Period Analysis of AAVSO Visual Observations of Semiregular (SR) Variable Stars. II

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Received October 26, 2012; revised January 8, 2013; accepted January 8, 2013

Abstract We have used visual measurements from the AAVSO International Database, and Fourier and self-correlation analysis to study the periodicity of 44 pulsating red giants, classified as semiregular: 16 SR, 15 SR:, 12 SRb, and one misclassified RV:. Within each of the three groups, the average degree of periodicity (or regularity) is about the same and there is a wide variety of behavior, from irregular to highly periodic. About a dozen stars show definite or possible double-mode pulsation, and half a dozen show evidence of a long secondary period.

1. Introduction

Pulsating red giants are classified in the *General Catalogue of Variable Stars* (GCVS; Kholopov *et al.* 1985) as Mira (M) variables if their visual amplitude is greater than 2.5 magnitudes, and semiregular (SR) or irregular (L) variables if their visual amplitude is less than that value. SR variables are subdivided into SRa and SRb (both giants), where SRb have less obvious periodicity than SRa, and SRc (supergiants). Percy and Terziev (2011, and references therein) described time-series analysis of AAVSO visual measurements of L-type pulsating red giants. Percy and Tan (2013) carried out a study of 55 SR variables—21 SRa and 34 SRb—using visual measurements from the AAVSO International Database (AID). They found that their behavior ranged from highly periodic to irregular. They used self-correlation analysis to define a simple index *k* of periodicity. Based on this index, the SRa variables were slightly more periodic than the SRb variables, but the distributions of *k* overlapped considerably. Of the 55 stars, 11 showed or possibly showed two radial periods, and at least 16 showed or possibly showed a long secondary period, an order of magnitude longer than the primary period.

This paper extends that study to a dozen more SRb variables, and to 31 which are classified as SR or SR:. We chose stars from a version of the old AAVSO Validation List, dating from a few years ago. We used the AAVSO Light Curve Generator to assess whether there was a sufficient number, distribution, and length of measurements for time-series analysis to be meaningful.

2. Data and analysis

We used visual observations of 44 SR variables in the AID, as listed in Table 1. We chose stars which had sufficient measurements but which had not been studied by Kiss *et al.* (1999) or Percy and Tan (2013). In fact, our star list inadvertantly included three stars which had been analyzed by Kiss *et al.* (1999), but this was useful because it provided a random check on the results. Note also that our datasets are over a decade longer than those of Kiss *et al.* (1999). Our list also included four stars which had been observed and analyzed by Tabur *et al.* (2009), a 5.5-year high-precision CCD photometric study of 261 nearby pulsating red giants. See section 3.1 for notes on these stars in common.

We used Fourier analysis and self-correlation analysis; see Percy and Tan (2013) and Percy and Mohammed (2004) for further information about the latter technique. For Fourier analysis, we used the AAVSO's TS software rather than PERIOD04, which we used in our previous papers. A few stars show low-amplitude variability with a period of one year or one month, which we ascribe to the Ceraski effect (Percy and Terziev 2011), a spurious physiological effect of visual observing.

3. Results

Table 1 gives the name of each star, the GCVS type, the *Variable Star Index* (VSX; Watson *et al.* 2012) period, the average observational error as determined from the intercept on the vertical axis of the self-correlation diagram, the *k* index of regularity as defined by Percy and Tan (2013), the presence or absence of a long secondary period (LSP), and information about the period(s) and amplitude(s) which we have determined. Notes about individual stars are contained in section 3.1. As did Percy and Tan (2013), we have indicated our "recommended" periods in bold face. Figures 1 and 2 show self-correlation diagrams and Fourier spectra for two representative stars, FK Pup and RS Cam. Diagrams for several other representative SR stars are given in Percy and Tan (2013).

The average values of *k* for each of the three types of variable are: 0.45 for SR, 0.43 for SR:, and 0.41 for SRb, that is, not significantly different. Percy and Tan (2013) obtained an average *k* value of 0.53 for their SRb stars. In each group, the *k* value ranges from 0.00 (irregular) to 0.8 or higher—distinctly periodic. Each group thus contains stars of a wide variety of regularity types.

