Astronomical and Astrophysical Transactions (*AApTr*), 2020, Vol. 31, Issue 4, pp. 451–458,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

RV Tau stars

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Received 1 October, 2019

A periodogram analysis of RVA and RVB stars was carried out using AFOEV database. Also the stars with an uncertain classification RVA: and RVB: were studied. Perhaps this class of stars contains objects of other types (Mira-type of early spectral subclasses, yellow semi-regular variables, cepheids). The mean light curves and phase portraits obtained as a result of the periodogram analysis were studied. The photometrical characteristics of the mean light curves were calculated and the atlas was created for 48 stars.

The star BI Cep, which was classified as RVA, was confidently classified by us as a semiregular variable (SR). Also, for four other stars, possible types of variability were specified.

Keywords: Pulsating stars

1 Introduction

RV Tauri (RVAB) stars are pulsating yellow supergiant stars whose light curves are characterized by alternating deep and shallow minima. They have spectral types F to G at maximum light, and K to M at minimum. The changes in the brightness are correlated with the changes of the spectrum. The period from one deep minimum to the next (the "formal" period) ranges from 30 to 150 days. The complete light amplitudes can reach 3–4 magnitudes in V (Samus et al., 2017).

George Preston and his collaborators (Preston et al., 1963) showed that they could be subclassified, spectroscopically, into:

A: G and K type (though the spectral type varies over the pulsation cycle), probably old Population I. The spectra can show a hydrocarbon group CH and cyano group CN, and titanium oxide TiO. This class was later subdivided into:

A1: TiO band present at minimum light;
and

A2: TiO band not present at minimum light.

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B: Fp type; as a rule, rich in carbon with weak absorption bands of metals and CH and CN bands of normal strength between secondary and primary maxima; probably old Population I.

C: Fp type with weak metal lines similar to stars B, but with no CH/CN bands.

The RVAB stars are heterogeneous, and not well understood. The alternation of deep and shallow minima may not be clear and strict, so, if the classification of the star is based on only a few cycles of the light curve, it may be misclassified as a Popular II Cepheid, if the minima do not alternate, or a yellow semi-regular variable, if the alternation appears irregular.

The pulsation of LPV interact with convection in a complex way. This leads to strong nonlinear effects: shock waves, mass loss, problems of radiation transfer in cold extended atmospheres. All this can lead to the transformation of the regular oscillations in the chaotic, for example, through successive doubling of the period. The radial velocity variations are typically a few tens of km per second. We know that the evolution after AGB at some point should lead the star across the HR-diagram to region of the white dwarfs, thereby passing through the instability strip for the last time. In this short stage of evolution, there may be Cepheids of W Virginis type with the highest luminosity and the longest period. Many of them are surrounded by dust, which is evidence of mass loss on AGB. Many of them show the characteristics of RV-type stars. And most RV-type stars show expected decreases in the period, although (O–C) diagrams are dominated by random, cycle-to-cycle period fluctuations. Analysis of the IRAS data show that the rate of mass loss seems to be decreasing, probably the stars go off with AGB. So the RV-type stars are executing blue loops from the AGB, or are in their final transition from the AGB to the white dwarf stage (Percy, 2007).

The main features characteristic of RV-type stars are:

- the greatest luminosity among type II Cepheids;
- the spectra belong mainly to the types G and K;
- the alternation of deep and shallow minima on the light curves.

In most cases, the light curves can be decomposed into two periodic signals: one with a formal period (the time between two adjacent deep minima) and the other with a fundamental period (the time between successive deep and shallow minima). The fundamental period is usually in the range of 20 to 75 days, and the formal period is doubled fundamental. Also, a number of stars show the variability of average brightness with a periodicity of 600 to 2600 days. Such stars have been classified as RVB, while those that do not show a change in average brightness are RVA.

The mechanism leading to oscillations like RV-type is still not fully understood. However, there are two main hypotheses that explain their nature. The first is that stars experience two-modal pulsations in which the periods are in a 2:1 ratio. The second is that the stars are undergoing low-dimensional chaos. As for the evolutionary status of these stars, they were first associated with objects after the asymptotic branch of giants, then this hypothesis was confirmed. However, in fact, the picture is much more complicated.

