JHA, xli (2010)

INVESTIGATION OF MEDIEVAL EUROPEAN RECORDS OF SOLAR ECLIPSES

F. RICHARD STEPHENSON, Durham University

1. *Introduction*

Throughout history, eclipses of the Sun have aroused considerable attention in a variety of cultures worldwide. In particular, total eclipses produce a sudden and dramatic fall in the level of daylight. Early records of these spectacular events frequently mention the onset of darkness and the appearance of several stars by day. Large partial solar eclipses may also be fairly impressive phenomena, sometimes producing a significant dimming of the sunlight and enabling one or two stars to be seen during the day.

Examination of the numerous reports of solar eclipses in the chronicles of medieval Europe (from around A.D. 750 to 1500) provides an intriguing insight into the effects of solar eclipses over a wide range of magnitudes on largely untrained and unsuspecting observers. Most of the dates of these events are precisely recorded. By comparing the observations with the results of current retrospective computation, it is possible to obtain useful information on a variety of topics. Results include (i) the variation in frequency of records as a function of magnitude; (ii) the minimum magnitude necessary for an eclipse to be noticed at all; and (iii) the minimum magnitude required to render stars visible by day. These themes form the main subjects of the present paper. It should be mentioned that the lunar orbital acceleration and long-term variations in the Earth's spin rate are now so accurately determined that the local circumstances of eclipses may be computed with high precision throughout the medieval period.

2. *Types of Solar Eclipse*

On the terrestrial surface as a whole, solar eclipses fall into two main categories: umbral and penumbral. During an umbral eclipse the tapering lunar shadow cone intersects the Earth, whereas during a penumbral eclipse the shadow cone fails to make contact with the terrestrial surface. On the basis of the extensive computations by Espenak and Meeus,[1] we know that in a typical century around 235 eclipses are visible over at least some part of the Earth. Of these, some 151 are umbral and 84 are penumbral.

Umbral eclipses fall into three categories: total, annular and annular-total. The lunar orbit around the Earth is significantly more elliptical than the terrestrial orbit around the Sun. Hence whether a particular umbral eclipse is total or annular, or a combination of both (i.e. annular-total), depends largely on the Earth–Moon distance. Very roughly speaking, when the Moon is in that half of its orbit that lies closest to

0021-8286/10/4101-0095/$10.00 © 2010 Science History Publications Ltd

the Earth, within a narrow zone on the terrestrial surface the lunar disc can completely cover the Sun for a short time (up to a maximum of about 7.5 minutes). However, at all places beyond this zone, the Sun is no more than partially obscured. In general, *annular* eclipses occur when the Moon is farther from the Earth than average. Under these circumstances, in those places where the Moon is directly in line with the Sun, a bright ring of sunlight is seen surrounding the lunar disc — which itself appears in silhouette. Annularity can last up to about 12.5 minutes. Outside the narrow zone of annularity, no more than a partial eclipse is visible.

When the Moon is close to its mean distance from the Earth, an *annular-total* eclipse may result. At some places where a particular annular-total eclipse is central, the Moon can cover the whole of the Sun for a few moments, while at other locations within the central zone the ring phase is briefly visible. Of the 151 umbral eclipses occurring in an average century, 62 are total, 78 are annular, and 11 are annular-total.

Since the size of the Moon's umbral shadow on the terrestrial surface is fairly small, both total and annular eclipses are rare at any one site. In a typical millennium, total eclipses occur only about 3 or 4 times at any given place, and annular eclipses rather more frequently — some 4 or 5 times. By comparison, partial eclipses of the Sun are much more frequent, occurring some 40 times in a century at any one location. However, unless a large proportion of the solar disc is covered by the Moon, the fall in the level of daylight may be insignificant and the eclipse may well pass unnoticed unless an observer is given advance warning.

3. *Observations of Solar Eclipses Recorded in Medieval Chronicles*

The solar eclipses reported in the many town and monastic chronicles of medieval Europe are unique in pre-modern world history. Not only are the records extremely numerous, they are often very detailed. Furthermore, the observations were made at a wide variety of locations. Yet only very rarely were observers forewarned of the occurrence of an eclipse (as the result of crude attempts at prediction).

