VARIABLE STAR OBSERVATIONS IN AN INTRODUCTORY ASTRONOMY COURSE

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Abstract

Criteria for the choice of stars used in an introductory astronomy course are discussed and a list of suitable bright variable stars is given. Consideration is given to the constraints of the academic calendar, student interest, and the probable sky conditions under which the students will have to observe. Variable star observations have been assigned to over 500 undergraduates and the results are discussed. Additional possible variable star observing projects are discussed.

1. Introduction

Non-science students taking an introductory astronomy course often indicate that a major reason they take the course is to learn more about the night sky, so that when they are outside they know more about "what is up there". A major problem in teaching an introductory astronomy course is making the connection between what one might lecture about (Newton's law of gravity, say) and the real universe students can see with their eyes at night. Student observations of variable stars offer one way of helping make this connection. They also help students learn the constellations (another big reason for taking astronomy survey courses) and appreciate the diurnal and annual changes in the sky.

I now regularly incorporate variable star observing into my introductory college astronomy courses. The idea of getting students to make variable star observations is, of course, not new (Levy 1987, for example, even suggests introducing variable stars to school children), but in planning student observations I found that there was relatively little information available in a readily digestible form, in particular about what stars are observable and what can and cannot be done. This paper is an attempt to provide such information.

2. Choice of Stars

2.1 Selection Criteria

Stars should satisfy the following criteria:

1. They must be bright enough to observe throughout their variability range.
2. There must be suitable comparison stars.
3. To keep student morale up there must be detectable variability during the course of a term (over two months ≈ 60 days, say).
4. They must be visible in the evening sky during the term.

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Most students do not own a telescope or binoculars. Only a quarter of my students have said they either owned or had access to binoculars. Most college campuses are in or close to cities, so the limiting naked eye magnitude (m_{lim}) is probably going to be 4.5. (*Sky & Telescope* magazine (MacRobert 1991) reports that its average reader lives under a m_{lim} = 4.5). Since reliable variable star estimates cannot be made within a magnitude of one's limiting magnitude this severely limits the choice of stars. Criterion 2 is usually satisfied. Criterion 3 makes most semiregular variables of small amplitude and uncertain or longish period relatively poor choices. Eclipsing variables are interesting if they are caught during the eclipse. Cepheid variables are good because they are always changing and have very convenient periods. Long period variables (Miras) suffer from the disadvantage that even the brightest spend most of their time below naked eye visibility.

2.2 Bright Variable Stars

If we restrict ourselves to stars visible from the USA which vary by at least half a magnitude and which are brighter than magnitude 5.0 at maximum and 6.2 at minimum, then the main "naked eye" variable stars are as given in Table 1. Most of these variable stars require either very good skies or the aid of a pair of binoculars. The semiregulars are probably not of interest to the casual student observer.

Table 1. Naked Eye Variable Stars (In order of RA)

Star	*Range*	*Period*	*Type* *	*Comments*
γ Cas	1.5 - 3.0	----	γ Cas	Little variability
ρ Per	3.3 - 3.8	50d?	SR	
β Per (Algol)	2.1 - 3.4	2.8673d	EA	Bright and easy
λ Tau	3.4 - 3.9	3.9529d	EA	P≈4d
α Ori (Betelgeuse)	0.4 - 1.3	≈2000d?	SR	Very slow variability
η Gem	3.2 - 3.9	232.9d?	SR	
RT Aur	5.1 - 5.8	3.7279d	δ Cep	Too faint
ζ Gem	3.7 - 4.2	10.1517d	δ Cep	Small amplitude
δ Lib	4.9 - 5.9	2.3274d	EA	Too faint
α Sco (Antares)	0.9 - 1.8	≈2000d?	SR	No suitable comparisons
u Her	4.8 - 5.4	2.0510d	EA	Too faint, small amplitude
α Her	3.0 - 3.9	90d?	SR	Bright
W Sgr	4.3 - 5.1	7.5947d	δ Cep	Too far south; faint
β Lyr	3.3 - 4.3	12.9346d	EB	Good period; easy
R Lyr	3.9 - 5.0	46d?	SR	
η Aql	3.5 - 4.5	7.1771d	δ Cep	
μ Cep	3.4 - 5.1	730d?	SR	
δ Cep	3.4 - 4.3	5.3663d	δ Cep	
ρ Cas	4.1 - 6.2	320d?	SR	Slow variability

* γ Cas = γ Cas star; SR = semiregular (or irregular red giant); EA = eclipsing binary (Algol type); EB = eclipsing binary (β Lyrae type); δ Cep = Cepheid variable.