2 Periodogram analysis, atlas of the light curves and the phase portraits

For periodogram analysis, the observations from the databases of AFOEV (`ftp://cdsarc.u-strasbg.fr/pub/afoev`), AAVSO (`http://aavso.org`) and ASAS (`http://www.astrouw.edu.pl/asas`) were used. A description of working with these databases can be found, for example, in the articles by Andronov & Marsakova (2006), Marsakova & Andronov (2006, 2007) and Vavilova et al. (2012). The extension of the wavelet analysis for irregularly spaced data was introduced by Andronov (1998). The methods for determination of the characteristics of individual extrema are reviewed by Andronov (2005), Andrych & Andronov (2019) and Andrych et al. (2020). The most recent review on various methods is presented by Andronov (2020), Andronov et al. (2020) and in this volume (Andronov & Chinarova 2020).

Period search was carried out for 48 stars. The least squares method is used for periodogram analysis. The method is described by Andronov (1994, 2003) and Fig. 1 shows examples of the periodograms. The trial frequency $f = 1/P$ is shown on the horizontal axis, and the value of the test function $S(f)$ (Andronov, 1994, 2020) is shown on the vertical axis. Also, a characteristic feature is the presence of two satellites near the main peak. Simple calculations show that the central peak is

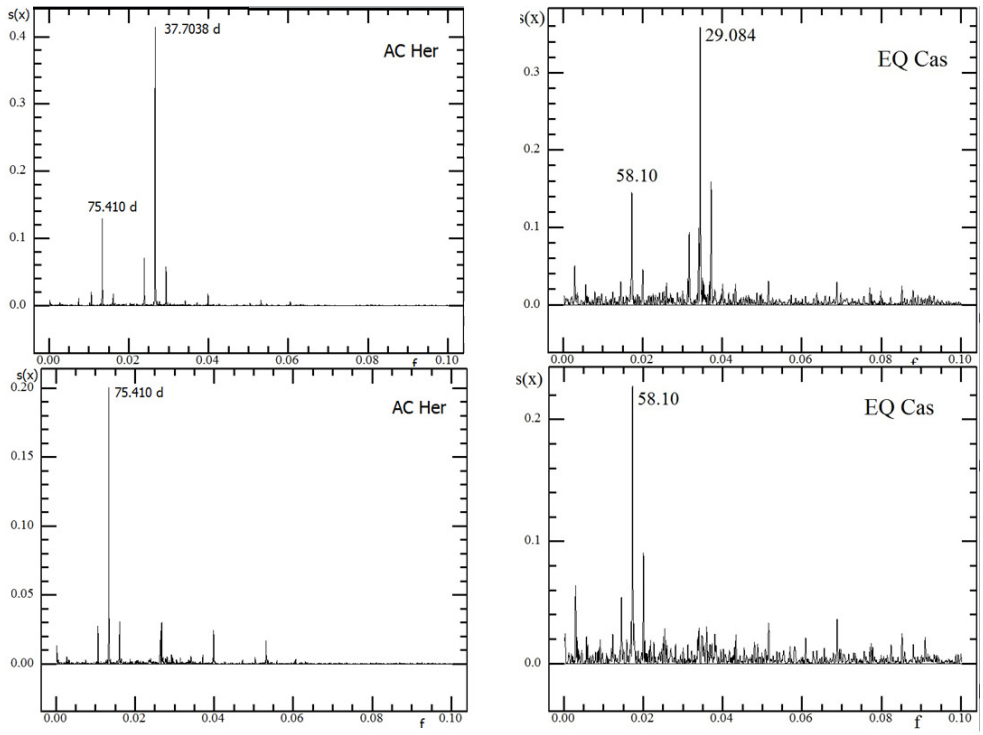


Figure 1 The periodograms for the RV-type stars AC Her and EQ Cas. In the second periodograms (bottom) we have "prewhitened" the data by subtracting the contribution with a period corresponding to the highest peak.

