Serb. Astron. J. № 184 (2012), 77 - 82
DOI: 10.2298/SAJ1284077L

UDC 524.384 : 524.386
Original scientific paper

WASP LIGHT CURVE OF THE ECLIPSING BINARY VZ CVn

O. Latković

Astronomical Observatory, Volgina 7, 11060, Belgrade, Serbia
E–mail: *olivia@aob.rs*

(Received: November 9, 2011; Accepted: February 29, 2012)

SUMMARY: The WASP light curve of the eclipsing binary VZ CVn, consisting of more than 14000 individual observations, is analyzed for photometric elements using the modeling code of Djurašević (1992). The spectroscopic parameters are adopted from the recent radial velocity work by Pribulla et al. (2009). The results of the study include new times of minimum light, an improved ephemeris, and the updated physical and orbital parameters of the system.

Key words. binaries: eclipsing – binaries: spectroscopic – stars: individual: VZ CVn

1. INTRODUCTION

The study of eclipsing binary stars is of great importance to astronomy as a whole, since they are our primary sources of empirical measurements of the properties of stars. In eclipsing binaries which also have double-lined spectra, the masses and radii can be measured to high precisions using purely geometrical arguments. Spectroscopic eclipsing binaries are excellent distance indicators both within our Galaxy and on extragalactic scales. While detached systems provide the best opportunities for testing the theory of stellar structure and evolution, close systems give us the unique chance to study tidal interactions and phenomena related to mass transfer and mass loss, such as the formation of accretion disks and circumbinary shells.

VZ CVn (HD 117777, HIP 66017) is a bright ($V_{\rm max} = 9.35$), eclipsing binary first discovered to be a variable by Strohmeier and Knigge (1960). Strohmeier et al. (1962) classified it as a β Lyrae system with an orbital period of 0.842 d, and it has been a target of photometric studies by Harris (1968), Ibanoğlu (1974), and Cester et al. (1977) that revealed the presence of intrinsic variability in the light curve. Ibanoğlu et al. (2007) detected γ Dor type oscillations on the primary component.

The first spectroscopic observations and radial velocity curves of VZ CVn were presented by Popper (1988), who classified the components as main sequence F2 and F8 stars but obtained anomalously large masses from the study of the radial velocity curves: $M_h \sin^3 i = 1.76 \pm 0.06 M_\odot$ and $M_c \sin^3 i = 1.37 \pm 0.03 M_\odot$. More recently, Pribulla et al. (2009) obtained the radial velocities and the spectroscopic parameters for the system using the Broadening Function method which yielded a lower total mass of the system, $(M_h + M_c) \sin^3 i = 2.676 \pm 0.007 M_\odot$. They also recommended the binary as a prime candidate for continuous, satellite photometric observations.

I analyze the WASP (Wide Angle Search for Planets) light curve of VZ CVn for photometric elements of the system, using the up-to-date spectroscopic parameters from Pribulla et al. (2009). The photometric data consists of more than 14000 individual measurements taken from 2004 and 2007. Detailed description of WASP instruments and the process of data reduction and cleaning is given in Section 2. New times of minimum light and an improved ephemeris are reported in Section 3, and the light curve is fitted with a binary star model by Djurašević (1992, 1998) in Section 4. The results are compared with previous studies in Section 5. Finally, in Section 6, I discuss the suitability of the WASP light curve of VZ CVn for the study of stellar oscillations, and I summarize my findings in Section 7.

2. WASP OBSERVATIONS

The photometric data used for this study comes from the WASP project dedicated to detection of transiting extra-solar planets (Pollacco et al. 2006). WASP operates two facilities, one in La Palma (SuperWASP-N) and one in South Africa (SuperWASP-S). Both instruments consist of eight small, wide-field telescopes on a common mount. All the telescopes use Canon 200mm telephoto lenses, and each is equipped with a custom filter resembling g+ r (Fukugita et al. 1996), and an e2v $2k \times 2k$ CCD camera. The data is reduced by a dedicated data analysis pipeline (Pollacco et al. 2006) which performs aperture photometry in three software apertures and then applies the SYSREM detrending algorithm (Tamuz et al. 2005) to the photometry from the second aperture.

