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Pulsations in Algols

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Abstract. We present a brief review of the recent results of photometric and spectroscopic surveys and 3-D hydrodynamic simulations of the mass-transfer for the class of oscillating mass-accreting components of Algols (oEA stars). These ground-based spectroscopic and space-based photometric surveys are aimed at detecting and studying the spectra of non-radial oscillations, to get precise orbits and parameters of the binaries, and studying the spectroscopic and the hydrodynamic nature of the mass-transfer. We discovered 47 new oEA stars in TESS data and carried out follow up spectroscopic observations of known and new oEA stars with the SALT telescope. We found that the co-existence of excitation of high-degree non-radial modes with a wide spectrum of low-degree modes is a common phenomenon in oEA stars.

1 THE CLASS OF oEA STARS

The class of oEA pulsators was introduced by Mkrtichian et al. [1, 2]. These are components of semi-detached eclipsing Algol-type binary systems with mass transfer. The A or F-type mass-accreting primaries in these systems lie in the instability strip and show δ Scuti-like pulsations. This means that the evolution of this group of pulsators inside the δ Sct instability strip is different from classical δ Sct-type stars in detached eclipsing binary systems. The unique property of oEA stars is the co-existence of global stellar oscillations with accretion. Non-stationary accretion keeps them in thermal imbalance and drives their evolution along the Main Sequence over evolutionary tracks that are different from those of classical δ Scuti stars. Mkrtichian et al. [2] suggested that the episodes of non-stationary and rapid mass transfer and accretion on the surface of the pulsating gainer can potentially change the oscillation properties and modal spectra. Non-stationary mass transfer can be forced by cyclic magnetic activity of the cool Roche lobe filling component. According to this hypothesis, the pulsational properties and modal spectrum of oEA stars can be cyclically variable over time. A decade-long monitoring of the bright active oEA star RZ Cas confirmed this prediction [3]. Therefore, Algol-type systems with oEA components have a high potential when studying the physics of mass-transfer using

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asteroseismology, and there is a need to discover the diversity of such systems with different orbital and component parameters. By 2018, more than 70 oEA-type systems had been found by Mkrtichian, et al. [3], mostly by photometry.

2. 3-D HYDRODYNAMIC SIMULATIONS OF THE MASS-TRANSFER IN ALGOLS

In Algol systems, the flowing matter that escapes the Roche lobe-filling K-giant via the Lagrange L1 point is directly hitting and accreting onto the surface of the oscillating gainer in short-period systems or accreting onto the surface from the accretion discs formed in a long period system. The physics of the interaction of the gas stream with the atmosphere of the pulsating star is quite complex. To find the physical model that explains the spectroscopic peculiarities in the observed spectra of the component we need a 3-D model of the structure of the gas flow, mass accretion, and formation of the accretion disk in the large space around the studied binary system. We undertook a series of 3D-hydrodynamic simulations for different oEA systems observed during THASSOS and SALT surveys. The calculations were made using the version 3-D code developed by Nazarenko and Glazunova [4]., which is based on the Large Particle Method developed earlier by Belotserkovskiĭ and Davydov [5]. Figure 1 shows some results of 3-D simulations obtained for the RZ Cas, TW Dra and AS Eri systems. For each system, we modelled different mass-transfer rates in order to find the structural differences in circumbinary gas flow and shock waves. We found almost conservative mass-transfer, with a mass-loss rate of less than one percent of the total mass transfer rate. An increase in the mass transfer rate changes the density of the gas stream and the structure of the circumbinary belt-like accretion annulus. These structural differences in the gas stream and circumbinary structures can explain the observed photometric and spectroscopic effects, namely orbital variations in pulsation amplitudes, the timely variable asymmetric Rossiter effect, and the variable intensity of He I lines reported in the RZ Cas and AS Eri systems by Nazarenko and Glazunova [4] and Mkrtichian et al. [11].