The chronicles are largely — but by no means exclusively — from the present-day countries of England, France, Germany and Italy; they mainly cover the period from about 600 to 1500. The language of the vast majority of these annals is Latin. Frequently more than 20 observations of the same eclipse are recorded in different chronicles — often from widely spaced locations. To judge from the available reports, few of the observers had any real interest in astronomy. Only rarely is there any evidence that the true cause of an eclipse was understood. The majority of records give no descriptive details, typically stating no more than "the Sun was eclipsed" (e.g., "solis eclipsis facta est" or "sol obscuratus est") — on a specified date. However, many further accounts are quite vivid, describing the occurrence of darkness (usually using the term *tenebrae*) and/or the visibility of stars (e.g. "stellae visae sunt") by day. Individual stars (or planets) are never identified. A rough estimate of the time of day when an eclipse occurred is often quoted — typically to the nearest hour or so. However, there is virtually no evidence of careful measurement of time.

During the eighteenth and nineteenth centuries, compilations of many medieval European chronicles were published in their original language. Among the most extensive collections are *Scriptores rerum Italicarum*; *Monumenta Germaniae historica, Scriptores*; *Rerum Britannicarum medii aevi scriptores*; and *Recueil des historiens des Gaules et de la France*. Each of these well-known works runs to many printed volumes.

Towards the end of the nineteenth century, exhaustive searches for medieval European solar eclipse reports in these and other anthologies were made by G. Celoria[2] and F. K. Ginzel,[3] with the object of improving knowledge of the lunar motion. Celoria confined his attention to reports of two total eclipses — those of 1239 Jun 3 and 1241 Oct 6 — both of which were widely observed in central and southern Europe. However, Ginzel assembled a vast number of records of more than 40 separate eclipses of various kinds, which were observed between 346 and 1415.

In their searches for eclipse records, Celoria and Ginzel included whatever observations they could trace, regardless of detail. They did not attach any special significance to total or even unusually large solar eclipses. For each individual eclipse account, they quoted the full text — whether it was lengthy or brief. They also specified the source of each report, wherever possible naming the place of observation.

A century or so after the work of Celoria and Ginzel, R. R. Newton,[4] in two substantial monographs, made extensive usage of their material in his studies of the terrestrial rotation and the lunar acceleration. Newton also made further careful literature searches of his own. The catalogues of medieval European eclipses that Newton published also show that he had no special interest in large solar eclipses. Any eclipse for which Newton could obtain access to a viable record is included below, whether the report was detailed or brief.

In his two monographs, Newton provided useful English translations of more than 500 individual eclipse reports from Europe between 563 and 1567. For each observation, he discussed the historical circumstances in some detail, as well as converting the dates to the Julian proleptic calendar. He also identified the place — or region — where the eclipse was seen. Fortunately, in the original sources most dates were accurately expressed (usually in terms of the traditional Julian calendar, involving usage of the Kalends, Ides and Nones). However, in a very few instances where only an approximate date was recorded, Newton derived an incorrect date and in undertaking the present investigation I have corrected these errors where possible. Newton tabulated the geographic co-ordinates of the various places of observation to the nearest 0.01°. In particular he also assigned to each report an estimated reliability: usually 0.05, 0.1, 0.2, 0.5 or 1. Although Newton's estimates of reliability are often conjectural, they nevertheless provide useful guidelines for interpreting the records.

4. *Eclipse Selection and Computation in the Present Paper*

As more recent studies reveal,[5] Newton's list of solar eclipses is by no means complete. Nevertheless, the medieval European eclipse records that he published are well suited for the present investigation. In addition to translations, in his later volume Newton also provided summaries of each observation in tabular form. These tables cover both the records contained in the earlier of his two monograph and those that he had subsequently discovered or reinterpreted. Eclipse reports which Newton cited prior to 733 and after 1502 are relatively sparse. Hence in the present survey, I have concentrated on the observations between 733 and 1502 for which Newton assigned a reliability of 0.5 or greater, and for which a specific town — rather than merely a region — is named. However, I have excluded the few reports from Constantinople, the Near East and Arab Spain that Newton cited.