2.3 The "Top" Naked Eye Variable Stars

If we adopt m_{lim} ≈ 4.5 and require that the star spend all its time at least a magnitude brighter than this, one is restricted to only four variable stars! These are α Ori (Betelgeuse), α Sco (Antares), β Per (Algol), and γ Cas. Of these γ Cas is irregular and does not vary very much for years (or even decades) on end. Betelgeuse and Antares do not vary much during a single term, and they have the problem of a lack of suitable comparison stars. This only leaves Algol! Algol is a superb eclipsing variable because of the large amplitude - well over a magnitude. Results of student observations of Algol are described in the next section.

If the students all have easy access to a sky with $m_{lim} \approx$ 5.0 - 5.5 then a number of other variable stars become accessible. Of the variables that reliably "do something", the best choices (after Algol) are the eclipsing binaries βLyr and λTau and the three bright northern Cepheids, δ Cep itself, η Aql, and ζ Gem. The semiregulars are not reliable enough performers. Of the eclipsing variables, βLyr is an excellent star because the period is long (almost 13 days) and its brightness between eclipses is continually changing (unlike the EA stars which spend most of their time between eclipses at maximum light). λTau has the problem that its period is very close to 4 days, so one might have the misfortune of all the primary eclipses occurring during daylight for a couple of months! The three Cepheids mentioned all make attractive targets because they are continually varying and an individual student can get a light curve from one observation a night over a week or two. The amplitude of ζ Gem is smaller than the amplitudes of δ Cep and η Aql, however.

I believe it is important to get students looking at the sky as soon as possible in the semester. Student interest is highest at the start of the semester, the apparent motions of the sky and the constellations are usually taught towards the start of the semester, and by the end of the semester students have less time because of exams and papers, etc. My choices of stars have therefore been:

1. Fall Semester: βLyr (whole class), η Aql (half the class), and δ Cep (the other half of the class). These are well placed until early November when students are required to turn in their observations.
2. Spring Semester: Algol (whole class). This star is visible until late March. It would also be possible to assign Algol in the late fall semester, but I have never done this. ζ Gem is well placed throughout the spring semester, but my experiences with η Aql and δ Cep suggest that most students would not get a good light curve for this small-amplitude Cepheid.

3. Student Observations of Algol

Students were given a finding chart, the magnitudes of a large number of stars near Algol (to two decimal places), log sheets, a table of Julian dates, graph paper, and instructions on how to use the fractional method and calculate the phase. For each observation they were instructed to use three pairs of comparison stars at a time and average the results to improve accuracy and reduce mistakes. Magnitudes were taken from *Sky Catalogue 2000.0* (Hirshfeld and Sinnott 1982). Initially the magnitudes were transformed to a passband exactly halfway between the peaks of the rod and cone responses of the eye. It was reckoned that this would give a better color transformation than V magnitudes (which correspond to the cone response of a non-dark adapted eye). This is also in agreement with the empirical study of AAVSO sequences by Stanton (1982). It was decided that for a class observing project, however, this refinement is unnecessary, particularly as the students are rarely properly dark-adapted before making the observations. In subsequent semesters students were given straight V magnitudes.

Initially, to avoid bias, I did not tell students the times of primary minima. Although this led to a good class light curve, it also led to most students not having the experience of seeing Algol in eclipse. I subsequently adopted the idea of telling the class the times when they could observe at least part of an eclipse. This was a list of dates with statements like "observe between sunset and 1am; Algol faintest between 9pm and 11pm". To get full credit for the assignment students had to make five observations (each the average of three estimates). They were told that if they were able to observe during one of the primary eclipse nights they could made observations as often as once every half hour (thus the whole assignment could be completed in one evening). On nights when a primary eclipse was not occurring they could only make one observation per night. These instructions led to good coverage of the primary eclipses and accommodated the different personal schedules of individual students. As was hoped, a number of students went beyond the minimum requirements in order to get better coverage of the light curve.

