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Lowest Limit of *w* in the New Moon's First Visibility Criterion of Bruin and its Comparison with the Maunder Criterion

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SUMMARY

The (Z, Az) criterion of Maunder for the first visibility of the New Moon is compared with the Bruin's (Z, a_L) criterion. It is found that the suggested lower cut-off limit of lunar width, $w = 0{\cdot}5$ arcmin, in the Bruin's criterion is too high and needs to be reduced to about $w = 0{\cdot}25$ arcmin; the two criteria are then found to be in excellent agreement. The criterion was used to develop global first visibility lines (referred to as Lunar Date Lines) for all the 12 months in 1980 and for 10 consecutive years for a particular lunar month to illustrate the nature of variability. These results are included.

INTRODUCTION

Although astronomical criteria of varying degrees of accuracy for prediction of the New Moon's first visibility have been available for quite some time, no investigation appears to have been undertaken to study the variability of the first visibility locations with latitude on a global scale. The earlier first visibility criteria saw significant improvements and usage at the hands of early Muslim astronomers through the seventh to the tenth centuries, e.g. al-Khwarizmi, al-Battani, etc. (for a recent discussion see Bruin 1977). The usage of these criteria appears to have gone out of wider/common usage in the following centuries. At the beginning of this century, Fotheringham (1910) developed a statistical criterion based on Schmidt's (1868) records of first visible crescents. With the addition of some new observations, the criterion was later modified by Maunder (1911) and the Indian Ephemeris lists and makes use of a slightly modified form of this criterion annually, e.g. Indian Ephemeris (1979) (for a discussion of the two updated versions see Ashbrook 1971). In view of a growing need for the use of an astronomical criterion to investigate the variability of the predicted first visibility locations with latitude for the purpose of a global lunar calendar (Ilyas 1978), Maunder's criterion was used to develop Lunar Date Lines (LDL) for several dates in 1979 (Ilyas 1979). However, in view of the rather small set of the primary data that was used for developing the statistical Fotheringham's criterion (and later versions), a serious problem remained as to the accuracy in predicted first visibility locations. Another criterion, developed on physical grounds (as the earlier Arabic criteria, but more precise) had recently become available (Bruin 1977). Accordingly an intercomparison was undertaken, the results of which are the subject of this paper.

CALCULATIONS

The system of calculations was essentially the same as in Ilyas (1979) in which a simplified algorithm developed by Moller (1978) for calculation of solar and lunar positional parameters was extended for conversion of equatorial coordinates (δ, ϕ) into local coordinates (Z, A_z) for a given place, the only input data consisting of time (Epoch) and place (longitude and latitude). The computerized calculations are performed for various global latitude–longitude combinations for the times of local sunset at each place for a lunar conjunction (normally the calculations are performed along latitude circles with 10–15° longitude intervals and moved up or down in 10° latitude intervals). Maunder's visibility criterion (Indian version) as listed by Ashbrook (1971), involving zenithal and azimuthal separation of the Moon from the setting Sun, was used to identify the global longitudes (one at each latitude) just meeting the minimum visibility requirements (Fig. 1). These longitudes (points a, b, c, d, in Fig. 1) are then plotted to form a boundary, called Lunar Date Lines (LDL) (see later); visibility to the west of such a boundary, along latitude circle improves due to the time lag for sunset (Ilyas 1978) as is obvious from Fig. 1. This system was slightly modified to include calculations of the

