Further Studies of "Irregularity" in Pulsating Red Giants

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Abstract In a previous paper (*JAAVSO* **37**, 2009, p. 71) we used self-correlation to analyze AAVSO visual observations of twenty-three L-type (irregular) pulsating red giants, and found that they exhibited a continuous spectrum of behavior, from truly irregular to semiregular. In this paper, we carry out Fourier analysis of the same stars, partly to investigate whether some of their irregularity might be due to multiperiodicity, and partly to look for evidence of possible spurious periods of one year and one month, due to the methodology of visual observing. We find evidence of such spurious periods in many stars. We have also analyzed an additional seventeen L-type pulsating red giants, using both self-correlation and Fourier techniques. Several show evidence of spurious one-month or one-year periods. Only XY Lyr, VY UMa, and possibly DY Vul and BU Gem show evidence of intrinsic periodicity. Several show little or no variability. The rest vary irregularly on time scales of a few hundred days. We find no evidence that irregularity in L-type variables is due to multiperiodicity.

1. Introduction

Cool red giants are all variable in brightness. They are classified in the *General Catalogue of Variable Stars* (GCVS; Kholopov *et al.* 1985) as Mira (M), semiregular (SR), or irregular (L). In a previous paper (Percy *et al.* 2009, hereinafter Paper 1), we showed, through self-correlation analysis of AAVSO visual observations, that the L-type variables show a spectrum of behavior, from truly irregular to semiperiodic. We also found evidence of a spurious one-year period in some of the stars, presumably due to a physiological phenomenon called the Ceraski effect. In a similar analysis of AAVSO visual observations of T Tauri stars (Percy *et al.* 2010), we found evidence of a spurious one-month period in some of the stars, presumably due to the same effect. The purposes of the present paper are several-fold: (i) to use Fourier analysis to confirm the results of Paper 1; (ii) to investigate whether the irregularity of some of the stars in Paper 1 is due to multiperiodicity, since self-correlation is not well suited for this purpose; (iii) to look for further evidence of spurious one-year and one-month periods in these stars; and (iv) to analyze some additional L-type variables which have sufficient visual observations in the AAVSO International Database. Please see Paper 1 for a more complete introduction to L-type variables.

2. Sources of data

Visual measurements of the twenty-three L-type stars, listed in Table 1 and taken from Paper 1, and of the seventeen L-type stars, listed in Table 2, came from the AAVSO International Database, spanning up to several decades. There are dozens of L-type red giant variables in the database but, for most of them, the data are sparse. Richard Kinne, AAVSO Headquarters, kindly provided us with a list of L-type stars in the database, listed in order of decreasing number of observations. The numbers of observations of the stars in Table 2 range from 19,863 (VY UMa) down to 3,642 (CT Del). The lengths of the datasets are typically 20,000 days.

The precision of visual measurements is known to be about 0.2 to 0.3 magnitude. The intercept on the vertical axis of the self-correlation diagram (e.g. Figure 1, top) is a measure of the average precision of the measurements and, for the stars in our samples, is consistent with the estimate above.

3. Analysis

Self-correlation is a simple method of time-series analysis that determines the characteristic time scale and amplitude of the variability, averaged over the dataset. For a discussion of its nature, strengths, and weaknesses, see Percy and Mohammed (2004) and references therein, and for its application to the present project, see Paper 1. Self-correlation analysis also provides a "profile" of the variability—the amount of variability as a function of time scale. As indicated in Paper 1, our self-correlation software and manual are publicly available. Fourier analysis was carried out using PERIOD04 (Lenz and Breger 2005).

4. Results

Figure 1 shows a sample self-correlation diagram and PERIOD04 Fourier spectrum. See Paper 1 for other examples of self-correlation diagrams of L-type variables. The results of the present paper are summarized in Tables 1 and 2. The columns in Table 1 give: the star name, the spectral type (generally from SIMBAD), the period(s) determined in Paper 1, and comments about the occurrence of spurious periods. Please see Paper 1 for more information about these stars.

