SOLAR AND LUNAR ECLIPSE MEASUREMENTS BY MEDIEVAL MUSLIM ASTRONOMERS, II: OBSERVATIONS

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1. INTRODUCTION

In our previous paper[1] (Paper I) we introduced the subject of solar and lunar eclipse observations recorded by the medieval Muslim astronomers Ibn Yūnus, al-Battānī and al-Bīrūnī. We considered such issues as the sources of data, motives for observation, calendrical questions, observational techniques, and our methods of computation. In the present paper, we give full translations of the observational records together with detailed comments based on our computations of individual eclipse circumstances.

Most of the available eclipse records (numbering about thirty) are preserved in *al-Zīj al-Kabīr al-Ḥākimī* of Ibn Yūnus.[2] A few additional observations are to be found in *al-Zīj al-Ṣābi'* of al-Battānī[3] and *Kitāb Taḥdīd al-Amākin li-Taṣḥīḥ Masāfāt al-Masākin*[4] and *al-Qānūn al-Mas'ūdī*[5] of al-Bīrūnī.

2. THE OBSERVATIONS

Each entry below begins with the computed date on the Julian calendar (including the weekday). For solar eclipses we have given only a single computed date, whereas for lunar eclipses we have quoted a double date — e.g. 854 Feb 16/17. Since the Islamic day begins at sunset, for lunar eclipses occurring before midnight there will be a discrepancy of one day between the Islamic date and the civil date. However, for lunar eclipses occurring after midnight there is no such discrepancy. By using double dates, we avoid any confusion. However, it should be noted that in computing the weekday for a lunar eclipse we have consistently used the second in a pair of dates (e.g. 854 Feb 17 was a Saturday). This practice should invariably lead to agreement with the Islamic weekday unless a textual error has occurred.

Also at the head of each entry is the type of eclipse (solar or lunar) and the computed magnitude. After the translation of each text, we make general remarks about the text followed by a comparison between the computed local circumstances of the eclipse with observation. Comparisons between computation and observation include magnitude, the measured altitude or local time (LT) for each phase, and whether the Sun or Moon rose or set eclipsed. Finally, when the Muslim astronomers have reduced their own altitude determinations to local time we have investigated the precision of their reduction. For all altitude measurements, no allowance for refraction is necessary since no measured altitude was less than about 5°. From the tables of Allen[6] such corrections amount to no more than 0.1°.

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Throughout we have used the term 'compute' in alluding to our results derived from astronomical theory. In contrast, we have restricted the term 'calculate' to predictions and reductions made by the Muslim astronomers themselves. Since many recorded times involve a reference (whether direct or indirect) to sunrise or sunset, we have had to assume that an observer made negligible error in fixing these times.

We take the opportunity to make an explanatory comment on Table 2 ("The twelve months in various calendars") in our Paper I. Certain Syrian and Islamic months in this table are followed by either I or II. To assist tabulation, these numbers are used in place of the Arabic equivalents in the text. For Syrian months, Tishrīn I corresponds to Tishrīn al-Awwal, Tishrīn II to Tishrīn al-Thānī (or Tishrīn al-Ākhir), Kanūn I to Kanūn al-Awwal and Kanūn II to Kanūn al-Thānī (or Kanūn al-Ākhir). For Islamic months, Rabī' I corresponds to Rabī' al-Awwal, Rabī' II to Rabī' al-Ākhir, Jumādā I to Jumādā al-Ūla and Jumādā II to Jumādā al-Ākhirah. We also note the following amendment: the last Persian month in the table should be Isfandārmad rather than Isfandār.

1. *Solar and Lunar Eclipses Recorded by Ibn Yūnus*

The following records of solar and lunar eclipses are based on observations in Baghdād by al-Māhānī and Banū Amajur and in Cairo by Ibn Yūnus himself.

Baghdād Observations: 829–933

(1) 829 Nov 30, Tuesday, solar (computed mag = 0.59); reported by Ḥabash.

"Aḥmad b. 'Abd Allāh known as Ḥabash said: 'There was a lunar eclipse after Nowrūz [i.e. the Persian word for a new day which is the first day of a new year — at the vernal equinox ~Mar 20] in the year 198 of Yazdijerd. (The prediction of the) calculations of (*al-Zīj*) *al-Mumtaḥan* and of Ptolemy were near to each other but that of Ptolemy was more accurate (indicating) that the distance (in longitude) between Baghdād and al-Iskandariyyah (Alexandria) is 50 minutes of an equal hour. As for the solar eclipse, which (occurred) in this year at the end of the month of Ramaḍān, all calculations (concerning the eclipse) were in error. The altitude of the Sun at the beginning of the eclipse was 7° as they (the astronomers) claim. The eclipse ended when the altitude of the Sun was about 24°, as though it was 3 hours of day (i.e. after sunrise)'."

Here we have a combination of a Persian year and an Islamic month. The year 198 of Yazdijerd (= 214/215 A.H.) covered the period from A.D. 829 Apr 28 to 830 Apr 27. It thus began soon after the start of 214 A.H. (A.D. 829 Mar 11) and extended slightly into 215 A.H. (which began A.D. 830 Feb 28). A date at the very end of Ramaḍān closely corresponds (within a day or so) to A.D. 829 Nov 30 — the calculated day of a solar eclipse visible in Baghdād.

The text seems to imply seasonal hours for the end of the eclipse (i.e. 3 hours of day).

COMPUTATIONS

(i) Actual solar altitude at first contact = 0.1° (i.e. just at sunrise). The altitude reported by the astronomers (7°) is thus seriously in error.
(ii) Solar altitude at last contact = 22.5°. This compares reasonably well with the measured value of ~24°.

(iii) The LT corresponding to the measured solar altitude of 24° is 9.52^h. LT of sunrise = 6.87^h, hence 1 seasonal hour = 0.855^h. Hence LT of last contact = 2.65^h = 3.10 seasonal hours after sunrise. This is close to the recorded LT as reduced by the observers from their altitude determination — i.e. 3 (seasonal) hours after sunrise.

(2) 854 Feb 16/17, Saturday, lunar (mag = 0.92); observed by al-Māhānī.

"This lunar eclipse was mentioned by al-Māhānī. 'There was an eclipse of the Moon in the month of Ramaḍān in the year 239 of al-Hijrah on the night of Saturday, the middle of the month. It was found by observation that the beginning of this eclipse was at 10 hours and something like $\frac{1}{2}$ of $\frac{1}{10}$ of an hour (i.e. $10;03^h$) after midday of Friday. We did not determine its times apart from the beginning. It was (also) found that the uneclipsed part of its body (i.e. disk) was (a little) more than $\frac{1}{10}$. The difference in the digits of the eclipse (i.e. magnitude) between calculation and observation, which is about a digit, could be due to the latitude of the Moon — which is, in reality, more than (predicted by) calculation — or it could be due to the diameter of the Earth's shadow — which is (in reality) less than (that indicated by) calculation.... As for the difference in the time of beginning between calculation and observation — not given in the text — this indicates that the Moon's position (i.e. longitude) was less in reality than by calculation....'"

The date is precisely equivalent to 854 Feb 16 (a Friday). This is one of several instances where the original altitude measurements of stars are not preserved.

The fact that only the time of first contact is reported is surprising; as an evening eclipse, the entire course of events should have been visible unless unfavourable weather intervened. Although the text does not specify whether equal or seasonal hours were used, since part of the measured interval was in daylight and part in darkness only equal hours would be meaningful.

COMPUTATIONS

(i) Linear magnitude = 0.92, corresponding to an area magnitude of 0.95. This is significantly greater than the observed value of a little less than $\frac{9}{10}$.
(ii) LT of first contact = 22.20^h, i.e. 10.20^h after midday. This compares with the measured value of approximately 10;03 (i.e. 10.05) hours.

(3) 854 Aug 11/12, Sunday, lunar (mag = 1.41); observed by al-Māhānī.

"This lunar eclipse was mentioned by al-Māhānī. 'The Moon was eclipsed on the night of Sunday 13th of the month of Rabī 'al-Awwal in the year 240 of al-Hijrah. It was found by observation that the time of beginning of the eclipse was when the altitude of (the star) *al-dabarān* (Aldebaran: α Tau) was 45;30° in the east. We did not find its times (accurately) except this time (i.e. of the beginning), which was exact and precise. We measured the time of the completion of (the first phase of) the eclipse, which is the time of the beginning of the staying (Arabic: *al-makth*) (in totality) and found it (to be) when the altitude of (the star *al-shi'rā*) *al-shāmiyyah* (Procyon: α CMi) was between 22° and 23° in the east. This (latter) measurement is not exact but approximate. We determined the time of the beginning from the altitude of *al-dabarān* by the astrolabe and found it to be 44° (of the celestial sphere) after midnight. The time of beginning was 8° later than its (calculated) time. We (also) determined the time (of the beginning of) the stay by the astrolabe, taking the altitude of (*al-shi'rā*) *al-shāmiyyah* as 23° and found it to be 23$\frac{1}{2}$ parts (i.e. degrees) of the celestial sphere after the (time of) beginning (of the eclipse).'"

