First Visibility of the Lunar Crescent

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Abstract
Astronomical observatories are often asked to predict the visibility of the young crescent moon by communities (especially Islamic and Karaite) which use traditional lunar calendars. The SAAO has provided such information for many years, but the early 1990s were a watershed of sorts. Astronomical visibility factors in those years created an unusually severe bias against visibility of the Ramadaan and Shawwall crescents from the southern half of the continent, relative to North Africa and the Mideast (to an extent not seen since the 1860s!). The perplexity caused by the resulting delay in sightings ultimately led to a much greater level of communication between astronomers and crescent-watching community. The SAAO began collecting, systematizing, and propagating the astronomical information available on the crescent visibility issue, the current results of which are summarized here.

Introduction to Young Crescents
First we review a few basics. Because of the earth's motion around the sun, the sun appears to move along a path through the sky called the **ecliptic**. The sun's position on this path (measured from the point where it crosses the equator moving north) is the sun's **celestial longitude**. Each new astronomical lunar month (lunation) begins at the moment when the center of the moon has the same celestial longitude as the center of the sun, from the perspective of the center of the earth, i.e. the moment when the moon "passes" the sun. This is the moment of astronomical **new moon**, and it occurs at the same instant everywhere since it does not depend in any way on the viewer's perspective.

At this time the moon is always invisible from the earth. When the moon first becomes visible again (always more, usually much more, than half a day after astronomical new moon), observers see a **young crescent moon**. Note that usually the moon does not have the same **celestial latitude** as the sun, but instead passes above or below it, so there is no eclipse. The kind of crescent considered here is typically much younger, fainter, narrower, and shorter than the bright arc which comes to most people's minds when they recall an occasion of having noticed the crescent. Sadly, much of the world's population is not privileged to enjoy the amazing sight of the thinnest, shortest crescents because of poor air transparency due to dust, haze, humidity, pollution, chronic cloudiness, and other hindrances to observing the celestial sky.

SAAO Crescent Visibility Program
The SAAO effort to clarify this issue for the public has been threefold. Firstly information has been collected and presented at our Lunar Crescent Visibility homepage on the Internet. Secondly critical observations have been carried out when possible. Lastly an annual brochure of visibility predictions for South Africa and, for comparative purposes, locations in the Middle East has been made available to visitors and by post.

The SAAO crescent homepage (**http://www.saao.ac.za/sky/vishome.html**) contains a database of all credible, critical observations which we were able to obtain from the literature, the Internet and our own efforts. The website has our annual visibility predictions, based upon the SAAO visibility criteria, that are founded on the observations in the database. The website also has links to related ones, two of which it would be remiss not to mention at this point. One is the Mooncalc program (**http://www.starlight.demon.co.uk/mooncalc**) by Monzur Ahmed which is extremely useful for all information relating to the predicted state and appearance of the moon, and is probably unsurpassed in its graphical depiction of the start of lunar months across the globe. The other site is the Islamic Crescents' Observation Project (**http://www.jas.org.jo/icop.html**), a global project organized by the

Arab Union for Astronomy and Space Science and the Jordanian Astronomical Society to gather information about actual crescent observations at the start of each lunar month, and about the official first day in different countries.

Our crescent observations are normally undertaken at Signal Hill, Cape Town, (long. 18.41°, lat. -33.92°, alt. 350m) which is easily accessible, borders directly on the South Atlantic, and enjoys a sea horizon for the entire annual azimuth range of the setting moon. The usual optical device is a pair of 20x80 binoculars (3.5° field) attached to an alt-az mount made by SAAO technician W.P.Koorts (**http://www.saao.ac.za/~wpk**), which is marked off in degrees. The pointing is calibrated on several convenient local landmarks, the sun, and any brighter planets available in the twilight. Signal Hill is an excellent location for spotting the most difficult crescents, and precise pointing with a very stable mounting contributes to the confidence in assessing the most challenging cases.

SAAO Crescent Visibility Database

The database at our website has been compiled in an effort to muster all sufficiently useful observations bearing on the issue of the visibility or otherwise of the crescent. Below is cited a sample entry to give an idea of the information tabulated for each event. This includes a critical attribute, the visibility judgment, in terms of the following basic scheme:

A
: Seen with the naked eye

B
: Seen with the naked eye, but remarked or inferred as being very near the limit of feasibility

C
: Not seen with the naked eye, but with binoculars

D
: Not seen with the naked eye or binoculars, but with a telescope

E
: Not seen with the naked eye, no optical aid mentioned

F
: Not seen even with optical aid

The database order is chronological. For brevity it is limited to crescents within a restricted altitude range relative to the setting sun, which excludes all relatively trivial sighting events. Multiple observers at the same event and nearly the same location are condensed to one entry based on the most successful credible outcome to save space. For further minor details see the website.

The basic sources for the "historical" sightings are the compilations by Schaefer (1988), Schaefer et al. (1993), Doggett and Schaefer (1994), Ilyas (1994), and Schaefer (1996). The numerical quantities in the database were rederived with the Interactive Computer Ephemeris (ICE) program supplied by the US Naval Observatory Almanac Office. A sample line from the database is:

date	place(person)	long	lat	alt(m)	zone	vis	set(rise) UT	dalt	daz	lag
2000 12 26	Sutherland	20.81	-32.38	1800	+2	A	15:48:14	6.8	7.0	42

The following abbreviations are used in the database, and some of the terms are used below:

long
: longitude of site

lat
: latitude of site

alt
: altitude of site in meters

zone
: time zone

vis
: visibility judgment from A-F scheme

set
: time of sunset (or sunrise if parenthesized)

dalt
: apparent altitude of the lower limb of the moon (with topocentric parallax and refraction corrections), at moment of sunset (or sunrise)

daz
: moon azimuth minus sun azimuth, at moment of sunset (or sunrise)\\

lag
: moonset(to nearest minute) minus sunset(to nearest minute), or analogously for moonrise and sunrise

arcl
: arc of light, the angle subtended at the center of the earth by the center of the moon and the center of the sun

%ill
: fraction of the lunar disk which is illuminated

time4
: time when center of the sun is at 4° below the horizon, which is reasonably close to the twilight time of optimum (though transient) visibility of the most difficult crescents

dalt4
: dalt at time4

daz4
: daz at time4

new moon
: time of nearest new moon by day, hour, and minute (UT)

Lunar Crescent Visibility

The great advantage of a quantitative online database of this sort is its utility for judging the likelihood of visibility of any future crescent based upon the record of past experience. The study and synthesis of crescent visibility criteria has been much advanced by recent work (Schaefer (1993), Ilyas (1994), Loewinger (1995), McPartlan (1996), Yallop (1997), and Fatoohi et al.(1998, 1999)), wherein may be found references to the earlier literature. At least a brief sketch of the factors involved is necessary for comprehending the results below.

It is clear that the chance for visibility of the crescent **increases** with the growth of the so-called arc of light, viz. the angular separation of the sun and moon. As the sun-moon angle increases, so does the thickness or diametric extent of the crescent. Also the circumferential extent grows to the complete 180° arc, and the surface brightness of the crescent increases with the illumination angle. Visibility is also promoted by the apparent diameter being enhanced, as near perigee.

The visibility of the crescent is clearly **decreased** by atmospheric extinction, viz. the effect of the opaqueness of the air through which we see the moon. This is due to the molecular nature of air and worsened by haze, humidity, pollution, etc. Within the last degree or two of finally setting, the moon lies behind a "wall of obscuration" because its light must penetrate such a large column of air that only a small fraction can reach the observer, typically a percent for the cleanest air to a percent of a percent or less for hazier conditions.

To perceive the local bright patch due to the crescent against the glowing, often colorful and mottled, twilight sky, that patch must have a sufficient brightness and shape contrast with its surroundings. Hence the crescent is easier to see (a) later in the twilight, at a given altitude, (b) higher or farther sideways from the sunset point, at a given time, and (c) through air layers which are cleaner and less mottled (typically higher than a few degrees altitude) regardless. The visibility of the crescent for a nearly borderline case would just cross the threshold of possibility some 15-20 minutes into the twilight as the sky brightness decays exponentially, and remain possible until a few minutes before setting when the crescent is prematurely "extinguished" by atmospheric extinction, or lost in confusion with haze mottling in the last 1-2° of altitude. The naked-eye impression during such time is of a very small brightening of elongated but otherwise rather indistinct shape. In an optical device such an extreme crescent is a short (90° or less), needle-thin arc, little brighter than its surrounds, giving a subjective impression of "sitting on" rather than "shining out" from the glow of the sky.

