Observations and light curve solutions of the W UMa binaries V796 Cep, V797 Cep, CSS J015341.9+381641 and NSVS 3853195

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Abstract Photometric observations in Sloan $g'$ and $i'$ bands of four W UMa binaries, V796 Cep, V797 Cep, CSS J015341.9+381641 and NSVS 3853195, are presented. Our observations showed that CSS J015404.1+382805 and NSVS 3853195 are the same star. We determined the initial epochs $T_0$ of all targets and found improved values for the period of NSVS 3853195. The light curve solutions of our data revealed that the components of each target are almost the same in terms of mass, temperature, radius and luminosity. The stellar components are G and K spectral types and undergo partial eclipses. All systems have barely-overcontact configurations and can be classified as H subtype W UMa binaries. We established that the relation between the luminosity ratio $l_2/l_1$ and mass ratio $q$ of our targets is approximately $l_2/l_1 = q^{1.5}$.

Key words: stars: binaries: eclipsing — stars: fundamental parameters — stars: individual (V796 Cep, V797 Cep, CSS J015341.9+381641, NSVS 3853195)

1 INTRODUCTION

The creation of a stellar evolutional scheme requires a knowledge of the fundamental parameters of stars in different stages of their evolution. Eclipsing binary systems, especially W UMa binaries, are the most important sources of such information. It is supposed that they result from the evolution of wide binaries by angular momentum loss and mass-ratio reversals (Stepien 2006; Qian 2003). Around 25\% of main-sequence star binaries have separations small enough so that when their primaries ascend the giant branch, mass transfer via Roche-lobe overflow marks the beginning of a common envelope phase (Willems & Kolb 2004). At this stage the two stars orbit within a single envelope of material, quickly losing angular momentum and spiraling towards each other (Webbink 1984; Ivanova et al. 2013). The common envelope phase is probably a short-lived stage that ends by envelope ejection and a tighter binary or by a merger. However, understanding the common envelope stage remains one of the most important unsolved problems in stellar evolution (Ivanova et al. 2013).

The components in a W UMa system have nearly equal surface temperatures in spite of their often greatly different masses (Binnendijk 1965). The model of Lucy (1968b), Lucy (1968a) explains this effect by a common convective photosphere in which two main sequence stars are embedded. As a result one should expect the observable luminosities to have another dependence on the mass ratio than would be the case of two main sequence stars in detached configuration. The condition for equal surface temperatures leads to specific period-luminosity-color (PLC) relations of W UMa stars (Rucinski 1994, Rucinski & Duerbeck 1997), allowing researchers to currently predict their absolute magnitudes $M_V$ to about 0.25 mag (Rucinski 2004). The PLC relations combined with easy detection make these binaries useful tracers of distance (Klagyivik & Csizmadia 2004; Gettel et al. 2006; Eker et al. 2009). Moreover, W UMa stars are im-
portant targets for modern astrophysics because they give information on the processes of tidal interactions, mass loss, mass transfer, angular momentum loss, and merging or fusion of the stars (Martin et al. 2011).

In this paper we present photometric observations and light curve solutions of four W UMa binaries: V796 Cep (GSC 04502–00138, TYC 4502–138–1), V797 Cep (GSC 04502–01040, 2MASS J04124764+8007522), CSS J015341.9+381641 and NSVS 3853195 (CSS J015404.1+382805). Table 1 presents the coordinates of our targets and available information on their light variability.

2 OBSERVATIONS

Our CCD photometric observations of the targets in Sloan $g'$, $i'$ bands were carried out at Rozhen National Astronomical Observatory with the 30-cm Ritchey-Chrétien Astrograph (located in the IRIDA South dome) using CCD camera ATIK 4000M ($2048 \times 2048$ pixels, 7.4 µm/pixel, field of view $35 \times 35$ arcmin). Information on our observations is presented in Table 2. In fact, the pairs V796 Cep, V797 Cep and CSS J015341.9+381641, NSVS 3853195 fall in two observed fields (see coordinates in Table 1).

The data were obtained during photometric nights with seeing within $1.1'' - 1.9''$ and humidity below 70%. Twilight flat fields were obtained for each filter, and dark and bias frames were also taken throughout the run. The frames were combined respectively into single master bias, dark and flat frames. The standard procedure was used for reduction of the photometric data (de-biasing, dark frame subtraction and flat-fielding) by software AIP4WIN2.0 (Berry & Burnell 2006).

