ASAS-SN Observations of Long Secondary Periods in Pulsating Red Giants

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Abstract About a third of all pulsating red giants (PRGs) have long secondary periods (LSPs), an order of magnitude longer than their pulsation periods (P). Although LSPs have been known for many decades, their nature and cause are uncertain. We have analyzed data on 45 PRGs, from the All-Sky Automated Survey for Supernovae (ASAS-SN), and combined the results with data from the literature to draw a few new conclusions about this phenomenon. LSPs have V amplitudes of up to 0.45 mag. The ratio LSP/P has a peak at 10 ± 1, and a broader distribution at 7 ± 1. There is no obvious correlation between LSP/P and LSP itself. Previous studies have suggested that the pulsation amplitude does not vary around the LSP cycle, but varies on longer time scales of 20–45 P. However, we find smaller variations in pulsation amplitude around the LSP cycle, which may be partly due to the effect of the LSP variations on the pulsation amplitude determination, but otherwise appear to be real and common.

1. Introduction

Red giant stars are unstable to pulsation, but their variability is complex, with "wandering" periods (Eddington and Plakidis 1929), variable pulsation amplitudes (Percy and Abachi 2013), and, in about a third of stars, "long secondary periods" (LSPs) of unknown cause (Wood 2000). Percy and Deibert (2016) and Percy and Leung (2017) used data from the American Association of Variable Star Observers (AAVSO) International Database (AID) to study the LSP phenomenon, following on the work of Mattei *et al.* (1998) and Kiss *et al.* (1999), and Fuentes-Morales and Vogt (2014) who used data from the original ASAS survey. Important studies of PRGs in the LMC have also been carried out by Wood (2000) and others, using data from other automated surveys.

In the present study, we supplement those studies of PRGs with new results from the analysis of data from the All-Sky Automated Survey for Supernovae—ASAS-SN (Jayasinghe *et al.* 2018, 2019). We look especially at the amplitudes of both the pulsation periods and the LSPs, since more attention has been paid to the periods than to the amplitudes.

Percy and Fenaux (2019) have recently analyzed data on PRGs from ASAS-SN, and pointed out some problems with the automated analysis and classification of PRGs by the ASAS-SN project. These arise from the complexity of PRGs' variability, as mentioned above. Knowing of and accounting for this complexity, it would now be possible to extract useful information from this very large sample (175,000!) of PRGs. In the present paper, we continue to explore the use of the ASAS-SN data to understand more about these stars.

2. Data and analysis

We analyzed the 45 ASAS-SN stars in Table 1, all of which were selected because their light curves showed the clear presence of both an LSP and variability on a time scale an order of magnitude shorter which was presumed to be pulsational variability. For this specific project, we restricted ourselves to stars with LSP ~ 500 days. Given the finite length of the ASAS-SN database (about 2,000 days), longer LSPs cannot be reliably identified and studied. The data were downloaded, and analyzed using the AAVSO VSTAR time-series package (Benn 2013), which includes a Fourier and a wavelet analysis routine.

3. Results

3.1. Pulsation periods and LSPs

Pulsation periods, LSPs, and their amplitudes were determined for a sample of 45 stars which were classified by ASAS-SN as SR, and which had LSPs of approximately 500 days as determined by a cursory inspection of their light curves. The results are given in Table 1. The columns list: the star name minus ASAS-SN-V-J, the pulsation amplitude, the LSP amplitude, the pulsation period P, the LSP, the apparent time scale for smaller pulsation amplitude variations (see sections below), and LSP/P. Here, "amplitude" is defined as the coefficient of the sine curve, corresponding to the period. The peak-to-peak "range" would be twice that.

3.2. LSP amplitudes

The amplitude of the LSP and its upper limit provide some information and constraints on possible causes for the phenomenon. Figure 1 shows a histogram of the amplitudes of all the LSPs in our new sample, as well as those in Percy and Deibert (2016), Percy and Leung (2017), and Fuentes-Morales and Vogt (2014).