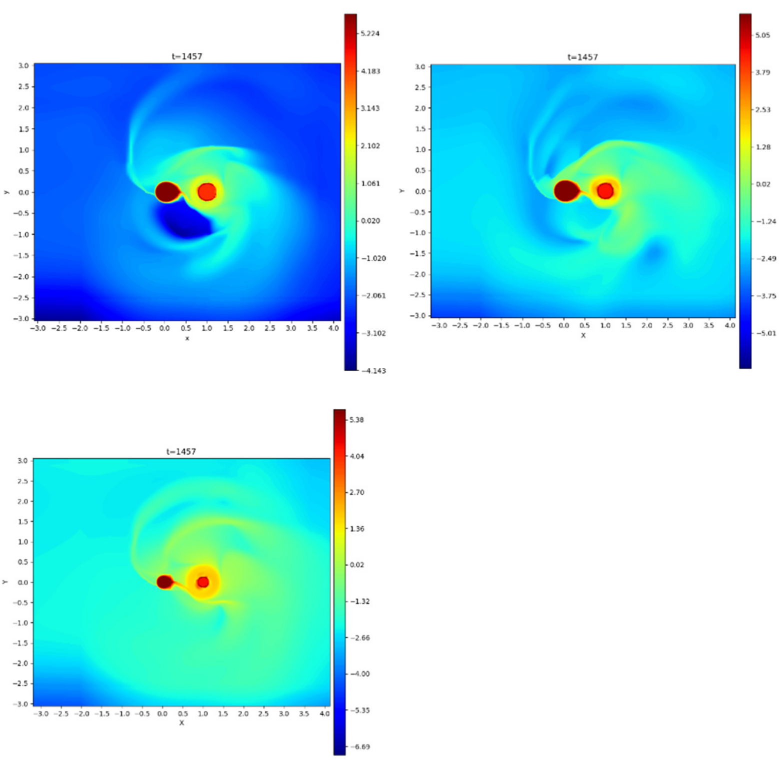

***Fig. 1**. 3-D hydrodynamic simulations of the mass-transfer and gas flow in the oEA systems RZ Cas (left), TW Dra (center) and AS Eri (right). This figure shows the particle density scale and the orbital plane (X-Y) cross section, based on Mkrtichian and Nazarenko.[6]).*

3 THE THASSOS SURVEY

Since the discovery of the class, >70 oEA-type systems have been found [3], mostly via ground-based photometry. In 2014–2019 at NARIT we carried out the photometric and the spectroscopic THAi Sky Survey of oEA Stars (THASSOS) in order to detect new oEA stars and to study their orbital, stellar, and pulsation parameters. For the photometric search for pulsations, we used the Thai Robotic Telescope Network of 70 cm telescopes located at different geographic longitudes (in Australia, China and the USA), and 60 cm Thai telescope PROMPT8 at CTIO (Chile). In total, 9 Algol-type systems were systematically monitored photometrically, and we discovered short-period pulsations in four of them, namely GQ TrA [7], VY Hya [8], UW Vir [9] and TT Vel [10]. For the THASSOS spectroscopic survey, we used the fiber-fed medium resolution (R=20,000) MRES echelle-spectrometer attached to the 2.4m Thai National Telescope at Mt. Doi Intanon (2450m). Our survey target list consisted of 15 known oEA systems, and for the majority of them we got complete orbital phase coverage. In particular, we got precise orbits for AS Eri, RX Hya and R CMa; the analysis of the spectra of the remaining target stars is ongoing.

4 THE TESS ALL-SKY SURVEY FOR oEA STARS

On 19 April 2018 NASA's Transiting Exoplanet Survey Satellite (TESS) was launched. During the 2018–2020 primary mission, TESS observed southern and northern hemisphere stars with its four wide-field cameras. We used the TESS 2-min cadence light curves of Algol stars for a massive all-sky survey aimed at detecting and studying new oEA stars. The open-access TESS light curve data were prepared by TESS Science Team, and we downloaded them from the Mikulski Archive for Space Telescopes (MAST). The out-of-eclipse light curves of all Algol-system with A-F primary components were consecutively analyzed. The pulsation spectra of newly discovered oEA stars have been analyzed in detail. The survey is ongoing, and detailed results of the discoveries of individual systems will be published in forthcoming papers. Here we briefly report preliminary results. To date, using the TESS data we have detected and classified 47 new oEA and 10 new δ Scuti stars in eclipsing binary systems. Figure 2 shows part of the light curve of the newly discovered oEA star V438 Vel. We investigated the pulsational spectra of previously known pulsators in AS Eri [11] and U Gru [12], and currently other discovered oEA stars are under analysis.

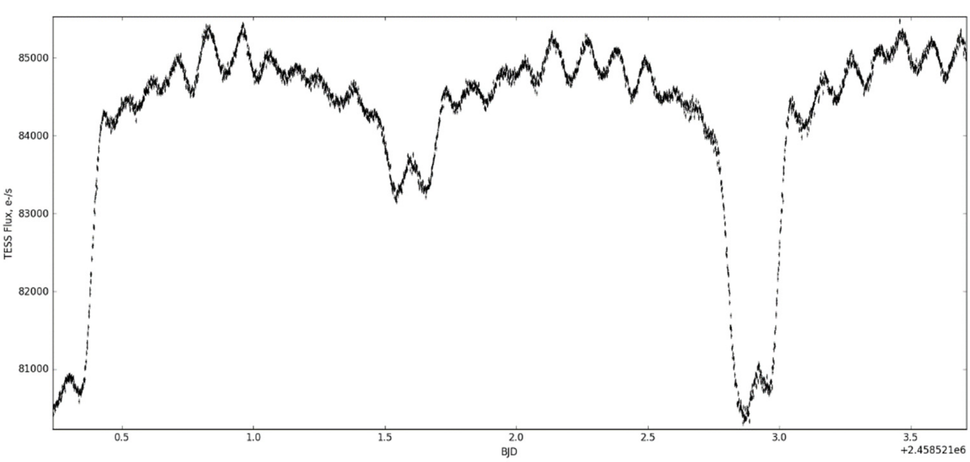

Fig. 2. The light curve of V438 Vel from the TESS space telescope. The high amplitude 0.132-day pulsations are clearly visible.

