New light curve solution of V568 Peg and first determination of its fundamental parameters

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Abstract. We present V, R_c photometric observations of the short-period W UMa star V568 Peg. They allowed us to improve its period. The light curve solution revealed that V568 Peg is an overcontact binary of A subtype with moderate fill-out factor. Its components are K stars which undergo partial eclipses. The mass ratio was estimated by q-search analysis. We established existing of big cool spot on the primary component with almost the same parameters during the last 4 years. Based on our light curve solution and the *GAIA* distance we calculated at the first time the masses, radii and luminosities of the components of V568 Peg.

Key words: binaries: close – binaries: eclipsing – methods: data analysis – stars: fundamental parameters – stars: individual (V568 Peg)

1. Introduction

The temperature difference of the components of W UMa binaries usually are around 100–300 K (only those of B subtype systems are above 1000 K) while their masses and radii may differ considerably (Binnendijk 1965, Lucy & Wilson 1979, Csizmadia & Klagyivik 2004). The model of Lucy (1968a, 1968b) explained this effect by a common convective photosphere which embedded two stars near or just above the Main Sequence. However, until now there is not a satisfactory explanation of the mechanism of energy transfer, the W phenomenon (the hotter component is the smaller star) and the internal structure of the W UMa binaries. Their future fate is also debatable issue: tight binary or merger (van Hamme 1982a,b; Li et al. 2007). The solutions of these problems requires rich statistics of well-determined global parameters of W UMa stars. The *GAIA* distances (Bailer-Jones et al. 2018) of a huge number of eclipsing binaries provide invaluable possibility for precise determination of their global parameters on the base of ground-based observations.

This paper presents V, R_c photometric observations of the short-period W UMa-type system V 568 Peg. It was observed 4 years ago in Sloan g', i' bands (Kjurkchieva et al. 2015, further on Paper I). The main goal of the new observations was to determine its fundamental parameters by the light curve solution and *GAIA* distance. This is the first study based on observations by the 10-inch Schmidt-Cassegrain telescope MEADE LX80 SC of the Shumen Astronomical Observatory.

2. Observations

The photometric observations of the target were carried out on Aug 13 2018. We used CCD camera SBIG ST-10XME (2184 × 1472 pixels, 6.8 μm/pixel). Focal reducer TS Optics f/6.3 provides increasing of the field of view from 20 × 14 arcmin with resolution 0.55 arcsec/pix to 32 × 22 arcmin with resolution 0.88 arcsec/pix (Kjurkchieva et al. 2018). The exposures in V and R_c filter were 90 s and 60 s and the mean photometric precision was 0.029 mag in both filters.

The photometric data were reduced by MaxIm DL 5. An aperture photometry was performed using four standard stars (Table 1) in the observed field whose coordinates were taken from the catalogue 2MASS (Skrutskie et al. 2006) while their magnitudes were from the NOMAD catalog (Zacharias et al. 2004).

The reduced data are accessible in the form of table as online supplemental data and at http://astro.shu.bg/V568Peg/.

Table 1. Coordinates and magnitudes of the target (V) and comparison (C) stars

Label	2MASS ID	RA	Dec	V	R_c
V	V568 Peg	23 08 13.01	+33 03 03.77	12.960	12.550
C1	23081802+3259237	23 08 18.03	+32 59 23.70	11.361	10.590
C2	23080030+3306284	23 08 00.30	+33 06 28.41	13.770	13.420
C3	23074178+3307567	23 07 41.79	+33 07 56.75	11.534	10.650
C4	23075759+3302504	23 07 57.60	+33 02 50.41	12.130	11.620

3. Light curve solution

We carried out the modeling of our data by the package PHOEBE svn (Prsa & Zwitter 2005). The observational data (Fig. 1) show that our target is an overcontact system and we modelled them using the corresponding mode "Overcontact binary not in thermal contact".