Each semester a class light curve was produced from a subset of the students' observations. Figure 1 shows about 170 good observations made by 50 students. Observations where inappropriate comparison stars were used or stars were misidentified have been omitted. It can be seen that these novice variable star observers have produced a respectable light curve. The rms error per point is magnitude ± 0.10. Since each point is the average of three estimates using different comparison stars, the rms error for a single estimate is magnitude ± 0.17.

4. Student Observations of Fainter Stars

The University of Oklahoma is in a town with frequently clear skies and only moderate light pollution. To make students aware of the concept of limiting magnitude and the effects of light pollution, they were required to calculate their m_{lim} using the standard method of star counts. In the fall semester they used the Square of Pegasus; in the spring semester they were given information on the standard International Meteor Organization triangles for determining limiting magnitudes (Roggemans 1989). From star counts m_{lim} can readily be determined to ± 0.2. From on campus m_{lim} was routinely found to be 5.0 - 5.2 and from the suburbs near campus it could get as good as 5.6. Experiments by the author proved that it was possible to estimate δ Cep from under the street lights outside the main dormitories. Student observations of δ Cep, η Aql, and β Lyr were therefore deemed possible.

Students in the fall semester were given information for these three stars similar to what was given to students in the spring semester for Algol, except that instead of having to calculate the phase of each star, they were given a table of phases for mid-evening for each night, since the periods of these stars are long and variations are slower than for Algol. The phases were calculated from the ephemerides given in the Royal Astronomical Society of Canada *Observer's Handbook*. Figures 2 - 4 show what can be achieved by a single observer over a period of 2 - 3 weeks. It should be pointed out that these light curves are better than what most students produced. To get a good-looking light curve the student had to be lucky enough to catch the variables at maxima and minima in addition to making good estimates.

It must be emphasized that student observations of these fainter stars will not be possible from all locations.

5. Practical Suggestions

The four biggest problems encountered were: (a) misidentification of the variable and comparison stars, (b) failure to understand the method, (c) using inappropriate comparison stars (comparison stars too bright or faint), and (d) student procrastination (putting off getting started too long until there were not enough clear nights left to finish the assignment).

5.1 Identification of Variable and Comparison Stars

By far the best way of clarifying the identification of the variable and comparison stars was to have help sessions on the observatory roof at night. I used the beam of a high intensity flashlight shielded by a tube of black paper to point out the variables and comparison stars and show the orientation of charts. If estimates were way off but and the student seemed to have understood the method, misidentification was usually the problem.

5.2 The Use of Photographs

After the problem of identification the next biggest problem was probably understanding the method. Night sessions could obviously be used to explain the method, but I find that using a slide in my office was just as effective. My standard way of explaining how to use the fractional method is to ask the student to find a star on a slide slightly brighter than the variable and one slightly fainter (the slide can be hand held up to a light or window). I next ask the student to pretend that the faintest star is zero and the brightest one is ten and ask "What is Algol on a scale of zero to ten?". I then explain how to complete the log sheet. I find that students achieve about the same accuracy or better from a slide in my office as they achieve with the real sky! A slide is also useful for clarifying misidentifications ("Which star do you think is Algol in this slide?"; "Point to the stars you used as your comparisons"). A Planetarium could also be used for making practice observations.

If you do not have a suitable photograph, the following settings will give a picture closely approximating what the eye sees: ISO 400 slide film, a standard 40- or 50-mm camera lens set at f/2.8, and a 30 second time exposure. You will need a steady tripod and a cable release.

5.3 Use of Appropriate Comparison Stars

Another important source of poor observations was the use of comparison stars too different in brightness from the variable (Capella and Aldebaran were sometimes used as comparisons for Algol!). This problem can be minimized by:

1. Marking clearly on the chart which stars should not be used as comparisons.
2. Not giving students magnitudes of stars they should not use as comparison stars.
3. Giving instructions that comparison stars must not differ in magnitude by more than, say, magnitude 1.3.

Providing personal supervision of a student making his/her first observation outside is undoubtedly the most important thing one can do to avoid all the problems mentioned. One teaching assistant with a relatively small section of students was able to supervise personally the students in making their first observations. Almost all of his students produced good observations, in contrast with the relatively small fraction (20%) of the rest of the class which produced good observations by following the written instructions and examples.

