Calculating and Observing the Crescent Moon

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The Lunar Ephemeris

The astronomical new moon is defined to occur when the geocentric apparent longitudes of the sun and moon are exactly equal. Although the average interval between new moons is approximately 29.53 days, any particular interval may vary from this average by up to about a quarter day. Thus an accurate calculation of the moon's phases requires accurate theories for the motions of the sun and moon. We can now calculate the position of the moon to better than 0.001 arc-second for dates in the current era. While this accuracy is required for scientific studies of the dynamics of the earth/moon system, it is not needed for calculating lunar phases. In practice, we calculate time of phases to an accuracy of one minute for several decades into the future.[1]

The Crescent Moon—Observation and Theory

Sightings of young lunar crescents are not only the basis of lunar calendars, they are a source of friendly competition among astronomers. While there have been a number of authentic sightings of the moon at ages of less than 20 hours, sightings at less than 15 hours are extremely rare.[2] Such

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1. B. L. Morrison, "Phases of the Moon 1960-2003," U.S. Naval Observatory Circular No. 119 (Nautical Almanac Office, U. S. Naval Observatory, 1968); R. L. Schmidt, "Phases of the Moon 2000-2049," U. S. Naval Observatory Circular No. 169 (Nautical Almanac Office, U. S. Naval Observatory, 1986).

2. J. Ashbrook, "Observing very thin lunar crescents," *The Astronomical Scrapbook* (Cambridge, MA: Sky Publishing, 1984).

sightings require optimal observing conditions and an experienced observer with keen eyesight.

Precise prediction of the time and location of first sighting is hampered by observational difficulties. Some of the relevant factors, such as the age of the moon, the elongation of the moon from the sun, and the position of the moon in its orbit, can be calculated accurately. Other factors depend on local observing conditions and may not be known in advance. Horizons are seldom perfectly flat, and the transparency of the air, even in good weather, depends on location, time of day and season. Ultimately, a successful sighting requires a perceptive and knowledgeable observer. These problems, of course, have not deterred astronomers from developing prediction models. A book by Ilyas offers a good survey and an extensive bibliography.[3]

Efforts by Bruin,[4] Ilyas,[5] and Schaefer[6] have resulted in new interest in the problems of calculating first visibility. Perhaps Ilyas's greatest contribution has been to shift concern away from estimating the minimum age or minimum altitude at which the crescent can be observed at a given location. Instead, taking a global perspective, he defines a curve on the earth's surface that determines the limit of first visibility as a function of longitude and latitude. He calls the curve the "international lunar date line" (ILDL). This line is the center of a zone of longitude in which the ability to sight the crescent depends critically on atmospheric conditions and the sensitivity of the observer. Locations west of this zone should see the crescent, provided weather is favorable. Locations east of the zone will not see the crescent until the next evening. Ilyas estimates the width of this zone to be about 30° east and west of the ILDL. Schaefer has adopted Ilyas's concept of the ILDL, but he has developed a more sophisticated theoretical model. A critical parameter in Schaefer's model is the visual extinction coefficient coefficient k_v, which can be measured by astronomical observations.

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3. M. Ilyas, *A Modern Guide to Astronomical Calculations of Islamic Calendar, Times & Qibla* (Kuala Lumpur: Berita Publishing, 1984).

4. Bruin, F. 1977. "The First Visibility of the Lunar Crescent." *Vistas in Astronomy* 21: 331–358.

5. Ilyas, *A Modern Guide to Astronomical Calculations of Islamic Calendar, Times & Qibla.*

6. B. E. Schaefer, *Proceedings of the Lunar Calendar Conference* (Herndon: IIIT, 1988).

Incorporated in this model are data from new observations that Schaefer has made at a variety of locations.

