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AUTOCORRELATION ANALYSIS OF TWO PULSATING RED GIANTS

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About 10 per cent of the naked-eye stars are pulsating red giants (PRGs), with amplitudes ranging from 0.01 to 10 magnitudes. The first PRG — Mira — was discovered over 400 years ago. Small-amplitude PRGs (SAPRGs), with amplitudes of 0.1 to 1 magnitude, and with early M spectral type, were surveyed by Stebbins & Huffer (1930). In past studies (e.g. Percy et al. 1996, Percy et al. 2001a,b), we found that autocorrelation analysis was a useful adjunct to light curves and Fourier analysis for determining the periods of these complex stars. It determines characteristic time scales by examining the cycle-to-cycle behaviour of the star, averaged over the dataset. The version of the autocorrelation method that we use (written by Matt Szczesny and Adrien Desjardins, and described by Percy & Sen 1991) is very simple: for each pair of measurements, the difference in magnitude is plotted against the difference in time, divided into appropriate "bins"; this "autocorrelation diagram" shows minima at integral multiples of the characteristic time scale. Each of the minima can be used to estimate the characteristic time scale. The height of the maxima is related to the amplitude of the variations; the height of the minima, above the zero point, is related to the average error of the measurements, and to the degree of irregularity of the variations; if the variability is irregular, then the minima do not persist with increasing Δt. Distortions or unequal depths of the minima may indicate the presence of multiple periods. Our algorithm is similar to the elegant "variogram" technique described by Eyer & Genton (1999).

Another form of autocorrelation analysis was published by Burki et al. (1978): the data in the light curve are moved sideways in time, and the scatter is assessed; when the shift is equal to the characteristic time scale (or an integral multiple thereof), then the fit is best. The purpose of this paper is to demonstrate the use of this second algorithm on two PRGs — one poorly-studied, and the other newly-discovered. Their light curves are shown in Figures 1 and 3. Figures 2 and 4 illustrate this algorithm; the horizontal axis is the sideways shift, in days; the vertical axis is a measure of the goodness of fit (lower θ indicates a better fit).

SX UMi (HD 126409, HIP 70245, SpT M) was initially observed by chance by two of us (JMGF & EGM) as part of another program, using a Starlight Xpress CCD camera with a Sony ICX027B chip and a Johnson V filter on two 6-cm refracting finder telescopes at Mollet and Esteve Duran Observatories. The Esteve Duran data were adjusted

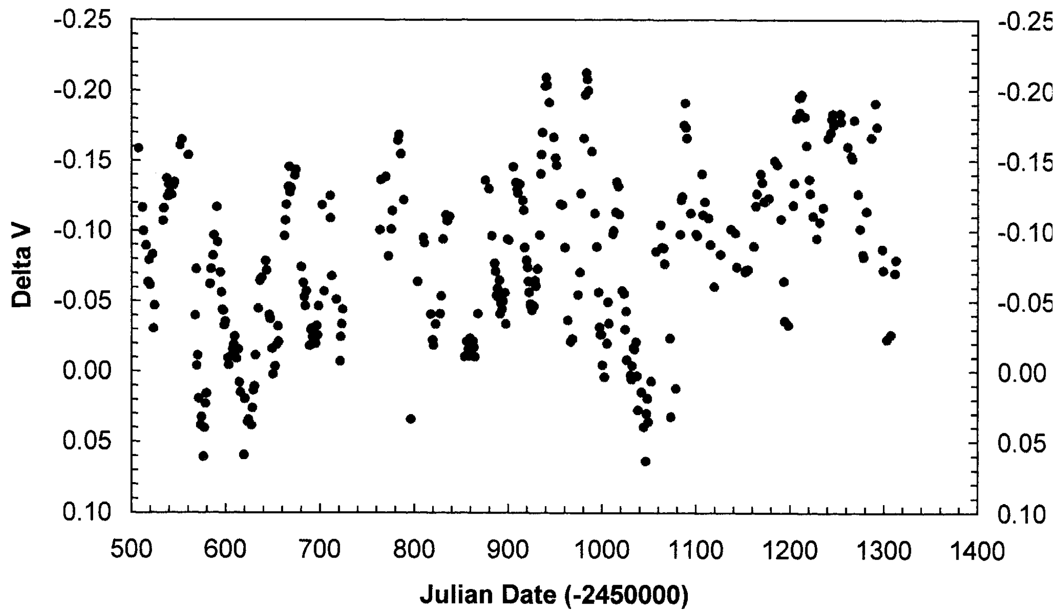

Figure 1. Differential V light curve of SX UMi, relative to HD 126048 ($V = 8.21$)

