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Visibility of the thin lunar crescent: the sociology of an astronomical problem (A case study)

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ABSTRACT

In the Islamic calendar, a new month starts the day after the first naked-eye sighting of the thin crescent, shortly after a luni-solar conjunction. The crescent can be observed after sunset in the general western direction. As the visibility depends strongly on the atmospheric conditions, the beginning of the Islamic new month cannot be predicted very precisely. Three times a year, because of religious events, officials of Islamic countries decree the beginning of the month on the basis of reports from witnesses who volunteer to watch the thin crescent. In the present study, we confront the dates as decreed by the officials with the astronomical data and criteria of earliest visibility. The data collection consists of 115 dates corresponding to the religious occasions in Algeria between 1963 and 2000.

We have found those dates to be largely inconsistent with the astronomical data. The rate of impossible cases (where the crescent was not present at all in the sky, let alone be visible) is about 17.4%. In more than half the cases, one or more of the absolute limits or all-time records of visibility was/were violated. And according to most or all the prediction criteria of visibility, there were about 80 % cases in error. We have also found that the error rates versus time correlate well with the sociological changes that occurred in Algeria between 1963 and 2000. Finally, we should emphasize that comparatively to Algeria, the error rates are higher in the Middle-East.

These results suggest that the officials must reconsider their approach in the determination of the beginning of the Islamic months.

Keywords: *Crescent visibility; Lunar Date Line; Lunar calendar; Islamic calendar*

1 INTRODUCTION

In the Islamic religion, religious dates and occasions are determined on the basis of the lunar calendar, which comprises 354 or 355 days. The month of Ramadan (the month of fasting) corresponds to the ninth month of the lunar year, and starts on the day following the observation of a new crescent, soon after a conjunction. The same rule holds for the day of 'fast-breaking', called 'Eid-ul-Fitr', which occurs a month later, again soon after a conjunction. As to the 'Sacrifice Feast', called 'Eid-ul-Adha', which corresponds also to the period of Pilgrimage in Mecca, it begins on the tenth day of the last lunar month (Dhul-Hijja). In all cases, on the night preceding the event, people watch with high attention the local horizon after sunset in an attempt to catch the thin new crescent. If the latter is seen, Muslims begin the feast (e.g. fasting, if that corresponds to the month of Ramadan) on the very next day, if not it is postponed to the following day. That is the approach used until today in practically all Muslim countries.

It is obvious, however, that this approach carries several drawbacks. One cannot, for instance, know the dates of these religious occasions in advance; it follows thus that each year a controversy (not to say anarchy) takes place, as some countries announce that the crescent has indeed been observed, while others announce the contrary. That translates then into one-day and sometimes two-day differences in the periods of fasting and in feast celebrations, even between neighbouring countries, when of course none of that can be justified. Moreover, public debate takes place, in which the masses and the media echo widespread criticism of this controversy, while officials attempt to justify their decisions. The officials unfortunately do not make astronomical facts and data an important part of their decisions, and in fact 'observations' of the lunar crescent are often announced before conjunction! Regrettably, experience – and the statistics of the present work – show that this occurs with an alarming frequency in the Islamic world. Consequently, there results a deep confusion in the minds of people, most of whom are unable to grasp the various aspects of the problem; they do not know whether to doubt the scientific input on the matter or rather criticize the officials who are in charge of adopting and announcing the dates of the religious occasions.

This situation is due to a number of factors that we have already discussed in detail in a book published in Arabic a few years ago (Guessoum *et al.*, 1997). In our view the most important of these factors, however, is the fact that both the officials and the jurisconsults (scholars of religious law), base their decisions on simple ideas that date back to the early Islamic era and ignore the huge development that has taken place in astronomy in general, and on the lunar crescent visibility problem in particular. Indeed, the classical Islamic jurisprudence states that if two trustworthy Muslim individuals (and in some schools, one is enough) bear-witness(es) that they(he) have(has) seen the lunar crescent, then the religious date (or month) is decreed. People and officials have thus come to accept the (obviously) doubtful testimony of a layman on the observation of the crescent and reject the calculations and explanations of professional astronomers. Most of the time, the testimony is accepted without any verification; all that is required of the witness is that he be 'trustworthy' (i.e. not a known liar or drunkard, or such), when it is a fact that optical illusions – and we know that in this problem they are more probable than one normally would think – can mislead even the very careful.

This kind of behaviour may come as a surprise to the reader and to a more rational audience, as in the West, where questions that fall in the prerogatives of science have for a long time been freed from outside interventions. But in the Islamic world, those factors are to be taken into account when attempting to resolve these kinds of problems, where astronomy intermingles with sociology and religious jurisprudence. Those factors have made it very difficult to devise a 'crescent' calendar, that is one based upon the observation of the new crescent. The crescent calendar obviously differs from the usual lunar calendar (based upon the conjunction), and is much more difficult to put together. The latter is rigorous, and today it poses no practical problems since the motion of the Moon is now known to a remarkable precision.

The problem of the visibility of the lunar crescent is very old, with the first systematic studies dating back to the early Islamic era (which began in the eighth century). Faced with the problem, the astronomers of that time developed several criteria for the detection of the new crescent, in order to allow the precise prediction of the start of the new month (Guessoum *et al.*, 1997). Based upon a purely geometrical approach, the criteria that were devised remained imprecise, mainly because they did not take into account the conditions of observation, which prove particularly important. We shall later present in some detail the modern works on the problem; however, we wish to emphasize that neither the works of the astronomers of the Islamic period nor those of the contemporary astronomers have been taken into account by the jurisconsults. Perhaps the reader will deem our remarks a little biased, as they mostly target the jurisconsults, but we believe they are justified, for two reasons: first the unquestionable conviction that this kind of problem can only be thoroughly solved using a scientific approach, and secondly the results of this study which show to what extent the present approach is flawed.