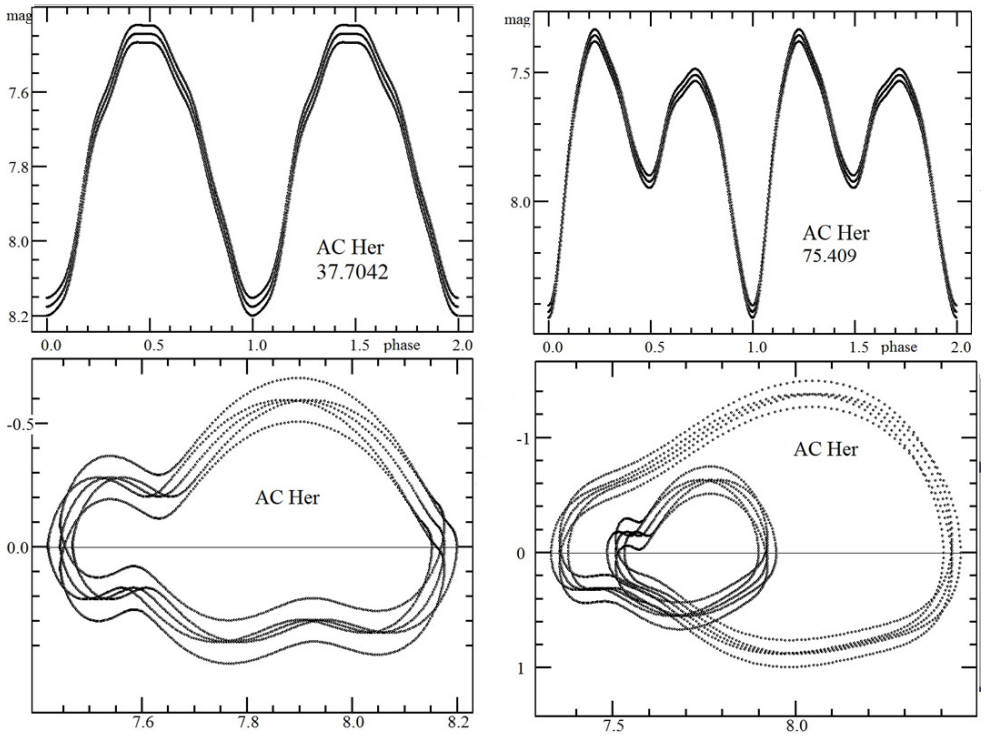


Figure 2 The mean light curves plotted with fundamental and formal periods and corresponding phase portraits for the AC Her.

usually exactly between the satellites. The distance between the central peak and the satellite is the beat period, i.e. the period of slow modulation of the light curve.

Further, the mean light curves, folded with the phase of best period (using the program MCV, Andronov & Baklanov, 2004).

The characteristics of the mean light curves were calculated and the atlas was created for 48 stars (Kudashkina & Andronov 2017a,b). This was done with the program FDCN (Andronov, 1994). Further, phase portraits were constructed and magnitudes are on the horizontal axis and its phase derivatives are on the vertical axis. The examples are shown in Fig. 2.

Theoretically, for sinusoidal oscillations, the phase portrait is an ellipse. Deviations from the ellipse are expected for non-sinusoidal waves, that is, if the degree of the trigonometric polynomial, smoothing the curve, more than one.

The calculation is performed in the cycle phase, the results for m, $\dot{m}$ are displayed with "3σ" corridors of errors on both coordinates. For RV Tauri type stars, the phase portraits are shown for short (fundamental) and long (formal) cycles of the variability. We can see that the short-period limit cycle is more stable and regular than the long-period cycle (Fig. 2).

3 Misclassified stars

We also found that several stars do not fit the RV-type description. Other works also mention them in this connection. For example, Zsoldos (1991) gives a list of the stars among which there is the star BI Cepheus. This star is almost certainly not RVA. Spectral type does not match RV-type stars, the period value is too large. There is no peak of the doubled period, typical for stars of this type (see Fig. 3). On the periodogram there is a double peak with very close values of periods. A similar result was obtained earlier for the semiregular variable RX Boo. In that case, the periodogram also had a double peak with a difference between the values of the periods of less than 20 days (Andronov & Kudashkina, 1988).