3.3. Ratios of LSP to pulsation period

Figure 2 shows a histogram of values of LSP/P. The peak is at 9–10, and there is also a broad, shallower distribution around 6–7. For the stars in Table 1, half have LSP/P = 10 ± 1, with the smaller broad distribution at 7 ± 1. For the stars analyzed by Fuentes-Morales and Vogt (2014) having LSPs, the peak values of LSP/P are 9 ± 1 and 5 ± 1, which is not inconsistent with our results.

3.4. A relation between LSP/P and LSP?

Previous studies have shown that shorter-period PRGs are more likely to be pulsating in an overtone mode, and longer

Table 1. Analysis of ASAS–SN observations of pulsating red giants.

Name (ASAS–SN–V)	*A(P)*	*A(LSP)*	*P(d)*	*LSP(d)*	*tA (d)*	*LSP/P*
191616.35+475823.7	0.21	0.08	54	506	428	9.4
200906.21–360621.9	0.27	0.08	50	502	460	10.0
102404.50–424432.1	0.07	0.04	43	534	600	12.4
092133.94–302421.6	0.41	0.11	53	500	—	9.4
073356.87–761029.5	0.19	0.08	50	537	453	10.7
101642.40–324246.4	0.09	0.05	47	497	500	10.6
221339.54+250026.2	0.18	0.06	70	510	550	7.3
175204.29–505333.5	0.06	0.04	51	530	458	10.4
201618.11–514426.6	0.29	0.08	63	449	680	7.1
181621.36–624528.8	0.15	0.07	67	408	437	6.1
072611.52–051112.8	0.21	0.17	120	526	—	4.4
165443.03–674130.3	0.22	0.11	52	521	—	10.0
061244.28–494217.4	0.06	0.04	52	511	—	9.8
071807.32–580600.5	0.32	0.06	60	485	406	8.1
223902.01+210756.5	0.20	0.10	84	511	1060	6.1
041209.77–581525.7	0.06	0.04	49	497	660	10.1
190736.39–283252.1	0.17	0.10	51	513	1010	10.1
200517.75+152705.5	0.29	0.14	87	494	—	5.7
043744.566+535304.7	0.28	0.09	67	667	—	10.0
183140.63–342342.4	0.17	0.09	54	530	580	9.8
185021.64–372919.3	0.07	0.04	55	504	—	9.2
050943.86+072725.6	0.09	0.05	50	530	—	10.6
073046.65–642648.2	0.24	0.09	55	523	—	9.5
195637.80+073255.0	0.28	0.10	84	537	650	6.4
042558.31+224004.7	0.33	0.08	63	511	530	8.1
024353.42+383555.7	0.24	0.08	62	510	—	8.2
060912.35–142851.3	0.10	0.06	52	538	—	10.3
202651.30+192639.8	0.17	0.06	62	493	460	8.0
202346.72+230928.2	0.20	0.10	65	486	—	7.5
173343.90–491900.9	0.10	0.05	60	489	—	8.2
202507.66+131360.0	0.26	0.09	55	520	—	9.5
075229.72–065927.9	0.34	0.10	66	506	—	7.7
065430.46–024530.5	0.16	0.08	69	507	400	7.3
180342.74–541714.9	0.20	0.09	56	527	940	9.4
160247.19–262523.7	0.09	0.19	54	547	—	10.1
120733.34–572501.6	0.14	0.20	56	377	430	6.7
192322.36+132404.5	0.15	0.17	47	349	—	7.4
200830.55–024558.2	0.21	0.14	44	700	750	15.9
165027.59–670623.6	0.16	0.18	42	512	440	12.2
190727.12–115432.9	0.07	0.19	25	346	—	13.8
184135.31–074400.7	0.10	0.15	27	415	—	15.4
201749.96+101629.5	0.15	0.15	50	374	367	7.5
085241.14–390810.0	0.20	0.11	29	290	290	10.0
143922.74–622255.9	0.20	0.18	30	365	265	12.2
042659.04–705401.3	0.10	0.08	35	344	920	9.8

period PRGs (such as Mira stars) are more likely to pulsate in the fundamental mode. If the LSP was correlated with, for example, the radius of the star, then LSP/P might be expected to be larger in short-period, first-overtone stars, and smaller in longer-period, fundamental-mode stars. Figure 3 shows the relation between LSP/P and LSP. No such trend is obvious.

