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Pulsations in Algols

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Abstract. We give a review of the present status of research on the pulsating components of Algol-type eclipsing binary systems and discuss the effects of mass transfer and circumstellar envelopes on observable pulsation properties of this recently formed group of stars.

1. The group of *oEA* stars

Five of the eight presently known members of a new group of A–F spectral type, mass-accreting Main Sequence pulsating components (gainers) of semi-detached Algol binaries were discovered in last two years, during two collaborative surveys of the Central Asian Network (Mkrtichian et al. 2002a) and South Korean (Kim et al. 2002b; Kim et al. 2002c) groups. Table 1 summarizes spectral classes of components and the orbital periods of systems. Tentative values of the pulsation

Table 1. Spectral classes, orbital and pulsation periods of *oEA* stars (LM = Lehmann & Mkrtichian, MG = Mkrtichian & Gamarova).

Name	Sp (Pr. + Sec.)	P_{orb} (days)	P_{puls} (min)	References for pulsation periods
Y Cam	A7 V+K1 IV	3.3055	95.74,78.77 97.17,81.22	Kim et al. (2002a)
AB Cas	A3 V+K0 IV	1.3669	83.93	Rodriguez et al. (1998)
RZ Cas	A3 V+K0 IV	1.1953	22.43,25.44	LM (2002)
R CMa	F1 V+K2 IV	1.1359	68.5	MG (2000)
AS Eri	A3 V+K0 III	2.6642	24.39,23.01, 23.34	Mkrtichian et al. (2002c)
TW Dra	A6 V+K0 IV	2.8069	80	Kusakin et al. (2001)
RX Hya	A8 V+K5	2.2816	74.26	Kim et al. (2002b)
AB Per	A5 V+G9 IV	7.16028	282.02	Kim et al. (2002c)

periods are given in the fourth column. All pulsating Algol gainers lie inside the classical δ Scuti star instability strip, close to the ZAMS (Mkrtichian et al. 2002b). We shall use the *oEA* (oscillating EA) designation for mass-accreting pulsating components in Algols, to distinguish them from the earlier designation EA/DSCT in the General Catalogue of Variable Stars (GCVS) which, by default, also includes detached systems with normal δ Scuti-type components.

We stress that *oEA* stars form a group of pulsators differing from classical δ Scuti stars. The main difference that marks *oEA* stars is their previous evolutionary life in close binary systems. During the Rapid Mass Transfer/Accretion (RMT/RMA) evolutionary stage, low-mass progenitors of *oEA* stars accreted a large portion of mass from Roche lobe overflow of the formerly massive secondary components and evolved rapidly, on a thermal time-scale, to higher mass and luminosity. They are now located on the H-R diagram close to the ZAMS and are at the slow-mass accretion (SMA) stage. SMA keeps them in thermal imbalance and causes their slow evolution *along the MS* toward higher masses and earlier spectral types. This evolution is a second difference between *oEA* stars, and δ Scuti and other stars in the lower instability strip. That is, in the mass-accretion process they do not follow the evolutionary tracks of normal MS or post MS δ Sct stars. Because of their oscillations, *oEA* stars are very attractive for asteroseismology studies.

2. The pulsation mode spectra and amplitude variability

The pulsation spectra of *oEA* stars have not been adequately investigated in multi-site campaigns, though stars such as Y Cam and AB Cas were investigated in the past from the single sites. The recent increase in the number of members of this group found by Ohshima et al. (2000), Mkrtichian & Gamarova (2000), Gamarova, Mkrtichian & Kusakin (2000), Kusakin, Mkrtichian & Gamarova (2001), Kim et al. (2002b) and Kim et al. (2002c) has brought new interest.

