

**Undergraduate Research Opportunity
Programme in Science**

**Lunar Visibility
and
the Islamic Calendar**

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1 Introduction

1.1 Basic Calendrical Concepts

Calendars are used to keep track of the motion of the earth, moon and sun. They are formed from the units of the day, month and year. The day arises due to the rotation of the earth about its axis; the month arises due to the revolution of the moon around the earth; while the year arises due to the revolution of the earth around the sun respectively. We shall discuss some basic calendrical concepts below.

The Earth and the Seasonal Markers

The Earth revolves anticlockwise around the sun in an elliptical orbit in an ecliptic plane, known as the plane of ecliptic. The ecliptic is the path of the earth around the sun on the celestial sphere. It makes an angle of 23.5° with the celestial equator. Simultaneously, the earth rotates anticlockwise around an axis that is tilted 23.5° with respect to the line perpendicular to the ecliptic. The tilt of the axis and the revolution of the earth around the sun give rise to seasons.

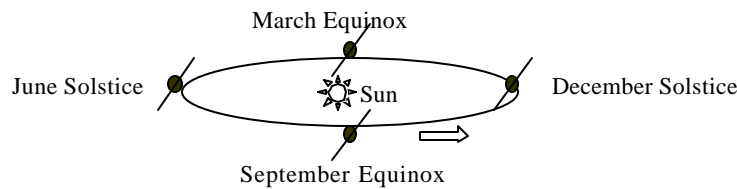


Fig. 1

The ecliptic intersects with the celestial equator at two points, known as the equinoxes. The solstices, on the other hand, are where the equator and the ecliptic are furthest apart. The equinoxes and the solstices are known as the seasonal markers. Let us look at the overall picture of the celestial sphere.

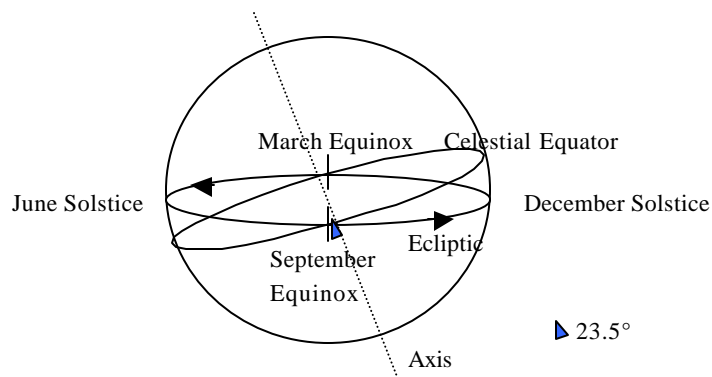
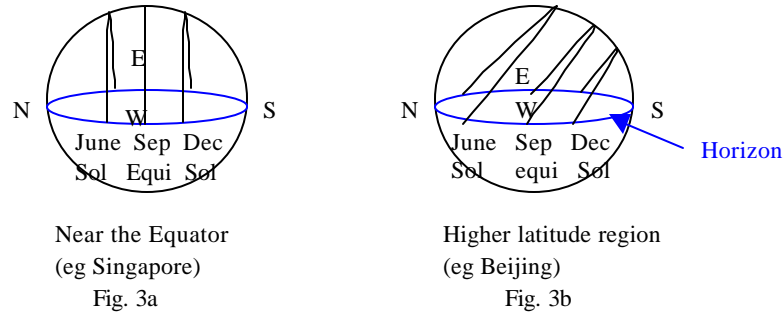


Fig. 2

March equinox (March 21) is the time when the sun passes the celestial equator from the southern to the northern hemisphere. Here, the length of day and night is equal. After the March equinox, the sun moves north until the June solstice

(June 22), where the northernmost rising position is. Here, people staying in the northern hemisphere experience the longest day, while those staying near the equator experience the same length of day and night because the sun rises from east to west for about the same length of time. Figure 3 shows the path of the sun in the sky for observers in Beijing and Singapore.



The sun then continues to move southward. As it reaches the September equinox (September 23), the day and night are almost equal in length again. The days shorten as the sun moves south until it reached the December solstice (December 22) where the southernmost rising position is. At this point, people staying in the northern hemisphere experience the shortest day.

Perihelion (near December solstice) is the point when the earth is closest to the sun. It occurs around 4th January every year. Aphelion (near June solstice) is the point when the earth is furthest away from the sun and occurs around 4th July.

The Coordinate Systems

Let's look at the three kinds of coordinate systems.

a) The Equatorial Coordinate System

Here, we measure the star's altitude with respect to the celestial equator, from 0° at the equator to 90° at the North Pole, and to -90° at the South Pole. This is called the **declination**. The declination corresponds to the terrestrial latitude.

The other positional coordinate of this system is known as the **right ascension** (RA). The right ascension is the arc distance (in degrees) measured from the point of March equinox (0°) along the celestial equator in the right-hand-side direction to the projection of the star onto the celestial equator. The right ascension corresponds to the terrestrial longitude.

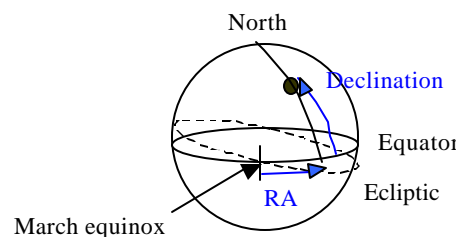


Fig. 4

b) The Ecliptic Coordinate System

Here, the star's positional coordinate is measured with respect to the ecliptic. **Celestial latitude** is measured perpendicularly from the ecliptic (0°) to the north (90°) and south (90°) ecliptic points, while **celestial longitude** is measured from the point of March equinox (0°) in the same way as the right ascension, except that it is along the ecliptic.

c) The Horizon Coordinate System

Altitude (Z) is the arc distance measured from the star to the horizon, while **azimuth (Az)** refers to the arc distance (in degree) measured from the north along the horizon to the projection of the star onto the horizon.

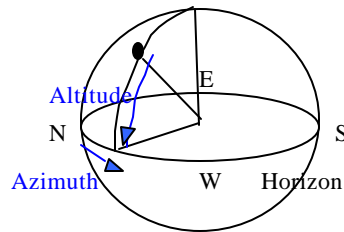


Fig. 5

Basic Quantity

We will see in the later part of the discussion that the relative positions of the sun and the moon are important in determining the visibility of the crescent moon. Let us define some basic quantity.

Relative azimuth (ΔAz)

This refers to the difference in azimuth between the moon and the sun

Moon's altitude at local sunset (Z or h)

This refers to the height of the moon above the local horizon.

Solar depression (s)

This refers to how low the sun is below the horizon.

Moonset lag

Moonset lag is the time interval between sunset and moonset

Arc of light (a_L)

The arc of light is defined as the elongation or angular distance between the sun and the moon.

Arc of separation (a_s)

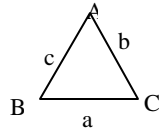
The arc of separation is the difference in RA (equatorial separation) between the sun and the moon, measured in degrees.

Spherical Trigonometry

The spherical trigonometric formulae are used to solve astronomical problems relating to the celestial sphere. Here, we will talk about the cosine formula to understand some basic concepts.

****The cosine formula**

$$\cos a = \cos b \cos c + \sin b \sin c \cos A \quad (\text{Spherical Trigonometry})$$



We will see how the arc of light is related to the cosine formula below:

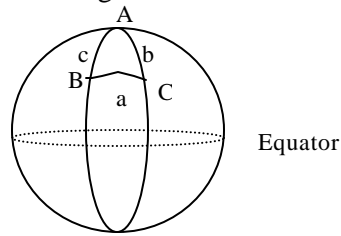


Fig. 6

The above is the terrestrial sphere, where $b = (90^\circ - \text{latitude1})$, $c = (90^\circ - \text{latitude2})$, $A = \text{longitude1} - \text{longitude2}$

Applying the cosine formula,

$$\begin{aligned} \cos a &= \cos (90^\circ - \text{lat1}) \cos (90^\circ - \text{lat2}) + \sin (90^\circ - \text{lat1}) \sin (90^\circ - \text{lat2}) \cos (\text{long} - \text{long2}) \\ &= \sin (\text{lat1}) \sin (\text{lat2}) + \cos(\text{lat1}) \cos(\text{lat2}) \cos (\text{long1} - \text{long2}) \end{aligned}$$

\Rightarrow

$$\cos a_L = \sin Z_s \sin Z_m + \cos Z_s \cos Z_m \cos (Az)$$

(Z_s = altitude of sun, Z_m = altitude of moon)

A slight variation to the above shows the relationship between the arc of light and the relative azimuth.

