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PERIODS OF ELEVEN K5-M0 PULSATING RED GIANTS

PERCY, JOHN R.[1]; NYSSA, ZOË[1]; HENRY, GREGORY W.[2]

[1] Department of Astronomy, University of Toronto, Toronto ON Canada M5S 3H8, e-mail: jpercy@erin.utoronto.ca

[2] Center of Excellence in Information Systems, Tennessee State University, Nashville TN 37203-3401 USA, e-mail: henry@schwab.tsuniv.edu

About 10 per cent of the naked-eye stars are pulsating red giants (PRGs), with amplitudes ranging from 0.01 to 10 magnitudes. According to Wood (2000), "red giant stars are probably the least understood of all variable stars". The first PRG — Mira — was discovered over 400 years ago. Small-amplitude PRGs, with amplitudes of 0.1 to 1 magnitude, and with early M spectral type, were surveyed by Stebbins & Huffer (1930). In the 1990s, several studies (Eyer & Grenon 1998, Grenon 1993, Jorissen et al. 1997) showed that K5-M0 giants were variable with amplitudes of less than 0.1 magnitude, and these were most likely PRGs. In particular, Henry et al. (2000) studied a large sample of variable K-M0 giants, estimated their variability time scales from the light curves, and presented a strong argument for pulsation as the cause of the variability of the K5-M0 giants. This paper presents the first detailed period analysis of a sample of these ultra-small-amplitude PRGs.

It is still not clear whether the Mira stars are pulsating in the fundamental mode, or in the first overtone. The small-amplitude PRGs appear to be pulsating in higher modes (Percy & Parkes 1998), in agreement with theoretical predications (Xiong et al. 1998). Since the pulsation modes of the ultra-small-amplitude PRGs is therefore of interest, it is important to determine their periods in as many ways as possible. This is because methods such as Fourier analysis have weaknesses (such as the possible occurrence of alias periods if there are periodic gaps in the data) which are not present in other methods such as our form of autocorrelation analysis. Also — many small-amplitude PRGs have a secondary period, an order of magnitude longer than the primary period, so it would be of interest to look for such long periods in ultra-small-amplitude PRGs. Koen & Laney (2000) have recently pointed out that there are about 30 PRGs in the *Hipparcos* Catalogue with periods less than 10 days, whose radii and masses imply that they are pulsating in very high overtones. We believe that these periods are spurious, and due to the aliasing properties of *Hipparcos* photometry (Percy & Hosick, submitted), but this points out the need to do careful period analysis using as many independent techniques as possible.

In the past (Percy et al. 1996), we found that light curves, Fourier analysis, and autocorrelation analysis were useful and complementary tools for studying small-amplitude PRGs. In our autocorrelation algorithm, we calculate the absolute value of Δmag, and

Table 1: Periods of Eleven Ultra-Small-Amplitude Pulsating Red Giants

HD	V mag	Spectral Type	V range	TS	period(s) - days
3346	5.16	M0 III	0.065	11	**11.5**, 15, 22:
84345	8.21	M0 III	0.056	15	**12.4**, 21.5
112975	7.51	M0 III	0.056	7	**6.9**
123232	7.73	M0 III	0.100	12	19.4, 35.7
145895	7.60	M0 III	0.043	10	**9.6**, 6-7:, 70:
155038	7.67	K5 III	0.037	5	**4.8**, 27:
175589	7.30	K5 III	0.041	8	**6.9**, 20:, 40:
196643	7.10	K5 III	0.044	7	7, 15
201298	6.18	M0 III	0.041	12	13, 40:
208530	7.85	M0 III	0.041	15:	**10.4**, 5:, 50:
215427	7.08	K5 III	0.054	30	16, 27:

