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Reviewed work(s):
Source: *Classical Philology*, Vol. 104, No. 3 (July 2009), pp. 354-375
Published by: The University of Chicago Press
Stable URL: http://www.jstor.org/stable/10.1086/650145
Accessed: 02/04/2012 07:32

ARDUA ET ASTRA: ON THE CALCULATION OF THE DATES OF THE RISING AND SETTING OF STARS

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From our earliest texts onward, we find classical authors referring to the time of year by means of the rising and setting of various stars and constellations. Hesiod (*Op*. 383–84) encourages us to begin the harvest at the rising of the Pleiades and to plow at their setting; Alcaeus (frag. 347a) encourages us to drink at the rising of Sirius; and Horace (*Carm*. 3.1.25–28) assures us that a man content with his lot is not disturbed at the setting of Arcturus or the rising of Haedus. Indeed, Quintilian suggests that a knowledge of the stars is necessary to understand poetry, because poets so often specify the time by the rising and setting of stars.[1] However, it is not just poets who rely on the stars to specify the time: we find a similar use in prose authors such as Thucydides or Hippocrates (e.g., Thuc. 2.78; Hippoc. *Aer*. 2.10–18, 11). This is unsurprising, as before the reform of Julius Caesar the calendars of the Greeks and Romans, with their erratic intercalations, were frequently out of step with the seasons and often gave no reliable indication of the time of year.[2]

It is often helpful to know when these phenomena actually took place; in some cases, such as Ovid's *Fasti*, such knowledge can inform both textual and literary criticism. In the *Fasti* Ovid provides over forty dates for the rising and setting of various stars and constellations, following the tradition of the Greek *parapegmata* (lists of risings and settings).[3] In the early nineteenth century, the German mathematician and chronologist Christian Ludwig Ideler published an article comparing Ovid's dates with those he calculated for Ovid's time;[4] he found that Ovid made a large number of errors in his dating, and since then criticism of this aspect of the poem has been

The task of preparing this article was made substantially easier by the computer software Planetary, Lunar, and Stellar Visibility by Noel Swerdlow and Rainer Lange (see the note to table 3), and I am very grateful to Professor Swerdlow for all his prompt (and patient!) responses to my many questions. I would also like to thank *CP*'s anonymous referees, whose helpful suggestions have made this article less confusing than it might otherwise have been.

1. Quint. *Inst*. 1.4.4: *nec si rationem siderum ignoret poetas [grammatice] intellegat, qui, ut alia mittam, totiens ortu occasuque signorum in declarandis temporibus utuntur.*

2. See, e.g., Caes. *B Civ*. 3.6.2, *ii nonas ianuarias naves solvit*; 3.9.8, *iamque hiems adpropinquabat*; 3.25.1, *multi iam menses erant et hiems praecipitaverat.*

3. For more information on the tradition of the *parapegma*, see Rehm 1941, 1949; Lehoux 2000; Hannah 2005, chap. 3.

4. See Ideler 1822–23.

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common.[5] More recently, however, some scholars have suggested that rather than astronomical incompetence, these seeming mistakes may show evidence of Ovid's deliberate manipulation of his sources for his own literary purposes.[6]

The example of the *Fasti* is instructive, as all analysis of the astronomical passages of the work has (until very recently) been based on Ideler's nineteenth-century article, despite the fact that methods for calculating modern dates have been refined considerably since then. The reluctance of scholars to calculate these dates for themselves is understandably not uncommon: in addition to the recent works on the *Fasti* that rely on the calculations of Ideler, we find, for instance, that Germaine Aujac's 1975 commentary on Geminus relies on the calculations of Georg Hofmann published in 1879.[7]

A problem that can arise when one does not make the calculations oneself is a lack of awareness of the many variables that are involved in the process of calculating these dates and of the various uncertainties that arise as a result. For example, although Ideler mentions some of the assumptions he is making, the uncertainties in his calculations have not filtered through into later commentaries, which tend to assume that these dates are precise. When Aujac discusses the disagreements between the dates in the *parapegma* attached to Geminus' *Isagoge* and those in Hofmann's tables, she raises the possibility that the calculations are wrong, but not that they might have a significant error margin.[8] In general it seems that some scholars have the not unreasonable idea that modern computational methods will provide a precise date for these phenomena;[9] those who do attempt to discover the possible error margin for these calculations are reassured that it is only on the order of plus or minus two days.[10] As we shall see, however, there are good reasons for thinking that the uncertainty surrounding these dates is in many cases considerably greater.

The purpose of this article is to review the various methods currently available to scholars for the calculation of these dates, some of which make it

5. E.g., Frazer 1929, 1: xx: "I can only hope that, in turning into English the German astronomer's exposure of Ovid's many errors concerning the starry heavens, I have not been guilty of fresh blunders, for my ignorance of astronomy is as profound as that of my author appears to have been." For lists of more such criticisms, see Robinson 2000, 40; Fox 2004, 92–93. For a defense of Ovid's accuracy, see Robinson 2000, 40–43; Fox 2004; Robinson 2007.

6. E.g., Gee 2002. For a discussion of the importance (or otherwise) of accuracy as a basis for literary criticism in the *Fasti*, see Robinson 2007.

7. An exception is West, who in his commentary on Hesiod's *Works and Days* (West 1978) calculated the dates for the various stars mentioned using the tables of Neugebauer (1922). He notes that these dates involve some margin of error (West 1978, 376–82). It is not clear if he made use of the corrections in subsequent publications by Neugebauer (1925, 1929).

8. Aujac 1975, 158. In her defense, however, it is generally said that these calculations have an accuracy of plus or minus two to three days. As I hope to show below, for practical purposes the error margin may be substantially wider.

9. E.g., Gee 2000, 205: "With the aid of computer programmes, one might calculate the exact dates of rising and setting of a given star at a given latitude in any particular year."

10. E.g., Neugebauer 1922. Schoch (Langdon, Fortheringham, and Schoch 1928) strongly asserts that his figures give an error margin of plus or minus one day.

very easy for scholars to perform these calculations themselves, and to examine more closely the various assumptions that such calculations require. I will also discuss the various problems involved with actually observing these phenomena.

SOME BASIC ASTRONOMY

In order to understand some of the issues involved, it may be helpful to begin with a little basic astronomy. I hope the text below is reasonably clear, but I have made available on the Web some diagrams and animations illustrating what follows.[11]

From the earth it seems as if the stars are on a sphere that rotates from east to west around the north celestial pole. So if we were at the earth's North Pole looking upward, the stars would appear to rotate in horizontal planes parallel to the horizon, never rising or setting. As we moved south and our latitude decreased, the north celestial pole would appear to move down in the sky, until when we reached the equator it would appear to be in the same horizontal plane as the horizon; the stars would appear to be rotating in vertical planes perpendicular to the horizon, and every star would rise and set.

It takes roughly twenty-three hours and fifty-six minutes for the celestial sphere to complete a full revolution, or one sidereal day.[12] That is to say, any star will reach the same point in the sky roughly four minutes earlier each successive night: for example, a star that crosses the eastern horizon at about 6 p.m. on January 1 will cross the horizon at about 5:40 p.m. on January 6. The sun moves slightly more slowly than the stars—the average time it takes to complete a full revolution being, of course, twenty-four hours.

"Rising" and "Setting"

In the range of latitudes of particular interest to the classicist, most stars will rise and set—in the ordinary sense of the words—once every sidereal day. That is to say, in any given twenty-three-hour, fifty-six-minute period, all stars apart from the circumpolar ones (which never rise or set) will cross the eastern and western horizons. These risings and settings may take place at any time during the night, when they will be visible, or during the day, when they will be invisible.

However, when Hesiod and others talk of the rising and setting of the stars, they are not using the ordinary sense of the words but rather referring to the rising and setting of the stars in a particular relation to the sun, namely, at or close to sunrise and sunset. In this astronomical sense, there are eight different risings and settings, each of which occurs only once a year: these are tabulated in table 1.

The "true" risings and settings take place when the star crosses the horizon at the same time as the sun: as the sky is still bright at these times, these

11. These can be found at http://www.ucl.ac.uk/GrandLat/permanent/robinson/astronomy.
12. The precise figure for the length of the mean sidereal day is 23 hours, 56 minutes, and 4.09 seconds.