The aim of this study is to show what kind of aberrations the present method used by the officials and jurisconsults is actually producing. For that, we have gathered the dates of all the Islamic feasts and religious occasions as they were adopted and applied in Algeria between 1963 and 2000; then we set ourselves to compare them with basic astronomical data and/or the various crescent visibility criteria (which we shall define and explain in later sections). And in that light – and without any pretensions from our part – our wish is to lead the officials and jurisconsults to review their method and approach, in other words to adopt a more rational and objective attitude *vis-à-vis* this problem. We should have liked to extend the study to other Muslim countries, in order for the conclusions to be more general, but we unfortunately could not obtain the necessary historical data. However, our personal experiences lead us to state that the results of such a wider study must not be essentially different from the present ones. Similar studies on other Islamic countries should be done, so that more thorough conclusions may be drawn.

The present paper has been structured as follows. Section 2 deals with the historical as well as recent developments on the problem of the visibility of the lunar crescent. In sections 3 and 4, we present and discuss the results of our investigation based on the astronomical and historical data. Finally, a brief conclusion is given in Section 5.

2 MAIN SCIENTIFIC WORKDS AND RESULTS ON THE PROBLEM

2.1 The Islamic Era

The problem of the detection of the lunar crescent was known before Islam. The most ancient observations that have come down to us date back to the Babylonian era (Bruin, 1977). However, rigorous studies of this problem go back only to the Islamic period (eight to fourteenth centuries), for in Islam the calendar is based upon the Moon, and therefore the astronomers were faced with this real-life, practical problem to solve. Research, both theoretical and observational, was undertaken during that period; computational methods were thus devised, and several first-visibility criteria for the new crescent were proposed. Many of the great, famous astronomers of that time worked seriously on this problem, among them: Ibn Tāriq (eight century), al-Khwārizmī (d. 863), al-Battānī (859-929), Ibn Yūnus (eleventh century), al-Tabarī (eleventh century), al-Tūsī (1207-1274). In the following paragraphs we wish to present a brief review of the criteria they developed; for a more thorough and detailed discussion, we refer the reader to the literature (Bruin, 1977; Hogendijk, 1988; Kennedy and Janjanian, 1965; King, 1988; and others).

The most famous first-visibility criterion of that era is that of the 12 degrees. This criterion states that the crescent can be observed only if the Moon sets at least 48 minutes after the Sun (i.e. that the arc of separation of the two luminaries along the equator is larger than 12°). Al-Khwārizmī used this criterion mainly to construct his prediction tables (Kennedy and Janjanian, 1965).

Another criterion, no less important, used by al-Tabarī (Hogendijk, 1988) states that the crescent will be seen if, at the time of moonset, the Sun has a certain depression (height below the horizon). The value of 9°.5 was often adopted.

We shall note that in these last two criteria, the azimuth of the Moon relative to the Sun is not taken into account, and thus both criteria depend upon only one parameter (or only one condition). More complicated criteria, combining several conditions, have been put forward by other astronomers. Al-Battānī included in his model both the azimuth and the Earth-Moon distance, which varies (Bruin, 1977). Ibn Yūnus considered the thickness of the crescent as well as the orbital velocity of the Moon (King, 1988), and, for the first time, noted the importance of meteorological and physiological conditions (ibid.).

All these criteria remained unsatisfactory, as they were all almost purely geometrical. Their lack of precision was not due to their usage of the Ptolemaic model, which constituted the basic of the works of all the astronomers of the Islamic era, but rather because they neglected the atmospheric conditions, even though some realized their basic importance.

2.2 The Modern Era

The problem of the visibility of the lunar crescent did not see any significant development for many centuries after the Islamic era. One had to wait until the beginning of the twentieth century, more exactly the year 1910, to witness the appearance of an important work, that of Fotheringham, who presented a new first-visibility criterion. A year later, Maunder proposed a slightly modified criterion on the same problem. These two new criteria had an important common characteristic with those of the Islamic era: they were all based on purely astronomical considerations, that is on the relative geometrical positions of the Sun, the crescent, and the observer. These criteria all had the same kind of formulation: the new crescent would be seen if the position of the Moon relative to the Sun satisfied such-and-such geometrical condition (or criterion).

Moreover, we can state that all the criteria adopted since the Babylonian era and until 1977 were of an astronomical nature, that is geometrical. For example, one may adopt as an elementary criterion the angular distance between the Sun and the Moon (the phase angle, for example, which corresponds to the angle between the two directions Earth-Moon and Earth-Sun) in any appropriate co-ordinate system. Ancient observations suggested that the crescent appears (or disappears) to the naked eye when the phase angle surpasses a value of some 173 degrees. Other observations indicated that the crescent becomes visible if about 1% of the surface of the lunar disk is lighted (in appearance); this translates to a phase angle of about 169 degrees. (Note that between these two values, there corresponds an average interval of time of about 7 to 8 hours – an indication of how various criteria gave quite different results.)

Another parameter that was often considered as a good predictor of the detection of the crescent is the interval of time Δt between sunset and moonset (called moonset-lag); this is the 'Babylonian' criterion (which in fact probably goes back to Indian observations), which states that the lunar crescent will only be seen if Δt is larger than 48 minutes. However, an analysis of a set of 201 observational data (Schaefer, 1988) stretching over more than 130 years (most of the observations having been made by Julius Schmidt in Athens during the nineteenth century), that analysis showed that the shortest interval ever recorded between sunset and moonset for an observed crescent is 22 minutes. The results also show, however, that the crescent is very difficult to observe when the Moon sets less than half an hour after the Sun.

A third parameter often taken as a predictor of the visibility of the crescent is the 'age' of the Moon (the elapsed time since the last conjunction). The ancient civilizations believed that one had to wait at least 24 hours after the conjunction to be able to see the new crescent, but an analysis of all recorded observations up to 1992 (Schaefer *et al.*, 1992) showed that the record of the youngest moon ever observed by a naked eye was then held by Julius Schmidt (1871): 15h 24min (this record was broken in 1990 by John Pierce: 15h exactly). For an observation made with binoculars, the record was broken in 1989: 13h 28 min; and for an observation made with a 20-cm telescope, the record was broken in 1996 by Jim Stamm: 12h 6 min. This criterion, called 'age criterion', is very useful for the acceptance (and especially the rejection) of a testimony, but it is very poor in predicting the start of the month.