It is clear that the astronomical factors governing the visibility will be those that specify, firstly, the path that the moon takes in ascending out of the sun's glare, and secondly, the speed with which the moon moves along this path. The first set of factors concerns the angle which the ecliptic makes with the horizon for a given location and season and the displacement of the moon north or south of the ecliptic due to the 5.15° tilt of the moon's orbital plane. The second set of factors concerns the moon's angular speed on the sky (which is greatest near perigee) and the relative lateness of sunset depending on longitude and season, which directly affects the age of the moon at local sunset. Clearly, the older the moon, the more vertical its celestial path upwards from the local western horizon, and the faster the moon is moving on that path, the more likely it is that a young crescent will be visible.

For each lunation (cycle of lunar phases), there will be a point on the Earth's surface where the crescent is vertically above the sun at sunset, and where the angular distance from the sun, etc. is just sufficient at sunset so that the crescent is marginally visible. That will be the easter-most point of visibility. Observers at the same latitude but farther west (assuming ideal atmospheric conditions) will find it progressively easier to see the crescent, as the moon will have moved farther from the sun by the time their location reaches the sunset line. North or south of the latitude of first visibility, the moon (for a given longitude) will lie closer to the local sunset horizon because from these places the moon will not appear directly above the sun. The event of first visibility for each latitude will consequently occur along a quasi-parabolic curve on the globe, with visibility occurring farther west as the latitude is farther north or south of the optimum.

Crescent Visibility Criteria

Since antiquity, astronomers and crescent observers have tried to find simple parameters which can be used to predict crescent visibility, usually by looking for a clear separation between occasions when the moon was visible and when it was not. A totally clear separation, however, is impossible even with an ideal parameter set: observers and conditions are both highly variable quantities.

Observers are by no means equally likely to look at the right spot at the right time, with the same visual acuity and properly aimed and focused equipment. Assuming good, properly corrected, eyesight, there are still factors like preparedness, experience, and having got various "teething troubles" out of the way beforehand, that can make a difference.

It is also clear that one must subdivide the visibility criteria into subcases for naked-eye and optically-aided viewing, since magnifying the crescent enhances its visibility. This is supported by the record ages for young crescents at the time of sighting: 15.4 hours with naked-eye, 12.7 hours with binoculars, and

12.2 hours with a telescope. That specified, one has to accept that there will be some inter-observer scatter due to eyesight, experience, and scruple of objectivity. It will be hard to reduce this inhomogeneity entirely, but sometimes there are clues about the weight to attach to significantly discrepant results.

The sensitive dependence upon atmospheric transparency is a second source of inhomogeneity in the outcome of attempted crescent sightings. Places with more cloud cover, heat and humidity, heavy urbanization and industry, biomass burning, soil and wind conditions conducive to dust and haze, etc. will be at a perennial disadvantage. However, excellent conditions would be occasionally possible even at a mediocre site, e.g. after the air is cleaned by a rainstorm, just as the best sites are not immune to appalling conditions. An observing location at high elevation generally improves the prospect of good transparency, but not inevitably so (e.g. botanical aerosols in the Great Smoky Mountains). The best one can hope for is that local weather and air transparency conditions are described by crescent observers in sufficient detail for others who would later make use of their findings.

One of the commonly used parameters related to crescent visibility, the "age of the moon" (i.e. the interval at sunset or time of sighting since the instant of new moon) serves to illustrate the third class of problem. It correlates with visibility very imperfectly due to celestial factors which are not adequately taken into account when an overly simplistic parameter is taken as a visibility index. In some circumstances it will be possible to see a moon 16 hours old, in others impossible to see a moon 36 hours old. Relying on the "age" alone leaves out other important factors such as the direction of the moon's celestial path away from the western horizon, the moon's angular speed along that path, and the size differential due to variable earth-moon distance.

(Some prefer to reckon the age from the moment of **topocentric** new moon: when the celestial longitudes of the sun and moon are equal from the perspective of a particular observing site. Although this may vary by as much as two hours from geocentric new moon, the distinction is essentially irrelevant for the predicting of visibility. The reason is that the Earth's rotation and the lunar motion ensure a very different topocentric geometry hours later at the moment of attempted sighting, and it is at that moment that the dependence of visibility on topocentric effects is best taken into account.)

The variable angular speed of the moon can be allowed for by using the arc of light for an index instead of the age, but the angle of the moon's celestial ascent out of the sunset glare remains a decisive but overlooked variable. A relatively large, bright crescent can elude detection if the season, latitude, and inclination of the lunar orbit prescribe a very low and shallow path of ascent from the western horizon.

The time delay between sunset and moonset (hereafter moonset lag) is a parameter that would seem to be an index of both the stage of growth of the crescent and the available grace period for the twilight to fade. The moonset lag may have usefulness when restricted to low latitude, but it is prone to inconsistencies when it can coincide with either a large arc of light observed at high latitude or a small arc of light observed at low latitude.

The apparent altitude and azimuth separation of the sun and moon at sunset, or at a slightly later time nearer to that for optimum visibility, is a two-parameter index of visibility. Sometimes the so-called arc of vision is used instead of the apparent altitude. The arc of vision is essentially the projection of the arc of light **perpendicular** to the local horizon direction, and thus resembles the apparent altitude except that it dispenses with topocentric parallax and refraction, and that the angle is taken between the sun and moon centers, not the horizon and moon's lower-limb. From these differences the arc of vision is typically 1 1/2° larger than the crescent altitude at sunset, dalt, with a typical scatter of about 1/2° due mostly to the variation of topocentric parallax with latitude.

Schaefer(1990) has modeled crescent visibility by a computer program built upon parametric equations from first principles for the physical processes upon which visibility is contingent. Proprietary software and an accurate atmospheric extinction factor are required for each event so modeled.

Predicting Visibility from the Moon's Altitude and Azimuth

The SAAO database permits one to test the usefulness of some of the visibility criteria available. Figures 1-3 address various aspects of using the moon's altitude and azimuth (relative to the sun) as parameters for predicting crescent visibility or invisibility. In these graphs, the x-axis gives the difference in azimuth (i.e. compass angle) from the sunset point to a point on the horizon directly below the moon's position at sunset, always converted to a positive number, since the moon's being right or left of the sun should be immaterial for visibility. The y-axis gives the apparent altitude above the horizon of the moon's lower limb at sunset. Successful sightings by naked eye observers (class A) are represented by large filled circles; a few filled circles crossed by a short horizontal line represent marginal sightings (class B). Large open circles represent cases where the crescent was visible through telescopes or binoculars, but **not visible** to the naked eye (class C). A short horizontal line crossing the open circle denotes visibility in a telescope only (class D) and not in binoculars nor by naked eye. Large 3-pointed delta symbols show the locations of crescents which were invisible both with optical aid and with the naked eye (class F). Small deltas represent unsuccessful sightings by naked eye observers without optical aid (class E, not as stringent at class F). Events at high latitude, taken here as at least 45° from the equator, are distinguished by a halo of small dots around the point. Note that the sightings and non-sightings are not implied to occur at the instant of sunset, but are attempted throughout (and typically only successful at a later stage during) the fading twilight. In the intervening interval the moon's offset from the sun has scarcely altered, except possibly in summer at high latitude (see below).

The solid curve in Fig. 1 is our attempt to delineate a boundary below which visual sighting is **improbable**, even given ideal viewing conditions (cloudless, clear air, skilled observers, etc.). We have used this curve, shifted to include even the most extreme optically-aided sighting, to generate the dotted line "best guess" boundary below which even optically-assisted sighting from the surface of the earth would be **impossible**. Clearly many more observations will be needed so that these lines can be more precisely and confidently defined, especially at large azimuth differences. More sighting attempts at **large** azimuth differences, in general from higher latitudes, are very much needed.

These lines are intentionally optimistic, taking account of all apparently reliable sightings and in practice visibility could be much worse. However, we consider that the important factor for verifying a lunar calendar is not what the average outcome would be for a random observer at an average, frequently turbid, site. What is more germane is what would be marginally achievable by objective, seasoned observers at an excellent site, but taking into account the vagaries of the weather.

