Unanswered or Intriguing Questions about Low-Mass Pulsating Yellow Supergiant Stars

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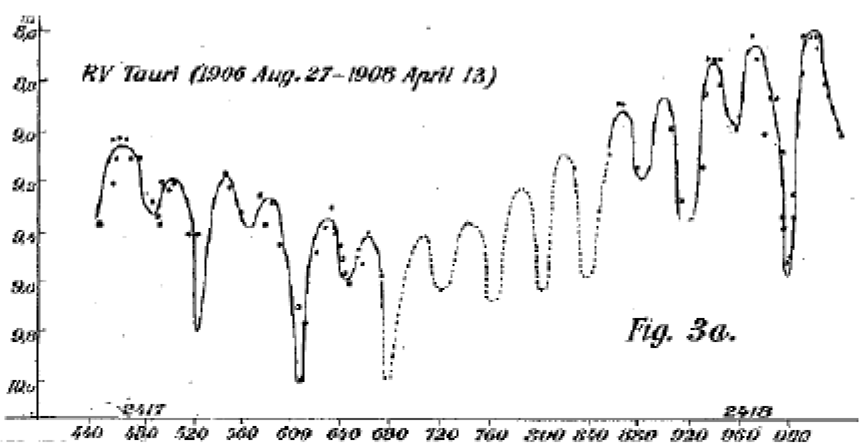
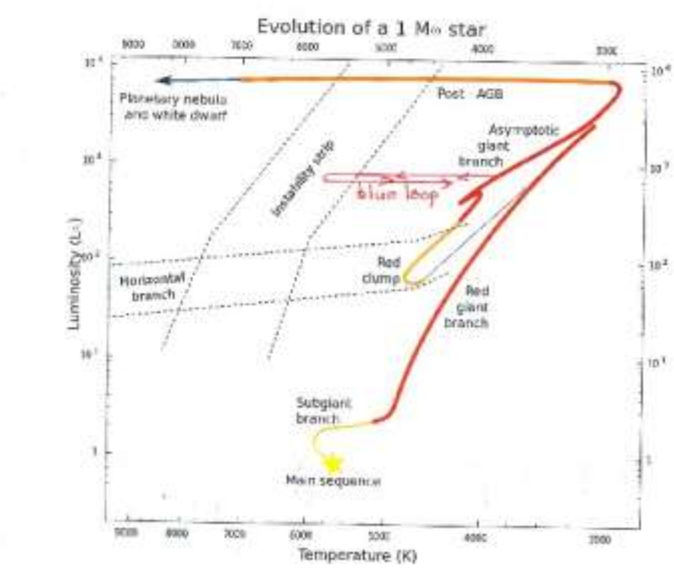
Low-mass pulsating yellow supergiants include W Virginis stars (Population II Cepheids), RV Tauri (RV) stars, which are characterized by alternating deep and shallow minima, and SRd stars, which are semiregular. These stars appear to be in rapid and interesting stages of evolution -- either executing "blue loops" from the asymptotic-giant branch (AGB) in the Hertzsprung-Russell diagram, or making the final transition from AGB star to white dwarf. In this **RV Tau** light curve, note the alternating minima, and the slow "long secondary period". This paper deals primarily with RV and SRd stars.



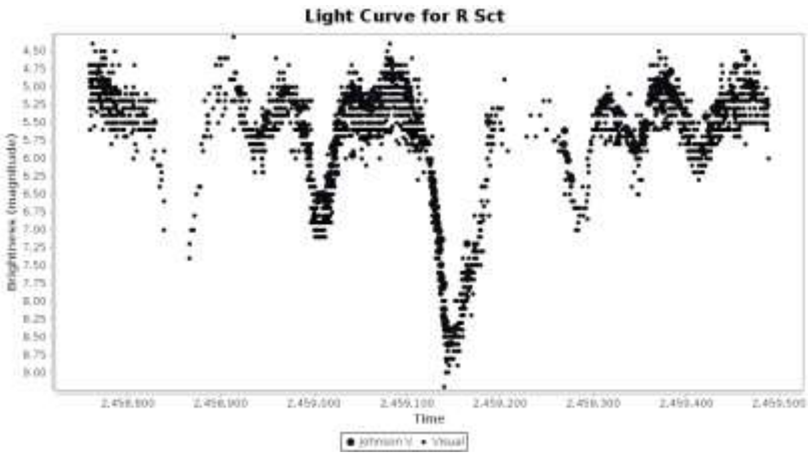
1. The Evolutionary Status of these Stars

These stars lie in the upper middle part of the famous Hertzsprung-Russell diagram which plots luminosity versus temperature. There are two ways that stars can enter this part of the HRD: (1) “blue loops” from the asymptotic giant branch (AGB) of the HRD, caused by thermonuclear instabilities in the core, and (2) the final transition of the star from the AGB to the white dwarf plus planetary nebula stage, after losing most of its outer envelope due to a massive stellar wind (Miller Bertolami 2016, Bono et al. 2020, Fadeyev, Y.A. 2020). One of the goals of our project was to see whether the evolution could be detected through period changes.