5 THE SALT SPECTROSCOPIC SURVEY OF SOUTHERN oEA STARS

The oEA stars are expected to be seen equator-on, which is the optimal inclination for the detection of sectoral (l = m) non-radial pulsations that have their greatest amplitudes around the stellar equator. Note that these high-degree (l,m>5) modes in photometric light variations have several orders of magnitude lower apparent amplitudes compared to low-degree mode (l,m<4) and are almost invisible in disk-integrated light. Indeed, the high-degree modes can be detected spectroscopically through variations of rotationally broadened line profiles. The detection of high-degree oscillation modes is important for asteroseismic analyses, as the small rotational period variations of pulsating mass-accreting components can be precisely measured using the Doppler effect [3]. These apparent variations have an effect on pulsation frequencies and are m-dependent. Thus, using variations in the frequencies of high-degree modes the accretion-driven timely variations in the rotation of the outer envelope can be precisely measured.

Our high-resolution spectroscopic survey of Southern oEA stars began in 2017 using the South African Large Telescope (SALT) at Sutherland Observatory, South Africa. We used the dual-beam fiber-fed high-resolution (R=40,000) echelle spectrograph HRS. The purpose of this on-going project is to extend the spectroscopic studies of non-radial pulsations to fainter equatorial and southern oEA stars; to find their accurate binary orbits and the parameters of the components; to detect and identify high-degree modes invisible in photometric studies; and to study the spectroscopic effect of the mass-transfer and accretion.

High-resolution spectroscopic time series of oEA stars have been reduced and analyzed using the Least Square Deconvolution (LSD) code of Glazunova et al. [16], allowing us to get a mean spectral line profile and increase the signal to noise ratio. The line profiles have been analyzed for the existence of non-radial pulsations. The survey data and the mode identification are still under investigation. Figure 3 shows the typical high-degree non-radial pulsation in line profile variations of oEA star VY Hya discovered during THASSOS survey.

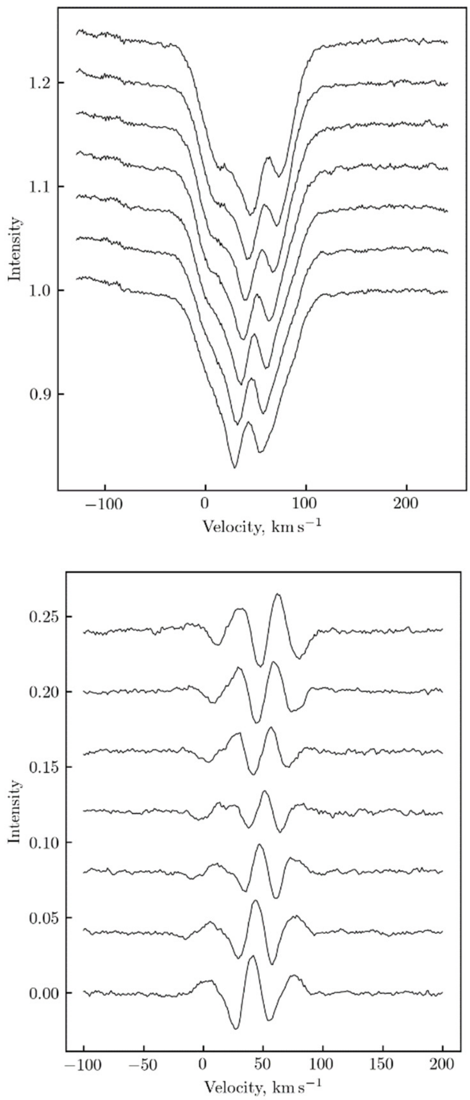

Fig. 3*. The discovery of high-degree prograding non-radial mode pulsations in VY Hya. Left: Line-profile variations in LSD profiles. Right: Line-profile variations in the residual profiles.*

6 CONCLUSIONS

We carried out photometric and spectroscopic ground-based surveys and used TESS space telescope data for an all-sky search for new oEA stars. We discovered about 50 new oEA stars and did follow up spectroscopic observations of new oEA stars with the 2.4m Thai National and the SALT telescopes. We found that the excitation of high-degree non-radial pulsations is a common phenomenon and co-exists with a wide spectrum of low-degree modes in oEA stars. We carried out 3-D hydrodynamic simulations for several oEA systems in order to study the influence of the mass-transfer rate on the spatial structure of gas flows in the systems.

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