3.1 Notes on individual SR stars

BI And There are periods of 165 and 288 days; the former is consistent with the VSX period of 159.5 days.

T Cae There are no obvious periods; the VSX period of 156 days is not apparent.

RS Cam There are periods of 90 and 160–170 days; the first is consistent with the VSX period of 88.6 days. There is also a very weak period of about 1,000 days which may be an LSP. Kiss *et al.* (1999) obtained periods of 966 (0.17), 160 (0.15), and 90 (0.12) days; the numbers in parentheses are the visual amplitudes, in good agreement with our results.

UV Cam There is a one-year period, with an amplitude of only 0.01, which is almost certainly spurious, and due to the Ceraski effect. There is also a possible LSP.

UW Cam There is a 530 ± 10-day period, which is consistent with the VSX period of 544 days.

VZ Cam The VSX period of 23.7 days may be present but, if so, the amplitude is less than 0.01 magnitude. Tabur *et al.* (2009) found several periods, none equal to 23.7 days.

AI Cam There is a period of 186 days, in good agreement with the VSX period of 187.5 days.

X Cnc There are periods of 193 and 371 days; the former is consistent with the VSX period of 180 days.

RT Cnc There is a weak period of about 90 days, which is consistent with the VSX period of 90.04 days. Kiss *et al.* (1999) found periods of 1,870 (0.08), 350 (0.08), and 193 (0.09) days; the numbers in parentheses are the visual amplitudes.

BC CMi There is a period of about 363 days; the amplitude (0.07) is a bit large for it to be a spurious (Ceraski effect) period. There is a probable 4,500-day LSP. The VSX period of 35 days, if present, has an amplitude less than 0.01. Tabur *et al.* (2009) found periods of 27.7, 143.3, and 208.3 days. This suggests that our 363-day period may be spurious.

AC Car The data are scattered, and the results uncertain, but there do not appear to be any significant periods; in particular, the VSX period of 99: days does not appear to be present.

V393 Cas There is a possible one-year period (probably spurious), but the amplitude is only 0.01 magnitude.

RS Cet There is a possible 250-day period but the amplitude is only 0.035 magnitude.

V1805 Cyg There is a period of 104 days, and possibly one of 55 days, and very possibly an LSP of 750 days.

LV Del This star is classified as RV: but the colors are indicative of a pulsating red giant. It has no visual measurements, but we analyzed about 60 V measurements. There are suggestions of periods of 9 and 100 days.

BG Dra There is a coherent period of 180.5 days.

BF Eri The data are sparse, and the results uncertain. The VSX period of 198 days does not appear to be present. The most likely period is 29 days.

Y Gem There are periods of 148 and 290 days; the VXS period is 160: days.

BQ Gem There are possible periods of 950 days, and half this value, but the amplitude is only 0.03 magnitude.

V566 Her The star is essentially non-variable.

RT Hya The 254-day period is not inconsistent with the VSX period of 245.5 days, but our results definitely favor the longer period. Kiss *et al.* (1999) obtained a single period of 255 days, with a visual amplitude of 0.20, in good agreement with our result.

AK Hya There is a period of 389 days; the VSX period of 75 days is not present in our data. Tabur *et al.* (2009) obtained periods of 78.6, 88.7, and 133.7 days.

HM Lib There is a period of 363.4 days, which is close to one year, but the amplitude seems too large for this to be a spurious (Ceraski) effect.

SV Lyn There is a period of 64.4 days, which is consistent with the VSX period of 70: days.

SX Mon There is a period of 400 days in the self-correlation diagram, but that period is not obvious in the Fourier spectrum. The VSX period of 77.67 days does not appear to be present.

EG Mus The results are uncertain; there are possible periods of 25 and 400 days.

CK Ori The star is essentially non-variable.

GP Ori There are periods of 183 and 351 days. The VSX period of 370: days may refer to the latter.

AZ Per There appears to be a period of 200–300 days. The VSX period is 305: days.