2. The Pulsation Period(s) in RV and SRd Stars

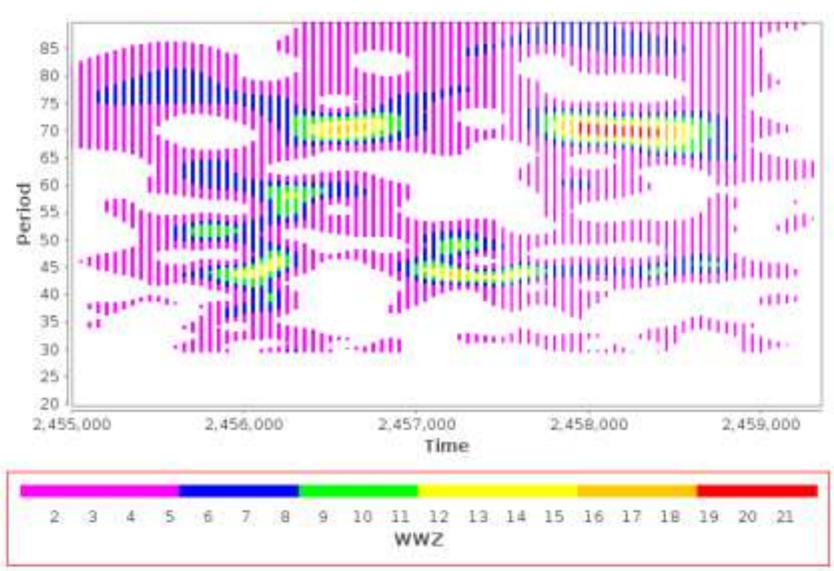
Although RV stars are defined by their alternating minima, they are often more irregular; this figure shows a portion of a light curve of the RV star **R Sct**, based on AAVSO visual data:



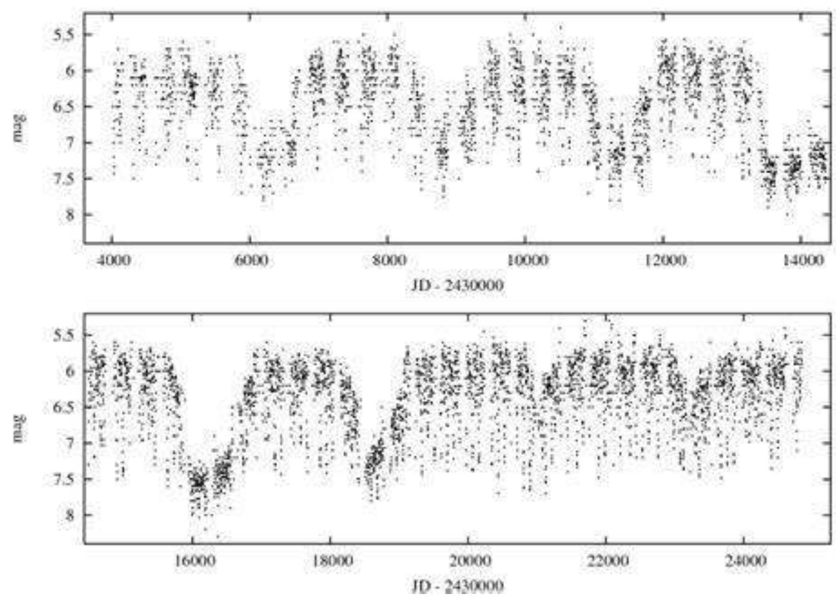
Alternating deep and shallow minima can be produced by two periods in an exact ratio of 2:1. Does the irregularity occur because the excited periods are not exactly in a ratio of 2:1? Or because of some other form of irregularity? See Percy, Hosick, and Leigh (2003). The period ratios found by Percy and Haroon (2021) range from 0.498 to 0.501 – not significantly different from 2:1. *What causes the irregularity of the alternating minima in RV stars?*

3. Stars with Two Pulsation Periods

RV stars appear to pulsate in two modes with periods in a ratio 2:1 (or can be modelled that way). If such a star pulsated with periods not in a ratio 2:1, they would presumably be classified as SRd. But there are few if any SRd variables which show two distinct periods not in a 2:1 ratio: V395 Cyg with periods 40.1 and 32.8 days, and LR Sco with possible periods of 70?, 105?, and 140? days. There is UU Her, which is famous for switching between periods of 45 and 72 days. The following **UU Her** wavelet plot (period versus time, with a measure of amplitude color-coded) shows the presence of periods around 45 and 72 days, each with variable amplitude. *Are there other SRd stars which are clearly bimodal, or appear to mode-switch?*