In total I have investigated more than four hundred individual solar eclipse observations discussed by Newton, ranging in date from 733 to 1502. The records relate to as many as 84 separate eclipses, of which 33 were total on the Earth's surface, 38 were annular, 7 were annular-total and 6 were partial. In some instances — notably in 840, 878, 1133, 1140, 1178, 1191, 1239 and 1241 — there are frequent reports of the same eclipse from many separate locations. However, other eclipse records originate from only a very few places. It seems likely that unfavourable weather may have been a significant factor at some eclipses, considerably reducing the number of potential observers. Thus, several eclipses which modern computation reveals were very large throughout much of Europe went unrecorded. Presumably on some of these occasions the sky was overcast throughout wide areas. However, scarcely any surviving eclipse reports make mention of cloud.

Throughout, I have focused on those eclipse reports between 733 and 1502 for which the precise place of observation could be established. In each case, I have computed the individual magnitudes (expressed as a fraction of the solar diameter obscured) and local times for every observation where Newton estimated the reliability as 1 or 0.5. All my computations were made using a lunar acceleration of –26 arcsec/cy^2, together with the ΔT results obtained by Morrison and Stephenson.[6] In all, I have compared 418 individual reports with the results of computation. Of these, 230 reports relate to eclipses which were total on the Earth's surface. The value of ΔT for any eclipse which I investigated could be estimated so accurately (typically within about 100 sec) that it was possible to compute each magnitude with high precision: to better than 0.01. Such a minor error does not significantly affect the various deductions made in this paper.

5. *Sample Descriptions of Total and Annular Eclipses*

Comparison of the 418 more reliable eclipse records selected from the work of Newton with the results of computation reveals that on as many as 76 occasions between 733 and 1502 one or other of the sites experienced a fully total eclipse of the Sun. Of these, more than 20 accounts clearly describe the total phase. One of the many accounts of totality is to be found in the chronicle of the monastery at Heilsbronn (Germany):

> In the year of the Incarnation of our Lord, 1133 ... on the 4th day before the Nones of August [Aug 2], the 4th day of the week, when the Sun was declining, towards the ninth hour the Sun in a single moment became as black as pitch and day was turned into night; very many stars were seen, objects on the ground appeared as they usually do at night … [*Notae Halesbrunnenses*].

Rather surprisingly, not a single report of a total eclipse makes a clear reference to the corona. Most records from sites within the computed zone of totality focus on the onset of darkness and/or the visibility of stars by day, without commenting on the appearance of the Sun itself. However, in many further instances where computation indicates that the Sun would be totally obscured, the occurrence of an eclipse is only briefly mentioned, without any indication that it was unusually large.

Although annular eclipses occur on the Earth's surface rather more frequently than their total counterparts, computation reveals that of the places recording eclipses in the observations listed by Newton only as few as 10 sites would actually experience the ring phase. Comparing this figure with the number of total eclipses experienced during the same interval (76) strongly suggests that the observers showed little interest in annular eclipses. In fact, only a single report suggests that a central annular eclipse was actually witnessed. This occurs in the annals of the monastery of Brauweiler (Germany):

> 1147. On Sunday, the 7th day before the Kalends of November [Oct 26], a solar eclipse occurred at the 3rd hour and persisted until after the sixth. The eclipse stood fixed and motionless for a whole hour, as noted on the clock [*horologium*].... During this hour, a circle of different colours and spinning rapidly was said to be in the way [*Annales Brunwilarenses*].

In the central zone, this eclipse reached a computed magnitude of 0.95. As was fairly usual at this period, it is evident that the observers were unaware of the true cause of the eclipse. The apparent spinning of the lunar disk ("a circle of different colours") is presumably an optical illusion, perhaps due to the observers' looking for too long directly at the bright Sun, which would then be more than 20° above the horizon. For other annular eclipses which, according to computation, were fully central at the places of observation, only the occurrence of an eclipse is mentioned — without any qualifying details.

Somewhat surprisingly, as many as nine reports relate to eclipses that were partial on the Earth's surface: 1009 (two accounts), 1186 (two), 1240 (one), 1399 (one), 1465 (two), and 1486 (one). Although the computed magnitudes at five of the places of observation were fairly large (between about 0.7 and 0.8), in the other four instances the magnitude was between 0.4 and 0.5.

Computation reveals that as many as 340 eclipses listed by Newton were partial where they were seen. However, clear descriptions of the partial phase are extremely rare. Most accounts merely note the occurrence of an eclipse without any indication of magnitude.