COMPUTATIONS

(i) Altitude of α Tau at first contact = 45.2° in the east, compared with the recorded figure of 45.5°.
(ii) Altitude of α CMi at second contact = 18.0° in the east; this is considerably less than the measured

altitude of between 22° and 23°, which however was said to be only approximate.
(iii) The LT corresponding to the measured altitude of α Tau (45.5°) is 2.93^h. This is identical with the recorded LT as reduced by the observers from their altitude determination — i.e 44° after midnight or 2.93^h.
(iv) The LT corresponding to the measured altitude of α CMi (23°) is 4.45^h. This compares with the recorded LT as reduced by observers from their altitude determination — i.e. 23.5° after first contact or 4.50^h. The actual interval between first and second contact was 1.19^h — much less than the estimated 1.57^h. The discrepancy largely originates from the serious error in the measured altitude of α CMi.

(4) 856 Jun 21/22, Monday, lunar (mag = 0.59); observed by al-Māhānī.

"This is the third lunar eclipse mentioned by al-Māhānī. 'There was an eclipse of the Moon on the night of Monday the middle of (the month of) Ṣafar in the year 242 of al-Hijrah, the second of (the month of) Khurdād, day Bahman (i.e. the second day of the month) in the year 225 of Yazdijerd. It was found by observation that the beginning of the eclipse was when the altitude of (the star) *al-dabarān* (Aldebaran: α Tau) was 9;30° in the east; the amount of the revolution of the (celestial) sphere from midnight to this time, as we determined (from this measurement) with the astrolabe was (equivalent to) 50°. We did not determine (all of) its times except (that of) the beginning. It was found (by observation) that the uneclipsed part of its body (i.e. disk) was more than one-quarter and less than one-third. The eclipsed part appeared to be greater than that indicated by calculation by (a little) less than a digit. The (observed) time of beginning was later than that indicated by calculation by about half an hour."

COMPUTATIONS

(i) Linear magnitude = 0.59, corresponding to an area magnitude of 0.58. The estimated area magnitude of between $\frac{2}{3}$ and $\frac{3}{4}$ is thus considerably in error.
(ii) Computed altitude of α Tau at first contact = 8.6° in the east, fairly close to the measurement.
(iii) The LT corresponding to the measured altitude of α Tau (9.5°) is 3.39^h. This is in fair accord with the recorded LT as reduced by the observers from their altitude determination — i.e. 50° after midnight or 3.33^h.

(5) 866 Jun 16, Sunday, solar (mag = 0.66); observed by al-Māhānī.

"This solar eclipse was mentioned by al-Māhānī. He said 'The Sun is to be eclipsed on Sunday the 28th of (the month of) Jumādā al-Ūlā in the year 252 of al-Hijrah, which is the 29th of (the month of) Urdībahisht in the year 235 of Yazdijerd. (According to calculation) the eclipse is to begin at 6 hours and $\frac{1}{2}$ of $\frac{1}{10}$ (i.e. 6;03^h after sunrise), the middle of the eclipse at 7 hours and $\frac{1}{6}$ (i.e. 7;10^h); the complete clearance at 8 hours and $\frac{1}{6}$ and $\frac{1}{10}$ (i.e. 8;16^h). Thus the total time (i.e. duration) of the eclipse is to be 2 hours and $\frac{1}{6}$ and $\frac{1}{2}$ of $\frac{1}{10}$ (i.e. 2;13^h), all in seasonal hours. The part of the Sun's diameter to be eclipsed is 9 digits and $\frac{1}{2}$ of $\frac{1}{6}$ (i.e. 9;05 digits), that is 8 digits of area of the Sun's circle. The positions (i.e. longitudes) of the Sun and Moon in view at the middle of the eclipse are 23;29° [can read 28;29°] in Gemini or (other tables indicate) the position of the Moon at that time as 28;47° in Gemini. It was found (by observation) that this eclipse began (a little) more than a third of an hour after *Zawāl*; the middle of the eclipse, as we estimated, was at 7 hours and $\frac{1}{3}$ and $\frac{1}{10}$ (i.e. 7;26^h after sunrise); then the eclipse cleared at $8\frac{1}{2}$ hours (i.e. 8;30^h). The (observed) times of this eclipse were found to be later than those determined by calculation by (an amount) between $\frac{1}{4}$ and $\frac{1}{3}$ of an hour. It was found that the latitude in view of the Moon (relative to the Sun) was to the south and the eclipsed (part) of the Sun's diameter, as we estimated, was more than 7 digits and less than 8 digits.'"

The month should be Jumādā al-Ākhirah, rather than the previous month Jumādā al-Ūlā; otherwise the recorded Islamic date (including the weekday) is correct. Elsewhere in the above text, it is stated that times are expressed in seasonal hours. No altitude measurements are preserved, only the reduced times.

Zawāl is close to midday but actually means the moment when the shadow of a gnomon begins noticeably to increase after the Sun transits the meridian. Presumably the time of first contact was determined from shadow lengths. The alphabetical symbols for 3 and 8 can be confused as a result of the presence or absence of a diacritical point.

COMPUTATIONS

(i) Magnitude = 0.66, in accord with the estimate of between 7 and 8 digits. The centre of the Moon would be about 0.2° below the centre of the Sun (in accordance with the text).
(ii) LT of sunrise = 4.82^h, and of sunset = 19.18^h. Hence 1 seasonal hour of day = 1.197 equal hours. LT of first contact = 12.36^h or 0.30 seasonal hours after midday. This is in good accord with "(a little) more than a third of an hour after *Zawāl*" of the text.
(iii) LT of maximum phase (rather than mid-eclipse) = 13.71^h, hence maximum phase = 8.89^h or 7.43 seasonal hours after sunrise. This is identical with the recorded interval of $7^h\ 26^m$.
(iv) LT of last contact = 14.97^h, hence last contact = 10.15^h or 8.48 seasonal hours after sunset. This is almost exactly the recorded figure of $8^h\ 30^m$.

All three measured times are remarkably accurate.

(6) 923 Jun 1/2, Monday, lunar (mag = 0.66); observed by Banū Amājūr.

"This lunar eclipse was calculated by 'Alī ibn Amājūr al-Turkī from *al-Zīj al-'Arabī* (i.e. the Arabic *Zīj*) of Ḥabash and observed by him and his son Abū al-Ḥasan and his freedman Mufliḥ. (He said) 'There was an eclipse of the Moon in (the month of) Ṣafar in the year 311 of al-Hijrah. We found that the (observed) times were different from those determined by calculation from the *Zīj* of Ḥabash. The Moon rose at sunset (already) eclipsed by $\frac{1}{4}$ or (a little) more of the digits of the diameter (i.e. 3 digits or a little more). The Moon was eclipsed by (a little) more than 9 digits of diameter. The middle of the eclipse was at $1\frac{2}{3}$ equal hours of night (i.e. after sunset). The clearance of the eclipse was at 3 equal hours (after sunset) and (that was) when the altitude of (the star) *al-ridf* (Deneb: α Cyg) was 29;30° in the east. Abū al-Ḥasan 'Alī ibn Amājūr said, after mentioning the observation, that the times of this eclipse (obtained) from calculation were defective. With regard to the digits, calculation from Ḥabash (*Zīj*) gave 8;7 digits of diameter (while) the perceived (i.e. observed) digits exceeded that by about a digit.'"

The alternative Arabic name for *al-ridf* is *Dhanab*, from which the modern name Deneb is derived.

COMPUTATIONS

(i) Magnitude = 0.66 (i.e. 8 digits), which is considerably less than the estimate of a liitle more than 9 digits.
(ii) LT of moonrise = 19.03^h. LT of first contact = 19.19^h. The Moon thus rose 0.16^h before the start of the eclipse. This clearly contradicts the recorded statement.
(iii) LT of mid-eclipse (i.e. maximum phase) = 20.56^h. LT of sunset = 19.14^h, hence LT of mid-eclipse = 1.42^h — i.e. significantly less than the recorded time of approximately $1^h\ 40^m$ after sunset.
(iv) Altitude of α Cyg at last contact = 29.2°, which compares well with the recorded value.
(v) The LT corresponding to the measured altitude of α Cyg (29.5°) is 21.96^h. This is in fair accord with the recorded LT as reduced by the observers from their altitude determination — i.e. 3 equal hours after sunset or 22.14^h.

(7) 923 Nov 11, Tuesday, solar (mag = 0.78); reported by Banū Amājūr.