There are no stars in Table 1 for which the Fourier spectrum contains two or more significant periods which might indicate multiperiodicity. By "significant," we mean having a signal-to-noise ratio greater than 3.

In Table 2, the columns give: the star name, the spectral type, the self-correlation Δ mags at 0 and 1,000 days, and comments. The value of Δ mag. at 0 days is a measure of the average observational error; it ranges from 0.21 to 0.38.

The difference between the Δ mags at 0 and 1,000 days is a measure of the amount of true variability on time scales less than 1,000 days.

In the "comments" column: Y and M indicate the presence or possible presence of a spurious period of one year or one month. Over half of the stars show a possible one-month signal, and over half show a possible one-year signal. Specifically: the following stars show a signal or suspected signal at a period of one year: SV Aur, RT Car, IZ Cas, AD Cen, DM Cep, XY Lyr, T Cyg, SV Cyg, V449 Cyg, CT Del, and WY Gem. The following stars show a signal or suspected signal at a period of one sidereal month: RT Car, AD Cen, DM Cep, W CMa, T Cyg, SV Cyg, CT Del, and BU Gem.

Four stars show a phenomenon that we have occasionally seen in the self-correlation diagrams of other stars: very weak minima at Δt of 200, 550, and 900 days: W CMa, WY Gem, TX Psc, and DY Vul. The amplitudes, however, are less than 0.02 magnitude. We suspect that this is a spurious effect—the Ceraski effect or something similar—somehow related to the lengths of the seasons, and of the seasonal gaps.

The following stars show less than 0.03-magnitude variability on time scales of up to 1,000 days, according to the self-correlation diagrams: SV Aur, IZ Cas, AD Cen, DM Cep, V449 Cyg, WY Gem, and TX Psc.

The only stars that appear to have a genuine period are: XY Lyr (121.6 days), VY UMa (121.8 days), and possibly DY Vul (95 days), and BU Gem (2,000 days). The amplitudes, in each case, are only 0.02 to 0.03 magnitude. The self-correlation diagram of SV Cyg shows some evidence for a low-amplitude period of 230 days, but it is not present in the Fourier spectrum.

The other stars show no repeating minima in the self-correlation diagram, only a profile that rises smoothly from Δt = 0 to Δt = a few hundred days or beyond. These stars are variable but truly irregular. As with the stars in Table 1, there are no stars which have two or more significant periods in the Fourier spectrum, which might be indicative of multiperiodicity.

None of the stars in Table 2 show evidence of long secondary periods, which are an order of magnitude longer than the pulsation periods (Nicholls *et al.* 2009), though most of the stars show some low-frequency (long period) noise.

5. Discussion and conclusions

Many stars in Tables 1 and 2 show signals at periods of one year and one sidereal month. As discussed by Percy *et al.* (2009, 2010), these are spurious, and due to the Ceraski effect, a physiological effect which results from the technique of visual observing. The stars are observed at different times of night during the year and month, and therefore in different orientations relative to the horizon. When the stars with and without this effect are plotted on the sky, there is no apparent pattern.

Several stars in Table 2 show only marginal variability, on time scales of 0 to 1,000 days, and are candidates for removal from the AAVSO visual observing program. Many of the stars in both Tables are "orphans," in that they have not been studied or classified in detail, and have been observed relatively sparsely. There are dozens of other L-type stars in the AAVSO International Database which have been observed even less frequently. Analysis of these stars may not produce meaningful results, but it would be worth doing in any case. It might reveal a few stars of special interest. For the rest, it would confirm that there is no particular need to continue observing them.

There are no irregular variables in Table 1 or 2 which show two or more significant peaks in their Fourier spectrum, which would be an indication of multiperiodicity. Thus there is no evidence that multiperiodicity causes some or all of the irregularity in these stars. For most of these stars, the amplitudes are small, and the irregular variability may be due to the effects of random convection cells and/or a complex mixture of low-level radial and non-radial pulsation modes.