The astronomical new moon of April 28, 1987 provided an opportunity for testing some of the prediction models. At the time of sunset on the east coast of the United States, the moon was about 22 hours old. By the time of sunset on the west coast, it was more than 25 hours old. The international lunar date line of Ilyas[7] predicted visibility for forty-eight contiguous states of the United States. Schaefer's ILDL[8] is based on an extinction value of $k_v = 0.3$. A traditional reference standard was provided by H. M. Nautical Almanac Office of the United Kingdom.[9] They determined the longitude and latitude at which the apparent altitude of the moon at sunset is 10°, and the sun and moon are at the same azimuth.[10] According to this, first sighting should occur at longitude 86°15'.4 west and latitude 33°30'.1 north. This is in the state of Alabama in the southeastern United States. Figure 1 shows the predictions from the models mentioned above. To illustrate the critical role played by atmospheric extinction, curves from Schaefer's model are shown for $k_v = 0.2$ and 0.4, where 0.2 is remarkably good and 0.4 is very bad transparency.

Observing Program

We tried to establish an observing program with a minimum of time, expense, and effort. Our goal was to create a good distribution of observers across the United States. A week before the event we began calling friends and colleagues to solicit their assistance. Observers were given the times of sunset and moonset, and the altitude and azimuth of the moon at sunset for their locations. They were asked to report whether the moon was sighted and the time of such a sighting. Environmental information, such as cloud cover was also requested. Although we began with about twenty observers on our list, word gradually spread and we picked up a much larger collec-

7. Ilyas, *A Modern Guide to Astronomical Calculations of Islamic Calendar, Times & Qibla.*

8. Schaefer, *Proceedings of the Lunar Calendar Conference.*

9. B. D. Yallop, "Earliest Sighting of the New Moon in 1987," RGO Astronomical Information Sheet, No. 50 (H. M. Nautical Almanac Office, Royal Greenwich Observatory, 1987).

10. B. D. Yallop, private communication. This criterion is based on the results of Bruin.

tion of observers than we had anticipated. In some cases, astronomy instructors took their classes out for an evening of practical observing. At one observatory, 75 visitors attending a star party were pressed into service. Figure 2 shows the locations of the observing sites. Table 1 lists these locations with times of sunset and moonset, and the position of the moon. In Table 2 we list results of the observations. Since some of our information came second hand, these tables may be incomplete and not entirely accurate. At the present time we know of about 180 observers at 46 localities.

The Observations

As any astronomer can tell you, the earth is shrouded in clouds. Figure 3 is a satellite photo of North America, taken at 5:31 p.m., eastern daylight time, on April 28. Where heavy cloud cover was not totally obstructing observations, haze vapor trails and thin clouds seemed to cause difficulties. Many of the observers reported some atmospheric obstructions, with the result that there were remarkably few sightings, considering the number of observing sites. In fact, the northeastern states had a snowstorm that evening, and much of the west coast had rain. In the midwestern states, where we expected the moon to be visible, clouds or haze made observations difficult or impossible.

Figure 4 shows locations from which the lunar crescent was sighted. The easternmost location is Washington, DC, where naked-eye sightings were made after the crescent was first located with binoculars. Along the east coast, initial sighting with binoculars was generally necessary for naked-eye observations. There were two exceptions to this. The first was an astronomy class from Appalachian State University in the mountains of North Carolina, in which a group of fifteen students observed the crescent without optical aids. (One student did use binoculars, but care was taken to ensure that he did not influence the other students.) Oddly enough, their instructor did not see the moon. By coincidence the instructor's vision had been checked that day as 20/25. Although the instructor is by no means elderly, this may be an indication that youthful eyes are preferable to experienced eyes. The second exception is enigmatic, and we must consider it as a possible observation. In Blackstone, Virginia, the crescent was apparently sighted by an eight-year-old girl. Her sighting was made at the time we would expect, midway between sunset and moonset. Subsequently she was able to draw the scene; her drawing is consistent with our expectations

(Figure 5). It is impossible to estimate the extent to which her claim of a sighting and her subsequent drawing had been influenced by prior knowledge and imagination. Her instructor, a young adult with good eyesight but a poor horizon, did not see the moon.

In the midwestern states, sightings were made only with binoculars. However, in the Gulf Coast states of Louisiana and Texas, purely naked-eye sightings were reported. From western states the crescent was clearly a naked-eye object.