The values of target (weighting) temperature T_m=$T_1L_1/(L_1 + L_2) + T_2L_2/(L_1 + L_2)$ determined by different ways are slightly different: T_m^{BV} = 5100 K is the value from the dereddened index $(B - V)$ and relation of Sekiguchi & Fukugita (2000); T_m^{gi} = 5000 K is the value from the dereddened index $(g' - i')$ and relation of Covey et al. (2007); T_m^{JK} = 4850 K is the value from the 2MASS dereddened index $(J-K)$ and relation of Cox (2000); T_m^{G} = 4800 K is the value determined by *GAIA* DR2 (*Gaia* Collaboration 2018). The different values of target temperature may appear due at least partially to the different phases of measurement of the color indices (T_m should be determined by measurements at quadratures).

The interstellar reddening was estimated based on the following considerations. The extinction A_V in the V568 Peg direction is 0.221 mag according to the NED database (Schlafly & Finkbeiner 2011) and 0.134 mag according to the 3D model of Arenou et al. (1992) for distance 253 pc (see Section 4). The extinction values of NED refer to distance above 500–600 pc while the distance to V568 Peg is considerably smaller. It was reasonable to reduce the extinction in all colors of the NED database by the same factor 0.61(=0.134/0.221) as in V. This rule was used for estimation of all dereddened indices.

Unfortunately, there were not spectra of V568 Peg for confident temperature determination. This problem may be overcame by low-dispersion spectral observations (for instance by future low-dispersion spectrograph of the 2-m telescope at NAO Rozhen). In our case $T_m = 4900$ K was adopted as some average value of the values determined by different ways.

We fixed the primary temperature $T_1 = T_m$ and searched for best fit varying initial epoch T_0, secondary temperature T_2, mass ratio q, inclination i and potential Ω. Coefficients of gravity brightening 0.32 and reflection effect 0.5 appropriate for late stars were assumed. We used linear limb-darkening law whose coefficients were interpolated (depending on stellar temperatures and filters) according to the tables of Van Hamme (1993). In order to reproduce the O'Connell effect of around 0.065 mag (Fig. 1) we put a cool spot on the primary and varied its parameters (longitude λ, latitude β, angular size α and temperature factor κ).

The mass ratio determination of the partially-eclipsed binary V568 Peg required q-search analysis. For this aim we varied the mass ratio in a wide interval, from 0.1 to 10.0. The q-search curve (Fig. 2) exhibits two minima. The first one at $q = 0.4$ is deeper and narrower while the second one at $q = 4$ is shallower and wider. The χ^2 value for $q = 4$ is around 3 times bigger than that for $q = 0.4$. We carried out detailed investigation of the solution around $q = 4$ by varying of all parameters but reached inconsiderable decreasing of χ^2 (by several %). That is why we chose as input value $q = 0.4$. Radial velocity measurements could provide confirmation of our choice although the spectral lines of the W UMa stars are broadened and blended that leads to low-precise determination of the spectral mass ratio (Frasca 2000, Bilir et al. 2005, Dall & Schmidtobreick 2005). Unfortunately, V568 Peg is too faint for radial velocity measurements based on spectral observations by the 2-m telescope at NAO Rozhen.

After reaching the best light curve solution we adjusted the stellar temperatures T_1 and T_2 around the value T_m by the formulae (Kjurkchieva & Vasileva 2015)

$$T_1^f = T_{\rm m} + \frac{c\Delta T}{c+1}; \quad T_2^f = T_1^f - \Delta T \tag{1}$$

where the quantities $c = l_2/l_1$ (the ratio of the relative luminosities of the stellar components) and $\Delta T = T_m - T_2$ are determined from the PHOEBE solution. In fact, formulae (1) are consequence of the T_m definition given earlier.

Last fitting procedure was carried out for fixed T_1^f and T_2^f to obtain the final and self-consistent solution.

PHOEBE gives as output parameters the relative (volume) radius $r_i = R_i/a$ of each component (R_i is linear radius and a is orbital separation). One can determine the luminosity ratio $c = L_2/L_1 = l_2/l_1$ from the PHOEBE output parameter $M_{bol}^2 - M_{bol}^1$. The output potentials $\Omega(L_1)$ and $\Omega(L_2)$ allowed to calculate the target fill-out factor $f = [\Omega - \Omega(L_1)]/[\Omega(L_2) - \Omega(L_1)]$.

