AAVSO PHOTOELECTRIC PHOTOMETRY AND HIPPARCOS PHOTOMETRY OF THE PULSATING RED GIANT AG CET

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Presented at the 87th Annual Meeting of the AAVSO, October 31, 1998; revised August 10, 1999

Abstract

The pulsating red giant AG Ceti was observed by the observers in the AAVSO photoelectric photometry program, and by the Hipparcos satellite. The data have been analyzed using light curves, autocorrelation diagrams, Fourier transforms, and phase diagrams. The AAVSO data show seasonal gaps, and the Hipparcos data are also distributed non-uniformly in time; we discuss the effects of these time distributions on the results. Autocorrelation analysis of the AAVSO data clearly shows a period of 60–80 days; this is confirmed by the Fourier analysis (period about 77.7 days), the phase diagram, and by the light curves. Evidence for this period in the Hipparcos data is much less clear; periods of 1 to 6 days are also suggested. The difference between the two sets of results may be due to the fact that the AAVSO data were obtained with a V filter, which is very sensitive to pulsational temperature variations in red giants, whereas the Hipparcos data were obtained with a very broad-band filter. AG Cet may be a binary with a pulsating red giant component, and a hotter, bluer component with a short period.

1. Introduction

The pulsating red giant AG Ceti (HIP 2215, HD 2438, M4III and type SRb (Hoffleit *et al*. 1983), V = 6.8 to 7.6 (Figure 1)) has been studied with data from the AAVSO photoelectric photometry (PEP) program, and from the Hipparcos database of epoch photometry. There are fundamental differences between the time distributions of the two datasets and their photometric systems, and these affect the analysis and results.

The AAVSO photoelectric measurements (Landis 1998) were obtained with a standard Johnson V filter. AG Cet was observed seasonally, when it was sufficiently above the horizon. This produces a periodicity of one year in the data, and leads to aliasing in the Fourier power spectrum—artificial peaks which are separated from the true peak by 1,2,3 ... cycles per year. In some cases, the alias peaks may be as high as (or higher than) the true peaks, and this makes the identification of the true period difficult or even impossible.

The Hipparcos mission was primarily astrometric, but it also obtained 100 or more photometric observations of 120,000 stars over more than three years, with a precision of typically 0.007 magnitude. The photometric filter was very wide, covering most of the visible spectrum. The Tycho component of the Hipparcos mission also obtained photometric data, on more than a million stars, with a precision of about 0.05 magnitude, in B and V filters. The AAVSO contributed both to the preparation of the star list for the mission, and to its scientific success (Turon 1997).

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The data from the Hipparcos mission are suitable for analyzing small-amplitude variable stars because of their high accuracy of the data; there are also limitations which affect the analysis. The satellite was equipped with two detectors which took measurements about 20 minutes apart. The rotational period of the satellite was about two hours. The timing of the observations was not pre-programmed; rather, measurements were made whenever the target star came into the field of view of the detectors. This caused a pattern of two measurements taken 20 minutes apart, followed by another pair of measurements about two hours later. This pattern was repeated until the satellite's orbit no longer allowed the star to be viewed. This created clusters of two to seven measurements over a few hours, followed by another cluster 20 to 30 days later. Unfortunately, the length of these gaps is often close to the pulsation period for a red giant. As a result, the light curves may not show complete cycles; autocorrelation and Fourier analysis (see next section) may also be adversely affected.

Furthermore, for stars such as red giants with periods of weeks to months, each cluster of measurements is effectively a single useful data point, as no variation would probably occur over such a short time span. This reduces the hundred or more measurements to about 15 to 25 useful points. This number of points, over three years, might show the period of a highly periodic star, or the period of a very long period star, but it does not allow for a statistically significant conclusion about the period of a semiregular variable, such as a red giant, with a period of 20 to 100 days. This time distribution can even be a problem in analyzing variables with periods of one to several days.