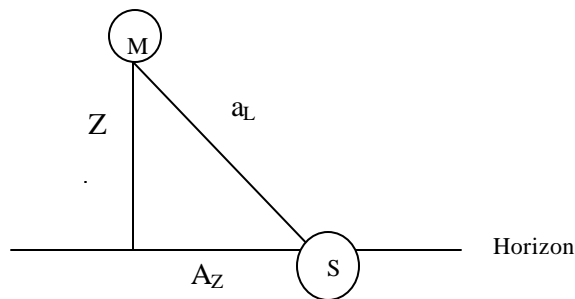


Fig. 7

$$\begin{aligned} \cos a_L &= \cos Z \cos Az + \sin Z \sin Az \cos 90^\circ \\ &= \cos Z \cos Az + 0 \end{aligned}$$

$$\Rightarrow Az = \cos^{-1} (\cos a_L / \cos Z)$$

In addition to the above cosine formulae, the relationship between the arc of light and the width of the crescent is also an important concept.

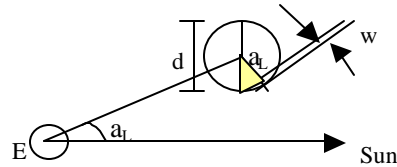


Fig. 8

$$\begin{aligned}
 w &= d/2 - d/2 (\cos a_L) \\
 &= d/2 (1 - \cos a_L) \\
 &= d \sin^2 (a_L/2), \text{ d = lunar diameter in km}
 \end{aligned}$$

The Moon, Conjunction and Crescent Visibility

The moon can be seen because it reflects sunlight. It revolves anticlockwise around the earth and this allows us to see the different phases of the moon. At *conjunction*, where the difference between the longitude of the sun and longitude of moon is 0° , the moon sets at almost the same time as the sunset. We call this moon the new moon. A few evenings after conjunction, the crescent will be visible. Gradually, as the moon revolves around its orbit around the earth, the moon will set after sunset. There comes a point when the moon falls in the same line as the sun and earth but on the opposite side of the earth. This moon is called the full moon. At this time, the moon sets at sunrise and rises at sunset. The moon continues to revolve around the earth until the new Moon occurs again, and the cycle repeats. The time period between one new Moon and the next new Moon is known as *lunation*, and varies between 29.27 and 29.84 days.

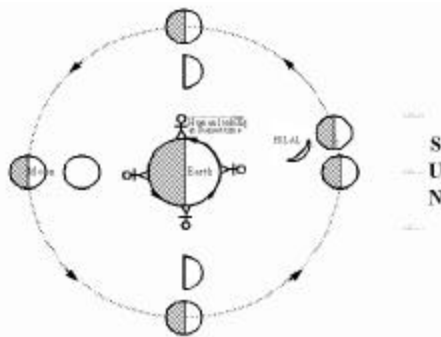


Fig. 9

Conjunction can occur when the moon is directly in front of the sun at new Moon or 5° away, as long as their celestial longitude of the moon and sun is the same. At higher latitudes (see fig. 3), the sun sets at a smaller angle to the horizon compared to that near the equator. Since the moon revolves near the ecliptic (0° to 5° difference), it also behaves similarly to the sun and sets at a smaller angle to the horizon. Near the equator, the sun sets almost perpendicularly to the horizon. The moon, too, sets almost perpendicularly to the horizon.

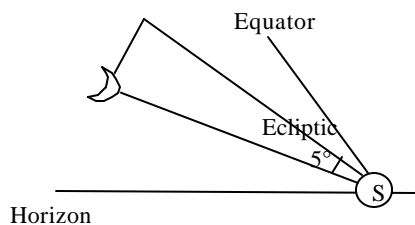
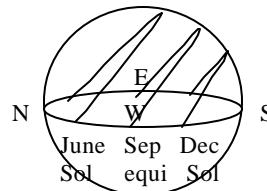


Fig. 10



Higher latitude region
(eg Beijing)

Fig. 3b

The Tropical Year

In the past, tropical year was defined as the time interval between two consecutive March equinoxes. However, it was found that the time interval between two March equinoxes, two June solstices, two September equinoxes and two December solstices are slightly different. (For more details, refer to <http://www.math.nus.edu.sg/aslaksen/calendar/>) Hence, to define it more accurately, the tropical year is the time interval for the sun's mean longitude to increase by 360° . Its length is about 365.2422 days.

1.2 Solar, Lunar and Lunisolar Calendars

Solar Calendars

Solar calendars aims to ensure that the seasonal markers do not move in the calendar year by adding leap days. They ignore the movement of the moon and only follow the movement of the sun. One example of such calendars is the Gregorian calendar, which is the most commonly used calendar today. The goal of the Gregorian calendar is to make the average Gregorian year equal the tropical year, so that the seasonal markers stay almost constant. However, a normal Gregorian year consists of 365 days and the tropical year consists of 365.2422 days. Since each normal year is about a quarter day shorter, the equinox moves forward a quarter day for three consecutive years. A leap year rule is then introduced to even it out at the fourth year. A leap year occurs when a particular year is divisible by 4 and not 100 or divisible by 400, and in a leap year, an extra day is added to February. For instance, 2000 is a leap year, while 1900 is not. One Gregorian year is divided into 12 months, with each month having a fixed number of days. The basic unit of the solar calendars is days.

Lunar Calendars

Lunar calendars aims to ensure that conjunction, crescent visibility, or full moon determines the start of the month. The basic unit of lunar calendars is the lunar month. Lunar calendars follow the lunar phase cycle and ignore the movement of the sun, hence, lunar years do not follow the seasons. The only lunar calendar used today is the Islamic calendar. A lunar year of the Islamic calendar consists of 12 months,

with each month beginning with the first sighting of the new Moon. (Muslim calendars are based on crescent visibility and not conjunction for religious reasons.) Since the Islamic calendar is not related to the tropical year, Islamic dates move back about 11 days each year. This is because each Muslim month consists of 29.5 days on average. Hence, in a year, there are about $12 \times 29.5 = 354$ days, i.e. the 12 lunar months per year “slips” away by about 11 days with respect to the solar year.

Lunisolar Calendars

Lunisolar calendars aims to approximate the tropical year by adding leap months. One example of such is the Chinese calendar, which consists of 12 months that begin at the new moon. A 13th month (leap month) is added a little less than every 3 years so that the calendar stays in line with the seasons. The basic unit of lunisolar calendars is the lunar month.

2 The Islamic Calendar and its History

2.1 The Islamic Calendar

Unlike the Gregorian calendar, which serves as an international standard for civil use, there are other calendars which are used for religious and cultural purposes, and are interesting to delve deeper in. One of them is the Islamic Calendar, which is strictly a lunar calendar. For religious reasons, the Quran specifies that the Muslim months start with the sighting of the new Moon at a given locale. Each year consists of 12 lunar months with no leap months and the names of the lunar months are:

- | | |
|--------------|-------------------|
| 1. Muharram | 7. Rajab |
| 2. Sarfar | 8. Sha ban |
| 3. Rabi a I | 9. Ramadan |
| 4. Rabi a II | 10. Shawwal |
| 5. Jumada I | 11. Dhu al-Q adah |
| 6. Jumada II | 12. Dhu al-Hijjah |

For the Islamic calendar, there are 7 days in a week, with each day beginning at sunset. Day 1 begins at sunset on Saturday and ending at sunset on Sunday. Day 5, which is calle Jum a, is a day for congregational prayers.

Determining the first day of every Islamic month is very crucial as it determines when the Muslim festivities will fall on. For instance, Muslims need to know when is the first day for fasting in the Ramadan month and when fasting ends (i.e. when to celebrate Hari Raya Puasa). Hence, many practices have been adopted to determine the first day of each lunar month.

Since the Islamic calendar is not related to the tropical year and has no fixed relationship with the seasons as mentioned earlier, important Muslim festivals which always fall in the same Hijri month, occur in different seasons. For example, Hari

Raya Puasa in 1998 fell on 30/1/1998; in this year, it falls on 16/12, and will continue to fall back 11 days earlier every year until it takes place in a different season. It is only over a 33-year cycle that Hari Raya Puasa will fall on almost the same day as the first year again. This is because $33 \times 11 = 363$ days.