"This solar eclipse was calculated and observed by Abū al-Ḥasan 'Alī ibn Amājūr from *al-Zīj al-'Arabī* of Ḥabash. This eclipse was at the conjunction (i.e. new Moon) of (the month of) Sha'bān in the year 311 (A.H.). We as a group observed (this eclipse) and clearly distinguished it. The estimate of all (observers) for the middle of the eclipse was that it occurred when the altitude of the Sun was 8° in the east; its clearance was at $2\frac{1}{5}$ seasonal hours (after sunrise), when the altitude of the Sun was 20°. We observed this eclipse at several sites on the 'Ṭārmah' (an elevated platform on the outside of the building). The estimate of Abū al-Ḥasan for the middle of the eclipse at his house was when the altitude of the Sun was 8°, as I estimated myself at my house before he arrived. The magnitude of the eclipse was $\frac{1}{2}$ and $\frac{1}{4}$ (i.e. $\frac{3}{4}$) of the Sun's diameter; the middle of the eclipse, which we estimated when the Sun's altitude was 8°, is to be when the elapsed time (after sunrise) was 0;50 seasonal hours, and the (celestial) sphere had revolved (through) 10;40°. (The interval) between the middle of the eclipse and its clearance in this observation was 1;22 seasonal hours; the (corresponding) time was 1;10 equal hours because the sphere revolved (through) 28;09° at the moment of clearance, which is (equivalent to) 1;53 equal hours. The middle would be at 0;43 equal hours. According to calculation from the conjunction tables in the Ḥabash *Zīj* the middle was at 0;31^h and its clearance at 0;44 hours, calculation being in advance of observation."

The statement that the eclipse "was at the conjunction of (the month of) Sha'bān" implies that it occurred at the new Moon of Sha'bān — i.e. the very end of the previous lunar month Rajab.

COMPUTATIONS

(i) The magnitude of 0.78 agrees very well with the observer's estimate ($\frac{3}{4}$).
(ii) Solar altitude at maximum phase = 7.4° in the east, rather close to the measured value.
(iii) Solar altitude at last contact = 18.2° in the east, significantly less than the recorded figure.
(iv) LT of sunrise = 6.78^h. Hence 1 seasonal hour of day = 0.870^h. The LT corresponding to the measured solar altitude at maximum phase (8°) is 7.56^h. This is in good accord with the recorded LT as reduced by the observers from their altitude determination: (a) 0;50 seasonal hours (0.73^h) after sunrise or 7.51^h; (b) 10;40° (0.71^h) after sunrise or 7.49^h; (c) 0;43^h (0.71^h) after sunrise or 7.94^h.
(v) The LT corresponding to the measured solar altitude at last contact (20°) is 8.72^h. This is in close accord with the recorded LT as reduced by the observers from their altitude determination — (a) $2\frac{1}{5}$ seasonal hours after sunrise or 8.70^h; (b) 28;09° (1.88^h) after sunrise or 8.66^h; (c) 1;53^h (1.88^h) after sunrise or 8.66^h.

(8) 925 Apr 11/12, Tuesday, lunar (mag = 1.08); observed by Banū Amājūr.

"This lunar eclipse was calculated and observed by Abū al-Ḥasan ibn Amājūr. This eclipse was on the night of Tuesday, the 15th of (the month of) Muḥarram, year 313 of al-Hijrah. He mentioned that the Moon was totally eclipsed and reported its five times (as found by calculation — but not given in the text). Then he said: 'I observed this eclipse. The beginning was when the altitude of (the star *al-simāk*) *al-rāmih* (Arcturus: α Boo) was 11° [can read 31]° in the east. The end of clearance was when the altitude of (the star) *al-nasr al-wāqi'* (Vega: α Lyr) was 24°.' He then said: 'The beginning of the eclipse would be when the time elapsed from the start of night (i.e. from sunset) was 0;55 seasonal hours; the observed time was later by 0;23 seasonal hours than that calculated from *al-Zīj al-Mumtaḥan* of Ḥabash. The end of clearance by observation would be at 4;36 seasonal hours; observation was (again) later than calculation by 0;17 seasonal hours.'"

COMPUTATIONS

(i) altitude of α Boo at first contact = 33.9°, which is in marked discord with the record. However, the altitude of the Moon at the time would be 11.0°. Presumably a scribe made an error in reporting either the reference object (i.e. α Boo instead of the Moon) or the elevation of the star. There is no other instance of the Baghdād astronomers measuring a lunar altitude. A possible alternative reading for 11 is 31; the alphabetical symbols for 10 and 30 can be confused by a careless scribe.
(ii) LT of sunset = 18.52^h, hence 1 seasonal hour of night = 0.913^h. LT of first contact = 19.52^h. Hence computed interval after sunset = 1.00^h or 1.10 seasonal hours. This is not in very good accord with the

recorded interval of 55 minutes seasonal (0.84^h).
(iii) Computed altitude of α Lyr at last contact = 24.7° in the east, in close agreement with the measured value.
(iv) The LT corresponding to the measured altitude of α Lyr at last contact (24°) is 22.77^h. This is in close accord with the recorded LT as reduced by the observers from their altitude determination — i.e 4^h 36^m seasonal hours after sunset or 22.72^h.

(9) 927 Sep 13/14, Friday, lunar (mag = 0.22); observed by Banū Amājūr.

"This lunar eclipse was calculated and observed by 'Alī ibn Amājūr from *al-Zīj al-'Arabī* of Ḥabash. This eclipse was on the night of Friday, in the year 315 of al-Hijrah. (Calculations showed): the (eclipsed) digits of diameter were 2;55; the equalized digits (i.e. of area) were 2;0. The beginning (was) at 10;14 hours of the night of Friday (i.e. after sunset on Thursday); the middle at 11;21 hours; the clearance at 9 [read: 0;09] hours of day on Friday (i.e. after sunrise); all hours are seasonal. He said: 'This eclipse was observed by my son Abū al-Ḥasan. The beginning of the eclipse was when the altitude of (the star) *al-shi'rā al-yamāniyyah* (Sirius: α CMa) was 31° in the east; the part of the celestial sphere which has revolved from sunset to the beginning of the eclipse was 148° plus a third of a degree and this is (corresponding to) 9;52 equal hours, which is 10;0 seasonal hours. The estimated digits of the eclipse was more than $\frac{1}{4}$ but less than $\frac{1}{3}$, as though it was 3$\frac{1}{2}$ digits. The calculated (time of beginning) exceeded that by observation by 14 minutes of a seasonal hour and the eclipsed part of the diameter (as determined) by observation exceeded that by calculation by 35 minutes (i.e. $\frac{35}{60}$) of a digit.'"

Although the month (and day of the month) is not cited, no other lunar eclipse apart from that identified above occurred in 315 A.H. (A.D. 927 Mar – 928 Feb). Confirmation of the calculated date is provided by the recorded weekday (Friday). In addition, the estimate of magnitude is in tolerable accord with calculation for this eclipse.

Equalized digits related specifically to area magnitude. Each was equal to $\frac{1}{12}$ of the visible area of the lunar or solar disk.

COMPUTATIONS

(i) The magnitude of 0.22 (i.e. 2.6 digits) is in fair accord with the observed figure of 3$\frac{1}{2}$ digits.
(ii) Altitude of α CMa at first contact = 32.8°, which is in fairly good accord with measurement.
(iii) 148$\frac{1}{3}$ is actually 9^h 53^m. LT of sunset = 18.16^h. 1 seasonal hour of night = 0.973^h. The LT corresponding to the measured altitude of α CMa at first contact (31°) is 3.97^h or 9.81^h after sunset (10.08 seasonal hours). This is in close accord with the recorded LT as reduced by the observers from their altitude determination — i.e (i) 148.3° or 9.89^h; (ii) 9^h 52^m (9.87^h); or (iii) 10 seasonal hours.

(10) 928 Aug 18, Monday, solar (mag = 0.25); observed by Banū Amājūr.

"This solar eclipse was calculated and observed by 'Ali ibn Amājūr. (According to calculation), the beginning is to be at 10;17,53 seasonal hours of the night of Monday, that is 11;16,06 equal hours; the middle at 0;11,51,36 seasonal hours of day on Monday, that is 0;10,55,06 equal hours; the clearance at 0;53,16,36 seasonal hours of day on Monday, that is 0;52,24,54 equal hours. He said: 'I observed this eclipse with my son Abū al-Ḥasan and Mufliḥ and (found) that the Sun rose (already) eclipsed by less than one $\frac{1}{4}$ of its surface. The eclipse continued to increase by an amount that we could preceive until $\frac{1}{4}$ (of its surface) was eclipsed. We observed the Sun distinctly (by reflection) in water. (We found that) it cleared and nothing of the eclipse remained and we distinguished the (full) circle of the Sun's body in water; (that was) when the altitude (of the Sun) was 12° in the east, less $\frac{1}{3}$ of a division of the (instrument) *al-ḥalaqah* (i.e. the ring), which is graduated in thirds (of a degree), that is (less by) $\frac{1}{9}$°. The eclipse digits were equal to those required by calculation from (*al-Zīj*) *al-Mumtaḥan*.'"