5.4 Other Suggestions

1. Have the students turn in one observation quite early in the term. Students cannot receive full credit for the assignment unless the first observation is turned in on time. This one observation is graded and returned with comments. This has two advantages: it gets students started early, and it catches mistakes early.

2. Remind students when the primary eclipse nights are and organize group events during primary eclipses (a suggestion of Levy 1987). These were popular with students and more were requested. A variable star is more interesting when it

actually varies!

3. Encourage the students to work with an "observing partner". They are able to assist each other in correctly identifying the comparison stars and discussing the precise brightness fractions. It had never occurred to me that visual variable star observing could be a social activity, but some students organized their own get-togethers on primary eclipse nights.

4. When lecturing on binary stars and stellar masses or on the Cepheid period-luminosity relationship and the distance scale, use student light curves of eclipsing binary stars or Cepheids as illustrations.

5. Show light curves of newly discovered comets and novae to illustrate how visual magnitude estimates are contributing to our knowledge of the behavior these objects.

6. Show a composite light curve of all observations made by the students (similar to Figure 1). Individual students can then see how their observations fit in with the rest, and gain a better understanding of experimental errors.

6. Additional Possible Projects

I suspect that some of the semiregular variables can be made interesting to the students if they are given a recent light curve to add their observations to, and if they are told that the star's behavior is unpredictable and that they are helping to find out how it is varying. α Her is a semiregular easy to observe which is well placed at the start of the fall semester.

Levy (1987) suggests having students following the fading of Mira or χ Cyg, starting observations at or just before maximum light (to aid the identification of the stars). Unfortunately, maxima occurring at convenient times occur only a few times per decade. Table 2 gives the dates of maxima of these stars which should occur when the stars are well placed in the evening sky (these predictions could be in error by several weeks). Cygnus is well placed at the start of the fall semester but even at maximum light χ Cyg requires binoculars and is hard to locate. There are also only three convenient maxima remaining this century. Mira, (o Cet) on the other hand, can be followed with the naked eye for several months, and can be followed through its entire cycle with a good pair of binoculars, but Cetus is not conveniently placed with respect to the academic calendar. It is only observable in the evening sky in the second half of the fall semester and the early part of the spring semester. In the fall of 1991, when Mira had gone through maximum in late August, I provided students with naked eye and binocular charts for Mira and gave it as an optional star which could be observed instead of the naked eye variable stars. Because of the difficulties of observing it nobody chose to follow it.

Table 2. Maxima of Mira and χ Cygni Observable in the Evening Sky.

Year	*Approx. Date*	*Star*
1995	Jul. 9	χ Cyg
1996	Aug. 20	χ Cyg
1997	Feb. 1	Mira
1997	Oct. 1	χ Cyg
1997	Dec. 28	Mira
1998	Nov. 25	Mira
1999	Oct. 22	Mira
2000	Sep. 19	Mira

Binoculars are a tremendous help to the student stuck with a bright sky. A typical inexpensive pair of binoculars magnifies 6-8x and can show stars down to about magnitude 4.0 - 4.5 fainter than the naked eye limit. For a typical sky of m_{lim} = 4.5 this makes stars as faint as magnitude 8.0 - 8.5 visible. The advantage of binoculars is several-fold:

1. The stars in Table 1 at the limit of naked eye visibility become readily observable.
2. A lot more Cepheids and eclipsing binaries become observable; roughly a factor of four more per magnitude is gained.
3. Whole new classes of stars become accessible (some of which show more spectacular variations than the naked eye variable stars). These include:
    a. A large number of Miras at maximum
    b. The brightest RV Tau stars (R Sct and U Mon)
    c. RR Lyr
    d. W UMa

The "downside" to binoculars is that they are moderately expensive pieces of equipment and one should beware of unfairly disadvantaging students who do not have them. However, some students have reported good results with cheap $19.95 "Tasco" 7x30 binoculars bought from large department stores. Given that students are probably paying $30-40 for their textbook in an introductory astronomy course it might not be unreasonable to require that they get a $20 pair of binoculars as well.