2.2 The History of Islamic Calendar

The history of the Islamic calendar dated back to as far as the seventh century AD, when Prophet Mohammed announced the use of a lunar Islamic calendar. But before the days of Prophet Mohammed (the **pre-Islamic era**: AD 570 – 632), the Arabs used a **lunisolar** calendar. This was because they found that the lunar calendar does not keep step with the seasons and thus, caused some difficulties. When they made a pilgrimage to Mecca in the 12th lunar month, they had to bring along an animal for slaughter as an act of sacrifice. However, with the lunar calendar not being able to keep up with the seasons, the Arabs had difficulties in finding food (crops could not be harvested) for the pilgrimage trip as well as the animals for slaughter. As such, they inserted a 13th month occasionally in order to keep the 12th in the autumn. As to when to insert the 13th month, it was decided by the calendar officials (the Nasa'a) of the Kinana tribe, but exactly when it was inserted was not known.

Prophet Mohammed announced the strict use of a **lunar** calendar shortly before his death in AD 632. It was only in AD 642 when Caliph Umar I set up the calendar and took 16 July AD 622 as the starting date of the **Islamic era**. This era is known as the era of *Hijra* (AH¹), where 622 was chosen to commemorate the *Hijra*, the date of Prophet's move from Mecca to Medina. (AD 622 = AH 1). However, this date was not the exact arrival date, though the two dates are probably near to each other.

3 Hari Raya Puasa and Hari Raya Haji

The two Islamic holidays in Singapore are Hari Raya Puasa and Hari Raya Haji. Hari Raya Puasa falls on the 1st day of the 10th Islamic month while Hari Raya Haji falls on the 10th day of the 12th Islamic month.

Since an Islamic year is shorter than a Gregorian year, the time period between any same Muslim dates is less than a Gregorian year. Therefore, any Muslim festivals can occur twice in the same Gregorian year. For instance, in 1999, Hari Raya Puasa fell on Jan 19; in 2000, it fell on Jan 8 and Dec 27. Since $365/11 = 33$, this “twice” Hari Raya Puasa per year will occur every 32 or 33 years. Also, Hari Raya Puasa will meet up with Chinese New Year for 2-3 years, and then continue on its 33 years cycle backwards through the calendar and meet up with Chinese New Year again after about 30-31 years.

¹ AH is Anno Hegirae in full and means the year of Hijra.

4 Different Approaches to the Islamic Calendar

4.1 The Arithmetical Islamic Calendar

Arithmetical Islamic calendars are constructed based on arithmetical calculations to make rough predictions of lunar visibility, where the number of days in a month alternate between 29 and 30. Each lunar year consists of 354 days (355 in leap years). In a leap year, an extra day is added to the 12th Islamic month to keep the calendar in step with the true phases of the Moon.

Leap years are years that follow the following algorithm: the number $year \bmod 30$ is one of the following: 2, 5, 7, 10, 13, 16, 18, 21, 24, 26, or 29. The table below shows a fixed cycle of 30 lunar years from year 1 to 30. The total number of days in this system of 30 Islamic years = $(354 \times 30 + 11) = 10631$; dividing this figure by 360 (30 years of 12 months), we will get the average lunation of the moon to be 29.53 days.

Year	No of Days	Year	No of Days	Year	No of Days
1	354	11	354	21	355
2	355	12	354	22	354
3	354	13	355	23	354
4	354	14	354	24	355
5	355	15	354	25	354
6	354	16	355	26	355
7	355	17	354	27	354
8	354	18	355	28	354
9	354	19	354	29	355
10	355	20	354	30	354

Now, when we are considering of constructing an Islamic calendar, we need to consider two conditions. Firstly, the mean lunation (= 29.53 days) is not whole number, yet, we need to assign an integral number of days to each month of the calendar. In this aspect, the arithmetical calendar has made a very good approximation as calculated above. However, the second thing that we have to consider is the variation of the lunation. This variation ranges between 29.27 and 29.84 days. That means if we adopt this arithmetical system, there is a possibility that the new Moon will occur one day before or after the proposed alternate dates. In this aspect, the arithmetical Islamic calendar is totally unacceptable. And it's because of this that none of the Muslim community uses this fixed system.

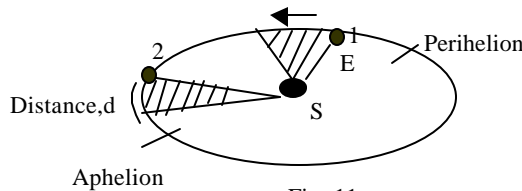


Fig. 11

Kepler's second law states that the radial line sweeps out equal areas ($A_1 = A_2$) in equal time ($t_1 = t_2$); and since the earth is nearest to the sun at perihelion (near winter solstice), it follows that $d_1 > d_2$. As a result, the earth moves at a greater speed ($s_1 > s_2$). As the moon revolves around the earth, the moon has to take a longer time to "catch up" with the faster motion of the earth around the sun, i.e. the lunation will be longer.

In contrast, at aphelion (near summer solstice), since the earth is furthest away from the sun where there is less gravitational pull, the earth revolves around the sun at a slower speed. While the moon is moving around the earth, it requires a shorter time period to "catch up" with the motion of the earth, i.e. lunation is shorter.

Therefore, the time where the new moon occurs depends on where the period of the year and cannot be based on a fixed number of days every month.

4.2 Islamic Calendar based on Observations

Traditionally, the first day of each Islamic month is determined based on the first sighting of the new Moon. Sighting of the new Moon is of religious importance among Muslims. However, there are many factors that affect the visibility:

Astronomical factors include:

1. Large moonset lag
2. Moon too young
3. Low altitude of the moon at sunset
4. Crescent width / elongation of moon from sun
5. Latitude and longitude of observer

Non-astronomical factors include:

1. Poor weather conditions
2. Atmospheric pollution
3. Poor eyesight of the observer / Use of optical aids

Due to all these, festive celebrations are sometimes held on different days by different countries, or even by different communities staying in different areas of the country.

4.3 Islamic Calendar based on Predictions

The calendar is based on astronomical data and theory. With the hope that Islamic festivals can be celebrated together on the same day within the whole country or community, predictions of when the crescent will be seen are being made. Nevertheless, it is not easy to predict the calendar or convert from one kind to another. Different criterions are being developed over the years to determine the beginning of the lunar months with greater accuracy and will be discussed later.

5 Practices in Different Countries

Traditionally, the first visibility of the new Moon to the naked eye marks the beginning of the month.

5.1 Physical Sightings

Some countries use sighting claims and have judges (Qadi) in different parts of the country to accept or reject claims. Example: India, Pakistan, Bangladesh, and Morocco.

Some countries use the calculations with the convention that if the moonset occurs after sunset (conjunction occurs), then the next day is the first day of the Islamic Month. Example: Saudi Arabia, which generally uses this method but sometimes deviates from this for the months of Ramadan, Shawwal, and Zul-Qa'dah, by using claims of sighting, or other reasons.

5.2 Calculations / Astronomical Criteria

Some countries use purely calculations with the convention that if the New Moon Birth has occurred and the moon sets 5 minutes after Sunset, then the next day is the first day of the month. Example: Egypt, where calculations are done for the Western boundaries of the country, which have a better chance of seeing the moon than other parts of the country.

Some countries adopt Wujudul Hilal criteria by calculations, such as Moon's age 8 hours, altitude above horizon 2 degrees, elongation 3 degrees at Sunset, then the following day is the first day of the Islamic Month. Examples: Malaysia, Singapore, Brunei and Indonesia.

Some countries adopt calculations with specific criteria, such as Moon's age, altitude above horizon, interval between sunset and moonset. If the moon fulfills these criteria at sunset, then the following day is the first day of the Islamic Month. Examples: Iran, Algeria, and Tunisia.

5.3 Physical Sightings and Calculations

Some countries adopt the actual sighting of the crescent with the assistance of astronomical calculations to screen out the mistaken claims and erroneous sightings. This is the most reliable and accepted method among scientists, as well as among most of jurists (Fuqahaa') of Islamic Shari'ah in recent times, including Dr. Yusuf Qaradawi and Dr. Taha Al-Alwani. Islamic Shura Council of North America (USA and Canada), and Jordanian Astronomical Society adopted this method. Recently, many organizations in Trinidad & Tobago, and Guyana have also adopted this method.

5.4 Following Other Countries

Some countries follow the news of the beginning of the month from Saudi Arabia. Examples: Qatar, Kuwait, UAE, Oman, Bahrain, Yemen, Turkey, Libya, and Afghanistan.