In some cases, it might be possible to combine the Hipparcos data with ground-based data such as AAVSO photoelectric data, which have a different time distribution and aliasing properties. A second problem then arises: the Hipparcos photometric system is much broader-band than the usual Johnson UBV system. A method has been described by Harmanec (1998) to transform Hipparcos photometry to the UBV system, if the star's (U-B) and (B-V) colors are known. This method works well for stars with "normal" spectra, i.e., for those with spectra which approximate a blackbody curve. Red star spectra, however, have strong TiO molecular absorption bands, which coincide with the V photometric band, so the transformation is much less effective for these stars.

2. Method

The methods used for determining the period of AG Cet were: light curves, autocorrelation analysis, discrete Fourier transforms, and phase diagrams.

The "ΔT diagram" was first examined to determine some aspects of the time distribution of the data; it shows the time distribution by plotting the time elapsed between consecutive measurements against the measurement number. In the Hipparcos data, for instance, the gaps between consecutive measurements tend to be either a few hours or less, or 20 to 30 days. This will affect the effectiveness of the methods of analysis listed above.

The light curve plots the magnitude of the star versus time. The light curve may show the star's period if enough measurements are available, with a suitable time distribution. In this case, the light curve will show clear and connected maxima and minima. If the measurements are sparse in number or time-distribution, the period may not be clear, especially if the variability is irregular.

In autocorrelation analysis, the difference in magnitude (without regard to sign) is plotted against the difference in time, for every pair of measurements. If the star is periodic, then two measurements will show a minimum difference when the time difference between them (ΔT) is one period; the minimum difference will be zero if there is no observational error in the measurements and the periodicity is exact. If the time difference ΔT between the measurements is half a period, then the difference in magnitude may range from zero to twice the amplitude of the variability (the latter occurs if one point is at maximum and the other is at minimum). In our version of the autocorrelation method, the time-difference axis is divided into 10–50 “bins” and the points within each bin are averaged with respect to difference in magnitude. The autocorrelation diagram will show minima at the length of the period, and multiples thereof, with maxima in between. Autocorrelation is not affected by aliasing. In the case of the Hipparcos data, there are very few measurements separated by 1–20 days, or 30–100 days, so it is very difficult to use this method to look for periods in the 1–100-day range. See Percy *et al.* (1993, 1996) for an example of the use of autocorrelation analysis of AAVSO data on pulsating red giants.

Discrete Fourier analysis multiplies the data by sine curves with different periods. If the period is incorrect, then the product is as often positive as negative, and the product will average to zero. If the period is correct, then the measurements and the sine curve will tend to have the same sign, so the product will be positive. The graph of the product against the period (or the frequency) is called the power spectrum. Peaks in the power spectrum may represent periods present in the data. They may also represent alias periods if the times of the measurements contain periodicities such as seasonal gaps.

The phase diagram is used to check whether the periods, determined by these methods, fit the data; the phase diagram can also be used to determine the average amplitude and shape of the light curve. The phase diagram folds the light curve so that the magnitudes of all points which are at the same phase in the cycle are plotted against that phase. In this way, all of the information in the light curve is mapped onto one single cycle or period.

3. Analysis of AAVSO data on AG Cet

AG Cet was added to the AAVSO photoelectric photometry program many years ago. Because it is too far south for most northern observers, however (declination –11°), and because of its relative faintness (V = 6.8 to 7.6, Figure 1), it has only recently been observed intensively—thanks especially to Mr. R.W. Jones in South Africa.

The data set contained 115 points. Light curves for separate seasons suggest periods of 40 to over 120 days with total ranges of up to 0.7 magnitude (Figure 1). The light curve also shows the expected seasonal gaps in the data. This may cause aliasing in the power spectrum with a period of one cycle per year (0.00274 cycle per day).

The autocorrelation diagram (Figure 2) shows a maximum at 30–40 days and a minimum at 50–80 days, suggesting a time scale of 60–80 days. The power spectrum (Figure 3) shows a distinct peak at a period of 77.7 days (frequency 0.0129 cycle/day). There is a series of other peaks in the power spectrum, separated by 0.00274 cycle/day, which are aliases. The phase diagram for the 77.7-day period (Figure 4) is well-defined, but shows scatter due to the variable amplitude of the cycles (Figure 1) and possibly due to long-term (years) variations which are found in many other pulsating red giants (e.g., Percy *et al.* 1996). We conclude from the AAVSO data that the period of the star is about 78 days—a typical period for a pulsating red giant (Percy *et al.* 1996).