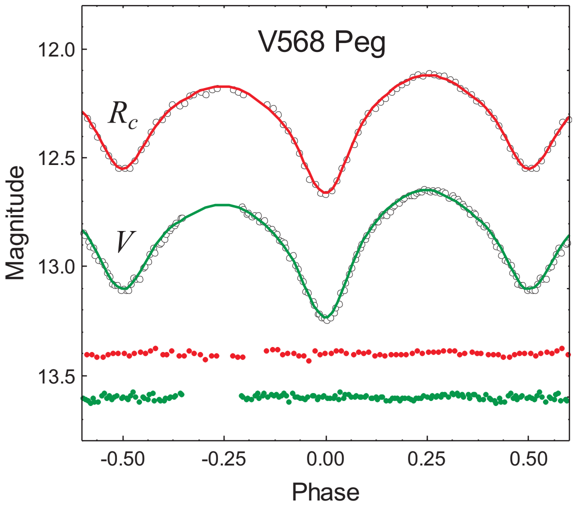

Fig. 1. Top: the folded light curves of V568 Peg and their fits; Bottom: the corresponding residuals (shifted vertically to save space)

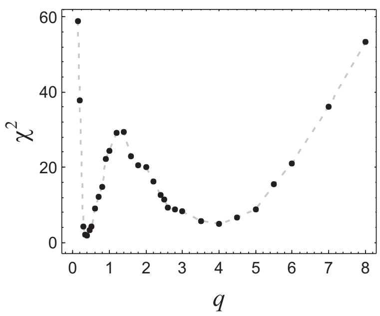

Fig. 2. q-search curve

We estimated the precision of the fitted parameters by the procedure described in Dimitrov et al. (2017).

Table 2 contains the final values of the fitted stellar and spot parameters and their uncertainties. Table 3 exhibits the calculated parameters: $r_{1,2}$, f and l_2/l_1. Their errors are determined from the uncertainties of fitted parameters. The synthetic curves corresponding to the parameters of our light curve solution are shown in Fig. 1 as continuous lines while Fig. 3 exhibits the 3D configuration of V568 Peg.

Table 2. Fitted parameters of the best light curve solution

T_0 - 2450000	P [d]	i [°]	q	T_1^f [K]	T_2^f [K]	Ω	β [°]	λ [°]	α [°]	κ	source
6925.380188(24)	0.247095(1)	76.3(1)	0.494(1)	5734(48)	5409(17)	2.786(2)	70(1)	75(1)	22.0(2)	0.85(1)	Paper I
6925.533810(14)	0.247095(2)	75.6(1)	0.403(3)	4963(30)	4713(23)	2.6343(1)	70(1)	75(1)	20.5(2)	0.88(1)	this paper

Table 3. Calculated parameters

r_1	r_2	f	l_2/l_1	source
0.462(6)	0.340(4)	0.265	0.35	Paper I
0.475(6)	0.317(9)	0.204	0.36	this paper

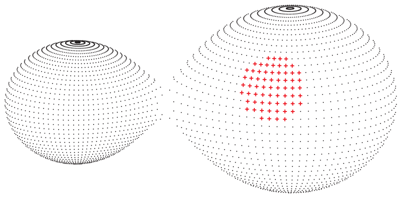

Fig. 3. 3D configuration of V568 Peg made using Binary Maker 3 by Bradstreet and Steelman (2002).