Some small countries follow the news of the beginning of the month from larger neighboring countries. Examples: New Zealand following the news from Australia, and Suriname following the news from Guyana.

Some countries follow the news of the beginning of the month from the first Muslim country that announces it. Examples: many European countries, and some Caribbean Islands.

Some countries/faith groups adopt pre-calculated calendar. Example: Bohra community, Ismaili community, and Qadiani community.

5.5 No Specific Method

Some countries don't adopt any specific thing! Their decision varies year by year according to different methods. Example: Nigeria.

Although it is possible to calculate the *position* of the moon in the sky with high precision, it is often difficult to predict if a crescent will be *visible* from a particular location due to the factors affecting visibility.

6 Prediction Criteria - Their Background and Reliability

Crescent visibility is a tough problem, involving orbital calculations, lunar scattering, atmospheric scattering and visual physiology. Since the Babylonians era, as far back as 500 C.E., astronomers have been trying to find ways to predict when the new Moon can be first seen every month. A simple criterion was developed and had been in use for centuries without much improvement. It was only until 1910, when Fotheringham deduced another set of criteria, which forms a crucial part of the development in lunar visibility prediction. While Fotheringham made use of fully observational data obtained from Athens, in 1977, another astronomer, Frans Bruin improvised on it with more theoretical basis. In 1984, Mohammad Ilyas then made further improvement to his criterion.

In the late 1980s, data was collected systematically from across North America. 1784 observations were collected and tested against various prediction criteria.

On 26 May 1990, a record breaking of a 15.0 hr young Moon was sighted with naked eye; and on 21 January 1996, the young Moon of 12.1 hr as seen through an 8-inch telescope!

Suppose the sun and the moon set together, since we require the moon to be >24 hrs old in order to be seen and the fact that the moon takes a month (

In 30 days – 360°
 In 24 hrs – 12°
 The moon lags 12° behind the sun.

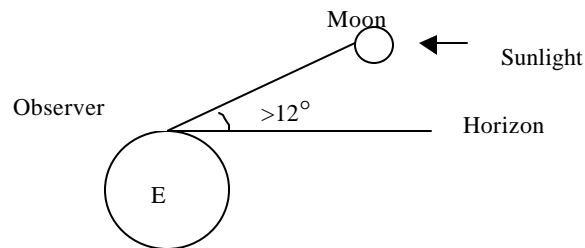


Fig. 12

Why does 12° correspond to 48 minutes?
 This is because the earth makes a full rotation of 360° in a day (24 hr).
 Hence,
 $24\text{hr} - 360^\circ$
 $48\text{min} - 48/(60 \times 24) = 12^\circ$

Moreover, from the prediction testing as mentioned above, (Doggett and Schaefer, 1994) a histogram of fraction wrong vs moon age is drawn, and it turned out that the model was extremely biased, with more than 50% error for moon age between 18 and 24 hrs old as well as frequent incorrect predictions over the whole range, showing poor accuracy.

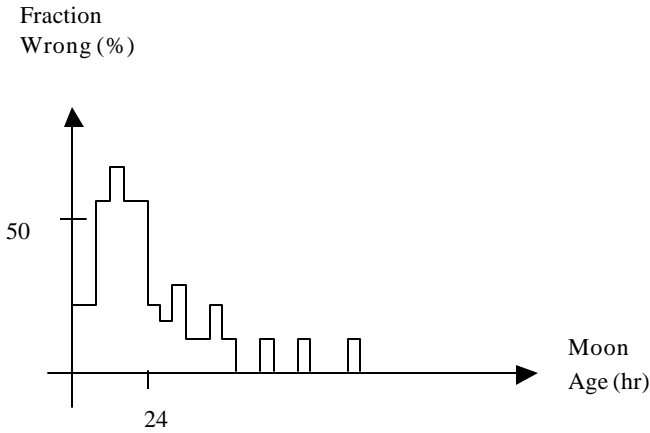


Fig. 13

The record breaking of a 15.0 hr (<24 hr) young Moon seen with naked eye and the fact that a 51.3 hr old Moon had been missed further show the inaccuracy of the simple moon age criterion.

As for the Moonset lag (>48 min) criterion, a histogram of fraction wrong vs moon age is drawn, and it turned out that there is a >50% error for moonset lags between 50-55 min, which is also a biased model.

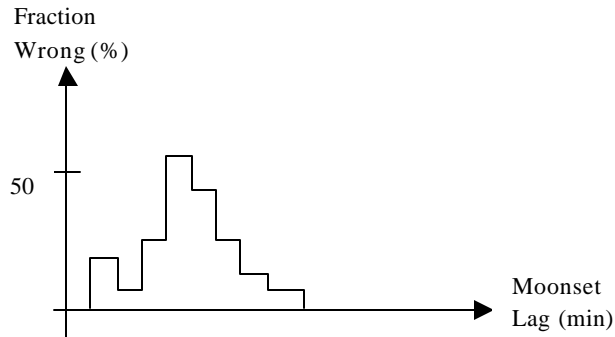


Fig. 14

In addition, this criterion is a simple observational criterion that does not take into account the position of the observer. At higher latitudes (see fig. 3b and fig. 10), the sun sets at a smaller angle to the horizon compared to that at near the equator. As a result, the moonset lag is much shorter. Before the sun has fully set (i.e. while the sky is still bright), the moon is already setting, and hence, the moon cannot be seen. However, near the equator, the sun sets almost perpendicular to the horizon. In the case, the sun sets very quickly and the sky gets dark much faster way before the moon sets. Therefore, the moon can be seen. The 48 min moonset lag has not taken this latitude condition into account and is not an accurate measurement. Moonset lags as short as 35 min have been seen and lags as large as 75 min have been invisible.

Therefore, the Babylonians' criterion of moon age and moonset lag is unreliable.

6.2 Fotheringham (Moon Alt, Rel Azimuth between moon and sun) 1910

In 1910, Fotheringham made a collection of 76 naked eye observations of the visibility and non-visibility of the crescent from 1859 – 1880, using mainly Schmidt's log at Athens. Schmidt is an astronomer in Athens and had contributed to the development of the Islamic calendar through his many observational data (see Schmidt, J., 1868, *Astr. Nachr*, On the earliest visibility of the lunar crescent in the evening sky). For each observed data set, Fotheringham calculated the moon's altitude and the relative azimuth separation at local sunset, and plotted a curve. The curve showed a clear dividing line between the positive (points above the curve) and the negative (points below the curve) observations.

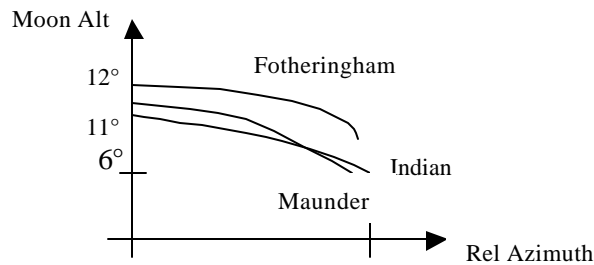


Fig. 15

To apply this criterion, a set of data of moon's altitude and relative azimuth is collected. If this set of data lies above the curve, then the crescent is visible. If the data lies below the curve, then the crescent is likely to be not visible.

From the curve, we observe that as the relative azimuth increases, the required moon altitude for it to be seen decreases, but the moon's altitude is required to be 6° . That is, the moon will not be visible if it is just above the local horizon. However, this criterion assumes that every part of the world had the same clarity of air as in Athens, be it the humid lowlands of East India or the high mountains of North India. It does not account for other important factor like seasons, latitudes, elevation, humidity and atmospheric clarity. And because these factors change with time of the year and location drastically, the threshold value of 6° not only varies from site to site, but also from month to month (lunation to lunation).

In addition, the calibrating of the dividing line based on all the observations might also cause inaccuracies. For moon directly over the sun, the greatest value for the moon's altitude is approximately 12° for Fotheringham, 11° for Maunder, 10.5° for Ilyas A and C (to be discussed later).

6.3 Maunder (Moon Alt, Rel Azimuth between moon and sun) 1911

In 1911, Maunder used Schmidt's data, together with more observations and plotted a curve lower than Fotheringham's. This is because Schmidt's observations at Athens were usually confined to older crescents, hence, positive observations were more liable to be mistaken than negative observations.

Similar to Fotheringham, the data were more accurate up to low latitudes. At higher latitudes where the atmosphere is not as clear, modification is needed.