Although the full date is not stated, it can fairly readily be established. The observation is cited between the records of two lunar eclipses: those of 927 Sep 13/14 and 929 Jan 27/28 (entries 9 and 11). Only one solar obscuration would be visible at Baghdād during this interval — that of 928 Aug 18, which indeed occurred on a Monday. Hence the date is firmly established.

COMPUTATIONS

(i) The linear magnitude of 0.25 corresponds to only about 0.14 of the area. This is considerably less than the recorded area magnitude. However, the statement that the Sun rose eclipsed a little before maximal phase is accurate. Sunrise would occur at a LT of 5.41^h, while the LT of maximal eclipse would be 5.67^h. The Sun would rise 0.18 eclipsed.
(ii) Altitude of Sun at last contact = 10.6°, significantly less than the seemingly carefully measured value of 11.9°.

(11) 929 Jan 27/28, Wednesday, lunar (mag = 1.19); observed by Banū Amājūr.

"This lunar eclipse was calculated and observed by Abū al-Ḥasan 'Ali ibn Amājūr. This eclipse was at the opposition (i.e. full moon) of (the month of) Dhu al-Ḥijjah, year 316 of al-Hijrah. (According to calculation) the degree of the opposition was 13;33 in Leo; the head (i.e. ascending node) of opposition was 17;37° in Aquarius.... The times of this eclipse in seasonal hours are: the beginning at 4;56 hours of night on Wednesday; the beginning of staying (in totality or in darkness) at 6;23 hours; the middle at 6;30 hours; the beginning of clearance at 7;50 hours [read 6;50]; the end of clearance at 8;10 hours. He said: 'I observed this eclipse at its beginning when the altitude of (the star *al-simāk*) *al-rāmih* (Arcturus: α Boo) was 18° [can read 33°] in the east; the time elapsed from the start of the night (i.e after sunset) (to the beginning) was 5 hours seasonal as required by calculation from (*al-Zīj*) *al-Mumtaḥan*....'"

In this instance, the term 'opposition' is used rather than the more common middle of the month.

COMPUTATIONS

(i) Altitude of α Boo at first contact = 31.1° in the east. Presumably a scribal error is responsible for the large discrepancy between measurement and computation. The most likely alternative to 18° would be 33°; the alphabetic symbols for these two numbers are easily confused.
(ii) LT of sunset = 17.30^h. 1 seasonal hour of night = 1.117^h. The LT corresponding to the measured altitude of α Boo at first contact (18°) is 22.78^h or 5.48^h (4.91 seasonal hours) after sunset. This is in close accord with the recorded LT as reduced by the observers from their altitude determination — i.e. 5 seasonal hours after sunset. However, this result is incompatible with the true (computed) altitude for α Boo of 31.1°, suggesting that the mistake was made when the altitude measurement was first written down.

(12) 933 Nov 4/5, Tuesday, lunar (mag = 1.42); observed by Banū Amājūr.

"This lunar eclipse was calculated and observed by 'Alī ibn Amājūr al-Turkī. He said: '(According to calculation) from *al-Zīj al-Mumtaḥan al-'Arabī* of Ḥabash, the eclipse opposition was on the night of Tuesday the 13th of (the month of) Dhū al-Qa'dah, in the year 321 of al-Hijrah. The degree of opposition was 18;44° in al-thawr (i.e. Taurus). The times in equal hours are: the beginning at $10;53^h$; the beginning of staying (in totality or darkness) at $12;08^h$; the (end of) staying at $13;35^h$ (all of these times are from the beginning of night — i.e. after sunset); the (end of) clearance at $1;18^h$ of day on Tuesday. The (equivalent) times of this eclipse in seasonal hours are: the beginning at $9;41^h$; beginning of staying at $10;42^h$; middle $11;27^h$; (end of) staying at $11;59^h$ (all of these times are from the beginning of night); the (end of) clearance at $1;30^h$ of day on Tuesday.' He said 'I observed this eclipse when it (i.e. the Moon) (entered) the smoke: *dakhana* (i.e. the shadow) and (that was) when the altitude of (the star *al-simāk*) *al-rāmiḥ* (Arcturus: α Boo) was 15° in the east and when the time elapsed from the start of the night (to the beginning) was 9;56 seasonal hours behind that required by calculation from the *al-Mumtaḥan Zīj*.'"

COMPUTATIONS

(i) Computed altitude of α Boo at first contact = 15.4° in the east, in excellent accord with observation.
(ii) LT of sunset = 17.30^h. 1 seasonal hour of night = 1.117^h. The measured altitude for α Boo of 15° corresponds to a LT of 4.56^h or 11.26^h after sunset (i.e. 10.08 seasonal hours). This is in good accord with the recorded time.

Cairo Observations: 977–1004

(1) 977 Dec 13, Thursday, solar (mag = 0.60); observed by Ibn Yūnus.

"This solar eclipse was in the early morning of Thursday the 28th of the month of Rabi 'al-Ākhīr, in the year 367 of al-Hijrah, which is the 22nd of the month of Ādhar in the year 346 of Yazdijerd. We, a group of scholars [ten names are given] attended at al-Qarāfah [a district of Cairo] in the Mosque of Abū Ja'far Aḥmad ibn Naṣr al-Maghribī to watch this eclipse. Everyone waited for the beginning of this eclipse. It began to be perceived when the altitude of the Sun was more than 15° but less than 16°. (Those) present all agreed that about 8 digits of the Sun's diameter were eclipsed, that is (a little) less than 7 digits of surface. The Sun was completely cleared when its altitude was more than 33° by about $\frac{1}{3}$ of a degree, as estimated by me, and agreed by all those present. The Sun and Moon in this eclipse were at their nearest distance (from the Earth — i.e. at perigee)."

COMPUTATIONS

(i) The linear magnitude of 0.60 (i.e. 7.2 digits) is fairly close to the observed figure of about 8 digits. A linear magnitude of 8 digits corresponds to 7.1 digits of area; this compares with rather less than 7 digits as reported in the text.
(ii) Solar altitude at first contact = 15.8° in the east, in excellent accord with observation.
(iii) Solar altitude at last contact = 33.8° in the east, once again very close to the measured value.
(iv) LT at the beginning = 8.42^h, about $1\frac{1}{2}$ hours after sunrise. This compares well with the statement by Ibn Yūnus that the eclipse began in the early morning.

(2) 978 Jun 8, Saturday, solar (mag = 0.50); reported by Ibn Yūnus.

"This solar eclipse was on Saturday the 29th of (the month of) Shawwāl in the year 367 of al-Hijrah, which is the 9th of the month of Khurdād in the year 347 of Yazdijerd, the 8th of (the month of) Ḥazīrān in the year 1289 of Alexander (IV), the 14th of (the month of) Bawūnah in the year 694 of Diocletian. A maximum of $5\frac{1}{2}$ digits of the Sun's diameter were eclipsed, according to estimation, that is 4 digits 10 minutes (i.e. $4\frac{1}{6}$ digits) of surface. The altitude of the Sun when a portion of the eclipse began to be perceived was 56° approximately. The completion of the clearance was when the altitude of the Sun was 26° or about so. The Sun and Moon were at their furthest (from the Earth — i.e. at apogee)."

COMPUTATIONS

(i) The linear magnitude of 0.50 (i.e. 6 digits) is fairly close to the observed figure of $5\frac{1}{2}$ digits. A linear magnitude of $5\frac{1}{2}$ digits corresponds to 4.9 digits of area; this compares with 4.2 digits as reported in the text.
(ii) Solar altitude at first contact = 58.9° in the west, considerably greater than the observed value.
(iii) Solar altitude at last contact = 25.1° in the west, in fair accord with the measured result.

(3) 979 May 14/15, Thursday, lunar (mag = 0.70); observed by Ibn Yūnus.

"This lunar eclipse was in (the month of) Shawwāl in the year 368 of al-Hijrah. The Moon rose eclipsed on the night whose morning was Thursday, the 25th of the month of Urdībahisht in the year 348 of Yazdijerd, which is the 15th of (the month of) Ayyār in the year 1290 of Alexander (IV), the 20th of (the month of) Bashons in the year 695 of Diocletian. More than 8 digits but less than 9 of the Moon's diameter were eclipsed. The time of its rising was near to the calculated time of opposition. The eclipse cleared when about one equal hour and a fifth of night had elapsed, as I estimated. The Moon in this eclipse was near to its middle distance (from the Earth)."

COMPUTATIONS

(i) The linear magnitude of 0.70 (i.e. 8.4 digits) is in adequate agreement with observation.
(ii) The Moon would indeed rise eclipsed. LT of moonrise = 18.87^h. LT of last contact = 20.01^h. Hence interval between moonrise and last contact = 1.14^h, which is close to the recorded figure of approximately 1.2 equal hours.

(4) 979 May 28, Wednesday, solar (mag = 0.45); observed by Ibn Yūnus.