One worry with the altitude-azimuth-at-sunset parameterization is that observers at high latitude in the summer would gain an advantage from the exceptionally long delays possible between sunset and moonset. The latitude would then enter as a "third parameter" potentially obscuring the criterion. One would then expect an improvement in the separation between visible and invisible cases by using the altitude and azimuth difference at a time better corresponding to that typical of marginal sightings. As this refinement is a small effect, a complicated estimate of the time seems unnecessary, and we have adopted the time when the sun center has a depression of 4° below the horizon as fiducial.

Fig. 2 shows the altitude difference versus the azimuth difference at the time of 4° solar depression. No apparent advantage for visibility discrimination can be seen in this diagram over Fig. 1 at this stage. It may be expected that high latitude data with very large azimuth differences will produce a clearer prediction in terms of this second approach.

Fig. 3 is another modification arising from Fig. 1, taking advantage of the fact that at a larger arc of light, the moon is both brighter and necessarily located at an azimuth where the sky brightness is dimmer than it would be near the sun. The increase of the arc of light can then compensate for a decrease of altitude difference, and by experiment a factor of 3 seems to allow the effects to cancel over a considerable range of azimuth difference. Keeping the limitations of the data in mind, it appears nonetheless possible to make a reasonably sound inference about the past or prospective visibility of a particular crescent observation by reference to the guidelines in Figs. 1-3.

Predicting Visibility from the Time Lag between Sunset and Moonset

Figs. 4-6 address various aspects of using the time delay between sunset and moonset (moonset lag) as a parameter for predicting crescent visibility or invisibility. Fig. 4 is most analogous to Figs. 1-3 since it uses exactly the same parameter for the x-axis, but plots the moonset lag on the y-axis. Although superficially similar in appearance, there is not as clean a separation of outcomes in Fig. 4 because a relatively large moonset lag **can** be compatible with a low crescent altitude at sunset even at middle-latitude sites. One might imagine that the scatter in this plot will only worsen with more data from high latitude where both extremes would be encountered -- large moonset lag at low altitude, and large arc of light at low moonset lag.

The public tends to guess at the visibility based on the two most readily available indices, namely the moon's age and the moonset lag. Fig. 5 illustrates why neither of these in itself is a satisfactory parameter on which to base a visibility prediction. Even quite old moons can be invisible if their altitude or travel-direction towards the horizon is such that they set quickly after sunset (short lag). Even crescents with a long moonset lag can be invisible if their travel-direction towards the horizon is very gradual, as is the case at high latitudes. Interestingly, the combination of both numbers, usually requiring no more than a good newspaper, can yield at least a not-unreasonable guess. It will not be very precise for a lag below 45 minutes, as in this regime the neglect of other decisive factors becomes a more serious problem.

Fig. 6 gives an improvement of the preceding by using the arc of light for the y-axis. In the light of the variation of the earth-moon distance, the arc of light should correlate better with the total brightness of the crescent and its angular separation from the sun (still subjected to variable topocentric parallax), than the age alone. It shows a more promising degree of discrimination between outcomes.

Numerical values of the criterion lines in Figs. 1-4

x = daz or daz4 (deg)	y = dalt (deg)		y=dalt4 (deg)		y=dalt+arcl/3 (deg)		y=lag (min)	
0.00	8.19	6.29	5.22	3.22	11.3	9.0	45.00	36.99
0.50	8.18	6.28	5.22	3.22	11.3	9.0	44.93	36.92
1.00	8.16	6.26	5.22	3.22	11.3	9.0	44.82	36.81
1.50	8.14	6.24	5.20	3.20	11.3	9.0	44.67	36.66
2.00	8.10	6.20	5.17	3.17	11.3	9.0	44.48	36.47
2.50	8.06	6.16	5.13	3.13	11.3	9.0	44.26	36.24
3.00	8.02	6.12	5.09	3.09	11.3	9.0	43.99	35.98
3.50	7.96	6.06	5.03	3.03	11.3	9.0	43.70	35.69
4.00	7.91	6.01	4.96	2.96	11.3	9.0	43.37	35.36
4.50	7.84	5.94	4.89	2.89	11.3	9.0	43.02	35.01
5.00	7.77	5.87	4.81	2.81	11.3	9.0	42.64	34.62
5.50	7.70	5.80	4.72	2.72	11.3	9.0	42.23	34.22
6.00	7.62	5.72	4.63	2.63	11.3	9.0	41.80	33.79
6.50	7.53	5.63	4.53	2.53	11.3	9.0	41.35	33.33

7.00	7.44	5.54	4.43	2.43	11.3	9.0	40.87	32.86
7.50	7.35	5.45	4.32	2.32	11.3	9.0	40.38	32.37
8.00	7.26	5.36	4.21	2.21	11.3	9.0	39.88	31.86
8.50	7.16	5.26	4.09	2.09	11.3	9.0	39.36	31.34
9.00	7.05	5.15	3.97	1.97	11.3	9.0	38.83	30.81
9.50	6.95	5.05	3.85	1.85	11.3	9.0	38.28	30.27
10.00	6.84	4.94	3.73	1.73	11.3	9.0	37.73	29.72
10.50	6.73	4.83	3.61	1.61	11.3	9.0	37.18	29.16
11.00	6.61	4.71	3.49	1.49	11.3	9.0	36.62	28.60
11.50	6.50	4.60	3.36	1.36	11.3	9.0	36.05	28.04
12.00	6.38	4.48	3.24	1.24	11.3	9.0	35.49	27.47
12.50	6.26	4.36	3.12	1.12	11.3	9.0	34.92	26.91
13.00	6.15	4.25	3.00	1.00	11.3	9.0	34.36	26.35
13.50	6.03	4.13	2.89	0.89	11.3	9.0	33.81	25.80
14.00	5.91	4.01	2.78	0.78	11.3	9.0	33.26	25.25
14.50	5.79	3.89	2.67	0.67	11.3	9.0	32.72	24.71
15.00	5.67	3.77	2.57	0.57	11.3	9.0	32.20	24.18
15.50	5.55	3.65	2.47	0.47	11.3	9.0	31.68	23.67
16.00	5.43	3.53	2.37	0.37	11.3	9.0	31.18	23.17
16.50	5.31	3.41	2.29	0.29	11.3	9.0	30.70	22.68
17.00	5.19	3.29	2.21	0.21	11.3	9.0	30.23	22.22
17.50	5.08	3.18	2.13	0.13	11.3	9.0	29.79	21.77
18.00	4.96	3.06	2.07	0.07	11.3	9.0	29.36	21.35
18.50	4.85	2.95	2.01	0.01	11.3	9.0	28.97	20.95
19.00	4.74	2.84	1.96	-0.04	11.3	9.0	28.59	20.58
19.50	4.64	2.74	1.93	-0.07	11.3	9.0		
20.00	4.53	2.63	1.90	-0.10	11.3	9.0		
20.50	4.43	2.53	1.88	-0.12	11.3	9.0		
21.00	4.33	2.43	1.88	-0.12	11.3	9.0		

Summary of Criterion Lines

Table 1 gives the numerical values of the lines shown in Figs. 1-4. If the crescent moon lies below the upper y-value figure for a given x-value (i.e. the upper curve), then a sighting is **improbable**, by which we mean that seeing the crescent without a telescope or binoculars is **exceedingly unlikely**. Sighting the moon with optical aid may be possible if the crescent is near the upper figure, but glimpsing it **visually** should be right at the extreme edge of perception if at all feasible. If the crescent lies nearer the lower y-value figure (i.e. the lower curve), then sighting the moon would be **exceedingly unlikely** even with optical aid. Crescent moons falling below the lower limit are considered to be genuinely **impossible** to see even with optical aid, because of their intrinsic lack of contrast with the surrounding sky brightness.

Table 2 gives the numerical values for the solid line shown in Figs. 5-6, below which visual sighting would be improbable.

Numerical values of the criterion lines in Figs. 5-6

x = lag (min)	y = age (hr)	y = arcl (deg)
28	39.53	20.26
30	34.80	19.08
32	30.07	17.66
34	26.81	16.16
36	25.04	14.68
38	23.26	13.33
40	21.49	12.17

42	19.72	11.23
44	17.94	10.53
46	16.48	10.06
48	15.95	9.82
50	15.43	9.77
52	14.90	9.87
54	16.21	10.08
56	17.17	10.35
58	17.82	10.64
60	18.22	10.92
62	18.42	11.13
64	18.47	11.27
66	18.43	11.33
68	18.35	11.30
70	18.28	11.22
72	18.28	11.15
74	18.27	11.15
76	18.27	11.15

The Annual and Long-Term Cycle between North-African/Mideast and Southern African Crescent Visibility

Some of the factors affecting lunar crescent visibility are seasonal, and therefore affect northern and southern hemisphere observers oppositely. The seasonal effect arises from the fact that the moon's path makes a much more favorable angle to the western horizon in spring than in autumn. A smaller effect is the changing time of sunset, depending on latitude. The result is to favor southern observers during September and October and northern observers during March and April, barring other considerations.