We used aperture photometry with a radius of 1.5 FWHM of the star image, along with sky background measurements with annuli enclosing a comparable area. The light variability of the targets was estimated with respect to nearby comparison (constant) stars in the observed field of each target, so called ensemble photometry. A check star served to determine the observational accuracy and to check constancy of the comparison stars. The CCD ensemble photometry calculates the difference between the instrumental magnitude of the target and a comparison magnitude obtained from the mean of the intensities of the comparison stars. The use of numerous comparison stars scattered over the CCD field considerably increases the statistical accuracy of the comparison magnitude (Gilliland & Brown 1988, Honeycutt 1992).

We performed ensemble aperture photometry with the software VPHOT. Table 3 presents coordinates of the comparison and check stars of our targets from the catalog UCAC4 (Zacharias et al. 2013) and their magnitudes from the catalog APASS DR9 (Henden 2016). The values in brackets correspond to standard deviations of the standard stars during the observational nights. The choice of comparison and check stars in the same field of view as the targets means practically equal extinctions for all stars. The transformation of the obtained instrumental magnitudes to standard ones was made manually. For this aim we used the mean color of the ensemble comparison star \begin{equation} \frac{(g' - i')_{comp}}{J} \end{equation} and transformation coefficients of our equipment (calculated earlier using standard star field M67). The calculated corrections of the instrumental magnitudes for our targets were from $-0.0008$ mag to $0.0003$ mag in $g'$ filter (within observational precision) and from $-0.0258$ mag to $0.0085$ mag in $i'$ filter.

We determined the times of individual minima (Table 4) by the method of Kwee & van Woerden (1956).

3 LIGHT CURVE SOLUTIONS

The light curves of our targets were solved by the code PHOEBE (Prša & Zwitter 2005). It is based on the Wilson–Devinney (WD) code (Wilson & Devinney 1971, Wilson 1979) but also provides a graphical user interface and modeling in Sloan filters associated with our observations. We used the traditional convention that Min. I (phase 0.0) is the deeper light minimum and the star that is eclipsed at Min. I is the primary component.

Mean temperatures $T_m$ of the binaries were determined in advance (see Table 6) on the basis of their infrared color indices $(J - K)$ from the 2MASS catalog and the calibration color-temperature of Tokunaga (2000). The preliminary runs revealed that all targets are overcontact systems. Hence, we applied mode “Overcontact binary not in thermal contact” of the code. Firstly we fixed $T_1 = T_m$ and varied the initial epoch $T_0$ and period $P$ to search for the best fitting for the phases of light minima and maxima. After that we fixed their values and simultaneously varied secondary temperature $T_2$, orbital inclination $i$, mass ratio $q$ and potential $\Omega$ to search for an accurate reproduction of the whole light curves. The data in $i'$ and $g'$ bands were modeled simultaneously.

We adopted coefficients of gravity brightening $g_1 = g_2 = 0.32$ and reflection effect $A_1 = A_2 = 0.5$ appropriate for late-type stars while the linear limb-darkening coefficients for each component and each color were updated according to the tables of van Hamme (1993). Solar metallicity was assumed for the targets because they consist of late stars from the solar vicinity. In order to reproduce the light curve distortions we used cool spots whose
parameters (longitude $\lambda$, angular size $\alpha$ and temperature factor $\kappa$) were adjusted.

After reaching the best solution we varied together all parameters ($T_2$, $i$, $q$, $\Omega$, $T_0$ and $P$) around the values from the last run and obtained the final model. In order to determine stellar temperatures $T_1$ and $T_2$ around the mean value $T_m$ we used the formulae (Kjurkchieva et al. 2016b)

$$T_1 = T_m + \frac{\Delta T}{c + 1},$$

Table 1: Parameters of Our Targets from the VSX Database

| Target       | RA          | Dec         | Period [d] | Amplitude [mag] | Type |
|--------------|-------------|-------------|------------|----------------|------|
| V796 Cep     | 01 41 36.39 | +80 04 19.1 | 0.3929661  | 12.20          | 0.65 | EW   |
| V797 Cep     | 01 42 47.64 | +80 07 52.3 | 0.270416   | 14.60          | 0.40 | EW   |
| CSS J015341.9+381641 | 01 53 41.95 | +38 16 41.1 | 0.347518   | 13.47          | 0.40 | EW   |
| NSVS 3853195 | 01 54 04.05 | +38 28 05.2 | 0.29253    | 13.52          | 0.39 | EW   |