TABLE 1. TECHNICAL TERMS FOR THE RISINGS AND SETTINGS

Phenomenon	Other terminology	Description
True morning rising (TMR)	(True) cosmical rising	The star crosses the eastern horizon with the sun. For the previous few days it has crossed the eastern horizon after sunrise (and was thus invisible). On the day of the true morning rising, it is below the horizon shortly before sunrise (and thus invisible) and will remain invisible as it crosses the horizon (as the day has now dawned and the sun's light obscures that of the star).
Apparent morning rising (AMR)	Heliacal rising, "first visibility"	The star crosses the eastern horizon shortly before the sun and is thus briefly visible (for the first time). With every morning that follows, the interval between the star's rising and sunrise increases: the star is visible earlier, and for longer. This is the first of many visible risings.
True morning setting (TMS)	(True) cosmical setting	The star crosses the western horizon as the sun crosses the eastern horizon. For the previous few days, the sun has risen before the star has set, and so as day dawned the star could be seen some distance above the western horizon. On the day of the true morning setting, the star is visible before sunrise, but its setting is obscured by the light of the rising sun.
Apparent morning setting (AMS)	(Visible) cosmical setting	The star crosses the western horizon just before sunrise and so can be seen to set (for the first time) in the morning twilight. With every morning that follows, the interval between the star's setting and the sunrise increases: this is the first of many visible settings.
Apparent evening rising (AER)	(Visible) acronychal rising	The star crosses the eastern horizon just after sunset. On previous days the star has crossed the horizon some time after sunset, and so its rising was easily visible. On subsequent days the interval between sunset and the star's rising diminishes, and the sky is too bright for the star's rising to be seen; by the time the sky is dark, the star is already some distance above the eastern horizon. Thus the apparent evening rising is the last visible rising of the star after sunset.
True evening rising (TER)	(True) acronychal rising	The star crosses the eastern horizon as the sun crosses the western horizon and is thus invisible. By the time the sky is dark enough for the star to be seen, it will have already risen and will be some distance above the eastern horizon.
Apparent evening setting (AES)	Heliacal setting, "last visibility"	The star crosses the western horizon shortly after sunset. On previous days the star has crossed the western horizon sometime after sunset, and so it could be seen for some time in the night sky and its setting was easily visible. This is the last visible setting of the star, as on subsequent days the star will have disappeared under the horizon by the time the sky is dark.
True evening setting (TES)	(True) acronychal setting	The star crosses the western horizon with the sun; by the time the sky is dark enough for stars to be seen, the star is beneath the horizon and so is invisible.

phenomena cannot be observed, and the dates can only be determined by calculation. The "apparent" risings and settings take place just before sunrise or just after sunset, when the sky is just dark enough for the star to be visible. Since the apparent phenomena are the only ones that can actually be seen, it seems clear that they are the phenomena referred to in the majority of literary texts and *parapegmata*; references to the true phenomena, which cannot be seen and whose dates cannot be ascertained without mathematical or mechanical assistance, are obviously of less practical use and tend to be confined to ancient handbooks on astronomy.[13]

In what follows, I use the terminology in the first column of table 1: it has the significant advantage of being clear and practical and also corresponds to the terms used by the Greeks themselves in the earliest extant handbooks.[14] The terms "heliacal," "acronychal," and "cosmical" are by contrast somewhat opaque, and they have been used by different scholars to refer to different phenomena.[15] The terms "first visibility" and "last visibility," while a little more helpful, can also be somewhat misleading, as there are some stars, such as Arcturus, that are always visible; these terms also apply to only two of the eight phenomena.

It is always the case that the apparent morning phenomena follow the true morning phenomena and the apparent evening phenomena precede the true evening phenomena. However, the order in which the apparent phenomena appear in relationship to one another and the order in which the true phenomena appear in relationship to one another vary with a star's position relative to the ecliptic (the sun's apparent path through the sky),[16] and the order of a star's true phenomena is not necessarily the same as that of its apparent phenomena (see table 2).

As we can see in table 2, both stars located north of the ecliptic show the same order in their true phenomena but a different order in their apparent phenomena, and the stars on the ecliptic and south of the ecliptic show different orders again in their true phenomena. Table 2 also illustrates how the interval between true and apparent phenomena can vary: in this instance we see intervals ranging from eleven days between the apparent and true

13. See Geminus 13.10: "For this reason the visible risings of the stars are announced in the public decrees. For the true [risings] are unobserved and unobservable, while the visible are both announced and observed" (trans. Evans and Berggren 2006). Not everyone agrees with this analysis, however: cf. Pritchett and van der Waerdern (1961), who argue that Thucydides divided up the year according to some apparent and some true phenomena; cf. also Ideler's (1822–23) analysis of the star passages in Ovid's *Fasti*, which assumes that the sources used by Ovid contained dates for true as well as apparent phenomena. While it is not impossible that such sources, which would have been more academic than practical, existed by the time Ovid was writing in the early first century C.E., it seems highly unlikely (given what we know of Greek mathematical and mechanical expertise) that they would have existed in Thucydides' lifetime.

14. E.g., the works of Autolycus (*On Risings and Settings*) and Geminus (*Introduction to Astronomy*, chap. 13).

15. E.g., Lockyer (1894, 120–22) seems to use the term "heliacal" instead of "apparent" and refers to the TES as the "cosmic evening setting"; Bickerman (1980, 143) seems to have misunderstood Ginzel's terminology (1906–14, 2: 520–22) and claims that "heliacal" means "near sunrise" and that "acronical" (*sic*) and "cosmical" imply "near sunset."

16. The order can also influenced by the latitude of the observer: see Evans and Berggren 2006, 63–70.

TABLE 2. THE ORDER OF THE PHENOMENA:
DATES CALCULATED FOR ROME, 44 B.C.E.

North of ecliptic				On ecliptic		South of ecliptic	
Capella (α Aurigae)		Denebola (β Leonis)		Regulus (α Leonis)		o Leonis	
TMR: Mar. 10	AMR: Apr. 7	TMR: Aug. 13	AMR: Aug. 31	TMR: Jul. 28	AMR: Aug. 14	TMR: Jul. 25	AMR: Aug. 17
TES: Jun. 6	AES: May 23	TES: Sep. 15	AER: Jan. 27	TER: Jan. 22	AER: Jan. 11	TMS: Jan. 12	AER: Jan. 8
TER: Sep. 12	AER: Aug. 21	TER: Feb. 7	AMS: Apr. 7	TMS: Jan. 24	AMS: Feb. 11	TER: Jan. 20	AMS: Jan. 29
TMS: Dec. 6	AMS: Dec. 19	TMS: Mar. 15	AES: Aug. 7	TES: Jul. 27	AES: Jun. 30	TES: Jul. 15	AES: Jun. 12

Note: The results of the true phenomena have been obtained using the algorithms of Meeus (1998) and thus are free of correction for refraction. The dates for the apparent phenomena have been obtained using the program Planetary, Lunar, and Stellar Visibility, details of which are given below table 3. For further details on the relationship between true and apparent risings, see Evans 1998, 190–97; Evans and Berggren 2006, 63–70.

evening risings of Regulus to thirty-nine days between the apparent and true evening settings of Denebola.[17]

PROBLEMS OF CALCULATION

Whatever method of calculation we use, the first thing to decide upon is the star whose rising or setting we wish to discover. This is by no means a trivial decision. While in some cases classical authors do specify a particular star (e.g., Arcturus) or an easily identifiable star cluster (e.g., the Pleiades), in other cases they do not, talking instead of constellations rather than individual stars. In the case of a large constellation such as Pegasus, this can be extremely confusing: when we read, for example, in the Geminus *parapegma* that "on the seventeenth day of Leo, for Euctemon . . . the Horse rises,"[18] to which star does this refer? Is it the first star of the constellation to rise (i.e., κ Pegasi)? Or the first bright star to rise (possibly ε, η, or β Pegasi)? Or the most constantly bright star (α Pegasi)? Our choice makes a substantial difference to the date, as there is a gap of nearly a month between the apparent morning risings of κ Pegasi and α Pegasi and a similar gap between the true

17. Compare the rule of thumb given by Autolycus in *On Risings and Settings* (2.1), that a star becomes visible once the sun is half a zodiac sign below the horizon: this is equivalent to fifteen degrees, which is approximately equivalent to fifteen days (see Evans and Berggren [2006, 67–68] for more details). Table 2 illustrates the possibility for error that such a rule of thumb would introduce if it were ever used to compile lists of dates.