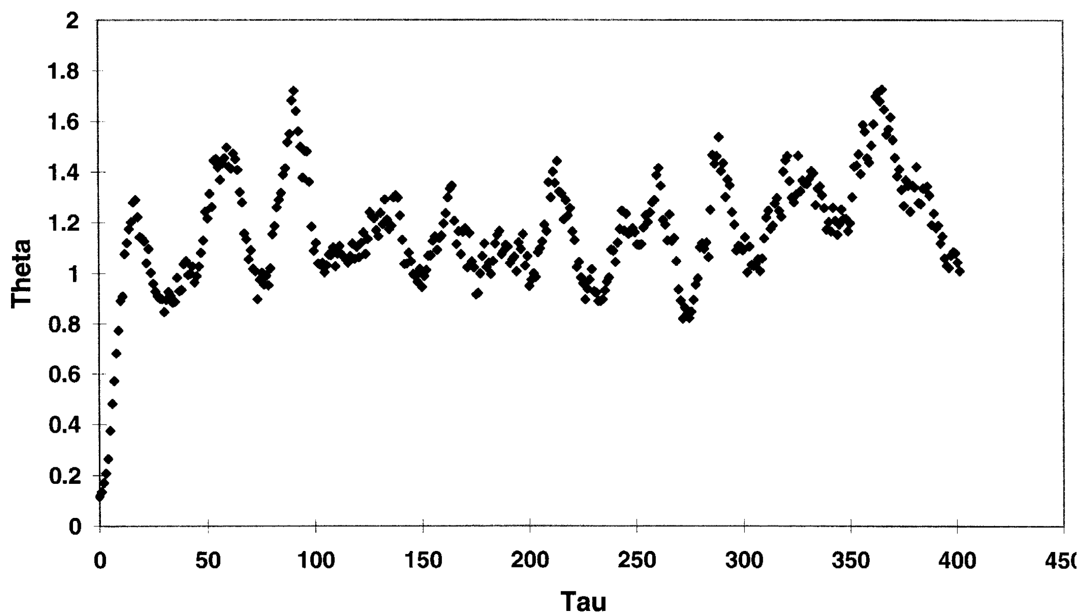

Figure 2. Autocorrelation diagram for the data in Figure 1

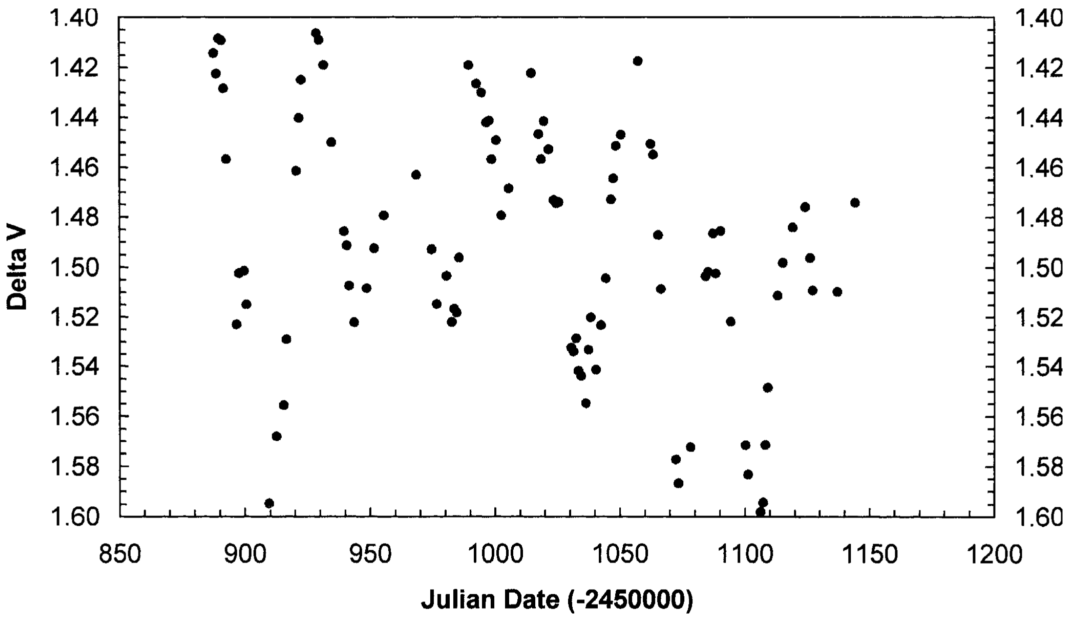

Figure 3. Differential V light curve of HD 190152, relative to HD 190323 ($V = 6.83$)

to match the Mollet data. In subsequent seasons, data were obtained with an 8-cm refractor at Mollet Observatory; no adjustment was necessary for these data. The comparison star was HD 126048 (HIP 70059, SpT K2) for which Perryman et al. (1997) give $V = 8.21$. The check star was HD 125917 (HIP 70006, SpT A3). Although HD 126048 is NSV 06640, Perryman et al. (1997) do not report any variability; the standard deviation is 0.013 (consistent with non-variability in a star of this magnitude); the maxima and minima are 8.35 and 8.39, respectively. Furthermore, our 335 measurements of HD 126048 relative to HD 125917 between JD 2450507 and 2451312 give a mean of +0.013 with a standard deviation of 0.0097, which is consistent with the observational error. We conclude that NSV 06640 was non-variable during the times that we and *Hipparcos* observed it. Synthetic aperture differential photometry was carried out. No correction for differential extinction was necessary, since the comparison stars were within $36'$ of the variable.

