STATE OF THE ART OF ISLAMIC (LUNAR) CALENDAR CALCULATIONS: AN OVERVIEW

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Abstract

A brief survey of the Islamic development of astronomy, especially in the context of lunar calendrical science, is followed by a discussion of the underlying basis of an international Islamic calendar. A brief account of the improvements to the scientific prediction of a new lunar crescent together with the nature of global visibility and related international lunar date lines are given. The paper provides an overall view of the progress on an international Islamic calendar.

INTRODUCTION

The Islamic calendar is a serious manifestation of astronomy involving several related disciplines—dynamical and optical physics, biophysics, and, of course, mathematical and spherical astronomy—therefore, astronomy presented a special challenge to the Muslims. Indeed, Muslims dominated scientific development for 700 years. According to George Sarton, the well-known historian of science, the Muslim domination of science (especially astronomy) was so complete for the first 350 years after the founding of Baghdad (762 A.C.), that he assigned each 50-year period of scientific achievement exclusively to a Muslim. Unfortunately, the sacking of Baghdad in 1258 A.C. at the hands of Hulagu Khan marked a major disaster to the development of science, for the world as a whole but especially for the Muslims. In the post decolonization phase after World War II, although Muslim countries began to pay attention to education, science and technology, applied and Islamic astronomy was left out and almost forgotten. Therefore, it is not surprising to see the annual chaos that accompanies the *'Īd* occasions: It is nothing more than a reflection of the scientific situation in the Muslim world.

The process of keeping track of time is almost as old as human civilization. Unsurprisingly, almost all early civilizations started with the lunar calendar—around the Mediterranean, the Babylonians, Greeks, Jews, and Egyptians; in the West, the Aztecs and Incas; and in the East, the Chinese and Hindus. Almost all of them started with the use of the purely lunar system, subsequently transforming it (through intercalation) into a luni-solar system in which the system is basically lunar. In the West it seems that the misuse of power by pontiffs (pre-Christian, Roman authorities) in the matter of intercalation angered Ceasar enough to cause him to shift to a purely solar calendar, thus weakening the lunar system's importance. However, the lunar calendar received a major boost when the Muslims adopted a purely lunar system (632 A.C.)—exact and fixed—of 12 lunar months. Prior to this the Makkans would change the sacred nature of the specific months (in which fighting was prohibited) to suit themselves through intercalation in a way similar to the Roman pontiffs. The Qur'an provides the following two pertinent verses.

> They ask thee concerning the new moons. Say: They are but signs to mark fixed periods of time in (the affairs of) men, and for Pilgrimage . . . (2:189)
>
> The number of months in the sight of Allah is twelve (in a year) . . . (9:36)

By using the first visibility of the crescent moon to determine the beginning of the new month (a practice observed in earlier times by many other calendar users like the Babylonians, Jews, Incas, Aztecs, etc.), the Islamic lunar calendar was made even more simple and self-contained. But more importantly, with the use of earliest visibility, the lunar calendar—already challenging to the fields of celestial mechanics, spherical astronomy, and mathematics—became scientifically challenging to the fields of observational astronomy and optical physics as well. During the entire Golden Era of Muslim science, working out the calendrical astronomy, including the prediction of visibility, became an intense, religious, and testing activity for the best scientific Muslim minds. However, very little serious attention has been paid to the development of the lunar calendar since the downfall of

Islamic science and the subsequent shift to the solar calendar, especially in the 19th century.

Today, if a calendar is to be globally useful, the dates have to be interrelated between any two places through a date line. Both lunar and solar systems are basically determined locally. Until nearly the end of the 19th century, Europe and the rest of the world determined time and date according to the local meridian of each place. The solar system, indirectly and somewhat accidently, began to be internationalized with the arbitrary adoption of Greenwich (in 1834) as prime meridian to facilitate determination of a ship's position at sea. Eventually, this gave rise to the international solar date line. Gradually, countries adopted the use of the arbitrary solar date line for calendrical use, some in more recent decades. The lack of a lunar date line resulted in the lunar calendar becoming stuck and getting left behind. The need for an international date line for lunar calendars—specifically in the context of the Islamic lunar calendar—came under serious consideration and study by me, and lately has become an operational issue.

Three essential elements underlie a date line and a unified international Islamic lunar calendar; namely, the astronomical prediction method of determing a new moon's visibility, its use on a global scale, and the considerations for its global (practical) application and implementation. A brief account of the recent progress in these areas is presented in the next sections.

ASTRONOMICAL PREDICTION METHOD

As we have noted earlier, a lunar calendar is a calendar of civilizations (see the table at the end of this paper). Almost every civilization has made use of it at one time or another, and many continue to use it today. Beginning a new month with the appearance of a new crescent was a natural thing to do in the ancient times. Even though, the purely lunar system was gradually transformed into a luni-solar system, the practice of using the first visible crescent remained in force with subsequent civilizations and was further strengthened by the Muslims.