18. See Aujac 1975, 99.

risings, as illustrated in table 3. When we read of Orion rising, we have an even larger number of stars to choose from.[19]

In some cases, the sources seem to be giving us some help in identifying the star: for example, again from the Geminus *parapegma*, "for Eudoxus, Orion begins to set in the evening" and "for Callippus, Sagittarius ceases rising,"[20] which might suggest that we should look at the first star to set and last star to rise, respectively (though even this is not certain).[21] However, even then there is confusion. Which star are we to take as the first star of Orion? To answer that question, we would need to know exactly how Eudoxus constructed the constellation. While we may get some help in this regard from Aratus, who used Eudoxus as a source, what are we to do for Euctemon? Even when we think we have a good idea of the stars that make up a constellation, there are still some surprises. For example, according to Aratus (*Phaen.* 205–7), the star in the head of Andromeda (α Andromedae) is also the star in the belly of Pegasus; this is presumably the "bright star in the navel" to which Eratosthenes refers ([*Cat.*] 1.18 Olivieri). Hipparchus (3.4.5) is aware of this star, but when he describes the last star to set, he refers not to this star (which should be the last star of Pegasus to set) but rather to γ Pegasi (see fig. 1).[22] Table 4 illustrates the different dates calculated for the apparent evening setting of various stars of Pegasus.

There are two more key variables necessary for all methods of calculation: the geographical latitude of the observer and the year of the observation. Specifying these variables for an author such as Ovid is not too problematic,[23] but uncertainty can arise in the case of the observations of some of the early Greek astronomers, who are said to have observed in a number of different locations.[24] It is often noted that both variables have an impact on the results of the calculation; this is true, though as we shall see, there is only a slight change with time, and the change with latitude is irregular—it is often, though not always, greater than the change with time.

Tables 5–8, respectively, give the dates of the apparent phenomena for α Coronae Borealis (a star north of the ecliptic), α Leonis (a star on the

19. Of course, in the case of smaller constellations, which may contain only one very bright star, the choice may be more obvious, but it is important to emphasize that in many cases we do not know for certain what exactly Euctemon or Eudoxus, e.g., observed when they decided that they had witnessed the apparent morning rising of the Dolphin and that, as a consequence, the choice of star is one of many uncertainties involved in the calculations.

20. See Aujac 1975, 106 and 104.

21. One of the referees of this article suggested that in the case of Euctemon and Eudoxus, a constellation "began to rise" when its first recognizable star became visible, rather than the first star of the constellation, though different authorities may have used different criteria.

22. See Hipp. 2.6.11: ἔσχατος δὲ ὁ ἐπὶ τῆς ὀσφύος λαμπρός. This is the same description he uses to identify the last star to rise (2.5.11), which cannot refer to α Pegasi.

23. Though of course it may be that he used sources from a different latitude, or a different time, or both.

24. See, e.g., Ptolemy, *Phaseis* (Heiberg 2: 67): "[Of the various astronomers] the Egyptians observed here, Dositheus in Cos, Philippus in the Peloponnese and Locris and Phocis, Callipus in the Hellespont, Meton and Euctemon at Athens and the Cyclades and in Macedonia and Thrace, Conon and Metrodorus in Italy and Sicily, Eudoxus in Asia and Sicily and Italy, Caesar in Italy, Hipparchus in Bithynia, Democritus in Macedonia and Thrace."

TABLE 3. DATES FOR RISINGS OF STARS IN PEGASUS, CALCULATED FOR ATHENS, 432 B.C.E.

Phenomenon	κ Peg.	ε Peg.	β Peg.	α Peg.
AMR	Jan. 19	Jan. 24	Feb. 3	Feb. 16
TMR	Dec. 22	Dec. 30	Jan. 8	Jan. 18

Note: Calculations for true phenomena were made using the algorithms of Meeus (1998), with data from the Tycho-2 Catalogue; those for apparent phenomena were made using the program Planetary, Lunar, and Stellar Visibility (PLSV) 3.0.1, by Rainer Lange and Noel Swerdlow (http://www.alcyone.de). For the *arcus visionis* I used the program's default variable *arcus*; for the critical altitude I used the magnitude of the star, except for stars with magnitudes below 0.5, for which I used 0.5 (see text below for discussion of these values). Note that since the writing of this article PLSV has been updated, and it may now produce slightly different results (usually within a day or so of the dates in this article). The table shows that the intervals between various true and apparent risings, while not identical, are similar; subsequent tables give only dates calculated for apparent risings, using the same program and values.

TABLE 4. DATES FOR THE AES OF STARS IN PEGASUS, CALCULATED FOR ATHENS, 432 B.C.E.

Phenomenon	ε Peg.	α Peg.	β Peg.	γ Peg.	α And.
AES	Jan. 17	Feb. 4	Feb. 13	Feb. 19	Feb. 27

Note: The star ε Pegasi is the first to set; α Pegasi is located in the middle of the constellation; β and γ Pegasi follow; and α Andromedae is the last star to set.

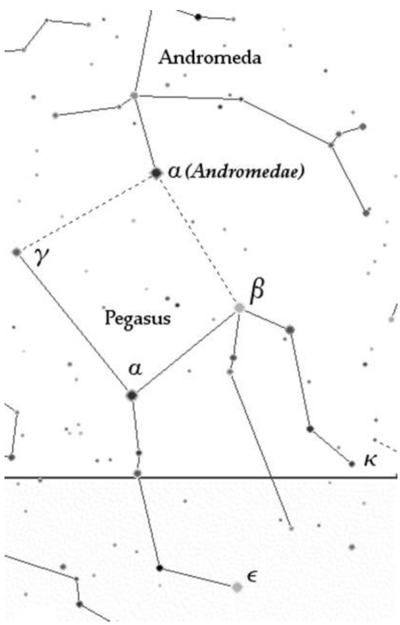

FIG. 1. The constellation Pegasus setting. This picture was generated by Chris Marriott's Sky Map Lite 2005, available from www.skymap.com.

TABLE 5. CHANGES IN DATES OVER TIME FOR α CORONAE BOREALIS
(North of the Ecliptic, Magnitude 2.21)

Phenomenon	300 B.C.E.	100 B.C.E.	44 B.C.E.	401 C.E.	Change in 700 Years
AMR	Oct. 6	Oct. 8	Oct. 8	Oct.11	+5 days
AES	Dec. 4	Dec. 3	Dec. 3	Dec. 1	−3 days
AMS	Jul. 15	Jul. 14	Jul. 13	Jul. 11	−4 days
AER	Mar. 6	Mar. 7	Mar. 7	Mar. 10	+4 days

TABLE 6. CHANGES IN DATES OVER TIME FOR α LEONIS
(Regulus; On the Ecliptic, Magnitude 1.4)

Phenomenon	300 B.C.E.	100 B.C.E.	44 B.C.E.	401 C.E.	Change in 700 Years
AMR	Aug. 11	Aug. 12	Aug. 12	Aug. 14	+3 days
AES	Jul. 2	Jul. 3	Jul. 3	Jul. 5	+3 days
AMS	Feb. 12	Feb. 14	Feb. 14	Feb. 18	+6 days
AER	Jan. 7	Jan. 9	Jan. 9	Jan. 12	+5 days

TABLE 7. CHANGES IN DATES OVER TIME FOR α PISCIS AUSTRINI
(South of the Ecliptic, Magnitude 1.23)

Phenomenon	300 B.C.E.	100 B.C.E.	44 B.C.E.	401 C.E.	Change in 700 Years
AMR	Apr. 29	Apr. 30	Apr. 30	May 2	+3 days
AES	Dec. 18	Dec. 21	Dec. 22	Dec. 28	+10 days
AMS	Jul. 23	Jul. 25	Jul. 26	Jul. 31	+8 days
AER	Sep. 4	Sep. 5	Sep. 5	Sep. 8	+4 days

TABLE 8. CHANGES IN DATES OVER TIME FOR α CANIS MAIORIS
(Sirius; South of the Ecliptic, Magnitude −1.46)

Phenomenon	300 B.C.E.	100 B.C.E.	44 B.C.E.	401 C.E.	Change in 700 Years
AMR	Jul. 30	Jul. 30	Jul. 30	Jul. 30	0 days
AES	May 2	May 2	May 2	May 3	+1 day
AMS	Nov. 21	Nov. 22	Nov. 22	Nov. 23	+2 days
AER	Jan. 4	Jan. 4	Jan. 5	Jan. 5	+1 day

ecliptic), α Piscis Austrini (a star south of the ecliptic), and Sirius (α Canis Maioris, also south of the ecliptic) in Rome over a period of time.[25]

25. The dates were calculated using PLSV; for more details and values, see table 3. For Sirius I have used a critical altitude of 0.5. The inclusion of Sirius in these tables was the suggestion of one of the referees of this article: as the referee noted, and the table confirms, Sirius is unusual in that its apparent morning rising, which was of great importance in antiquity, keeps the same date for hundreds of years. The changes in dates for the true phenomena of these various stars show a similar pattern.