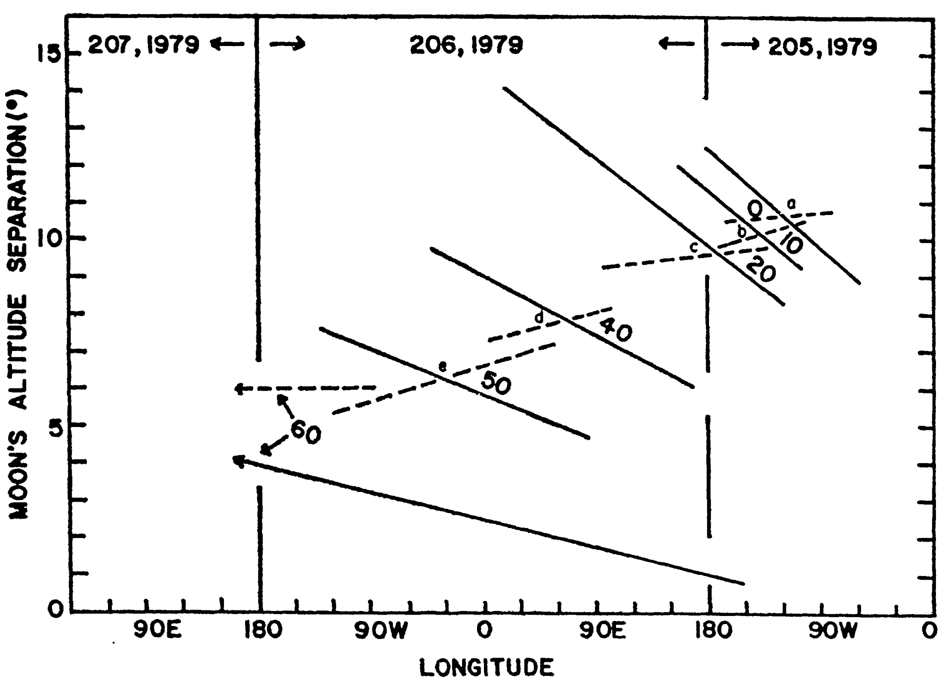

FIG. 1. The unbroken lines represent the variation of the Moon's altitude separation from the Sun at local sunset as a function of longitude for several N latitudes (0, 10, ..., 60). The numbers 205, 206 and 207 refer to the solar day numbers in 1979. The broken lines indicate the values of minimum altitude separation required by the visibility criterion for the lunar azimuthal separation from the Sun corresponding to the actual altitude separation at each location (unbroken line). For each latitude, the longitude where the minimum visibility conditions are met is given by intersection of the two curves (a, b, c, . . .). These longitude–latitude combinations are then used to form a geographical boundary meeting minimum visibility conditions and referred to as a Lunar Date Line (LDL) as shown in Figs 3, 4 and 5.

'arc of light', a_L in order to develop the LDL using Bruin's criterion involving zenithal separation of the Moon and its arc of light, a_L, from the setting Sun (for the purpose of calculations of longitudes meeting the minimum visibility criterion at each latitude, only the minima points of h + s (altitude separation) *v.* *w* (cresent's width) set of curves in Bruin (1977) are of interest).

DISCREPANCY IN RESULTS

Application of the Bruin's criterion (in which $w \simeq 0{\cdot}5$ arcmin or $a_L \simeq 14{\cdot}8°$ has been suggested as the lower cut-off level) to the calculated positional data indicated a large inconsistency in the first visibility longitudes as compared to Maunder's criterion based values; the longitudes at the lower latitudes meeting Bruin's minimum limit were found to have a relative shift to the west by about 70–80° in longitude in a systematic manner. It was found to be as a result of the lower cut-off value of $w = 0{\cdot}5$ arcmin being too high but as this could not be solved directly through a discussion with Bruin (private communication 1980), the following approach of intercomparison was adopted.

INTERCOMPARISON AND LOWER LIMIT OF *w*

The calculations were performed for several 1979 conjunctions over the $\pm 70°$ latitude range for each longitude just meeting Maunder's minimum visibility criterion (Z and A_z separation) at local sunset and the corresponding values of a_L were listed out which were then plotted against the altitude (or zenithal) separation of the Moon from the setting Sun at the longitude as shown in Fig. 2. Also shown in the Fig. 2 are data points (minimum altitude separation for each value of a_L (or w)) from the minimum visibility curves from Bruin (1977). It is found that Bruin's data are in excellent agreement with thus inverted data for $a_L \geqslant 14{\cdot}8$ (or $w \geqslant 0{\cdot}5$ arcmin). It may also be noted from Fig. 2 that generally at the lower latitudes the values of a_L at the longitudes just meeting Maunder's minimum visibility criterion are less than the suggested lower limit of 14·8°. The two criteria are thus found to be consistent and in good agreement at all latitudes if the lowest limit of a_L is considered to be about 10·5° (i.e. $w \simeq 0{\cdot}25$ arcmin) instead of 14·8° ($w = 0{\cdot}5$ arcmin) (from a rough extrapolation of Bruin's curves to $a_L = 10{\cdot}5°$, the corresponding required values of the h + s are found to be consistent with the data in Fig. 2). Hence it is concluded that Bruin's suggestion that 'the curves for $w < 0{\cdot}5$ arcmin are unimportant' is an overstatement and in fact much lower values (up to about 0·25 arcmin) are acceptable but with corresponding higher values of the zenithal separation. The statistical criterion of Maunder is thus found to be quite accurate (since Bruin has stated his criterion to be accurate to within a few arcminutes), despite the relatively small set of observational data employed for it, and may be used with greater confidence for further investigations into the nature of Lunar Date Lines. As examples, calculated LDL for various Islamic months in 1980 and for a particular Islamic month over the decade are shown in Figs 3 and 4 to illustrate the nature and variability of first visibility longitudes (i.e. Lunar Date Lines) which are seen to be of parabolic nature with a systematic motion with time