The other criteria proposed and used until 1977 all rested on a generally simple astronomical rule related to the angular separation between the Sun and the Moon.

Fotheringham's (1910) criterion simply considered the difference in height (called 'arc of vision') between the two celestial objects, and stated that the crescent can be seen if that relative height is greater than 12 degrees. When the relative azimuth of the two objects is quite large, this limit of 12° is reduced (to 10° for instance, when the relative azimuth is 20°). This criterion was established empirically by Fotheringham, on the basis of 76 observations, gathered mostly by Julius Schmidt between 1859 and 1880.

In 1984 Ilyas proposed another criterion of the same kind (a critical condition between the height and the azimuth). However, Ilyas was not so much concerned with obtaining a condition for a local observation, but rather to globally determine the regions where the new month would begin (on a given date) and those where it would have to be postponed to the following night. For this purpose, he took the whole Earth map and, taking some 300 points one by one, he tried to determine for each latitude the point where the crescent would first be seen. He thus defined a line of first-visibility, which he called a Lunar Date Line; this he did with the help of computer programs which allow the computation of the Moon's position (in the astronomical and local sense) at the time of sunset, the precise moment of conjunction, etc.

We note that Doggett and Schaefer (1992) have shown that all of these geometrical criteria remained poor in precision, at least in the determination of the Lunar Date Line.

The astronomical approach adopted by the Muslim scholars as well as the western researchers at least until 1977 proved unable to solve the problem of the visibility of the lunar crescent in a definitive and satisfactory manner. The biggest flaw of this method was that each criterion thus proposed did not seem to be valid for very different regions of the world, as they were often empirically constructed from observational data gathered from a specific site (say Athens). Indeed, the observational conditions for Mecca during the winter, Karachi during the spring, Marrakech during autumn, and London during the summer time could hardly be the same. In fact, it is today accepted as a given fact that the visibility of the crescent depends crucially upon the local conditions. Most of the astronomers who worked on this problem were undoubtedly aware of this aspect, but they probably left it out of their models because of the great inherent difficulty in taking it into account.

The original model of Bruin (1977) tried to taken these factors into account by pioneering a new approach to the problem. Bruin proposed to use the ratio of the brightness of the Moon and that of the sky at a given moment as perceived by an observer; this takes empirically into account the limits of visual detection, the effects of atmospheric transmission, as well as other secondary factors. Knowing the limit of detection of the human eye, it is possible to deduce if the Moon can or cannot be observed in each case and situation. So the problem is transformed simply into a calculation of the brightness of the Moon and the sky for the time and place of interest, then computing the apparent contrast between the two, and finally comparing this with the limit of visual detection.

It is obvious that the astrophysical model of Bruin is very different in its approach from the (rather simple) models or criteria proposed by the astronomers who dealt with the problem before him. However, we must note and emphasize the fact that this model was taking the observing conditions only globally and indirectly, and therefore was suffering of the same flaw and defect as the astronomical criteria. One still needed to find a way to introduce the absorption effects, corresponding to the observing conditions, for a given place and time. In the following years, some corrections were introduced on Bruin's astrophysical model, including the reflectivity of the lunar soil, the atmospheric transmission, the seasonal effects, the atmospheric observational conditions, and the human eye's capacity to detect a given contrast.

The most complete and sophisticated model of this kind to have been proposed and constructed to this day is that of Schaefer (1988, 1990). In this model, one computes a quantity denoted by R, the logarithmic ratio between the actual brightness of the Moon to the required brightness of the Moon for it to be observed in the specified conditions: $R = \log [R_{calc}/R_{min}(vis)]$, which is in effect a logarithmic measure of the lunar visibility. The atmospheric, geographic, and physiological factors go into the latter quantity $R_{min}(vis)$. We may consider R as a measure of the probability of seeing the crescent in given observing conditions.

There are several parameters and factors that go into this model; however, it appears that the most influential parameter in determining the probability of observing the crescent is the degree of pollution and humidity of the site. The relative humidity is an essential factor in this model, because it induces the atmospheric haze which absorbs the flux of light coming from the Moon. It is obvious that the thicker the haze, the more difficult the observation of the crescent will be; it was noted, for example, that in Los Angeles, where the smog (a layer of smoke and fog in the city sky) is substantial, very few people could see the young Moon, compared to the neighbouring regions. Similarly, stratospheric dusts constitute a major obstacle to the lunar visibility, the dust absorbing and diffusing non-negligible quantities of lunar photons. In desert regions, for example, sand storms carry large amounts of dust into the air and atmospheric layers, which translates into a relatively high extinction factor of the incident light flux.

2.3 Observational Data

As models were being produced with greater numbers and frequency and were now based upon astrophysical and atmospheric considerations, it was becoming more and more necessary to evaluate them on experimental bases; in other words, observational campaigns were becoming crucial. We note that the authors of this work had thought of performing such a task, by organizing observing campaigns in Algeria for the religious occasions mentioned earlier, such as the beginning of the month of Ramadan and the 'fast-breaking feast'; in fact, we had submitted to the local press calls for widespread group observations, but the social conditions unfortunately did not allow for such endeavours to succeed. We also intended to call on the Arab and Muslim religious institutions to supply us with information on the actual dates of religious occasions during the last 20 or 30 years, in the aim of confronting them with astronomical calculations and thus producing results and propositions as rigorous and precise as possible. The present work is thus a partial realization of those objectives, as we have been able to obtain that kind of historical data (the start of the months of Ramadan, Shawwal, and Dhul-Hijja) for Algeria since its independence (1962), and we here present the results of their confrontation with the astronomical calculations and the conclusions that we draw from that.