Even for stars which show no minima, it is possible to define a characteristic time scale on the basis of how fast the self-correlation diagram rises to its plateau, i.e., by comparing the rise to plateau with the rise to first maximum in a star that is periodic. To a first approximation, the time scale would be of the order of the value of Δt at which the diagram reached the plateau. The characteristic time scales, for the stars in Tables 1 and 2, are several hundred days.

The analysis of the stars in Tables 1 and 2 supports the main conclusion of Paper 1: L-type variable red giants show a continuous spectrum of behavior, from irregular, to marginally periodic, to semi-periodic. The analysis also shows the value of systematic, long term visual observations of variable stars, especially those which are not periodic, or which may have long term variability.

6. Acknowledgements

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References

Kholopov, P. N. *et al.* 1985, *General Catalogue of Variable Stars*, 4th Edition, Moscow.

Lenz, P., and Breger, M. 2005, *Commun. Asteroseismology*, **146**, 53.

Nicholls, C. P., Wood, P. R., Cioni, M. -R. L., and Soszynski, I. 2009, *Mon. Not. Roy. Astron. Soc.*, **399**, 2063.

Percy, J. R., and Mohammed, F. 2004, *J. Amer. Assoc. Var. Star Obs.*, **32**, 9.

Percy, J. R., Esteves, S., Lin, A., Menezes, C., and Wu, S. 2009, *J. Amer. Assoc. Var. Star Obs.*, **37**, 71.

Percy, J. R., *et al.* 2010, *J. Amer. Assoc. Var. Star Obs.*, submitted.

Table 1. Self-correlation analysis of L-type variables.

Star	*Spectrum*	*Period*	*Comments*
U Ant	C5,3(NB)	350, 2000	—
V Aps	MB	irr.	—
VW Aql	M5III:D	800	M
UX Cam	M6	1000	—
AA Cas	M6III: D	75	—
PY Cas	M5III: D	irr.	M:
WW Cas	C5,5(N1)	irr.	—
ST Cep	M3Iab:C	300-400	—
AT Dra	M4IIID	333, 4000	M:, Y:
UW Dra	K5pvC	360 (?)	Y
GN Her	M4IIID	irr.	—
OP Her	M5II-IIIC	75, 650	—
TT Leo	M7D	irr.	Y:
HK Lyr	C6,4(N4)	250	Y:, M
T Lyr	C6,5(R6)	400	Y:, M
TU Lyr	M6	150	Y:, M
X Lyr	M3.5III:D	200, 6500	M
TY Oph	C5,5(N)	irr.	—
EX Ori	M7III	100, 500	—
ST Psc	M5D	700	—
t4 Ser	M5II-III	100, 1200	M
CP Tau	C5,4(N)	1250	M
X Tra	C5,5(NB)	500	Y:

Note: In Comments field, Y *or* M *indicates the presence or possible presence of a spurious period of one year (Y) or one month (M).*

Table 2. Time-series analysis of 17 additional L-type variables.

Star	*Spectrum*	*Δm(0)*	*Δm(1000)*	*Comments*
SV Aur	M1	0.22	0.23	Y
RT Car	M2Iab:	0.30	0.39	Y, M
IZ Cas	K8	0.33	0.36	Y, no M
AD Cen	K3(II)-M3e	0.21	0.23	Y, M:
DM Cep	M3D	0.32	0.35	Y:, M:
W CMa	C6,3(N)	0.38	0.44	M
T Cyg	KIIIC	0.22	0.30	Y:, M:
SV Cyg	C5,5-C7,4(N3)	0.38	0.45	Y:, M:
V449 Cyg	M1-4	0.23	0.26	Y
CT Del	M7	0.31	0.36	Y:, M:
BU Gem	M1-2Ia-Iab	0.27	0.37	M
WY Gem	M2epIab + B	0.26	0.28	Y:, no M
XY Lyr	M4-5Ib-II	0.23	0.29	no M
BL Ori	C6,3(Nb,Tc)	0.28	0.36	
TX Psc	C7,2(N0,Tc)	0.26	0.28	M
VY UMa	C6,3(N0)	0.27	0.29	no Y, M
DY Vul	M3-6	0.24	0.28	no M

