β-CEP PULSATOR IN THE ECLIPSING BINARY V381 CAR: MODE IDENTIFICATION AND SEISMIC MODELLING

A. Miszuda[1], J. Daszyńska-Daszkiewicz[1] and W. Szewczuk[1]

Abstract.

We re-determine the binary orbit of the single-line eclipsing binary V381 Car. After subtracting the fitted eclipse light-curve, we performed a Fourier analysis in each Strömgren passband. We found 5 independent frequencies, and made mode identifications from the photometric observables and from the spectroscopic IPS diagrams. We identified three frequencies; ν_1 and ν_2 are prograde quadrupole modes, and ν_4 is a dipole zonal mode. Another two frequencies were most probably higher-degree modes.

We constructed preliminary seismic models to fit the dominant frequency and to investigate instability of the whole frequency range observed.

Keywords: stars: early-type, oscillations, binaries: eclipsing,

1 Introduction

HD 92024 (B1 III) is a single-lined (SB1) eclipsing binary with $m_V = 9.02$ mag, located in the open cluster NGC 3293. It was found by Balona (1977) that the system undergoes eclipses and that its light exhibits variations of β Cephei type. Engelbrecht & Balona (1986) subsequently detected two oscillation frequencies, $\nu_1 = 5.640\,\mathrm{d}^{-1}$, $\nu_2 = 7.669\,\mathrm{d}^{-1}$, and after re-examining the data Engelbrecht (1986) detected a third frequency $\nu_3 = 7.17\,\mathrm{d}^{-1}$. Jerzykiewicz & Sterken (1992) acquired *uvby* photometry, and confirmed ν_1 and ν_3. The authors derived an orbital period, $P = 8.3245 \pm 0.0001$ d, for the system

Freyhammer et al. (2005) observed V381 Car for 15 nights between 2002 December and 2003 April. We combined those data with previous observations from Jerzykiewicz & Sterken (1992) and Engelbrecht & Balona (1986), and collected 1617 observational points through *uvy* filters and 1690 through a *b* filter. With the FEROS echelle spectrograph we also acquired 103 high-resolution spectra, and found that V381 Car is an SB1 system. We derived the parameters of the system by combining the spectroscopic and photometric data. The primary has a mass of about 15 $M_\odot$, while the secondary has a much lower mass ($\sim 3\ M_\odot$) and contributes only about 2% to the total flux.

2 Binary modelling and pulsational analysis

Using observations collected by Freyhammer et al. (2005), we recalculated the binary model. Since we did not acquire any new observations we used orbital parameters from Freyhammer et al. (2005) to correct the photometric observations for variability caused by orbital motion. The contribution of the secondary to the total light is only about 2%, so we could assume that the pulsations originated in the primary. In order to detect the light variations that were not affected by the secondary's contribution, we extracted from the light-curve the primary eclipses observed with the *b* filter, obtaining 1293 data points. We performed a Fourier analysis on those data points, and found 5 frequencies with S/N > 3.8 (see Table1̃). One of the frequencies that we found could be a high-order radial g mode.

2.1 Mode identification

Following the mode identification technique based on phase differences and amplitude ratios from multi-colour photometry (see e.g. Balona & Stobie 1979; Stamford & Watson 1981; Daszyńska-Daszkiewicz et al. 2002), we attempted to determine the spherical harmonic degree for each frequency. In this study we used a set of

[1] Astronomical Institute, University of Wrocław, ul. Kopernika 11, 51-662 Wrocław, Poland

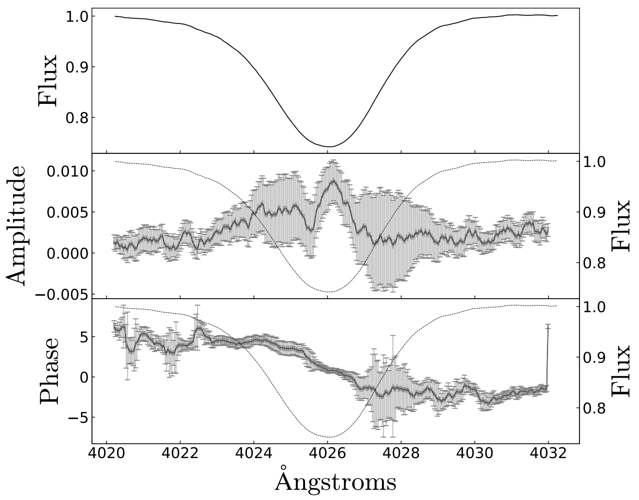

Fig. 1. IPS diagram calculated for the He I line $\lambda\,4026.191$ Å. The mean profile is shown in the top panel; amplitude and phase diagrams for the ν_1 frequency are in the middle and bottom panels, respectively.