The WASP light curve of VZ CVn has 14515 data-points observed from 2004 to 2007. The detrended data was used for the analysis after being cleaned of extreme outliers by iterative sigma-clipping at the 4σ level, reducing the data-set to 13377 data-points.

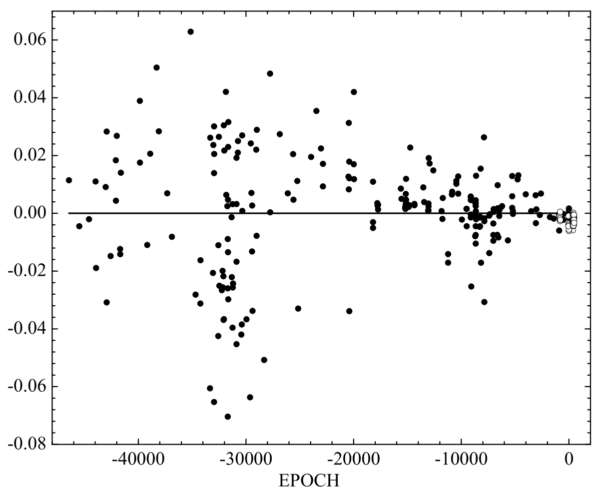

Fig. 1. *The O-C residuals between the times of minimum light and the best fitting ephemeris. Times of minimum light taken from the literature are marked with full circles, and those calculated from WASP data as a part of this study are marked with open circles.*

3. PERIOD DETERMINATION

All available times of minimum light of VZ CVn were collected from the literature by Ibanoğlu et al. (2007), who found no evidence supporting period variability. I measured another set of 60 minima from the WASP data (given in Table 1), and used the ephemeris from Ibanoğlu et al. (2007) to determine the preliminary cycle number of each minimum and compute its O-C, to which a straight line was fitted, resulting in the following ephemeris:

$$MinI = HJD\ 2453860.3913(2) + 0.84246184(3) \times E$$

The O-C diagram with the new ephemeris is plotted in Fig. 1 and there is no indication of any form of period change. Since the secondary minima show no departure from phase 0.5, I also conclude that the eccentricity of the system is negligible.

Table 1. Times of minimum light from WASP data.

JD+2450000	Type	JD+2450000	Type
3129.5547(4)	II	4158.6200(2)	I
3132.5033(2)	I	4161.5712(3)	II
3135.4522(2)	II	4163.6758(2)	I
3137.5575(2)	I	4166.6237(3)	II
3138.4003(3)	I	4169.5688(8)	I
3146.4040(2)	II	4171.6797(3)	II
3151.4583(4)	II	4190.6324(2)	I
3154.4068(2)	I	4191.4788(4)	I
3156.5121(3)	II	4195.6893(7)	I
3159.4610(2)	I	4204.5340(4)	II
3162.4091(2)	II	4206.6420(4)	I
3167.4665(3)	II	4210.4303(3)	II
3170.4148(2)	I	4212.539(1)	I
3175.4688(2)	I	4214.6462(7)	II
3194.4226(7)	II	4215.4867(3)	II
3829.637(2)	II	4217.5921(7)	I
3830.483(2)	II	4218.4356(2)	I
3832.585(2)	I	4220.5419(5)	II
3833.4291(2)	I	4222.6459(6)	I
3853.6457(3)	I	4223.4903(2)	I
3854.4882(7)	I	4226.4388(3)	II
4120.7089(4)	I	4228.5432(6)	I
4123.6575(4)	II	4231.4930(2)	II
4141.7713(3)	I	4234.4408(2)	I
4142.6139(5)	I	4236.5480(9)	II
4147.6694(3)	I	4247.5022(8)	II
4150.6169(8)	II	4250.4496(2)	I
4152.7248(4)	I	4252.5547(5)	II
4153.5649(3)	I	4263.5064(4)	II
4155.6704(4)	II	4266.4560(3)	I

4. LIGHT CURVE ANALYSIS

The analysis of the light curve was done using the modeling program of G. Djurašević (Djurašević 1992, see also Djurašević et al. 1998). The model of the binary is based on Roche geometry and the light curve fitting procedure is based on the simplex algorithm. The fitting is done through an iterative cycle of corrections to model parameters, minimizing the sum of squared residuals between the observed and the synthetic light curve, $\Sigma(O-C)^2$.