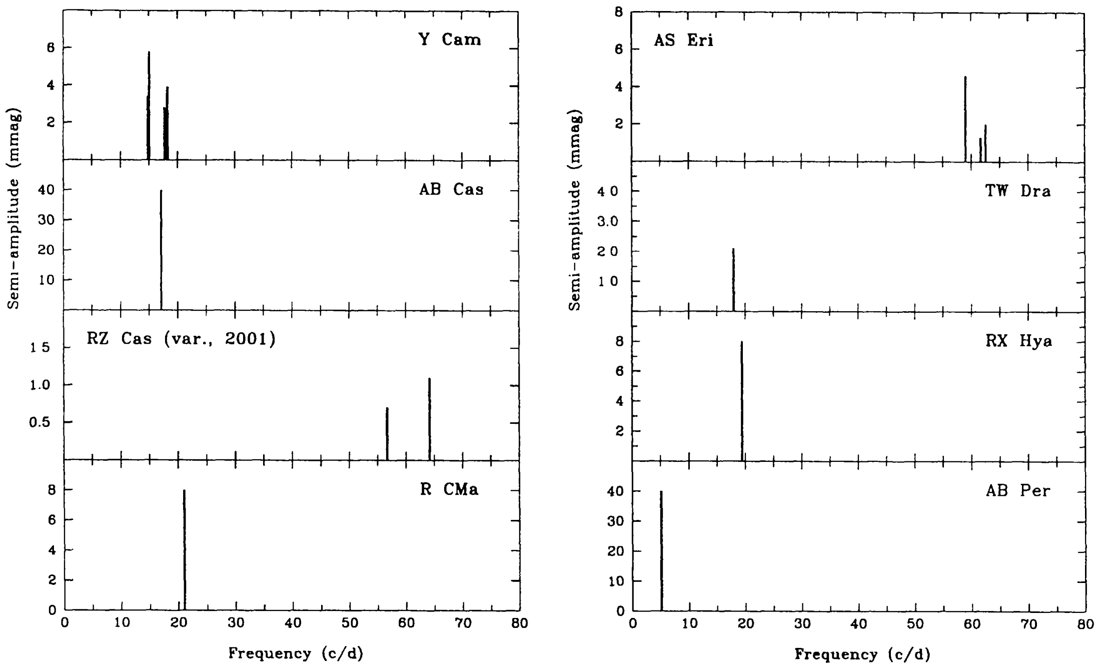

Figure 1. Schematic frequency spectra of *oEA* components of Algols.

Several campaigns for two new members – AS Eri and RZ Cas – were carried out in 1999–2001. Our brief review of pulsation spectra of some of *oEA* stars is based on these recent results.

Tentative schematic frequency spectra of members of the *oEA* pulsators are shown in Fig. 1. The frequency range of excited pulsation modes in *oEA* stars lies within the domain of frequencies of δ Scuti stars, with two exceptions. The 22–25 min oscillations in the RZ Cas and AS Eri gainers are the shortest pulsation periods so far found to be excited in non-magnetic main-sequence A–F stars in the instability strip.

AB Cas and **Y Cam:** These systems are among those with well-studied pulsations. Rodriguez et al. (1998) recently confirmed monoperiodic pulsations in AB Cas. Kim et al. (2002a) detected four pulsation frequencies in Y Cam and suspect long-term amplitude mode variability.

RX Hya and **AB Per:** Pulsations of gainers in these systems were discovered during the survey of the South Korean group. RX Hya shows a dominant pulsation with a period of 74.26 min (Kim et al. 2002b), while AB Per shows slow variability with three periods, one of which is 282 min (Kim et al. 2002c). This period seems to be close to the frequency range of gravity modes. Further multisite observations of the frequency spectrum of AB Per are desirable.

AS Eri: Rapid pulsations of the gainer in AS Eri were discovered during the CAN survey of Algol systems (Gamarova, Mkrtichian & Kusakin 2000; Mkrtichian et al. 2001). The first multisite photometric campaign on AS Eri confirmed the excitation of rapid pulsations in AS Eri with frequency f_1=59.031 d^{-1}. New analysis revealed second and third oscillation modes with frequencies respectively f_2=62.563 d^{-1} and f_3= 61.673 d^{-1} (Mkrtichian et al. submitted).