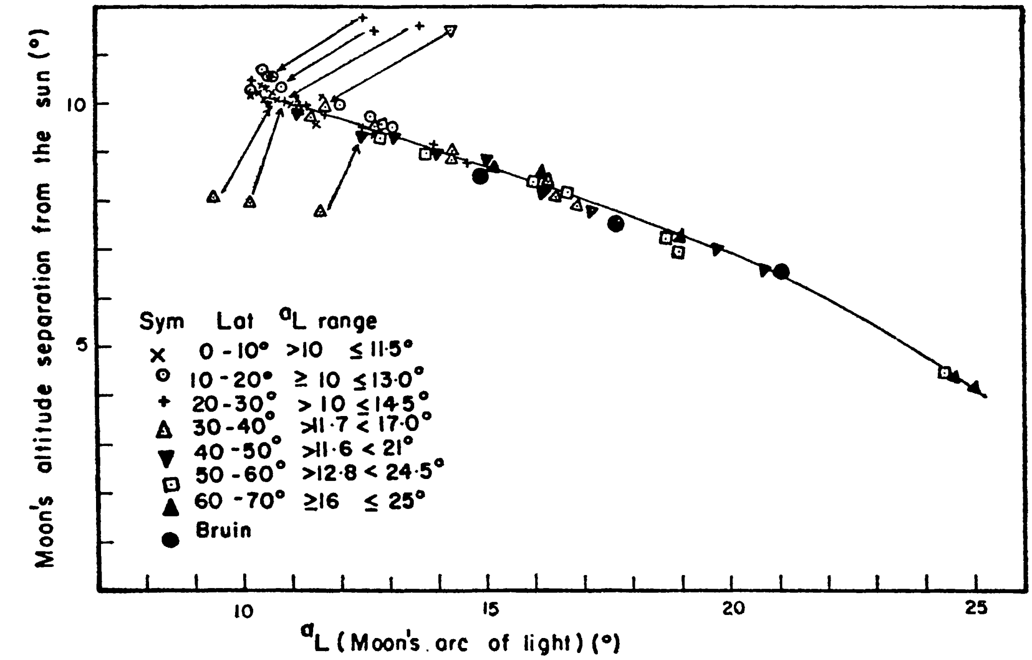

FIG. 2. Variation of Moon's altitude separation and its arc of light from the setting Sun at places where Maunder's minimum visibility criterion is just met together with the data from Bruin for minimum visibility condition. The a_L range for various latitudes is also indicated (for discussion see text).

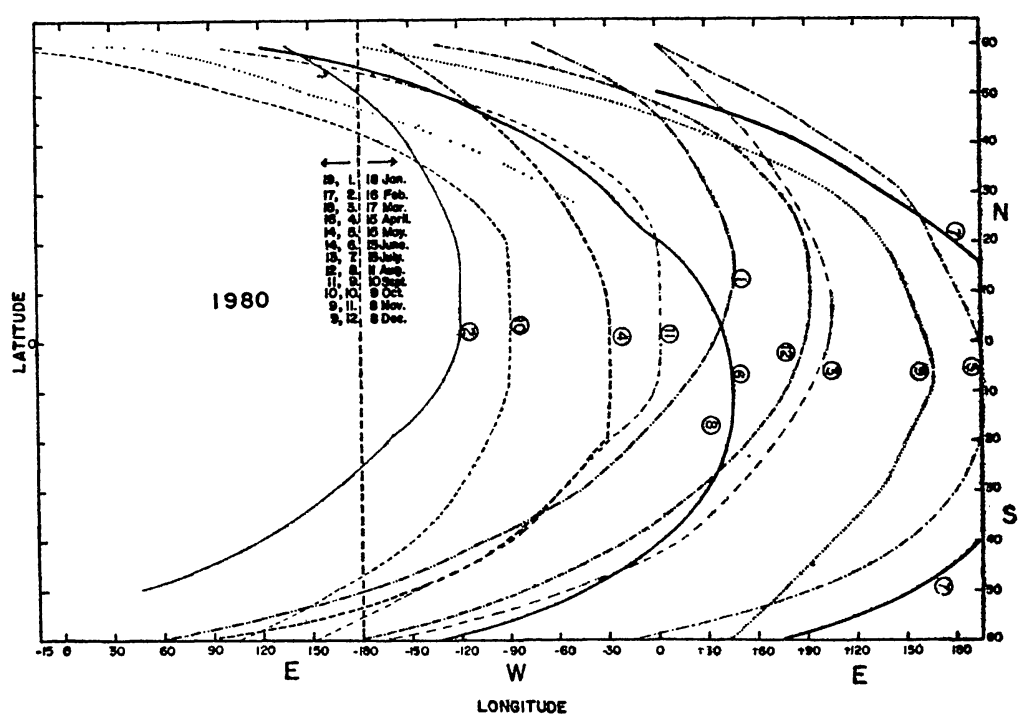

FIG. 3. Geographical variability of calculated first visibility based Lunar Date Lines (LDL) for the 12 months in 1980.