It is important to be aware that the precise direction and extent of the change in date depends on the star's position relative to the ecliptic; for example, the AES of α Piscis Austrini (located south of the ecliptic) fell on December 18 in 300 B.C.E., but on December 28 in 401 C.E., moving forward by ten days, in contrast to the AES of α Coronae Borealis (north of the ecliptic), which moved backward by three days over the same period. It should also be noted that as the calendar year gets a little out of sync with the solar year toward the end of our four-year leap-year cycle, a slight change in the date may be observed: for example, the AMS of α Leonis fell on February 15 in 41 B.C.E. but on February 14 in 40 B.C.E. However, as we can see, in general the rate of change with time remains small.[26]

A variation in latitude, however, causes more substantial changes in the date, though not in a uniform fashion. Tables 9–12 give the dates of the apparent phenomena for, respectively, a star north of the ecliptic (α Coronae Borealis), a star very close to the ecliptic (Regulus, or α Leonis), and two stars south of the ecliptic (α Piscis Austrini and Sirius, or α Canis Maioris) for a variety of latitudes.[27]

One often reads that a change in latitude has a significant effect on the dates of the phenomena. However, tables 9–12 show that this statement is misleading: while it is sometimes true, it is not always the case, as the size of the change depends on the position of the star relative to the ecliptic and also on the particular phenomena concerned. The point is, however, that any uncertainty in location can have a substantial impact on the results of our calculations that may not be easy to discern.

These three factors (the star observed and the latitude and year of the observation) are fundamental to any calculation of the risings and settings. But the different methods of calculation also have other variables that can affect the outcome.

Until recently, the only method used for calculating the dates of the apparent phenomena was based on a method developed by Ptolemy nearly two thousand years ago: the key variable involved here is the *arcus visionis*, the minimum distance necessary between the sun (below the horizon) and the star (assumed by many scholars to be at the horizon) for the star to be visible as it rises or sets (see figs. 2–4).[28] The value of the *arcus visionis* will change with the star's magnitude (as obviously the sun must be further away from a dim star than a bright star for the star to be visible); some scholars also

26. This means that observations made in one location remain valid for that location (for all practical purposes) for many years.

27. The calculations for the apparent phenomena were made with the program Planetary, Lunar, and Stellar Visibility, using the option Calculate Arcus Visionis from Magnitude. The critical altitude used in each case was the magnitude of the star, according to the Tycho-2 Catalogue. This is a rule of thumb for the critical altitude that Schaefer (1986, 1987a) has called into question, but my concern here is not to predict the dates accurately but rather to give a rough idea of the variation in dates.

28. Different scholars use the term *arcus visionis* in different ways: for Ptolemy, Ideler, Schoch, and PLSV, the *arcus visionis* refers to the distance between the sun and the horizon (where in many cases it is assumed that the star is to be found); scholars such as Bruin (1979) and Schaefer (1987b) use the term to include the distance between the sun beneath the horizon and the star above the horizon.

TABLE 9. CHANGES IN DATES IN 44 B.C.E. WITH CHANGES IN LATITUDE FOR α CORONAE BOREALIS (North of the Ecliptic, Magnitude 2.21)

Phenomenon	Alexandria (31°13′)	Athens (38°)	Rome (41°52′)	Athens/ Rome	Alexandria/ Rome
AMR	Oct. 18	Oct. 12	Oct. 6	−6 days	−12 days
AES	Nov. 15	Nov. 25	Dec. 7	+12 days	+22 days
AMS	Jun. 21	Jul. 5	Jul. 15	+10 days	+24 days
AER	Mar. 19	Mar. 13	Mar. 8	−5 days	−11 days

TABLE 10. CHANGES IN DATES IN 44 B.C.E. WITH CHANGES IN LATITUDE FOR α LEONIS (Regulus; On the Ecliptic, Magnitude 1.4)

Phenomenon	Alexandria (31°13′)	Athens (38°)	Rome (41°52′)	Athens/ Rome	Alexandria/ Rome
AMR	Aug. 12	Aug. 13	Aug. 14	+1 day	+2 days
AES	Jul. 7	Jul. 3	Jul. 1	−2 days	−6 days
AMS	Feb. 6	Feb. 9	Feb. 11	+2 days	+5 days
AER	Jan. 12	Jan. 11	Jan. 11	0 days	−1 day

TABLE 11. CHANGES IN DATES IN 44 B.C.E. WITH CHANGES IN LATITUDE FOR α PISCIS AUSTRINI (South of the Ecliptic, Magnitude 1.23)

Phenomenon	Alexandria (31°13′)	Athens (38°)	Rome (41°52′)	Athens/ Rome	Alexandria/ Rome
AMR	Mar. 23	Apr. 12	May 1	+19 days	+39 days
AES	Jan. 2	Dec. 27	Dec. 22	−5 days	−11 days
AMS	Aug. 2	Jul. 29	Jul. 26	−3 days	−7 days
AER	Aug. 16	Aug. 26	Sep. 5	+10 days	+20 days

TABLE 12. CHANGES IN DATES IN 44 B.C.E. WITH CHANGES IN LATITUDE FOR α CANIS MAIORIS (Sirius; South of the Ecliptic, Magnitude −1.46)

Phenomenon	Alexandria (31°13′)	Athens (38°)	Rome (41°52′)	Athens/ Rome	Alexandria/ Rome
AMR	Jul. 19	Jul. 26	Jul. 30	+4 days	+11 days
AES	May 12	May 6	May 2	−4 days	−10 days
AMS	Nov. 30	Nov. 25	Nov. 22	−3 days	−8 days
AER	Dec. 27	Jan. 1	Jan. 5	+4 days	+9 days

make an adjustment for the horizontal distance (the difference in azimuth) between the star and the rising (or setting) sun.[29] Figures 2–4 illustrate the various ways in which the phrase *arcus visionis* has been interpreted.

29. E.g., Schoch (1924a, 1924b, and in Langdon et al. 1928), followed by Baehr (1955).

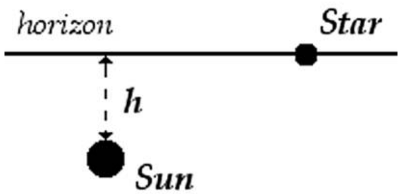

FIG. 2. The traditional use of the term *arcus visionis* refers to the vertical distance *h* between the sun and the star, located on the horizon; this usage assumes that the star is visible as it crosses the horizon.

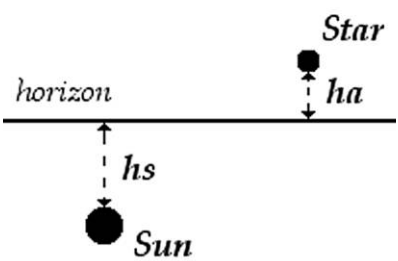

FIG. 3. An alternative use of the term *arcus visionis* (as used in PLSV): here it refers to the vertical distance *hs* between the sun and the horizon. This usage assumes that the star must be a certain distance above the horizon to be visible. The vertical distance between the sun and the star (*hs* + *ha*) is therefore greater than the *arcus visionis*.