Conclusions

Of the models tested, the ILDL of Schaefer with extinction coefflcient $k_v = 0.3$ best defines the limit of the sightings. Since we had no observers on the Atlantic Ocean, we did not thoroughly test the model of Ilyas. It appears, however, that for this lunar crescent, Ilyas's ILDL provided an optimistic eastern limit of observability. Further observations are needed to test these models. Such observations may lead to a reduction in the width of the zone in which sightings critically depend on observing conditions.

Since the weather cannot be controlled, every effort should be made to aid the observer. Observers should be located with flat, unobstructed western horizons, should know where to look, and should clearly understand what to look for. The use of binoculars is highly recommended. Some observers estimated that their sighting was delayed because the moon appeared somewhat north of where they were looking. One observer initially mistook a small vapor trail for the crescent. Observers who used binoculars invariably sighted the crescent before naked-eye observers. And having once found the crescent with binoculars, the observer had an advantage in making a naked-eye sighting. If these points seems obvious, they are often ignored by people making or judging observations.

This study raises a few questions for future research. Do youthful observers have an advantage in making naked-eye sightings? The possibility of deterioration of the eye with age might be tested by controlled experiments in a planetarium. What role does mass psychology play in group observing? Does the initial report of a sighting stimulate real or imagined sightings by other observers in the group? If secondary sightings are real, do they result from increased concentration or from knowing more precisely where to look?

Acknowledgments

In preparing this observational experiment, we imposed upon the good will of many friends and colleagues. Invariably they responded with interest and good will. Many went well out of their way to make and communicate their observations. When we feel that all reports have come in, we shall publish a list of all participants. Two individuals must be singled out, however. At meetings of the International Astronomical Union in 1985 we were fortunate to meet Dr. Mohammad Ilyas. He discussed his work with us and elicited our interest in a conference on the lunar calendar. In addition, we must acknowledge the interest and assistance of Dr. Bradley Schaefer. He shared his theoretical work with us in advance of publication, and he organized a large group of the observers.