6. *Frequency of Eclipse Records as a Function of Magnitude*

Studies of the frequency with which medieval European eclipse records vary as a function of the computed magnitude leads to some interesting results. Of the 418 eclipse reports in the selected period to which Newton assigned a reliability of at least 0.5, he estimated a reliability of 1 in as many as 308 instances and 0.5 in the 110 further examples. For the whole suite of 418 data, the frequencies as a function of computed magnitude (in steps of 0.05) are as follows: magnitude 1.00 or greater (76 observations); magnitude 0.95–0.99 (87 observations); 0.90–0.94 (79); 0.85–0.89 (64); 0.80–0.84 (39); 0.75–0.79 (24); 0.70–0.74 (21); 0.65–0.69 (7); 0.60–0.64 (3); 0.55–0.59 (3); 0.50–0.54 (4); 0.45–0.49 (3), 0.40–0.44 (4), 0.35–0.39 (1); 0.30–0.34 (3). No recorded eclipse attained a computed magnitude of less than 0.30. These results are displayed in the form of a histogram in Figure 1.

In general, Figure 1 shows a fairly sharp and steady decline in frequency with decreasing magnitude below 0.85. The median magnitude is around 0.93. Clearly, the greater the magnitude of an eclipse, the higher the probability of its being recorded. In particular, very few eclipses of magnitude less than 0.70 were recorded.

Some features of Figure 1 need comment. The reduced frequency for eclipses that reached a magnitude greater than 1.00 is to be expected. All of these were, of course, total eclipses. However, more than half of the complete set of observations were of eclipses which were no more than annular on the Earth's surface.

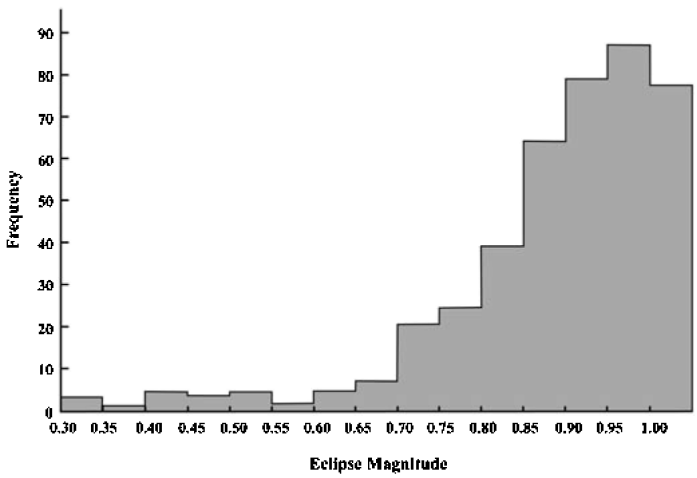

FIG. 1. The relative frequency as a function of computed magnitude with which solar eclipses were recorded in medieval European chronicles.

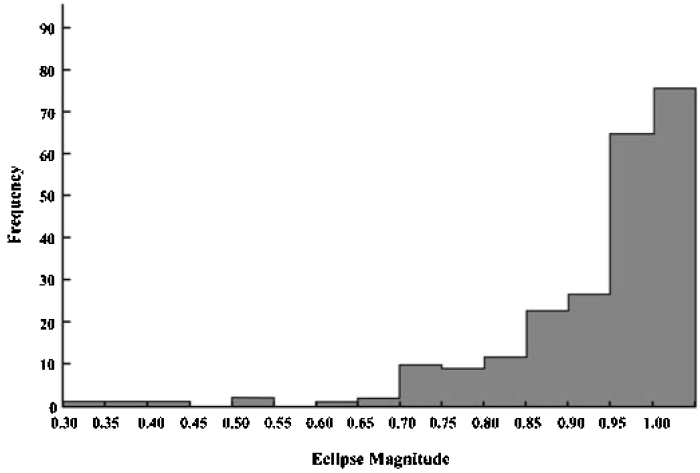

FIG. 2. The relative frequency as a function of computed magnitude with which solar eclipses that were total on the Earth's surface were recorded in medieval European chronicles.