I adopted the values of the mass ratio ($q = M_c/M_h = 0.8252$) and separation ($a_{orb} = 5.2937 R_\odot$) from the radial velocity study by Pribulla et al. (2009), and the temperature of the hotter component (T_h = 7000 K) from the study of the binary by Ibanoğlu et al. (2007). The values for the bolometric albedo and the gravity darkening exponents were kept fixed at their theoretical values: $A_h = 1.0$ and $\beta_h = 0.25$ (von Zeipel 1924) for the primary, for which I assume a radiative envelope, and $A_h = 0.5$ and $\beta_h = 0.08$ (Lucy 1967) for the secondary, for which I assume a convective envelope, according to the estimated effective temperatures from the study by Ibanoğlu et al. (2007).

Limb darkening was applied using the nonlinear approximation of Claret (2000) and tables of limb darkening coefficients calculated for the WASP passband by A. Prša[1]. The coefficients are interpolated at each iteration for the current values of the effective temperature and the surface gravity. The details of this procedure are explained in Djurašević et al. (2004).

The results of fitting are given in Table 2. The errors for the adjusted parameters were estimated by running the fitting procedure with the minimal and maximal values for the mass ratio as obtained by exaggerating the uncertainties reported by Pribulla et al. (2009) by an order of magnitude (in order to allow for a greater range of possible solutions), and by adopting the deviation of parameter values between these solutions as a measure of uncertainty. The errors for the absolute system parameters are then derived analytically from the errors of model parameters.

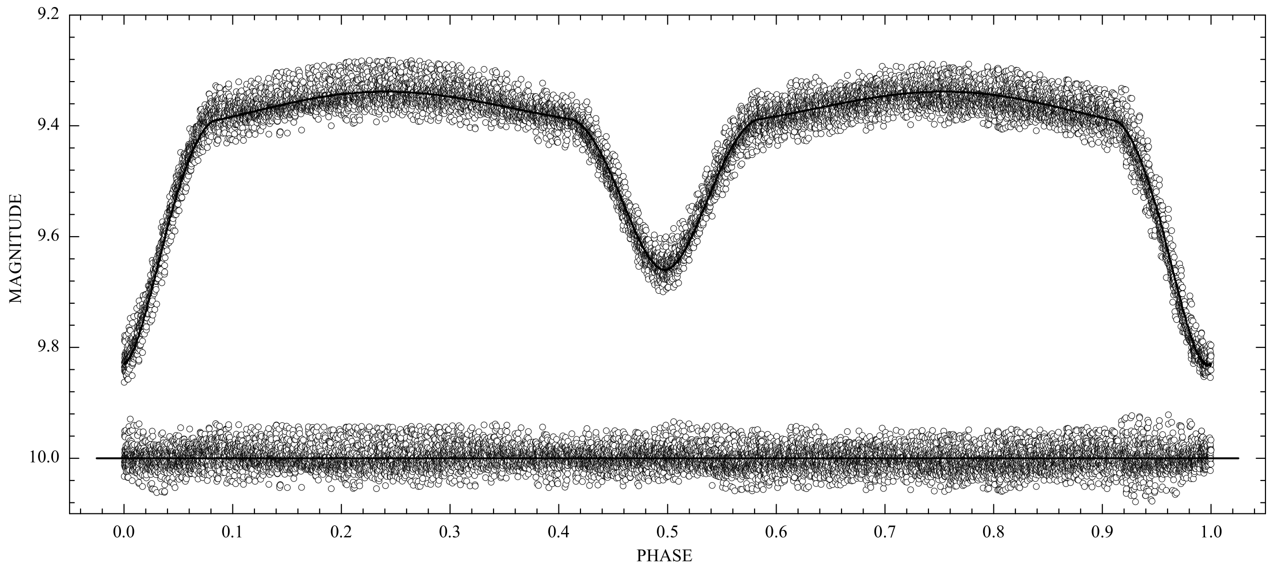

Fig. 2. *The WASP light curve of VZ CVn (open circles) and the best fit from our model (black line), with the residuals shifted from zero and plotted at the bottom.*

