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Discovery of a deep, low mass ratio overcontact binary GSC 03517–00663 *

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Abstract When observing blazars, we identified a new eclipsing binary named GSC 03517–00663. The light curves of GSC 03517–00663 are typical of EW-type light curves. Based on the observation using the 1 m telescope at the Weihai Observatory of Shandong University, complete *VRI* light curves were determined. Then, we analyzed the multiple light curves using the Wilson-Devinney program. It was found that GSC 03517–00663 has a mass ratio of $q = 0.164$ and a degree of contact of $f = 69.2\%$. GSC 03517–00663 is a deep, low mass ratio overcontact binary. The light curves of GSC 03517–00663 show a strong O'Connell effect, which was explained by employing a dark spot on the secondary component.

Key words: stars: binaries: close — stars: binaries: eclipsing — stars: individual (GSC 03517–00663)

1 INTRODUCTION

W UMa type stars are usually contact binaries, where both component stars are in contact with each other and share a common convective envelope. This type of binary is usually composed of two cool, main-sequence stars with spectral types of F to K and they normally show typical EW-type light curves, where light variation is continuous and has a very small difference between the depths of the two minima. The nearly equal depths of the two minima reveal that the effective temperatures of both components are very similar despite having different component masses (Qian et al. 2014).

A deep, low mass ratio overcontact binary is a system which has a mass ratio of $q < 0.25$ and an overcontact degree of $f > 50\%$. This kind of binary is in the late evolutionary stage. The final stages of its evolution are still not well understood. There are several clues that it can be the progenitors of rapidly-rotating single giants (blue stragglers and FK Com type stars) which form by the coalescence of the two components through continuing angular momentum loss (Eggleton & Kiseleva-Eggleton 2001). More observations and investigation of this type of binary are needed.

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In this paper, we present *VRI* light curves of a W UMa type binary GSC 03517–00663 ($\alpha_{2000} = 17^{\rm h}28^{\rm m}55.14^{\rm s}$, $\delta_{2000} = +50°16'17.5''$). GSC 03517–00663 is a new binary discovered by us when we were observing blazars. This paper has the following structure. CCD observations, discovery and orbital period determination of GSC 03517–00663 are shown in Section 2. In Section 3, investigation of the light curves is presented. Conclusions are drawn in Section 4.

2 OBSERVATION, DISCOVERY AND PERIOD DETERMINATION

While analyzing the observational data directed toward the study of a blazar (OT 546), we found that one of the field stars varied more than 0.4 magnitudes (V band) during one night. Neither the GCVS nor the NSV catalogues contain this star, so we concluded that it is a newly identified variable star. According to the GSC 1.2, this star is named GSC 03517–00663.

CCD photometric observations of GSC 03517–00663 were carried out in May and June, 2009 and October, 2012, using a PIXIS 2048B CCD camera attached to the 1.0 m Cassegrain telescope (Hu et al. 2014) at the Weihai Observatory of Shandong University. The PIXIS camera has 2048×2048 square pixels (13.5×13.5 μm pixel^{-1}), providing an effective field of view of about $11.8' \times 11.8'$. The standard Johnson and Cousins filters (V, R and I) were used during our observations. The typical integration times for each image were 200 s, 150 s and 120 s in the V, R and I bands, respectively. The reductions of observations were conducted using the APPHOT package of IRAF[1] software. All data were processed with bias and flat-field correction. One of the CCD images is shown in Figure 1, where "V" refers to the variable star (i.e. GSC 03517–00663), "C" to the comparison star and "CH" to the check star. Standard stars B ($\alpha_{2000.0} = 17^{\rm h}28^{\rm m}24.6^{\rm s}$, $\delta_{2000.0} = 50°14'35.6''$) and H ($\alpha_{2000.0} = 17^{\rm h}28^{\rm m}14.3^{\rm s}$, $\delta_{2000.0} = 50°12'40.2''$), taken from Fiorucci & Tosti (1996), were used as the comparison star and check star, respectively.

The Jurkevich method (Jurkevich 1971) was applied to all the V band data for periodicity analysis. The Jurkevich method is based on the expected mean square deviation and can process unequally spaced observations, so it is less inclined to generate a spurious periodicity compared with a Fourier analysis. It involves testing a series of trial periods and the data are folded according to the trial periods. By applying these phases around each trial period, all data are divided into m groups. The variance V_i^2 for each group and the sum of each group variance V_m^2 are computed. If a trial period equals the real one, V_m^2 would reach its minimum. The results derived by the Jurkevich method using $m = 50$ are shown in Figure 2. The minimum value indicates a period of 0.295025 d.