V466 Per The data are sparse, and the results uncertain, but there appears to be a 60-day period; there is no VSX period.

R Pic There is a period of 167 days, which is consistent with the VSX period of 170.9 days.

TV Psc There is a weak signal at a period of 50 days (consistent with the VSX period of 49.1 days) but the amplitude is only 0.015 magnitude. Tabur *et al.* (2009) obtained periods of 55.1, 216.5, and 266.7 days.

RT Pup There is a strong one-year period in the Fourier spectrum, but not in the self-correlation diagram; there is a 1,990-day LSP. The VSX period of 100: days does not appear to be present.

FK Pup Data are sparse; periods of 250 and/or 500 days may be present.

T Ret There are periods of 57 and (possibly) 101 days; the former is consistent with the VSX period of 59.7 days.

V4152 Sgr There appears to be a period of 363 days, and the amplitude is a bit too large to be spurious. The VSX period of 20.0 days does not appear to be present.

FG Ser The results are complicated. There seems to be a 370-day period with an amplitude (0.15 magnitude) which is too large to be spurious, and a possible 120-day period.

W Sex A 201-day period is present. There is no evidence for the VSX period of 134 days.

X Sex A period of 205 days is present.

TU Tau A period of 207 days is present, in good agreement with the VSX period of 200.2 days; a period of 416 days may also be present.

RZ UMa There are periods of 147 and 247 days, but no evidence for an LSP. The VSX period of 115 days does not appear to be present.

RR UMi No periods stand out. In particular: the VSX period of 43.3 days, if present, has an amplitude less than 0.01.

X Vel There appears to be a period of about 300 days, but it does not stand out in the Fourier spectrum. There is no evidence for the VSX period of 140 days.

NSV 3043 There are periods of 373 and (possibly) 182 days. The VSX period of 28.4 days does not appear to be present.

4. Discussion

The mean values of *k* for the three classification types are about the same. This amplifies the conclusion of Percy and Tan (2013) that there is much overlap between SRa and SRb types. In other words, the types are only marginally meaningful.

For about 70 percent of the stars in Table 1, our results provide new or improved periods for the stars, and/or information about their amplitudes and possible long secondary periods. Therefore, there is useful science within these archival visual observations!

As Percy and Tan (2013) found in their study, the ratio of the radial periods in double-mode SR stars lies in the range 0.48 to 0.58, being slightly greater for shorter-period stars.

Very few of the stars in Table 1 show long secondary periods (LSPs). This may be partly because the stars in this study are, on average, less studied and less variable than those studied by Percy and Tan (2013); most of these are classified only as SR or SR:. The number and extent of the measurements are also smaller, on average. This makes it more difficult to detect long-term variations which could truly be described as "periodic." The cause of these long secondary periods is presently unknown (Nicholls *et al.* 2009).

As in our previous studies of SR and L variables, using visual observations, we occasionally find low-amplitude periods of about one year, which may be due to the Ceraski effect, a physiological effect which is a result of the visual observing procedure. When the period that we find is of low amplitude and equal to one year, within the errors of determination, it is not possible to be sure whether the period is real or spurious. PEP or CCD observations would help.

There are still some SR variables in the AID with sufficient measurements for analysis—but very few. We have "harvested" most of the variables which are ripe for analysis. Any with fewer observations would be even more challenging to analyze and interpret.

This project, like our previous projects, has three goals: to do useful science with AAVSO data—especially visual data; to provide students such as co-author Kojar with projects which develop and integrate science and math skills; and to show AAVSO observers how their measurements contribute to science and education. We believe that we have succeeded in those goals.

5. Conclusions

We have studied the periodicity of 44 pulsating red giants of types SR, SR:, or SRb, using visual measurements from the AAVSO International Database, and Fourier and self-correlation analysis. We find new or improved periods for most of these stars. For each of the three types, the degree of periodicity ranges from high to nearly none, but is about the same on average for each group. A dozen of the stars show definite or possible double-mode pulsation, and about half a dozen show long secondary periods of unknown cause. The results of this and our previous papers show that there is still significant science to be found in the AAVSO's database of visual measurements.

