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V2653 Ophiuchii with a pulsating component and $P_{puls} - P_{orb}$, $P_{puls} - g$ correlations for γ Dor type pulsators

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HIGHLIGHTS

- We present new spectroscopic observations of binary V2653 Oph.
- We estimate the membership of the open cluster Collinder 359.
- Using the photometric data we have made frequency analysis.
- We find empirical relations that Ppuls Porb and Ppuls log g.
- We present the underlying physics behind the correlations.

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ABSTRACT

We present new spectroscopic observations of the double-lined eclipsing binary V2653 Ophiuchii. The photometric observations obtained by *ASAS* were analyzed and combined with the analysis of radial velocities for deriving the absolute parameters of the components. Masses and radii were determined for the first time as $M_p = 1.537 \pm 0.021\ M_\odot$ and $R_p = 2.215 \pm 0.055\ R_\odot$, $M_s = 1.273 \pm 0.019\ M_\odot$ and $R_s = 2.000 \pm 0.056\ R_\odot$ for the components of V2653 Oph. We estimate an interstellar reddening of 0.15 ± 0.08 mag and a distance of 300 ± 50 pc for the system, both supporting the membership of the open cluster Collinder 359. Using the out-of-eclipse photometric data we have made frequency analysis and detected a periodic signal at 1.0029 ± 0.0019 c/d. This frequency and the location of the more massive star on the HR diagram lead to classification of a γ Dor type variable. Up to date only eleven γ Dor type pulsators in the eclipsing binaries have been discovered. For six out of 11 systems, the physical parameters were determined. Although a small sample, we find empirical relations that $P_{puls} \propto P_{orb}^{0.43}$ and $P_{puls} \propto g^{-0.83}$. While the pulsation periods increase with longer orbital periods, they decrease with increasing surface gravities of pulsating components and gravitational pull exerted by the companions. We present, briefly, the underlying physics behind the correlations we derived.

1. Introduction

Main-sequence and subgiant stars of spectral type A to F in detached and semi-detached eclipsing binaries are very interesting targets for asteroseismic studies, i.e., the determination of the boundaries of instability strip by interpreting the observed oscillation characteristics. Indeed, eclipsing binaries containing A–F stars offer the possibility of determining accurate masses and radii for the components. Unique advantage is if the binary resides in a cluster, determination of the fundamental properties and, in particular for systems belonging to the open clusters, can be used to address relevant astrophysical issues, such as chemical compositions, age and the distance of two stars with accurate masses and radii, allowing a much more discriminating test of physical ingredients of theoretical models.

We present a study of the detached *Algol* type eclipsing binary, which is probably a member of the open cluster Collinder 359 (Zejda et al., 2012). We have obtained complete light curves from the photometry obtained by *Hipparcos* (Perryman et al., 1997) and All Sky Automated Survey, ASAS, (Pojmanski, 2002). We have also obtained an extensive spectroscopy using the FRESCO échelle spectrograph at the telescope of Catania Astrophysical Observatory.

Ochsenbein (1980) measured the visual magnitude of 8.90 mag with a precision of one tenth of a magnitude and a color of G5 using "microfiche" photographic observations for V2653 Oph. The eclipsing character of V2653 Oph (HD 162811;BD+03°3514; HIP 87511; V = 9.49, B-V = 0.60 mag)[1] was discovered by the *Hipparcos* satellite mission, the primary eclipse having an amplitude of 0.09 mag. The depth of the secondary minimum is nearly equal to that of the

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[1] Adopted from the SIMBAD astronomical data base.

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primary one. The first eclipse light curve was roughly revealed by the *Hipparcos* observations. Kazarovets et al. (1999) designated it as V2653 Oph in the 74TH NAME-LIST OF VARIABLE STARS, and classified it as an eclipsing binary. In recent years, large-scale photometric surveys, such as All Sky Automated Survey (ASAS) (Pojmanski, 1997), *MOST*(Walker et al., 2003), *CoRot*(Baglin et al., 2009), *Kepler* (Gilliland et al., 2010) etc., have been conducted with the main aim of looking for transiting exoplanets. The valuable by-product of this search has been the very large number of well sampled eclipsing binary light curves. One of the eclipsing binaries observed at the Las Campanas Observatory as part of the ASAS was V2653 Oph. Yet the astrophysical parameters are not obtained for the system.

2. Observation and data reduction

The 91cm telescope of the Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Catania (INAF–OACT) was used to carry out spectroscopy of the target. Details of the telescope and the echelle spectrograph are given by Çakırlı et al. (2008). Observations were carried out during eleven nights between 21 June–05 July 2008. Exposure times were fixed for target star at 2400 s.

The reduction of the spectra was done by using the NOAO/IRAF package.[2] The *Th-Ar* emission line spectra were used to calibrate the wavelength references of each observations. The S/N ratio of the spectra was at least ∼90.