With the exception of the eclipse of 1033, which attained a magnitude of 0.994 in the narrow central zone, no annular eclipse in the present study attained a magnitude of more than 0.97 on the Earth's surface and most magnitudes ranged from 0.93 to 0.96. Hence the majority of observations of eclipses with computed magnitudes in the range 0.95 to 0.99 were of those which were generally total on the Earth's surface; few annular eclipses are included in this category.

The above features are apparent from comparison between Figure 1 and Figure 2. The latter diagram shows the frequency distribution, as a function of computed magnitude, for the 230 eclipses that were total on the terrestrial surface. Not only is the frequency highest for eclipses of magnitude greater than 1.00, there is a very sharp decrease in frequency for magnitudes less than 0.95.

Although comparison between Figures 1 and 2 is instructive, only Figure 1 is of any real historical significance. This provides a useful indication of the likely distribution of computed magnitudes for solar eclipses reported by unsuspecting and untrained observers over any randomly chosen interval of several centuries — for example the period covered by the ancient Greek and Roman texts. However, since both Babylonian and Chinese astronomers systematically made attempts at predicting solar eclipses, a much more uniform frequency distribution would be expected for their observations.

It is not possible to use Figure 1 to estimate the actual degree of success achieved by a typical observer in detecting eclipses of any particular magnitude. The intervals covered by different medieval chronicles varied widely, while unfavourable weather would also be a major factor. However, some useful general results can still be obtained from the diagram. For instance, it may be inferred that eclipses of all magnitudes less than 0.80 are only about 20 per cent as likely to be recorded as those with magnitudes of at least 0.80. More significantly, it is apparent that eclipses with magnitudes less than about 0.70 were very rarely recorded, and presumably were rarely noticed.

Nevertheless, a surprising number of eclipses of very small magnitude were reported. Eleven observations relate to eclipses that reached a computed magnitude of less than 0.50 where they were seen. These eclipses occurred on: 1009 Mar 29 (two observations: mag = 0.47, 0.48), 1018 Apr 18 (one observation: mag = 0.41), 1087 Aug 1 (one observation: mag = 0.43), 1118 May 22 (one observation: mag = 0.49), 1181 Jul 13 (one observation: mag = 0.30), 1186 Apr 21 (two observations: each mag = 0.43), 1232 Oct 15 (one observation: mag = 0.30), 1288 Apr 2 (one observation: mag = 0.34), and 1361 May 5 (one observation: mag = 0.39). With only a single exception (one of the observations in 1009), Newton assigned a reliability of unity to each of these various records. I have carefully investigated the recorded dates of these observations and in each case I have been able to establish their reliability.

In three of the above instances, the Sun would rise or set eclipsed and thus the eclipse would be relatively easy to observe. For example, the record of the eclipse of 1018 Apr 18 in the *Chronicon of Thietmarus* may be translated as follows: "In those days the Sun before its setting appeared to several to be halved in a wondrous fashion." This eclipse reached a computed magnitude of 0.41 at Merseburg (Germany); at maximal phase the solar altitude was only 2°.

Possibly in some of the other examples of small eclipses where the Sun was relatively high in the sky, thin cloud might have assisted observation. Alternatively, a chance sighting might occasionally have been made — e.g. by someone's catching sight of the image of the Sun as reflected in water or taking a casual glance towards the Sun. However, although the probability of detecting an eclipse of magnitude less than 0.5 is clearly very small, it is evident that occasionally events of this kind can indeed be noticed by unsuspecting observers.

Among the 418 observations investigated in this study, the very smallest eclipse to be seen was that of 1232 Oct 15. This reached a computed magnitude of only 0.30 at the place of observation: Cologne. The report in the *Annales Colonienses maximi* may be rendered as follows: "A partial eclipse of the Sun was seen after midday in the same year; (it was) not, however, very notable." The computed maximal phase occurred at a local time of 13.6 h, in good accord with the record.

7. *Reports of Stars by Day*

In the two compilations by Newton, as many as 58 reports of solar eclipses to which he assigned a reliability of 0.5 or 1 describe the visibility of one or more stars by day. All but five of these records relate to eclipses which computation indicates were generally total on the Earth's surface. Of the 58 separate accounts that mention stars, 36 refer to eclipses that were fully total at the appropriate place of observation.