In planning any student observing activity it is important that the instructor try it out in advance to verify that it really is feasible, to find hidden pitfalls, and to be sensitive to potential student difficulties. One should remember that the instructor is not the student. As a rule of thumb I reckon that one should expect a student to take about three times as long as an instructor to make and reduce an observation.

Information on many of the naked eye variables mentioned here (and on some southern hemisphere stars) can be found in introductory books on variable star observing, such as Glasby (1971), Levy (1989), and Isles (1991), in past issues of *Sky & Telescope* magazine, and in a series of articles by John Isles in the British magazine *Astronomy Now*. The articles by Isles include visual light curves for most of the naked eye variables. Hoffmeister, Richter, and Wenzel (1985) give a table of bright variables slightly fainter than in my Table 1. Petit (1987) gives convenient lists of the brightest members of each class of variable. Current ephemerides for some bright variables are given each year in the Royal Astronomical Society of Canada *Observer's Handbook*. For instructors who wish to start incorporating visual variable star observations into their courses the author will make copies of his charts and comparison star lists available for reproduction free of charge.

7. Conclusions

The number of interesting variable stars which can be readily observed by students is very small. Only Algol can be observed under very poor sky conditions. If slightly better skies (or binoculars) are available, then interesting results can also be obtained for the eclipsing variable βLyr and the Cepheids ηAql and δCep from observations made on only a few nights.

References

Glasby, J. S. 1971, *The Variable Star Observer's Handbook*, Norton, New York.
Hirshfeld, A., and Sinnott, R. W. 1982, *Sky Catalogue 2000.0, Volume 1: Stars to Magnitude 8.0,* Cambridge University Press, Cambridge.

Hoffmeister, C., Richter, G., and Wenzel, W. 1985, *Variable Stars,* Springer-Verlag, New York, 286.
Isles, J. E. 1991, *Webb Society Deep-Sky Observer's Handbook Volume 8 - Variable Stars,* Enslow Publishers, Hillside, NJ.
Levy, D. H. 1987, *J. Amer. Assoc. Var. Star Obs.,* 15, 282.
Levy, D. H. 1989, *Observing Variable Stars,* Cambridge University Press, Cambridge.
MacRobert, Alan M. 1991 *Sky & Telescope,* 81, 262.
Petit, M. 1987, *Variable Stars,* Wiley, New York.
Roggemans, P. 1989, *Handbook for Visual Meteor Observations,* Sky Publishing Corp., Cambridge, MA, 68-69.
Stanton, R. H. 1981, *J. Amer. Assoc. Var. Star Obs.,* 10, 1.

