunar calendrical practice is very old. Almost all early civilizations, Babylonian, Aztec, Inca, Hindu, Chinese, Greek, Jewish, and Muslim, made use of the lunar system in the past, as many do today. And if it was not for the Caesar's Pontiff playing around with the intercalation practice, and then for the Christian Church's need to tackle the problem of Easter date (McNally 1983), perhaps most of us, including the West, still would have been using the lunar calendrical system in either a pure or mixed (i.e. luni-solar) form as do the Muslims, Hindus, Jews and Chinese today.

Determination of when to expect the new lunar crescent's first visibility was a primary scientific challenge for the Ancients (it still is!). However, the Babylonians, quite early, had established a simple one-parameter rule of 'moonset lag' to determine the start of a new month. It remained in calendrical use with the later communities of the Middle East, Hindus, Greeks, Chinese, and early Muslims -- without any significant change or improvement. It was only around 500 A.D. that the Hindus began to recognise the importance of other parameters, especially the lunar crescent's width, in the determination of the earliest visibility. Later, Muslim astronomers like al-Battānī, al-Khwārizmī, al-Farghānī, and Ḥabash studied the problem more thoroughly and provided a more comprehensive and universal solution. Although al-Battānī is reported to have

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remarked: "the Ancients did not understand the phenomenon completely, but only approximately", he nevertheless appreciated its usefulness by stating that the simple criterion was a "good starting point" (Bruin 1977). But how good?

Development of a modern comprehensive criterion of earliest lunar visibility was first attempted in the early years of this century by Fotheringham and Maunder who made use of Schmidt's twenty year long careful observations of youngest lunar crescents at Athens. The information was inverted into a two-parameter criterion that could be considered of universal nature. But it remained obscure for the next sixty years, when the current Islamic interest brought it to the surface. Around this time, an independent theoretical treatment of the problem by Bruin (1977) was presented. Subsequently, the two criteria were combined (Ilyas 1981), and the composite criterion was further improved leading to an updated, observational/theoretical compatible prediction system with greater confidence (Ilyas 1983; 1984a; 1984b). The new criterion opened the way for the necessary global lunar visibility calculations and International Lunar Date Line work through a computer-based global calculation system (Ilyas 1982).

Since the Babylonian criterion was in use for a remarkably long period, and included the Muslim astronomers of later centuries like al-Ṣūfī and al-Kāshānī among its users, it is of great interest to examine the 'moonset lag' as a universal criterion for lunar visibility. The global calculation system enabled us to develop a new 'moonset lag' criterion and thus allowed a test of validity for the Ancient's simple criterion on a global scale. It is the purpose of this paper to discuss the results of this analysis.

New Moonset Lag Criterion

The Global Lunar Visibility Prediction Calculation System (or global calculation system) is a self-contained extensive algorithm which has been discussed in detail elsewhere (Ilyas 1984b). Briefly, it incorporates a number of basic solar and lunar positional programs, and enables the generation of various parameters, including moonset and sunset times at any specified (or grid-point) locations. For each new moon, a longitude (λ_o) is identified at which the minimum condition of visibility at local sunset has been met, latitude by latitude. At these λ_o various parameters are calculated and printed out. The moon's age and moonset lag at these critical longitudes (λ_o) provide the critical data to construct a simple, one-parameter criterion of lunar visibility. The results, based on sixty-one lunar months (1979-1983) at different latitudes, are shown in Fig. 1. The 'moonset lag' data at different (northern) latitudes (0^o, 30^o, 40^o, 50^o, 60^o,) are plotted as a function of season (day-number of year: 1-365). We notice that there is a slight seasonal trend at lower latitudes, but the data (not shown here) are essentially confined to the curves. However, at higher latitudes, not only is the seasonal trend much more strong, but there is also a large scattering of the data, with the effect being particularly strong in the summer season. This is shown by the envelopes or dotted lines around the mean lines — (the seasonal dependence prevails at the southern latitudes (Ilyas 1984b)). At the lower latitudes, the data may be reasonably defined by lines of constant 'moonset lag' (minutes), but at the higher latitudes the departure is too significant:

0^o : 41 ± 1 (±2 all data)

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30^o : 46 ± 2 (±4 all data)
40^o : 49 ± 4 (±9 all data)
50^o : 55 ± 10 (±15 all data).