The mean light curves of BI Cep plotted with these periods are shown in Fig. 4.

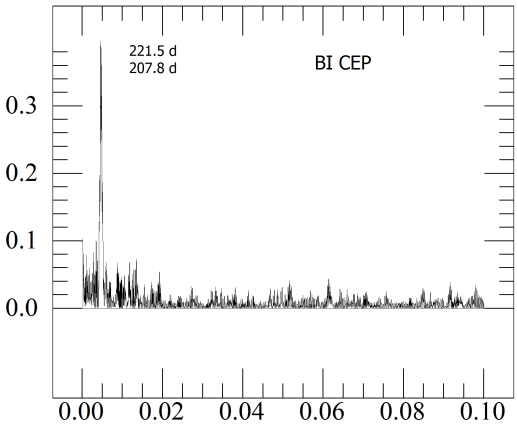


Figure 3 Periodogram of the BI Cep: P_1=221.5 ± 0.2, P_2=207.8 ± 0.3

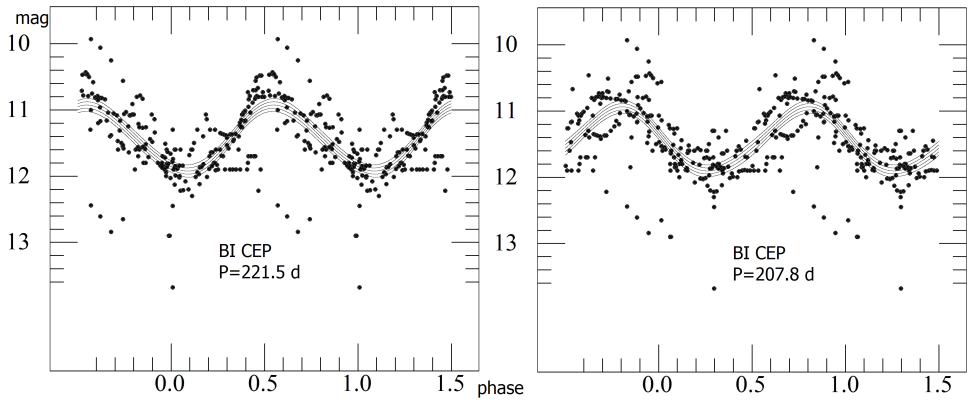


Figure 4 Reclassification of the star BI Cep – Sp M5e, type – SR.

Four more objects raised doubts about their RV type. They are shown in Table 1. However, we cannot confidently exclude them from the list of RV-type stars.

Table 1 Misclassified RV Tauri stars.

Star	Sp	P(GCVS)	P*	Type
OR Her	?	210	196.2 ± 0.6	SR? RV?
V 609 Oph	M6II	195	98.0 ± 0.3	SR?
DY Aql	G8e-M3Ia	131.86	65.674 ± 0.004	RVA? SR?
QV Aql	?	135	68.27 ± 0.01	SR? RV?

*Calculated in this work.

4 Conclusions

The RV-type stars have the same type of periodograms, which usually contain distinct peaks of the main and formal (doubled period). Both of these peaks are beats of periods close in frequency, the peaks of which are also visible on periodograms.

The mean light curves are represented well enough by the periods found, which will allow further determination of a set of photometric parameters to search for correlations between them.

In our opinion, an important result is the creation of an Atlas of the mean light curves of RV-type stars, as it was done earlier, for stars of Mira Ceti type (Kudashkina & Andronov, 1996) and semiregular variables (Chinarova & Andronov, 2000); a review of these studies is given in Kudashkina (2019).

Also of interest is the morphological analysis of periodograms and their classification.

Acknowledgements

The author expresses her gratitude for useful discussions to the authors of the international study in the framework of projects "Inter-Longitude Astronomy" (Andronov et al., 2003, 2014, 2017, 2020; Tvardovskyi et al., 2020), "Ukrainian Virtual Observatory" (Vavilova et al., 2012) and "Astroinformatics" (Vavilova et al., 2017).

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