The observed *VRI* band light curve folded according to the period of 0.295025 d is shown in Figure 3. From this figure, it is seen that the data observed in 2009 appear to smoothly merge and the light variation is consistent with a W UMa type eclipsing binary. Ten times of light minima were determined and are listed in Table 1. Using the following ephemeris

$$\mathrm{Min.I} = \mathrm{HJD}2454974.2478 + 0.295025E\,, \tag{1}$$

the $O - C$ values are calculated and are listed in Table 1. Then, through a least squares solution, a new linear ephemeris is determined from all these data,

$$\mathrm{Min.I} = \mathrm{HJD}2454974.24763 \pm 0.00045 + 0.29502416 \pm 0.00000034\,E\,. \tag{2}$$

3 LIGHT CURVE ANALYSIS

Using the fourth version of the Wilson-Devinney program (Wilson & Devinney 1971; Wilson 1990, 1994; Wilson & Van Hamme 2003), we analyzed the V, R and I light curves of GSC 03517–00663.

[1] IRAF is distributed by National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

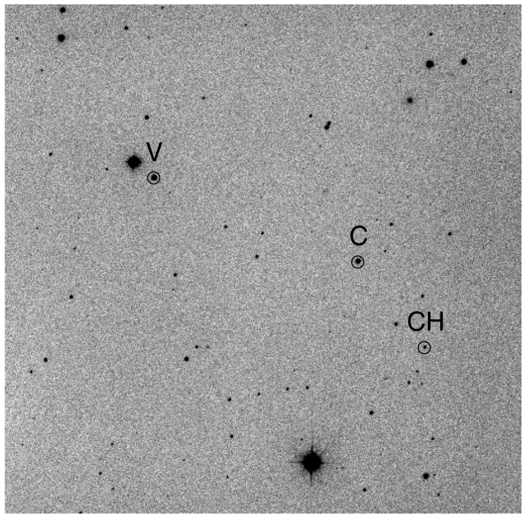

Fig. 1 CCD image in the field of view around GSC 03517–00663. "V" refers to the variable star (i.e. GSC 03517–00663), "C" to the comparison star and "CH" to the check star.

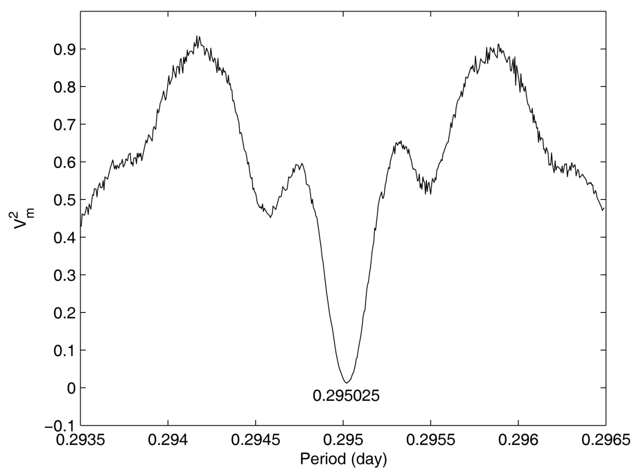

Fig. 2 Relationship between the trial period and V_m^2 using all the V band data.

According to the Naval Observatory Merged Astrometric Dataset (NOMAD, Zacharias et al. 2004), the color index of GSC 03517–00663 can be derived to be $B - V = 0.62$, which corresponds to the spectral type of G2 according to Cox (2000). The gravity darkening coefficients of the two components were taken to be $g_1 = g_2 = 0.32$ for a convective atmosphere from Lucy (1967). The bolometric albedo coefficients of the two components were fixed at $A_1 = A_2 = 0.5$ for convective atmospheres following Ruciński (1969). The bolometric and bandpass limb-darkening coefficients of the two components were taken from van Hamme (1993).

Starting with the solutions given by mode 2, we found that the solutions usually converged when both components fill their Roche lobes. So, the final iterations were performed in mode 3, which corresponds to the contact configuration. The quantities that were varied when computing the solutions

Table 1 Newly Determined Times of Light Minima for GSC 03517–00663

JD (Hel.)	Errors	Min.	E	$O-C$
2454974.2478	±0.0003	p	0	0.0000
2454975.2797	±0.0004	s	3.5	–0.0007
2454977.1995	±0.0017	p	10	0.0015
2454978.2289	±0.0004	s	13.5	–0.0017
2454979.2646	±0.0003	p	17	0.0014
2454982.2136	±0.0003	p	27	0.0001
2455003.1605	±0.0003	p	98	0.0003
2455005.0752	±0.0005	s	104.5	–0.0027
2455005.2255	±0.0006	p	105	0.0001
2456207.0061	±0.0002	s	4178.5	–0.0037