4. Analysis of Hipparcos data on AG Cet

The dataset contained 92 points. The light curve (Figure 5) does not indicate any particular period. Note that the range is much less than the range in V (Figure 1) because of the difference in the photometric systems. Note also the clusters of measurements. There seems to be significant variability within these clusters of measurements which are only a few hours apart.

The ΔT graph (Figure 6) clearly shows that many consecutive measurements are much less than a day apart. The clusters are separated by large intervals of time, typically about 25 days. These gaps will hinder the identification of periods in the range of 20–100 days. Effectively, there are only 20 useful points for investigating periods in this range.

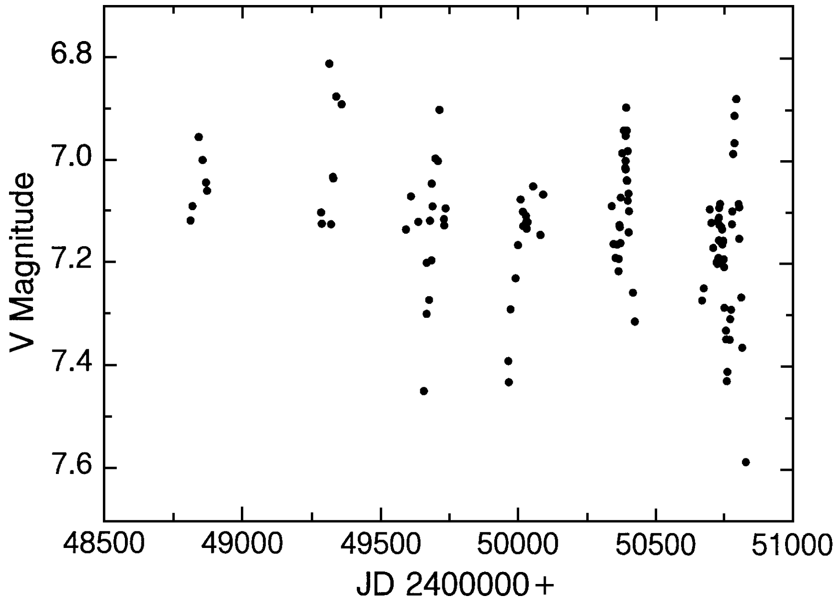

Figure 1. The AAVSO photoelectric V light curve for AG Cet. The seasonal gaps are apparent. There is no long-term variation, but there are variations of up to 0.7 magnitude within seasons.

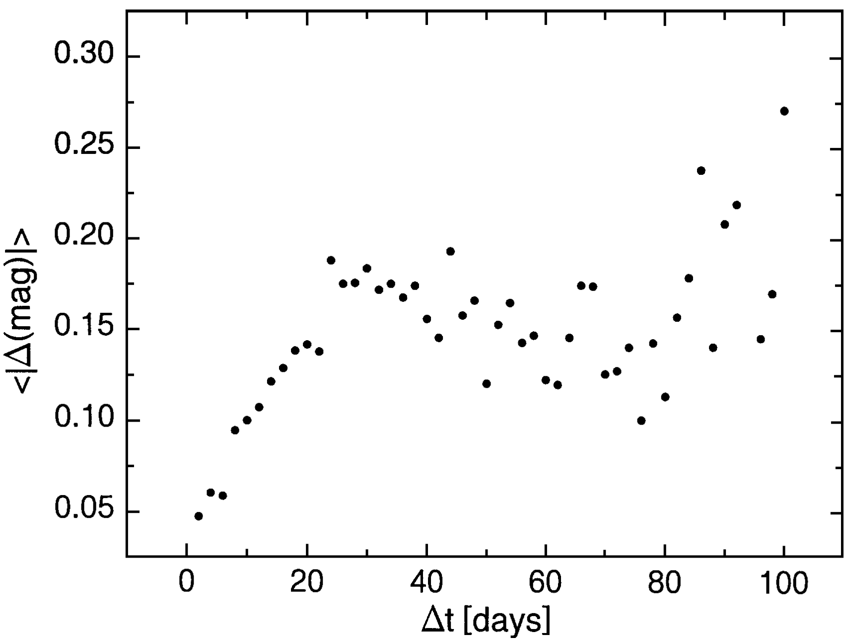

Figure 2. The autocorrelation diagram for the data in Figure 1 shows a broad minimum at a time difference of 50–80 days, and a maximum at 30–40 days.