3.5. Does pulsation amplitude vary around the LSP cycle?

If the LSP produces significant changes in the *physical* properties of the pulsating star, then it is possible that these produce changes in the pulsation amplitude around the LSP cycle. The time scales of amplitude variation in PRGs tend to be 20–45 times the pulsation period (Percy and Abachi 2013; Percy and Deibert 2016), whereas the LSPs tend to be 5–10 times the pulsation period. This suggests that the pulsation amplitude does *not* vary significantly on the LSP time scale. Percy and Di (2018), using AAVSO data, also found this to be

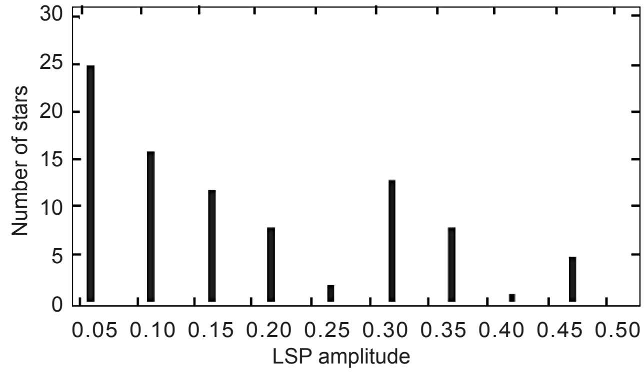

Figure 1. Histogram of the amplitudes, in magnitudes, of LSPs for PRGs in our sample. As described in the text, there are biases against small to medium amplitudes, and for medium to large ones. Amplitudes of up to 0.45 magnitude are found in these stars.

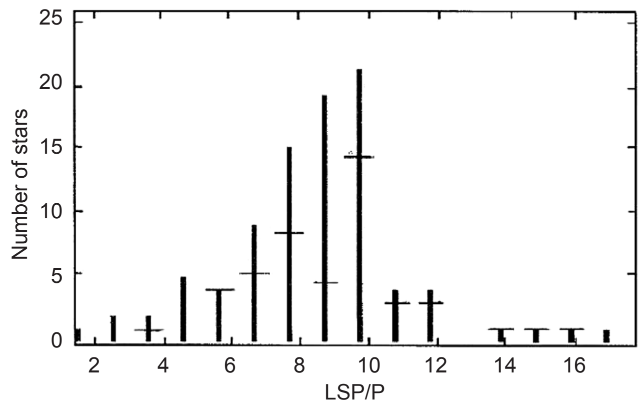

Figure 2. Histogram of ratios of LSP/P for PRGs in our sample, and PRGs in the sources given in section 3.2. There is a strong peak at 10 ± 1, a small number at 7 ± 1, and a very few larger than 12. The horizontal bars are the results for the ASAS-SN stars listed in Table 1.

the case in four stars, for which there was sufficiently dense coverage in the AID.

These studies, however, used decay parameters of 0.001 in VSTAR to average out the scatter in the AAVSO visual data. ASAS-SN data do not have this scatter, and are reasonably dense, so we have used them, with a decay parameter of 0.01, to investigate this question in more detail. The significance of the decay parameter is discussed by Templeton (2004) and in more detail by Foster (1996), who created the WWZ wavelet analysis tool. The decay parameter sets the width of the Gaussian window function. To quote Templeton (2004): "The algorithm fits a sinusoidal wavelet to the data, but as it does so, it weights the data points by applying the sliding window function to the data; points near the center of the window have the heaviest weights in the fit, while those near the edges have smaller weights. The window slides along the data set, giving us a representation of the spectral content of the signal at times corresponding to the center of that window." A slow decay averages the spectral properties over a longer time span. A fast decay averages them over a shorter time span, and therefore gives finer detail, though based on fewer data points, and therefore with potentially lower accuracy.

We found the situation to be somewhat more complicated. Smaller amplitude variations are found on a shorter time scale.