More than half of the remaining observations at which stars were seen (14) were

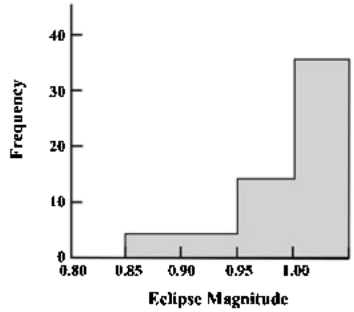

FIG 3. The relative frequency as a function of computed magnitude with which stars were reported at solar eclipses in medieval European chronicles.

made at eclipses that attained a computed magnitude of at least 0.95. Eight of these eclipses reached a magnitude of 0.98 or 0.99. Four further sightings of stars occurred during eclipses at which the Sun attained a magnitude of between 0.90 and 0.94 and four more at magnitudes between 0.85 and 0.89. There were no reported sightings of stars at eclipses that attained a magnitude of less than 0.85. These results are plotted in Figure 3.

Although Venus is usually readily detectable in full daylight with the unaided eye by trained observers — as early Chinese records reveal — it is apparent that only a fairly large eclipse enabled medieval European observers to detect *any* stars (including planets). Surprisingly, stars were recorded on only five occasions at eclipses that computation reveals were generally annular: 1147 (1 sighting), 1191 (2), 1033 (1), 1147 (1). None of these sightings occurred where the eclipse was central, in marked contrast to total obscurations of the Sun.

In summary, it may be concluded that for casual observers, stars are seldom reported unless the magnitude is greater than about 0.98. In particular, for eclipses that were generally annular, it is rare for stars to be noticed at all. This latter result is not unexpected. In an annular eclipse in which 0.95 of the solar diameter is covered, only 0.90 of the surface area is obscured by the Moon. However, for a total eclipse where 0.95 of the diameter is covered, as much as 0.96 or 0.97 of the solar disk is covered.

Incidentally, the smallest eclipse in medieval times known to me that rendered even a single star visible was that of 1310 Jan 31. This event was not cited by Newton. A translation of this record is as follows:

> 1310, on the last day of January, at the 8th hour at Avignon, there was an eclipse of the Sun and it was unusually eclipsed, and was remarkably scintillating. There appeared just as at nightfall a single star, according to the opinion of the crowd. Then indeed a notable semicircle was seen, which lasted beyond the ninth hour ... (*Ptolomaei Lucensis Historia ecclesiasticae*).

At the time, Venus, 28°E of the Sun, would be well placed. Although at Avignon the magnitude was only 0.83, from the record it seems that the observers had scanned the sky with unusual alacrity.

8. *Conclusion*

It is my hope that the above deductions based on the investigation of medieval European reports of solar eclipses may prove helpful in the study of the numerous allusions to solar eclipses in ancient Greek and Roman writings. For many of these events, the date of occurrence and interpretation are often problematical. The medieval observations indicate that only large eclipses would be likely to be noticed, while visibility of stars by day would suggest a very large eclipse indeed.

REFERENCES

1. F. Espenak and J. Meeus, *Five millennium catalog of solar eclipses: –1999 to +3000 (2000 BCE to 3000 CE), revised* (Greenbelt, MD, 2009).
2. G. Celoria, "Sull' eclissi solare totale del 3 Giugno 1239", *Memorie del Reale Istituto Lombardo di Scienze e Letteri, Classe di scienze matematiche e naturali,* xiii (1877), 275–300, and "Sugli eclissi solari totali del 3 Giugno 1239 e del 6 Ottobre 1241", *ibid.*, 367–82.
3. F. K. Ginzel, "Astronomische Untersuchungen über Finsternesse, II", *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften, Wien, Naturwiss. Classe*, lxxxviii (1884), 629–755, and "Astronomische Untersuchungen über Finsternesse, III", *ibid.*, lxxxix (1884), 491–559.
4. R. R. Newton, *Medieval chronicles and the rotation of the Earth* (Baltimore, 1972), and *The Moon's acceleration and its physical origins* (Baltimore, 1979).
5. See, for example, F. R. Stephenson, *Historical eclipses and Earth's rotation* (Cambridge, 1997).
6. L. V. Morrison and F. R. Stephenson, "Historical values of the Earth's rotational clock error ΔT and the calculation of eclipses", *Journal for the history of astronomy*, xxxv (2004), 327–36.