RU Cam: The Reluctant Cepheid Revisited

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Abstract Skilled amateur astronomers can still make significant contributions to variable star research, even in this age of massive automated sky surveys. Among other things, they can identify and/or observe stars with unusual properties or behavior. RU Cam, a 22-day carbon-rich Population II Cepheid (CW variable), is one such star. In 1965, Serge Demers and Don Fernie discovered that it had abruptly decreased in full amplitude from 1.0 to 0.1 magnitude. It was subsequently observed intensively until the 1990s, especially at the Konkoly Observatory, and this enabled theoretical discussions about the possible nature of the star's pulsation. The cause of the amplitude decrease was and still is not clear. Observations have been more sporadic since the 1990s. There is some AAVSO V photometry, and sparse AAVSO visual photometry from before the amplitude decrease to the present. More recently, RU Cam was observed by the All-Sky Automated Survey for Supernovae (ASAS-SN) from 2014 to 2018, and by the Transiting Exoplanet Survey Satellite (TESS) over two pulsation cycles. In this paper, I analyze the ASAS-SN data and the AAVSO data for possible changes in the period and the amplitude. The period has remained more-or-less stable at 22 ± 1 days and, since 1965, the full amplitude has continued to vary from less than 0.1 to about 0.3 on a time scale of hundreds of days (tens of pulsation periods), reminiscent of the variability of red SR variables. An attempt to follow the period changes using the (O–C) method was unsuccessful because of the sparseness of the data. I therefore suggest that this star should be monitored systematically, preferably in UBV. It is well-placed for northern observers.

1. Introduction

RU Cam is a 9th magnitude, carbon-rich 22-day Population II Cepheid (W Virginis or CW) pulsating variable star. In 1965–1966, it abruptly decreased in V full amplitude from 1 to 0.1 magnitude (Demers and Fernie 1966). This generated much interest and many papers. In a comprehensive paper, Szeidl *et al.* (1992) published photometry of RU Cam on 1,343 nights between 1966 and 1982, and discussed the long-term changes in the star's period and amplitude. After 1965–1966, RU Cam continued to vary with a period of about 22 days, with a small and variable amplitude. Figure 1 shows the changing amplitude with time, based on AAVSO visual data and wavelet analysis.

Kolláth and Szeidl (1993) discussed possible explanations for the star's behavior. They concluded that the regular part of the star's pulsation disappeared in 1965, leaving only an erratic or irregular component. They found no evidence for multiperiodicity, or low-dimensional chaos, but did not rule out higher-dimension chaos, or other stochastic effect—possibly caused by dynamical processes in the star's atmosphere. For a general understanding of CW variables, and related objects, the review by George Wallerstein (2002) is still useful.

Prior to 1965, the period of RU Cam was about 22.16 days, and the (O–C) diagram subsequently showed a constant linear decrease to about 21.75 days, plus wave-like fluctuations (Szeidl *et al.* 1992; Percy and Hale 1998). These fluctuations can be modelled as random cycle-to-cycle fluctuations, similar to those which occur in Mira stars (Percy and Hale 1998).

What has happened to RU Cam since then? In this paper, I use data from the AAVSO International Database (Kafka 2020), the All-Sky Automated Search for Supernovae (ASAS-SN: Jayasinghe *et al.* 2018, 2019), and some limited data from the Transiting Exoplanet Survey Satellite (TESS; STScI 2020) to study the period and amplitude of the star. The visual observations were quite numerous after 1965, but have become increasingly sparse. Some AAVSO photoelectric observations were obtained over the years. There are five seasons of data from ASAS-SN, but only two pulsation cycles from TESS.

2. Data and analysis

In order to study the changing period and amplitude of RU Cam, the ASAS-SN data and the AAVSO visual observations were analyzed using the Fourier and wavelet analysis routines in the AAVSO time-series analysis package VStar (Benn 2013). The TESS data were too limited for time-series analysis. Note: in the literature, the term "amplitude" is generally used to indicate the peak-to-peak range, whereas VStar gives, as amplitude, the coefficient of the sine curve representing the period. I will use the term "full amplitude" for the former, and "semi-amplitude" for the latter.

3. Results

The period of RU Cam, prior to 1965, was 22.16 days, and was decreasing (Szeidl *et al.* 1992, Figure 3). After 1965, it was fluctuating around 21.75 days (Szeidl *et al.* 1992, Figure 5). The fluctuations appear to be cyclic (but not periodic), with a typical length of 600 days, or 25 periods. The authors do not mention this, but it is relevant because of its similarity to the behavior of other pulsating variables such as SR stars. Percy and Hale (1998) showed that the fluctuations could be modelled by random cycle-to-cycle fluctuations, but there was also a weak time scale of about 20 periods (their Figures 1 and 2).

The periods which we obtained from Fourier analysis, and their sources, are listed in Table 1. Figure 2 shows the Fourier spectrum of the ASAS-SN observations, determined using VStar.

