Self-Correlation Analysis of the Brightness Variability of Symbiotic Stars: A Pilot Project

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Abstract About one-third of pulsating red giants show secondary periods which are an order of magnitude longer than the main pulsation period. The causes of the long secondary periods (LSPs) are unknown, but some may result from the effects of a binary companion. We have carried out self-correlation analysis of EG And, AX Per, CH Cyg, CL Cyg, AG Peg, and Z And, using both visual and photoelectric data. Five of the stars show variability which is orbit related: the time scale is equal to the orbital period, or half the orbital period. However, the pulsational variability, if any, is very low amplitude, compared with normal red giants of the same spectral type.

1. Pulsating red giants

When sun-like stars approach the end of their lives, they expand and cool, and become red giant stars. When a red giant becomes cooler than 4000K—which corresponds to spectral type K5III—it becomes unstable to pulsation, and becomes a pulsating red giant. On average, the *V* amplitude increases from millimagnitudes at spectral type K5III, to many magnitudes at spectral type M9III; the latter variables would be Mira stars. About 10 per cent of the stars in *The Bright Star Catalogue* (Hoffleit 1982) are pulsating red giants, most with small amplitudes. Until recently, they were not well understood, but long-term photometry by Automatic Photometric Telescopes (Percy *et al.* 2001) and by the AAVSO Photoelectric Photometry Program (Percy *et al.* 1996) has provided new insights. Periods have been determined for these stars; they correspond to low-order radial (in-and-out) pulsation modes. Many of the stars pulsate in two or more radial modes, and this has made it possible to estimate the masses of these stars; they are similar to the mass of the sun (Percy *et al.* 2004). Over a third of these stars have long secondary periods, an order of magnitude longer than the radial pulsation periods.

2. Long secondary periods

The long secondary periods have now been observed in many samples of pulsating red giants, including those in the Large Magellanic Cloud (Wood 2000). Their cause is unknown. Peter Wood, who is a leading expert on the observation and theory of pulsating red giants, has considered many possible causes—a radial or non-radial pulsation mode, obscuration by dust-laden winds, rotation of a spotted star, a convection-induced oscillatory thermal mode, and the effect of a binary companion. There is evidence against each of these being the main cause. Wood *et al.* (2004) concludes that "the long secondary periods are the only unexplained type of large-amplitude stellar variability known at this time."

3. The binary hypothesis

Although it is clear that the binary hypothesis cannot explain the long secondary periods in all pulsating red giants, it is possible that it can explain the long secondary periods in some of them. In the spectroscopic binary catalogue of Batten *et al.* (1989), and in the list of binary stars published by Harmanec (2001), there were 17 binaries with an M giant component. Unfortunately the M giant had usually not been studied for pulsation. Therefore, since there is a correlation between spectral type and pulsation period for pulsating red giants, we used the known spectral type of the M giant, along with the known pulsation periods of M giants of various spectral types (Percy *et al.* 1996, 2001) to estimate what the pulsation period was likely to be. In 13 out of the 17 stars, the estimated pulsation period was a factor of 8 to 12 times smaller than the binary period. (For bright pulsating red giants known to have both a pulsation period and a long secondary period, the median ratio is 10.) So the binary hypothesis has some promise, for some pulsating red giants. Symbiotic stars are a type of binary system which, by definition, contain a red giant. We therefore decided to investigate the variability of a number of symbiotic stars, partly because the pulsations of the red giants in these systems have not usually been studied, and partly in the hope that such a study might shed some light on "the mystery of the long secondary periods." EG And, one of the stars on our monitoring program (Percy *et al.* 2001), is already known to be a symbiotic star.

4. Symbiotic binary stars

Symbiotic stars are those whose spectra show evidence of a cool component and a hot component. The cool component is an M giant, sometimes a Mira star. The hot component is usually a white dwarf, but occasionally a hot main sequence star, or very occasionally a neutron star. The hot component is surrounded by an accretion disc of material acquired from the cool component. The orbital periods of symbiotic stars are generally between 200 and 1000 days. About half are eclipsing variables. Very few are ellipsoidal variables, which suggests that the cool component does not usually fill its Roche lobe.

The variability of symbiotic stars is very complex. As binary stars, they may exhibit eclipsing or ellipsoidal variability, or a reflection effect of the illumination of the cool component by the hot one. There may be irregular variability due to variable dust obscuration in the system. There may be flickering due to unstable mass accretion from the cool component onto the accretion disc, or from the accretion disc onto the hot component. The accretion disc may oscillate in a quasi-periodic way, or it may erupt, as in a dwarf nova. The hot component may oscillate, and the cool component will almost certainly do so. Because of this complexity, symbiotic stars should be monitored, preferably photoelectrically, on a long-term basis. See the book by Corradi *et al.* (2003) for a recent, comprehensive review of symbiotic stars.