Using long-term observational records, a simple astronomical rule (criterion) for prediction of the new moon's earliest visibility was laid down as early as the Babylonian era, and remained in general use during the latter civilizations of the Jews, Chinese, Greeks, Hindus, and Muslims. Around the 4th century A.C., the Hindus begun to treat the problem on mathematical and physical grounds. But it was to the credit of the Muslims (in view of its enormous importance) that after intensive work, purely physics-based prediction methods were evolved and continually improved upon, notably by Yaqub Ibn Tariq, Habash, al Khwarizmi, Moses, al Battani, al Farghani, Thabet, al Sufi, and al Tusi. However, as Islamic science and astronomy declined, the prediction methods which they developed stagnated and then, gradually, were all but forgotten.

Nevertheless, because lunar visibility is of general astronomical interest, a modern attempt at developing a criterion was made at the beginning of this century using a new observational data set, taken from Greece. But this criterion remained obscured until it was brought out into the Islamic world.[1] At the same time, another purely theoretical, physics-based method, a modern improvement to the 11th century Islamic method, was developed by Bruin.[2] These two independent methods were found to be in serious conflict with each other and thus unreliable for use until I was able to identify the error and thus produce a combined, theoretical-observational criterion based on the two independent methods. The criterion has been further improved upon by me at the two extremes and now represents a good starting point, taking into consideration the effects of such variables as:

- the moon's distance from the earth, the crescent's width and light intensity;
- the brightness of the sky near the western horizon at sunset;
- the lunar mountains' shadowing effect;
- the atmospheric refraction effect; and
- the human eye's role as a detector of contrast.

It is very desirable to develop simpler techniques (or criterion) which are relatively easy to use but fairly good as a first degree approximation. With this in mind, Ilyas developed two separate criterion. One of these is based on the moon's age and the other on moonset lag from sunset. The latter is exceptionally simple and accurate up to mid-latitudes. The basic criterion may need slight improvements for specific regions for which elaborate observational work is needed, But, in any case, the principal features of a uniform calendar are expected to remain unchanged.

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[1] Mohammad Ilyas, "Sighting of a New Moon." J. Muslim World League (Makkah) 4 no. 11 (September 1977): 38.

[2] F. Bruin, "The First Visibility of the Lunar Crescent," Vistas in Astronomy 21 (1977): 331.

GLOBAL VISIBILITY OF THE NEW MOON AND LUNAR DATE LINE

Given a reliable astronomical prediction method (criterion), it is not difficult to make use of it for prior determination of the expected visibility at the evening and the commencement of the new Islamic month for any desired place. Indeed, this was a routine practice in the Islamic world from the 8th century onwards. However, in modern times, one needs to examine the matter globally. To make the necessary computations over the entire earth's surface (for several consecutive days for each new month) requires nothing short of a modern computer. Indeed, without today's developments in computational machines, this kind of work would be practically impossible. And without making such calculations globally, the study of a realistic international calendar, fulfilling religious needs, would not be possible. In fact, even though the necessity and the basic concept of the Islamic lunar date line—the backbone of an international calendar—had been developed,[3] it was only in 1978, when the first set of such charts were issued, that the nature of global visibility and a proper lunar date line became clear. The following years saw a continuous build up, leading to the publication of global data set.[4]

Without going into too many of the technicalities, we can look at the outcome of the global scale computations. The basic issue is to relate the phenomena of "first visibility" at two places A & B, where B is either to the east, west, north, or south of A. The basic questions that arise are:

1. If we expect the visibility at A what happens to it at B?
2. Is there general systematic behavior and continuity or only random behavior?
3. If the moon is sighted at A first, will the moon be sighted at A first again the next month?

To answer the above questions, the underlying computations are rather involved and complex but the outcome is very simple and satisfying. This is illustrated schematically in the figure below. We note that at each latitude circle, there is a critical longitude at which the moon is expected to become visible first because the minimum astronomical conditions are satisfied (at

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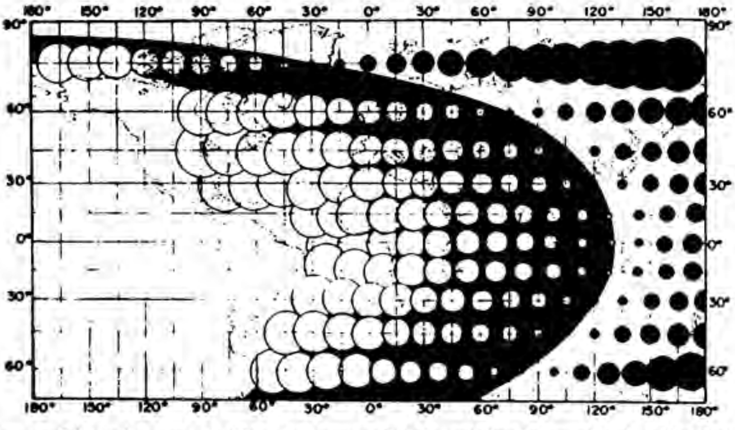
[3] Mohammad Ilyas, "Sighting of a New Moon."