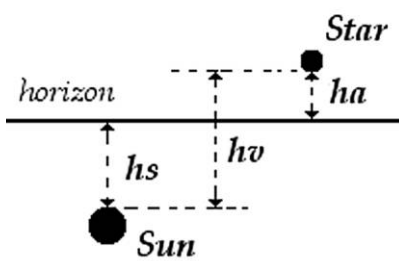

FIG. 4. Another use of the term *arcus visionis* (as used by, e.g., Schaefer): here it refers to the vertical distance *hv* between the sun and the star—i.e., the distance between the sun and the horizon added to the distance between the horizon and the star (*hs* + *ha*).

TABLE 13. CHANGES IN DATES CORRESPONDING TO CHANGES IN *ARCUS VISIONIS* FOR REGULUS (α Leonis; Close to the Ecliptic, Magnitude 1.36)

Phenomenon	av = 6	av = 7	av = 6[a]	av = 8	av = 9	av = 10	av = 11
AMR	Aug. 1	Aug. 2	Aug. 2	Aug. 4	Aug. 5	Aug. 6	Aug. 7
AES	Jul. 15	Jul. 13	Jul. 13	Jul. 12	Jul. 10	Jul. 8	Jul. 6
AER	Jan. 12	Jan. 11	Jan. 14	Jan. 10	Jan. 9	Jan. 8	Jan. 7
AMS	Feb. 2	Feb. 3	Jan. 31	Feb. 5	Feb. 7	Feb. 9	Feb. 10

Note: Values calculated using PLSV, for Athens in 432 B.C.E. "av" = *arcus visionis*; "ca" = critical altitude (zero unless otherwise specified).
a. ca = 1.

It is somewhat surprising to discover that for many years the values in use for the *arcus visionis* of stars of differing magnitudes were those deduced by Ideler from dates found in Ptolemy for stars of the first and second magnitude;[30] the *arcus visionis* for less bright stars was then extrapolated from these.[31] However, the precise values of the *arcus visionis* are far from certain: for example, the values in Paul Neugebauer's first set of tables,[32] used by Martin West in his Hesiod commentary,[33] were corrected by Neugebauer in later versions,[34] following the work of Carl Schoch, who suggested a revised set of values, derived from the Babylonian observations in the first millennium B.C.E.[35] Other scholars use other sets of values: for example, Anthony Aveni uses those of J. Norman Lockyer, while Frans Bruin compares a variety of values with those he obtained through observation.[36] In some cases we find individual values for the calculation of the individual phenomena.[37] Table 13 illustrates the difference that a change in the *arcus visionis* can make for each of the various phenomena.

As we can see, a change in the *arcus visionis* of one degree can affect the date of the calculation by one to two days. This is somewhat reassuring in that calculations based on different values will be roughly the same, but again it alerts us to the fact that there are uncertainties in the results obtained.

A more serious concern is that many calculations for the dates of the apparent phenomena assume that the star is visible at the moment that it crosses the horizon; however, this is almost never the case, owing to haze, refraction (the bending of light in the atmosphere), and atmospheric extinction (i.e., the reduction in brightness of a star as its light passes through the

30. See Ideler 1816–17. Vogt (1920) performed similar calculations, but with different results.
31. Ideler 1822–23, 140.
32. Neugebauer 1922.
33. West 1978.
34. Neugebauer 1925, 1929. West (1978) does not say whether he uses the revised values for the *arcus visionis*. He is aware that these values are based on assumptions, however, and that other values may be more appropriate—for example, on pp. 383–84 he suggests using an *arcus visionis* of 18 degrees, rather than Ideler's 16.
35. Schoch 1924a, 1924b; Langdon et al. 1928.
36. Aveni 1972; Lockyer 1894; Bruin 1979.
37. E.g., Baehr 1955.

atmosphere, due to dust, pollution, water, movement of air molecules, etc.). A star must reach a certain angular height—the critical altitude—above the horizon in order to be visible, and the value we assign to this variable can have a significant impact on the results, as we shall see.

Until recently, the calculation of the dates of rising and setting via the Ptolemaic method was an extremely laborious process involving the use of tables such as those of Neugebauer and Ulrich Baehr.[38] However, there is now available an extremely flexible and accessible tool for this purpose, namely, the PC program PLSV, mentioned above.[39] The program uses a range of values for the *arcus visionis* based on Schoch,[40] but it also allows for an *arcus visionis* that varies directly with magnitude; additionally, it allows the user to adjust the *arcus visionis* manually. The program can also take account of the critical altitude of the star. The problem is to decide what value to choose for this variable. Swerdlow and Lange raise this problem in the extremely clear documentation that accompanies the program, and they admit that there is no simple solution. This is how they conclude the section entitled "Sources of Computations and Cautions Concerning Accuracy":

> It appears from trial calculations that changes in the critical altitude produce greater differences in the dates of phenomena than *reasonable* changes in the arcus visionis, so *the critical altitude must be set with great care*. The user is encouraged to experiment with different parameters to find which appear to produce the most accurate, or most reasonable, results, although in the absence of reliable observations for comparison, it is difficult to say what most accurate or most reasonable is. (Italics in the original)

While this is an honest answer and one that impresses upon the user just how uncertain the business of calculating dates can be, it is not terribly helpful to the scholar whose interest is primarily in, say, Ovid's *Fasti* and who just wants a quick answer to the question, When did Sirius have its apparent morning rising? Such a scholar may be relieved to hear of the existence of a rule of thumb commonly used by archaeoastronomers, according to which the critical altitude is taken to be equal to the magnitude of the star.[41] As we shall see, however, this rule of thumb is not without some serious problems, to which we shall return below. Table 14 illustrates the difference a change in critical altitude makes to the calculations for the fairly dim star α Delphini (magnitude 3.76); also included are values for the critical altitude calculated according to the astrophysicist Bradley Schaefer's method (discussed below), using a limiting magnitude (i.e., the magnitude of the faintest star that can be seen at the zenith in a fully dark sky) of 6 and visual extinction factors of 0.2 and 0.3 (these variables correspond to an observer with good eyesight observing on a clear night and a

38. Neugebauer 1922, 1929; Baehr 1955.

39. The program calculates the apparent phenomena directly, but the dates of the true phenomena can be obtained from the list of rising and setting times that the program can create (it should be noted, however, that these calculations involve correction for refraction and thus give times for a visible rather than theoretical rise). The accompanying documentation provides a useful account of the methods for calculating the dates of the various phenomena and discusses in some detail the question of accuracy.

40. Schoch in Langdon et al. 1928.

41. As used, e.g., by Thom (1967, 15).

TABLE 14. CHANGES IN DATES CORRESPONDING TO CHANGES IN CRITICAL ALTITUDE FOR α DELPHINI, CALCULATED FOR ROME IN 44 B.C.E.

Phenomenon	Critical altitude 0	3.76	5.3[a]	8.9[b]	Difference from ca 0 to ca 9
AMR	Dec. 29	Jan. 3	Jan. 5	Jan. 10	+12 days
AES	Jan. 13	Jan. 8	Jan. 7	Jan. 3	−10 days
AER	May 21	May 25	May 27	May 31	+10 days
AMS	Aug. 22	Aug. 18	Aug. 16	Aug. 13	−9 days

Note: "lm" = limiting magnitude; "vef" = visual extinction factor. These values are from Schaefer 1986, 1987a.
a. lm = 6; vef = 0.2.
b. lm = 6; vef = 0.3.

night of average visibility, respectively). The calculations are made for Rome in 44 B.C.E., using PLSV with variable *arcus visionis* based on the magnitude.

As table 14 shows, our choice regarding whether or not to take the critical altitude into account, and what value to use, has a significant impact on the results of our calculations. As mentioned above, a common rule of thumb has been to use the magnitude of the star for the critical altitude. However, this is one of a number of common assumptions regarding the calculation of apparent phenomena that has been questioned by Schaefer, on the basis of his research into the visibility of celestial objects.[42] He argues that this rule of thumb for the critical altitude is erroneous and only begins to approximate to the correct figure when dealing with bright stars in exceptionally clear conditions, such as those found in the Chilean desert;[43] such a rule of thumb will clearly be of little use for Greece or Rome. He also notes that the traditional formula for calculating refraction sometimes underestimates the effect of refraction at the horizon,[44] and he has developed a new method for calculating the dates of the apparent morning rising and apparent evening setting, based not on the *arcus visionis* but rather on estimates of the limiting magnitude of the night sky and visual extinction.[45] These variables are influenced by various factors, such as the position of the moon, the humidity of the sky, air temperature, altitude, the eyesight of the observer, pollution,

42. See particularly Schaefer 1993b. For a brief summary, see Schaefer 2000. On the general application of his findings to the use of astronomy in historical studies, see Schaefer 1999.

