Do the Pulsation Properties of Red Giants Vary around their Long Secondary Period Cycle?

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Abstract We have used visual and Johnson V observations from the American Association of Variable Star Observers (AAVSO) International Database, and the AAVSO VSTAR time-series package, and (O-C) analysis to investigate possible changes in the pulsation period and amplitude of the pulsating red giants U Del, EU Del, X Her, and Y Lyn around the cycle of their long secondary periods (LSPs). We find no such changes in period or amplitude. This suggests (weakly) that the process which causes the long secondary periods does not change the physical properties of the visible hemisphere of the stars significantly as the LSP cycle proceeds.

AAVSO keywords = AAVSO International Database; Photometry, visual; pulsating variables; giants, red; period analysis; amplitude analysis

ADS keywords = stars; stars: late-type; techniques: photometric; methods: statistical; stars: variable; stars: oscillations

1. Introduction

About a third of pulsating red giants (PRGs) show a long secondary period (LSP), 5 to 10 times longer than the pulsation period, depending on the pulsation mode (Wood 2000, Percy and Bakos 2003). The cause of the LSP is uncertain. This is one of several unexplained phenomena in PRGs. The purpose of this short paper is to investigate whether the pulsation period and/or the amplitude changes around the LSP cycle.

We do this by examining four stars – U Del, EU Del, X Her, and Y Lyn – which have well-determined LSPs, and which have precise photoelectric/CCD observations as well as visual observations in the database of the American Association of Variable Star Observers (AAVSO). The pulsation properties of the four stars are given in Table 1, which lists the pulsation period P in days, its visual semi-amplitude, the LSP in days, and its visual semi-amplitude. They are average values; it is known that the pulsation periods and the LSPs and their amplitudes “wander” with time.

2. Data and Analysis

We used visual and Johnson V (PEP or CCD) observations from the AAVSO International Database (AID: Kafka 2018), the AAVSO VSTAR time-series analysis package (Benn 2013) which includes both a Fourier analysis and a wavelet analysis routine, and (O-C) analysis to study the periods and amplitudes of the four PRGs.
3 Results

3.1 Previously-Known Time Scales of Period and Amplitude Variation

It is already known, from the study of dozens of stars, that the periods of PRGs vary or “wander” on time scales of about 40 pulsation periods (Eddington and Plakidis 1929, Percy and Colivas 1999, Percy and Qiu 2018), and the amplitudes of PRGs vary on time scales of 20-35 pulsation periods (Percy and Abachi 2013, Percy and Laing 2017). This is strong evidence that the pulsation periods and amplitudes do not vary primarily on the same time scale as the LSPs, which are only 5-10 pulsation periods in length.

3.2 Specifically-Determined Time Scales of Period and Amplitude Variations

We used the wavelet routine in VSTAR to study the change in period and amplitude in the last three LSP cycles in the four program stars, to see whether there might be three cycles of period and/or amplitude variation. The results are given in Table 2, which lists the star, the JD range (minus 2400000), and a description of the behavior of the pulsation period and amplitude.

In no case does the period or amplitude vary on the LSP time scale. The variations are much slower than the LSP, and consistent with the time scales given in section 3.1.

3.3 (O-C) Analysis of Period Variations versus LSP Phase

(O-C) analysis (Percy 2007, p. 68) is an alternative method for studying period changes with time. Our stars have precise Johnson V observations which can be used to determine times of maximum in the pulsation cycle. We also have accurate values of the pulsation period and LSP.

EU Del is best suited for this analysis, and will be used to demonstrate it. Its pulsation period and LSP are especially well-determined. It has extensive photometry which can be used to determine times of pulsation maximum. Table 3 lists times of pulsation maximum, minus 2400000, their (O-C) values, and their LSP phase, using the first pulsation maximum as t(0).

Figure 1 shows a plot of pulsation (O-C) versus LSP phase. There is no correlation; Figure 1 is a scatter diagram. Similar results were obtained for the other three stars. There was no
correlation between (O-C) and LSP phase. (O-C)s during a single LSP cycle were either constant within the observational error, or varied slowly as part of the longer timescale variability discussed above.