However, we were very pleasantly surprised to learn that just such campaigns had been thought of by Ilyas around 1989 and that a large network for the execution of the International

Islamic Calendar Programme had been progressively set up throughout the largest possible part of the Islamic world. (Details of the Programme and its progress so far can be found in Ilyas, 1997, and Ilyas and Kabeer, 2000.)

And we were even more surprised to learn that many such campaigns have been conducted in the same period in the United-States at the instigation of Schaefer. Five such vast campaigns were thus conducted (in 1987 April, 1988 July, 1989 April, 1989 May, and 1990) with the support of the American press and media (both general and scientific).

The results were truly impressive: no less than 2500 volunteers sent in reports on their observations, containing very useful information on the conditions and results of their observations, which immediately translated into an improvement of the list of observations made since 1859 from 201 to 251 independent observations. But much more important than that is the fact that these observation campaigns have been conducted and supervised by experts, which made the surveys much more precise and the information thus collected much more useful. Several aspects of the problem have thus been statistically treated for the first time: i) determination of successful observational percentages in the aim of comparing the various models; ii) filtering the principal factors from the secondary ones in the problem; iii) study of some aspects, such as the exact length of the crescent at the moment of observation, either by naked eye or by instruments (binoculars, telescopes, cameras, etc.); iv) precise measurement of the total time of actual observation, again either by naked eye or by instruments.

The results of these observation campaigns confirmed *experimentally* that, apart from the atmospheric visibility conditions, the probability of observing the crescent increases gradually as one goes west, a fact known for a long time (since it is simply due to the Moon's motion around the Earth). To make the point clearer – as it has direct consequences on the conclusions we shall draw later in this work – if at sunset in Saudi Arabia the crescent's age is 13 hours, it will be practically impossible to see (as the all-time record is 15h, as stated earlier), while in Morocco it will be 16 or 17 hours old, and its observation will thus be possible, though extremely difficult. If, on the other hand, the crescent is seen in Saudi Arabia, meaning its age is more than 15 hours, it will be over 18 hours old in Algeria and Morocco, and its observation, aside from weather conditions, should be even easier.

The observation campaigns resulted in several other important conclusions, concerning for instance the improvement that the usage of an instrument brings, and also the important light shed on the possibility of human error in the claim of observation itself.

Indeed the most important result to arise from the analysis of the observation data collected in those campaigns is, in our view, the scientific deduction that there is a probability P_0 that a person, otherwise objective and in good faith, claiming to have observed the new crescent cannot possibly be correct. In fact, we had already pointed out, in earlier articles, that such a probability must exist, for various reasons (illusions, ignorance, etc.), and we had even proposed to quantify it on statistical observational bases (Meziane and Guessoum, 1991, 1992). Doggett and Schaefer (1992) have in fact shown that there exist about 15% of 'positive errors', which are cases where the crescent cannot be observed and people claim to have seen it, and 2% of 'negative errors', that is cases where the crescent is trivial to see and people claim not to have seen it. Obviously it is the 15% value, corresponding to the definition of P_0, which interests us; for that simply means that in order to have 2 people claiming (in error) that they have seen a crescent on a given night, all we need is to assemble a group of a dozen persons, even in small groups! This conclusion is obviously laden with consequences with regard to the Islamic jurisprudence criteria (which we mentioned in the introduction) concerning the adoption of testimonies and the proclamation of a religious date. We must, however, warn that this 15% value is very approximate, as it was deduced from a very small set of observers (only about 20) all in one site, and we need therefore to conduct other campaigns, especially in Muslim countries, in order to better estimate this error percentage, as we had proposed in the above-mentioned articles.

Another very important aspect of the problem, as we shall see later, resides in the knowledge of the length of the crescent at the moment of observation. We have known for almost 70 years (Danjon, 1932) that the young crescent, when seen with the naked eye, hardly ever extends on a 180° arc. In fact, Danjon showed that the smaller the phase angle (defined earlier) the shorter the crescent arc, measuring 90° when the Moon-Sun separation is only 10°, and vanishing when the two objects are within 7° of each other. This is the famous Danjon limit, which has often been used as a crescent visibility criterion. We must first note that this limit applies only to human (naked-eye) observations; that is telescopes and cameras are subject to a similar limit, but not necessarily the same value (7°). Secondly, and more important still, we wish to note the important remark made by Ilyas with this regard, namely that this 7° value is very uncertain; Ilyas in fact suggested that a limit closer to 10°.5 be adopted (Ilyas, 1981, 1994). Why? Because the data upon which Danjon's analysis and deduced value rest contain very few points in the (critical) domain between 0° and 20°, and only one for angles less than 10°; thus the extrapolation to small angles can be made in quite a different way, leading to a different limit than Danjon's. Ilyas showed that if that crucial one point below 10° were cancelled or thrown out, the limit would automatically be raised to 10°.5 (Ilyas, 1981).

This is not at all, as it might appear to the reader, a purely academic and useless debate between scientists, each claiming that his analysis is the correct one. For this 7° limit has been very largely adopted as a prediction criterion concerning the visibility of the lunar crescent. In fact, in 1978 a conference was held in Istanbul (one of the most important to have been organized in the Islamic world on this problem), a gathering of jurisconsults and astronomers in the aim of solving both the problem of predicting the dates of religious occasions (such as Ramadan and Eid) and the more general (and more important) problem of the Islamic calendar. A committee was set up to produce a set of 'recommendations', but these soon became cited more as 'decisions'. Unfortunately it appears that this committee poorly studied the problem and decided what follows: "the crescent will be considered as visible if the Moon is more than 8° from the Sun and higher than 5° with respect to the local horizon."

From where did these values – and this 'new' criterion – come? Ilyas, surprised as we were by this 'recommendation', wrote to the committee's chairman asking for clarification and referencing and received the following reply: "Concerning the 8°, the committee adopted Danjon's limit (7°) and decided to add 1° for 'safety'; as to the height of 5°, that was deduced from observational data collected and filed at the Kandili Observatory."