Table 2: Journal of Our Photometric Observations

| Target                      | Date         | Exposure $g'$ | Exposure $i'$ | Number $g'$ | Number $i'$ |
|-----------------------------|--------------|---------------|---------------|-------------|-------------|
| V796 Cep, V797 Cep          | 2015 Oct 25  | 90            | 120           | 125         | 125         |
|                             | 2015 Oct 26  | 90            | 120           | 84          | 82          |
|                             | 2015 Oct 27  | 90            | 120           | 60          | 59          |
|                             | 2015 Oct 28  | 90            | 120           | 146         | 146         |
| CSS J015341.9+381641, NSVS 3853195 | 2015 Nov 07 | 60            | 90            | 85          | 84          |
|                             | 2015 Nov 08  | 60            | 90            | 67          | 75          |
|                             | 2015 Nov 11  | 60            | 90            | 84          | 84          |
|                             | 2015 Nov 12  | 60            | 90            | 43          | 42          |
|                             | 2015 Nov 13  | 60            | 90            | 84          | 85          |

Table 3: List of the Standard Stars

| Label  | Star ID       | RA           | Dec         | $g'$         | $i'$         |
|--------|---------------|--------------|-------------|--------------|--------------|
| Target 1 | V0796 Cep       | 01 41 36.39  | +80 04 19.10 | 12.320       | 11.789       |
| Target 2 | V0797 Cep       | 01 42 47.64  | +80 07 52.30 | 14.966       | 14.025       |
| Chk    | UCAC4 851–002007 | 01 41 16.52  | +80 04 21.76 | 13.755 (0.010) | 13.018 (0.010) |
| C1     | UCAC4 851–002085 | 01 45 07.01  | +80 10 45.03 | 13.238 (0.011) | 12.534 (0.011) |
| C2     | UCAC4 851–002011 | 01 41 28.03  | +80 11 18.42 | 13.870 (0.010) | 13.351 (0.012) |
| C3     | UCAC4 851–002002 | 01 40 56.97  | +80 02 08.49 | 14.205 (0.011) | 13.452 (0.013) |
| C4     | UCAC4 850–002062 | 01 41 51.38  | +79 56 58.55 | 13.257 (0.007) | 12.651 (0.009) |
| C5     | UCAC4 851–002028 | 01 54 30.68  | +38 29 00.15 | 13.104 (0.014) | 11.754 (0.009) |
| C6     | UCAC4 643–007188 | 01 54 30.68  | +38 29 00.15 | 13.104 (0.014) | 11.754 (0.009) |
| Chk    | UCAC4 644–007104 | 01 54 12.54  | +38 36 49.06 | 13.975 (0.016) | 13.902 (0.018) |
| C1     | UCAC4 644–007165 | 01 54 04.61  | +38 35 54.88 | 14.112 (0.011) | 13.419 (0.015) |
| C2     | UCAC4 643–007180 | 01 54 23.95  | +38 35 42.60 | 14.061 (0.014) | 13.369 (0.015) |
| C3     | UCAC4 643–007204 | 01 54 50.23  | +38 33 52.57 | 13.971 (0.019) | 13.147 (0.015) |
| C4     | UCAC4 643–007182 | 01 54 26.03  | +38 29 38.62 | 13.720 (0.009) | 13.012 (0.011) |
| C5     | UCAC4 643–007126 | 01 53 26.47  | +38 30 02.18 | 13.702 (0.016) | 12.978 (0.013) |
| C6     | UCAC4 642–006881 | 01 51 12.52  | +38 23 56.10 | 13.937 (0.012) | 12.907 (0.011) |
| C7     | UCAC4 642–006842 | 01 53 30.38  | +38 20 34.86 | 13.929 (0.024) | 13.071 (0.018) |
| C8     | UCAC4 642–006908 | 01 54 36.06  | +38 20 04.67 | 14.068 (0.013) | 11.491 (0.014) |
| C9     | UCAC4 642–006921 | 01 54 46.30  | +38 19 35.13 | 13.161 (0.021) | 11.764 (0.014) |
| C10    | UCAC4 643–007147 | 01 53 51.89  | +38 28 10.11 | 12.849 (0.018) | 12.191 (0.014) |
Fig. 1 Illustration of the $q$-search analysis for V796 Cep: the different isolines circumscribe the areas whose normalized $\chi^2$ are smaller than the marked values; the empty circle corresponds to the final value of the mass ratio and orbital inclination given in Table 5.

\[ T_2 = T_1 - \Delta T, \]

where $c = l_2/l_1$ (luminosity ratio) and $\Delta T = T_m - T_2^{PH}$ were taken from the last PHOEBE fitting.