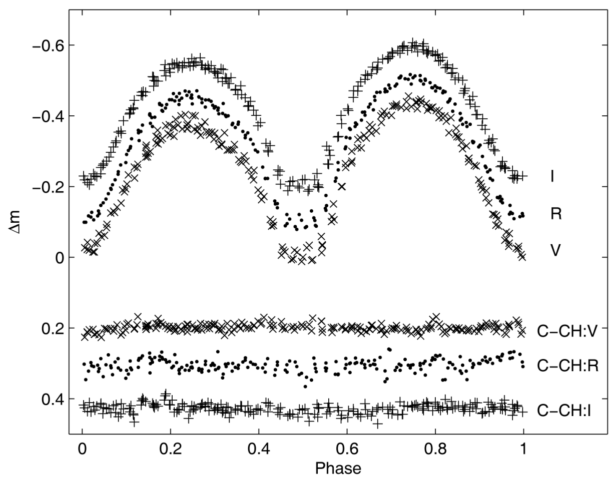

Fig. 3 *VRI* light curves of GSC 03517–00663 observed in 2009. The phases were calculated using Eq. (1). Different symbols represent different bands.

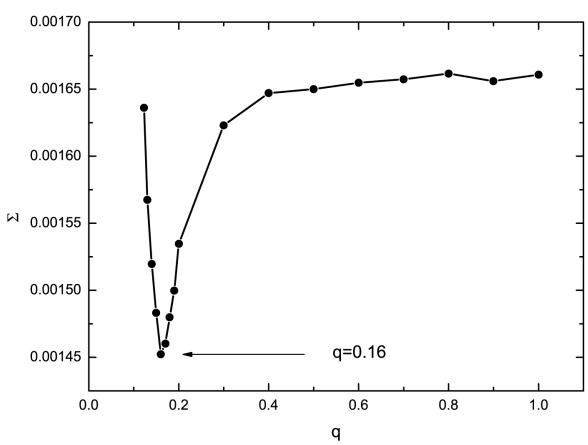

Fig. 4 Relation between $\sum$ and q for GSC 03517–00663.

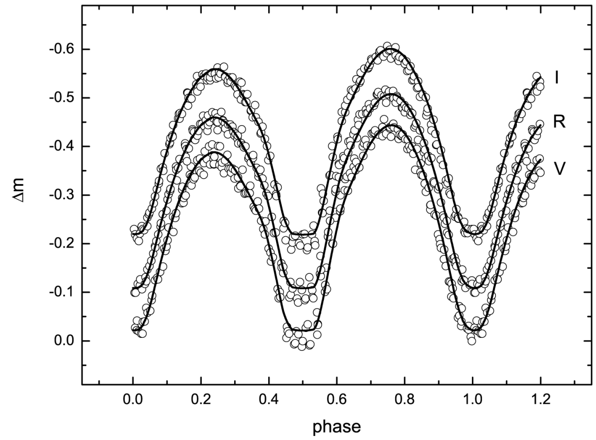

Fig. 5 Observed (*open circles*) and theoretical (*solid lines*) light curves of GSC 03517–00663.

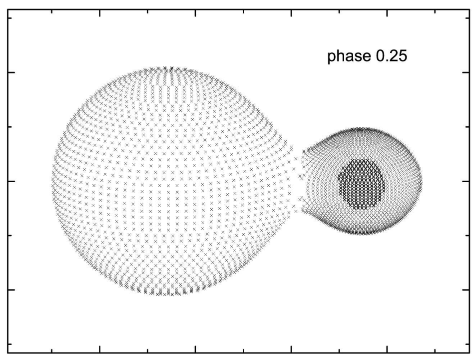

Fig. 6 Configuration of the low mass ratio, deep overcontact binary GSC 03517–00663 at phase 0.25.

were the mass ratio q, the effective temperature of the secondary component T_2, the monochromatic luminosity of the primary component in the V, R and I bands L_1, the orbital inclination i and the dimensionless potential of the primary component Ω_1 ($\Omega_1 = \Omega_2$). An obvious O'Connell effect can be seen in the light curves of GSC 03517–00663, and solutions were calculated for the two cases with and without a spot. In case one, a solution with one dark spot on the secondary component leads to a good fit for the light curves. Since GSC 03517–00663 is a newly discovered binary, no mass ratio has been obtained. A q-search method was used to determine the mass ratio. Solutions were carried out for a series of values of the mass ratio (from 0.123 to 1.0). The relation between the resulting sum Σ of weighted square deviations and q is plotted in Figure 4. The minimum value was obtained at $q = 0.16$. Then, we chose $q = 0.16$ as an initial value and made it an adjustable parameter. When the solution converged, the result was determined. The solutions based on the two cases are listed in Table 2. The residual of the solution with the spot is much smaller than that without the spot. Therefore, we adopted case one as the final solution. The comparison between the observed and the theoretical light curves is shown in Figure 5. Figure 6 shows the configuration of this system at phase 0.25.