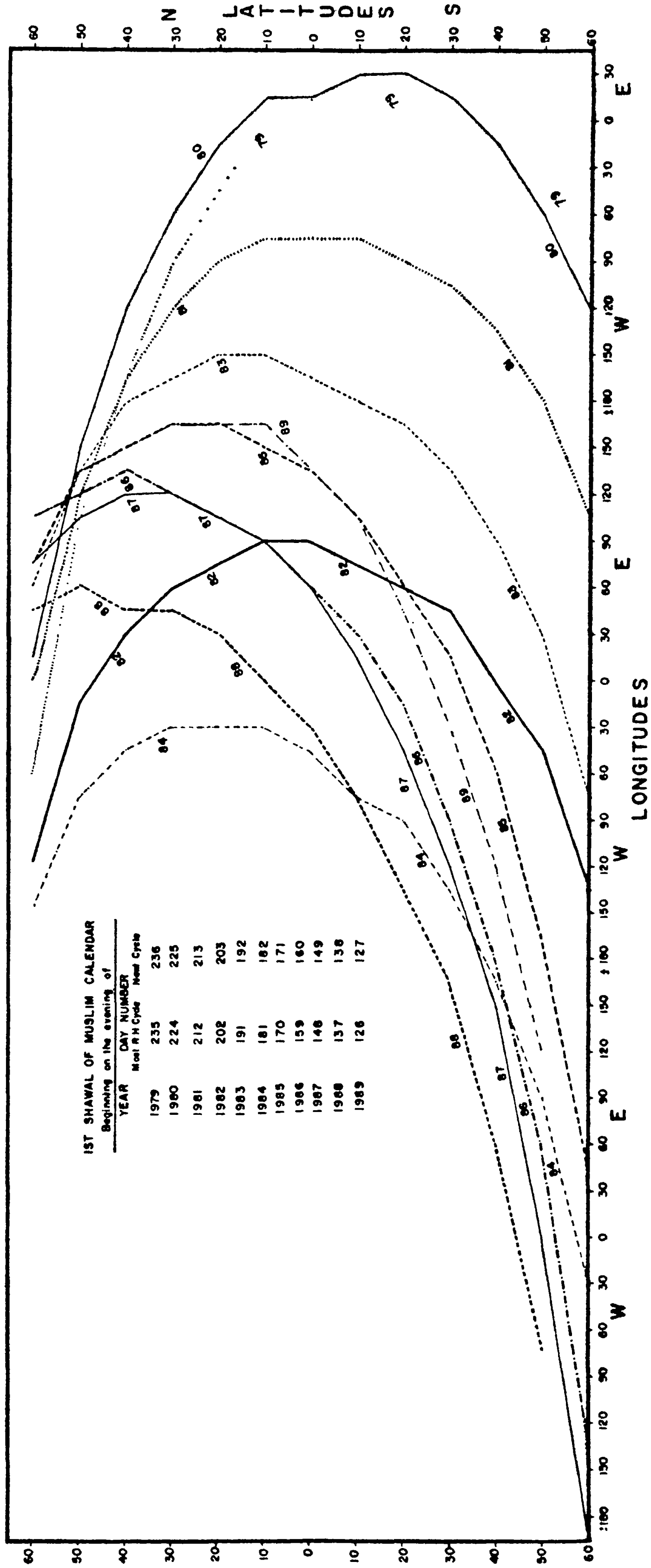

FIG. 4. Geographical variability of the LDL through a decade for the beginning of a particular month (1st Shawwal)