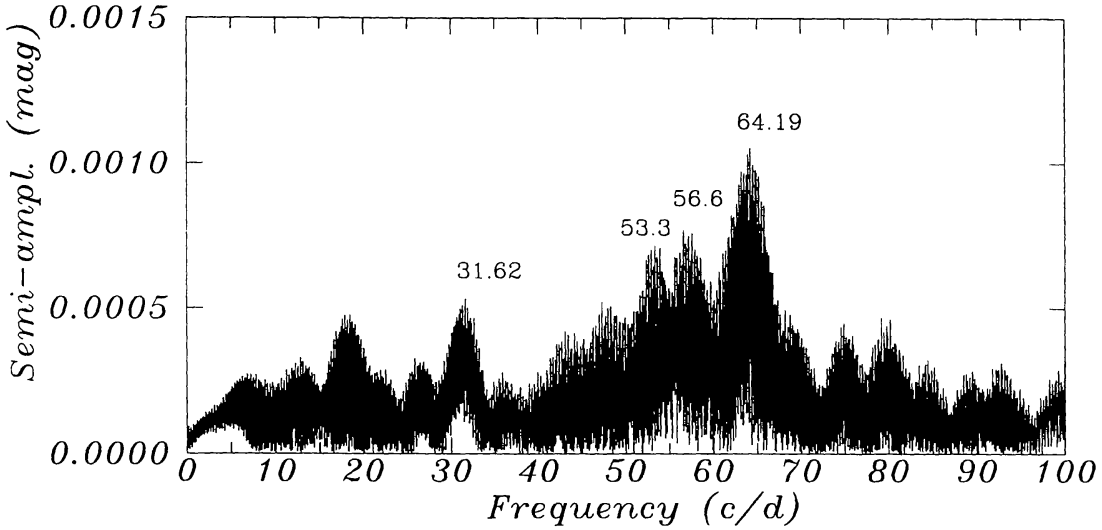

Figure 2. DFT spectrum of a sub-set of photometric observations of RZ Cas obtained at the Mount Laguna and Sierra Nevada Observatories during the 2001 campaign. Monoperiodic and large semi-amplitude (8 mmag) in the 1997–2000 oscillations are shifted in 2001 data to at least two (61.2 and 56.6 d^{-1}) low-amplitude modes.

These modes are related to the 5–6 overtone oscillations. Their periods are among the shortest ones excited in non-magnetic, non-degenerate A–F spectral class stars in the instability strip.

RZ Cas: Short-period variability of the A3V gainer in the Algol system RZ Cas was detected with the dominant frequency of 64.192 d^{-1} (period 22.43 min) and semi-amplitude of 8–10 mmag by Ohshima et al. (1998, 2001).

Three consecutive campaigns were undertaken in 1999, 2000 and 2001. Monoperiodic oscillations with a dominant period of 22.43 min were confirmed during the 1999 (Rodriguez et al. 2002) and 2000 (Mkrtichian et al. in prep.) campaigns.

Results of the 2001 photometric and spectroscopic campaigns on RZ Cas, exploring the binary orbit and the effect of accretion and the non-stationary circumstellar envelope on pulsations, were unexpected. The monoperiodic 1997–2000 oscillations were shifted in 2001 to at least two low-amplitude modes with oscillation frequencies 64.19 d^{-1} and 56.6 d^{-1} and with photometric semi-amplitudes below 2 mmag (see Fig.2). Both oscillations were confirmed in RV data with amplitudes 150–350 $m\,s^{-1}$. Thus, during the 2000/2001 season, the semi-amplitude of the dominant oscillation mode in RZ Cas decreased by an order value (to 1–2 mmag), and the oscillation spectrum became multiperiodic. This is a first observational evidence of rapid changes in the pulsation spectrum and a strong instability in pulsation amplitudes in oEA stars.