The position of the moon in its orbit can also favor either northern or southern hemisphere observers since, while a young crescent, the moon can be as much as 5 degrees north or south of the ecliptic. For example in 2000 the moon is farthest north of the ecliptic for the young crescent on September 28 (favoring northern observers), and furthest south of its "average path" at sunset for the April 5 young crescent (favoring southern observers).

These two effects (seasonal and moon-orbit), can cause a one-day difference between the dates when northern and southern observers **even at nearly the same longitude, and at comparable distance from the equator**, are enabled to sight the crescent moon, especially when their effects act in concert. In 2000 we witness the two effects being six months "out of synch," and tend to oppose and cancel. Hence the 2000 dates of first visibility tend to agree very well between Southern Africa and Northern Africa/Mideast. The supposition of similar crescent visibility conditions holding for most lunar calendar observers in a restricted longitude zone has been invoked by Ilyas (1994) to suggest a compromise three-longitude-zone global lunar calendar, as a start toward a Unified World Islamic Calendar, in place of the proliferation of lunar calendars occurring under the present multi-domain system. Unfortunately the quasi-parabolic shape of the line of first visibility, together with the strong but intermittent north-south visibility differences, causes the actual visibility dates to differ with latitude within an Ilyas zone as markedly as they would differ from one longitude zone to its neighbor.

To clarify the north-south effect we have calculated a parameter we dub the North-South Advantage (NSA). It is the altitude difference of the crescent moon as seen by an observer from latitude +30° minus that as seen by an observer from latitude -30°, for a crescent with an ecliptic longitude of 12° greater than that of the setting sun, a very typical configuration for sightings. The seasonal and moon-orbit effects just discussed can obviously cause changing advantages amounting to many degrees of crescent altitude as perceived from north or south of the equator, which when large enough will inevitably affect lunar calendar synchrony. A positive NSA favors the north, a negative one the south, and zero NSA means equal accessibility of the crescent to both.

Fig. 7 illustrates the effect by showing the NSA for an 240-year period. The horizontal axis shows the day of the year and the vertical axis the NSA, **lined off in divisions of 10**°. Notice that the NSA varies strongly with the season for several years, followed by several more years where the variation is much reduced. This shows the consequence of the moon-orbit effect alternately enhancing and then canceling the underlying seasonal effect, in the rhythm of the 18.61 year regression of the lunar orbit node. Societal interest in the Ramadaan and Shawwall crescents being what it is, we plot the latter as vertical arrows in the diagram. One sees that many decades go by with little advantage to either hemisphere in sighting the crescent for this particular lunar month and its predecessor. Thus the extreme and in recent memory unprecedented **disadvantage** accruing to southern Ramadaan/Shawwall observers in the early 1990s occasioned some understandable perplexity and controversy. A compensating, extreme southern advantage will occur from about 2005 onwards.

One has to look back to the 1860s to find as large a southern handicap, 130 years before the early 1990s occurrence. The overall cycle has a periodicity of 130 years or 7 lunar nodal regression cycles. The pattern appears to be one of 4 nodal cycles with no large NSA followed by three of which two show a large NSA, hence: N N N N Y N Y, where Y or N denote the presence or absence of a large one-sided NSA in a given nodal cycle. This accounts for the gap of 38 years between the large NSA years around 1992 and 2030, and the gaps back to the corresponding NSA peaks 130 before.

Conclusions

We have discussed the empirical data on lunar crescent visibility and find prediction criteria that are quite satisfactory to explain the past record of credible, critical observations. In the process we have examined a wide range of possible parameters and their merits and shortcomings as predictors.

A novel realization has been the extremely large and time-variable visibility advantage that can temporarily hold sway from north to south across our continent. The southern delays in sighting the Ramadaan and Shawwall crescents in the early 90s furnished a case in point of this occasionally dominant effect, which should be borne in mind by crescent watching communities that compare with results originating far to their north or south.

The Internet and computer-controlled telescopes have opened up the field for new rapid progress, but careful and objective observing, with dependable pointing, are as indispensable as ever. Some apparent needs remain: attracting the engagement of skilled observers at higher latitudes, and pursuing the rather unspectacular task of providing high quality **negative** sightings when occasions warrant.

While better observing and communication technology, and a more global and objective approach are contributing to a more realistic concept of the conditions for visibility and invisibility, the long-standing problem of erroneous sightings remains. On the encouraging side, we have been gratified by the widespread, substantial compatibility of the results achieved by different observers at different locations, **IN GOOD CONDITIONS**. The sobering lesson that we have taken away from this work is the lack of due skepticism **IN POOR CONDITIONS** (indeed a reluctance to recognize bad observing conditions for what they are) which handicaps the search for the actual boundaries of true visibility. A frank account of the relevant weather conditions to accompany all sighting reports would provide an important check on this tendency.

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Fig. 1
The circles are sightings by naked-eye (filled) or optical device (open), while the pointed symbols are non-sightings; finer distinctions are explained in the text.

Fig. 2
As Fig. 1, but the positions are plotted corresponding to the time when the sun is 4° below the horizon, closer to the time of maximum probability of sighting.

Fig. 3
As Fig. 1, but a coefficient of 1/3 times the arc of light has been added to the ordinate, as explained in the text.

Fig. 4
As Fig. 1, but the ordinate is the time lag between sunset and moonset (or moonrise and sunrise).

Fig. 5
As Fig. 1, but the abscissa is the time lag between sunset and moonset, and the ordinate is the time lage between new moon and sunset, thus the moon's age.

Fig. 6
As Fig. 5, but the ordinate is the arc of light, as explained in the text.

Fig. 7 upper left, 1770 and 1850 ...
Fig. 7 lower left, 1810 and 1890 ...
Fig. 7 upper right, 1930 and 2010 ...
Fig. 7 lower right, 1970 and 2050 ...
The North-South Advantage from 1770-2089, shown as solid lines during the course of each year, with each vertical division corresponding to an NSA of 10°. A long up-arrow signifies an extreme northern advantage, southern disadvantage, in viewing the Shawwall crescent, such as recurs in two spells within each 130 year cycle (see circa 1860, 1900, 1990 and 2030).