[4] Mohammad Ilyas, *A Modern Guide to Astronomical Calculations of Islamic Calendar, Times, and Qibla* (Kuala Lampur: Berita, 1984).



the time of local sunset). To the east of this critical longitude, the "chance of visibility" decreases rapidly (growing dark disks) due to earlier arrival of sunset. To the west, the "chance" increases rapidly (growing white disks) due to the delayed occurrence of the local sunset, allowing the moon to appear higher, bigger, and brighter. Thus, the line joining the first visibility longitudes at different latitudes becomes the (Islamic) international lunar date line (ILDL). Due to some uncertainty (an inherent property of an observational event) in the prediction "criterion," there is a corresponding uncertainty zone around the ILDL covering approximately 20° to 30° in longitude on each side. In this zone, we can expect to sight or miss the new moon. To the west of this zone, we definitely expect to sight the moon under clear weather conditions; and to the east of this zone, the moon will be sighted the next evening. This is a new dimension to our understanding of global visibility, calling for serious attention from our religious scholars.

ILDL'S GLOBAL APPLICATION AND IMPLEMENTATION

Basically, the ILDL is a natural demarkation line, similar to the arbitrarily fixed (systematized) solar date line, and thus allows the transformation of the local lunar calendar into an international lunar calendar without affecting the basic condition of (expected) "local visibility" at each and every place. In other words, if everyone adhered to the "local condition of expected visibility" in deriving their local calendars, without worrying about anybody else, the end result would be a systematic and unified international Islamic calendar with global continuity. Also, because such a (calculated) calendar would be closest to the actual sighting situation, it would allow adjustments for occasional departures of "acutal sighting" from the calculated dates without seriously affecting the entire calendar. For example, a month calculated to be 29 days may change to 30 and an adjacent one to 29 (mainly in the uncertainty zone only).

The ILDL is not necessarily a vertical straight line. In general, it is a curved line with greatest curvature at higher latitudes. Therefore, certain simplifications may need to be made to the ILDL at higher latitudes. This matter is one of the areas to come under serious scientific and religious consideration in the immediate future. A vertical line approximation, whereby a vertical line drawn at the apex of the calculated ILDL is used for the general international Islamic calendar, has several good justifications, including the ruling for sufficiency of a single (acceptable) observation of sighting for the whole country. A first cycle approximation and similar other matters have been discussed at length elsewhere and need not be repeated here.

An important consideration will be the global observance of important religious events like *'Īd al Fitr* and Hajj, and the question of whether everyone can celebrate these events on the same day, worldwide, without scientific absurdity. In the light of our new understanding of global visibility patterns and the resultant international date line, etc, it is not difficult to see that the date line transforms the local date into an international date. Any event thus begun from the date line would be on the same day globally (i.e., within 24 hours around the global surface). But of course, there is the religious question of actual sighting especially for certain events like *'Īd al Fitr*. It will be for the *ulamā* to examine the underlying issues which have been identified elsewhere.[5]

Regardless of how we decide to determine the specific dates like *'Īd al Fitr* or the first day of *Ramaḍān*, the most important point is that the same criteria be implemented everywhere in the Muslim world. Indeed, today the absurdly differing dates between different Muslim countries and the resultant chaos we experience each year on the occasions of the *'Īds* are due more to variations in calculations and less to the adoption of calculations by some countries and actual sightings by others. Using the practice of actual sighting for one or two important events would tend to give a seriously different date only if the calendar had been calculated wrongly according a criterion other than "expected" visibility. In this case one may be trying to sight the new moon on the 28th day of the month, as is the practice in many countries!

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[5] Ibid.

CONCLUDING REMARKS

In the light of the foregoing discussion, it is clear that the issues confronting the development of the Islamic calendar are, to begin with, of a scientific nature, even though some religious considerations need to be addressed. The most urgent matter is that of uniform implementation of a general purpose international Islamic calendar; that is, only the "expected visibility" criterion for the advance calculations of calendrical dates should be used. Side by side, we need to build up the scientific aspects necessary for the perfection of calendrical science and related astronomy. Indeed, having seen it evolve over the last 15 years, I can now say that, as a result of intense efforts at various levels, there is considerable understanding of this need throughout the Muslim world. More importantly, progress is already being made toward coordinating an international effort to develop an international Islamic calendar program. A series of seminars and regional meetings are being held and this very meeting is a link in this chain. A good many institutions are taking a keen interest in the development of this work. These are very positive developments. We just have to continue working toward perfection and communication with patience.