Although PHOEBE (as WD) works with potentials, it provides the possibility to calculate all values (polar, point, side and back) of relative radius $r_i = R_i/a$ of each component ($R_i$ is linear radius and $a$ is orbital separation). In the absence of radial velocity curves we set $a = 1$ as default because from photometry only we cannot determine binary separation. Moreover, PHOEBE yields bolometric magnitudes $M_{bol}^i$ of the two components as output parameters in conditional units (when radial velocity data are not available). However, their difference $M_{bol}^2 - M_{bol}^1$ determines the true luminosity ratio $c = L_2/L_1 = l_2/l_1$. Fillout factor $f = [\Omega - \Omega(L_1)]/[\Omega(L_2) - \Omega(L_1)]$ can be also calculated from the output parameters of the PHOEBE solution.

In order to take into account the effect of expected correlation between the mass ratio and orbital inclination, we carried out $q$-search analysis as described in Kjurkchieva et al. (2016b). For this aim we fixed the component temperatures and radii as well as the spot parameters and calculated the normalized $\chi^2$ for a two-dimensional grid along $i$ and $q$. Figure 1 illustrates the result from this $q$-search procedure for the target V796 Cep.

Table 6 displays the calculated parameters: stellar temperatures $T_{1,2}$; stellar radii $r_{1,2}$ (back values); fillout factor $f$; ratio of relative stellar luminosities $l_2/l_1$. Their errors are determined from the uncertainties of output parameters used for their calculation. Table 7 gives information on the spot parameters. The synthetic light curves corresponding to our solutions are shown in Figure 2 as continuous lines.

The mean ($g', i'$) residuals for the final fittings are: (0.005, 0.007) for V796 Cep; (0.021, 0.022) for V797 Cep; (0.009, 0.012) for CSS J015341.9+381641; (0.009, 0.013) for NSVS 3853195. The mean ($g', i'$) residuals of the standard stars (Table 3) for the first and second pairs of targets are correspondingly (0.010, 0.011) and (0.017, 0.015). Hence, our fittings are excellent for the three targets and very good for the faint star V797 Cep (Fig. 2). The small imperfectness of our modeling may be due to inadequate treatment of the over-contact binaries (Prša et al. 2016) or to long exposures (Kipping 2010).

4 CONCLUSIONS

The main results from the light curve solutions of our data are as follows:

(1) We determined the initial epochs $T_0$ of the four targets (Table 5).

(2) We improved the period of NSVS 3853195 (Table 5) based on all photometric data: CRTS, NSVS, SWASP and IRIDA. The previous period values of the other three targets fitted our data well.
### Table 4: Times of Minima for Our Targets.

| Target   | Min. I            | Min. II           | IRIDA cycle |
|----------|-------------------|-------------------|-------------|
| V0796 Cep | 2457321.43582(9)  | –                 | 0.0         |
|          | –                 | 22457322.41776(13)| 2.5         |
|          | 2457323.40045(19) | –                 | 5.0         |
|          | –                 | 2457324.38263(8)  | 7.5         |
|          | 2457324.57929(1)  | –                 | 8.0         |
| V0797 Cep | 2457321.31715(74) | –                 | 0.0         |
|          | –                 | 2457321.45201(25) | 0.5         |
|          | 2457321.58629(22) | –                 | 1.0         |
|          | –                 | 2457322.26135(33) | 3.5         |
|          | 2457322.39815(24) | –                 | 4.0         |
|          | –                 | 2457323.34511(22) | 7.5         |
|          | 2457324.29034(18) | –                 | 11.0        |
|          | –                 | 2457324.42626(3)  | 11.5        |
| CSS J015341.9+381641 | –             | 2457333.44320(11) | –0.5        |
|          | –                 | 2457333.61496(31) | 0.0         |
|          | –                 | 2457334.48599(14) | 2.5         |
|          | 2457338.47982(18) | –                 | 14.0        |
|          | –                 | 2457340.39396(31) | 19.5        |
|          | 2457340.56578(15) | –                 | 20.0        |
| NSVS 3853195 | –               | 2457333.44266(9)  | –0.5        |
|          | –                 | 2457333.59001(21) | 0.0         |
|          | –                 | 2457334.46774(15) | 3.0         |
|          | –                 | 2457338.41610(11) | 16.5        |
|          | –                 | 2457338.56296(13) | 17.0        |
|          | 2457339.44062(12) | –                 | 20.0        |
|          | –                 | 2457340.46366(14) | 23.5        |