The variability must, however, be analyzed by a method which can deal with its complex and often-irregular nature. We have previously used one such method—self-correlation analysis—successfully to analyze similar stars (Percy and Mohammed 2004).

5. Self-correlation analysis

Self-correlation analysis is a simple method of time-series analysis which measures the cycle-to-cycle behavior of the star, averaged over all the data. It is suitable for semiregular variables, and those with seasonal gaps in the data. It is a useful adjunct to Fourier analysis. See the recent paper in this *Journal* by Percy and Mohammed (2004) for a more complete description of the method.

The self-correlation diagram plots the average magnitude difference, Δm, against the difference between the times of observation, Δt. The key features of the self-correlation diagram are as follows: (i) there are minima at multiples of the period (if any); (ii) the minima will gradually disappear with increasing Δt if the variability is not strictly periodic; (iii) the value of Δm, as Δt approaches zero, is the average observational error; (iv) the difference between the height of maximum and minimum is approximately 0.9 times the average semi-amplitude of variability.

6. Data

We began by analyzing visual data from the AAVSO, and from the AFOEV. At the time that we began this project AAVSO data was not yet available on-line, but the AFOEV data was available on-line through SIMBAD. We soon realized that, although the visual data were suitable for analyzing the large-amplitude variability due to the binary motion, they were not sufficiently accurate to detect and measure the smaller-amplitude variability due to pulsation. We used photoelectric data on EG And and CH Cyg from the AAVSO Photoelectric Photometry Program, and on other symbiotic stars from Skopal *et al.* (2002), and from Belyakina (1965, 1970, 1986).

7. Results

In this section, we show three self-correlation diagrams for the dominant variability, which is correlated with the orbital period. We also show two diagrams which suggest (though weakly) small-amplitude variability which may be due to pulsation. The amplitudes quoted below are taken from the average difference between the maxima and the minima in the self-correlation diagram. The periods are taken from Mikołajewska (2003). Skopal (2003) reviews previous information about the relation between the dominant variability and the orbital period: in each case, we confirm Skopal's result.

7.1. EG And

This star is already known to vary with periods of 28 and 240 days (Percy *et al.* 2001). The latter is half the binary period, so the longer-period variability is presumably caused by the ellipsoidal shape of the primary; the shorter-period variability is pulsational.

7.2. AX Per

The dominant feature in the self-correlation diagram is the series of minima at multiples of 700 days, with an amplitude of a few tenths of a magnitude. The minima do not persist, and this suggests that the light curve is dominated by other irregular, long-term variations. The time scale of 700 days is close to the binary period of 682.1 days, so this variability is presumably due to the reflection effect. There is also weak evidence in the self-correlation diagram of the photoelectric data, from Skopal *et al.* (2002) for a time scale of 200±10 days, but the amplitude is less than 0.05 magnitude. The nature of this variability, if it is real, is uncertain.

7.3. CH Cyg

The binary period is 5750 days. The self-correlation diagram of the AAVSO photoelectric data shows a minimum at about 2200 days, but the dataset is not long enough to identify such long time scales reliably. That time scale is not present in the self-correlation diagram of the Skopal *et al.* (2002) data, so it probably reflects irregular long-term behavior. There are also inflections in the self-correlation diagram at multiples of 90–100 days; this time scale is consistent with one which has been found by other authors (e.g. Beyer 1948 who found 97.4 days, and Gaposchkin 1952 who found 97 days); it is presumably a pulsation period.

7.4. CI Cyg

The dominant feature of the self-correlation diagram (Figure 1) is a series of minima at multiples of about 850 days with an amplitude of about 0.2 in m_V. The intercept on the vertical axis, 0.2 magnitude, is the average error of the measurements, which is typical for visual data. The time scale is close to the binary period of 855.3 days, so this variability is presumably due to the reflection effect. There is marginal evidence in some sub-sets of the AFOEV data, consisting of inflections on the self-correlation diagram, for a time scale of 75±5 days, which would presumably be a pulsation period, but the amplitude is only 0.01–0.02 magnitude.

7.5. AG Peg

The self-correlation diagram (Figure 2) of the data of Belyakina (1965, 1970, 1986) shows time scales of about 800 days, with an amplitude of about 0.2 in *V*. The time scale is close to the binary period of 816.5 days; so this variability is presumably due to the reflection effect. There is some evidence for a period of 24 days (Figure 3), which would presumably be a pulsation period, but the amplitude is only about 0.02 in *V*. The intercepts on the vertical axes are about 0.01 which is typical for the observational error in photoelectric photometry.