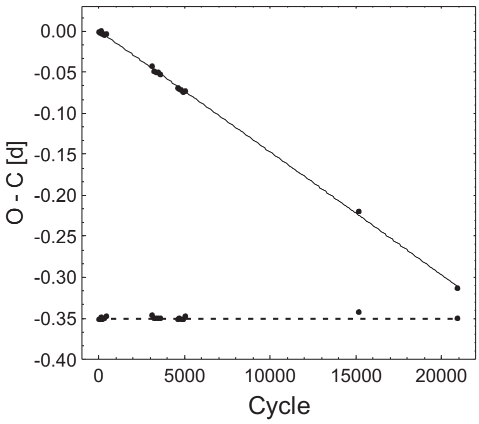

Fig. 4. O-C diagram of V568 Peg: the three clusters of points correspond to WASP data while the last two points to our two solutions

4. Global parameters of V568 Peg

The *GAIA* distance of V568 Peg is 253 pc (Bailer-Jones et al. 2018). It allowed us to calculate the target global parameters by the following procedure.

(a) We obtained the target absolute magnitude $M_V = 5.884$ mag by the formula of distance modulus using its visual magnitude $V = 12.81$ mag at quadrature (the extinction A_V=0.134 was estimated according to Arenou et al. (1992)).

(b) The bolometric magnitude $M_b = 5.794$ mag was calculated from M_V and the bolometric correction BC = -0.36 mag (Masana et al. 2006) corresponding to temperature 4900 K.

(c) The total luminosity $L = 0.537$ L$_\odot$ was obtained from M_b.

(d) The individual luminosities $L_1 = 0.394$ L$_\odot$ and $L_2 = 0.143$ L$_\odot$ were calculated by L and ratio $c = L_2/L_1 = 0.36$ from the PHOEBE solution.

(e) The component radii $R_1 = 0.851$ R$_\odot$ and $R_2 = 0.569$ R$_\odot$ were determined from the individual luminosities L_i and temperatures T_i (Table 2).

(f) The orbital axis $a = 1.796$ R$_\odot$ was calculated from the absolute radii R_i and relative stellar radii r_i (Table 3).

(g) The total mass $M = 1.272$ M$_\odot$ was determined by the third Kepler law based on the orbital axis a and target period P.

(k) The individual mases $M_1 = 0.907$ M$_\odot$ and $M_2 = 0.365$ M$_\odot$ were obtained from M and the mass ratio q (Table 2).

5. Analysis of the results

The comparison of the parameter values of the new solution (Tables 2–3) with the previous one (Paper I) led to the following results.

(1) The difference in inclination is negligible.

(2) There is small difference in relative component radii (1.5 % for the primary radius and 7 % for the secondary radius).

(3) The temperature differences of the components $\Delta T = T_1^f - T_2^f$ are close while the component temperatures themselves T_1^f, T_2^f differ by around 700 K (Table 2). This is an illustration of the known fact that the light curve solution is strongly sensitive to ΔT but not to the individual temperatures. Thus, the two solutions could be considered as similar in temperature parameters. This is supported by almost the same luminosity ratios of the two solutions (Table 3). We assume that the new solution is more confident due to the determination of its T_m value by several dereddened color indices.

(4) The values of the mass ratio differ by 18 %. We attributed the difference to using of third light (of around 0.065) in the previous solution (Paper I) because the new V, R_c data can be well-reproduced by the parameters of old solution including the the same third light value. But we assume that the new solution is more reasonable because it does not require an art third light (invisible around the target). Moreover, the new q value is more confident because it is obtained by detailed q-search analysis.

(5) The biggest difference of the two solutions is the value of the initial epoch T_0 (Table 2). It implies shorter period than the known value. To check this supposition we determined times of light minima of SWASP data (Butters et al. 2010). From the O–C diagram (Fig. 4) we derived the period value of 0.2470800±0.0000003 d.

(6) The closeness of the spot positions and spot parameters of the two solutions (Table 2) means existing of stable large cool spot on the primary component during the last 4 years, i.e. during around 5740 cycles.

6. Conclusion

Our V, R_c observations of V568 Peg revealed that the target is an overcontact binary of A subtype with moderate fill-out factor. Its components are K stars which undergo partial eclipses. The new data allowed us to improve the target period while the *GAIA* distance provided a possibility to calculate the masses, radii and luminosities of its components.

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