Table 1. Observing Sites

City	ST	Long.	Lat.	Time Zone	Sun-set	Moon-set	Moon's Alt @ SS	Moon's Az @ SS
Hanover	NH	72.3	43.7	EDT	19:48	20:52	9.5	288.7
Weston	MA	71.3	42.4	EDT	19:41	20:44	9.6	288.4
Cambridge	MA	71.1	42.4	EDT	19:40	20:43	9.6	288.4
Montpelier	VT	72.6	44.3	EDT	19:50	20:56	9.6	288.7
Glastonbury	CT	72.6	41.7	EDT	19:45	20:48	9.6	288.3
Stormville	NY	73.7	41.6	EDT	19:49	20:52	9.7	288.3
Hamilton	NY	75.6	42.8	EDT	19:59	21:03	9.7	288.4
Ithaca	NY	76.5	42.4	EDT	20:02	21:06	9.7	288.4
Ocean City	MD	75.1	38.4	EDT	19:49	20:48	9.7	288.0
Washington	DC	77.0	38.9	EDT	19:57	20:58	9.8	288.0
State College	PA	77.9	40.8	EDT	20:04	21:07	9.8	288.1
Easton	PA	75.2	40.7	EDT	19:53	20:56	9.8	288.1
Blackstone	VA	78.0	37.1	EDT	19:58	20:57	9.9	287.8
Chapel Hill	NC	79.1	35.9	EDT	20:00	20:59	9.9	287.8
Greenville	NC	77.4	35.6	EDT	19:53	20:51	9.8	287.8
Boone	NC	81.7	36.3	EDT	20:12	21:11	9.9	287.8
Tampa	FL	82.5	28.0	EDT	20:02	20:55	9.9	287.8
Fort Myers	FL	81.9	26.6	EDT	19:58	20:50	9.8	287.8
Atlanta	GA	84.4	33.8	EDT	20:18	21:16	10.0	287.7
Macon	GA	83.7	32.8	EDT	20:14	21:11	10.0	287.7
Columbus	OH	83.0	40.0	EDT	20:23	21:26	10.0	288.0
Warren	MI	83.0	42.5	EDT	20:28	21:34	10.0	288.3
Lansing	MI	84.6	42.7	EDT	20:35	21:41	10.0	288.4
Tuscaloosa	AL	87.5	33.2	CDT	19:30	20:28	10.1	287.7
Chicago	IL	87.7	41.9	CDT	19:46	20:51	10.0	288.2
New Orleans	LA	90.1	30.0	CDT	19:36	20:31	10.1	287.8
St. Louis	MO	90.2	38.6	CDT	19:50	20:53	10.2	287.9
Columbia	MO	92.2	39.0	CDT	19:58	21:02	10.3	287.8
Des Moines	IA	93.6	41.6	CDT	20:09	21:15	10.3	288.1
Austin	TX	97.7	30.3	CDT	20:06	21:04	10.5	287.6
Mt Locke	TX	104.0	30.7	CDT	20:32	21:31	10.6	287.6
Denver	CO	105.0	39.7	MDT	19:51	20:57	10.6	287.8
Rocky Ford	CO	103.7	38.0	MDT	19:43	20:47	10.6	287.7
Socorro	NM	106.9	34.1	MDT	19:49	20:50	10.7	287.6
VLA	NM	107.6	34.0	MDT	19:52	20:53	10.7	287.6
Tucson	AZ	110.9	32.2	MST	19:02	20:03	10.9	287.6
Flagstaff	AZ	111.6	35.2	MST	19:10	20:13	10.8	287.6
Salt Lake City	UT	111.9	40.8	MDT	20:20	21:29	10.9	287.8
Walla Walla	WA	118.3	46.1	PDT	19:57	21:14	10.9	288.4
Costa Mesa	CA	117.9	33.7	PDT	19:32	20:36	11.1	287.5
Santa Barbara	CA	119.7	34.4	PDT	19:41	20:45	11.1	287.5
Oakland	CA	122.2	37.8	PDT	19:56	21:04	11.3	287.5
Los Angeles	CA	118.4	34.1	PDT	19:35	20:38	11.1	287.5
Pasadena	CA	118.1	34.2	PDT	19:34	20:38	11.1	287.5
Mt Hamilton	CA	121.6	37.3	PDT	19:53	21:00	11.2	287.5
Victoria	BC	123.4	48.5	PDT	20:23	21:45	10.9	288.8

Table 2. Results of Observations

City	ST	No. of Observers	Crescent Sighted	Binoculars Used	Weather
Hanover	NH	1	No		snow
Weston	MA	1	No		snow
Cambridge	MA	4	No		snow
Montpelier	VT	1	No		snow
Glastonbury	CT	1	No		clouds
Stormville	NY	1	No		clouds
Hamilton	NY	1	No		clouds
Ithaca	NY	1	No		clouds
Ocean City	MD	1	No		clouds
Washington	DC	10	Yes & No	Yes & No	haze & cloud
State College	PA	1	No		clouds
Easton	PA	1	No		clouds
Blackstone	VA	2	Yes & No	No	
Chapel Hill	NC	1	No		clouds
Greenville	NC	1	No		clouds
Boone	NC	17	Yes & No	Yes & No	clear, haze
Tampa	FL	3	No		clear, haze
Fort Myers	FL	1	Yes	Yes	
Atlanta	GA	2	No	No	clear
Macon	GA	1	No	No	haze
Columbus	OH	1	No	No	cloudy
Warren	MI	1	No		clouds
Lansing	MI	1	Yes	Yes & No	haze
Tuscaloosa	AL	1	No		haze
Chicago	IL	5	No		clear
New Orleans	LA	1	Yes	No	
St. Louis	MO	1	No		clouds
Columbia	MO	7	No		clouds
Des Moines	IA	1	No	Yes	vapor trails
Austin	TX	2	Yes		
Mt Locke	TX	82	Yes	Yes & No	
Denver	CO	1	No		clouds
Rocky Ford	CO	1	No		clouds
Socorro	NM	1	No		haze
VLA	NM	2	No		clouds
Tucson	AZ	1	No		clouds
Flagstaff	AZ	1	No		clouds
Salt Lake City	UT	1	Yes	Yes	cloud bands
Walla Walla	WA	10	No		thunderstorm
Costa Mesa	CA	1	No		clouds
Santa Barbara	CA	2	No		clouds
Oakland	CA	1	No		fog
Los Angeles	CA	1	No		cloudy
Pasadena	CA	2	No		fog
Mt Hamilton	CA	1	Yes		clouds
Victoria	BC	1	No		clouds

Figure 1.

