Stars and their variability observed from space
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THE NON-RADIAL PULSATION PATTERN OF THE ALGOL STAR RZ CAS

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Abstract. We have introduced a Python-based computer programme that extends the capabilities of the pixel-by-pixel method of the FAMIAS package to perform an automated frequency search when there is a large number of non-radial pulsation modes. It also determines the error estimates of the frequencies detected, which has not been possible with the pixel-by-pixel method. We applied the programme to time-series of spectra obtained for the short-period Algol-type star RZ Cas in different epochs, to search for changes in its pulsation pattern indicative of active and inactive phases of mass transfer. We present here the first results.

Keywords: Stars: variables: delta Scuti, Asteroseismology, Methods: data analysis

1 Introduction

The oscillating eclipsing Algol stars (oEA stars) were introduced as a subclass of variable stars by Mkrtichian et al. (2002). They are active, semi-detached Algol-type systems in which the mass gainer shows δ Sct-like oscillations. Stars of this type enable one to investigate the interaction between episodes of rapid mass-transfer and excited oscillations. RZ Cas is the best-studied object within the group (see e.g., Mkrtichian et al. (2018) for a review). We monitored the star spectroscopically over more than a decade with the aim of investigating correlations between changes in its amplitudes of excited pulsations modes, $v\sin(i)$, orbital period, and the occurrence of episodes of mass-transfer. From time-series of spectra we could determine pulsation modes of low l degree from measured radial velocities (RVs), while high-degree modes can be found from line-profile variations (LPV). In the latter case, the FAMIAS package (Zima 2008) provides a useful tool by its pixel-by-pixel method. However, a large effort in interactive data handling (pre-whitening data for successively found frequencies) is necessary when applying it to stars that show a rich frequency spectrum, like the δ Sct stars. It has not been possible so far to estimate errors for the frequencies determined. We tried to rectify those limitations by writing our own Python code that is compatible with FAMIAS, adopting its basic methods but extending its capabilities.

2 Observations, Methods and Application

Spectra of RZ Cas were obtained with the TCES spectrograph at the 2-m telescope of the Thüringer Landessternwarte Tautenburg in 2001, 2006, 2008, 2013, and 2014 with a resolving power of $R = 30\,000$, and in 2015 and 2016 at $R = 58\,000$; more were obtained in 2009 with the HERMES spectrograph at the 1.25-m Mercator telescope on La Palma at $R = 85\,000$. We used the LSDbinary package (Lehmann et al. 2018) to calculate the individual least-squares decomposed (LSD) profiles of the two components, together with their RVs. We cleaned the RVs of the primary component for orbital motion and nightly trends, and used the residuals to search for frequencies of low-degree modes with PERIOD04 Lenz & Breger (2005). For the high-degree modes we used our Python-based extension of FAMIAS. It works similarly to the pixel-by-pixel method in FAMIAS but performs the alternating steps of Fourier analysis, least-squares fitting, and pre-whitening of data completely automatically in a cyclic way until all significant contributions have been found. The cut-off criterion that it applied is therefore similar to that made by Breger et al. (1993). In addition, it optimizes all frequencies in each step, and contains a least-squares fitting method that optimizes the final set of frequencies to find their uncertainties as well. We used the programme, together with the LSD profiles of the primary component shifted for orbital motion, for frequency searches, and FAMIAS for subsequent mode identification.

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3 Preliminary Results

LSDbinary enabled us to decompose the RVs and LSD profiles of the two components of RZ Cas. The LPV of the primary component shows a rich frequency spectrum. Low frequencies are dominated by the rotation frequency and up to six of its harmonics, i.e., we see time-varying surface structures, possibly caused by spots and/or an accretion disk of varying density. In the high-frequency domain we see rapidly changing non-radial pulsation patterns. Different modes are excited in different epochs and with different amplitudes (Fig. 1, left). The main mode at $f_1 = 64.2\,\mathrm{c\,d^{-1}}$, which also dominates the photometric variations (e.g. Mkrtichian et al. 2018), was present in the RV variations in all the years, and could also be found from LPV in 2014–2016. We derived $l, m = 1, 0$, which gave a distinctly better fit to the observed amplitude across line-profile variations than did $l, m = 2, 1$ as deduced from photometry (Fig. 1, right). We found further high l-degree modes with FAMIAS that could not be detected in the RV variations. In the 2006 and 2009 data we observed strong contributions close to $70\,\mathrm{c\,d^{-1}}$, and weak ones in the 2001 and 2013 data; we identified them as high l-degree sectoral modes. From the different l numbers and the small difference in frequency we concluded that we had observed two different modes, one in 2001 and 2006, and one in 2009 and 2013.

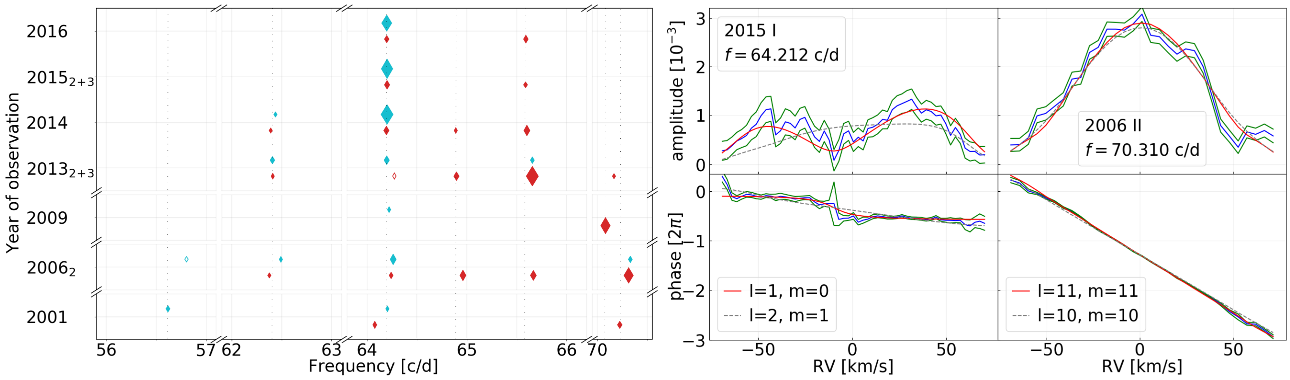

Fig. 1. Left: Frequencies found in different epochs from RV (blue) and LPV (red). The sizes of diamonds scale with the pulsation amplitudes (separately for the two methods). Right: Examples of observed amplitudes and phases across the line-profile contributions (blue), with errors (green) and the best-fitting theoretical curves (red and dotted grey).

4 Conclusions

Our results showed the capabilities of the new methods like LSDbinary and our Python-based FAMIAS extension. We confirmed the seasonal changes of frequencies of pulsation modes in RZ Cas found by Mkrtichian et al. (2018) from light-curve analysis, and interpreted them as acceleration and braking of surface rotation of the mass-accreting star. Relations obtained between changes in pulsation frequencies and amplitudes, the orbit-to-rotation synchronisation factor, and $v\sin(i)$ of the primary component of RZ Cas, will be published in a forthcoming paper, together with a detailed pulsation mode analysis.

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