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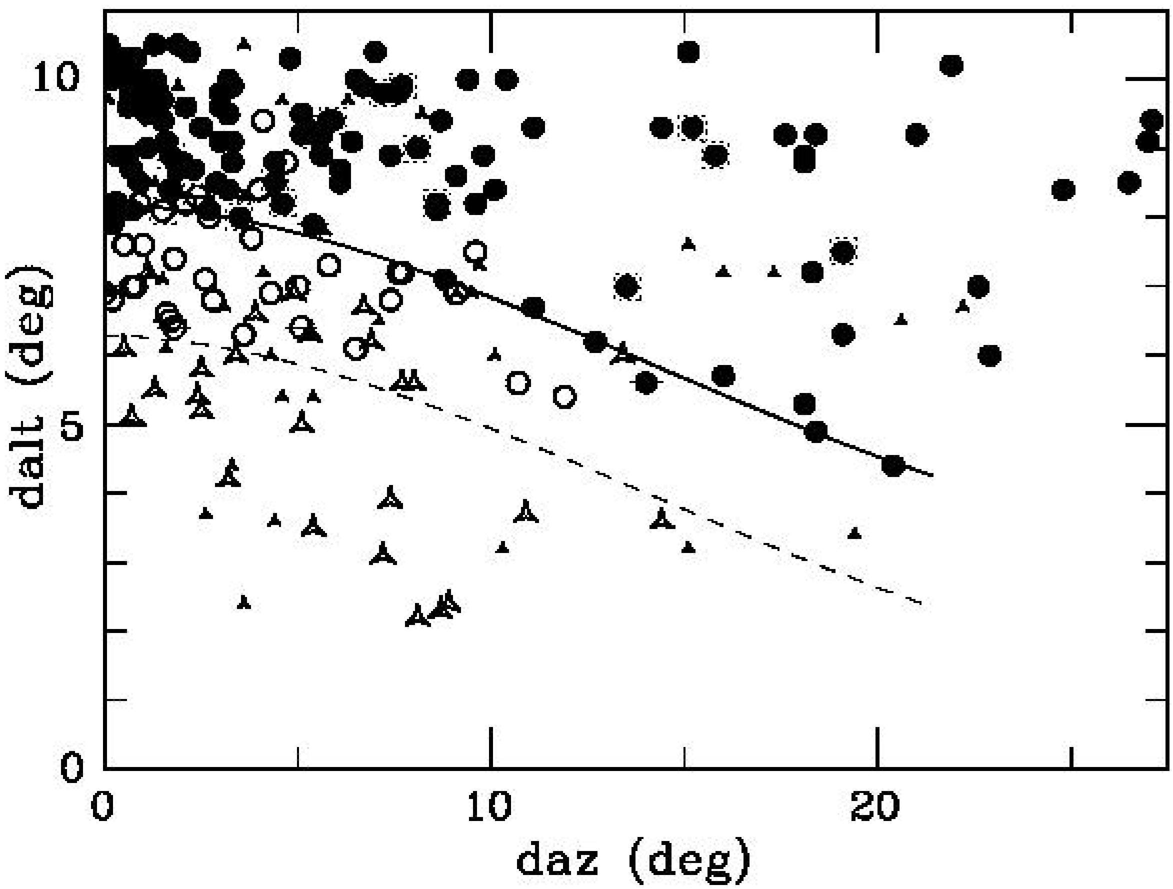
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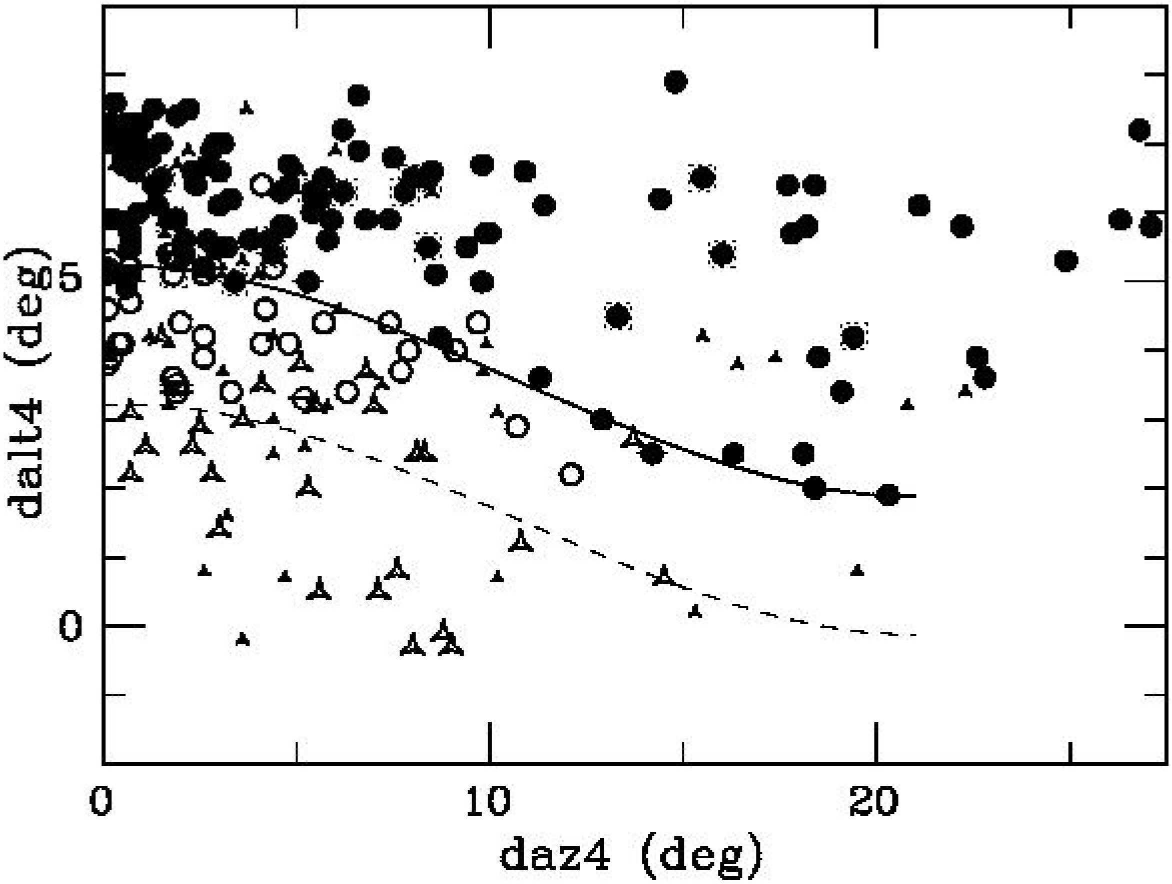

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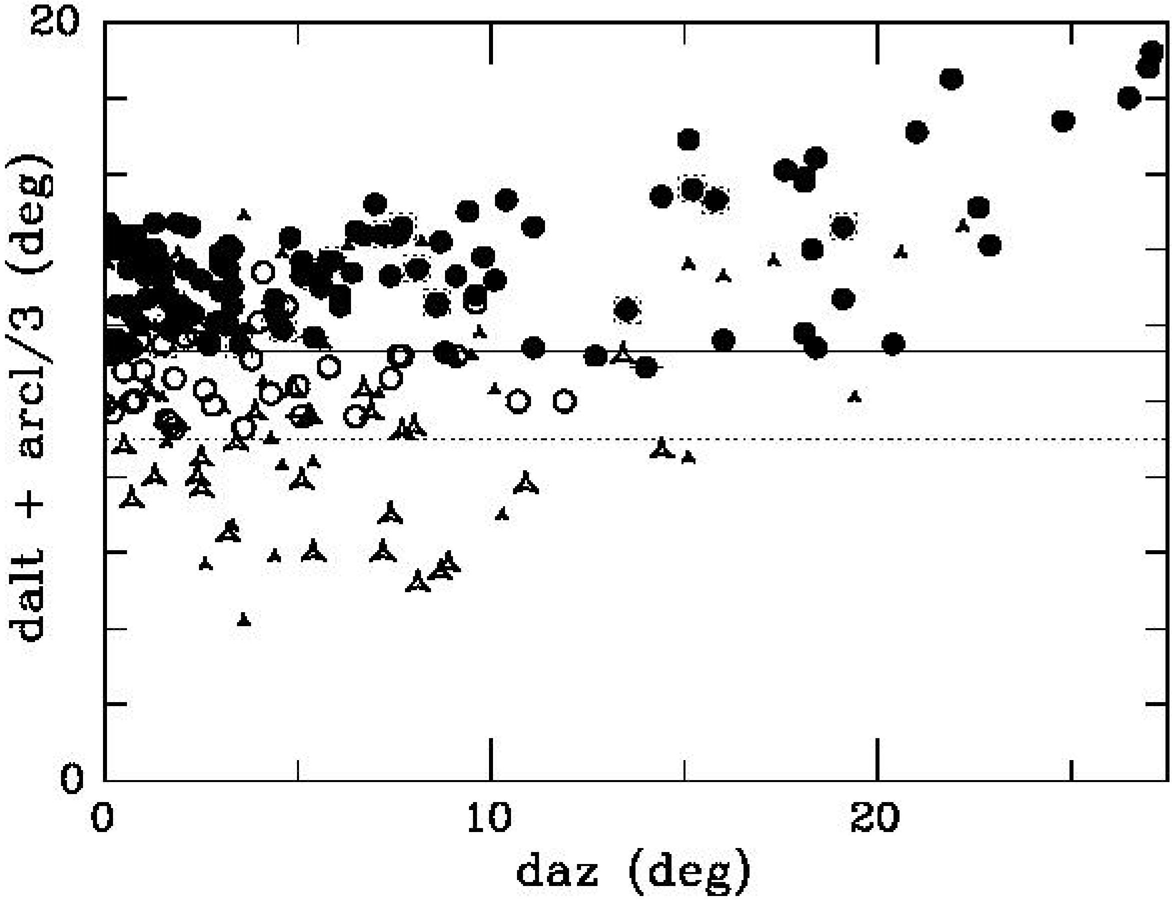
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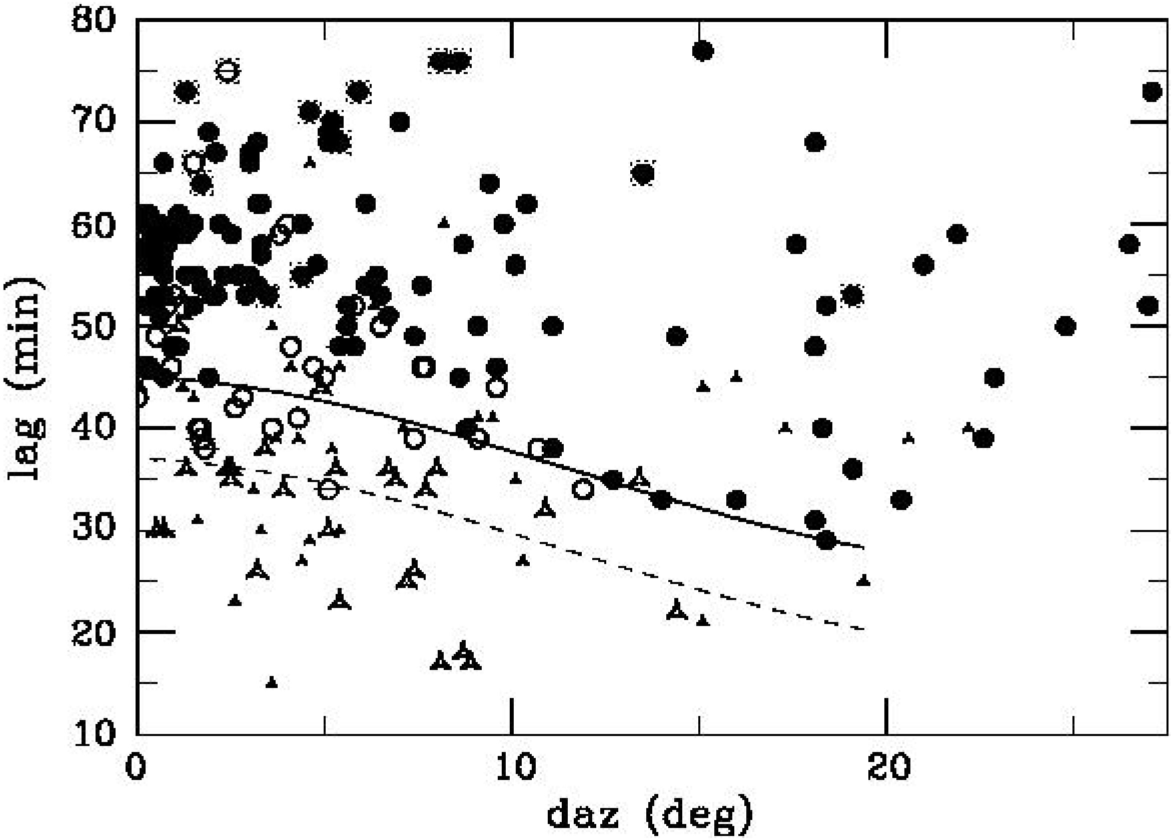