Predictions of first visibility of crescent moon of April 28, 1987. The curves specify the International Lunar Date Line (ILDL) as predicted by Ilyas and Schaefer. The point of first visibility according to an old Babylonian rule, as used by Yallop is marked in Alabama.

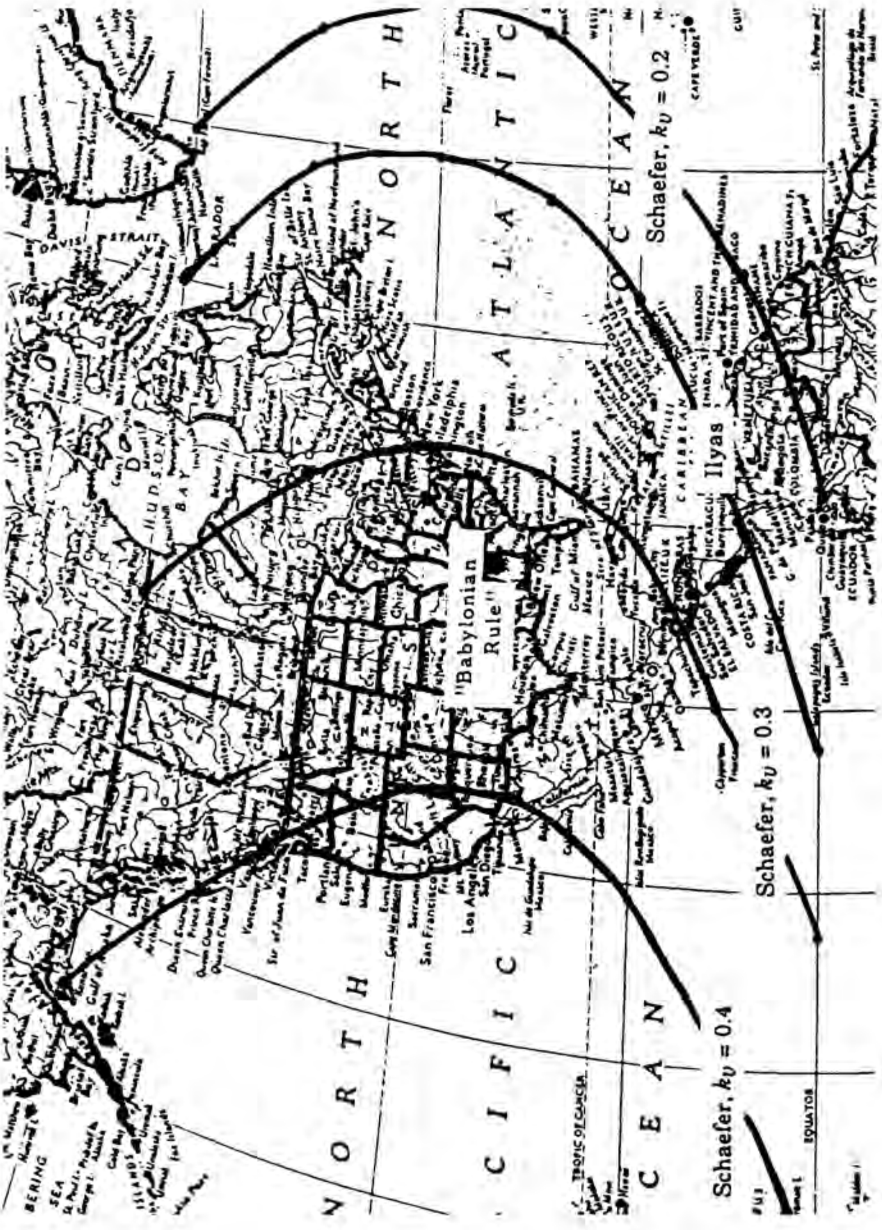

Figure 2.
Locations of Observing Sites, April 28, 1987.