7.6. Z And

The dominant feature of the self-correlation diagram (Figure 4) of the AFOEV data is a series of minima at multiples (13 or more) of 380 days, with an amplitude of about 0.1 in m_V. This time scale is about half the orbital period of 758.8 days, so this variability is presumably ellipsoidal. The persistence of the minima indicates that the behavior is highly periodic, and supports the notion that it is orbit-related. There is some evidence for a period of about 24 days in the photoelectric data of Skopal *et al.* (2002) (Figure 5).

8. Discussion

We have shown that self-correlation analysis may be a useful tool for analyzing photometric observations of symbiotic stars. We were especially interested in finding periods which might be due to the pulsation of the cool component, since pulsational variability has not yet been detected in many of these stars. We were partially successful in this regard. The main problem was that we did not have many long photoelectric datasets, other than those of EG And and CH Cyg (the latter from the AAVSO Photoelectric Photometry Program). We plan to collaborate in future with astronomers who have accumulated long datasets for other purposes.

It is also clear that the pulsational variability in these symbiotic stars is very low amplitude (if it is present at all), compared with that in normal red giants of the same spectral type. This will add to the challenge of detecting and studying pulsational variability in other symbiotic stars with cool components in the M3–7III range.

9. Acknowledgements

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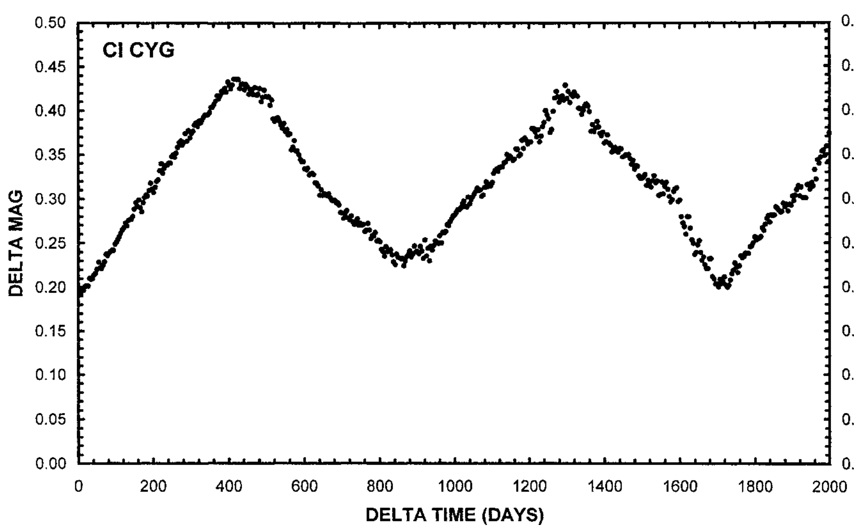

Figure 1. The self-correlation diagram of AFOEV visual data on CI Cyg. Minima occur at multiples of the 855.3-day binary period. The intercept on the vertical axis, 0.20 magnitude, is the mean observational error of the data.

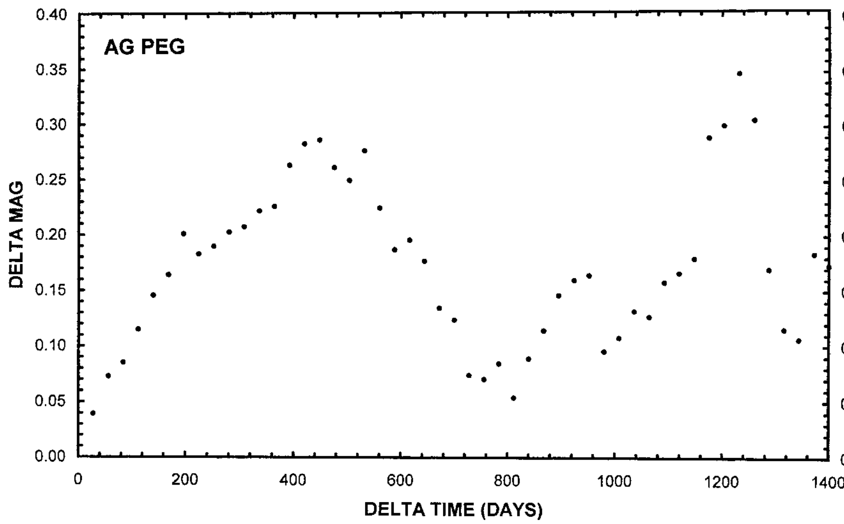

Figure 2. The self-correlation diagram of photoelectric data on AG Peg. The first minimum is consistent with the 816.5-day orbital period.