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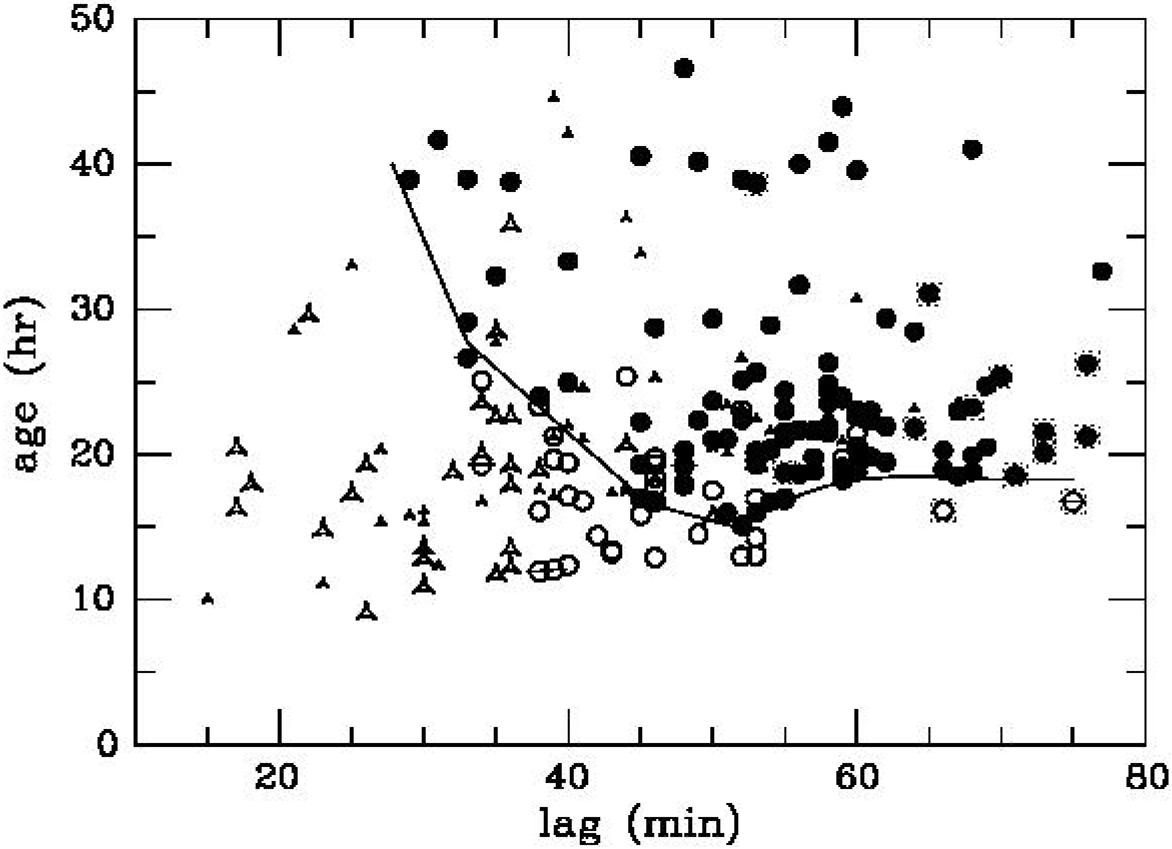

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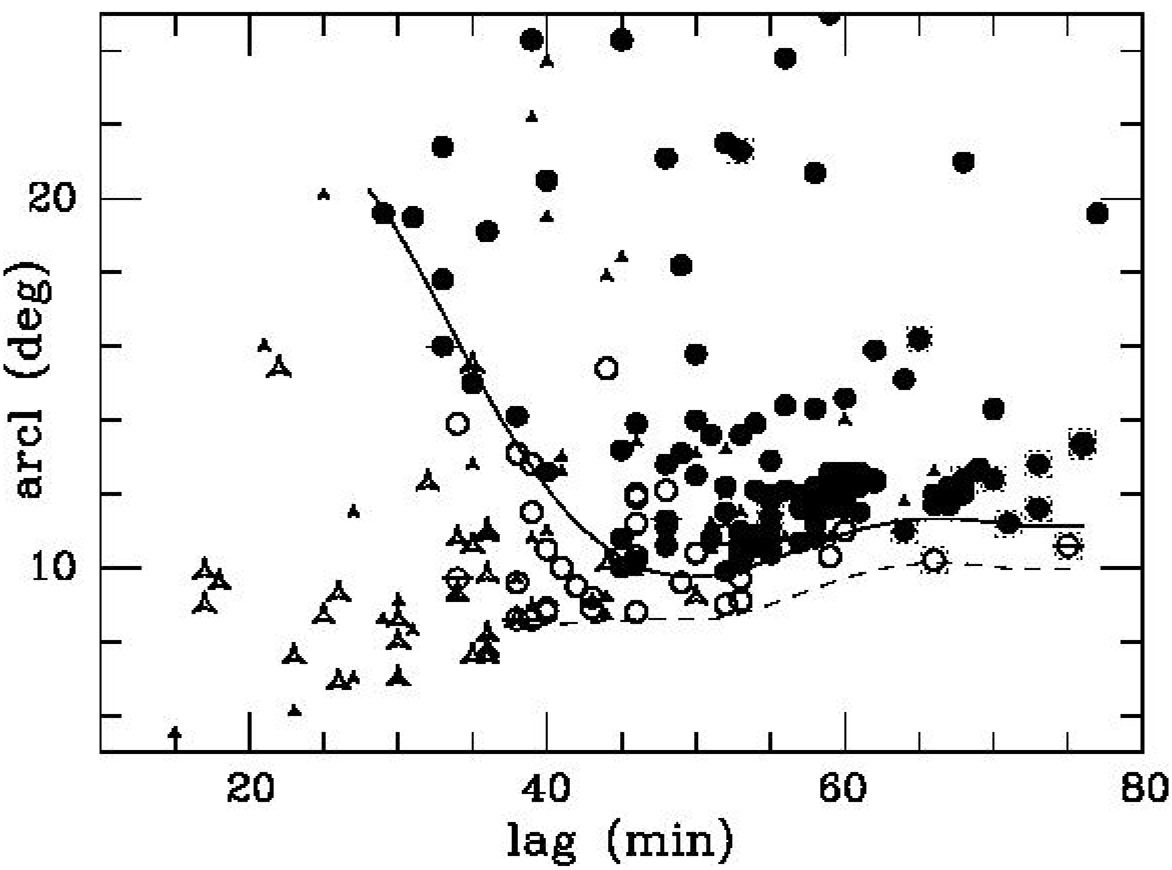

