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The low mass ratio contact binary system V728 Herculis

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HIGHLIGHTS

- The multi-colour light curve of V728 Her is obtained.
- A period analysis is applied to collected times of minimum light.
- The light and radial velocity curves of V728 Her are analyzed simultaneously.
- We prove that the system is a deep, low mass contact binary.

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ABSTRACT

We present the orbital period study and the photometric analysis of the contact binary system V728 Her. Our orbital period analysis shows that the period of the system increases ($dP/dt = 1.92 \times 10^{-7}$dyr^{-1}) and the mass transfer rate from the less massive component to more massive one is 2.51×10^{-8} $M_{\odot}y^{-1}$. In addition, an advanced sinusoidal variation in period can be attributed to the light-time effect by a tertiary component or the Applegate mechanism triggered by the secondary component. The simultaneous multicolor *BVR* light and radial velocity curves solution indicates that the physical parameters of the system are $M_1 = 1.8M_{\odot}$, $M_2 = 0.28M_{\odot}$, $R_1 = 1.87R_{\odot}$, $R_2 = 0.82R_{\odot}$, $L_1 = 5.9L_{\odot}$, and $L_2 = 1.2L_{\odot}$. We discuss the evolutionary status and conclude that V728 Her is a deep ($f = 81\%$), low mass ratio ($q = 0.16$) contact binary system.

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1. Introduction

V728 Her is a member of the group of low mass ratio ($q \leq 0.25$) contact binary systems. The light variation of the system was first detected by Kurochkin (1977). The author calculated the orbital period of the system as $0^d.44625$. Nelson et al. (1988) proposed that the spectral type of the system is F3. The authors observed the light curves of the system in three filters. They also improved the orbital period value to $0^d.471302$. The *BV* light curves were published by Agerer et al. (1988) who redetermined the equatorial coordinates of the system. Samec and Butcher (1989) presented photoelectric *B* and *V* light curves. A light curve solution and a period study of V728 Her was introduced by Samec (1990). The author noticed the mass transfer from the secondary to primary component. Nelson et al. (1995) analyzed the BVI_c light curves and radial velocity curve of the system by assuming two different models. They concluded that the system is a contact binary whose components have convective envelopes. Nelson (1999) investigated the change in the orbital period and emphasized the probability of sudden or gradual increase. The system was listed by Pribulla et al. (2003) and Gettel et al. (2006) in their field contact binary catalog and bright contact binary catalog, respectively. Brát (2005) noticed the asymmetric behavior of the light curve which could not be seen in many previous studies. Christopoulou et al. (2012) noted that the previous analyses are not very reliable because of the individual peculiarities in the light of the system. Finally, Yang and Qian (2015) included the system to their statistical study of 46 deep, low mass ratio overcontact systems.

In the next section, details of our observations are explained. An investigation of variation in the orbital period of the system is presented in Section 3. In Section 4, the simultaneous analyses of light and radial velocity curves are presented. We discuss the results and give the concluding remarks in the last section.

2. New observations

CCD observations of the system were made in Cousins/Bessel *B*, *V* and *R* filters attached to the 1.22-m telescope of Çanakkale Onsekiz Mart University Observatory. The observational data cover

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Table 1
Calculated times of minimum light.

HJD	Type
2456485.47292(1)	I
2456489.48011(1)	II

5 nights between June and July 2013 (HJD 2456451.4422 to HJD 2456489.5570). 409 points in *B* filter, 378 in *V* filter and 401 in *R* filter were collected during the observations. Our mean photometric errors are 0.003 in *B* and *V*, 0.002 in *R* filters. The comparison and check stars were chosen as TYC 3081-1028-1 and TYC 3081-571-1 respectively. Observational light curves of the system are plotted in Fig. 2. Table 1 lists two times of minimum light derived by using the Kwee–van Woerden method (Kwee and van Woerden, 1956).

The light curve of the system shows magnitude difference between two maxima. The primary and the secondary minima are round bottomed and their depths are very close to each other, $-0^m.38$ and $-0^m.37$, respectively. A slight asymmetry, which is previously mentioned by Samec (1990), can be seen in the phase interval between 0.15 and 0.25.

3. Orbital period analysis

Agerer et al. (1988) improved the orbital period value of the system by using the least-squares method. Nelson et al. (1995) obtained eight minimum times and applied an orbital period analysis. Eighty times of minimum light were collected and analyzed by Samec (1990). The author indicated a drastic period increase in the *O–C* curve. Nelson (1999) fitted the *O–C* curve using the least-squares method and represented the curve by both straight line and parabola. The author noted the possibility of sudden period increase at about 2479th cycle. Nelson (1999) also mentioned that the variation could be attributed to a gradual increase in the orbital period. The times of minimum light which are obtained after the year 2000 cleared the behavior of the *O–C* curve.