HD 190152 (BD+15° 4029, GSC 01617-02068, PPM 137505, SAO 105602, not in the *Hipparcos* catalogue, SpT M) is a previously-unknown variable which was also observed by chance by two of us (JMGF & EGM) as part of another program, using an 8-cm refractor at Mollet Observatory, and the same CCD camera and reduction techniques. The comparison star was HD 190323 (HIP 98788, SpT F8), for which Perryman et al. (1997) give $V = 6.83$, and the check star was HD 190067 (HIP 98677, SpT G5).

Figure 1 shows the differential V light curve of SX UMi, relative to HD 126048 ($V = 8.21$). The mean V is about 8.1. Semi-regular variations, with a cycle-count period of about 35 days and a total range of 0.27 magnitude, are apparent, as are long-term variations in amplitude and mean magnitude. Figure 2 shows the autocorrelation diagram of the data, using the Burki et al. (1978) algorithm. On the horizontal axis, τ is the sideways shift in time; on the vertical axis, θ is the goodness of fit (lower θ indicates better fit). The first two minima give a period of about 38 days, but the shallowness and the distorted appearance of the first and third minima suggest that a second period may also be present. Using all undistorted minima gives a period of 37 ± 1 days. The same data were used as a test of wavelet analysis of SAPRGs (Percy & Kastrukoff 2001), and

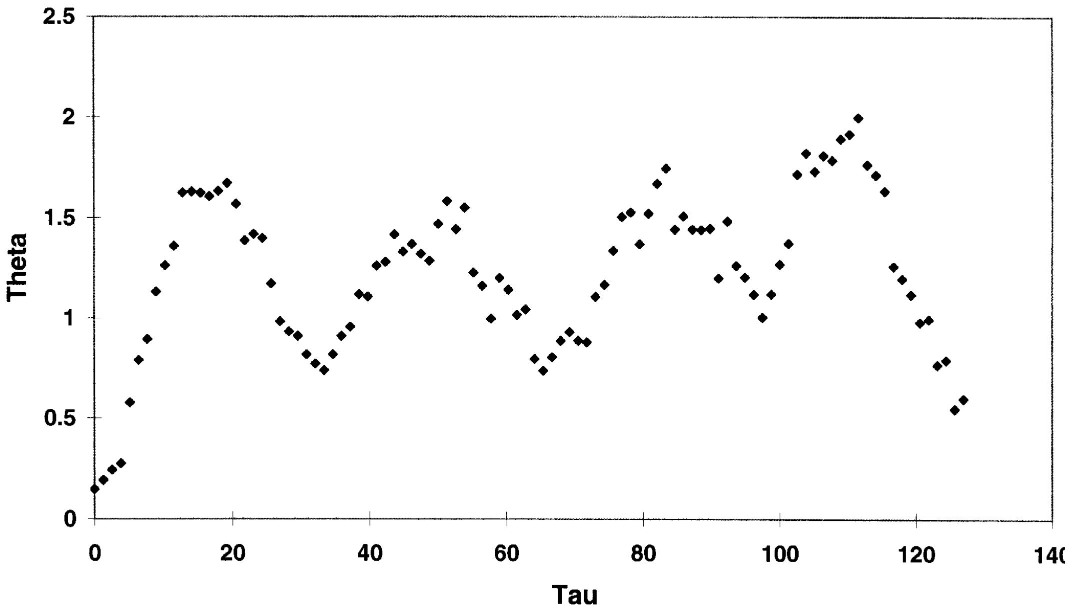

Figure 4. Autocorrelation diagram for the data in Figure 3

gave a mean period of 38 days.

Figure 3 shows the differential V light curve of HD 190152, relative to HD 190323 (V = 6.83). The mean V is about 8.3. Semi-regular variations, with a cycle-count period of 34 days and a total range of 0.2 magnitude, are apparent. Figure 4 shows the autocorrelation diagram of the data in Figure 3, using the Burki et al. (1978) algorithm. The four distinct minima give a period of 32 ± 1 days for this previously-unknown variable.

We conclude that the Burki et al. (1978) algorithm can be useful for autocorrelation analysis of small-amplitude pulsating red giants. We report period determinations, using this algorithm, for SX UMi and HD 190152 — a newly discovered variable.

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