[1] http://phoebe.fiz.uni-lj.si/?q=node/110

Table 2. Physical and orbital parameters of VZ CVn.

Data and fit	
Number of observations	13377
$\sum(O-C)^2$	5.4178
σ	0.0201
Fixed parameters	
$q(M_c/M_h)$	0.8252±0.002
$a_{\rm orb}[R_\odot]$	5.2937±0.005
$T_h[K]$	7000±100
A_h	1.0
A_c	0.5
β_h	0.25
β_c	0.08
$f_h = f_c$	1.0
Adjusted parameters	
$i[^o]$	79.4±0.1
T_c[K]	6120±40
F_h	0.783±0.005
F_c	0.678±0.005
Ω_h	4.224±0.003
Ω_c	4.638±0.002
Absolute system parameters	
$R_h[R_\odot]$	1.58±0.04
$R_c[R_\odot]$	1.24±0.03
$M_h[M_\odot]$	1.54±0.05
$M_c[M_\odot]$	1.27±0.04
$\log(g_h)$	4.23±0.07
$\log(g_c)$	4.35±0.06
$M_h^{\rm bol}$	2.9±0.3
$M_c^{\rm bol}$	4.1±0.3
$L_h/(L_h+L_c)$	0.738

5. THE PHYSICAL PROPERTIES OF VZ CVn

The WASP light curve of VZ CVn and the fit obtained from the modeling are shown in Fig. 2. The light curve appears to be symmetrical with moderate out-of-eclipse variation and night-to-night variability with an amplitude of about 0.08 mag. Although the modeling code allows the inclusion of bright and dark spots and even an accretion disk, the light curve of VZ CVn is well described by the basic model, as can be seen from the relatively flat residuals in Fig. 2.

According to this model, VZ CVn is a detached system comprising two relatively similar main sequence stars. The primary was classified as F2 and the secondary as F8 by previous authors, and the parameters obtained from the model in this study are in excellent agreement with the properties of main sequence stars of those spectral types. The primary is slightly distorted due to the tidal effects, but neither component is close to filling its Roche lobe, as can be seen in Fig. 3, which shows the geometry of the system at phase 0.25.

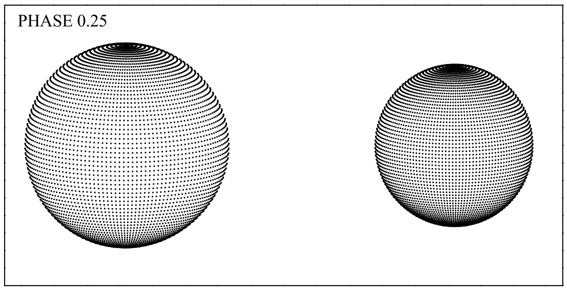

Fig. 3. *The appearance of VZ CVn at phase 0.25.*

Compared to the photometric solution of Ibanoğlu et al. (2007), which was based on spectroscopic elements from Popper (1988), and thus on an overestimated total mass of the system and an underestimated mass ratio, the solution obtained in this paper gives a smaller primary and a larger and slightly cooler secondary with a greater contribution to the total luminosity of the system. Namely, Ibanoğlu et al. (2007) obtained $L_h/(L_h+L_c) = 0.8327$ in the B filter and $L_h/(L_h+L_c) = 0.8007$ in the V filter, while the present model gives $L_h/(L_h+L_c) = 0.738$. Other differences between the solutions can be ascribed to the usage of different spectroscopic elements.