6.4 Indian (Moon Alt, Rel Azimuth between moon and sun) 1900 C.E.

The Indians plotted a curve which is slightly lower than Maunder's using a slightly modified criterion. (see Ashbrook 1971, Sky & Telescope)

6.5 Bruin (Moon Alt, Crescent Width) 1977

In 1977, Bruin developed a set of criterion which was based mainly on theory. This criterion of his is based on the crescent width and the moon's altitude at sunset, while taking into account illumination of sky, light intensity of crescent, crescent width, solar depression, contrast for human eye, humidity, elevation, etc. The width of the moon is suggested to be >0.5 arcmin for possible visibility.

Data was collected and a graph of h , $h+s$ is plotted against s for chosen values of w (or a_L). To determine visibility, find the correspondent $h+s$ data for a given width. If the curve lies above the curve, then there is visibility. For instance, if we find that on a certain evening after a new moon, $h+s = 10^\circ$, we draw a horizontal line across the curves. This line will intersect at 2 points, A and B. The crescent will be visible for the first time at A and will remain visible for 6° of solar dip (about 30 minutes) until point B.

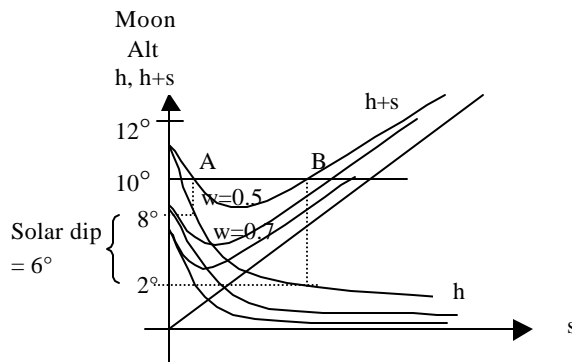


Fig. 16

The Bruin's criterion is consistent internally with those observational data of

Maunder	Bruin	
$^{\circ}$	$(h+s)$	6° (because $s=0^{\circ}$ at local sunset)
A_Z	a_L	$^{\circ}$ (because $A_Z = \cos^{-1}(\cos a_L / \cos Z) **$
20°		$\Rightarrow A_Z = \cos^{-1}(\cos 21.5^{\circ} / \cos 6^{\circ})$
		$\Rightarrow = 20^{\circ}$
		where $w = d \sin^2(a_L/2)$, d = lunar diameter in km

At low attitude, the Bruin's criterion is rather accurate as it takes into account the factors mentioned above, which account for the different visibilities in different areas. Also, when plotting a histogram of fractional errors, none of the data gave a >50% error.

However, the consistency is only desirable up to low latitudes. From mid latitudes onwards, there exist great discrepancies in the results; hence, the criterion is incomplete and erroneous.

In addition, studies have shown that his criterion for visibility required a wider crescent ($w > 0.5$ arcmin) than that for Maunder's. This requirement of crescent width was later found to be too high and reduced to > 0.25 arcmin by Ilyas.

6.6 Ilyas A (Moon Alt, Elongation) 1984

In 1984, Ilyas based on observational data and plotted a curve with moon's altitude at sunset against the arc of light (a_L) or sun-moon elongation or the angular separation between the sun and the moon. The crescent will be visible if the properties of the crescent lie above the curve and invisible if below the curve.

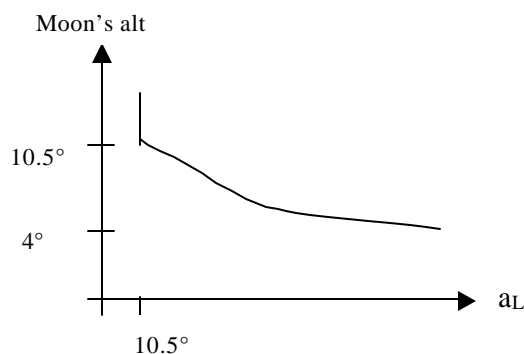


Fig. 17

Bruin	Ilyas A
From low to mid latitudes	From low to high latitudes and to very large elongation
$(h+s) \quad 6^{\circ}$	

6.7 Ilyas B (Lag, Latitude)

Dating back to the times of the Babylonians, the moonset lag provides one of the simplest astronomical criteria for earliest lunar visibility. However, this criterion is based mainly on lower latitudes. What happens when we talk about viewing the crescent at other latitudes? The Ilyas B criterion is then modified from the Babylonians with compensation in latitudes. The moonset lag at local sunset was calculated for each longitude for various latitudes and for 70 consecutive lunations. The results are: at lat 0° lag $41(\pm 2)$ min; 30° : $46(\pm 4)$ min; 40° : $49(\pm 9)$ min; 50° : 55

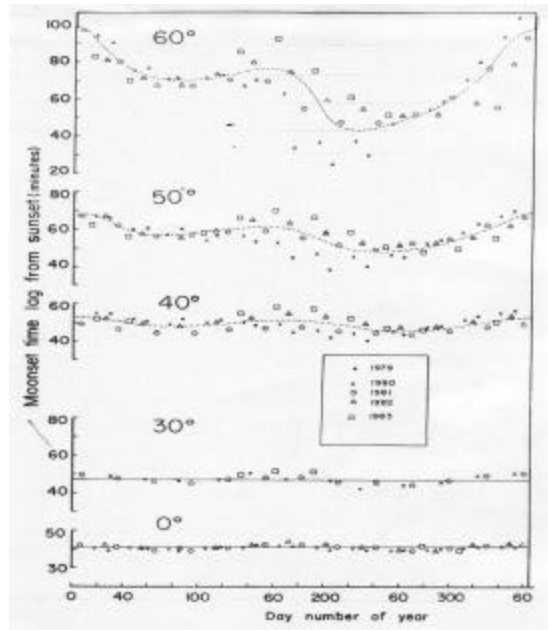


Fig. 18

We see from the resulted graph that the prediction for the earliest lunar visibility was very constant from low to mid latitudes.

However, this criterion is a simpler approximate criterion. At high latitudes (eg 60°), the data were not consistent and the graph fluctuates (data scatter). This may be due to large elongations. Note that the data have the least scatter in the spring season followed by autumn and winter, and the greatest scatter in summer. This shows that the prediction entails a large uncertainty. Here, we observe that seasonal dependence at higher latitudes is not taken into consideration for this criterion.

6.8 Ilyas C (Moon Alt, Rel Azimuth between moon and sun) 1988

In 1988, Ilyas made a slight modification of the Ilyas A criterion using some trigonometry formula**. A curve is plotted with moon's altitude against relative azimuth. As the elongation a_L or the relative azimuth A_Z is extended, the path cannot follow a because this will be overestimating; the path also cannot follow b because at high latitude, Z will then become negative, ie the moon cannot be seen.

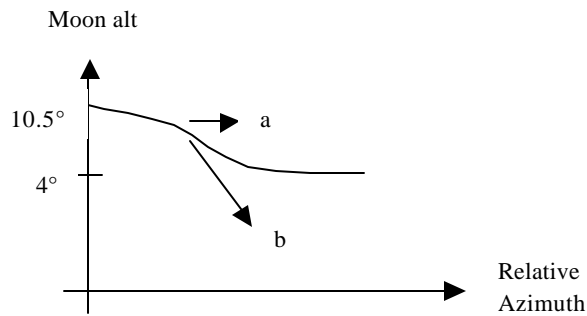


Fig. 19

Bruin	Ilyas A	Ilyas C
	Z vs a_L	Z vs A_Z (by using $A_Z = \cos^{-1}(\cos a_L / \cos Z)^{**}$)
	$a_L = 10.5^\circ$	$A_Z = \cos^{-1}(\cos 10.5^\circ / \cos 10.5^\circ) = 0$
(h+s) 6°		

6.9 RGO 67 (Moon Alt, Elongation)

RGO is the Royal Greenwich Observatory. On MoonCalc, the criterion is based on the rule that the best time and place for making the earliest sightings are when the moon is vertically above the sun at sunset so that the relative azimuth = 0° and where the altitude of the moon at sunset is 10° . From books, moon is visible when $Z > 5^\circ$ when s (solar depression) $> 3^\circ$ and $a_L = 10^\circ$. Both the criterion given in books and used by MoonCalc do agree with each other.