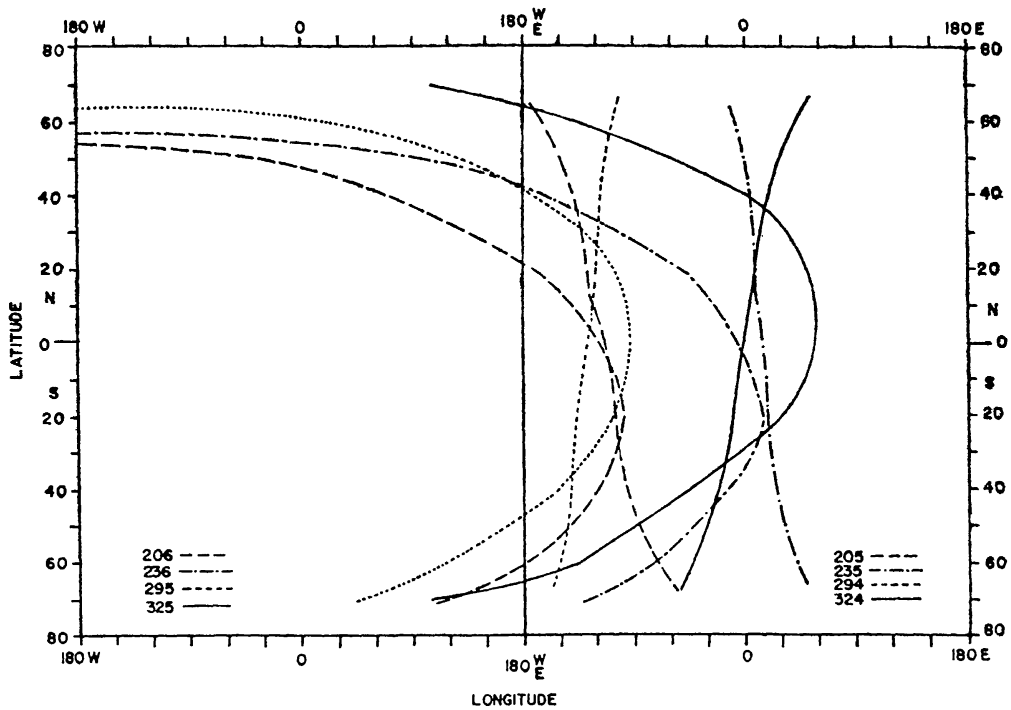

FIG. 5. Geographical locations of (expected) visibility based Lunar Date Lines (parabolic) for four conjunctions in 1979. (The numbers 205, 206, etc., refer to the day numbers of the solar dates.) Also included are 24 hr lunar age lines (at local sunset).

geographically (i.e. to eastern or western longitudes). In Fig. 5, some of the LDL are compared with '24-hour lunar age lines at local sunset' (Ilyas 1978) for several conjunctions and it is observed that the apex longitude of each LDL may be approximated by the 22 ± 2 hr lunar age at sunset.

CONCLUSIONS

The suggestion of the lower limit of $w = 0{\cdot}5$ arcmin in Bruin's criterion of first visibility of the New Moon is found to be too high and $w \geqslant 0{\cdot}25$ arcmin is found to be a more realistic limit. The two independent criterion of Bruin and Maunder are found to be in excellent agreement and since Bruin's criterion has a very small uncertainty (a few arcmin), Maunder's form of the first visibility criterion may be used with a similar confidence.

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REFERENCES

Ashbrook, J., 1971. *Sky and Telescope*, **42,** 78–79.
Bruin, F., 1977. *Vistas in Astronomy*, **21,** 331–358.
Fotheringham, J.K., 1910. *Mon. Not. R. astr. Soc.*, **70,** 527–530.
Ilyas, M., 1978. *J. Mal. Br. Roy. Asiatic Soc.*, **51** (2), 58–68.
Ilyas, M., 1979. *Islamic Culture*, **53,** 133–136.
Indian Ephemeris, 1979. India Meteorology Depart, Calcutta.
Maunder, E.W., 1911. *J. Brit. astr. Assoc.*, **21,** 355.
Moller, G.H., 1978. *Optical Spectra*, **12** (6), 88–89; and **12** (8), 10.
Schmidt, S., 1968. *Astr. Nachr.*, **71,** 201.

NOTE ADDED IN PROOF

Bruin's data shown in Fig. 2 are the values taken from his curves (in Fig. 9). However, on a close examination, a difference of about 0·5° is found to be between his data in the text (p. 340) and the curves for several points (P and C), the former being lower. There may, thus, be a need to shift his curves upwards by this amount; especially those for smaller ω. A corresponding shift to his data in Fig. 2 (this paper) would make the agreement even better.

Kandilli Observatory (Turkey) has recently suggested the use of an "$a_L \geqslant 8°$ & $h+s \geqslant 5°$" criterion (Dr. Dizer, Private communication, 1980). The degree of invalidity and underestimation of this may be seen by comparison with the curve in Fig. 2 (elaborate discussion elsewhere).