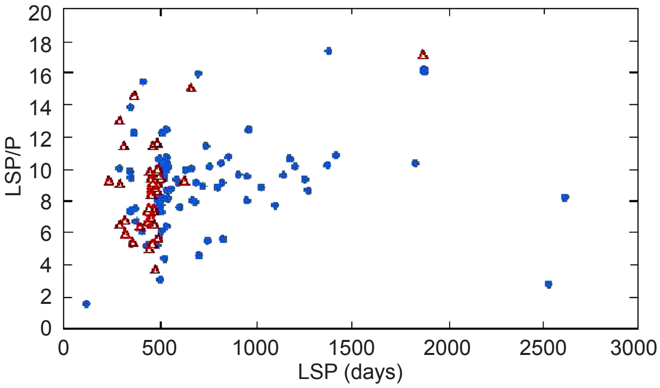

Figure 3. The relationship between LSP/P and LSP. There is no obvious relation. See text for discussion. The red triangles are the results for the stars listed in Table 1. The blue filled circles are the results for other stars, in the sources given in section 3.2.

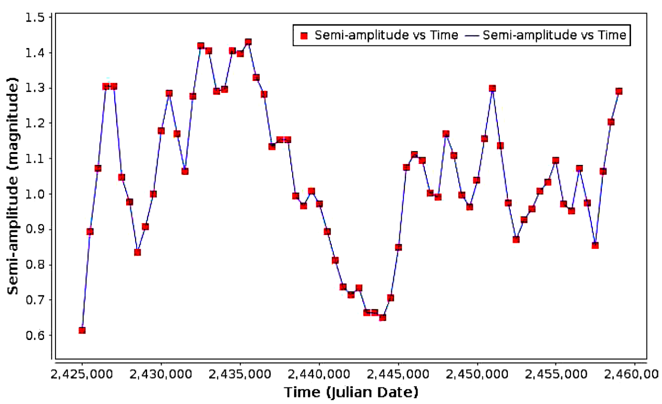

Figure 4. For T Ari: the pulsation amplitude in magnitudes versus time, using a decay parameter of 0.01 in vstar, showing both the slow variations (tens of thousands of days) and the smaller variations on a time scale comparable to the LSP, which is 2600 days in this star (Percy and Deibert 2016).

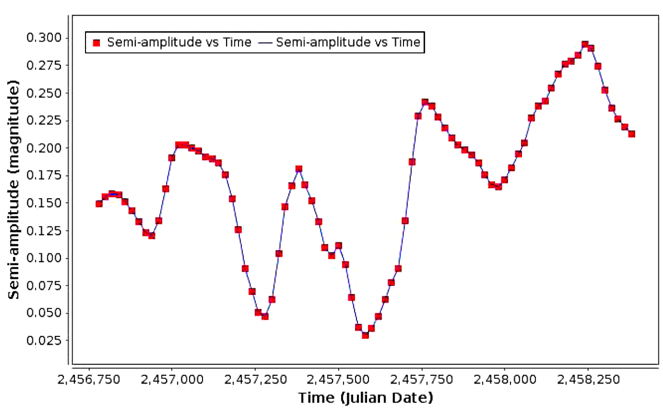

Figure 5. For ASASSN-V J165027.59-670623.6: the pulsation amplitude in magnitudes versus time, using a decay parameter of 0.01 in vstar, showing both the slow variations (time scale two thousand days) and the substantial variations on a time scale comparable to the LSP, which is about 500 days in this star (Table 1).

The second-last column in Table 1 lists the time scales (tA in days) of these variations, as determined by wavelet analysis. This will be discussed in more detail in section 4.

4. Discussion

4.1. Periods and LSPs

The stars were chosen to have LSPs of *approximately* 500 days, but the derived values range between 300 and 700 days, though the statistical uncertainty of these is obviously large, since the lengths of the datasets are only about 2,000 days. Most of the pulsation periods are about 50 days. In this sense, our star sample is not an unbiased one.

4.2. LSP amplitudes

There are several biases in the histogram of LSP amplitudes (Figure 1). The ASAS-SN stars in Table 1 were chosen to have a conspicuous LSP, as well as visible shorter-period variations which were presumed to be due to pulsation. Stars with LSPs from Percy and Deibert (2016), Percy and Leung (2017), and Fuentes-Morales and Vogt (2014) are less biased, but LSPs with amplitudes below 0.10 are still less likely to be detected. So the true shape of Figure 1 is more likely to be a smooth drop-off from 0.00 to the apparent upper limit of 0.45. This upper limit provides some constraint on the possible LSP mechanism, which remains uncertain. Figure 1, when compared with Figure 3 in Percy and Deibert (2016), confirms that there is no shortage of large-amplitude (~0.3–0.4 mag) LSPs, even for LSPs as low as 500 days.

