ON THE CRESCENT'S VISIBILITY

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Introduction

A month in the Islamic lunar calendar begins on the day following the first evening during which the waxing crescent becomes visible. Thus, the central problem in the preparation of Islamic calendars in advance is to formulate the computational procedures for determining the youngest visible phase of the moon. In temperate latitudes, the crescent to start a new lunar month is sometimes visible during the evening of the 29th day of the previous month, and if it is not visible on that evening, then it definitely becomes so during the next evening. So the crucial time for which one needs to determine whether or not the crescent will be visible is the evening of the 29th. At the moment, there does not seem to be any single inviolable criterion to decide definitely whether or not the crescent will be visible at a specified location during an evening in question. But taken together, a number of conditions enable one to make such predictions with high success probabilities.

Jurisprudential (*Fiqhi*) Considerations

The problem of predicting the crescent's visibility by computation has a number of aspects related to the Islamic jurisprudence. First, there is always the question as to what is the legal status of computed predictions. Computed prayer hours enjoy a high degree of confidence. For example, people take the accuracy of the sunset time tabulated in most prayer schedules for granted, and perform the evening prayer and break their Ramadan fast at that time without ever bothering to check the sunset by observation. Suppose it were possible to predict the crescent's visibility with the same degree of confidence with which the time of sunset can be predicted. Will the predicted crescent then be acceptable without corroboration by actual sighting?

Then there is the question of atmospheric conditions, such as clouds, fog, and dust, and man-made factors such as industrial pollution and artificial light, which obviously affect the crescent's visibility. These conditions are too numerous and unpredictable to be taken into consideration, so that in making any prediction one has to assume a transparent atmosphere. Will it be acceptable to start a new month from the crescent which is found by computation to be definitely visible, but which cannot be actually sighted because of the clouds in the sky?

Consider another difficulty: In predicting the crescent's visibility, one has to take into account the geographical location of the observer. It is an astronomical fact that on the same evening the crescent may be visible in one location but not in another. When the crescent is not uniformly visible (or invisible) all over the world, the locations of probable visibility and non-visibility are, in this author's opinion, separable on a

Mercator map of the world by a single parabolic-shaped curve. The curve is concave toward the west and symmetric with respect to some line of latitude. Thus, the crescent's visibility zone starts from a certain point and then continues westward from it, spreading more and more in the north and south directions. The author calls this curve the *Visibility Separator Parabola*, or VSP for short. The position of the VSP varies each month, that is, its vertex has a different location on the earth each month. Of course, the VSP does not respect political boundaries. Should the Islamic Calendar then be considered a strictly local entity, with fasting and the Islamic feasts observed in different locations of the world on possibly different days, depending on which side of the VSP these locations lie? Or should some convention be adopted to unify the calendar for larger regions such as countries, or at least large areas in the case of countries like USA and USSR that have a large east to west extent? For such a convention, one could simply modify the VSP along political boundaries in the way the International Date Line is derived by modifying the line of 180 degrees longitude. Or should there be just one calendar for the whole world? This could be based upon the crescent's visibility in some fixed location, say Makkah. Actually, a better choice of the fixed location may be the 180 degrees longitude (or the International Date Line), because once the crescent is visible there it will continue to be visible elsewhere on the earth, and the "lunar date" and the "solar date" will progress through the world in perfect synchrony.

Yet another difficulty arises from the following astronomical phenomenon: in the locations of very high latitudes, say above 60 degrees, the crescent many not be visible at all on several nights in a row. (There, unlike in the temperate latitude zones, the crescent is not bound to become visible at the latest by the 30th evening each month.) Thus if the months of 29 days are allowed strictly based on the actual sighting of the crescent, then in the high-latitude locations there may occur too many consecutive months of 30 days each. How can the calendars of these locations be synchronized with the calendars in the rest of the world (if the synchronization is, indeed, necessary)?

Such questions arise quite naturally whenever the matter of predicting the crescent's visibility or constructing the Islamic calendar is being discussed. To answer them is up to the Islamic jurisprudential experts. This paper is concerned only with the astronomical aspects of the problem of predicting the visibility of the crescent at a given geographical location on a given date, assuming the sky to be clear.