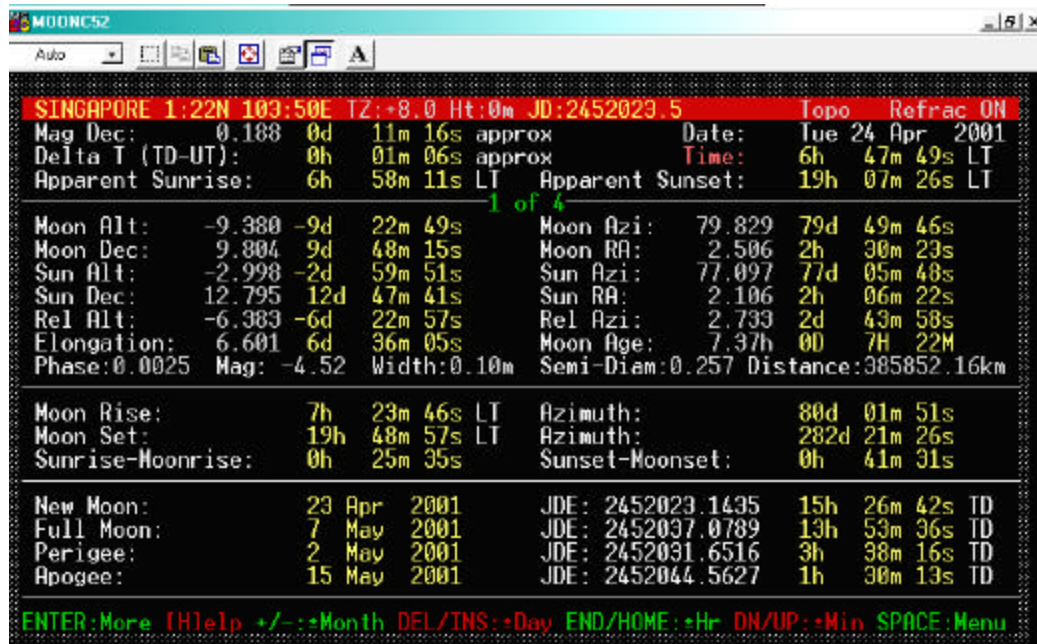


Fig. 20

We see that the sun's altitude is now $>3^\circ$, however, the moon's altitude is still below the horizon (-9.380°), and $a_L = 6.601^\circ < 10^\circ$, hence, the moon is not visible on 24/4/2001, according to RGO 67. Of course, when we look at the 2nd screen,

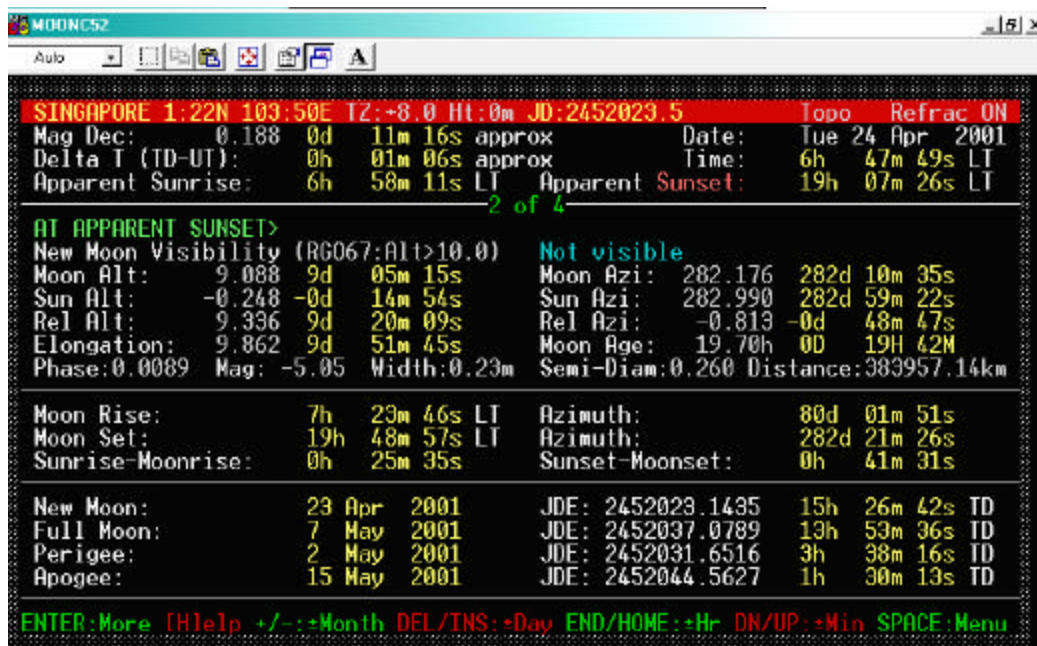


Fig. 21

We see that the moon's altitude is $<10^\circ$ and the relative azimuth = -0.813° , hence, as shown on the screen, the moon is not visible. The moon will then be seen on the following evening.

The RGO had produced a series of information sheets which tabulated predicted first moon sightings and also had a website <http://www.rog.nmm.ac.uk/index.html>. Where the old Royal Greenwich Observatory was located, the prime meridian runs through the telescope of the building. The eastern hemisphere of the world, longitude east, is below it, and the western hemisphere is above it. The two hemispheres meet at 180° longitude on the opposite side of the globe.

6.10 Shaukat (Moon Alt, Crescent Width)

Shaukat's criterion makes use of over 900 observations, collected over a period of 150 years in different locations of the world. For every observation, I calculated all the parameters that are important for sighting. A multivariable statistics analysis is conducted to find when visibility occurs and when non-visibility occurs. In MoonCalc: moon's altitude must be $>3.4^\circ$ at sunset and $(alt/12.7) + (crescent\ width\ in\ arcmin/1.2) > 1$.

We do not know the exact criteria that lead to the figures used above. Nevertheless, Dr Shaukat is a research scientist since 1967 and has been a consultant

on moon sighting for the Islamic Society of North America and had developed a website on moon sighting (<http://www.moonsighting.com>). His criterion is one of those more reliable one.

6.11 Yallop (Rel Alt, Crescent Width) 1980's

Yallop made use of 295 (non) sightings information and develop a criteria from the Indian and Bruin criteria. This criterion depends on a parameter 'q', where 'q' is derived from the relative geocentric altitude of the moon and the topocentric crescent width at 'best time', ie sunset time + (4/9) moonset lag.

However, as this criterion depends on 'best time', it is not always that accurate, because once we apply the criterion to local sunset, then the result will become more pessimistic than at 'best time'. At the same time, global visibility zones are also west shifted by 5° of longitude.

7 The Islamic Calendar in Saudi Arabia

7.1 The Umm al-Qurrah Calendar

Before 1420 AH 16 April 1999, if the moon's age at sunset is ≥ 12 hours, then the **previous** day is the first day of the Islamic month, according to the old Saudi Arabian calendar criteria. (Jordanian Astronomical Society Webpage: <http://www.jas.org.jo/icop.html>)

For example, let 29th Dec of a certain year be 29 Sha'ban. If the moon sets before sunset and is only seen later in the night at 11 pm on 29th Dec, then at 5 pm the following day 30th Dec, the moon's age will be 18 hours (≥ 12 hours). Thus, 30th Dec will be declared as first day of Ramadan, even though conjunction does not occur and the new Moon was not seen at sunset.

Starting from 1420 AH 17 April 1999, Saudi changed their criteria. Now, Saudi starts the lunar month if the moon sets **after** the sun on the 29th day of the previous month, as seen from Mecca, otherwise, the next day is 30th of the month and the day after is the first day of the new month. Although the new criteria are much better than the old ones, it still ignores the actual sighting of the crescent. Also, at certain months they begin the month while the moon is not yet in conjunction. Setting of the moon after the sun does not always imply that the Moon reached conjunction.

For example, on 7 December 1999 (29 Sha'ban), the sun will set in Mecca at 17:38 LT, and the moon will set at 17:29. So since the Moon will set before the Sun, 08 December is not 1 Ramadan. Consequently, 1 Ramadan will be on 9 December.

However, in most cases (c. 85%) the lunar crescent will still be too young to be visible with the naked eye on the first evening of the month and about once a year, the month will still commence before the new Moon.

These anomalous month beginnings are caused by the fact that the sun and the moon do not set perpendicularly at the latitude of Mecca. When the moon is near its most northerly ecliptic latitude moonset can occur after sunset even before the sun and the Moon have reached conjunction.

Most people think that Saudi Arabia always adopts the actual sighting of the crescent as the basis to start Islamic month. However, previous years showed that Saudi Arabia adopts the astronomical calculations and totally ignores the actual sighting.