We note that Trabucchi *et al.* (2017) found that, in the Large Magellanic Cloud, LSPs seem to have an upper limit to their amplitude of 0.4 mag, or slightly higher, shown in their Figure 7.

It is possible that some stars have a large LSP amplitude and a small pulsation amplitude, so that the LSP is then interpreted as a pulsation period. Percy and Fenaux (2019) identified a few such stars.

It is also possible that all PRGs—even including Mira stars—have LSPs, but that most of them have amplitudes which are too small to be detected. This is a possibility that is worth investigating—if it is practically possible.

4.3. Ratios of LSPs to pulsation period

One possible interpretation is that the larger values of LSP/P occur when P is a first-overtone pulsation mode (P1), and the smaller values occur when P is the fundamental mode (P0). In that case, the large number of LSP/P values around 10 suggests that about half of the stars are pulsating in the first overtone, whereas the stars with LSP/P around 7 are pulsating in the fundamental mode. The ratio P1/P0 varies between 0.45 and 0.65 for these stars (Xiong and Deng 2007; Percy 2020).

4.4. A relation between LSP/P and LSP?

Since shorter-period PRGs are known to pulsate in the first overtone, whereas longer-period ones pulsate in the fundamental, there might be a trend between LSP/P and LSP. Figure 3, which includes data from Percy and Deibert (2016) and Morales-Fuentes and Vogt (2014), shows no evidence for that. Figure 5 in Percy and Deibert (2016), which includes LSPs up to 3,000 days, confirms this lack of a trend. Our result is also consistent with Fuentes-Morales and Vogt (2014), Figure 4.

4.5. Does pulsation amplitude vary around the LSP cycle?

The *a priori* reasons for believing that the pulsation amplitude does not vary significantly around the pulsation cycle are: (1) the dominant time scale for pulsation amplitude is 20–45 pulsation periods, whereas the time scale of the LSP is 5–10 pulsation periods; and (2) Percy and Di (2018) did not find any significant variation in pulsation amplitude during the LSP cycles of four stars.

We have re-examined this question. In particular: we have reduced the decay parameter in the VSTAR wavelet analysis. This gives finer resolution for study of the period and amplitude variation though, because it determines these over shorter intervals—typically one pulsation cycle—it does not have the advantage of averaging out the scatter over more than one pulsation cycle. We find that the individual pulsation cycles are affected (sometimes significantly) by the LSP variability, so this effect may be *partly* due to the method of analysis. The longer-time-scale variations are still present. Figures 4 and 5 show two examples. Table 1, column 6 gives the time scale τA, in days, of the smaller, shorter-period variations in pulsation amplitude. These shorter-period variations may have been averaged out in our previous studies. In this column, a blank entry indicates that there were no detectable amplitude variations.

A detailed comparison of the LSP light curve and the pulsation amplitude variability as determined by wavelet analysis with a short decay parameter shows clearly that the two are *not in phase*; they indeed have similar but unequal time scales. This can be seen in the AAVSO data for U Del and Y Lyn, which are especially densely covered. There is no consistent relation between the times of maximum pulsation amplitude and the phase in the LSP cycle.

5. Conclusions

This study provides an example of how data from the ASAS-SN survey, because of their accuracy and density, can provide useful information about the behavior of PRGs, including the poorly-understood LSP phenomenon. Specifically, we have derived information about the amplitudes of the LSPs, and their upper limit, and about the relationship between LSP/P and LSP (assuming it to be related to radius). We have also been able to study variations in pulsation amplitude on time scales of the LSP to tens of pulsation periods.

One limitation of the ASAS-SN survey is that the datasets are only about 2,000 days long. This limits the precision of the derived periods, and limits the extent to which we can study very long time scale phenomena in these stars. There are also the inevitable seasonal gaps in the data, which can lead to confusing aliases in the Fourier spectrum.

This project is also an example of the kind of project which can be carried out by an undergraduate student, who can develop and integrate their science and math skills, motivated by doing real science with real data.

6. Acknowledgements

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