43. Schaefer (1987a) provides BASIC code for a program to calculate the critical altitude. The underlying equations are presented in more detail in Schaefer 1986. See also Schaefer 1993a, 1993b. The code can be downloaded at http://media.skyandtelescope.com/binary/extinc.bas. The results that support the rule of thumb correspond to observations made in Cerro Tololo Observatory, in the middle of the Chilean desert, which, as Schaefer (1986, 39) remarks, is "one of the very best sites in the world" for astronomical observation.

44. Schaefer and Liller 1990.

45. See Schaefer 1985, which contains BASIC code to perform these calculations and some typical values for the limiting magnitude and visual extinction in various locations; see also Schaefer 1987b, which presents more detailed information about the method and the data set on which it was based. The code can be downloaded at http://media.skyandtelescope.com/binary/heliac.bas.

and ambient light.[46] For bright stars in good conditions, the results from Schaefer's method are roughly similar to those reached by the traditional method; but for dim stars in poor conditions, there can be a substantial difference.[47] Of course, Schaefer's method is not without its own uncertainties: for example, how does one establish the air quality, temperature, or humidity for Athens on a particular day in the fourth century B.C.E.?[48]

So what does this mean for anyone wishing to calculate the dates of these apparent phenomena? To get some idea of the spread of dates that results from using different methods (or different values within the same method), it will be helpful to compare the dates that we can find either in modern sources or by using modern tools for calculation.[49] In addition to the programs I have already mentioned, also included in tables 15–18 are calculations from one other source, the Web-based utility from the astrophysicist Karine Gadré.[50] All the calculations I have performed are for Rome, using a latitude of 41°52′48″, for 44 B.C.E.

The tables show that for the most part scholars are in rough agreement as to when these phenomena take place (with the exception of Hofmann's calculations for Vindemiatrix, where he comes up with a very different set of dates, perhaps owing to a mistake in his calculations). They also illustrate, as expected, that Schaefer's method produces similar results to the Ptolemaic method for bright stars in good conditions; but once conditions become less than optimal we begin to notice a substantial difference. The largest difference between any two dates in tables 15–18 (with the exception of Vindemiatrix) is found between Hofmann's date for the apparent evening setting of Regulus (July 8) and the one calculated by Schaefer for bad conditions (June 27), a difference of eleven days; but a considerable difference is also found between the dates obtained via Schaefer's method for good and bad conditions (limiting magnitude/extinction factor of 6/0.2 and 5/0.3, respectively) for Vindemiatrix (August 26 vs. August 15).

As we have seen, the calculation of the dates for the apparent phenomena is based on a number of factors: even if we are confident about the star,

46. Schaefer (1998) provides BASIC code for a program to calculate limiting magnitude. The underlying equations are presented in more detail in Schaefer 1993b (along with various extinction coefficients for various geographical locations) and in the abbreviated version found in Schaefer 1993a. The code can be downloaded at http://media.skyandtelescope.com/binary/vislimit.bas.

47. See, e.g., Schaefer 2000, where his calculations for the dates of the apparent morning rising of Sirius in Ancient Egypt are roughly similar to those reached by traditional methods.

48. All these values will of course change with the seasons. Schaefer attempts such a reconstruction for Ancient Egypt (Schaefer 2000) and for Ancient Greece (Schaefer 2001).

49. In tables 15–18, Ginzel's results come from Ginzel 1906–14, 520–23. The code given in Schaefer (1985), used for the results based on Schaefer, is based on a vernal equinox of March 21. The figures produced here have been adjusted for the date of the vernal equinox in Rome in 44 B.C.E. (March 23). The variables in tables 15–18 correspond to an observer with good eyesight, observing on a clear night (limiting magnitude of 6) in good and average conditions (extinction factor of 0.2 and 0.3, respectively) and to an observer observing on a less clear night (limiting magnitude of 5) in average conditions (extinction factor of 0.3).

50. http://www.culturediff.org. At the time of writing, a utility on this site calculates the date of the heliacal rising of a star without requiring the user to estimate any variables such as the *arcus visionis*, critical altitude, limiting magnitude, or visual extinction. However, it does not calculate the dates for all the other phases, nor will it at the current time give a date for stars visible all year round, such as Arcturus.

Table 15. Range of Dates Calculated for Arcturus
(α Bootis; North of the Ecliptic, Magnitude 0.16) in Rome, 44 b.c.e.

Apparent Phenomenon	Hofmann	Ideler	Ginzel	PLSV 0.16	Schaefer 6/0.2	Schaefer 6/0.3	Schaefer 5/0.3
MR	Sep. 12	—	Sep. 19	Sep. 20	Sep. 20	Sep. 23	Sep. 23
ES	Nov. 9	—	Nov. 9	Nov. 10	Nov. 10	Nov. 4	Nov. 4
ER	Feb. 25	Feb. 27	Feb. 26	Feb. 23	—	—	—
MS	Jun. 16	Jun. 10	Jun. 12	Jun. 17	—	—	—

Note: In tables 15–18, the number in the PLSV column heading is the critical altitude, and the numbers in the Schaefer column headings are the limiting magnitude and the visual extinction factor.

Table 16. Range of Dates Calculated for Alcyone
(One of the Pleiades, η Tauri; Close to the Ecliptic, Magnitude 2.84) in Rome, 44 b.c.e.

Apparent Phenomenon	Hofmann	Ideler	Ginzel	PLSV 2.84	Gadré	Schaefer 6/0.2	Schaefer 6/0.3	Schaefer 5/0.3
MR	May 27	May 28	May 27	May 30	May 29	May 30	Jun. 3	Jun. 7
ES	Apr. 11	Apr. 8	Apr. 7	Apr. 6	—	Apr. 4	Apr. 1	Mar. 31
ER	Sep. 19	Sep. 25	Sep. 24	Sep. 26	—	—	—	—
MS	Nov. 13	Nov. 9	Nov. 7	Nov. 8	—	—	—	—

Table 17. Range of Dates Calculated for Vindemiatrix
(ε Virginis; North of the Ecliptic, Magnitude 2.82) in Rome, 44 b.c.e.

Apparent Phenomenon	Hofmann	Ideler	PLSV 2.82	Gadré	Schaefer 6/0.2	Schaefer 6/0.3	Schaefer 5/0.3
MR	Oct. 6	Sep. 18	Sep. 20	Sep. 21	Sep. 21	Sep. 23	Sep. 26
ES	Nov. 22	—	Aug. 31	—	Aug. 26	Aug. 20	Aug. 15
ER	Mar. 4	Feb. 14	Feb. 15	—	—	—	—
MS	Jun. 18	—	May 15	—	—	—	—

Table 18. Range of Dates Calculated for Regulus
(α Leonis; Close to the Ecliptic, Magnitude 1.4) in Rome, 44 b.c.e.

Apparent Phenomenon	Hofmann	Ideler	PLSV 1.4	Gadré	Schaefer 6/0.2	Schaefer 6/0.3	Schaefer 5/0.3
MR	Aug. 12	—	Aug. 14	Aug. 14	Aug. 13	Aug. 16	Aug. 16
ES	Jul. 8	Jul. 6	Jul. 1	—	Jul. 2	Jun. 27	Jun. 27
ER	Jan. 14	—	Jan. 11	—	—	—	—
MS	Feb. 12	Feb. 6	Feb. 11	—	—	—	—

latitude, and epoch involved in our calculations, there are assumptions to be made about the *arcus visionis*, the critical altitude, the limiting magnitude, or the extinction coefficient depending on our choice of method. All these variables can have a significant effect on the outcome of the calculations, but there is no clear agreement as to what the right value for these variables is. As Swerdlow and Lange remark, the "calculation of visibility phenomena is plagued by uncertainties that will only be resolved by a body of reliable observations that does not yet exist."[51] However, if we use these dates or make the calculations with an awareness of the assumptions we are making, we can nevertheless hope that they provide a rough estimate of the dates of the actual phenomena, and the above tables show that the various methods are in general agreement.