The analysis was complicated, in some cases, by the fact that the pulsation amplitude sometimes decreased to close to zero at some epochs as part of its long-term variation. It was therefore difficult to identify times of pulsation maximum around those times.

3.4 Pulsation Amplitude versus LSP Phase

U Del, EU Del, and X Her have series of Johnson V observations which can be used to estimate the pulsation amplitude. Table 4 lists the semi-amplitudes (to be consistent with the output of VSTAR) and the mean JDs (minus 2400000) of such series. In none of the three stars is there a relation between pulsation amplitude and LSP phase. Figure 2 shows one example: for U Del. The graph of pulsation semi-amplitude versus LSP phase is a scatter diagram. On the other hand: Table 4 shows that the pulsation amplitude varies more slowly, on a time scale of several LSPs (20-35 pulsation periods), consistent with the discussion in section 3.1.

4. Discussion

There is no generally-accepted and proven explanation for the “wandering” pulsation periods, variable amplitudes, and LSPs in pulsating red giants. The wandering pulsation periods have been modelled as random cycle-to-cycle fluctuations. These might be connected with random convective motions. Large convective cells have long been predicted to occur in the outer layers of PRGs, and have recently been imaged on a PRG (Paladini et al. 2018). The turnover times and rotational-variability times of these are expected to be much longer than the pulsation period; see Percy and Deibert (2016) for a discussion.

One might expect LSP-phase-dependent variations in pulsation period and amplitude if the LSP was produced by significant changes in the physical properties of the stellar surface facing the observer. This would include the turnover of large convective cells, or the rotation of large
convective cells onto and off the visible hemisphere. On the other hand: if the LSP was due to a well-detached binary companion, or to a large cloud of dust, orbiting the star, or any other external process, then the stellar surface and its pulsation properties would not be expected to change significantly. The binary scenario is discussed by Soszyński and Udalski (2014). EG And is a specific example. It has a pulsation period of 29 days and an LSP of 242 days (Percy et al. 2001). The LSP is exactly half of the orbital period of 483.3 days (Kenyon and Garcia 2016). Many other PRGs are likely to have binary companions.

5. Conclusions

From a study of four well-studied pulsating red giants with LSPs, we find no evidence that the pulsation period and amplitude vary with LSP phase. Both vary on much longer (and different) time scales. Our results suggest, weakly, that the LSP process – whatever it is – does not produce significant variations in the physical properties of the visible hemisphere of the star.

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Table 1: Four Pulsating Red Giants with Long Secondary Periods

| Star   | P days | A mag | LSP days | A(LSP) mag |
|--------|--------|-------|----------|-------------|
| U Del  | 117.8  | 0.05  | 1157.4   | 0.20        |
| EU Del | 62.688 | 0.06  | 624.2    | 0.06        |
| X Her  | 101.37 | 0.06  | 738.0    | 0.08        |
| Y Lyn  | 134:   | 0.08  | 1251.6   | 0.34        |

Table 2: Pulsation Period and Amplitude Variations in Pulsating Red Giants

| Star   | JD range   | P variation | A variation  |
|--------|------------|-------------|--------------|
| U Del  | 54788-58260| discontinuous| monotonic decrease |
| EU Del | 56388-58260| discontinuous| one cycle   |
| X Her  | 56046-58260| half-cycle  | monotonic decrease |
| Y Lyn  | 54504-58260| discontinuous| half-cycle   |