"This solar eclipse was in the late afternoon of Wednesday 23 [read: 28th] of (the month of) Shawwāl in the year 368 of al-Hijrah, which is the 8th of (the month of) Khurdād in the year 348 of Yazdijerd, the 28th of (the month of) Ādhār [read: Ayyār] in the year 1290 of Alexander (IV), the 3rd of (the month of) Bawūnah in the year 695 of Diocletian. The eclipse was perceptible when the altitude of the Sun was $6\frac{1}{2}°$. About $5\frac{1}{2}$ digits of the Sun's diameter were eclipsed, as I estimated, that is 4;10 digits of surface. The Sun set eclipsed. I estimated that what was eclipsed of the Sun in this year, I mean the year 368 of al-Hijrah at the end of Shawwāl, was similar in view to that at the end of Shawwāl of the preceding year, I mean the year 367 of al-Hijrah."

The last sentence by Ibn Yūnus that the eclipse in 368 A.H. occurred at the end of Shawwāl confirms that the date was certainly the 28th (not the 23rd). The alphabetic symbols for 3 and 8 can be confused as a result of the presence or absence of a diacritical point.

COMPUTATIONS

(i) The linear magnitude of 0.45 (i.e. 5.4 digits) is very close to the observed figure of approximately $5\frac{1}{2}$ digits. As mentioned previously, a linear magnitude of $5\frac{1}{2}$ digits corresponds to 4.9 digits of area; this compares with 4.2 digits as reported in the text.
(ii) The Sun would set about 0.40 eclipsed at 18.98^h. Solar altitude at first contact = 7.2° in the west, in good accord with observation.
(iii) LT at the beginning = 18.31^h, not much more than half an hour before sunset. This compares well with the statement by Ibn Yūnus that the eclipse began in the late afternoon.

(5) 979 Nov 6/7, Friday, lunar (mag = 0.84).

"This lunar eclipse was in the month of Rabī' al-Ākhīr in the year 369 (of al-Hijrah), on the night whose morning was Friday the 13th of the month, which is the 21st of the month of Ābān in the year 348 of Yazdijerd, the 7th of (the month of) Tishrīn al-Thānī in the year 1291 of Alexander (IV), the 10th of (the month of) Hatūr in the year 696 of Diocletian. A group of scholars gathered to observe this eclipse. They estimated that what was eclipsed of the Moon's circular surface was 10 digits. The altitude of the Moon when they perceived the eclipse was $64\frac{1}{2}°$ in the east. The altitude when its clearance continued (*istamarra*) [read: completed (*istatamma*)] was 65° in the west. The Moon's distance from the centre of the Earth in this eclipse was the same as that in the preceding eclipse which was in Shawwāl in the year 368 of al-Hijrah (i.e. near to its middle distance)."

COMPUTATIONS

(i) The linear magnitude of 0.84 (i.e. 10.1 digits) is equivalent to 10.6 digits of area, rather more than the estimated area magnitude.
(ii) Lunar altitude at first contact = 65.1° in the east, fairly close to the observed figure.
(iii) Lunar altitude at last contact = 66.2° in the west, rather greater than the measured value.

(6) 980 May 2/3, Monday, lunar (mag = 1.61); observed by Ibn Yūnus.

"The Moon was totally eclipsed in (the month of) Shawwāl in the year 369 of al-Hijrah on the night whose morning was Tuesday, the 14th of the month of Urdībahisht in the year 349 of Yazdijerd. A group of scholars gathered to observe this eclipse. They perceived the trace of the eclipse when the altitude of the Moon was $47\frac{2}{3}$° [can read $40\frac{2}{3}$°]. The eclipse cleared when about $\frac{3}{5}$ of an equal hour remained to the end of the night (i.e. before sunrise). Our gathering to observe this eclipse was in the Mosque of Ibn Naṣr (al-Maghribī) at al-Qarāfah."

The day of the week is in error; it should be Monday rather than Tuesday.

COMPUTATIONS

(i) Lunar altitude at first contact = 40.2° in the west. There is an obvious error in the recorded altitude of the Moon; this significantly exceeds the meridian altitude (42.5°). However, a possible alternative reading for the altitude is $40\frac{2}{3}$° — the alphabetical symbols for 47 and 40 could be confused by a careless scribe.
(ii) LT of sunrise = 5.25^h. LT of last contact = 4.76^h or 0.49^h before sunrise. The recorded figure of approximately 0.6^h is thus slightly over-estimated.

(7) 981 Apr 21/22, Friday, lunar (mag = 0.18); observed by Ibn Yūnus.

"This lunar eclipse was in the month of Shawwāl in the year 370 of al-Hijrah, on the night whose morning was Friday the 3rd of the month of Urdībahisht in the year 350 of Yazdijerd, the 22nd of (the month of) Nīsān in the year 1292 of Alexander (IV), the 27th of (the month of) Barmūdah in the year 696 of Diocletian. We gathered to observe this eclipse at al-Qarāfah in the Mosque of Ibn Naṣr al-Maghribī. We perceived the beginning of this eclipse when the altitude of the Moon was approximately 21°. About one-quarter of the Moon's diameter was eclipsed. The Moon cleared completely when about one-quarter of an hour remained to sunrise."

As the eclipse ended shortly before sunrise, the Moon must have been to the west of the meridian when its altitude was measured. Presumably the interval before sunrise was in seasonal hours; since the date was still fairly close to the equinox, the difference would be minimal.

COMPUTATIONS

(i) The magnitude of 0.18 (i.e. 2.2 digits) is rather less than the estimated magnitude.
(ii) Lunar altitude at first contact = 19.9° in the west, fairly close to the observed figure.
(iii) LT of sunrise = 5.39^h. LT of last contact = 5.33^h or only 0.06^h before sunrise. The recorded figure of approximately $\frac{1}{4}$ hour is thus considerably over-estimated.

(8) 981 Oct 15/16, Sunday, lunar (mag = 0.36); observed by Ibn Yūnus.

"The Moon was eclipsed in the month of Rabī' al-Ākhīr, in the year 371 of al-Hijrah on the night whose morning was Sunday. About 5 digits of diameter were eclipsed. The altitude of the Moon at the contact from outside (external or first contact) was about 24°, as I estimated. The observed time (of first contact) was in advamce of the calculated time by about $\frac{2}{3}$ of an equal hour."

COMPUTATIONS

(i) The magnitude of 0.36 (i.e. 4.3 digits) is quite close to the estimated magnitude.
(ii) Lunar altitude at first contact = 24.8° in the west, fairly close to the observed figure. The text omits the direction in which the Moon was located.

(9) 983 Mar 1/2, Friday, lunar (mag = 1.07); reported by Ibn Yūnus.

"This lunar eclipse was in the month of Ramaḍān in the year 372 of al-Hijrah on the night whose morning was Friday, the 15th of the month, in the month of Isfandār in the year 351 of Yazdijerd. The Moon was totally eclipsed. The altitude of the Moon when the eclipse became perceptible was 66°. The altitude when the Moon cleared completely was 35 plus $\frac{1}{2}$ and $\frac{1}{3}$ (i.e. 35;50°); the Moon was totally dark for about an hour. The observed time exceeded the calculated (time) by nearly $\frac{2}{3}$ of an equal hour".

COMPUTATIONS

(i) Lunar altitude at first contact = 65.8°, the Moon being almost exactly on the meridian. Although the recorded altitude slightly exceeds the meridian altitude, this still represents a good measurement.
(ii) Lunar altitude at last contact = 37.7° in the west, considerably more than the observed figure. The text omits the direction in which the Moon was located.
(iii) Duration of totality = 0.65^h. The recorded time during which "it was dark" thus represents an overestimate.

(10) 985 Jul 20, Monday, solar (mag = 0.28); observed by Ibn Yūnus.

"This solar eclipse was in the late afternoon on Monday at the end of (the month of) Ṣafar in the year 375 of al-Hijrah. The altitude of the Sun when I perceived its eclipse by eye was 23° approximately. The altitude was 6° when nothing of its eclipse remained to be perceived by the eye. A maximum of $\frac{1}{4}$ part of the Moon's diameter was eclipsed."

COMPUTATIONS

(i) The magnitude of 0.28 (i.e. 3.4 digits) is quite close to the estimated magnitude of $\frac{1}{4}$ (i.e. 3 digits).
(ii) Solar altitude at first contact = 26.1° in the west, suggesting a measured altitude of 28° rather than 23°. The alphabetical symbols for 3 and 8 can be confused as a result of the presence or absence of a diacritical point. Although the text does not directly specify the direction of the Sun, it is implied by the reference to the afternoon. The computed LT was 16.68^h, which was fairly late in the afternoon; sunset occurred at 18.87^h.
(iii) Solar altitude at last contact = 8.3° in the west, also much greater than the measured value.

(11) 986 Dec 18/19, Sunday, lunar (mag = 0.91); observed by Ibn Yūnus.