Astronomical Background

At this point, it is necessary to state a few elementary astronomical facts. Both the sun and the moon appear to move from the east to the west in the sky, making a full circle around the earth daily. But the moon is slightly slower than the sun in this apparent motion, and lags more and more behind the sun as each day passes. This is why the moon rises and sets later and later on each successive day. Now as the sun and the moon both circle westward in the sky, with the moon doing so at a slower speed, the moon appears to move further and further east of the sun as time passes. In this continuous eastward motion, with respect to the sun's position in the sky, the moon completes a whole circle in about $29\frac{1}{2}$ days.

The moon has no light of its own, and is visible solely owing to its illumination by the sun. Although exactly one-half of the moon's spherical surface is always sunlit, the portion of its illuminated surface visible from the earth varies depending upon the relative positions of the sun and the moon in the sky. Since these relative positions go through a cycle monthly, the phases of the moon recur each month. The further apart the moon is from the sun, the larger is the fraction of the illuminated surface visible from the earth, and the larger does the moon appear in the sky. For example, the moon is "full" when it is at the maximum distance of half the circle of the sky from the sun: we see the full moon when the sun and the moon are at the opposite ends of the sky — the full moon rising from the east approximately when the sun is setting in the west. By contrast, the closer to the sun does the moon get, the thinner its phase: The slender new crescent appears when the moon's position in the sky is so close to the sun that the moon sets shortly after sunset.

The paths of the sun and the moon on the sky are about the same. So the moon just passes the sun once a month during its eastward travel around the sun. At this moment, the moon is neither to the east nor to the west, but possibly a bit to the north or the south of the sun's place in the sky. Astronomers refer to this moment as the *new moon* or, more specifically, the *astronomical new moon* since in the popular language the phrase 'new moon' generally refers to a young moon. At the new moon phase, the moon is almost directly between the sun and the earth. Consequently, the moon's illuminated surface is turned away from the earth, and the dark side faces the earth. The 'new moon', therefore, is completely invisible. The invisible 'new moon', whose time in commonly found listed in almanacs and newspapers, should not be confused with the visible young crescent which starts a new month in the Islamic calendar.

The crescent is not likely to be visible until the evening following the day of the 'new moon' phase, or frequently, even an evening later. Only if the 'new moon' phase occurs around dawn, can the crescent sometimes be seen during the evening of the same day. The time elapsed since the most recent 'new moon' phase is termed the *moon's age*. When first visible, the crescent seldom has an age of less than 18 hours, though a few sighting of the crescents about 15 hours old are on record. But on the other extreme, the crescent may occasionally have an age of as much as 40 hours when visible for the first time. From the time of the 'new moon' the moon's age can be easily computed for the evening during which there is some likelihood of the crescent being visible. If the age turns out to be less than 18 hours, then it is quite improbable that the crescent will be seen. Similarly, if the moon's age is more than, say, 30 hours, then the probability of the crescent's visibility is high. But what if the moon's age turns out to between these limits, say, 22 hours? One really cannot say anything other than there is a fifty-fifty chance of the moon's being visible. Thus the age of the moon furnishes only a probable answer in some cases, and no answer at all in others.

Why does it take the moon so long after its 'new moon' phase to become visible? There are a number of conditions that must be met. During the evening after the 'new moon', the crescent may be too thin to be visible in the twilit sky, and being too close to the sun, it may simply set by the time the evening sky becomes dark enough. In a sense, the visibility conditions define a "window" which is open only for a brief time during the evening of the 29th day of a lunar month. The crescent may or may not happen to pass across the window while the window is open. If the crescent "misses" the window, it will not be seen that evening, and another 24 hours will have to pass before it becomes visible the next evening.

It follows that the phases of the moon look about a day larger on the same date in a month following a month of 30 days than in a month following a month of 29 days: The crescent of the first day after a month of 30 days is about as large as the crescent of the 2nd day after a month of 29, and the full moon occurs about 13 days after month of 30 and 14 days after a month of 29. This is so because it is after all a matter of just a few hours, sometimes a few minutes, that the crescent "misses" to be visible on the evening of the 29th, and grows by a full day by the next evening. Hence, incidentally, just because the crescent first observed on the evening of the 30th date may look quite large, one should not doubt the previous evening's negative observation or infer that the crescent ought to have been visible an evening earlier.