4. "Long Secondary Periods" in RV and SRd Stars

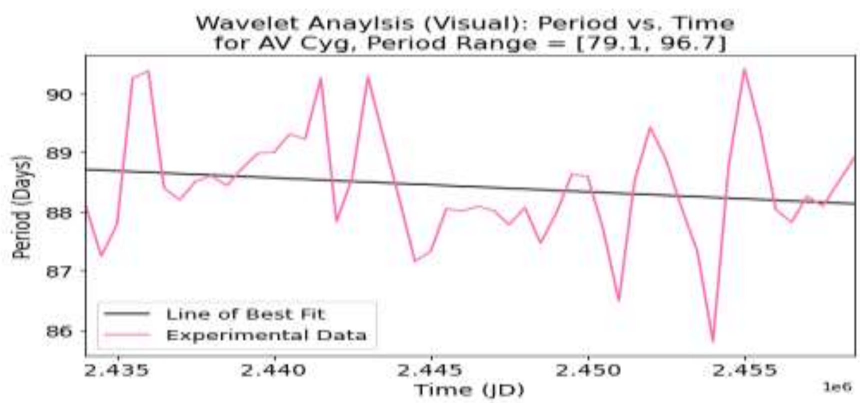


Many RV stars show long secondary periods (LSPs), 10-20 times the pulsation periods, and are subclassified as RVb stars. The figure shows the AAVSO visual light curve of **U Mon**, with an LSP of about 2500 days. That phenomenon has been explained by binarity (Fokin 1994, Pollard et al. 1996, Kiss and Bodi 2017, among others), the companion being enveloped by a dust cloud. At least a third of pulsating red giants have LSPs (Wood 2000), and these have also been explained as due to binarity in an elegant recent paper by Soszynski et al. (2021).

But do SRd stars show LSPs; or are they rare; or have they escaped detection? Searches include Percy and Ursprung (2006), Percy (2015), Percy and Haroon (2021), the only candidates being RU Cep and WW Tau.

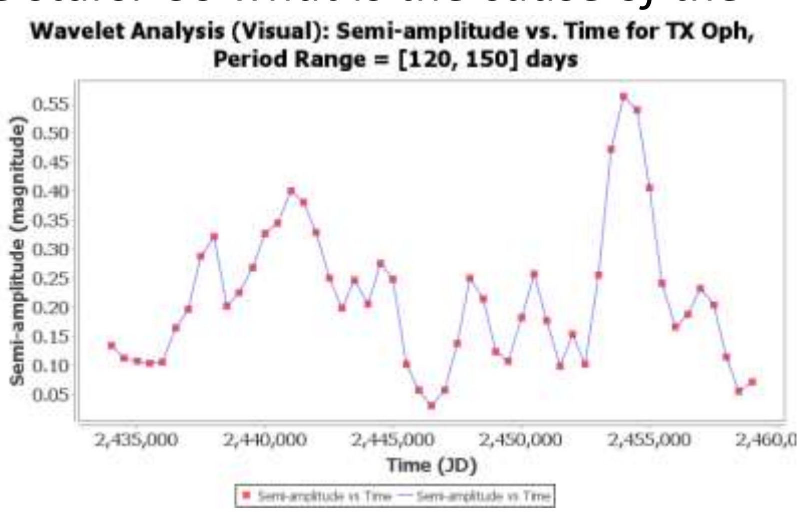
5. Period Changes

The likely stages of evolution of these stars last for thousands or tens of thousands of years, so sustained observations (such as AAVSO visual) may be able to detect them. This is usually done with the classic (O-C) method. The problem is that the (O-C) diagrams are dominated by period "wandering" (Eddington and Plakidis 1929) which can be modelled as random cycle-to-cycle fluctuations, but whose cause is unknown. Percy and Haroon (2021) have experimented with using wavelet analysis, using the AAVSO VSTAR package, to measure the period changes (see figure, showing data for **AV Cyg**), to estimate the "characteristic evolution times". The period changes are still greatly affected by period wandering, but the wavelet method makes use of all available observations. *Is this a useful alternate approach?*



6. Pulsation Amplitude Changes

Several papers have shown that these stars' pulsation amplitudes vary by up to a factor of 10 or more, on a time scale of 20-40 pulsation periods (Percy (2015), Percy and Haroon (2021)); see figure for **TX Oph**. In the case of RVb stars, Kiss and Bodi (2017) have shown that these amplitude changes are correlated with the LSP. Amplitude variations are found in pulsating red giants (Percy and Abachi 2014), but do not seem to be related to the LSPs in those stars. *So what is the cause of the pulsational amplitude variations in RV and SRd stars? And are SRd stars semi-regular because they are bimodal, or because their amplitude varies, or because of an LSP – or more than one of these?*



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Take-Home Message: AAVSO observations are valuable, and in some cases unique. Keep on observing!

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