Asymptotic Giant Branch Stars
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Multiperiodicity in semiregular variables

L.L. Kiss & K. Szatmáry

Department of Experimental Physics and Astronomical Observatory, JATE University, Szeged, Dóm tér 9, H-6720 Hungary

Abstract. We present a detailed period analysis for 98 red semiregular variables by means of Fourier and wavelet analysis of long-term visual observations carried out by amateur astronomers. The overwhelming majority of the studied stars show multiperiodic behaviour. We found two significant periods in 62 variables, while there are definite signs of three periods in 13 stars. 20 stars turned out to be monoperiodic with small instabilities in the period. Since this study deals with the general trends, we want to find only the most dominant periods.

The distribution of periods and period ratios is examined in the ($\log P_1, \log P_0/P_1$) plots. Three significant and two less obvious sequences are present which can be explained as the straight consequence of different pulsational modes. This hypothesis is supported by the multiperiodic variables with three periods. A clear distinction between C-rich and O-rich stars has been found in these diagrams suggesting a connection between the chemistry and pulsational characteristics.

1. Introduction

Mira and semiregular variables (SRVs) are pulsating low and intermediate mass red giants located on the asymptotic giant branch (AGB). The importance of these variables is highlighted by the fact that they are primary sources of the diffuse interstellar matter. The observed pulsational behaviours may lead to a better understanding of inner physical processes having crucial effects on the stellar evolution.

SRVs have amplitudes smaller than 2.5 mag. in V, while typical periods range from 25 to hundreds of days. Their basic properties (classification, temperature, luminosity, space distribution, important spectral features) were studied in a series of papers by Kerschbaum and his collaborators (e.g. Kerschbaum & Hron 1992, Kerschbaum & Hron 1994, Kerschbaum & Hron 1996). There has been an increasing evidence for a close relationship between the SRVs and Miras. Kerschbaum & Hron (1992, 1994) claimed that some stars are more closely related to Miras than the pure classification suggests. Szatmáry et al. (1996) found V Boo to have a dramatically decreasing amplitude over decades of time mimicking evolution from Mira to semiregular state. A similar phenomenon was found by Bedding et al. (1998) for R Dor, which implies that long period semiregulars may be a subset of Mira variables.

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A detailed review on the mode of pulsation is given by Percy & Polano (1998), who showed that higher overtone pulsation is suggested by the observations (up to the third and fourth overtone). Wood (1998) presented 5 different period-luminosity sequences for the LMC red variables based on the MACHO photometric database, concluding similarly to Percy & Polano (1998) that even third and fourth overtones could be the dominant excited modes. Bedding et al. (1998) claim that the observed mode switching in R Dor occurs between the first and the third overtone. All these studies strengthen the idea that fundamental and first overtone pulsation in SRVs is an oversimplified assumption and the complex light variations may be due to many simultaneously excited modes.

The main aim of this study is to present a detailed light curve analysis for 98 SRVs based on long-term visual observations. The basic intention is to call for attention by demonstrating the general trends and the most interesting phenomena. A similar analysis was done by Andronov (1998).

2. Observations

The bulk of the analysed data were taken from three international databases of visual observations. These belong to the Association Française des Observateurs d'Etoiles Variables (AFOEV[1]), the Variable Star Observers' League in Japan (VSOLJ[2]) and the Hungarian Astronomical Association – Variable Star Section (HAA/VSS[3]).

The main selection criterion in choosing the sample was the length and the continuity of the light curves. In order to reach high resolution in the frequency domain, we usually kept only those stars with at least 10 years long data series. This corresponds to a frequency resolution ($\sim$length^{-1}) of $2.7 \cdot 10^{-4}$ cycles/day. But the usual length of the analysed data is about 50 years, occasionally 70-80 years (see the list of stars in Kiss et al. 1998).

In order to decrease the effects of scatter due to visual uncertainties, we averaged the light curves. The averaging procedure consists in taking 10-day bins and calculating the mean value from the individual points. Since the typical time scale in the sample of semiregular variables is about one hundred days this binning procedure does not smooth too much the light variations. A rough estimate of the resulting improvement in precision is as follows. The error of an individual observation is about ± 0.3 mag. For a given 10-day bin with 10 points within it, the standard error of the mean value will be $0.3/\sqrt{10} \approx 0.1$ mag. The amount of data and their distribution in our sample in most cases enable such precision. We have to mention that extremely deviant points in the original data were rejected during a close visual inspection at all light curves.