However, as noted by Ilyas, Danjon's limit is a necessary but not sufficient condition for crescent visibility, meaning that the Moon may be 12° or 15° away from the Sun and not be seen, not to mention the fact (explained above) that the 7° value itself is a disputed one! Secondly, the Kandili observations have been made at a site located at more than 40° of terrestrial latitude, so they can hardly be generalized. Finally, we must note that these two conditions have been casually juxtaposed, without the slightest consideration of any possible relation or correlation between the two. This example (or anecdote) is enough to show how a poor understanding of the problem can lead to erroneous and dangerous proclamations!

But one may ask: does such an erroneous criterion (like the one stated by the Istanbul conference) have an important consequence on the determination of the religious dates? In fact, the above Istanbul criterion translates into a more than seven-hour advance in the starting of a month, or put in another way, it leads to a lunar date line situated more than 100° east of the correct one! In practice thus, if the correct criteria declare the month to begin some day in all regions west of Algeria, then the Istanbul criterion wrongly makes the month also begin in the large region situated between Indonesia and Algeria! This is undoubtedly a good real-life example of how the problem has been misstudied and mishandled.

Lastly, we wish to remind ourselves and the reader that the thin new crescent always takes a concave orientation, meaning that the centre of its approximate semi-circle is always above the crescent, or stated in another way, that its two ends always point (partly or completely) upward. In fact, one may compute in advance the degree of orientation of the crescent to the East or to the West; we usually adopt the symbols of the watch to describe the orientation: for example, 2h-7h or 4h-9h. This allows us thus to also confront the observational data or reports, especially the doubtful ones, to the predicted orientation in order to filter out the wrong ones. This is one of the tests we had proposed in earlier articles for the acceptance or rejection of reports of observations (Meziane and Guessoum, 1991, 1992), and it is in fact one of the arguments used by Doggett and Schaefer (1992) to estimate the probability of positive errors (15%), and also by Schaefer *et al.* (1992) to reject the 'new records' of crescent observations reported by Durrani (1990), according to whom two groups of observers established a new record when they "observed" the new crescent for the start of Ramadan in 1990 May.

2.4 Criteria for Accepting or Rejecting 'Positive' Observations

As is well known to astronomers (professionals as well as amateurs), the observation of the new crescent is not an easy task. Several astronomical and, more importantly, atmospheric conditions must be satisfied for the thin crescent to be visible. We have also often stressed the fact that it is very easy, even for experienced observers, to commit errors of appreciation when attempting to spot the crescent. But we astronomers have now obtained the necessary scientific tools that allow us to filter out reports of observation and thus put an end to the confusion presently prevailing between different Muslim countries and often even within the same country.

If the prediction of the crescent observation is not an easy thing, which explains the existence of various criteria for it, the rejection of an erroneous observation is in general not very difficult. That is because an incorrect observation cannot contain all the correct characteristics of the new crescent (position, timing, orientation, etc.) which one may compute and determine in advance. For instance, we know that the new crescent has to this day never been seen within less than 22 minutes of sunset, that no one has ever observed a moon younger than 15 hours (after conjunction), and that the Moon is practically impossible to see if it is less than 7° away from the Sun. These three conditions alone would be sufficient to eliminate a large part of erroneous claims of observations, especially when these are completely ridiculous, such as when they are claimed to have been made before conjunction or after moonset! A simple check suffices to throw away such a report. The aim of this paper is precisely to quantify the percentages of error made in Muslim countries such as Algeria merely because such simple rules are not followed.

3 THE HISTORICAL AND ASTRONOMICAL DATA

In order to perform our comparative study, we needed two kinds of data. The first collection of data, which we termed 'the historical data', consisted of the actual dates as adopted for the religious occasions we have been considering, namely the start and end of Ramadan, and the Sacrifice Feast (or, indirectly, the start of the month of Dhul-Hijjah), from 1963 to 2000 January. For each lunar year we therefore have 3 dates (or data). But since the lunar year consists of only 354 or 355 days, it may happen that we get 4 dates during one Julian year, as was the case, for instance, in 1968 and 1997. These historical data were obtained by consulting the archives of the Algerian press, mainly from the daily newspapers *El-Moudjahid*, *E-Chaab*, *El-Djoumhouria*, and *Alger-Republicain*.

But in order to analyse these data, we needed the relevant astronomical information, which we computed for the city of Algiers, that is longitude +3° 2′ and latitude + 36° 42′. (See the remark below.)

Lunar and solar ephemerides can be obtained by using many computer programs and software, which today are available to the amateur as well as the professional astronomer. For our work, we used the Interactive Computer Ephemeris (ICE), which is available from the Nautical Almanac Office (of the U.S. Naval Observatory). This program gives more than satisfactory results, with an adopted refraction of 34′ at the horizon.

One last remark before presenting our analysis and results. It would have been interesting to know, for each date of the past religious occasions, where the crescent was 'observed', the precise location as well as the meteorological conditions then and there, in order for the comparative analysis to be more precise. Indeed the reader may object that an observation we may declare erroneous may actually be possible if it was made at an extreme western point of Algeria; however a quick calculation will show that such local considerations induce only slight differences between Algiers and others cities or regions of Algeria. Moreover, we could not find any such specifically-local information, for in Algeria the oral tradition still prevails in many aspects of social life (such as this one). Therefore we have used the astronomical data as computed for the city of Algiers.

4 RESULTS AND DISCUSSION

The results of this comparative study between the historical data and the astronomical predictions and criteria for the observation of the crescent are summarized in the histograms (Figures 1-5) shown below. However, in order to correctly understand the methods we have used in obtaining our results, and also in order to better appreciate their meaning and implication, we should like to provide the reader with a few explanations and remarks.

We have adopted two types of criteria in our comparative analysis: the first group consists of three 'rejection criteria', that is limits or records that are well established and accepted by the experts in the problem; the second group consists of two 'prediction criteria' for the observation (or visibility) of the crescent on a given evening of interest.