"This lunar eclipse was on the night whose morning was Sunday, the 15th of (the month of) Sha'bān in the year 376 of al-Hijrah. The eclipse became noticeable when the altitude of the Moon was 24° in the west. I estimated the (first) contact and it was when the altitude was $50\frac{1}{2}$° [can read $30\frac{1}{2}$°]. About 10 digits of the Moon's diameter were eclipsed. The observation was in the Mosque of Abū Ja'far Aḥmad ibn Naṣr al-Maghribī at al-Qarāfah in the presence of Abū Aḥmad ibn 'Āṣim and 'Abd al-Raḥman ibn 'Īsā ibn Ṭabyān. The Moon set eclipsed."

COMPUTATIONS

(i) The magnitude of 0.91 (i.e. 10.9 digits) is fairly close to the estimated magnitude.

(ii) Lunar altitude at first contact = 26.8° in the west, considerably greater than the measured value. There is an obvious discrepancy between the two lunar altitudes at the start of the eclipse. The estimated altitude of the Moon at true first contact (due to a delay in noticing the start of the eclipse) would probably be only one or 2° more than 24° — much closer to the computed figure. Clearly the recorded $50\frac{1}{2}°$ is a scribal error. Since the Moon set eclipsed, the estimated altitude at first contact cannot possibly have been as much as 50.5°. The alphabetical symbols for 50 and 30 can be confused by a careless scribe. The alternative of $30\frac{1}{2}°$ is more acceptable, requiring a quite reasonable ΔT value of 2650 sec.
(iii) The Moon would indeed set eclipsed at 7.02^h. It would then be $\frac{3}{4}$ in shadow.

(12) 990 Apr 12/13, Sunday, lunar (mag = 0.74); observed by Ibn Yūnus.

"This lunar eclipse was on the night whose morning was Sunday the 16th of (the month of) Muḥarram in the year 380 of al-Hijrah. $7\frac{1}{2}$ digits of the Moon's diameter were eclipsed, as I guessed. The Moon cleared when the ascendant was the beginning of *al-dalw* (Aquarius). The altitude of the Moon when the eclipse began, I mean at the time of (the first) contact, was 38°."

COMPUTATIONS

(i) The magnitude of 0.74 (i.e. 8.9 digits) is appreciably greater than the estimated figure.
(ii) Lunar altitude at first contact = 42.2° in the east, considerably greater than the measured value. Although the text does not directly state that the measured altitude relates to the Moon, no other reference object is mentioned. The azimuth direction is also omitted.
(iii) The time of end is expressed in an unusual manner. Taking the longitude of the first degree of Aquarius as 300.5° leads to R.A. and dec values of 20.18^h and –20.2°. As the Sun was then in R.A. 1.72^h, a LT for last contact of 1.27^h may readily be deduced, which compares with the computed LT of 1.51^h.

(13) 993 Aug 20, Thursday, solar (mag = 0.96); reported by Ibn Yūnus.

"This solar eclipse was in the forenoon on Sunday the 29th of (the month of) Jumādā al-Ākhirah in the year 383 of al-Hijrah, which is the 6th of the month of Shahrīwar in the year 362 of Yazdijerd, the 20th of (the month of) Āb in the year 1304 of Alexander ((IV), the 27th of (the month of) Mesri in the year 709 of Diocletian. The eclipse began when the altitude of the Sun was 27° in the east and ended (i.e. reached its maximum phase) when the altitude was 45° in the east. The Sun cleared when its altitude was 60° in the east. About $\frac{2}{3}$ of it (i.e. the Sun's surface) was eclipsed."

COMPUTATIONS

(i) The linear magnitude of 0.96 (i.e. 11.5 digits or nearly total) is equivalent to 0.95 of area. This is considerably greater than the estimated figure of about $\frac{2}{3}$; the difference is surprising. The eclipse was independently reported to be total, mentioning darkness and the visibility of stars, by the Cairo chronicler, al-Maqrīzī.[7] However, al-Maqrīzī lived more than four centuries after the event and his source is unknown.
(ii) Solar altitude at first contact = 28.7° in the east, significantly greater than the measured value.
(iii) Solar altitude at maximal phase = 44.0° in the east, reasonably close to the observed value.
(iv) Solar altitude at last contact = 59.8° in the east, very close to the measured figure.
(v) The LT at the beginning of the eclipse = 7.79^h, more than 2 hours after sunrise and thus well into the forenoon.

(14) 1001 Sep 5/6, Saturday, lunar (mag = 0.86); observed by Ibn Yūnus.

"This lunar eclipse was in (the month of) Shawwāl in the year 391 of al-Hijrah at the start of the night of Saturday, the 14th of the month, which is the 25th of the month of Bahman in the year 370 of

Yazdijerd. The Moon cleared when about 2 seasonal hours of night had elapsed (i.e. after sunset). I saw, the Moon before its clearance and it was like a crescent."

This is the only lunar observation for which Ibn Yūnus does not say "the night whose morning was...".

COMPUTATIONS

LT of last contact = 19.87^h. LT of sunset = 18.24^h. 1 seasonal hour of night = 0.960^h. Hence last contact = 1.63^h after sunset or 1.68 seasonal hours. Presumably the "2 hours" of the text is only approximate.

(15) 1002 Mar 1/2, Monday, lunar (mag = 1.44); reported by Ibn Yūnus.

"This lunar eclipse was on the night whose morning was Monday the 15th of the month of Rabīʿ al-Ākhir in the year 392 of al-Hijrah, which is the 17th of the month of Isfandārmad in the year 370 of Yazdijerd. The Moon was totally eclipsed and had a staying (*al-makth*: i.e. in totality or in darkness). The eclipse began when the altitude of (the star) *al-simāk al-rāmiḥ* (Arcturus: α Boo) was (either) 12° or 52° east and when the altitude of (the star) *al-ḥādī* (Capella: α Aur) was 14° in the west. The altitude of (the star *al-simāk*) *al-rāmiḥ* at the complete clearance was 35°."

COMPUTATIONS

(i) altitude of α Boo at first contact = 53.4° east. In the original manuscript, the alphabetic numerals can equally be read as 12 or 52 due to the absence of diacritical points. This was also noted by the source of Caussin.
(ii) Altitude of α Aur at first contact = 13.7° west, very close to the measured figure. The star *al-ḥādī* definitely corresponds to α Aur, whereas Caussin had been somewhat doubtful as to its true identity.
(iii) Altitude of α Boo at last contact = 79.2° in the east. In this case it is not possible to satisfactorily restore the altitude measurement. There is a possibility of a mistake made by a careless scribe writing 35 instead of 75, when using alphabetical numerals.

(16) 1004 Jan 24, Monday, solar (mag = 0.98); observed by Ibn Yūnus.

"This solar eclipse was in the sign of *al-dalw* (Aquarius) and was in the late afternoon of Monday the 29th of the month of Rabīʿ al-Awwal in the year 394 of al-Hijrah which is the 24th of (the month of) Kānūn al-Ākhīr in the year 1315 of *al-Iskandar ibn Fīlibs al-Yūnānī* (i.e. Alexander IV, son of Philip the Greek), the 28th of (the month of) Ṭūbah in the year 720 of Diocletian, and also the 10th of the month of Bahman in the year 372 of Yazdijerd. The Sun was eclipsed until what remained of it resembled the crescent Moon on the first night of the month. I estimated that 11 digits of it (i.e. the Sun's surface) was eclipsed. The altitude of the Sun when the eclipse became noticeable in it (i.e. on its disk) was 16½° in the west; thus I estimated (the altitude) at the beginning to be 18½°. About quarter of the diameter was eclipsed when the altitude was 15° and half of the diameter was eclipsed when the altitude was 10°. The eclipsing was complete (i.e. maximum phase) when the altitude was 5°."

COMPUTATIONS

(i) The linear magnitude of 0.98 is equivalent to an identical area magnitude. This corresponds to 11.8 digits (or just short of annularity) and is somewhat greater than the estimated figure of 11 digits. However, it closely corresponds to the appearance of the crescent Moon on the first day of the lunar month.
(ii) Solar altitude at first contact = 19.1° in the west, which compares favourably with the observer's estimate of 18.5°. Ibn Yūnus's adjustment of as much as 2° to the measured altitude at the start suggests that the eclipse was not noticed until it was already fairly well advanced. The altitude correction represents a delay in sighting the eclipse — by as much as 0.15^h.

(iii) Solar altitude when 0.25 of the diameter eclipsed = 15.9° in the west, in fair accord with measurement.
(iv) Solar altitude when 0.5 of the diameter eclipsed = 12.7° in the west, significantly greater than the observed figure.
(v) Solar altitude at maximum phase = 6.6° in the west, also appreciably greater than the observed value. Because the magnitude was so large, it would be fairly easy for the observers to define the moment of maximum eclipse. The Sun would set still partially obscured; this explains the lack of any reference to last contact.

2. *Solar and Lunar Eclipses Recorded by al-Battānī*

(1) 883 Jul 23/24, Wednesday, al-Raqqah, lunar (mag = 0.95); observed by al-Battānī.