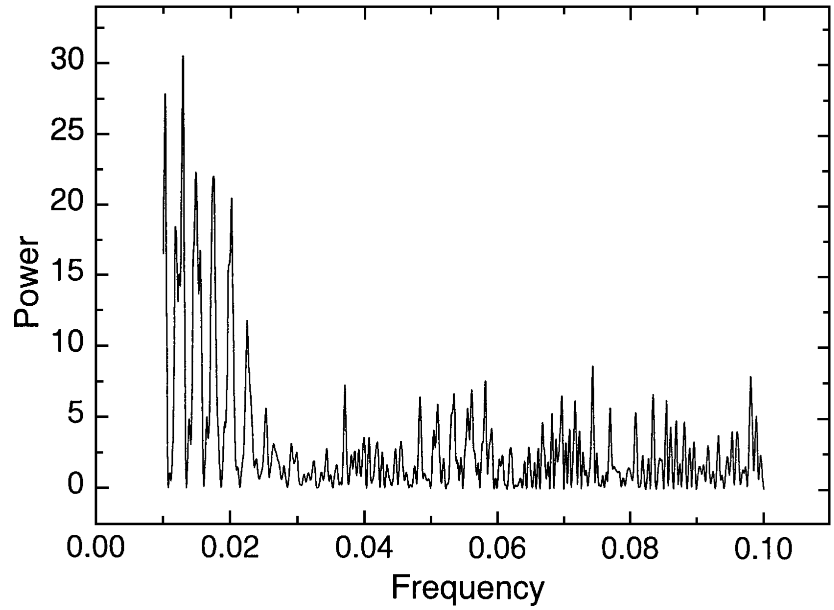

Figure 3. The power spectrum for the data in Figure 1 shows a distinct peak at 77.7 days. This is consistent with the seasonal light curves, and the autocorrelation analysis. The equally-spaced peaks are aliases, due to the seasonal gaps in the data.

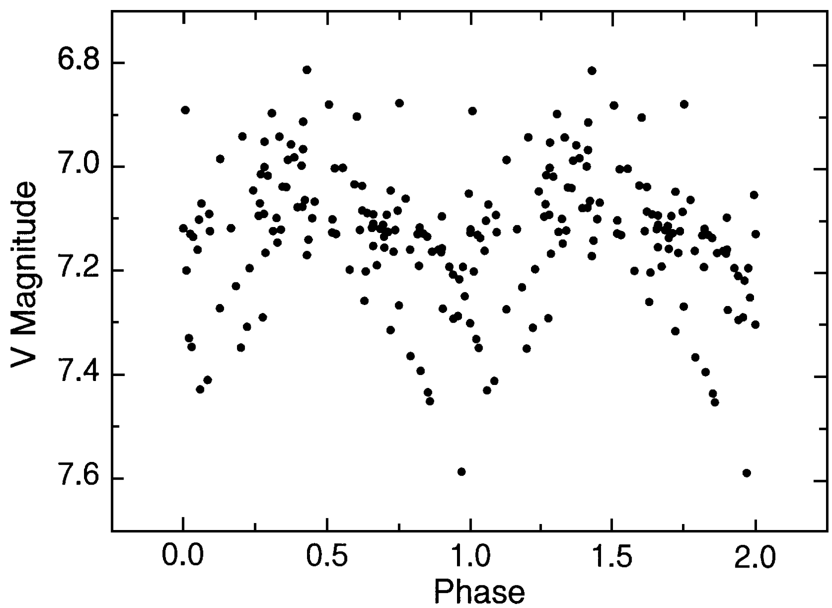

Figure 4. The phase diagram for a period of 77.7 days shows scatter, due to the semiregular behavior, including the variable range of variability.