Table 3: Pulsation Semi-Amplitudes (V) versus LSP Phase for Three Stars

|   | U Del | EU Del | X Her |
|---|-------|--------|-------|
| JD A N.phase | JD A N.phase | JD A N.phase |
| 48180 0.10 0.00 | 47400 0.35 0.30 | 56475 0.43 0.95 |
| 48550 0.05 0.32 | 47780 0.25 0.91 | 56875 0.21 1.49 |
| 48885 0.12 0.61 | 48175 0.25 1.54 | 57175 0.37 1.89 |
| 49250 0.15 0.92 | 48525 0.30 2.10 | 57250 0.33 2.00 |
| 49650 0.10 1.27 | 48920 0.35 2.73 | 57310 0.35 2.08 |
| 49975 0.10 1.55 | 49250 0.25 3.26 | 57575 0.30 2.44 |
| 50400 0.05 1.92 | 49650 0.20 3.90 | 57900 0.20 2.88 |
| 51080 0.10 2.51 | 50000 0.21 4.46 | 57950 0.25 2.94 |
| 51840 0.20 3.16 | 50350 0.23 5.02 | 58225 0.15 3.32 |
| 52200 0.27 3.47 | 50700 0.15 5.58 |          |
| 52500 0.20 3.73 | 51100 0.18 6.23 |          |
| 52900 0.30 4.08 | 51450 0.25 6.79 |          |
| 53260 0.18 4.39 | 51825 0.18 7.39 |          |
| 53650 0.30 4.73 | 52175 0.15 7.95 |          |
| 53975 0.25 5.01 | 52575 0.23 8.59 |          |
| 54350 0.40 5.33 | 52920 0.10 9.14 |          |
| 54725 0.10 5.66 | 53260 0.25 9.69 |          |
| 56550 0.10 7.23 | 54000 0.13 10.87 |          |
| 56950 0.10 7.58 | 54360 0.50 11.45 |          |
| 57300 0.15 7.88 | 55100 0.20 12.64 |          |
| 57650 0.22 8.18 | 56525 0.20 14.92 |          |
| 58025 0.17 8.51 | 56950 0.18 15.60 |          |
|          | 57250 0.23 16.08 |          |
|          | 58050 0.13 17.36 |          |
Table 4: (O-C) versus LSP Phase for EU Delphini

| JD  | (O-C) d | N.phase | JD  | (O-C) d | N.phase | JD  | (O-C) d | N.phase |
|-----|---------|---------|-----|---------|---------|-----|---------|---------|
| 47450 | 0.0     | 0.00    | 49560 | -21.4   | 3.38    | 52952 | -14.5   | 8.81    |
| 47502 | +12.9   | 0.08    | 49622 | -22.1   | 3.48    | 53267 | -13.0   | 9.32    |
| 47689 | -11.8   | 0.38    | 49682 | -24.8   | 3.58    | 53998 | -34.2   | 10.49   |
| 47752 | -11.4   | 0.48    | 49937 | -20.5   | 3.98    | 54385 | -23.4   | 11.11   |
| 47815 | -11.1   | 0.58    | 50000 | -20.2   | 4.09    | 54315 | -30.7   | 11.00   |
| 47877 | -11.8   | 0.68    | 50304 | -29.6   | 4.57    | 55078 | -19.9   | 12.22   |
| 48188 | -14.2   | 1.18    | 50376 | -20.3   | 4.69    | 55144 | -16.6   | 12.33   |
| 48385 | -5.3    | 1.50    | 50439 | -20.0   | 4.79    | 55502 | -34.8   | 12.90   |
| 48500 | -15.7   | 1.68    | 51114 | -34.6   | 5.87    | 55878 | -34.9   | 13.50   |
| 48567 | -11.4   | 1.79    | 51417 | -45.1   | 6.36    | 56562 | -40.4   | 14.60   |
| 48673 | -3.4    | 2.10    | 51484 | -40.7   | 6.46    | 56898 | -17.9   | 15.14   |
| 48874 | -17.8   | 2.28    | 51749 | -26.5   | 6.89    | 56998 | -43.3   | 15.30   |
| 48949 | -5.5    | 2.40    | 51807 | -31.2   | 6.98    | 57203 | -26.3   | 15.62   |
| 49139 | -3.6    | 2.71    | 51860 | -40.7   | 7.07    | 57261 | -31.0   | 15.72   |
| 49194 | -11.3   | 2.79    | 52183 | -31.3   | 7.58    | 57650 | -18.1   | 16.34   |
| 49254 | -14.0   | 2.89    | 52489 | -38.7   | 8.07    | 58008 | -36.3   | 16.91   |
| 49316 | -14.6   | 2.99    | 52570 | -20.4   | 8.20    | 58056 | -51.0   | 16.99   |