The three rejection criteria are the following:

1) The moon-age criterion, which states that the crescent has never been observed – in a scientifically verified and credible manner – when its age (i.e. the elapsed time between conjunction and the moment of observation) was less than 15h, a record broken by John Pierce in 1990 after it was held by Julius Schmidt since 1871, according to the analysis of Schaefer *et al.* (1994).
2) The moonset-lag criterion (the elapsed time Δt between sunset and moonset), which states that the crescent has never been observed – again in a scientifically verified and credible manner – when this elapsed time was less than 22 minutes (Ilyas, 1981). In fact, for median latitudes, such as Algeria's or most of the Muslim lands', this limit, according to Ilyas, is closer to 30 minutes. However, in order to be as strict and rigorous as possible in our results and conclusions, we preferred to adopt the absolute world limit of 22 minutes in our analysis.
3) Danjon's limit, which states that the crescent has never been observed – again in a scientifically verified and credible manner – when the angular distance between the Sun and the Moon (at the time of sunset) was less than 7°. We did explain above that some researchers, such as Ilyas, take a stronger limit (around 10°), but here also we have preferred to adopt the more conservative and largely accepted limit of 7° in an effort to insure a greater objectivity in our analysis.

As to the prediction criteria for the observation of the crescent, we have chosen the following two (for the reasons explained below) among the dozen or so that can be found in the literature:

1) Ibn Tāriq's criterion, an astronomer of the eighth century, first because we wished to show to what extent the religious occasions are wrongly determined today even by ancient Muslim standards; and we have chosen Ibn Tāriq's compared to Ibn Yūnus', Tabarī's, al-Khwārizmī's or others', because according to Doggett and Schaefer (1994), it is the most precise of all the criteria of the Islamic era. According to Ibn Tāriq, the new crescent is observable if, at the time of sunset, one of the two following conditions is satisfied:

$$\Delta t > 48 \text{ min} \quad \text{and} \quad \text{Ang. Sep.} > 11°.25$$

or

$$\Delta t > 40 \text{ min} \quad \text{and} \quad \text{Ang. Sep.} > 15°.$$

2) Ilyas's criterion, although it is not the most precise or the most sophisticated (Schaefer's is), simply because it is one of the most recent of the geometrical criteria (those based upon the angular relationship between the Sun, the Moon, and the observer at the time of sunset), and because it is, according to its author, the result of an attempt at unification between the geometrical approach and the astrophysical approach of Bruin (1977). It is also very simple and easy to apply.

We thus constructed a comparative table between the historical data and the astronomical data. Out of these comparisons we deduced our first important result: the number of cases where the beginning of the month was declared (i.e. some observation of the crescent was evidently accepted) while the conjunction had not yet taken place and/or the Moon had set before the Sun; in other words, that the observation of the crescent was strictly impossible. Out of 115 cases in all, we have counted 20 such impossibilities, a rate of 17.4%.

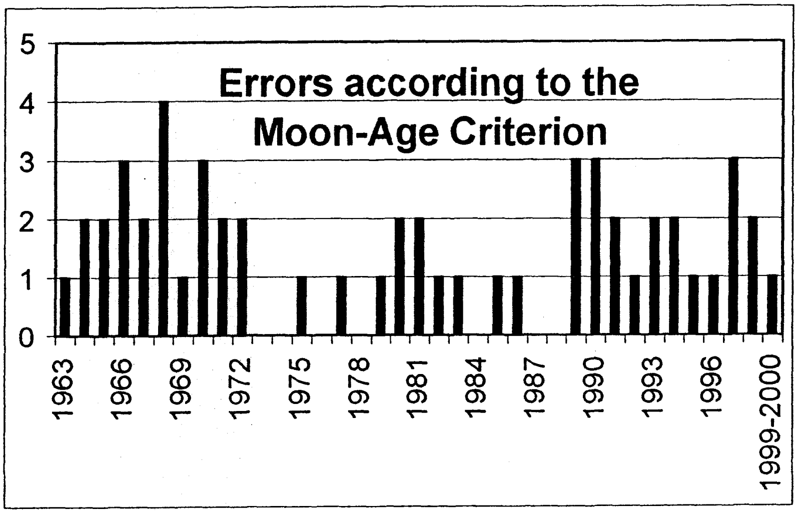

Figure 1. Number of error cases according to the Moon-age criterion, for each year from 1963 to 2000.

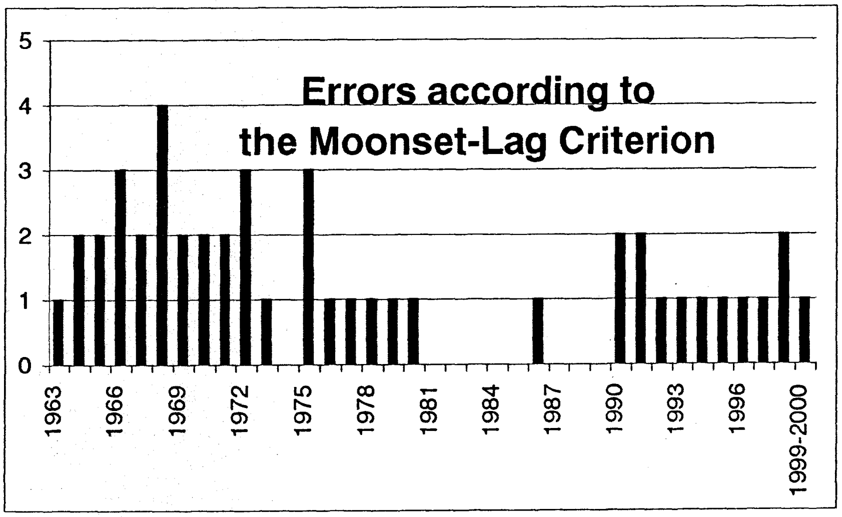

Figure 2. Number of error cases according to the Moonset-lag criterion, for each year from 1963 to 2000.