OBSERVING THE ACTUAL PHENOMENA

Having examined the problems of calculation, we now need to pay particular attention to the problems of observation. If we have predicted by the best methods that Arcturus will have its apparent morning rising the following week, can we be certain that we will see it on the appropriate day? Things are perhaps not quite that simple: the above calculations assume a flat horizon, whereas in reality areas of the sky may be obscured by aspects of the landscape. Furthermore, as Bruin remarks, "The precise observation of heliacal phases is difficult, because at such a moment the star is only just visible and there is often a haze near the horizon (particularly near the sea . . .). Even for a trained observer the date may easily be a few days wrong."[52] Schaefer's account of his attempt to observe the heliacal rise of κ Gemini is particularly instructive:[53]

> During a recent 20-day trip to CTIO [Cerro Tololo Inter-American Observatory], I tried to spot the heliacal rise of κ Gem on every morning. On the 3rd and 4th mornings, the visibility of θ Gem (of equal magnitude but 2° higher than κ Gem) promised the heliacal rising of κ Gem on the 5th morning. However, five cloudy nights occurred. Then on the last moonless clear night, the zodiacal light and occasional cirrus prevented κ Gem from being sighted. Then came three cloudy nights. For the next five days the waning Moon moved closer to the eastern horizon with the effect of keeping κ invisible. . . . The next two nights were cloudy. The final result is that I never did see κ Gem during my trip to CTIO. In this (not untypical) case, the zodiacal lights, clouds, and Moon delayed the heliacal rise date by over two weeks.

The above example demonstrates the difficulties that can surround an attempt to observe a particular phenomenon on a particular occasion. We

51. From the help file to PLSV, under the section "Sources of Computations and Cautions Concerning Accuracy." The largest collection of observations we have—and, as a consequence, the data against which methods of calculations are most often calibrated—consists of ancient observations, the very data that we are hoping to verify using the modern calculations. It should be noted that Aveni (1972), Bruin (1979), and Schaefer (1987b) have tested their figures against a number of their own observations.

52. Bruin 1979, 387.

53. Schaefer 1987b, 27.

might hope that early astronomers such as Euctemon and Eudoxus, when they were compiling their *parapegmata*, were able to factor out such atmospheric disturbances by compiling their lists from observations made over a number of years and thus to obtain a certain degree of accuracy. However, lest we assume that astronomy in the ancient world was somehow more straightforward in a time without streetlights and pollution, let us see what Claudius Ptolemy, the father of astronomy himself, has to say on the subject.

In his *Almagest*, Ptolemy describes a method for calculating the dates of the apparent phenomena of the fixed stars. However, he concludes the passage with a list of the reasons why he will not actually use the method himself: the computation is too complicated, he says, and too time consuming. He also has this to say (*Alm.* 8.6 = 1: 203 Heiberg):[54]

> In respect of the actual observations of the phases it is laborious and uncertain, since [differences between] the observers themselves and the atmosphere in the regions of observation can produce variation in and doubt about the time of the first suspected occurrence, as has become clear, to me at least, from my own experience and from disagreements in this kind of observations. (Trans. Toomer)

He concludes (*Alm.* 8.6 = 1: 204 Heiberg), "For the time being we content ourselves with the approximate phases which can be derived either from earlier records or from actual manipulation of the [star-]globe for any particular star" (trans. Toomer).[55]

Somewhat later he appears to have modified his position and returned to this mathematical method to make various calculations that are recorded in the work known as the *Phaseis*.[56] However, he only calculated the dates for stars for the first and second magnitude. In defending this decision, he has this to say (*Phaseis* 2: 12 Heiberg):[57]

> But one should pardon the fact that we have not incorporated some of the dimmer stars that are named by the more ancient [authorities] either in the treatise on this subject itself or here, e.g., Sagitta, the Pleiades, the Haedi, Vindemiatrix, Delphinus, and any other such [constellation], since the fault is not grave, especially since the last and first appearances of such small stars are absolutely difficult to judge and observe, and one might remark that our predecessors handled them more by guesswork than by observation of the actual phenomena. (Trans. Jones)

54. τὸ κατ᾽ αὐτὰς τῶν ἀστέρων φάσεων τηρήσεις ἐργῶδές τε εἶναι καὶ οὐκ εὐκατανόητον καὶ τῶν ὁρώντων αὐτῶν καὶ τῶν κατὰ τοὺς ὁρωμένους τόπους ἀέρων ἀνόμοιον καὶ ἀβέβαιον τὸν χρόνον τῆς πρώτης ὑποψίας ποιεῖν δυναμένων, ὡς ἔμοιγε ἀπό τε αὐτῆς τῆς πείρας καὶ τῆς ἐν ταῖς τοιαύταις τηρήσεσι διαφορᾶς γέγονεν εὐκατανόητον.

55. Some have argued that the variety of values for the *arcus visionis* that can be derived from the dates in the *Phaseis* suggest that rather than calculating all the various dates, Ptolemy read many of them off a star globe (e.g., Neugebauer 1975, 930–31).

56. The first part of the work, in which he discussed his method, appears to have been lost.

57. τὸ μέντοι τινὰς τῶν παρὰ τοῖς παλαιοτέροις κατωνομασμένων ἀμαυροτέρων ἀστέρων μὴ προσεντετάχθαι παρ᾽ ἡμῖν μήτε ἐν αὐτῇ τῇ τῆς πραγματείας συντάξει μήτε νῦν, οἷον Ὀιστόν, Πλειάδας, Ἐρίφους, Προτρυγητῆρα, Δελφῖνα, καὶ εἴ τις τοιοῦτος, συγχωρητέον, εἰ μὴ βαρὺ τὸ αἴτημα, μάλιστα μὲν διὰ τὸ δυσδιακρίτους καὶ δυσκατανοήτους εἶναι παντάπασιν τὰς τῶν οὕτω σμικρῶν ἀστέρων ἐσχάτας καὶ πρώτας φαντασίας, κεχρῆσθαί τε τοὺς πρὸ ἡμῶν αὐταῖς ἀπὸ στοχασμοῦ τινος μᾶλλον ἢ τηρήσεως ἐξ αὐτῶν τῶν φαινομένων ἄν τις κατανοήσειεν. The translation is from a draft translation of the text by Alexander Jones.

This is a very telling comment—not only does Ptolemy point to the difficulty of observing the risings and settings of stars such as the Pleiades, but he also is very unimpressed by the accuracy of the observations of his predecessors, who were presumably no amateurs. From the point of view of observation, we can compare the table in Schaefer in which Schaefer compares the dates he reached by observation with those reached by calculation:[58] there are frequent discrepancies, and for average viewing conditions his findings suggest an error margin of at least plus or minus five or six days for a dim star such as Alcyone.[59]

It seems, then, that not only the calculation but also the observation of the apparent phenomena of these stars is far from being an exact science.[60] We have seen that when calculating dates for these phenomena we have to make a number of choices, each of which can affect the result of our calculations. Any uncertainty in these choices can correspond to a greater or lesser uncertainty in our results. We have also seen that there are uncertainties when observing apparent phenomena: while a particular star and the sun may be in the same position in the sky at the same time every year, atmospheric conditions do not show the same precise regularity, and one cannot be certain that one will actually observe the same phenomenon on the same date every year. Thus, when Hesiod tells us that Arcturus rises sixty days after the solstice (*Op.* 564–67), this has to be at best a rough estimate. Further complications in observation and calculation could be explored: the difference that observational experience and acuteness of vision can make to the dating of a phenomenon; the question of which data to use for the calculations (different modern star catalogues have different standards of accuracy); and how to access those data (magnitudes in the Tycho-2 catalogue are not all given in the same system). There may also be further decisions to make: Which phase is the author referring to?[61] Is it true or apparent?[62]

58. Schaefer 1987b, 20 (table 1).

59. Ancient sources present a number of problems of their own: it is quite possible that some sources preserve dates taken from observations made in a different latitude and in a different epoch (e.g., a first-century B.C.E. Roman calendar might use a source originating from third-century B.C.E. Alexandria) or even dates taken from a variety of sources (e.g., Pliny's agricultural calendar in his *Natural History*, Book 18); in the process of transmission accurate dates may be miscopied, or names of constellations muddled; and as Professor Swerdlow reminds me, there is always the possibility that the dates are in some way conventional or schematic and not dependent on real observations at all.