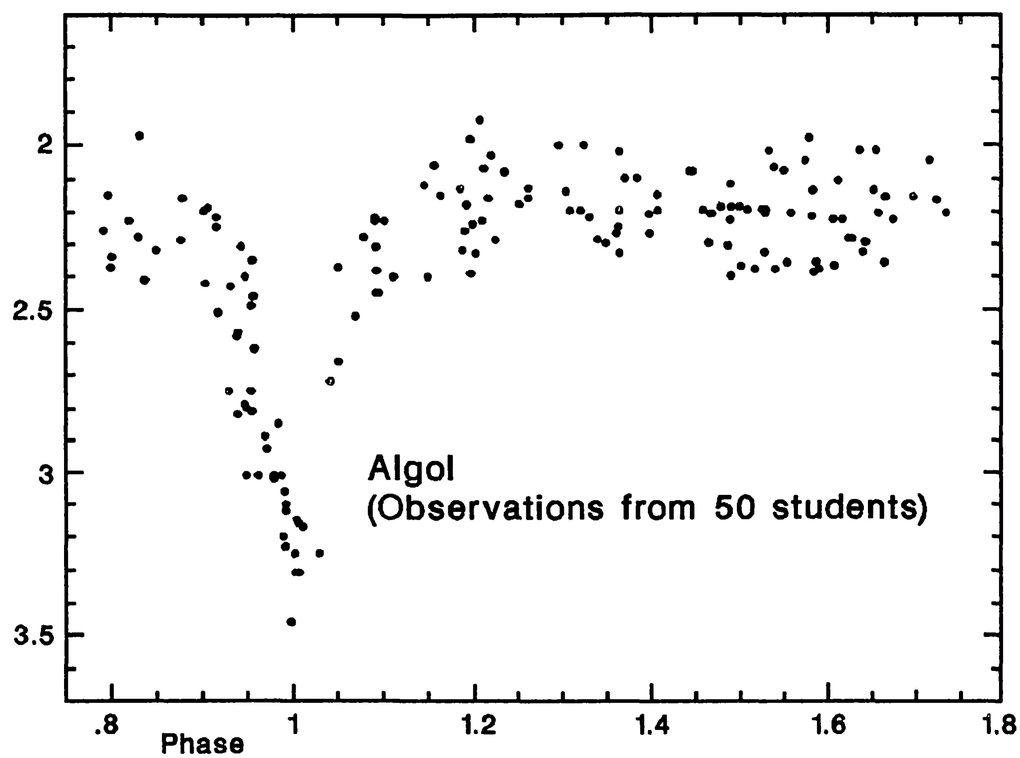

Figure 1. Composite light curve of Algol (βPer) from 170 observations made by 50 mostly non-science college students (see text for details).

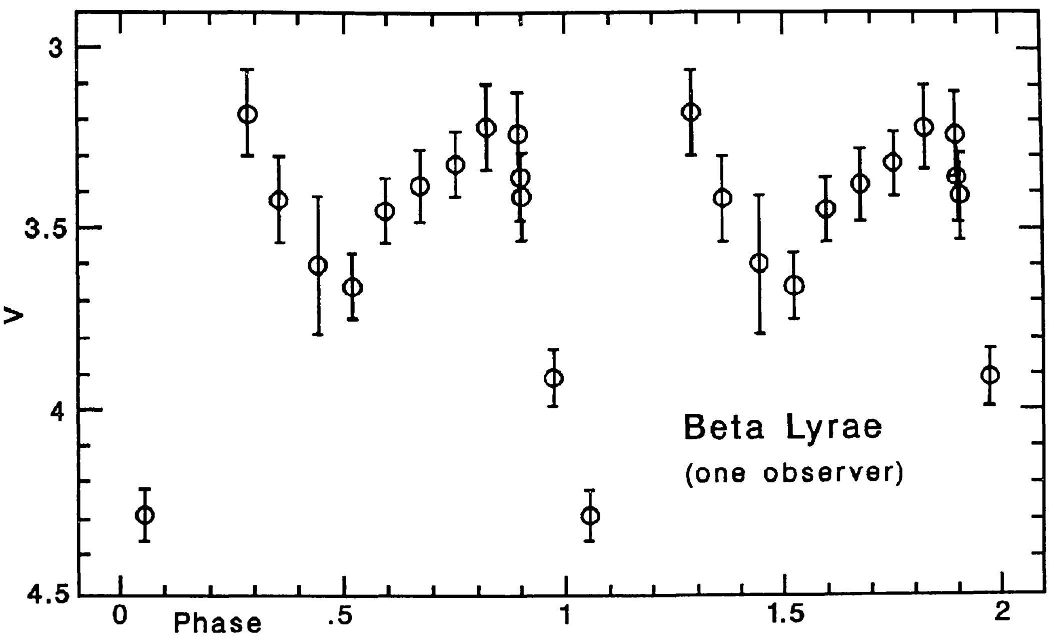

Figure 2. Light curve of the eclipsing binary β Lyr obtained by a single observer (mostly naked eye observations) over a period of three weeks. Each point represents the average of estimates made using a number of pairs of comparison stars on a single night (except for one night at phase 0.9 for which three consecutive estimates are shown). The error bars were calculated on the basis of internal consistency.