Δtime for every pair of measurements, and plot the first (averaged in bins) against the second, over an appropriate range of Δtime. Minima occur at multiples of the period or characteristic time scale. Since our algorithm differs from conventional autocorrelation, we shall hereafter use the term *self-correlation* — a term suggested by I. Cummings (1999). It is similar to the "variogram" method described by Eyer & Genton (1999) (Eyer 2001, private communication). Note that our autocorrelation diagram is not a phase diagram, or a power spectrum. We have used this combination of three techniques to analyze new and existing data on 11 stars in Henry et al.'s sample (these authors estimated the periods of these stars by visual inspection of the light curves only). The data were obtained with a robotic telescope, as described by Henry et al., between JD 2450700 and 2451000 (but with a seasonal gap for most stars), except for HD 3346, for which there were four seasons of data, and HD 215427, for which there were three. The number of data points per season ranges from 40 to 180. Data were obtained through both a blue and a yellow filter; both sets of data gave the same period results.

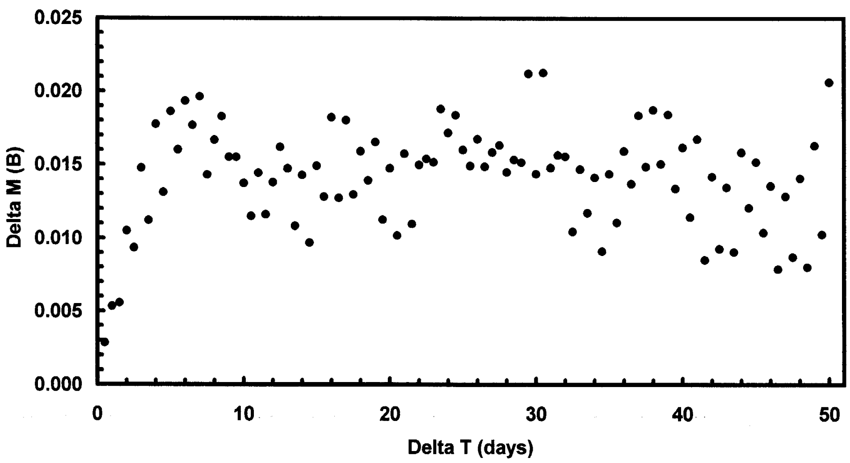

Figure 1. The selfcorrelation diagram for HD 3346. The first maximum (at 5.5 to 7.5 days), and the first minimum (from 11 to 15 days), are consistent with the periods of 11 and 15 days which appear in the power spectrum.

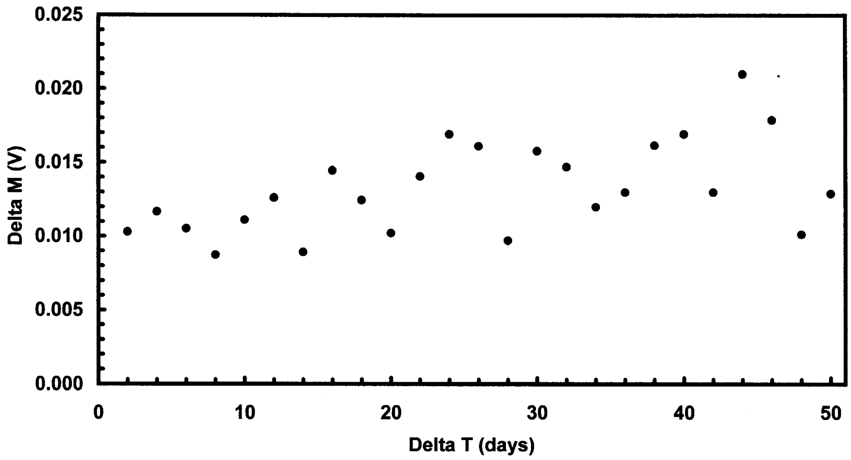

Figure 2. The selfcorrelation diagram for HD 112975. Note the minima at multiples of 6.9 days.