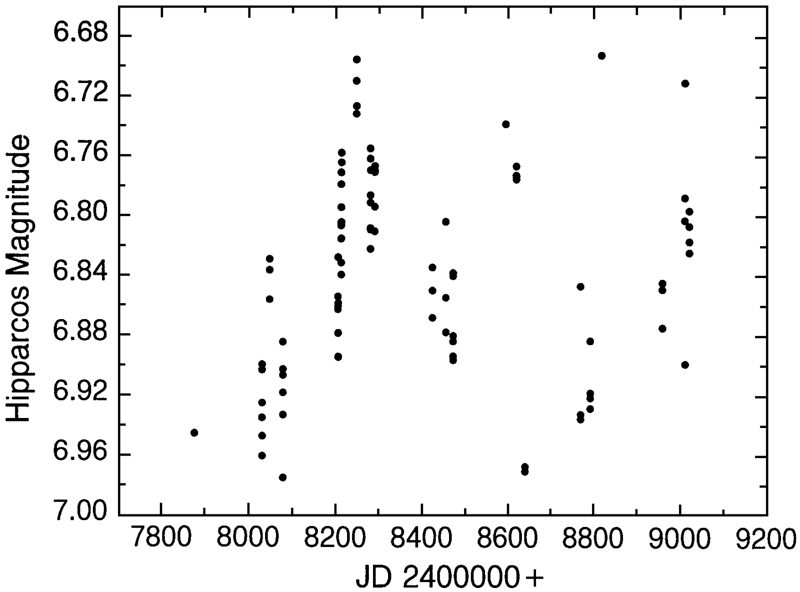

Figure 5. The Hipparcos light curve for AG Cet. The clusters of measurements, closely-spaced in time, are apparent. The scatter within clusters implies that the time scale of the variability is short—a day or so.

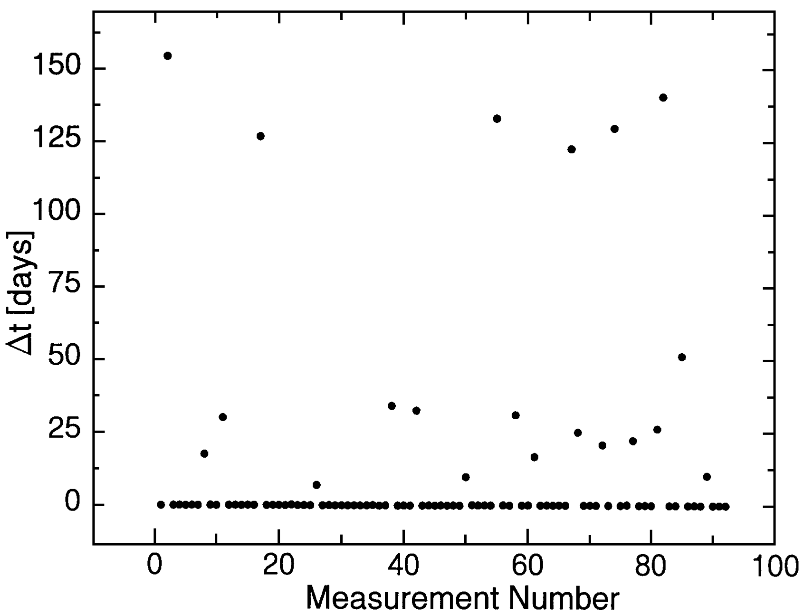

Figure 6. The ΔT graph of the Hipparcos measurements of AG Cet shows the clustering of the measurements in time. For the study of periods longer than about a week, there are effectively only 20 measurements.

The autocorrelation diagram (Figure 7) shows a broad minimum between 60 and 80 days but, in the power spectrum (Figure 8), no period in this range stands out. There were several peaks in the power spectrum with comparable heights (1.715, 11.714, 4.769, 11.026, 5.490, 1.298, and 1.652 days); phase diagrams for three of these are shown in Figure 9a–c. Each of them seems to provide a good fit to the data, with a mean range of 0.15 magnitude. Recall, however, that there are few if any pairs of measurements which are 1–10 days apart.