Discussion

The results in Fig. 1 enable us to compare, in a straightforward manner, the Ancients' criterion of earliest lunar visibility, moonset lag greater than 48 minutes ($a_s \geq 12^o$). Considering the latitude of the place of observation, Babylon (32^oN), we notice that although strictly speaking, for the comparable latitude, the criterion deviates from this single factor —seasonally independent— criterion, the difference is rather insignificant. The fact that seasonal trend is not strong at these latitudes must have been noted by these early observers, thereby settling for a single factor criterion. Of course, we can quickly notice that there is a strong latitude dependence in the criterion, and therefore at the higher as well as the lower latitudes there are significant departures. At the lower latitudes, although the seasonal effect is almost negligible, the absolute magnitude of the Ancient's criterion is an overestimate.

On the whole, the Babylonian criterion is an excellent estimation, applicable to most of the lower latitudes. This must have been why it remained in favour with most of the later astronomers, including the Hindus and Muslims, who were located at the lower latitudes. Still, as al-Battānī pointed out, it was an excellent but approximate estimate. It is not clear to me whether the Babylonians arrived at this figure of "48 minutes" from the "age" of earliest visibility, knowing that approximately the moon had to be about "one day" old to become visible. A simple treatment shows that on the average the moon elongates from the sun by slightly more than 12^o per day, and as a result the moon transits a meridian 49 minutes later than the sun on each subsequent day (see Appendix 1). However, it seems to be more likely that they would have directly noted the separations (in degrees) of youngest visible crescents over a long period and arrived at the excellent figure of 12^o separation. This is because of the fact that to produce the same separation, the moon's age varies more significantly, giving a wider spread (Fig. 2). In any case, the Babylonians must have collected their observational data with great care, which produced the remarkably good simple criterion.

Concluding Remarks

We notice that the Babylonian simple criterion is a good starting point up to mid-latitudes. Of course, for higher precision one should employ the season-latitude dependent curves even at the lower latitudes. Even so, the 'moonset lag' criterion remains quite simple considering the accuracy. The 'visibility-criterion proper' is somewhat involved and requires considerable computation. But for chronological purposes of earlier records, one can relatively easily make use of the moonset lag criterion with considerable confidence. Also, to a layman this criterion is more meaningful, since he can easily understand that the (local) moonset must follow after the (local) sunset, and not before (i.e. conjunction must take place before local sunset time) on the evening for which the new crescent's visibility is being evaluated.