"This lunar eclipse was observed by us at the city of al-Raqqah on the 23rd of (the month of) Tammūz in the year 1194 of *Dhū al-Qarnayn* (the "Two-horned", i.e. Alexander IV, the son of Philip), which is the year 1206 after the death of *al-Iskandar* (i.e. Alexander III, the Great). The middle of the eclipse was at a little more than 8 equal hours after midday. A little more than $\frac{1}{2}$ plus $\frac{1}{3}$ (i.e. $\frac{5}{6}$ or 10 digits) of the Moon's diameter was eclipsed.... According to calculation from Ptolemy('s tables) $\frac{1}{2}$ plus $\frac{1}{3}$ plus $\frac{1}{8}$ (i.e. $\frac{23}{24}$ or $11\frac{1}{2}$ digits) of the Moon's diameter was to be eclipsed and the time of the middle of the eclipse in advance of the observed time by nearly $\frac{1}{2}$ plus $\frac{1}{4}$ (i.e. $\frac{3}{4}$) of an equal hour. In this eclipse the Sun was at its furthest distance (apogee) and the Moon was at its middle distance less by $1\frac{1}{2}$ parts approximately."

COMPUTATIONS

(i) The magnitude of 0.95 (i.e. 11.4 digits) is significantly greater than the estimated figure of a little more than $\frac{5}{6}$ (10+ digits).
(ii) LT of mid-eclipse = 19.68^h or 7.68^h after midday. Hence the record of "8 equal hours and a small amount" represents a considerable overestimate.

(2) 891 Aug 8, Sunday, al-Raqqah, solar (mag = 0.87); observed by al-Battānī.

"This solar eclipse was observed by us at the city of al-Raqqah on the 8th of (the month of) Āb in the year 1202 of *Dhū al-Qarnayn* (the Two-horned, i.e. Alexander IV), which is the year 1214 after the death of *al-Iskandar* (i.e. Alexander III, the Great). The middle of the eclipse was at one seasonal hour after midday. (A little) more than $\frac{2}{3}$ of the Sun (i.e of surface) was eclipsed in view. According to calculation from Ptolemy('s tables), more than $\frac{1}{2}$ plus $\frac{1}{4}$ (i.e. $\frac{3}{4}$) of the Sun (i.e. Sun's surface) was to be eclipsed, and the (time of) middle of the eclipse was about an hour before observation. The Sun and Moon in this eclipse were at their furthest distance (i.e. at apogee)."

COMPUTATIONS

(i) The linear magnitude of 0.87 (i.e. 10.4 digits) is equivalent to 0.84 of area magnitude. This is considerably greater than the estimated value of more than $\frac{2}{3}$ (8+ digits).
(ii) LT of mid-eclipse (maximum phase) = 12.88^h or 0.88^h after midday. 1 seasonal hour of day = 1.14^h, hence LT of mid-eclipse = 0.77 seasonal hours after midday. This is considerably less than the recorded figure.

(3) 901 Jan 23, Friday, Anṭakyah, solar (mag = 0.67); observed by al-Battānī.

"This solar eclipse was observed by us at the city of Anṭakyah on the 23rd of (the month of) Kānūn al-Thānī in the year 1212 of *Dhū al-Qarnayn* (i.e. Alexander IV), which is the year 1224 after the death of al-Iskandar (i.e. Alexander III, the Great). The middle of the eclipse was about $3\frac{2}{3}$ equal hours before midday. (A little) more than $\frac{1}{2}$ of the Sun (i.e Sun's surface) in sight was eclipsed. In this eclipse the Sun was at its nearest distance (perigee) and the Moon was nearly at its middle distance."

COMPUTATIONS

(i) The linear magnitude of 0.67 (i.e. 8.0 digits), equivalent to 0.59 of area magnitude, is in fair accord with the estimated value of slightly more than $\frac{1}{2}$.
(ii) LT of mid-eclipse (maximum phase) = 8.13^h or 3.87^h before midday. This is rather more than the recorded interval of about 3.67^h.

(4) 901 Jan 23, Friday, al-Raqqah, solar (mag = 0.68); reported by al-Battānī.

"This eclipse was observed by someone on our behalf at the city of al-Raqqah (at the same date as above). The middle of the eclipse was (a little) less than $3\frac{1}{2}$ equal hours before midday. (A little) less than $\frac{2}{3}$ of the Sun (i.e. Sun's surface) in view was eclipsed. According to calculation from Ptolemy('s tables), the Sun should have been totally eclipsed, and the (time of) the middle of the eclipse was later than the observed time by about two hours. Such a discrepancy is not acceptable."

This is a continuation of the preceding account. It is not clear whether concerning the accuracy of the calculation using Ptolemy's tables relates to Anṭakyah or al-Raqqah. Our computed magnitude for the two sites is almost identical and the local times differ by only 0.2^h.

COMPUTATIONS

(i) The linear magnitude of 0.68 (i.e. 8.2 digits), equivalent to 0.60 of area magnitude is fairly close to the observed result of less than $\frac{2}{3}$.
(ii) LT of mid-eclipse (maximum phase) = 8.36^h or 3.64^h before midday. This is rather more than the recorded interval of less than $3\frac{1}{2}$ equal hours.

(5) 901 Aug 2/3, Sunday, Anṭakyah, lunar (mag = 1.06); observed by al-Battānī.

"This lunar eclipse was observed by us at the city of Anṭakyah on the 2nd of (the month of) Āb in the year 1212 of *Dhū al-Qarnayn* (i.e. Alexander IV), which is the year 1224 from the death of *al-Iskander* (i.e. Alexander III, the Great). The middle of the eclipse was at approximately 15 plus $\frac{1}{3}$ (i.e 15;20^h) equal hours after midday. The Moon was eclipsed by less than its diameter by a small amount. In this eclipse the Sun was at its furthest distance (apogee) and the Moon at its middle distance less than by $1\frac{1}{2}$ parts approximately."

COMPUTATIONS

(i) This eclipse was marginally total (mag = 1.06), but the record implies that the Moon was never completely enveloped in the Earth's shadow. The discrepancy could have arisen from the marked variation in brightness across the lunar disk since the totally eclipsed Moon would be very close to the edge of the shadow.
(ii) LT of mid-eclipse (presumably when the shadow was deepest) = 14.89^h after midday. This is considerably less than the recorded interval of approximately $15\frac{1}{3}$ equal hours.

(6) 901 Aug 2/3, Sunday, al-Raqqah, lunar (mag = 1.06); reported by al-Battānī.

"This eclipse was observed (by someone on our behalf) at the city of al-Raqqah (at the same date as above). The middle of the eclipse was approximately 15 plus $\frac{1}{3}$ and $\frac{1}{4}$ (i.e. 15;35 equal hours) after midday. In this eclipse the Sun was at its furthest distance (apogee) and the Moon at its middle distance less than by $1\frac{1}{2}$ parts approximately".

This is part of the preceding account. Presumably the quoted magnitude (i.e. "less than its diameter by a small amount") is based on observations made at both Anṭakyah and al-Raqqah.

COMPUTATIONS

(i) The estimate of magnitude has already been discussed in the previous entry.
(ii) LT of mid-eclipse (as before) = 3.08^h or 15.08^h after midday. This is considerably less than the recorded interval of approximately 15.58^h.

3. *Solar and Lunar Eclipses Recorded by al-Bīrūnī*

(1) 873 Jul 28, Tuesday, Nīshāpūr, solar (annular: mag = 0.94); observed by al-Irānshahrī.

"This solar eclipse was observed by Abū al-'Abbās al-Irānshahrī at Nīshāpūr early in the morning on Tuesday the 29th of the month of Ramaḍān in the year 259 of al-Hijrah, which is the 13th of the month of Tīr in the year 242 of Yazdijerd.... He mentioned that the Moon's body (i.e. disk) was in the middle of the Sun's body. The light from the remaining uneclipsed portion of the Sun surrounded it (i.e. the Moon). It was clear from this that the Sun's diameter exceeded in view that of the Moon" [*al-Qānūn al-Mas'ūdī*].

The recorded date is exactly correct. Attention was drawn to this observation by Goldstein.[8] Although long before al-Bīrūnī's own time, al-Irānshahrī cited it as evidence that the angular diameter of the Sun could exceed that of the Moon. Ptolemy (*Almagest*[9]) had implied that annular eclipses could not take place because he believed that the apparent lunar diameter at apogee was equal to the apparent solar diameter. This issue was still being debated in seventeenth-century Europe.

Goldstein[10] notes that none of the works of al-Irānshahrī survives, but this author is mentioned by al-Bīrūnī in several other places.

COMPUTATIONS

The eclipse would indeed be annular at Nīshāpūr, 0.94 of the solar diameter (i.e. 11.3 digits) being covered at maximal phase early in the morning (LT = 5.6^h; solar altitude = 7°).

(2) 1003 Feb 19/20, Saturday, Jurjān, lunar (mag = 0.14); observed by al-Bīrūnī.