5. Discussion

Autocorrelation and Fourier analysis of the AAVSO photoelectric data on AG Cet leads to a single period (77.7 days) which is consistent with the V light curves, and with the expected behavior of a pulsating M4 giant. Analysis of the Hipparcos data, however, leads to a more ambiguous result. The 77.7-day period is weakly visible in the autocorrelation diagram, but not in the power spectrum. The light curves suggest that significant variability may occur on a short (days) time scale, and the power spectrum contains peaks corresponding to periods in that range. The fact that the heights of the peaks corresponding to several periods and the fits to the phase curves for these periods are comparable, suggests that none of these periods is more likely than any other, and that none of them may be correct.

It is also possible that AG Cet is a double star consisting of an M4III star with a bluer companion. There are two pieces of evidence for this: (i) the (B-V) color of AG Cet is about 0.2 bluer than a normal M4 giant; this would be true if the red giant had a bluer companion with significant brightness; (ii) Hipparcos classifies AG Cet as a "variability-induced mover"—duplicity is inferred from a photocentric motion which is attributed to the variability of one of the components. There is no information about the nature of the possible companion, or about its variability type.

6. Conclusion

The AAVSO photoelectric data suggest a 77.7-day period in the M4III star AG Cet. The Hipparcos data suggest that there may also be a bluer companion with a period of less than 10 days. It is also possible that this latter result is spurious, and somehow due to the nature and time distribution of the Hipparcos photometric data.

7. Acknowledgements

We thank the Natural Sciences and Engineering Research Council of Canada, and the Summer Career Placement Program (Government of Canada) for supporting this research. We also thank the AAVSO photoelectric observers—especially R.W. Jones—and the AAVSO photoelectric data archivist Howard J. Landis for their essential contributions to this project.

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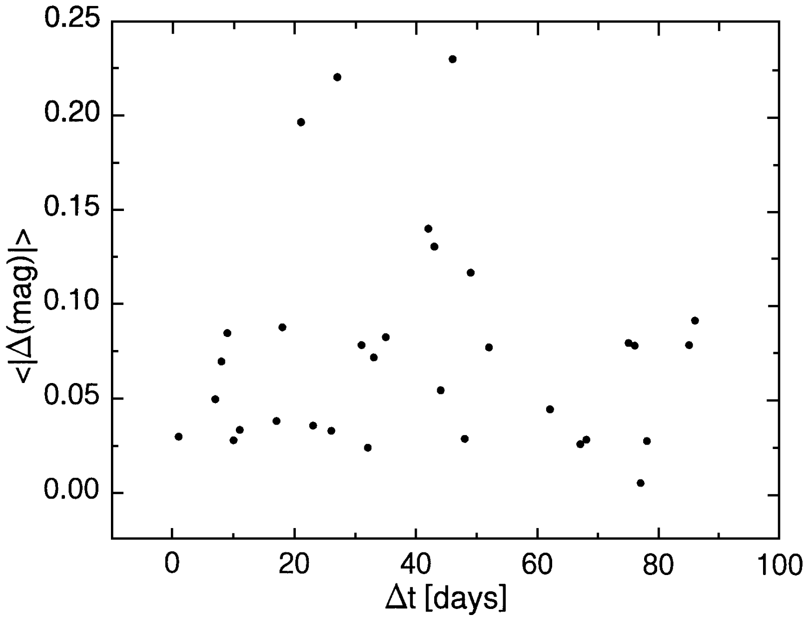

Figure 7. The autocorrelation diagram for the data in Figure 5 does not clearly suggest a period. The 78-day period, found in the AAVSO photoelectric data, may or may not be present.