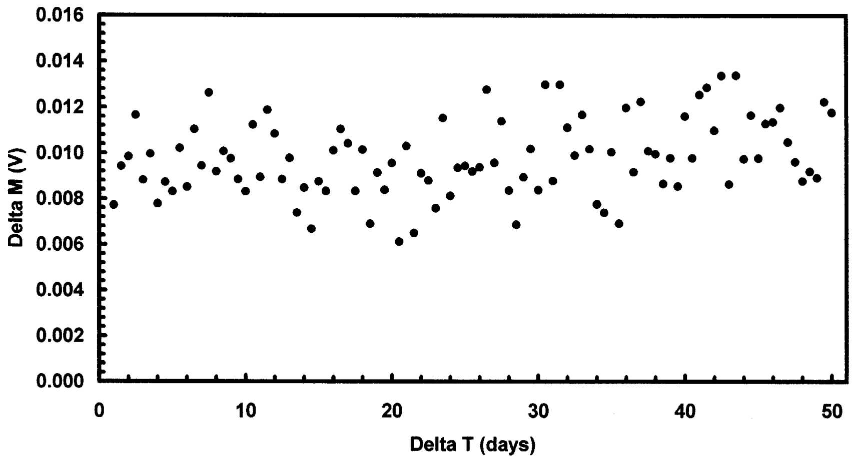

Figure 3. The selfcorrelation diagram for HD 155038. The alternating maxima and minima are consistent with a period of 4.5 days.

Table 1 lists the pertinent information about the stars, and the results. TS is the variability time scale in days found by Henry et al. (2000). The second-last column lists the period(s) determined in this paper. Values in bold face are most secure; those marked with a colon (:) are most uncertain. The following notes apply to individual stars: **HD 3346**: power spectra show an 11.5-day period in each of four seasons, 15-day period in three seasons, and 22-day period in two seasons; selfcorrelation diagram (hereafter *acf*: Figure 1) is consistent with periods of 11.5 and 15 days. **HD 84345**: power spectrum suggests periods of 21.5, 12.4, and 30.5 days, in order of decreasing power; acf is consistent with first two. **HD 112975**: 6.9-day period is conspicuous in the power spectrum and acf (Figure 2). **HD 123232**: visual inspection of the light curve (hereafter LC) suggests about 18-day cycles; power spectrum and acf are consistent with 19.4- and 35.7-day periods. **HD 145895**: 9.6-day period is conspicuous in the power spectrum and acf; power spectrum and LC also suggest a period of 70±10 days. **HD 155038**: a period of

4.8 days is present in the power spectrum and acf (Figure 3). **HD 175589**: periods of 6.9 and 20 days are present in the power spectrum and acf; power spectrum and LC also suggest a time scale of 40 days. **HD 196643**: both power spectrum and acf give a weak signal at 7 and possibly 15 days. **HD 201298**: power spectrum and acf are consistent with a period of 13 days; possibly longer-term variations. **HD 208530**: 10.4-day period is conspicuous in the power spectrum and acf; possible variations on a time scale of 40-50 days. **HD 215427**: power spectrum and acf are consistent with a period of 16 days in each season; possible 27-day period.

Preliminary analysis of another season of data (2000-2001) shows good to excellent agreement, for the stars with well-determined periods (Percy & Nyssa, to be published). Several more seasons of data may be necessary to determine, completely, the periods in these stars (e.g. Percy et al. 1996).

The data are not well suited for looking for long-term variability, but several stars — notably HD 84345, HD 112975, HD 145895, HD 208530 and HD 215427 — show some evidence for variability on time scales of 100 days or more, with amplitudes of a few hundredths of a magnitude.

The results indicate that ultra-small-amplitude PRGs behave as small-amplitude PRGs do: they have one or two periods which are consistent with radial pulsation periods; they are semi-regular at best; some have longer-term variations with about the same amplitude as the shorter-term variations. Fourier analysis and auto/selfcorrelation analysis are both useful in understanding the behaviour of these stars. We are now in the process of determining the probable pulsation modes in these stars, by determining their pulsation constants (Q-values). Very preliminary results indicate that the ultra-small-amplitude PRGs, like the small-amplitude PRGs, pulsate in the fundamental, first, second, or third overtone.

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