7.2 The Saudi Arabian Solar Zodiac Calendar

The above calendar is officially adopted in Saudi Arabia for all religious and practical purposes. However, for some key dates Saudi Arabia also employs a solar zodiacal calendar that nearly runs parallel with the Gregorian calendar. National Day, commemorating the unification of the Kingdom of Saudi Arabia on 22 September 1932, is annually observed on the day when the Sun enters the sign of Libra, which now corresponds with either 22 or 23 September. Since 1989 the Saudi Arabian fiscal year officially commences on the day when the Sun reaches the longitude 11° Capricorn and runs until the day when the Sun reaches the longitude 10° Capricorn in the next year. In an average sense, these limits correspond with the Gregorian dates 1 January and 31 December – the occasional one-day shifts caused by the Gregorian leap day are disregarded.

8 The Islamic Calendar in Singapore

The Islamic Religious Council of Singapore - Majlis Ugama Islam Singapura (MUIS), releases the Islamic Calendar in Singapore. Presently, the religious ministers of Brunei, Indonesia, Malaysia and Singapore hold an unofficial meeting every year to coordinate the major Muslim holidays in Singapore with Malaysia, Brunei and Indonesia like Hari Raya. These countries decide upon the official date of the first day of every Muslim month based on the Mabims² criteria*:

At sunset on the 29th day of the lunar month,

- (i) the moon must reach an altitude of 2°
- (ii) the sun-moon elongation must be 3°
- (iii) the age of the moon from conjunction of sunset must be 8 hrs old

However each country is not bound to follow due to religious or political reasons. For instance, Indonesia declares the Hari Raya Puasa date different from the rest of the 3 countries.

² **Mabims** stands for Menteri Agama Brunei Indonesia Malaysia Singapore.

8.1 History of Islamic Calendars in Singapore

In the 50s and 60s, the Muslim calendar in Singapore was based on sightings of the moon from Sultan Shoal, the southernmost part of Singapore. In the 70s, MUIS decided to use predictions. The Muslim calendar in Singapore is based on latitude 1 20' 34" N and longitude 103 51' 08" E, where the Islamic Centre of Singapore (old MUIS building) is. If the moon was above horizon during sunset of the 29th day of the month, even if the moon is just 1°, the new month would start. In the 80s they decided to follow a variation of the 1978 Istanbul criterion where the altitude of the Moon should be more than 7° at sunset. In the 90s, they switched to the 2°, which is the simplification of the Mabims criteria*.

8.2 Analysis of the Islamic Calendar in Singapore based on Ilyas C, RGO 67 and Shaukat

Based on the reliability and limitations of the above criterions, we compare Ilyas C, RGO 67 and Shaukat criterions for the Islamic Calendar in Singapore.



The date of the criterion agrees with Mabims.

Calendar 1998

Month	Muslim	Age of Moon on				Mabims	Agreement Ratio
		Mabims	Ilyas_C	RGO 67	Shaukat		
Jan	30/1(P)	29/1				29.31 hr	3/12
Feb	28/2	27/2	28	28	28	17.90 hr	
Mar	29/3	28/3	29	29	29	8.00 hr	
Apr	28/4	27/4				23.43 hr	
May	27/5	26/5	27	27	27	15.59 hr	
Jun	25/6	25/6 (24/6)	25	25	25	31.38 hr	
Jul	25/7	24/7	25	25	25	21.55 hr	
Aug	23/8	22/8	23	23	23	9.15 hr	
Sep	22/9	21/9	22	22	22	18.00 hr	
Oct	22/10	21/10				24.71 hr	
Nov	20/11	20/11 (19/11)	20	20	20	30.42 hr	
Dec	20/12	19/12	20	20	20	12.34 hr	

Calendar 1999

Month	Muslim	Age of Moon on				Mabims	Agreement Ratio
		Mabims	Ilyas_C	RGO 67	Shaukat		
Jan	19/1(P)	18/1	19	19	19	19.50 hr	
Feb	18/2	17/2				28.70 hr	
Mar	19/3	18/3	19	19	19	16.47 hr	
Apr	17/4	17/4 (16/4)	17	17	17	30.78 hr	

May	17/5	16/5				23.02 hr	4/12
Jun	15/6	14/6	15	15	15	16.13 hr	
Jul	14/7	13/7	14	14	14	8.87 hr	
Aug	13/8	12/8				24.10 hr	
Sep	11/9	10/9	11	11	11	13.06 hr	
Oct	11/10	10/10				23.33 hr	
Nov	9/11	9/11 (8/11)	9	9	9	30.96 hr	
Dec	9/12	8/12	9	9	9	12.43 hr	

Calendar 2000

Month	Muslim	Mabims	Age of Moon on			Agreement Ratio
			Ilyas_C	RGO 67	Shaukat	
Jan	8/1(P)	7/1	8	8	8	16.97 hr
Feb	7/2	6/2		7	7	22.29 hr
Mar	7/3	7/3 (6/3)	7	7	7	30.03 hr
Apr	6/4	5/4	6	6	6	16.99 hr
May	5/5	5/5 (4/5)	5	5	5	30.91 hr
Jun	4/6	3/6				22.91 hr
Jul	3/7	2/7	3	3	3	19.91 hr
Aug	1/8	31/7	1	1	1	8.86 hr
	31/8	30/8				24.84 hr
Sep	29/9	28/9	29	29	29	15.09 hr
Oct	29/10	28/10				26.88 hr
Nov	27/11	26/11	27	27	27	11.70 hr
Dec	27/12(P)	26/12	27	27	27	17.75 hr

The cells highlighted in blue indicate “problematic” dates, namely 25/6/98, 20/11/98, 17/4/99, 9/11/99, 7/3/00, 5/5/00. They are “problematic” because they do not follow the rule. If the moon is visible on say, 5/5/00 evening, then the official first day of that Muslim month should fall the following day, 6/5/00. In the Mabims column, the dates not in the brackets indicates the day when the all three of the Mabims criteria are fulfilled.

However, MUIS specifies that out of the three Mabims criteria, the moon’s altitude (2°) is the only deciding factor for visibility, while the other two will determine the degree of visibility. Let’s see it more clearly on MoonCalc:

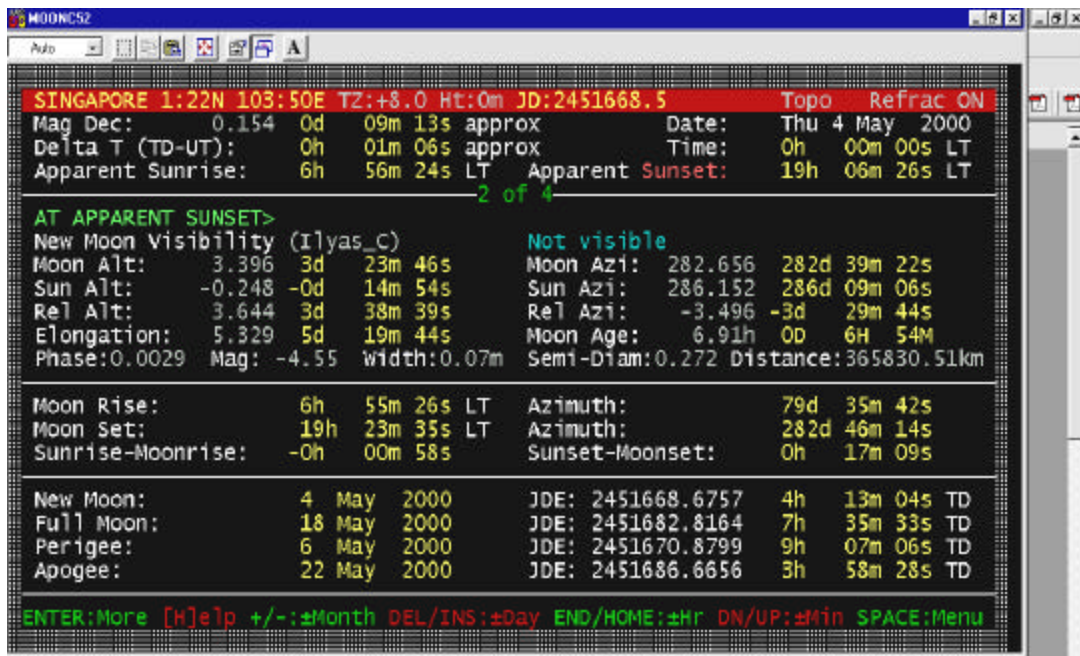


Fig. 22

On 4/5/00

Altitude of the moon is 3.396° 2°

Elongation is 5.329° 3°

Moon Age is 6.91hr < 8hr (Does not satisfy one of Mabims criteria)

However, since the moon's altitude is already 2° , it means that the moon is visible on the evening of 4/5/00 and not 5/5/00.