6. Acknowledgements

We thank the hundreds of AAVSO observers who made the observations which were used in this project, and we thank the AAVSO staff for processing and archiving the measurements. We also thank the referee for useful suggestions. This project was supported by the University of Toronto Work-Study Program. It made use of the SIMBAD database, which is operated by CDS, Strasbourg, France.

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Table 1. Periodicity analysis of AAVSO visual observations of SR variables.

Star	*Type*	*VSXP(d)*	*δv*	*k*	*LSP?*	*Period(s)/Amplitude(s) (days)*
BI And	SR	**159.5**	0.20	0.22	N	165/0.10, 288/0.10
T Cae	SR	156	0.28	0.00	N	none
RS Cam	SRb	**88.6**	0.27	0.69	Y	90/0.15, 160–170/0.05, 1000/0.03
UV Cam	SR:	294:	0.34	0.00	Y?	year/0.02, 7000:/0.05
UW Cam	SR	**544**	0.15	0.62	N	530 ± 10/0.25
VZ Cam	SR	23.7	0.15	0.17	N	none:
AI Cam	SR:	**187.5**	0.10	0.71	N	186:
X Cnc	SRb	180	0.27	0.6:	N	**193**/0.06, **371**/0.08
RT Cnc	SRb	**90.04**	0.32	0.33:	N	90 ± 10/0.02
BC CMi	SRb	35	0.13	0.55	Y?	363(year?)/0.07, 4500:/0.07
AC Car	SRb	99:	0.15	0.00	N	none:
V393 Cas	SR	393	0.19	0.00	N?	year/0.01
RS Cet	SR:	—	0.18	0.00	N?	250:/0.035
V1805 Cyg	SR:	—	0.05	0.59	Y?	**104**/0.1, 55:/0.05, 750/0.03
LV Del	RV:	—	0.05V	—	N?	9:, 100: (V data)
BG Dra	SR:	—	0.14	0.79	N	**180.5**/0.50
BF Eri	SR	198	0.25	0.3:	N	29:/0.1,
Y Gem	SRb	160:	0.28	0.53	N	**148**/0.05, **290**/0.05
BQ Gem	SRb	50:	0.17	0.7:	N	475:/0.03, 950:/0.02
V566 Her	SR:	137	0.20	0.00	N	non-var?
RT Hya	SRb	245.5	0.27	0.79	N	**254**/0.20
AK Hya	SRb	75	0.12	0.43	Y?	**389**/0.05
HM Lib	SR:	—	0.09	0.88	N	**363.4**/0.15
SV Lyn	SRb	70:	0.25	0.00	N	**64.4**/0.04, year/0.03
SX Mon	SR	77.67	0.25	1.00	?	400:/0.1:
EG Mus	SR:	140:	0.30	0.47	N	25:, 120:/0.02, 400/0.10
CK Ori	SR:	—	0.21	0.00	N	non-var?
GP Ori	SR:	370:	0.40	0.83	N?	**183**/0.31, **351**/0.23
AZ Per	SR	**305:**	0.15	0.90	N	200–300/0.1
V466 Per	SR	—	0.25	0.65	N	60:/0.10
R Pic	SR	**168**	0.30	0.67	N	167/0.60
TV Psc	SR	**49.1**	0.17	0.3:	N	50:/0.015
RT Pup	SRb	100:	0.45	0.00	Y	year?, 1990/0.07
FK Pup	SR	502	0.25	0.56	N?	250:/0.15, 500:/0.15
T Ret	SR	**59.7**	0.15	0.33	N	57/0.05, 101/0.05

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Table 1. Periodicity analysis of AAVSO visual observations of SR variables, cont.