"This lunar eclipse was on the night of Saturday the 14th of the month of Rabī' al-Ākhīr in the year 393 (of al-Hijrah). I observed the beginning and clearance at Jurjān by the altitude of the (two stars) *al-Shi'rayān* (i.e. *al-shi'rā al-yamāniyyah* — Sirius: α CMa — and *al-shi'rā al-shāmiyyah* — Procyon: α CMi). The Moon was eclipsed by $\frac{1}{4}$ of its diameter by estimate. The longitude difference between Jurjān and Ghaznah is 2;21 minutes of day. The middle of the eclipse at it (presumably at Ghaznah) was 19;11 (minutes of day) after midday of Friday, the 6th of the month of Isfandārmadh in the year 1751 of Bukhtinassar (i.e. Nabonassar)" [*al-Qānūn al-Mas'ūdī*].

At the end of this and the following two entries, al-Bīrūnī mixes the day and month of the Persian calendar with the year in the old Egyptian calendar.

In this observation, al-Bīrūnī reduced the measured time of mid-eclipse from Jurjān to Ghaznah using the longitude difference between the two cities. A minute of day ($\frac{1}{60}$ of a day) was equivalent to 0.4 of an equal hour. al-Bīrūnī's longitude difference between the two cities corresponds to 0.94^h or 14.1°. The actual longitude difference between Jurjān and Ghaznah is 0.933^h (13.99°) — virtually identical with al-Bīrūnī's result. Unfortunately al-Bīrūnī does not record the LT of observation at Jurjān.

COMPUTATIONS

(i) The magnitude of 0.14 (i.e. 1.7 digits) is significantly less than estimated value of ¼ of the diameter.
(ii) LT of mid-eclipse at Ghaznah = 19.62^h or 7.62^h after midday. Hence mid-eclipse was estimated to occur 7.67^h after noon at Ghaznah. Hence computation is in excellent accord with observation concerning the time.

(3) 1003 Aug 14/15, Sunday, Jurjān, lunar (mag = 0.14); observed by al-Bīrūnī.

"This lunar eclipse was on the night of Sunday the 13th of (the month of) Shawwāl in the year 393 (of al-Hijrah). I observed it at Jurjān by the altitudes of (the two stars) *al-nasrān* (i.e. "the two eagles": *al-nasr al-ṭā'ir* — Altair, α Aql — and *al-nasr al-wāqi'* — Vega, α Lyr) and (the star) *al-'ayyūq* (i.e. Capella, α Aur). The middle of the eclipse at Ghaznah occurred when more than ¼ of its diameter was eclipsed and that was 31;21 (minutes of day) after midday of Saturday the 2nd of the month of Shahrīwar in the year 1751 (of Nabonassar)" [*al-Qānūn al-Mas'ūdī*].

al-Bīrūnī followed the same procedure as in the previous example of estimating the LT for mid-eclipse at Ghaznah from the measurement at Jurjān.

COMPUTATIONS

(i) The magnitude of 0.14 (i.e. 1.7 digits) is significantly less than estimated value of ¼ of the diameter. It is curious that both eclipses in this year had virtually identical magnitudes and both were equally overestimated by the observers.
(ii) LT of mid-eclipse at Ghaznah = 0.28^h (after midnight) or 12.28^h after midday (Saturday). Mid-eclipse was estimated to occur 12.54^h after noon at Ghaznah. Hence computation is in fair accord with observation concerning the time.

(4) 1004 Jul 4/5, Wednesday, Jurjāniyyah, lunar (mag = 0.17); observed by al-Bīrūnī.

"This lunar eclipse was on the night of Wednesday the 14th of the month of Ramaḍān in the year 394 (of al-Hijrah). I observed its middle at Jurjāniyyah of Khwārizm and found it to be 36;32 (minutes of day) after midday of Tuesday the 22nd of the month of Tīr in the year 1752 (of Nabonassar). Ghaznah is east of Jurjāniyyah by 1;42,12 (minutes of day)" [*al-Qānūn al-Mas'ūdī*].

In this instance, al-Bīrūnī did not mention the clock stars which he used to determine the local time of observation.

It seems most likely that on this occasion the place to which the local time refers is Jurjāniyyah; the allusion to Ghaznah would appear to be incidental. (The longitude difference between Ghaznah and Jurjāniyyah according to al-Bīrūnī is equivalent to 0.68^h or 10.2°; this compares with the true figure of 0.62^h or 9.27°.)

COMPUTATIONS

LT of mid-eclipse at Jurjāniyyah 2.89^h (after midnight) or 14.89^h after midday (Tuesday). Mid-eclipse was measured to occur 14.61^h after noon. Hence computation is in good accord with observation concerning the time.

(5) 1019 Sep 16/17, Thursday, Ghaznah, lunar (mag = 0.76); observed by al-Bīrūnī.

"This lunar eclipse was (seen) at Ghaznah in (the month of) Jumādā al-Ūlā, in the year 410 (of al-Hijrah). I observed it and (found that) at the moment when the indentation at (the edge of) the full Moon became noticeable the altitude of (the star) *al-'ayyūq* (Capella, α Aur) from the east was slightly less than 66°, that of (the star) *al-shi'rā al-yamāniyyah* (Sirius, α CMa) was 17°, that of (the star) *al-shāmiyyah* (Procyon: α Cmi) was 22°, and that of (the star) *aldabarān* (Aldebaran, α Tau) was 63°; all in the east. All these (altitude measurements) necessitate that the beginning of the eclipse would be when approximately 8 hours of night had elapsed (i.e. after sunset). Some astronomers from Khurāsān predicted that the completion of the clearance would be when $10\frac{1}{4}$ hours of night had elapsed. Since night hours were then nearly equal to daytime hours, because the Sun was in the last degrees of Virgo, this would be when 1 plus $\frac{1}{2}$ and $\frac{1}{4}$ (i.e. $1\frac{3}{4}$) hours of night remained (i.e. before sunrise). It was clear to the sight that the world was lit up, the stars had disappeared, the Sun was about to rise, and the Moon was about to set behind the mountains which screened it. A small portion of the eclipse (still) remained in its body (i.e. disk) and I was unable to observe it (i.e. the time of completion of clearance) exactly" [*Kitāb Taḥdīd*].

All four star altitudes refer to first contact. Since visibility of the eclipse was eventually interrupted by mountains, last contact could not be observed from Ghaznah.

It is a pity that this eminent astronomer omitted to report in his *al-Qānūn al-Mas'ūdī* the measured altitudes of the various clock stars which he used at the two eclipses in 1003 and presumably on a further occasion in 1004 (see above). Had he done this, it would have proved possible for us to verify his original measurements, as in the present example.

COMPUTATIONS

(i) Altitude of α Boo at first contact = 66.8° east, which compares with the measured "slightly less than 66°".
(ii) Altitude of α CMa at first contact = 17.5°, compared with the measured 17°.
(iii) Altitude of α CMi at first contact = 22.9°, compared with the measured 22°.
(iv) Altitude of α Tau at first contact = 63.1°, compared with the measured 63°.
All of the above four measurements are thus consistently accurate.
(v) LT of sunset = 18.10^h. Reduction of the altitude determinations reported by al-Bīrūnī would lead to LTs for first contact between 2.29^h and 2.38^h, or some 8.33^h after sunset. This may be compared with his statement that the eclipse began approximately 8 hours after sunset.
(vi) LT of last contact = 5.59^h, or about 0.3^h before sunrise. The sky would thus be very bright. The altitude of the Moon would then be +4.7°. Evidently the "distant mountains" subtended at least this elevation on the horizon.

3. CONCLUSION

In writing this and the previous paper we have had several aims. Firstly, we have produced for the benefit of historians of astronomy and astronomers generally a careful and accurate translation from the Arabic of all the accessible eclipse records by medieval Muslim astronomers. In particular, we have been able to correct a number of textual errors, especially in the use of alphabetical symbols for numerals. We have also carefully investigated the accuracy of the dates of each eclipse — which are often recorded using a variety of calendars. Finally we have studied in detail the precision with which the various observations were made.

With regard to dating accuracy, we have mainly concentrated on the dates expressed in terms of the Islamic calendar — which is used by both Ibn Yūnus and al-Bīrūnī. We have also investigated the dates on the Syrian calendar as utilized by al-Battānī and Ibn Yūnus. In general, we have found the dating accuracy to be high, errors seldom exceeding a single day.

Eclipse magnitudes were only crudely estimated using the unaided eye and for these the precision proves to be mediocre — typically about 1 digit. Nearly all altitude measurements (whether of the Sun, Moon or selected bright stars) were quoted to the nearest degree, which is the likely accuracy achievable with a hand-held astrolabe. Most of these measurements prove to be of this order of precision, as do the quoted reductions from altitude to local time (typical error some 5 minutes).

The measurements of altitude and time are among the most accurate eclipse observations in the whole of the pre-telescopic period and are far superior to contemporary measurements from other civilizations. They are thus of considerable value in modern astronomical studies such as Earth's past rotation.

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