Two tests were made to check the reliability of the resulting mean light curves. The first is a comparison with available simultaneous photoelectric V-measurements. Although the spectral response function of the human eye differs

[1] `ftp://cdsarc.u-strasbg.fr/pub/afoev`

[2] `http://www.kusastro.kyoto-u.ac.jp/vsnet/gcvs`

[3] `http://www.mcse.hu/vcssz/data`

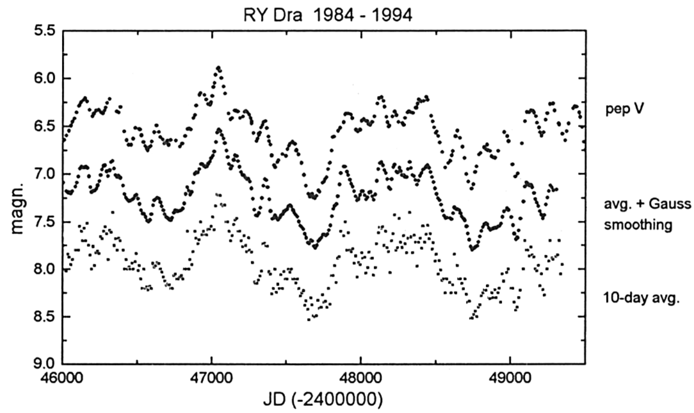

Figure 1. Comparison between the photoelectric and visual observations for RY Dra. See text for further explanation.

from the Johnson V filter, there were several attempts to calibrate the transformations. Stanton's (1981) formula is: $m_{vis.} = V + 0.182\ (B - V) - 0.15$. According to the available photoelectric observations of semiregular variables, their $B - V$ colours change with much smaller amplitudes than the V brightnesses do, thus it is a straightforward simplifying assumption that there is a constant shift between the photoelectric V and visual light curves. This is, of course, true only at a level of about 0.1 mag., which is in the range of the scatter of visual data.

A direct comparison is shown in Fig. 1 where we plotted visual data of RY Dra with simultaneous photoelectric V-measurements carried out by R.R. Cadmus (personal communication). The top curve is the photoelectric one, while the bottom curve is the corresponding 10-day mean of visual data. The middle curve is a noise filtered version of the lower curve, where noise filtering was done by a simple Gaussian smoothing with 8 days FWHM. Note, that while the visual curves were shifted in vertical direction for clarity, the distance between the smoothed visual and the photoelectric curves is the real difference caused by the colour effects. The observed average shift of 0.60 mag. is in good accordance with the predicted 0.44 mag. by Stanton's formula ($\langle B - V \rangle \approx$ 3.3 for RY Dra). The agreement between the visual and photoelectric curves are very good. A similar conclusion can be drawn using HIPPARCOS Tycho-V data (ESA 1997[4]): visual observations define light curves highly parallel to the photoelectric ones.

The second test was similar to that of Szatmáry & Vinkó (1992). We analysed artificial triply periodic data which simulated the typical observations: a 16 000 days long time-series with Gaussian noise added in order to adjust the signal-to-noise ratio to be about 100 and 1. Original periods and amplitudes could be determined with high accuracy even from the low quality data suggesting that the length of data is much more important than the actual S/N ratio.

[4]http://astro.estec.esa.nl/Hipparcos

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3. Results

We calculated Discrete Fourier Transforms (DFT) of the finally adopted time-series. We did not try to extract as many periods as possible from the power spectra because the excited frequencies in semiregular variables are not so stable over time (see e.g. Mattei et al. 1998). The DFT may contain many peaks due to the cycle-to-cycle variations, therefore accepting those false peaks would be misleading. Our approach was to accept only the highest and most significant periodicities which were tested by whitening, cleaning and alias filtering. One-year alias peaks occur in many stars, while in some cases cross-production terms are present too (e.g. $f_0, f_1, f_0 \pm f_1$). We did an iterative period determination, where we checked the consistency of the fitted harmonics with the light curve itself after every step.

Among the studied 98 semiregulars we have found 20 purely monoperiodic stars and 62 stars with unambiguous multiperiodic behaviour (49 bi- and 13 triperiodic). We did not find any peak higher than the calculated noise level in 16 variables. We present the triply periodic SRVs in Table 1 with the determined periods and their amplitudes. The period uncertainty was estimated from the width of the peaks in the spectra at 90% of maximum. It has to be noted, that amplitude values have smaller significance because of the instability of the periods. This aspect was studied by wavelet analysis, which is a useful tool for studying temporal variations in the frequency content (see e.g. Bedding et al. 1998, Barthès & Mattei 1997, Szatmáry et al. 1996, Gál & Szatmáry 1995). Therefore, the actual amplitude values listed in Table 1 have only informative meaning about the relative strength of the periodicities found.

Table 1. Triply periodic variables. ΔT is the length of the analysed time series in days.

Star	$\langle m \rangle$	ΔT	P_0	A_0	P_1	A_1	P_2	A_2
U Cam	8.2	26800	2800(100)	0.13	400(30)	0.09	220(5)	0.09
RS Cam	8.7	25000	966(10)	0.17	160(1)	0.15	90(1)	0.12
ST Cam	7.3	28000	1580(10)	0.10	372(3)	0.12	202(2)	0.08
X Cnc	6.7	25800	1870(10)	0.08	350(3)	0.08	193(1)	0.09
Y CVn	5.7	28500	3000(100)	0.08	273(3)	0.06	160(2)	0.05
AF Cyg	7.2	26600	921(10)	0.08	163(1)	0.11	93(1)	0.11
TX Dra	7.6	26800	706(2)	0.10	137(1)	0.06	77(3)	0.07
UW Her	8.1	8600	1000(10)	0.09	172(1)	0.08	107(1)	0.09
Y Lyn	7.5	8500	1300(50)	0.41	611(10)	0.13	134(2)	0.12
Y UMa	8.6	32000	324(1)	0.16	315(1)	0.09	164(2)	0.06
RX UMa	10.6	33200	201(1)	0.37	189(1)	0.26	98(0.5)	0.16
V UMi	8.1	29000	737(10)	0.06	126(2)	0.04	73(0.5)	0.06
SW Vir	7.6	8500	1700(50)	0.15	164(1)	0.13	154(1)	0.20