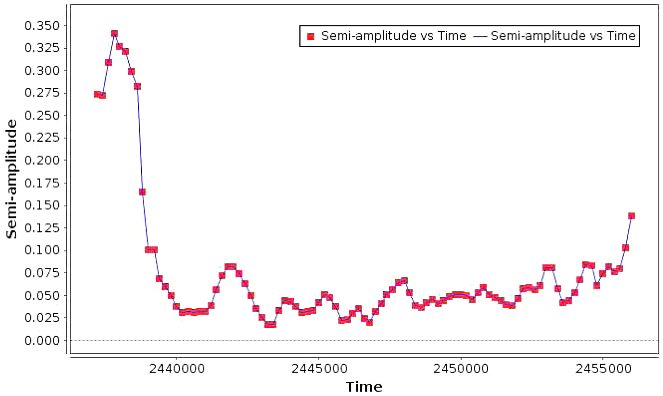

Figure 1. The change in the semi-amplitude of pulsation of RU Cam with time, using AAVSO visual data and the wavelet routine in the AAVSO VStar time-series analysis package. The final increase is spurious, and depends on a very few observations. This is an example of how the sparseness of recent data negatively affects the analysis.

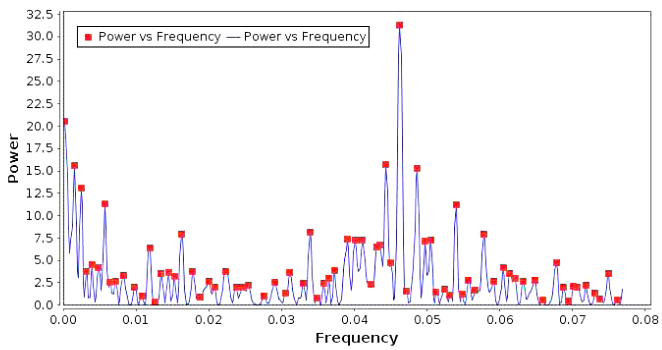

Figure 2. The Fourier spectrum of the ASAS-SN observations of RU Cam, as determined with VStar. The period of 21.62 days is consistent with that determined by Szeidl *et al.* (1992) from earlier data.

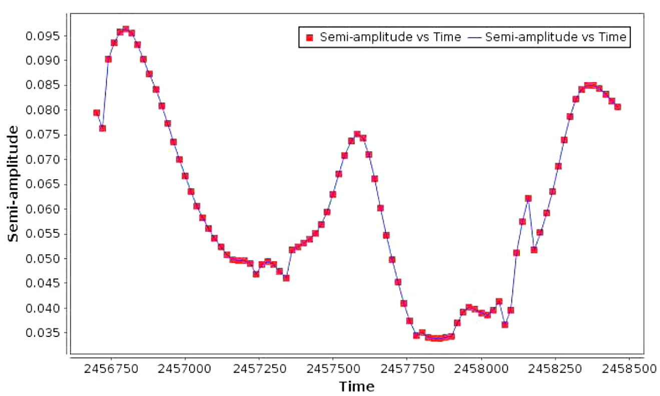

Figure 3. The variations of the semi-amplitude of RU Cam, derived by wavelet analysis from ASAS-SN data. The amplitude variation is consistent with that observed by Szeidl *et al.* (1992).

These are the mean periods and semi-amplitudes for the datasets; they will be affected by the slow fluctuations in both the period and the semi-amplitude. The uncertainties in the periods in Table 1, typically one day, are such that the periods are not significantly different. In particular, the period from the recent ASAS-SN data is the same as that before 1965.

The TESS data covered two cycles of variability: JD 2458842.5–2458867.5, and 2459010.0–2459035.0, in each case with a two-day gap in the middle. The semi-amplitudes of the two cycles were 0.01 and 0.045, respectively, showing the time variation of the pulsation amplitude.

Table 1. Periods and semi-amplitudes determined from Fourier analysis.

P (*days*)	*A* (*mag.*)	*Source*
21.45	0.04	AAVSO since 2450000 (Kafka 2020)
23.30	0.06	AAVSO visual 2450000–51000 (Kafka 2020)
20.17	0.05	AAVSO visual 2451000–52000 (Kafka 2020)
21.90	0.06	AAVSO visual 2452000–53000 (Kafka 2020)
21.41	0.06	AAVSO PEP (Kafka 2020)
21.62	0.04	ASAS-SN (Jayasinghe *et al.* 2018, 2019)
22.28	0.06	Hipparcos/Tycho (Perryman *et al.* 1997)

Table 2. Times of minimum, cycle numbers, (O–C) values, sources.