### Table 5: Values of the Fitted Parameters

| Star            | \(T_0\)    | \(P\)  | \(q\)  | \(i\)  | \(\Omega\) | \(T^H_{2}\) |
|-----------------|------------|--------|--------|--------|------------|------------|
| V796 Cep        | 2457321.43582(9) | 0.392966 | 0.948(2) | 70.7(1) | 3.612 (7) | 6400(19)   |
| V797 Cep        | 2457321.31715(74) | 0.270416 | 0.886(2) | 64.7(1) | 3.52 5(2) | 4625(42)   |
| CSS J015341.9+381641 | 2457333.61496(31) | 0.347518 | 0.892(2) | 70.0(2) | 3.490(1) | 5607(28)   |
| NSVS 3853195    | 2457333.59001(21) | 0.292524(4) | 0.899(2) | 69.8(1) | 3.539(3) | 5592(30)   |

### Table 6: Calculated Parameters

| Target         | \(T_{in}\) | \(T_1\)  | \(T_2\)  | \(r_1\) | \(r_2\) | \(f\)  | \(L_2/L_1\) |
|----------------|------------|---------|---------|--------|--------|-------|-------------|
| V796 Cep       | 6407       | 6410(19)| 6403(19)| 0.421(1) | 0.409(1) | 0.101 | 0.951       |
| V797 Cep       | 4770       | 4833(44)| 4688(42)| 0.424(1) | 0.403(1) | 0.075 | 0.771       |
| CSS J015341.9+381641 | 5715       | 5765(29)| 5657(28)| 0.434(1) | 0.414(1) | 0.166 | 0.867       |
| NSVS 3853195   | 5688       | 5733(31)| 5637(30)| 0.425(1) | 0.406(1) | 0.089 | 0.865       |

### Table 7: Parameters of the Cool Spots of the Targets

| Star            | \(\beta\) | \(\lambda\) | \(\alpha\) | \(k\)  |
|-----------------|----------|-------------|-------------|-------|
| V796 Cep        | 90(5)   | 35(1)       | 5.0(1)      | 0.90(1)        |
| CSS J015341.9+381641 | 90(5)   | 90(1)       | 20.0(1)    | 0.80(1)        |
| NSVS 3853195   | 80(5)   | 120(1)      | 25.0(2)    | 0.95(1)        |
Fig. 2 The folded light curves of the targets with their fits and the corresponding residuals (shifted vertically by different amounts to save space).

Fig. 3 3D configurations of the targets.

(3) Our observations revealed that CSS J015404.1+382805 and NSVS 3853195 are the same star (but the International Variable Star Index (VSX) database identified two stars).

(4) The components of each target are almost the same in terms of mass, temperature, radius and luminosity (Tables 5 and 6).

(5) The stellar components of all targets are G and K spectral types and they undergo partial eclipses.
Table 8 Parameters of Cool Spots on the Targets