6. INTRINSIC VARIABILITY

Ibanoğlu et al. (2007) analyzed newly obtained and archival photometric data for VZ CVn in search of the evidence of pulsation, based on the position of the primary star in the HR diagram, which is inside the instability strip for γ Doradus stars. Variables of γ Dor type exhibit slow multiperiodic pulsations with 1 to 3 cycles per day and typical amplitudes around 0.015 mag. Ibanoğlu et al. searched their data for pulsation signals using conventional techniques based on the Fourier transform, and found two signals above the 4 sigma noise level, which allowed them to confirm that the primary star of VZ CVn is a pulsator of γ Dor type according to the criteria given by Henry et al. (2005).

In terms of photometric accuracy, the WASP light curve of VZ CVn should be suitable for detection of pulsational variability, since it can be used to detect shallow planetary transits. However, the data suffers from daily and other larger, irregular gaps.

Nevertheless, I attempted a frequency search in the residuals after subtracting the light curve fit from the data. To avoid the largest gaps, this analysis was limited to the data collected from January to June 2007. The Fourier periodogram for frequencies between 0 and 10 cycles per day is given in Figure 4, together with the spectral window function that displays extreme daily aliasing. In this periodogram, the dominant peak is at $\nu = 0.9659 \pm 0.0002 d^{-1}$ and has an amplitude of 0.0084 ± 0.0003 mag. This frequency coincides with the measurements of Ibanoğlu, who found a signal at $\nu = 0.9357 \pm 0.0002 d^{-1}$, although the amplitude I obtained is significantly smaller than Ibanoğlu's (0.017 ± 0.002 mag in B and 0.014 ± 0.002 mag in V filter).

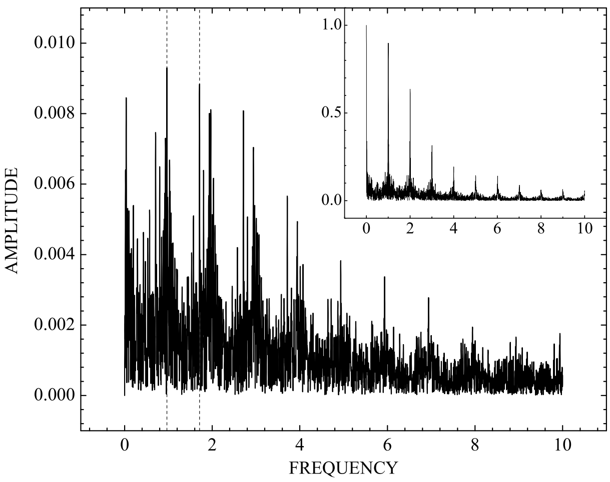

Fig. 4. *The Fourier periodogram of the residuals after subtracting the orbital solution from the light curve of VZ CVn, for the data subset observed in 2007. The spectral window function is plotted in the inset, and the frequencies of two detected signals, at 0.9659 and 1.7101 cycles per day are marked with dashed lines.*

The second highest peak in the periodogram is at $\nu = 1.7101 \pm 0.0002 d^{-1}$ with an amplitude of 0.0087 ± 0.002 mag. However, a superposition of sinusoidal signals at these frequencies and amplitudes doesn't fit the residuals well. Moreover, the difference in amplitudes of these two peaks and their sidelobes at $\pm 1 d^{-1}$ is comparable to the noise level, so these detections are questionable.

It is interesting to note that none of the peaks in the periodogram in Fig. 4 seems to correspond to the orbital period of the system (the orbital frequency is $\nu = 1.1871$), which I take as a confirmation of the excellence of the fit of the model to the observations.

7. SUMMARY

VZ CVn is a bright, detached binary consisting of an F2V primary which exhibits γ Dor variability, and a F8V secondary.

The WASP light curve of this system was analyzed in order to update the orbital parameters of the binary and the physical properties of the components. I measured 60 new times of minimum light and updated the ephemeris, confirming that the period of the system is constant.