Table 2 Photometric Solutions for GSC 03517–00663

Parameters	Without Spot	Errors	With Spot	Errors
$g_1 = g_2$	0.32	Assumed	0.32	Assumed
$A_1 = A_2$	0.5	Assumed	0.5	Assumed
$x_{1\mathrm{bol}}, x_{2\mathrm{bol}}$	0.648, 0.647	Assumed	0.648, 0.647	Assumed
$y_{1\mathrm{bol}}, y_{2\mathrm{bol}}$	0.207, 0.221	Assumed	0.207, 0.221	Assumed
x_{1V}, x_{2V}	0.762, 0.745	Assumed	0.762, 0.745	Assumed
y_{1V}, y_{2V}	0.232, 0.256	Assumed	0.232, 0.256	Assumed
x_{1R}, x_{2R}	0.670, 0.653	Assumed	0.670, 0.653	Assumed
y_{1R}, y_{2R}	0.250, 0.267	Assumed	0.250, 0.267	Assumed
x_{1I}, x_{2I}	0.576, 0.560	Assumed	0.576, 0.5604	Assumed
y_{1I}, y_{2I}	0.244, 0.256	Assumed	0.244, 0.256	Assumed
T_1 (K)	5800	Assumed	5800	Assumed
$q\,(M_2/M_1)$	0.162	±0.003	0.164	±0.002
$\Omega_{\rm in}$	2.1344	Assumed	2.1416	Assumed
$\Omega_{\rm out}$	2.0303	Assumed	2.0359	Assumed
T_2 (K)	6024	±29	6075	±18
i	77.125	±0.733	77.446	±0.484
L_{1V}/L_V	0.8013	±0.0008	0.7878	±0.0005
L_{1R}/L_R	0.8068	±0.0007	0.7947	±0.0004
L_{1I}/L_I	0.8107	±0.0006	0.7997	±0.0004
Ω_1=Ω_2	2.0803	±0.0099	2.0685	±0.0070
r_1(pole)	0.5164	±0.0027	0.5201	±0.0019
r_1(side)	0.5713	±0.0042	0.5774	±0.0031
r_1(back)	0.5968	±0.0053	0.6047	±0.0039
r_2(pole)	0.2351	±0.0065	0.2422	±0.0044
r_2(side)	0.2468	±0.0080	0.2554	±0.0056
r_2(back)	0.2993	±0.0215	0.3203	±0.0186
f	52.0%	$\pm9.5\%$	69.2%	$\pm6.7\%$
θ(radian)	–	–	1.406	±0.290
ϕ(radian)	–	–	1.593	±0.071
r(radian)	–	–	0.484	±0.046
$T_f(T_d/T_0)$	–	–	0.647	±0.086
$\Sigma W(O-C)^2$	0.0144		0.0055	

4 RESULTS AND DISCUSSION

In this paper, we presented a newly discovered W UMa binary GSC 03517–00663. Using the Jurkevich method, the orbital period of GSC 03517–00663 was determined to be $P = 0.295025$ days. Based on the V, R and I light curves, photometric solutions for the newly discovered eclipsing binary GSC 03517–00663 have been derived. We found that the mass ratio of GSC 03517–00663 is $q = 0.164$ and that the degree of contact, defined by $f = (\Omega_{\rm in} - \Omega)/(\Omega_{\rm in} - \Omega_{\rm out})$, is $f = 69.2\%$. Like V857 Her, QX And, EM Pis and XY Leo (Qian et al. 2005, 2007, 2008, 2011), GSC 03517–00663 is a deep, low mass ratio overcontact binary.

The spectral type of GSC 03517–00663 is G2 and it is a solar-like binary system. The deep convective envelope along with fast rotation can produce strong magnetic activity. The disagreement between the two maxima of the light curves was explained by the presence of a dark spot on the common convective envelope of the secondary component.

GSC 03517–00663 is a solar like deep, low mass ratio overcontact binary. It may be the progenitor of a blue straggler/FK Com-type star. Future observations are needed to determine the evolution of the binary and to analyze the orbital period variation.

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