Figure 3.
Weather Satellite Photograph, April 28, 1987, 5:31 p.m., EDT.

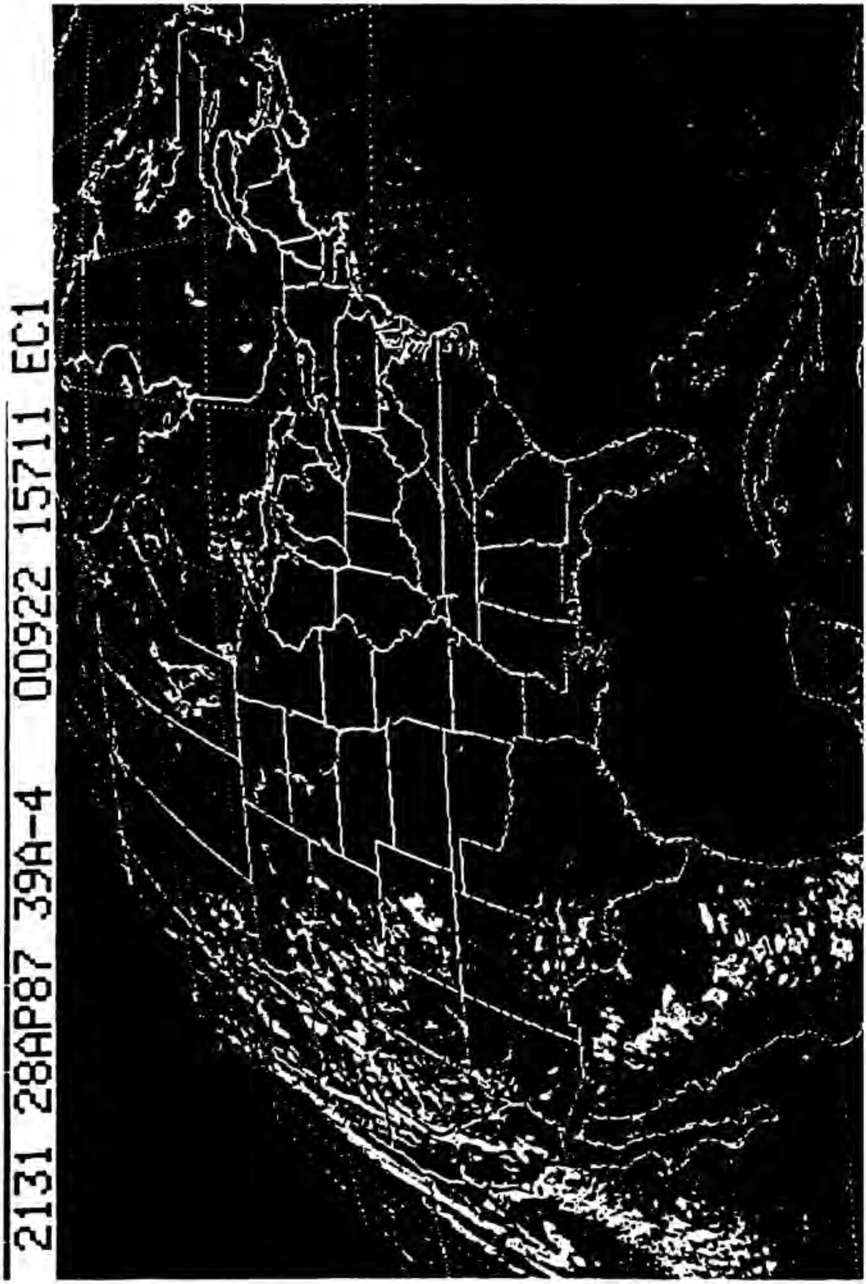

Figure 4.
Sites Where Crescent Moon Was Sighted on April 28, 1987

Figure 5.
Drawing of Lunar Crescent by Takeisha Tucker, Age 8,
of Blackstone, Virginia, on April 28, 1987