	Frequency	S/N	ℓ	m
ν_1	5.6406	7.4	2	+1, +2
ν_2	6.6563	6.1	2	+1, +2
ν_3	8.1624	5.7	2,4,6	–
ν_4	0.5117	4.9	1	0
ν_5	1.0703	3.9	2,4,6	–

Table 1. Frequencies of V381 Car extracted from the Strömgren b passband (second column). The signal-to-noise ratio and the results of the mode identifications are given in the last three columns. The angular degree ℓ was obtained from photometry, and the azimuthal order (m) from spectroscopy.

evolutionary and oscillation models along with Strömgren photometry. Only for three out of five frequencies did we find an unambiguous identification of ℓ (see Table 1).

To determine the azimuthal order (m), we constructed IPS diagrams (Intensity Period Search diagrams, see Gies & Kullavanijaya 1988; Telting & Schrijvers 1997). We analysed 10 smoothed points in the He I (4026.191 Å) line (see Fig 1). From phase changes along the profile of that line we determined that ν_1 and ν_2 are prograde modes, while ν_4 is a zonal mode. We were not able to identify m for ν_3 and ν_5. The results of all the mode identifications are given in Table 1.

2.2 Seismic modelling

In order to find the best seismic models we calculated a grid of models with masses in the range $M = 13.1$–$15.3\,M_\odot$ in incremental steps of $dM = 0.2\,M_\odot$, rotation $V_{\rm rot} = 70$–$150\,{\rm km\ s^{-1}}$, with steps of $dV_{\rm rot} = 10\,{\rm km\ s^{-1}}$, and overshooting from the convective core, $f_{\rm ov}$, taking the values 0.01–0.04, with $df_{\rm ov} = 0.01$. We assumed an initial hydrogen abundance $X_0 = 0.71$ and metallicity $Z = 0.02$. The value of the metallicity was chosen to be equal to Z derived for NGC 3293 which hosts V381 Car (Trundle et al. 2007).

Frequency $\nu_4 = 0.5117$ is the centroid mode, so at first a set of models fitting this frequency was selected. Unfortunately, frequencies ν_1 and ν_2 do not have unambiguous identification of m, therefore instead of fitting models to the centroid we have to consider different m values. Using $\nu_m \approx \nu_0 + m\nu_{\rm rot}$ one can impose a condition that $|m_1|(\nu_{1,obs} - \nu_{1,m_1}) = |m_2|(\nu_{2,obs} - \nu_{2,m_2})$ where m_1 and m_2 are equal to 1 or 2. From our set of models only three of them met our condition with an accuracy better than 0.01. We found that $V_{\rm rot} \geq 100\,{\rm km\ s^{-1}}$and $f_{\rm ov} \geq 0.02$ are preferred.

3 Conclusions

This work presented an analysis of multi-colour photometric and spectroscopic data of the eclipsing binary V381 Car. We re-determined the observed frequencies, identified the mode degree (ℓ), and determined constraints on the azimuthal order (m) for three out of the five frequencies observed.

We constructed preliminary seismic models, and obtained some promising results, especially some constraints on rotation and overshooting from the convective core. However, in order to reproduce fully the pulsational observables we will have to extend our studies.

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References

Balona, L. A. 1977, MmRAS, 84, 101

Balona, L. A. & Stobie, R. S. 1979, MNRAS, 189, 649

Daszyńska-Daszkiewicz, J., Dziembowski, W. A., Pamyatnykh, A. A., & Goupil, M. J. 2002, A&A, 392, 151

Engelbrecht, C. A. 1986, MNRAS, 223, 189

Engelbrecht, C. A. & Balona, L. A. 1986, MNRAS, 219, 449

Freyhammer, L. M., Hensberge, H., Sterken, C., et al. 2005, A&A, 429, 631

Gies, D. R. & Kullavanijaya, A. 1988, ApJ, 326, 813

Jerzykiewicz, M. & Sterken, C. 1992, MNRAS, 257, 303

Stamford, P. A. & Watson, R. D. 1981, Ap&SS, 77, 131

Telting, J. H. & Schrijvers, C. 1997, A&A, 317, 723

Trundle, C., Dufton, P. L., Hunter, I., et al. 2007, A&A, 471, 625