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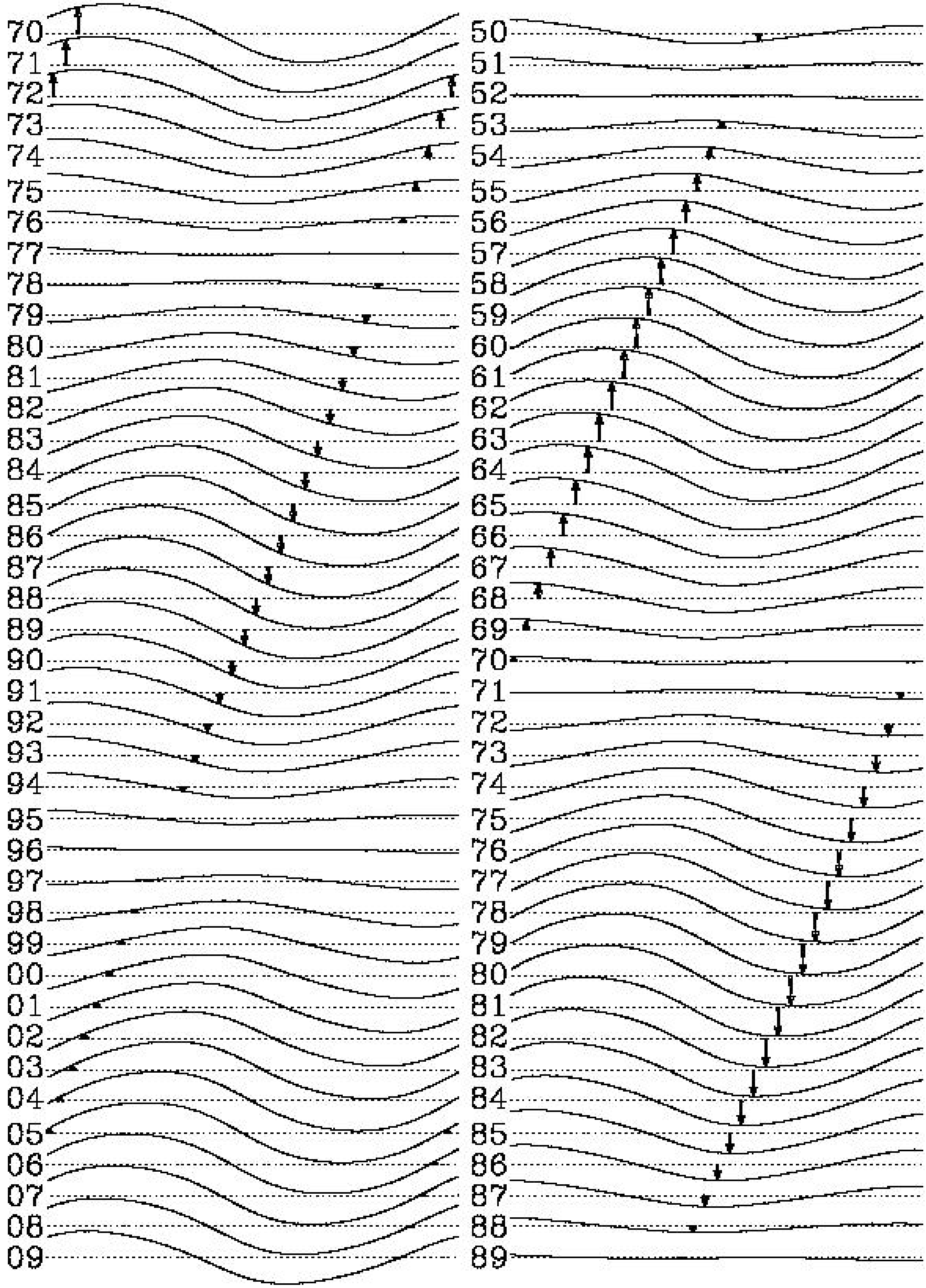
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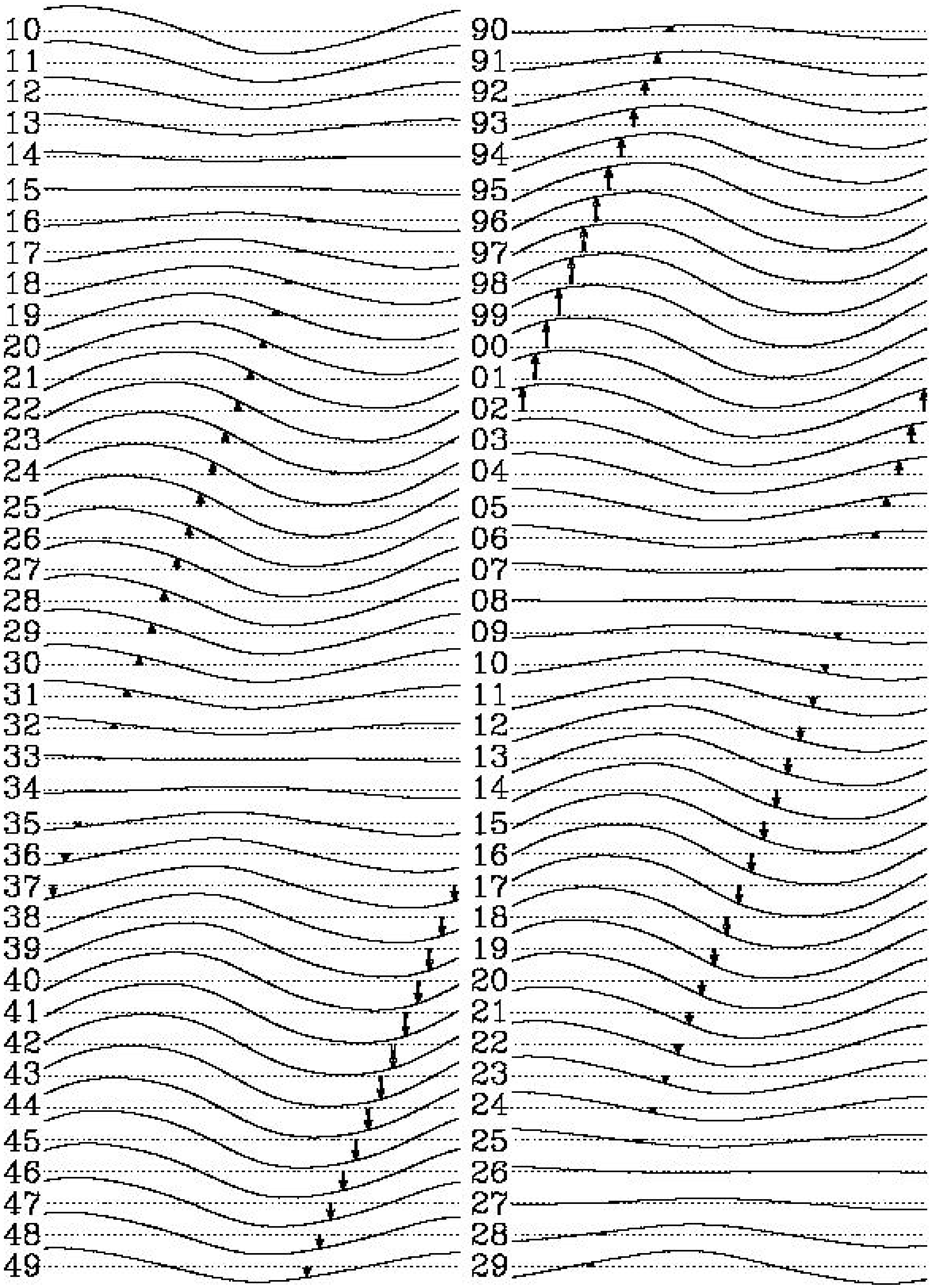