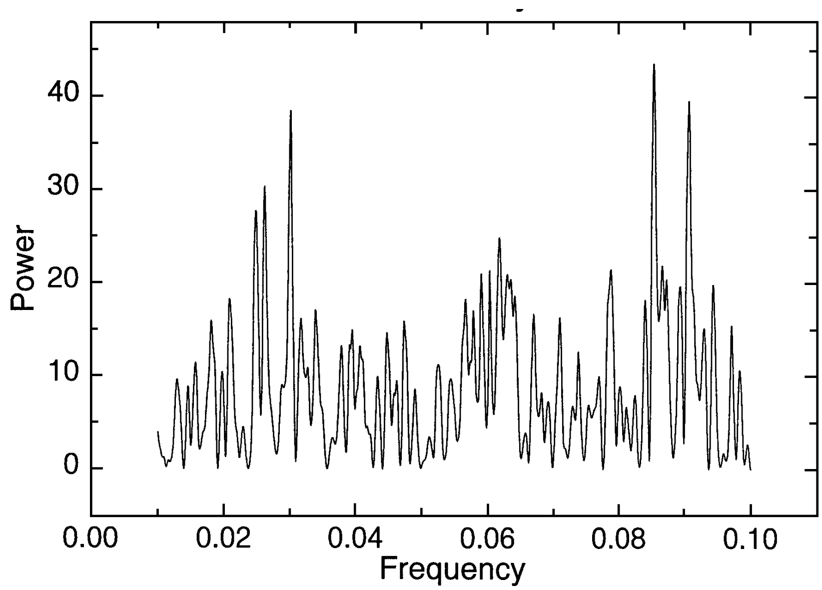

Figure 8. The power spectrum for the data in Figure 5 is noisy. The 78-day period is not apparent.

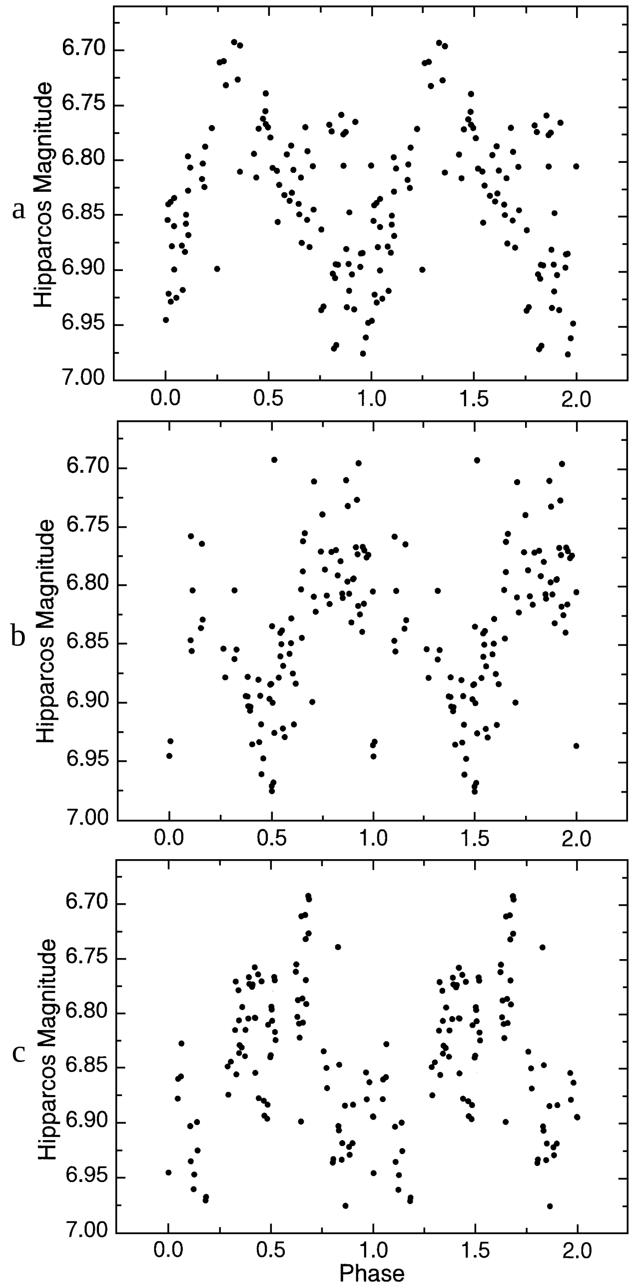

Figure 9a–c. Phase diagrams for the data in Figure 5, using periods of (a) 1.298 days; (b) 1.652 days; (c) 5.490 days. These and other periods (see text) all provide an equivalent fit to the data, which casts doubt on their significance.