60. I have said little about the calculation of true phenomena here. While the dates reached by modern calculations are more secure (though even then they can vary depending on whether or not one includes correction for refraction, which one probably should not), given that these dates can only be reached by calculation or by use of an instrument such as a star globe, again they can give us only a rough idea of what the ancients thought of as the dates of the true phenomena: it would depend on the data and methods used for their calculations, the accuracy of the sky globes, etc.

61. For example, Horace's contented man need not fear the setting of Arcturus or the rise of the Kids, though he does not specify in either case whether these phenomena took place in the morning or the evening. The morning setting took place in Rome in 44 B.C.E. in mid-June (June 16, according to PLSV), the evening setting in early November (November 9). The morning rising of the Kids took place in early May (May 8 for ε Aurigae; May 19 for η Aurigae), the evening rising in late August (August 30 for ε Aurigae; September 10 for η Aurigae). It is usually thought that the contented man here does not fear the autumnal or wintry rains and winds associated with these two stars.

62. Again, it seems reasonable to assume that these would usually be apparent phenomena; but see n. 13.

Were we to have all the right data, such as precise figures for the visual extinction factor of the skies in Ancient Greece (for the appropriate season), or exact details of the critical altitude for a particular star, then it may be that these calculations could indeed provide an accuracy of plus or minus two days. It may be that further research will provide these data, and refine these methods further. In the meantime, however, for those who just want to know when they should be "soaking their lungs with wine" in accordance with the instructions of Alcaeus,[63] or beginning to plow their fields, following Hesiod,[64] I hope that the above discussion will enable them to use either modern tools such as Planetary, Lunar, and Stellar Visibility or the calculations of previous scholars with a clearer understanding of the uncertainties involved and thus of the kind of accuracy that we can expect—namely, a rough guide rather than a precise date.

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63. The morning rising of Sirius took place in late June in Mytilene in 600 B.C.E. (June 22, according to PLSV).

64. The morning rising of Alcyone (η Tauri) took place in late May in Ascra in 700 B.C.E. (May 22, according to PLSV).

LITERATURE CITED

Aujac, G. 1975. *Géminos: Introduction aux Phénomènes*. Paris.

Aveni, A. 1972. Astronomical Tables Intended for Use in Astro-Archaeological Studies. *AmerAnt* 37: 531–40.

Baehr, U. 1955. *Tafeln zur Behandlung chronologischer Probleme, Teil I–III*. Karlsruhe.

Bickerman, E. J. 1980. *Chronology of the Ancient World*². London.

Bruin, F. 1979. The Heliacal Settings of the Stars and Planets, Parts 1 and 2. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, Series B: Physical Sciences* 82: 385–410.

Evans, J. 1998. *The History and Practice of Ancient Astronomy*. New York.

Evans, J., and J. L. Berggren. 2006. *Geminos's Introduction to the Phenomena: A Translation and Study of a Hellenistic Survey of Astronomy*. Princeton, N.J.

Fox, M. 2004. Stars in the *Fasti*: Ideler 1825 and Ovid's Astronomy Revisited. *AJP* 125: 91–133.

Frazer, J. G., ed. 1929. *Publii Ovidii Nasonis "Fastorum" libri sex, Edited with Translation and Commentary*. 5 vols. London.

Gee, E. 2000. *Ovid, Aratus and Augustus*. Cambridge.

———. 2002. *Vaga signa*: Orion and Sirius in Ovid's *Fasti*. In *Ovid's "Fasti": Historical Readings at Its Bimillennium*, ed. G. Herbert-Brown, 47–70. Oxford.

Ginzel, F. K. 1906–14. *Handbuch der mathematischen und technischen Chronologie*. Leipzig.

Hannah, R. 2005. *Greek and Roman Calendars: Constructions of Time in the Classical World*. London.

Heiberg, J. L., ed. 1898. *Claudii Ptolemaei opera quae extant omnia*. Leipzig.

Hofmann, G. 1879. Ueber die bei griechischen und römischen Schriftstellern erwähnten Auf- und Untergänge der Sterne. *Programm des k.k. Gymnasiums in Triest, veröffentlicht am Schlusse des Schuljahres 1879*.

Ideler, C. L. 1816–17. Ueber den Kalender des Ptolemäus. *Abhandlungen der Königlichen Preußischen Akademie der Wissenschaften zu Berlin*, 165–214.

————. 1822–23. Über den astronomischen Theil der *Fasti* des Ovid. *Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin*, 137–69.

Langdon, S., J. Fortheringham, and C. Schoch. 1928. *The Venus Tablets of Ammizaduga*. London.

Lehoux, D. R. 2000. *Parapegmata*. Ph.D. diss. University of Toronto. http://www.collectionscanada.ca/obj/s4/f2/dsk2/ftp03/NQ53766.pdf.

Lockyer, J. N. 1894. *The Dawn of Astronomy: A Study of the Temple-Worship and Mythology of the Ancient Egyptians*. London.

Meeus, J. 1998. *Astronomical Algorithms*[2]. Richmond, Va.

Neugebauer, O. 1975. *A History of Ancient Mathematical Astronomy*. 3 vols. Berlin.

Neugebauer, P. V. 1922. *Tafeln zur astronomischen Chronologie*. Teil 3, *Hilfstafeln zur Berechnung von Himmelserscheinungen*. Leipzig.

————. 1925. *Tafeln zur astronomischen Chronologie*. Teil 3, *Hilfstafeln zur Berechnung von Himmelserscheinungen*[2]. Leipzig.

————. 1929. *Astronomische Chronologie*. 2 vols. Berlin.

Pritchett, W. K., and B. L. Van Der Waerden. 1961. Thucydidean Time Reckoning and Euctemon's Seasonal Calendar. *BCH* 85: 17–52.

Rehm, A. 1941. *Parapegmastudien: Mit einem Anhang Euktemon und das Buch "De signis."* Munich.

————. 1949. Parapegma. *RE* 36.3: 1295–1366.

Robinson, M. 2000. Prolegomena to the Study of Ovid's *Fasti*, with a Commentary on Book 2, 1–532. D.Phil. diss., University of Oxford.

————. 2007. Ovid, the *Fasti*, and the Stars. *BICS* 51: 129–59.

Schaefer, B. 1985. Predicting Heliacal Risings and Settings. *Sky and Telescope* 70: 261–63.

————. 1986. Atmospheric Extinction Effects on Stellar Alignments. *Archaeoastronomy* 10: 32–42.

————. 1987a. Extinction Angles and Megaliths. *Sky and Telescope* 73: 426.

————. 1987b. Heliacal Rise Phenomena. *Archaeoastronomy* 11: 19–33.

————. 1993a. Astronomy and the Limits of Vision. *Archaeoastronomy* 11: 78–90.

————. 1993b. Astronomy and the Limits of Vision. *Vistas in Astronomy* 36: 311–61.

————. 1998. To the Visual Limits. *Sky and Telescope* 95.5: 57–60.

————. 1999. Astronomy in Historical Studies. *Archaeoastronomy* 14.1: 89–108.

————. 2000. New Methods and Techniques for Historical Astronomy and Archaeoastronomy. *Archaeoastronomy* 15: 121–36.

————. 2001. The Latitude of the Observer of the Almagest Star Catalogue. *Journal for the History of Astronomy* 32: 1–42.

Schaefer, B., and W. Liller. 1990. Refraction near the Horizon. *Publications of the Astronomical Society of the Pacific* 102: 796–805.

Schoch, C. 1924a. *The* Arcus Visionis *in the Babylonian Observations*. Oxford.

————. 1924b. The *Arcus Visionis* of the Planets in the Babylonian Observations. *Monthly Notices of the Royal Astronomical Society* 84: 731–34.

Thom, A. 1967. *Megalithic Sites in Britain*. Oxford.

Toomer, G. J., ed. and trans. 1984. *Ptolemy's "Almagest."* London.

Vogt, H. 1920. Griechische Kalender V: Der Kalender des Claudius Ptolemäus. *SBHeid* 5.

West, M. L. 1978. *Hesiod: "Works and Days."* Oxford.