It is a fortunate circumstance that the prediction of the visibility of each crescent can be made independently of other crescents. The time of each 'new moon' is exactly computable. Consequently, the probable date for each 'crescent' sighting can be determined directly. Thus the error in predicting a previous month's crescent has no cumulative effect on the prediction any successive crescents. Nor, by the same reason, is there any need to trace back through the years if the calendar for some year in the past is desired.

Basic Criteria for the Crescent's Visibility

Now let us consider a few more conditions for the crescent's visibility. Were the moon a perfect sphere with a smooth spherical surface without mountains and craters, it would have assumed a crescent phase, no doubt very thin, immediately after the 'new moon' phase. (Even at the time of the 'new moon', except when there is a solar eclipse, the moon is not truly in the line joining the sun and the earth, and a crescent phase would ideally be possible.) But the shadows cast by the moon's mountains obscure its surface so that the crescent phase just does not form until the moon is at a sufficient angular distance from the sun. This limiting distance has been determined by Danjon to be 7 degrees [2]. But even after the crescent has formed, it is too thin to be visible for some time. It seems safe to say that the moon must move at least 10 degrees away from the sun to become visible [3].

Now since the moon travels a full circle or 360 degrees around the sun in slightly less than 30 days, it moves eastward at the average speed of 12 degrees per day, or half a degree per hour. At this speed, the moon should take about 20 hours to move 10 degrees from the sun. But the moon's motion is actually more complex, so that the requisite number of hours varies considerably from time to time. Although the angular distance between the sun and the moon is not given in almanacs for all hours, it can be computed from the tabulated positions of the sun and the moon on the evening of observation, and can be used to make a prediction about the crescent's visibility.

The angular distance between the sun and the moon does not fully describe the relative positions of those two bodies. While their angular distance may be the same at two occasions, they can have different east-west and north-south separations with quite different chances of the crescent's visibility. Generally speaking, the more to the north or south of the sun it is, the more there are the chances of being visible, compared to the situation when it is directly to the east of the sun. Or in other words, when it is directly to the east of the sun, the moon sets in approximately the same place as the sun and should be high up to be visible than when it sets on either side of the sun.

This consideration is the basis of still another crescent visibility criterion, which was, arguably, proposed originally by the great Muslim astronomer Al-Biruni in the 10th century A.D. [4], and was rediscovered by Fotheringham in the 20th century [5], and further improved by Maunders [6]. At the time of sunset, the sun is on the horizon, so the eastward displacement of the moon from the sun is just the altitude of the moon. The north-south distance between the sun and the moon is their azimuth difference. The criterion states that for the crescent to be visible, the moon's altitude at sunset should be greater than a certain threshold value which depends on the azimuth difference between the sun and the moon. The threshold values have been derived empirically from the recorded results of successful and unsuccessful attempts to observe the crescent. Ashbrook [1, 2] quotes three sets of values of the altitude threshold vs. azimuth difference. Rizvi [4], attributing the criterion to Al-Biruni, gives still another set of values. The author used these values and a few others based on some recent observations, and found the following relation to be a good curve-fit relating the threshold value, t, of the altitude and the corresponding absolute value, a, of the azimuth difference between the sun and the moon:

$$t = 10.3743 - 0.013714a - 0.0097143a^2$$

To apply this criterion, the actual altitude of the moon at sunset should be compared with the computed threshold. If the former quantity is greater than the latter one, the chances of the crescent's visibility can be declared to be high, otherwise they are low.