3. Asteroseismic approach for asynchronicity determinations

Mkrtichian et al. (2001) noted that for Algol systems the precise gainer rotation period, and hence asynchronicity coefficient, may be estimated asteroseismically with unprecedented accuracy. The first application of this technique was to AS Eri, for which the frequency separation between the f_2 and f_3 modes $\Delta_{3,2} = f_3 - f_2$ was approximately twice the rotation frequency estimated spectroscopically, and was interpreted as the spacing of the rotationally split sectorial prograde (l, m, n)=(2,-2,6) f_2 mode and zonal (l, m, n)=(2,0,6) f_3 mode (Mkrtichian et al. 2002c). Accurate asteroseismic determinations for the gainer are as follows: Rotation frequency $\Omega_{\rm rot}$=0.4449 d^{-1} ($P_{\rm rot}$=2.2477 days); asynchronicity coefficient $F_{\rm asyn}$=1.185; equatorial velocity 35.35 km s^{-1}.

Essential progress in accurate asynchronicity determinations in Algols may be achieved by increasing the number of known pulsating components and by detailed studies of their pulsation spectra in multisite campaigns.

4. Eclipse mode identification

Eclipse NRP mode identification is an attractive possibility for eclipsing binaries. The first application of this technique, to the Algol system RZ Cas, is Gamarova et al. (these proceedings). This attempt of mode identification in RZ Cas revealed the importance of possible hidden multiperiodicities. Some NRP modes, invisible in a disk-integrated light, may be found in light curve pulsations during primary eclipse because of spatial filtration of modes controlled for a given (l, m) mode by the time-variable geometry of eclipse. For some modes their contributions during eclipse may increase in order values and hence complicate the eclipse-mode identification. It is also possible that screening by a gas-stream or a circumstellar envelope during eclipse could produce additional spatial filtering of NRP, and be a factor complicating mode identification.

5. 2-D and 3-D hydrodynamic simulations of mass transfer in RZ Cas

Hydrodynamic 2-D and 3-D simulations of mass transfer in a given binary system with an *oEA* pulsating component may give *a priori* information about effects of attenuation or screening by gas stream or envelope on pulsations. We will discuss such effects in next section. The 2-D simulations (covering the space surrounding the binary, including all the Lagrangian points L1–L5) and 3-D simulations (covering the space around gainer) for the RZ Cas system (Nazarenko & Mkrtichian, in prep.) show the direct impact of a gas stream with the surface of the gainer and the formation of an inhomogeneous gas envelope that surrounds equatorial latitudes of oscillating gainer. The 2-D simulation of the circumbinary gas envelope is shown on a left panel of Fig. 3.

6. Effects of the circumbinary envelope on pulsations

During the 2001 RZ Cas observations (Lehmann & Mkrtichian 2002) the simultaneous radial velocity amplitudes of both modes varied through the orbital cycle,