It must be pointed out that the Islamic calendrical system is the simplest of all lunar calendars in use. The implementation of the single calculation/prediction system and subsequent improvements would go a long way to make it a living system of common use. Perhaps it would be suitable to end this paper with a quotation from a note of caution I wrote not long ago:

> In recent years there has been a tendency to arrange for a two- or three-day seminar to come up with solutions there and then. This kind of quick solution approach has, it seems, done more harm than good. The underlying science has been forgotten through centuries of neglect. All kinds of simplifications have been introduced to bypass the required rigors of physics and mathematics, so that now we have to relearn and advance Islamic astronomy all over again. The process has to be slow with constant and continuous effort. Modern scientific methods are such that what we work out today is open for review and refinement tomorrow. Our approach will have to be to find an acceptable interim short-range solution to a problem, if possible, while working on a more perfect long-term solution.

Table Summary of Development of Astronomical Criterion: B.C.–1986

Period	Astronomers	Criterion	Remarks
–B.C.	Ancient (babylonians)	$a_s \geq 12^\circ$ (or moonset 48 min. after sunset)	based on observation
–B.C.	Chinese Greeks (Aratos. Berossos of Chaldeon [300 B.C.], Ptolemy)		using Babylonian rule, not much attention to this area
–500 A.C.	Hindus (Surya Sidhanta & Panch Sidhantika)	$a_s \geq 12^\circ$	perhaps based on Ancients' observations (elaborate system of calculations developed and importance of lunar width realized).
767–778	Ya 'qub ibn Tariq		tables for calculation
740–840	Habash		calculation system developed
–830	Al Khwarazmi	$9.5^\circ < a_L$	—
831–861	Moses ibn Maimon (Maimonides)	$9^\circ < a_L < 24^\circ$ $a_D + e > 22^\circ$	general
850–929	Al-Battani	$a_s < 12^\circ$	Autumn and Spring
	Al-Farghani	(when a_L is large)	(calculation system developed)
826–901	Thabit b. Qurra	$11^\circ \leq a_L \leq 25^\circ$	—
–986	'Abd al Rahman al Sufi	$a_S \geq 12^\circ$	(follows Babylonian rule)
973–1048	Al Biruni		refers to Habash and Battani
1258–1274	Nasir al Din al Tusi		—
15th Century	Ghiyath al Din al Kashani	$a_S \geq 12^\circ$	as Babylonian; begin sighting 24 mins. past sunset
1910-1911	Fotheringhim & Maunder	$a_D\,(\Delta Z) \geq f(Z, A_Z)$	(or $a_S > 11^\circ$–12° for ΔA_Z –0: observational)
1977	Bruin	$a_S(\Delta Z) \geq f(Z_{ms}W)$	theoretical, incomplete and erroneous
1981–1984	Ilyas	$a_D(\Delta Z) \geq f(a_L, \Delta Z)$	composite of two independent criteria
1983	Ilyas	Age ≥ f(lat., season, yr.)	simpler approximate criterion
1981-1994	Ilyas	$a_S \geq$ f(lat., season) (moonset lag [min.]): 41 ± 2 at 0°, 46 ± 4 at 30°; 49 ± 9 at 40°; 55 ± 15 at 50°	more accurate, shows quality of Ancients more general rule for upto mid-latitudes

Definition of symbols for positional parameters

L=Longitude of geographical location
ϕ=Latitude of geographical location
λ=Longitude (Ecliptic) of a heavenly body
β=Latitude (Ecliptic) of a heavenly body
α=Right ascension (equatorial) of a heavenly body
δ=Declination (equatorial) of a heavenly body
A_Z=Azimuth (bearing on the local horizon circle w.r.t. geographical north) of a heavenly body
A=Altitude (from local zenith) of a heavenly body
Z=Zenith ($Z = 90^\circ - A$) angle of a heavenly body

a_D=Arc of descent between two heavenly bodies, local ($a_D = Z_1 - Z_2 = A_1 - A_2$)
a_S=Arc of separation between two heavenly bodies.
e=Elongation between two heavenly bodies (i.e., direct angular separation of angle subtended at earth) Bruin (1977) has defined e as longitudinal separation (i.e., $\lambda_1 - \lambda_2$) and must not be confused with the general definition as above.
a_L=Arc of light (same as e in sun-moon system)
w=Width of the lunar crescent ($w = d \sin^2(a_L/2)$)
d=Lunar diameter