Star	*Type*	*VSXP(d)*	δv	*k*	*LSP?*	*Period(s)/Amplitude(s) (days)*
V4152 Sgr	SR:	20.0	0.31	0.36	N?	363(year?)/0.06
FG Ser	SR:	—	0.30	0.43	N	370:/0.15, 120:
W Sex	SR	134	0.35	0.62	N	**201**/0.07
X Sex	SR:	—	0.20	0.68	N	**205**/0.20
TU Tau	SR:	**200.2**	0.50	0.7:	N	207/0.07, 416:/0.06
RZ UMa	SRb	115	0.28	0.29	N	**147**/0.03, **247**/0.05
RR UMi	SR:	43.3	0.18	0.00	N?	none
X Vel	SR	140:	0.35	0.47	N?	year:/0.05
NSV3043	SR	28.4	0.18	0.53	N	182:/0.05, 373/0.05

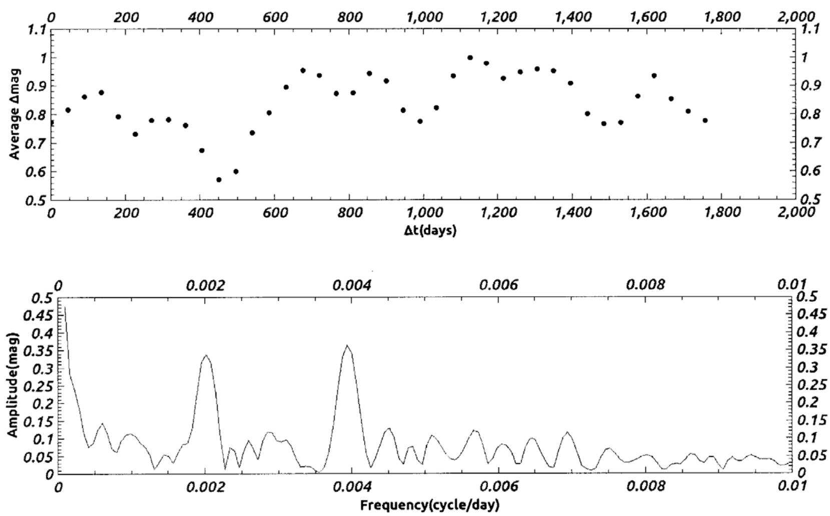

Figure 1. Self-correlation diagram (top) and Fourier spectrum (bottom) for FK Pup. Periods of approximately 250 and 500 days are present, producing the alternating deep and shallow minima in the self-correlation diagram, and the two peaks in the Fourier spectrum. The Fourier spectrum rises at very low frequencies, indicating some very slow variations. The VSX period is 502 days.

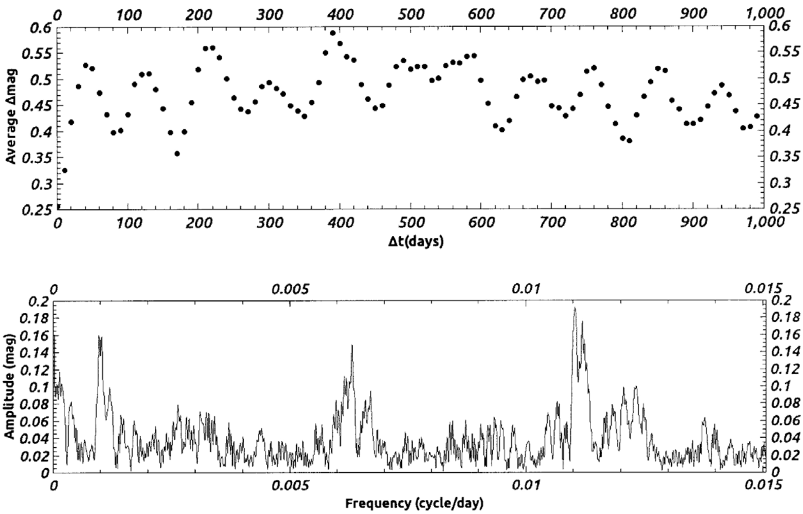

Figure 2. Self-correlation diagram (top) and Fourier spectrum (bottom) for RS Cam. Periods of 90 and 160–170 days are present, producing the alternating deep and shallow minima in the self-correlation diagram, and the two peaks in the Fourier spectrum. There is also a peak at a period of about 1,000 days, which we assume to be a long secondary period. The VSX period is 88.6 days.