Another simple condition for the crescents visibility is furnished by the time of moonset. The crescent cannot be seen at all, of course, if it sets before the sun. Thus the crescent's visibility can be definitely ruled out if the moonset time is found to be earlier than the sunset time. Since the sunset and moonset times are usually listed in newspapers, this check is very easy to make. But even after the sunset time, it takes a while before the sky becomes dark enough for the young, thin crescent to become visible. The interval from the sunset to the approximate time when the bright planets and stars start becoming visible is called the *civil twilight*. The end of the civil twilight is defined to be the time when the sun's center is 6 degrees below the horizon. The duration of the civil twilight depends upon the geographic location as well as the season of the year. The time of the end of the civil twilight is easy to compute. The time provides a useful check on the crescent's visibility since one cannot expect to see the new crescent if it sets much before the end of the civil twilight.

How reliable are the criteria mentioned above? Actually, well-documented observational data to support the majority of both positive and negative predictions exist only in the case of the azimuth difference vs. altitude threshold criteria of Fotheringham and Maunders. But their data are quite old and comprise less than 100 observations, confined mainly to Greece and England. Also, their criteria are based upon empirical judgment but lack any clear theoretical explanation. On the other hand, the Danjon criterion of 7–10 degrees angular distance between the sun and the moon has a solid theoretical justification. But while as a negative criterion it seem impeccable, it's reliability as a positive criterion (using a distance of, say, 10 degrees) is yet to be demonstrated. That the moonset should not occur much before the end of the civil twilight seems a reasonable condition, but the exact cut-off point is unclear (except, of course, the trivial limit of the sunset time). The criterion using the moon's age, which seems to be the one most popularly used, is the least sound and trustworthy of all.

Taken together, the above-mentioned criteria do enable one to make predictions with some chances of success. The author has employed a composite of these criteria in a computer program to verify many reliable observations correctly.

But the performance of these criteria is far from perfect: generally they suffice in making good negative predictions in many cases, but leave the matter of visibility unsettled in quite a few cases of interest. It is clear that we need better and stronger criteria.

Critical Need of Observational Data

A prerequisite to developing any reliable criterion is a large, varied base of observational data. Reports of crescent sightings are occasionally found in amateur-astronomical journals, such as *Sky and Telescope*. But what one really needs are observations carried out month after month all over the world with the record of both the successful and failed attempts to sight the crescent. The observation record should include the geographical location of the observer, the data and the exact time of observation, the moon's observed position, the description of any optical aid used, the atmospheric condition, etc. Redundant data are quite useful and should be retained. For example, the moon's observed position checked against the computed position can tell whether the observed object was indeed the moon. It is worth mentioning here that man-made objects now abound in the sky, and are at times mistaken to be the crescent. What one believes to be the crescent may occasionally be a piece of jet smoke or an airplane flying very high in the observer's line of sight. The best way to avoid illusion is to plan the sighting carefully, have the position of the moon pre-computed for observation, and verify the naked-eye observation with a binocular or a telescope.

Observational data is worthless for the purpose of developing a criterion if not obtained and recorded according to strict scientific standards. The record of witness reports of crescent sightings are often lacking in this regard, and are inadmissible in formulating or validating the criteria, even though they are traditionally the basis for celebrating Islamic festivals.

For example, consider the celebration of the pilgrimage in the Hijri year 1398. This pilgrimage was held on Thursday, November 9, 1978. Since the Zul Hijjah 9 presumably corresponded to November 9, Zul Hijjah 1 should have fallen on November 1, and the crescent should have been observed on October 31, 1978. But the actual time of the relevant "new moon phase" was October 31, 1978 at 20:07 Greenwich Mean Time. At this time, it was already late evening in most of the Middle East. So the alleged crescent observation took place before even the new moon phase! Such an observation report defies all standards of credulity, and is certainly unacceptable scientifically. In fact, the pilgrimage dates in several preceding years have also been too early to be consistent with the most elementary astronomical facts, and make most of the recent historical record of traditional witness reports highly suspect.

Conclusion

Non-Muslim astronomers have no particular interest in developing the criteria for deciding the crescent's visibility, as this problem has no practical significance in modern astronomy. Thus, the task of solving this problem lies squarely on the shoulders of the Muslim researchers. The problem does seem important for the Muslim world, for its satisfactory solution will go a long way toward ending the situation of confusion and chaos that prevails at present. There seems to be no reason why this problem cannot be solved satisfactorily within a few years if an earnest, concerted research effort is directed toward it.

References

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