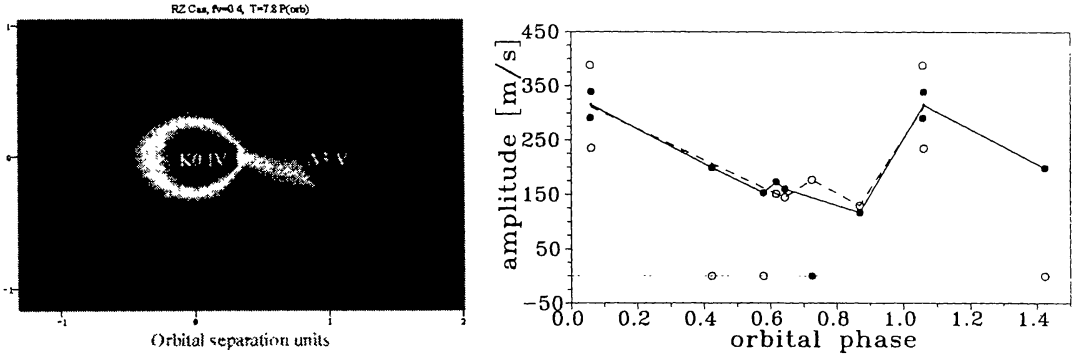

Figure 3. Left panel: 2-D hydrodynamic simulations of mass transfer in RZ Cas. The gas stream-atmosphere interaction coefficient f_v=0.4 was used and calculations were stopped at 7.8 orbital periods. The logarithm of the particle density distribution in the orbital plane is shown. Right panel: The orbital modulation of pulsation radial velocity amplitudes of 64.19 d^{-1} (solid line) and 56.6 d^{-1} (dashed line) modes in RZ Cas during the 2001 campaign. Points with zero amplitude correspond to nights when that mode was under the detection threshold.

with a minimum at $\phi \simeq 0.9$ and a maximum just after primary eclipse at $\phi \simeq 0.1$ (see right panel of Fig. 3). The RV amplitude modulation is marked by orbital changes in the line-of-sight particle column density distribution in the equatorial plane, as shown by the 2-D and 3-D hydrodynamic simulations (Nazarenko & Mkrtichian in prep.). The RV amplitude is a maximum at orbital phases just after primary eclipse ($\phi \approx 0.1$) when line-of-sight averaged particle number is a minimum, and decreases in the phase interval 0.1 to 0.9 as the particles number increases. It is a minimum at phase 0.9 when the gas stream is projected on the surface of pulsating gainer. Moreover, the effect of gas-envelope screening was found in the orbital radial velocities of the gainer, and manifested as an anomalous amplitude ratio of orbital RV curve jumps in the Schlesinger-Rossiter effect. This is the first detection of a gas envelope screening effect on NRP, and the first detection of an anomalous Schlesinger-Rossiter effect in Algols.

7. Conclusions

Pulsations of gainers in Algol-type systems are now an established phenomenon. Pulsations of gainers in eclipsing binaries provide new, unique tools to study processes in Algol systems. Accurate rotation periods of gainers, and hence asynchronicities, can be measured using NRP mode splitting. Mode identification, a basic problem in observational asteroseismology, can be done in eclipsing binary systems using the spatial filtration method (Gamarova et al. these proceedings). The changes of the mean density of gainer caused by accretion of matter can affect the pulsation periods and pulsation properties of *oEA* stars, and can be used to estimate mean accretion rates (Mkrtichian et al. 2002b). This effect works on dynamical and thermal time scales. It is unclear how rapid mass transfer/accretion episodes, initiated by magnetic activity of the masslosing star, can affect pulsation properties and mode selection mechanisms in gainers on a term scales from weeks to years.

The rapid changes of pulsation spectra and modal amplitudes in the RZ Cas gainer during 2000–2001 (i.e., on a times scales of months) may be a signature of accretion-driven changes of pulsation properties of the A3 V gainer under rapid non-stationary accretion episode(s) that have occurred before.

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Discussion

Peters: Do I understand you correctly that the pulsational effects are seen only in the low-mass (e.g. A–F primaries) Algols, and could you comment on how you correct for variability in the secondary?

Mkrtichian: We only focus on A–F primaries in the instability strip. But there will also be many B pulsators in Algols, their pulsation period should be longer, what complicates extraction of pulsational variability in a short-period (< 2 d) Algol. We search for short-term pulsations and any long-term variability of the secondary is simply removed during the extraction of pure pulsational variability.

Peters: Could you justify your empiric mass-transfer rate of $10^{-7} M_\odot\ \mathrm{y}^{-1}$? Was this a measured value for a particular system? Measured rates are sometimes orders of magnitude smaller, although transient rates could be this large.

Mkrtichian: We use the mass-transfer rate of 10^{-7}–10^{-8} for our 2-D hydrodynamic simulation in RZ Cas to see what happened with the gas envelope during the drastic increase of the mass transfer rates. The estimations of rates based on orbital-period abrupt changes are of the same order, but I think that they are not the good approach for estimating the mass-transfer rate.

David Mkrtichian with daughter Karine