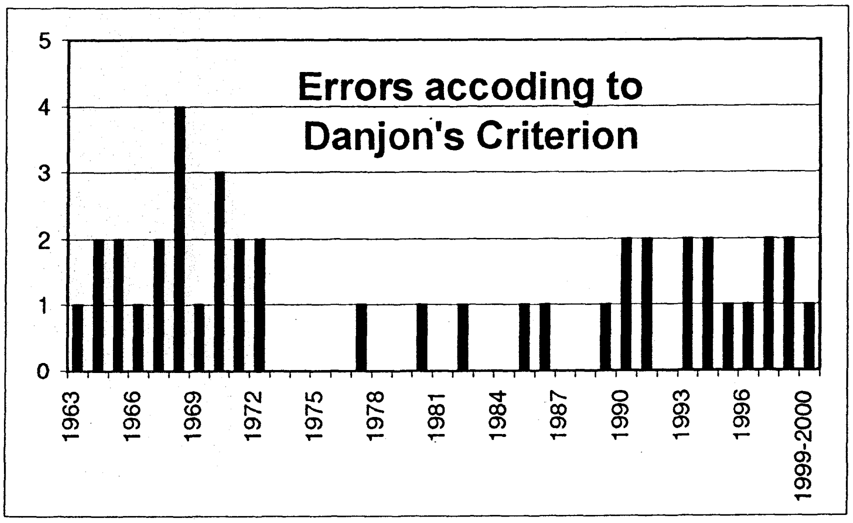

Figure 3. Number of error cases according to Danjon's criterion, for each year from 1963 to 2000.

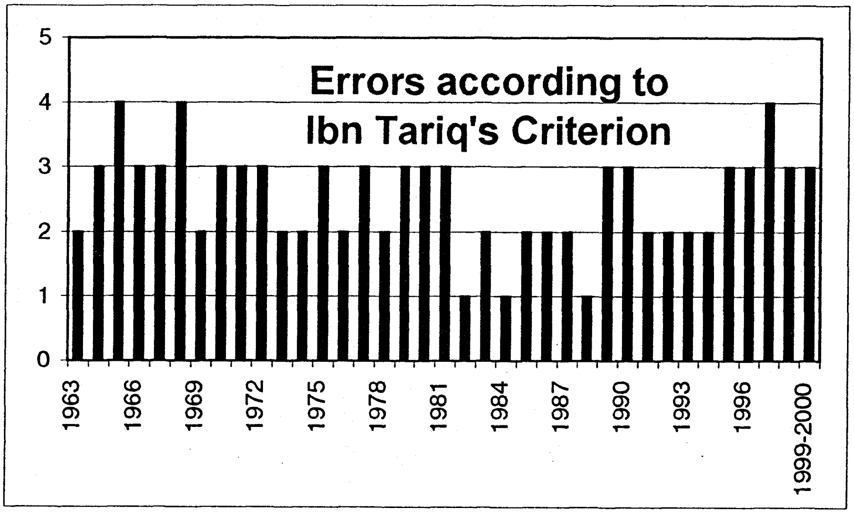

Figure 4. Number of error cases according to Ibn Tāriq's criterion, for each year from 1963 to 2000.

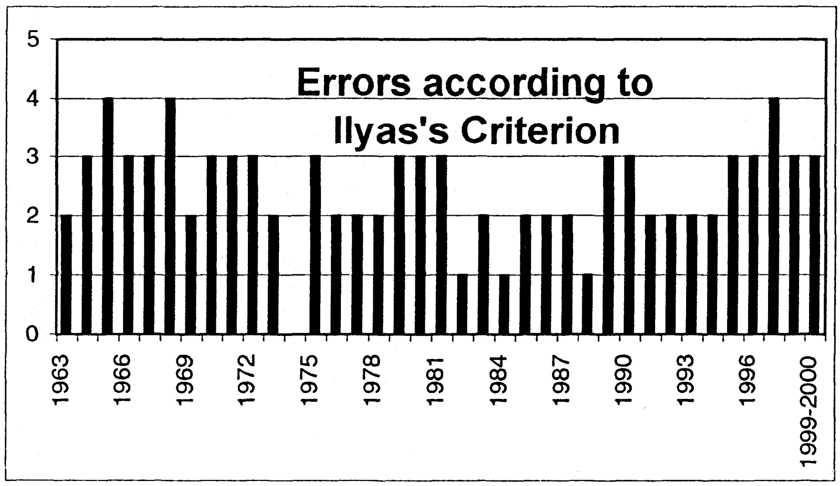

Figure 5. Number of error cases according to Ilyas's criterion, for each year from 1963 to 2000.

But the most important work of analysis was undertaken on the basis of the two groups of criteria described above, from which we have obtained several interesting results. First we have counted the cases where the crescent could not be seen according to each criterion; secondly, and with the aim of studying the progress made (or lack thereof) by Algeria with regard to this problem, we have computed the rates for two periods, 1963-1990 and 1991-2000. The results, which we shall discuss below, are given in Table 1.

These results speak for themselves: in almost half the cases, one or more of the absolute limits (or records) was/were violated, while according to the prediction criteria in 4 out of 5 instances the officials who decreed the start of the month were in error; moreover, these numbers do not take into account the atmospheric conditions which, if unfavourable, can force the postponing of the new month by one day, even though the astronomical conditions may allow for the observation of the crescent in principle, thereby raising the error count.

Moreover, when comparing the results for the three time periods of interest (1963-1990; 1990-2000; 1963-2000), we see clearly that the situation has got worse; indeed, the rates of error for the last decade, when astronomical studies and publications on the problem have increased manifold, are much higher than their counterparts in the earlier years. Most staggering is the doubling of the rate of impossible 'sightings' between the two periods 1963-1990 (when it was *only* 13.3%) and 1991-2000 (when it reached a very high 28.1%)!

Table 1: Numbers and percentages of error cases according to the 3 rejection and the prediction criteria, computed for the three time periods of interest: 1963-1990; 1991-2000; 1963-2000.