| Star                           | $q$  | $l_2/l_1$ | $f$  | Reference            |
|-------------------------------|------|----------|------|----------------------|
| AD Cnc                        | 0.77 | 1.00     | 0.08 | Qian et al. (2007)   |
| BI Vul                        | 0.97 | 1.22     | 0.04 | Qian et al. (2013)   |
| CSTAR 038663                  | 0.89 | 1.13     | 0.10 | Qian et al. (2014)   |
| 1SWASP J174310.98+432709.6    | 1.00 | 0.65     | 0.23 | Kjurkchieva et al. (2015a) |
| NSVS 11234970                 | 0.99 | 0.55     | 0.21 | Kjurkchieva et al. (2015a) |
| NSVS 11504202                 | 0.98 | 0.71     | 0.00 | Kjurkchieva et al. (2015a) |
| NSVS 11534299                 | 0.87 | 0.77     | 0.00 | Kjurkchieva et al. (2015a) |
| NSVS 1776195                  | 0.83 | 0.96     | 0.00 | Kjurkchieva et al. (2015b) |
| NSVS 111026                   | 0.79 | 1.00     | 0.07 | Kjurkchieva et al. (2015b) |
| NSVS 2244206                  | 0.73 | 0.53     | 0.26 | Kjurkchieva et al. (2016a) |
| NSVS 908513                   | 0.71 | 0.60     | 0.15 | Kjurkchieva et al. (2016a) |
| V5766264.4+570907             | 0.77 | 0.63     | 0.16 | Kjurkchieva et al. (2016a) |
| CSS J171508.5+350658          | 0.89 | 0.64     | 0.00 | Kjurkchieva et al. (2016b) |
| USNO-B1.0-1395-0370184        | 0.97 | 0.90     | 0.01 | Kjurkchieva et al. (2016c) |
| USNO-B1.0-1395-0370731        | 0.85 | 0.83     | 0.25 | Kjurkchieva et al. (2016c) |
| NSVS 2459652                  | 0.786| 0.73     | 0.17 | Kjurkchieva et al. (2016d) |
| NSVS 7377875                  | 0.898| 0.84     | 0.11 | Kjurkchieva et al. (2016d) |
| V796 Cep                      | 0.95 | 0.95     | 0.10 | this paper           |
| V797 Cep                      | 0.89 | 0.77     | 0.07 | this paper           |
| CSS J015341.9+381641          | 0.89 | 0.87     | 0.17 | this paper           |
| NSVS 3853195                  | 0.90 | 0.86     | 0.09 | this paper           |

Fig. 4 Distribution of fillout factor–mass ratio for W UMa stars: red triangles are for shallow contact high mass ratio targets; black circles are for targets with decreasing periods from the sample of Yang (2013).

(6) All targets have overcontact configurations with a small fillout factor (Fig. 3, Table 6). This means that they are probably newly formed contact binaries (Qian et al. 2014).

(7) Three binaries exhibited the O’Connell effect, which was reproduced by cool spots (Table 7) on their primary components. They indicate magnetic activity on these targets.

(8) All our targets have mass ratio $q \geq 0.88$ (Table 5), i.e. they can be classified as H subtype W UMa systems (with $q \geq 0.72$). Csizmadia & Klagyivik (2004) revealed that the different subtypes of W UMas are located in different regions on the mass ratio – luminosity ratio diagram (their fig. 1) but above the line $l_2/l_1 = q^{4.6}$ representing the mass-luminosity relation for MS detached stars. Our targets support this conclusion and the relation between their mass ratio and luminosity ratio is $l_2/l_1 = q^{1.5}$, i.e. close to that of Lucy (1968b).

(9) The investigation of shallow-contact binary stars with high mass ratios is important for modern astrophysics because they are considered to be newly formed contact configurations, at the beginning of contact evolution (Qian et al. 2014). The most detailed studies of this type refer to the binaries AD Cnc (Qian et al. 2007), BI Vul (Qian et al. 2013) and CSTAR 038663 (Qian et al. 2014). They revealed that these cool, short-period (0.25–0.28 d), shallow-contact binaries exhibit strong magnetic activity (including optical 0.2 mag flares of CSTAR 038663) and multiple period changes. Recently we observed and modeled (in the same way) shallow-contact W UMas of H subtype (Table 8). On the fillout factor–mass ratio diagram (Fig. 4), the targets from Table 8 fall in the bottom right (red triangles) due to their small fillout factors (0.0–0.25) and high mass ratios (0.7–1.0). On the same diagram, the contact binaries with decreasing periods from the sample of Yang et al. (2013) cluster (black circles) in the upper left from our sample because they have intermediate fillout factors (0.05–0.30) and
moderate mass ratios (0.3–0.6). One could speculate that deep-contact W UMas would form an additional third cluster left and upwards from the first two clusters on the diagram. So, the fillout factor–mass ratio diagram can be interpreted with an evolutional meaning: through the common envelope phase the position of a given star will describe a trace starting from the bottom right and ending in the upper left side of the diagram.

More investigations of shallow-contact binary stars with high mass ratios will provide more statistics on their global parameters and opportunity for further study of the rapid evolution of binary stars that have reached the contact stage. The present study is only a step in that direction.

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