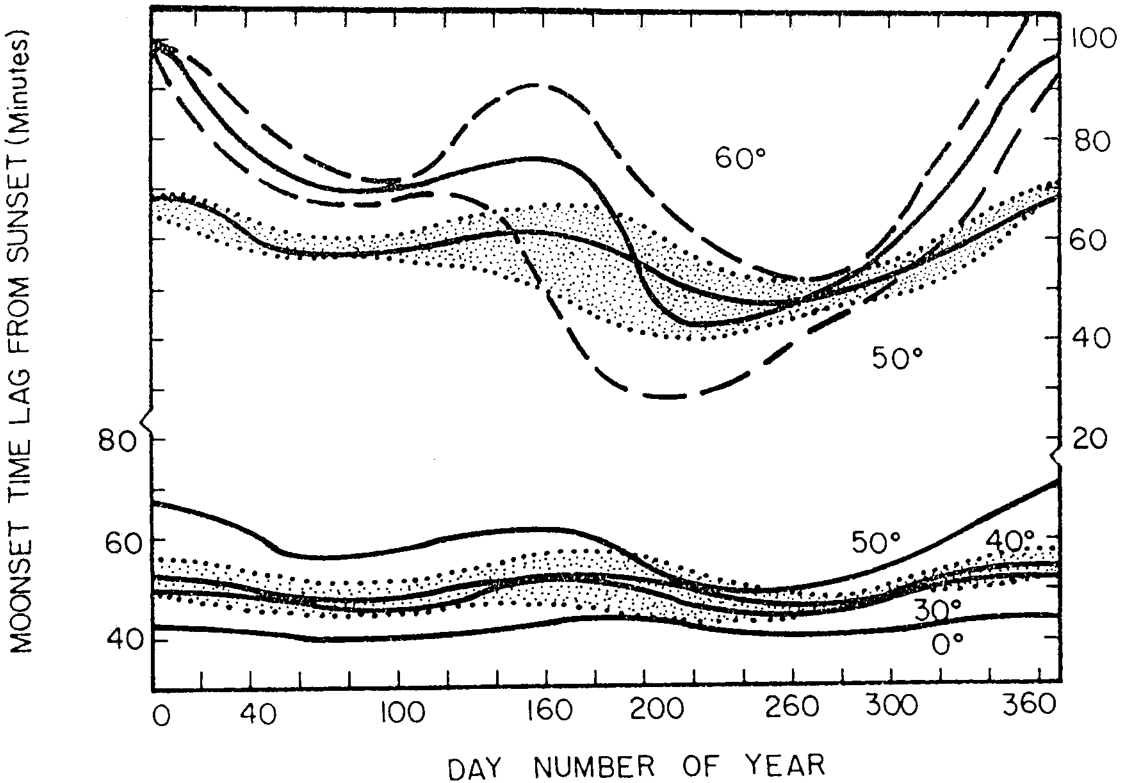

Fig. 1: Seasonal variability of minimum (local) moonset lag for earliest visibility of the new lunar crescent. Lower set: 0°, 30°, 40°, and 50°; the envelope around the mean line for 40° shows the limits of spread in inverted data. Upper set for 50° and 60°: the envelope around 50° mean line and the dashed lines around 60° mean line show the limits of spread in the data. The relative large spread in the summer season is obvious.