JD (*min.*)	*N*	*(O–C)* (*days*)	*Source*
2445254	284	–2.6	Szeidl *et al.* (1992)
2449628	485	–15.4	Berdnikov (2008)
2450195	511	1.6	AAVSO vis (Kafka 2020)
2450377	519	10	AAVSO V (Kafka 2020)
2450418	521	6.6	AAVSO V (Kafka 2020)
2450541	527	–1.4	AAVSO vis (Kafka 2020)
2450543	527	1.5	AAVSO V (Kafka 2020)
2451490	571	–9.0*	AAVSO vis phased (Kafka 2020)
2451552	573	9.2*	AAVSO vis phased (Kafka 2020)
2452432	614	–2.5*	AAVSO vis phased (Kafka 2020)
2452947	638	–9.4*	AAVSO vis phased (Kafka 2020)
2452718	627	1.1	AAVSO V (Kafka 2020)
2453124	646	–6.1	AAVSO V (Kafka 2020)
2453147	647	–4.9	AAVSO V (Kafka 2020)
2456932	821	–4.0	ASAS–SN (Jayasinghe *et al.* 2018, 2019)
2457371	841	–0.5	ASAS–SN (Jayasinghe *et al.* 2018, 2019)
2458061	873	–6.4	ASAS–SN (Jayasinghe *et al.* 2018, 2019)
2458857	909	+6.6:	TESS (STScI 2020)
2459024.5	917	+0.1	TESS (STScI 2020)

I then used (O–C) analysis to attempt to follow changes in the period since the work of Szeidl *et al.* (1992). Table 2 lists times of pulsation minimum, cycle numbers, (O–C) values in days, and their sources. The TESS data yielded two times of minimum, but the first is highly uncertain because of the small amplitude, and the noise in the data. Following Szeidl *et al.* (1992), I used times of pulsation minimum, because they were considered better-defined. I also used the same ephemeris for the C values, namely C = JD 2439079.6 + 21.75N. Unfortunately, for much of the time interval, the data are too sparse to yield times of minimum. This is especially true between JD 2450000 and 2453000. Table 2 includes four times (marked with asterisks) that were derived by phasing together observations within 500-day intervals, but these do not yield a consistent pattern; it is unclear how many cycles are contained between JD 2450000 and 2453000. An (O–C) diagram has therefore not been plotted.

The amplitude of RU Cam varies slowly. This can be seen in Figure 1 of Kolláth and Szeidl (1993), which is based on the data in Szeidl *et al.* (1992). Specifically, the amplitude rises and falls on a time scale of about 430 days, on average, or about 20 pulsation periods, judging from that Figure. The variation is certainly not periodic. Figure 3 shows the semi-amplitude variation in the ASAS-SN data. It varies from 0.035 to 0.095 on a time scale of roughly 800 days, or about 35 pulsation periods.

4. Discussion

The mean period of RU Cam has not undergone long-term systematic change since 1965, but has fluctuated around the value of 21.75 days, obtained by Szeidl *et al.* (1992). The fluctuations can be modelled as random, cycle-to-cycle fluctuations, such as occur in Mira stars. Mira stars are strongly affected by convection—much more so than in a warmer star like RU Cam. So the cause of RU Cam's fluctuations is unclear.

The amplitude variation in RU Cam is rather similar to that in red semiregular (SR) variables, whose amplitudes vary by up to a factor of 10 on a time scale of 20–40 pulsation periods (Percy and Abachi 2013). It might be useful to study other small-amplitude yellow pulsating variables. Small-amplitude CW stars are, unfortunately, very rare.

Why did RU Cam stop pulsating—almost? The usual answer is that it had evolved out of the instability strip. Its physical properties were no longer such that it was unstable to radial pulsation. But that's just a hypothesis. The constancy of the period, over the past 50 years, places some limits on the rate of evolution of the star (see below).

And what is the nature of its present pulsation, with a wandering period and a variable amplitude—much like the SR variables? Can we really attribute it to stochastic or atmospheric effects? The latter question might be solved through more systematic observation.

Fortunately, there are some very recent theoretical studies which may help to answer some of these questions (Bono *et al.* 2020; Fadeyev 2020). Fadeyev (2020) concludes that W Virginis stars are low-mass post-AGB (asymptotic giant branch) stars that are experiencing the final helium flash. His Figures 4 and 5 shows predicted rates of period change, as a function of period, after the second crossing of the blue edge of the pulsation instability strip. His units are seconds per year. The rate of period change in RU Cam appears to be no greater than 0.5 day in 60 years, or 720 seconds per year—within the range of the models which are plotted in Fadeyev's (2020) Figures 4 and 5. Further comparison with the models is beyond the scope of this paper.

5. Conclusions

For over half a century, the variability of RU Cam has been consistent: a period of about 21.75 days, about which there are slow fluctuations, and a full V amplitude which varies between 0.00 and 0.30 on time scales of 20 to 40 pulsation periods. Perhaps this is the "new normal" for this star. But will it continue?

RU Cam deserves to be monitored systematically, preferably in UBV filters. Its amplitude decrease was highly unusual. Its period and amplitude variations continue, and they may tell us about the evolution and the stochastic processes in this and other types of pulsating stars.

6. Acknowledgements

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