We obtained two minimum times (Table 1) and collected 121 times of minimum light from the database of Czech Astronomical Society[1]. Therefore, the orbital period change of the binary was investigated by using 123 times of minimum light in total. Since the main shape of the *O–C* curve (Fig. 1) is an upward-parabola, mass transfer from the less massive (secondary) component to the more massive one is expected. In addition, a sinusoidal variation superposed on the parabola can also be seen in the *O–C* curve. The sine-like variation in which both the primary and the secondary minima follow the same trend can mainly occur as a result of two different physical phenomena: (i) the light–time effect which is observed because of the presence of an external third body and (ii) the Applegate mechanism which is generally seen in magnetically active components of binary stars.

We first analyze the data by combining mass transfer and third body assumptions. The `LITE` code (Zasche et al., 2009) which is based on the simplex algorithm was used to calculate the resulting parameters. The code solves the input data to represent it by following formula:

$$\mathrm{HJD(MinI)} = T_0 + P_0 \times \mathrm{E} + \mathrm{Q} \times \mathrm{E}^2 + \frac{a_{12}\sin i'}{c}\left[\frac{1-e'^2}{1+e'\cos\upsilon'}\sin(\upsilon'+\omega') + e'\sin\omega'\right]$$

where T_0 is the epoch for the primary eclipse, P_0 is the orbital period and *E* is the integer eclipse cycle number of the binary system.

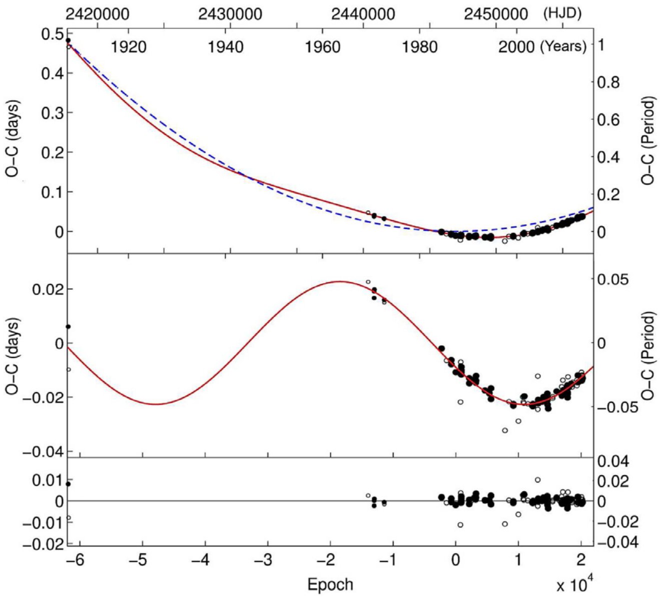

Fig. 1. Plot of the period analysis. The dashed and solid lines in the uppermost panel show the parabolic variation and the sinusoidal variation superposed on the parabola. The middle panel shows the sinusoidal fit after removal of the upward parabolic variation. We represent in the lowest panel the final residuals yielded after the analysis.

Table 2
Final results of the orbital period analysis. P' denotes the period of tertiary component. *A* and $f(m)$ refer to the semi-amplitude of the sinusoidal variation and the mass function. Formal error estimates are given in parenthesis.

Parameter	Value
T_0 (HJD)	2446949.845(2)
P_0 (d)	0.4712889(1)
Q	$1.2438(8)10^{-10}$
P' (yr)	75.9(9)
$a_{12}\sin i'$ (AU)	3.9(1.9)
A (d)	0.02(1)
$f(M)$ ($M_\odot$)	0.01(4)

The orbital parameters of the tertiary component are the semi-major axis a_{12}, the inclination of the eclipsing pair about the third body i'. υ' refers to true anomaly of the position of the center of mass. The sinusoidal variation shows that the orbital eccentricity of the third body (e') is zero, therefore, the longitude of the periastron of the binary (ω') and the time for periastron passage of the tertiary component (T_0') are undefined.

The *O–C* curve and the final fit of the solution are shown in Fig. 1. The result of the analysis shows that the increment in the orbital period is $dP/dt = 1.92 \times 10^{-7}$ dyr^{-1}. The increase in the period implies a mass transfer rate of $dm/dt = 2.51 \times 10^{-8}$ $M_\odot$yr^{-1} according the formula given by Singh and Chaubey (1986) who assumed that the mass transfer between the components is conservative. Additionally, a third companion with an orbital period of 76 years can be assigned to the sinusoidal variation. The results of the solution are listed in Table 2. The probable mass values of the tertiary component were computed as 0.9, 0.5 and 0.4 $M_\odot$ for inclination values of 30°, 60° and 90°, respectively.

Addressing the sine-like variation to the Applegate mechanism, on the other hand, requires to calculate the subsurface magnetic fields of the components. Applegate (1992) suggested that some modulations in the orbital periods of eclipsing binaries are observed because of the interactions between orbit and the shape of the magnetically active component. The Applegate mechanism

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[1] http://var.astro.cz.

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