Calendar 2001

						Age of Moon on	
Month	Muslim	Mabims				Mabims	Agreement Ratio
			Ilyas_C	RGO 67	Shaukat		
Jan	26/1	25/1	26	26	26	22.20 hr	
Feb	25/2	24/2				26.99 hr	
Mar	26/3	25/3	26	26	26	9.88 hr	
Apr	25/4	24/4		25	25	19.70 hr	
May	24/5	23/5	24	24	24	8.35 hr	4/12
Jun	23/6	22/6				23.25 hr	
Jul	22/7	21/7	22	22	22	15.54 hr	
Aug	20/8	19/8	20	20	20	8.30 hr	
Sep	19/9	18/9				24.58 hr	
Oct	18/10	17/10	18	18	18	15.49 hr	
Nov	17/11	16/11				28.19 hr	
Dec	16/12(P)	15/12	16	16	16	14.23 hr	

Calendar 2002

						Age of Moon on	
Month	Muslim	Mabims				Mabims	Agreement Ratio

			Ilyas_C	RGO 67	Shaukat	
Jan		14/1		15	15	21.77 hr
Feb	14/2	13/2				27.67 hr
Mar		14/3	15	15	15	9.24 hr
Apr		13/4	14	14	14	15.81 hr
May		13/5		14	14	24.35 hr
Jun		11/6	12	12	12	11.40 hr
Jul		11/7				24.83 hr
Aug		9/8	10	10	10	16.00 hr
Sep		8/9 (7/9)	8	8	8	31.94 hr
Oct		7/10				23.63 hr
Nov		5/11	6	6	6	14.26 hr
Dec	6/12(P)	5/12				27.37 hr

4/12

Calendar 2003

Age of Moon on						
Month	Muslim	Mabims	Ilyas_C	RGO 67	Shaukat	Mabims Agreement Ratio
Jan		3/1	4	4	4	14.79 hr
Feb	3/2	2/2				24.53 hr
Mar		3/3	4	4	4	8.74 hr
Apr		2/4	3	3	3	15.89 hr
May		2/5	3	3	3	22.87 hr
Jun		1/6				30.81 hr
Jul		30/6	1	1	1	16.60 hr
		30/7				28.40 hr
Aug		28/8		29	29	17.74 hr
Sep		27/9 (26/9)	27	27	27	31.83 hr
Oct		26/10				22.01 hr
Nov	25/11(P)	24/11	25	25	25	11.90 hr
Dec		24/12				25.37 hr

5/12

Calendar 2004

Age of Moon on						
Month	Muslim	Mabims	Ilyas_C	RGO 67	Shaukat	Mabims Agreement Ratio
Jan	23/1	22/1	23	23	23	14.21 hr
Feb		21/2				26.05 hr
Mar		21/3	22	22	22	12.56 hr
Apr		20/4	21	21	21	21.78 hr
May		20/5				30.25 hr
Jun		18/6	19	19	19	14.75 hr
Jul		18/7				23.88 hr
Aug		16/8	17	17	17	9.83 hr
Sep		15/9		16	16	20.57 hr
Oct		14/10	15	15	15	8.08 hr
Nov	14/11(P)	13/11		14	14	20.39 hr
Dec		12/11	13	13	13	9.52 hr

3/12

Calendar 2005

						Age of Moon on	
Month	Muslim	Mabims	Ilyas_C	RGO 67	Shaukat	Mabims	Agreement Ratio
Jan	12/1	11/1				23.19 hr	3/12
Feb		9/2	10	10	10	12.88 hr	
Mar		11/3				26.12 hr	
Apr		9/4	10	10	10	14.64 hr	
May		9/5				26.35 hr	
Jun		7/6	8	8	8	13.24 hr	
Jul		7/7		8	8	23.22 hr	
Aug		5/8	6	6	6	8.18 hr	
Sep		4/9	5	5	5	16.37 hr	
Oct		4/10		5	5	24.47 hr	
Nov	4/11(P)	2/11	3	3	3	9.43 hr	
Dec		2/12	3	3	3	19.91 hr	

In 2005, we observe that according to Mabims criteria on MoonCalc, the crescent can be seen on 2/11/05, yet, the official Hari Raya Puasa falls on 4/11/05. The question is, why isn't Hari Raya Puasa on 3/11/05, since the crescent is visible on 2/11/05? This is because, the values on MoonCalc are slightly different from that of the programme used by MUIS. Below is the data that you would see on MoonCalc for 4/11/05:

SINGAPORE 1:22N 103:50E TZ:+8.0 Ht:0m JD:2453676.5 Topo Refrac ON

Mag Dec: MAGMODEL.DAT file not found Date: Wed 2 Nov 2005

Delta T (TD-UT): 0h 01m 11s approx Time: 0h 00m 00s LT

Apparent Sunrise: 6h 46m 14s LT Apparent Sunset: 18h 50m 14s LT

2 of 4

AT APPARENT SUNSET>

New Moon Visibility (Ilyas_C) Not visible

Moon Alt: 2.080 2d 04m 47s Moon Azi: 250.994 250d 59m 38s

Sun Alt: -0.248 -0d 14m 54s Sun Azi: 255.163 255d 09m 46s

Rel Alt: 2.328 2d 19m 41s Rel Azi: -4.169 -4d 10m 09s

Elongation: 4.931 4d 55m 53s Moon Age: 9.43h 0d 9h 26m

Phase:0.0023 Mag: -4.48 Width:0.06m Semi-Diam:0.260 Distance:383971.17km

Moon Rise: 6h 42m 02s LT Azimuth: 106d 19m 46s

Moon Set: 19h 01m 43s LT Azimuth: 251d 02m 45s

Sunrise-Moonrise: -0h 04m 12s Sunset-Moonset: 0h 11m 29s

New Moon: 2 Nov 2005 JDE: 2453676.5595 1h 25m 37s TD

Full Moon: 16 Nov 2005 JDE: 2453690.5407 0h 58m 36s TD

Perigee: 10 Nov 2005 JDE: 2453684.5110 0h 15m 51s TD

Apogee: 23 Nov 2005 JDE: 2453697.7628 6h 18m 30s TD

ENTER:More [H]elp +/-:Month DEL/INS:Day END/HOME:Hour DN/UP:Min SPACE:Menu

Fig. 23

Altitude of the moon is 2.080° 2°

Elongation is $4.931^\circ \pm 3^\circ$

Moon Age is $9.43\text{h} \pm 8\text{h}$

All three of the Mabims criteria (using MoonCalc) are satisfied. However, the programme that MUIS uses shows an altitude of the moon to be $< 2^\circ$ (i.e. the moon is not above the horizon at local sunset and hence, cannot be seen). The moon will then be seen only on the following evening and 4/11/05 will be Hari Raya Puasa.

Extending our analysis to the agreement ratio between the 3 criterions and Mabims, we realize that they agree for at most 5 (out of 12) months per year. While Mabims criteria is decided upon by the 4 countries, we do not know the basis of these results.

9 Conclusion

We have seen how Hari Raya Puasa and Hari Raya Haji (or more precisely, the first day of the Muslim month) can be determined, be it by physical moon-sighting or prediction criterions. Yet, the problem of predicting when the new Moon will become visible is indeed both astronomical and physical. The visibility of the thin lunar crescent is of cultural and religious importance, since the lunar phase cycle is the basis for the Islamic calendars of the Muslim communities. Therefore, the determining of the first day of the month based on physical moon sighting always carries the essence of the Muslim religion. However, physical moon sighting has its own error and limitations too; and for countries that do not have clear skies to observe the moon like Singapore, calendar planning is important for festive celebrations. Thus, criteria which control the phenomenon are being studied with great effort. With so much discussion on the different prediction criterions, we see that none of them is 100% accurate. Therefore, these criterions are being looked into year by year to obtain greater accuracy. One may question the reliability of astronomical software being used today. But MoonCalc is considered to be one of the more reliable one. You may ask if there is the possibility of having a worldwide Islamic calendar for all the countries to celebrate the Muslim festivals together. Nevertheless, some countries use a slightly different set of criteria from one another because of religious reasons, while others do not agree upon the same date of Muslim festivals due to political reasons. What is hoped to achieve in the future development of the Islamic Calendar then, is the improvement of the accuracy of the prediction criterions.

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