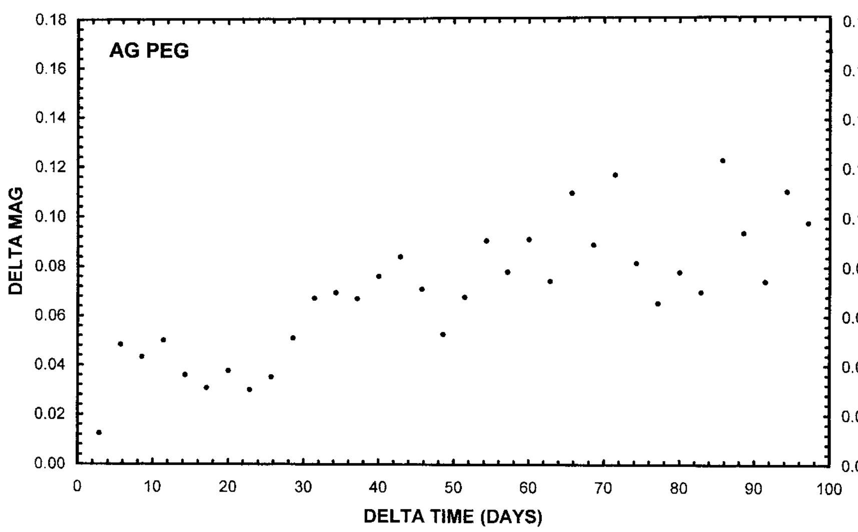

Figure 3. The self-correlation diagram of photoelectric data on AG Peg, for shorter time scales. There is weak evidence for minima at multiples of 24 days, which might be a pulsation period.

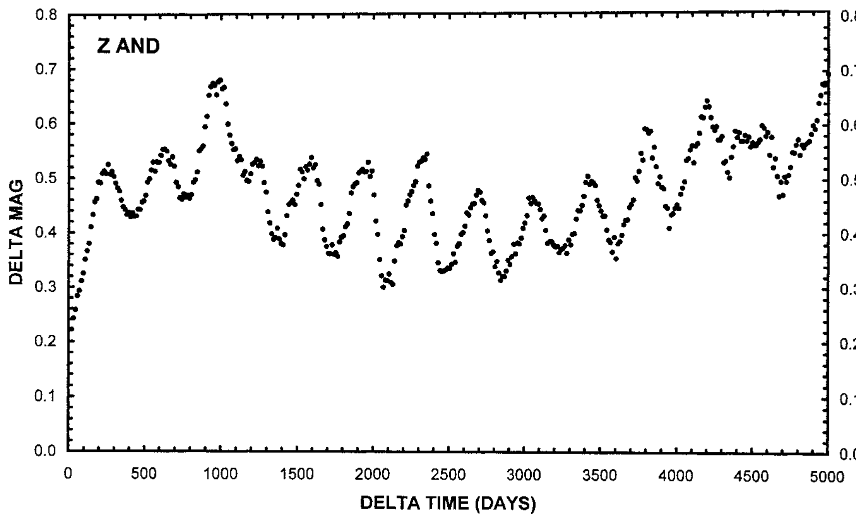

Figure 4. The self-correlation diagram of AFOEV visual data on Z And. There are minima at multiples of half the 758.8-day orbital period.

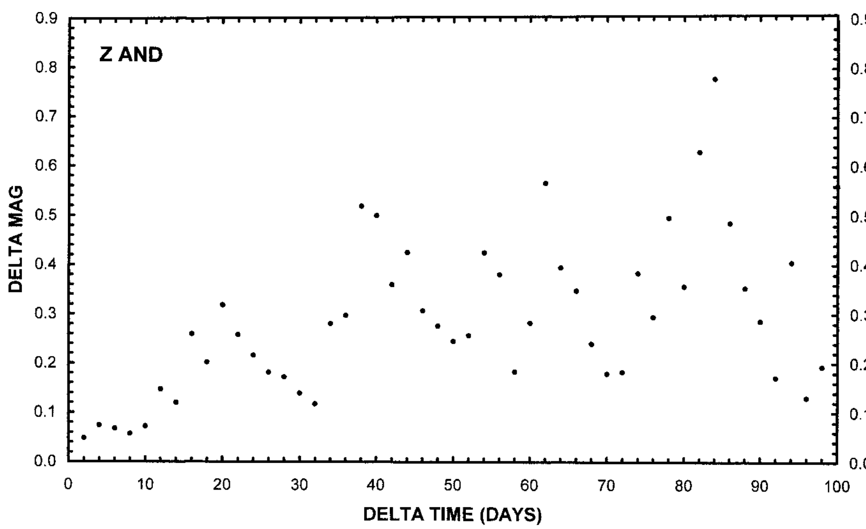

Figure 5. The self-correlation diagram of photoelectric data on Z And. There is weak evidence for minima at multiples of 24 days, which might be a pulsation period.