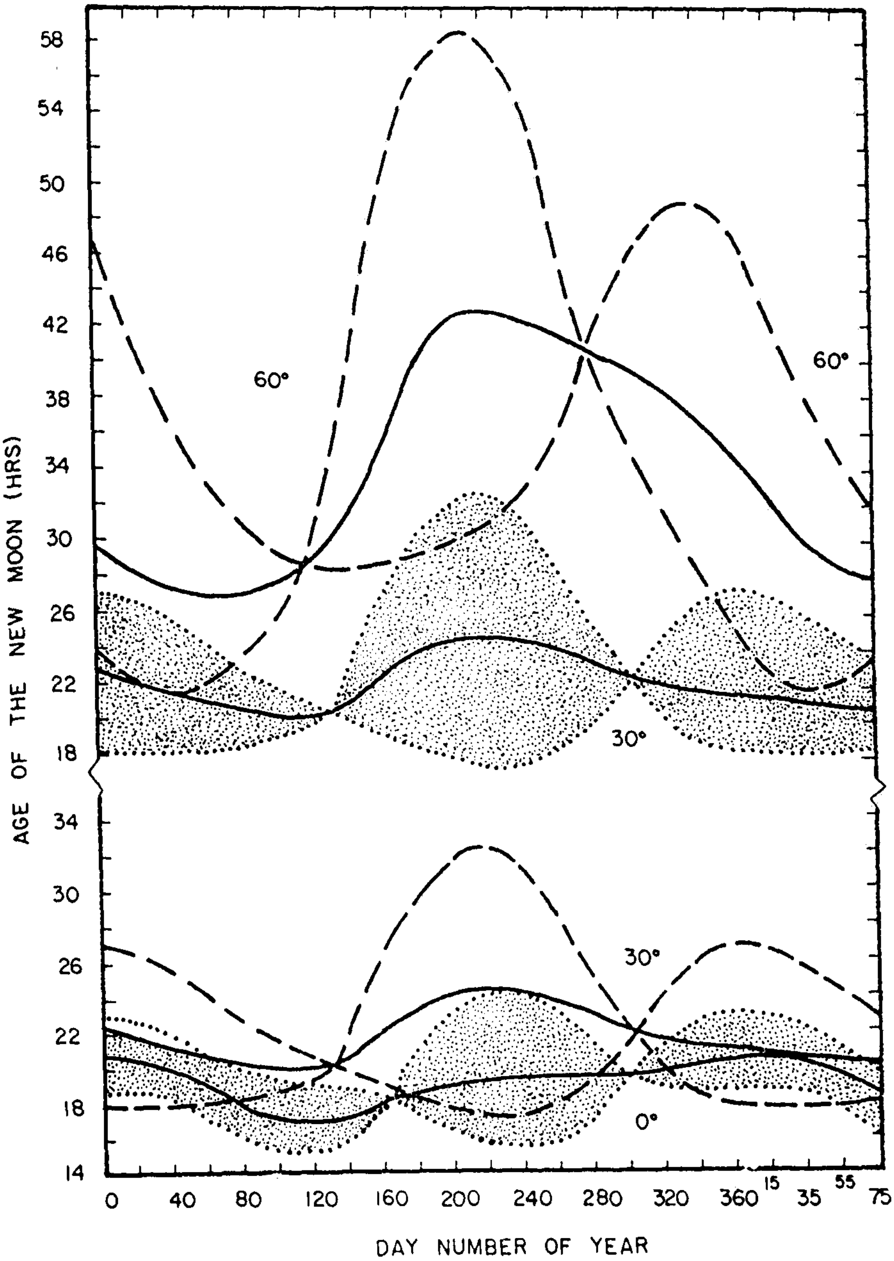

Fig. 2: Seasonal variability of minimum 'moon's age' (at local sunset) requirement for earliest visibility at three latitudes. The envelopes and the dotted lines show the limits of spread in inverted data. The 'age' shows a greater variability and therefore less accuracy of the criterion especially at the higher latitudes.

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Appendix: Approximate Diurnal Separation of the Moon

Sun's (apparent) annual motion (360^0 in 365 days)	= 1^0 /day
Sun's (apparent) diurnal motion due to earth's rotation	= 360^0/day
Sun's net (apparent) diurnal motion	= 359^0/day
Moon's (true) monthly motion (360^0 in 29.5 days)	= 13.2^0/day
Moon's (apparent) diurnal motion (due to earth's rotation	= 360^0/day
Moon's net (apparent) motion	= $(360-13.2)^0$ /day $\simeq 14.5^0$/hour
Moon's motion relative to Sun	$\simeq -(13.2-1)^0$ /day $\simeq -12.2^0$/day
Hence, the Moon separates from the Sun at an average rate	$\simeq 12.2^0$/day

The Moon moves 14.5^0 per hour on average w.r.t. earth (i.e. a meridian). Hence to cover 12.2^0 -- a separation over one day from the Sun, the Moon would require an extra 0.84 hours (better average: 49 minutes) to cross a meridian compared to the Sun i.e. the Moon would lag behind the Sun by about 50 minutes a day in transiting a meridian and this may be used to determine the time of upper transit, rise or set with respect to the Sun. (We may refer to conjunction or a known instant at which the 'lag' or separation is known).

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DISCUSSION

E.S.Kennedy: To what extent does the lunar latitude vitiate a criterion based on the age of the moon ?

M. Ilyas : I suppose, the lunar latitude would be a parameter in actual visibility, hence the lunar age rule is to be regarded as a first approximation only.

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