The analysis of the light curve was based on the recent radial velocity study by Pribulla et al. (2009), which, among other results, gives a lower total mass of the system compared to previous measurements, and thus resolves the discrepancy between the masses of the components and their radiative properties, noted by Popper (1988). The photometric parameters of the system were obtained by fitting the model of Djurašević (1992) to the observations, and the residuals after subtracting the modeled light curve from the observations were further analyzed in search for intrinsic pulsational variability.

Two frequencies were detected in the data, one of which corresponds to the signal detected by Ibanoğlu et al. (2007). Although the WASP data set is rich and provides an excellent coverage of the orbital period, I repeat the recommendation given by Pribulla et al. (2009), that VZ CVn should be made a target of continuous satellite observations in order to gain a better understanding of the variability of the pulsating primary component.

Acknowledgements – The author acknowledges the support of the Ministry of Science and Education of the Republic of Serbia through the project "Stellar Physics", No. 176004.

REFERENCES

Cester, B., Mardirossian, F., Pucillo, M.: 1977, *Astron. Astrophys.*, **56**, 75.
Claret, A.: 2000, *Astron. Astrophys.*, **363**, 1081.
Djurašević, G.: 1992, *Astrophys. Space Sci.*, **196**, 241.
Djurašević, G.: 1992, *Astrophys. Space Sci.*, **197**, 17.
Djurašević, G., Zakirov, M., Hojaev, A., Arzumanyants, G.: 1998, *Astron. Astrophys. Suppl. Series*, **131**, 17.
Djurašević, G., Albayrak, B., Selam, S. O., Erkapić, S., Senavci, H. V.: 2004, *New Astron.*, **9**, 425.
Fukugita, M., Ichikawa, T., Gunn, J. E., Doi, M., Shimasaku, K., Schneider, D. P.: 1996, *Astron. J.*, **111**, 1748.
Harris, A. J.: 1968, *Astron. J.*, **73**, 164.
Henry, G. W., Fekel, F. C., Henry, S. M.: 2005, *Astron. J.*, **129**, 2815.
Ibanoğlu, C: 1974, *Astron. Astrophys. Space Sci.*, **13**, 119.
Ibanoğlu, C., Tas, G., Sipahi, E. and Evren, S.: 2007, *Mon. Not. R. Astron. Soc.*, **376**, 573.
Lucy, L. B.: 1967, *Zeitschritft fr Astrophysik*, **65**, 89.
Pollacco, D. L. et al.: 2006, *Publ. Astron. Soc. Pac.*, **118**, 1407.
Popper, D. M.: 1988, *Astron. J.*, **95**, 190.
Pribulla, T., Rucinski, S. M., Debond, H., De Ridder, A., Karmo, T., Thomson, J. R., Croll, B., Ogloza, W., Pilecki, B. and Siwak, M.: 2009, *Astron. J.*, **137**, 3646.

Strohmeier, W. and Knigge, R.: 1960, *Veroff. Remeis-Sternwarte*, **6**.
Strohmeier, W., Knigge, R., Ott, H.: 1962, *Verff. Remeis-Sternwarte*, **13**.
Tamuz, O., Mazeh, T., Zucker, S.: 2005, *Mon. Not. R. Astron. Soc.*, **356**, 1466.
von Zeipel, H.: 1924, *Mon. Not. R. Astron. Soc.*, **84**, 665.

WASP КРИВА СЈАЈА ЕКЛИПСНО ДВОЈНОГ СИСТЕМА VZ CVn

O. Latković

Astronomical Observatory, Volgina 7, 11060, Belgrade, Serbia
E–mail: *olivia@aob.rs*

UDK 524.384 : 524.386
Оригинални научни рад

Анализирала сам WASP криву сјаја еклипсно-двојног система VZ CVn, која се састоји од преко 14000 индивидуалних мерења, користећи модел Ђурашевића (1992). Спектроскопске елементе сам преузела из скорашње студије радијалних брзина коју су представили Прибула и сарадници (2009). Резултати овог рада укључују нова мерења времена минималног сјаја, исправљену ефемериду и побољшане физичке и орбиталне параметре система.