Photometric observations of the system obtained and published in ASAS-3 were used to construct the V-band light curve. For calculation of the orbital phases we tried to improve a better epoch and an orbital period for the system. An orbital period of about 4.394 days was estimated from the photometric observations of the system by the *Hipparcos* mission. We searched for orbital period using data combined from the *Hipparcos* and ASAS surveys. Analysis of Variance (AoV) algorithm developed by Schwarzenberg-Czerny (1989) and implemented in the VarTools light curve analysis program (Hartman et al., 2008) was used for detection of sharp periodic signals. We obtained the period and *False Alarm Probability* of peaks which are significant at a level greater than 3σ. We detect significant peaks in the power spectra at periods between 2–5 days, the most significant being at 4.39 days. We improved the light elements of the system using the Wilson–Devinney code (Wilson and van Hamme, 2003). The light and radial velocity curve of the system is phased with the following ephemeris and period:

$$T_{\rm minI} = 2453189.668(58) + 4^{d}.3942894(48) \times E. \quad (1)$$

The orbital period is very close to that estimated by Otero et al. (2005). The radial velocities and photometric observations were phased using these light elements.

3. Spectroscopic data

3.1. Radial velocity analysis

Radial velocities (RV) of the components were derived with a standard cross correlation algorithm, IRAF's tool FXCOR. We used the wavelength interval 4500 – 5000 Å, which is rich in metallic lines. As cross correlation template, we chose the nearby primary target ι Psc (F7 V) of similar spectral type and we used, for reference, as the RV standard. The radial velocities of the components were derived by fitting two Gaussian curves with the FXCOR function and presented in Table 1. The radial velocities were analysed using the RVSIM software program (Kane et al., 2007). The parameters are presented in Table 2 and the fits are compared with the observations in Fig. 1.

[2] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc.

Table 1
Heliocentric radial velocities of V2653 Oph. The columns give the heliocentric Julian date, orbital phase and the radial velocities of the two components with the corresponding standard deviations.

HJD–2400000	Orbital	V2653 Oph			
	phase	V_P	σ	V_S	σ
54638.34598	0.6729	84.2	0.6	−83.2	0.7
54639.33703	0.8984	44.2	0.9	−55.4	0.7
54640.33176	0.1248	−81.2	1.1	55.6	1.1
54641.34108	0.3545	−81.2	0.9	51.4	0.4
54642.34823	0.5837	50.1	1.1	−55.3	1.1
54643.35360	0.8124	81.5	1.0	−84.3	0.6
54644.38749	0.0477	−41.3	1.4	21.2	0.7
54647.37993	0.7287	92.4	0.7	−88.5	0.7
54649.36320	0.1800	−100.2	0.8	66.5	1.2
54651.35779	0.6339	71.4	0.8	−71.2	1.3
54654.34120	0.3129	−95.6	0.7	66.2	1.1

Table 2
Results of the radial velocity analysis for V2653 Oph.

Parameter	V2653 Oph	
	Primary	Secondary
K (km s^{-1})	83 ± 1	93 ± 1
V_γ (km s^{-1})	−8.41±0.43	
Average O-C (km s^{-1})	0.5	0.9
$a\sin i$ ($R_\odot$)	15.9 ± 0.1	
$M\sin^3 i$ ($M_\odot$)	1.50 ± 0.10	1.25 ± 0.18
e	0.0	

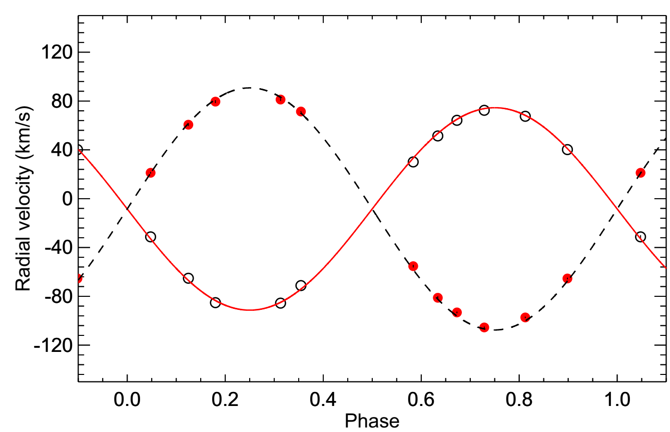

Fig. 1. Radial velocities phased with the Eq. 1 of the primary (open circles) and secondary (red filled circles) component of V2653 Oph. Error bars are shown by vertical line segments, which are smaller than symbol sizes. The solid and dashed lines are the computed radial velocity curves for the component stars. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

3.2. Determination of the atmospheric parameters

The width of the cross-correlation function (CCF) is a good tool for the measurement of $v\sin i$ of a star. We used a method developed by Penny (1996) to estimate the $v\sin i$ of each star composing the investigated double–lined eclipsing binary system from its CCF peak by a proper calibration based on a spectrum of a narrow-lined star with a similar spectral type. The rotational velocities of the components were obtained by measuring the FWHM of the CCF peak related to each component in five high-S/N spectra acquired near the quadratures, where the two spectra have the largest relative difference in radial velocity. The CCFs were used for the determination of $v\sin i$ through a calibration of the full-width at half maximum (FWHM) of the CCF peak as a function of the $v\sin i$ of artificially broadened spectra of a slowly rotating standard star (ι Psc, $v\sin i \simeq$3 km s^{-1}, e.g., by