In order to examine the general distribution of the obtained periods, we made pairs of periods in 62 multiperiodic variables and plotted the period ratios against the shorter periods in Fig. 2. Three very significant sequences can be

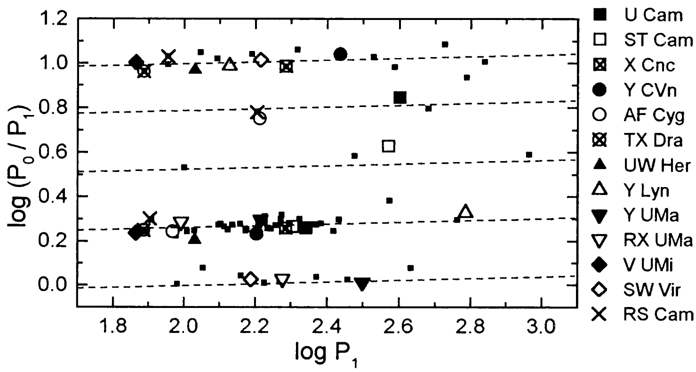

Figure 2. The Petersen diagram for all multiperiodic semiregulars. Triply periodic variables are plotted separately.

seen while two others may also occur. All of them are marked by dashed lines which were drawn as follows. We fitted a least-square linear trend to the most populated sequence and shifted that line to match the other sequences. It is very interesting how parallel these ridges are. One would expect such a separation between stars pulsating in different modes, assuming that the periodicities are due to pulsation. The most populated region contains stars with period ratios between 1.80 and 2.00. Mattei et al. (1998) pointed out that in their sample 63% of the multiperiodic stars (19 out of 30) fall in that range. Our larger sample supports this result very well, as 40 of 62 stars have period ratios around 1.90 ± 0.15 (65%).

The upper sequence in Fig. 2 is populated by stars with period ratios around 10. This is a well-known period ratio for semiregulars (e.g. Houk 1963, Percy & Polano 1998). The intermediate ratios were not discussed in the earlier papers, although they are present in the observational data to a smaller extent (see Figure 6 in Mattei et al. 1998).

The assumption of different modes can be tested with the triply periodic variables. The fact that their period ratios fit very well the five sequences is a supporting evidence. Recently, Bedding et al. (1998) have studied the mode switching in R Dor ($P_{long}/P_{short} = 1.81$), where they conclude that it probably pulsates in the first and third overtones. Furthermore, they suggest that all stars with similar period ratios do pulsate in the same modes. Wood et al. (1998) presented multiple structures in a diagram similar to Fig. 2 for the LMC red variables and again higher modes than fundamental and first overtone were suggested. We have to note that other possible explanations could not be excluded, as quasi-periodic cycles might be caused by other physical mechanisms than pulsation (e.g. duplicity, rotation, dust-shell dynamics).

We have tried to find connections between the periods, period ratios and several main physical properties, such as the infrared JHKL'M colours (Kerschbaum & Hron 1994), galactic latitude, mass-loss rates. Eventually no correlation has been found with these parameters. What we found is that there is a clear distinction between the O-rich and C-rich variables. Two regions can

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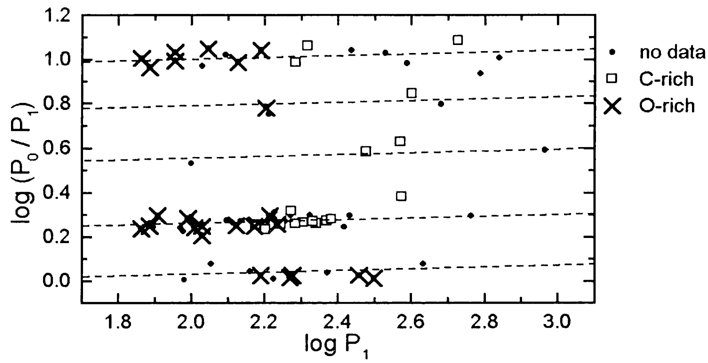

Figure 3. C-rich and O-rich occupy different regions in the Petersen diagram with quite narrow border around $P_1 \approx 160$ days.

be defined according to occurrence of stars with different abundances. There is no C-rich star in the lowest sequence while the border between the two types is quite narrow, centered around $P_1 \approx 160$ days. Therefore, there is likely some connection between the chemistry and pulsation which needs further theoretical investigation.

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