Criterion	**Number and Percentage of Error Cases** between 1963 and 1990	**Number and Percentage of Error Cases** between 1991 and 2000	**Number and Percentage of Error Cases** between 1963 and 2000
Moon Age	36/83 = 43.4%	18/32 = 56.3%	54/115 = 47.0%
Moon Lag	31/83 = 37.3%	13/32 = 40.6%	44/115 = 38.3%
Angular Separation	26/83 = 31.3%	15/32 = 46.9%	41/115 = 35.7%
Ibn Tariq	67/83 = 80.7%	27/32 = 84.4%	94/115 = 81.7%
Ilyas	64/83 = 77.1%	27/32 = 84.4%	91/115 = 79.1%

Moreover, when comparing the results for the three time periods of interest (1963-1990; 1990-2000; 1963-2000), we see clearly that the situation has got worse; indeed, the rates of error for the last decade, when astronomical studies and publications on the problem have increased manifold, are much higher than their counterparts in the earlier years. Most staggering is the doubling of the rate of impossible 'sightings' between the two periods 1963-1990 (when it was *only* 13.3%) and 1991-2000 (when it reached a very high 28.1%)!

Then, in order to better investigate this overall trend, we plotted histograms counting the number of errors for each year, for reasons that we explain below. As was stated earlier, in principle there are 3 religious occasions to determine each year (the beginning and end of Ramadan and the start of the month of Dhul-Hijjah), and thus a maximum error number of 3 each year. However, in 1965, 1968, and 1997 there were 4 occasions, because the lunar year is shorter by 10 or 11 days than the solar year. That is why on our histograms, one may find 4 errors in a given year instead of the maximal 3.

Our results can thus be read directly from the histograms. We shall simply note that the number of years where all three occasions were incorrectly decreed is truly alarming, especially if we base ourselves on the prediction criteria.

What is the value of these histograms? Their value is mainly sociological. We wanted to see whether the Muslim society (taking the Algerian society as a sample) is making progress in solving this problem or not. If the Muslim society had been progressing on this question, we would have seen on the histograms a gradual decrease in the number of errors made each year. (By error we particularly mean the violation of one of the three limits/records.) However, the histograms do not show that, or at least not clearly; they show that in Algeria the problem has gone through 3 periods: the first, between 1963 and 1972, when the number of errors was practically maximal each year (twenty or more out of 32 dates in all); the second, from 1973 to 1988, when the number of errors was rather limited (around ten out of 48 possible cases); and the third, from 1989 to 2000, when the number of cases suddenly jumped up very sharply (about 20 out of 35 possible cases). In fact, if one considers the prediction criteria (Ibn Tariq or Ilyas), the average error is found to be quasi-constant at about 2.5 per year.

We should like to suggest here a possible sociological explanation for these results. After independence (1962) in Algeria, the absence of experts (especially astronomers) on this problem probably made the officials adopt the dates decreed in the Middle-East, where, according to our personal experience, the cases of error are more numerous and flagrant than in the western part of the Muslim world. Then, in the seventies and with the beginning of a correct understanding of the nature of the problem and of the methods needed to resolve the confusion, the Algerian institutions probably called on the experts to help them and propose credible calendars, which translated into a substantial decrease in the number of errors over a period of 15 years. Finally, toward the end of the eighties, and with the resurgence of fundamentalist religious stands and the insistence that the scientific computational methods be rejected in favour of the traditional laymen naked-eye observations (without even any verification or confrontation), a drastic increase in the number of error cases was immediately witnessed.

Two remarks before concluding. First, we wish to recall that the atmospheric conditions have not been taken into account in this study. Our analyses could have been more accurate if we had gone back to the meteorological archival reports and checked whether an 'observed' crescent could be rejected on such grounds (even if it does not violate any of the astronomical conditions). Schaefer did do such a work, in a different context, for two American locations and the following periods: 1930-31, 1935-36, and 1940-41; this allowed him to reject a certain number of 'positive' cases. Error percentages would then automatically have been higher.

The second remark we should like to emphasize is a more important one and concerns the rates error that would be found if a similar study were performed in the Middle-East; and here we do strongly recommend that it be conducted. Error rates in the East are necessarily higher than those obtained in this research (for Algeria) because, due to the Moon's rotation around the Earth, if the observation of the crescent turns out to be impossible in Algeria, then it is automatically impossible in all eastern lands, except for slight latitude effects. But in our personal experience we have never known a case where the month was decreed in the East after it had been declared in the West; most often it is the contrary – by a day or more! Therefore we expect the average number of errors each year to be close to 3 in the East! Furthermore, because of the distance and time-zone difference between Algeria and the East, there must be many more cases where the start of the month was decreed there while the conjunction had not yet occurred; therefore the percentage of totally erroneous cases (flagrant impossibilities) there must be much greater than the 17.4 % determined for Algeria!

5 CONCLUSION

Facing the total confusion that we see and live in the Muslim world today concerning the problem of correctly determining the dates of religious occasions, we decided to scientifically investigate the historical dates adopted in Algeria between 1963 and 2000. The results of this work show that the error rates obtained do not depend upon the visibility criterion being used, since both ancient prediction criteria (such as Ibn Tāriq's) and recent ones (such as Ilyas's) give practically the same result: around 80 % error cases. We also should like to note that the percentage of cases presenting an absolute impossibility was found to be as high as 17.4%. And, very importantly, we have explained that error rates in the Middle-East are necessarily larger (perhaps we might say much larger) than those obtained for Algeria.

These must, in our view, be urgently considered by the officials as a resounding no-confidence vote on the part of astronomy regarding the methods they (the officials) have been adopting. These results should also draw the attention of the jurisconsults that their approach contains a much-too-large intrinsic error probability, and must therefore be modified and improved. This paper was deliberately written in a simple non-technical style for it to be accessible to the largest educated public. It is our hope that officials and jurisconsults finally come to the understanding that there are questions in which science has a lot, if not all, to say, and that they cannot continue to ignore the tremendous development of human activity and science in such fields where they (the officials) continue to claim an exclusive control.

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