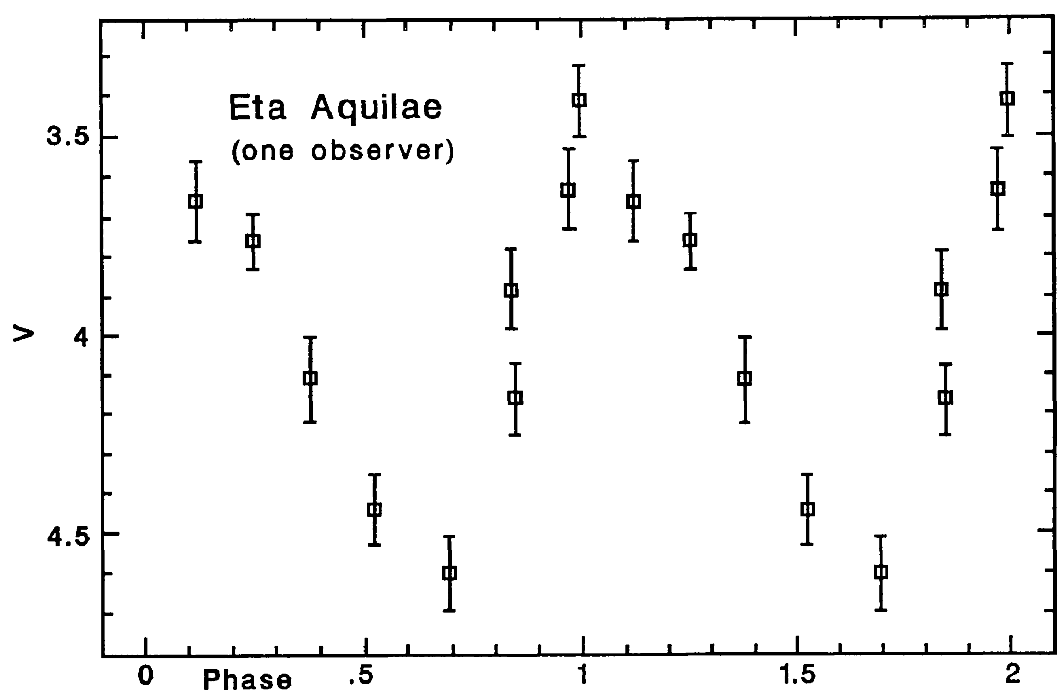

Figure 3. Light curve of the Cepheid η Aql obtained by a single observer over a two week period (naked eye and binocular observations). Details are as in Figure 2.

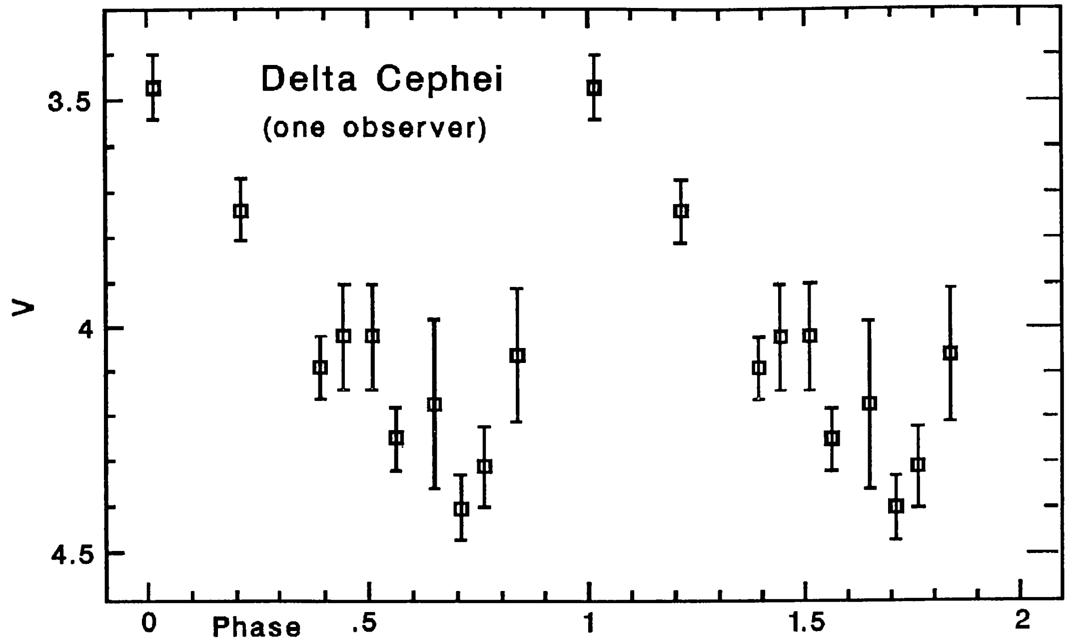

Figure 4. Light curve of δ Cep obtained by a single observer over a two week period (naked eye and binocular observations). Details are as in Figure 2.