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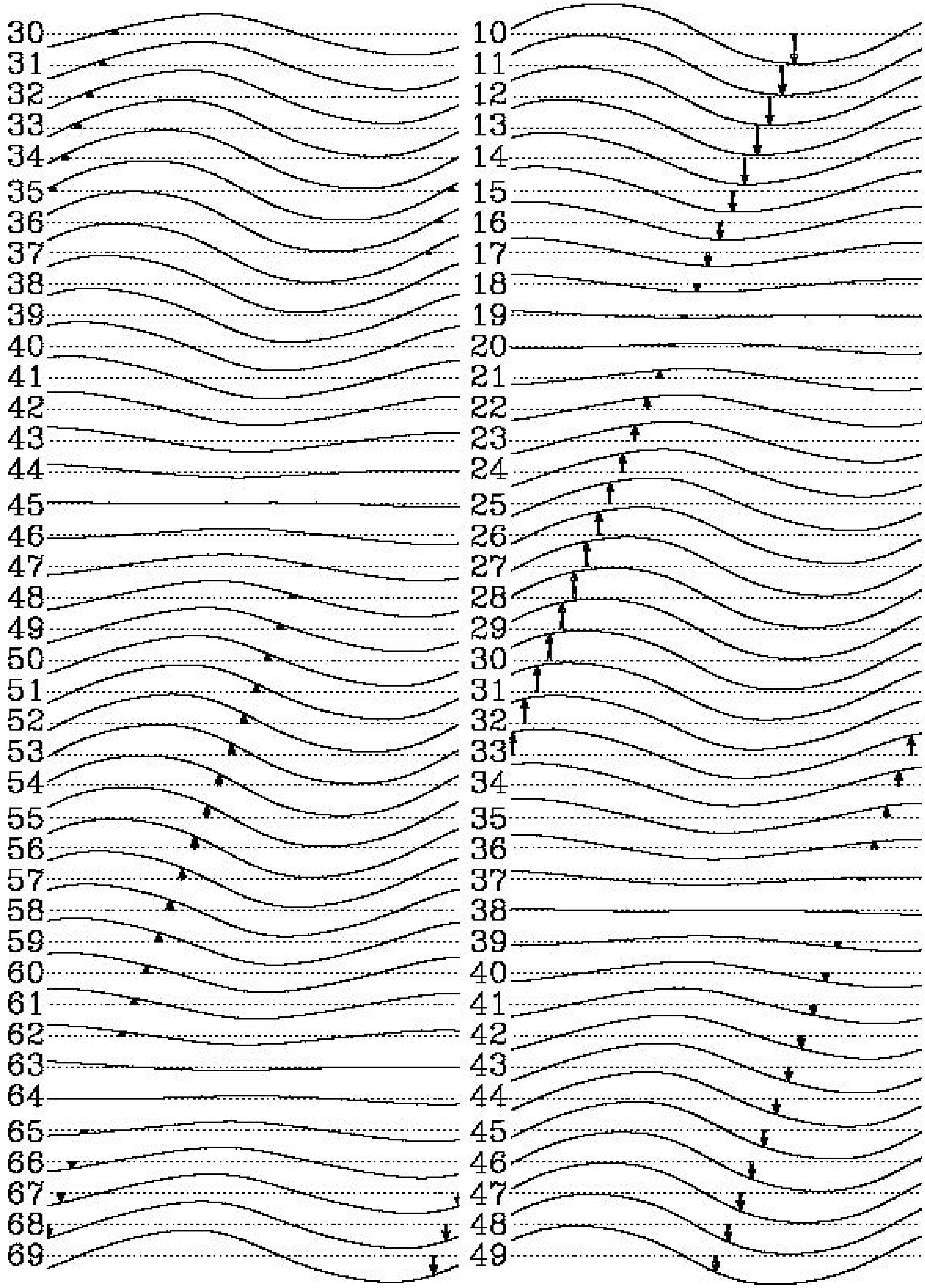
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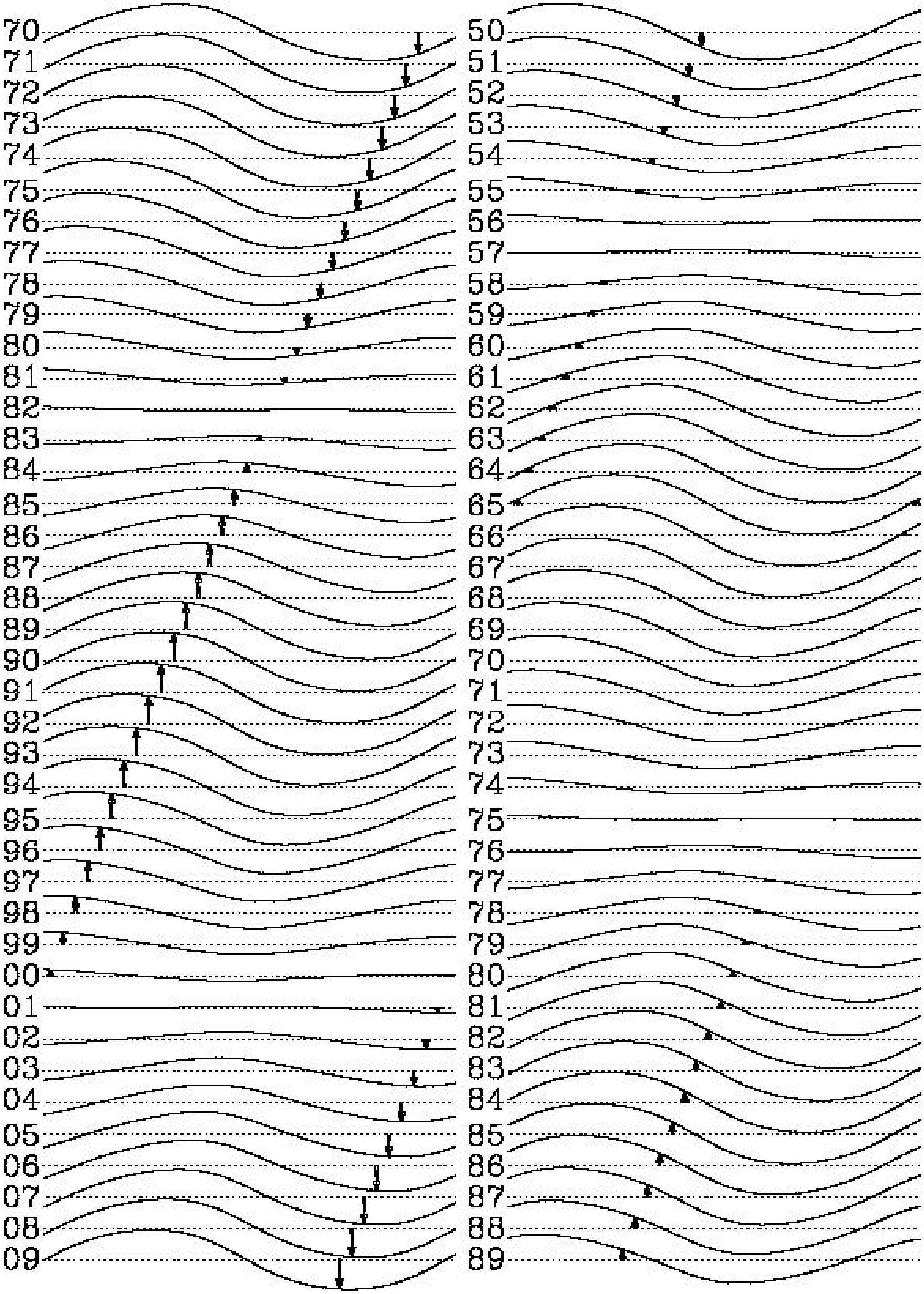
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