Note: In Comments field, Y *or* M *indicates the presence or possible presence of a spurious period of one year (Y) or one month (M).*

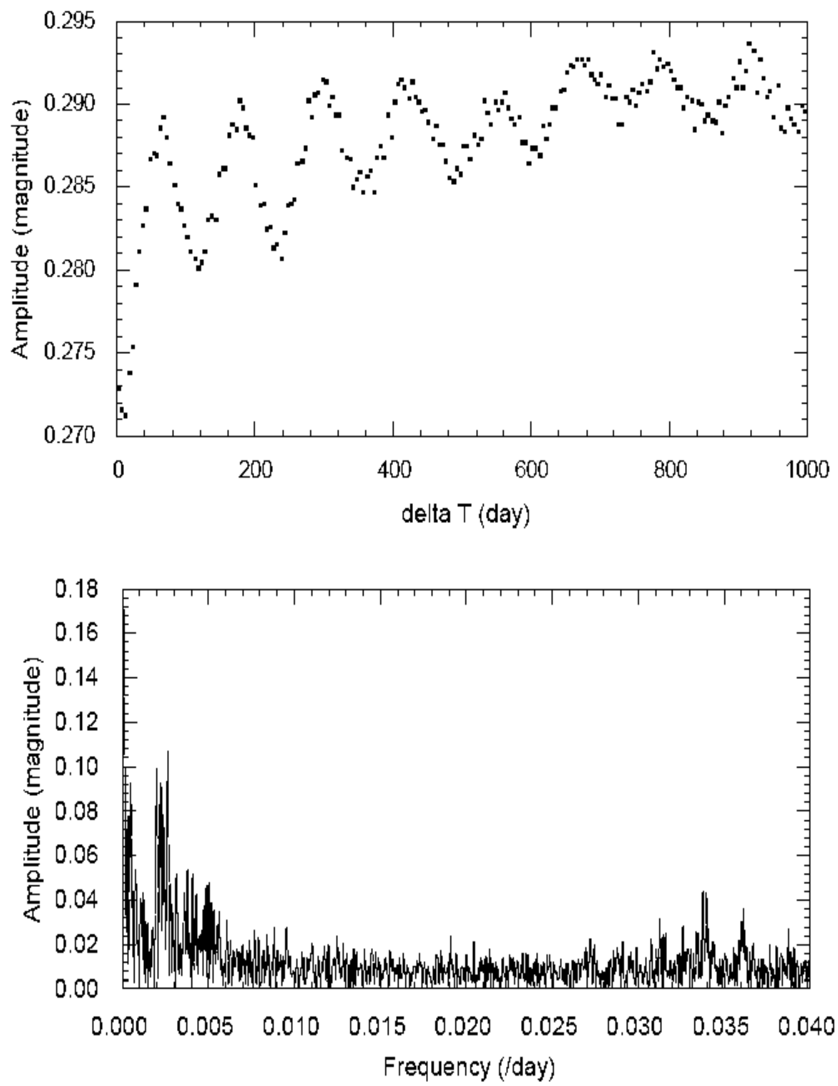

Figure 1. Top: self-correlation diagram for VY UMa, showing minima at multiples of 121.8 days, the period. Bottom: the PERIOD04 Fourier spectrum for RT Car, showing spurious periods at one year (f = 0.00274) and one sidereal month (f = 0.0366), but no periods that are intrinsic to the star.