Discovering a deep, low mass ratio overcontact binary

GSC 03517–00663

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Abstract When observing the 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. 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).

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

In this paper, we presented $VRI$ light curves of a W UMa type binary GSC 03517−00663 ($\alpha_{2000} = 17^h28^m55.14'', \delta_{2000} = +50^\circ16'17.5''$). Do you mean GSC 03517−00663 is a new binary discovered by us when we were observing blazars? This paper follows the following structure. CCD observations, discovery and orbital period determination of GSC 03517−00663 are shown in Section 2. In Section 3, light curves investigation of the light curves is presented. Conclusions are discussed in Section 4.

2 OBSERVATION, DISCOVERY AND PERIOD DETERMINATION

Do you mean While analyzing the observational data directed toward the study of blazars (OT 546), we found that one of the field stars varied more than 0.4 magnitudes ($V$ band) during one night? Note: According to an online search, our editorial staff found other authors call this source “OT 546" instead of “OT546". Please confirm that this is the correct name of the object. 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 $\times$ 2048 square pixels (13.5 $\times$ 13.5 $\mu$m pixel$^{-1}$), providing an effective field of view of about 11.8$'$ $\times$ 11.8$'$. The standard Johnson and Cousins filters ($V$, $R_c$ 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. Do you mean The reductions of observations were conducted using the APPhot package as part of the IRAF\footnote{Do you mean IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.} procedures software.\footnote{Do you mean IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.} All data were processed by 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 ($\alpha_{2000.0} = 17^h28^m24.6'', \delta_{2000.0} = 50^\circ14'35.6''$) and H ($\alpha_{2000.0} = 17^h28^m14.3'', \delta_{2000.0} = 50^\circ12'40.2''$), 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. Do you mean The Jurkevich method is based on the expected mean square deviation and the can process unequally spaced observations, so it is less inclined to generate a spurious periodicity comparing with a Fourier analysis. It involves testing a series of trial periods and the data are folded according to the trial periods. According to their By applying these phases around each trial period, all data are divided into $m$ groups.\footnote{Do you mean The observed $VRI$ light curve folded according to the period of 0.295025 days is shown in Figure 3. From this figure, it is seen that the data observed in 2009 appear to smoothly merged smoothly and the light variation is of consistent with a W UMa type eclipsing binary. Ten times of light minimum were determined and are listed in Table 1.\footnote{Do you mean The observed $VRI$ light curve folded according to the period of 0.295025 days is shown in Figure 3. From this figure, it is seen that the data observed in 2009 appear to smoothly merged smoothly and the light variation is of consistent with a W UMa type eclipsing binary. Ten times of light minimum were determined and are listed in Table 1.}} The variance $V_m^2$ 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 the period of 0.295025 d.

Do you mean The observed $VRI$ band light curve folded according to the period of 0.295025 days is shown in Figure 3. From this figure, it is seen that the data observed in 2009 appear to smoothly merged smoothly and the light variation is of consistent with a W UMa type eclipsing binary. Ten times of light minimum were determined and are listed in Table 1.\footnote{Do you mean The observed $VRI$ light curve folded according to the period of 0.295025 days is shown in Figure 3. From this figure, it is seen that the data observed in 2009 appear to smoothly merged smoothly and the light variation is of consistent with a W UMa type eclipsing binary. Ten times of light minimum were determined and are listed in Table 1.} Using the following ephemeris

$$\text{Min.I} = \text{HJD2454974.2478} + 0.295025 E,$$

\[1\]
Discovery of a Deep, Low Mass Ratio Overcontact Binary GSC 03517–00663

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

<table>
<thead>
<tr>
<th>JD (Hel.)</th>
<th>Errors</th>
<th>Min.</th>
<th>E</th>
<th>O – C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2454974.2478</td>
<td>±0.0003</td>
<td>p</td>
<td>0</td>
<td>0.0000</td>
</tr>
<tr>
<td>2454975.2797</td>
<td>±0.0004</td>
<td>s</td>
<td>3.5</td>
<td>−0.0007</td>
</tr>
<tr>
<td>2454977.2289</td>
<td>±0.0017</td>
<td>p</td>
<td>10</td>
<td>0.0015</td>
</tr>
<tr>
<td>2454979.2646</td>
<td>±0.0004</td>
<td>s</td>
<td>13.5</td>
<td>−0.0017</td>
</tr>
<tr>
<td>2454982.2136</td>
<td>±0.0003</td>
<td>p</td>
<td>17</td>
<td>0.0014</td>
</tr>
<tr>
<td>2455003.1605</td>
<td>±0.0003</td>
<td>p</td>
<td>27</td>
<td>0.0001</td>
</tr>
<tr>
<td>2455005.0752</td>
<td>±0.0005</td>
<td>s</td>
<td>104.5</td>
<td>−0.0027</td>
</tr>
<tr>
<td>2455005.2255</td>
<td>±0.0006</td>
<td>p</td>
<td>105</td>
<td>0.0003</td>
</tr>
<tr>
<td>2456207.0061</td>
<td>±0.0002</td>
<td>s</td>
<td>4178.5</td>
<td>−0.0037</td>
</tr>
</tbody>
</table>

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,

$$\text{Min.1} = \text{HJD}2454974.24763 \pm 0.00045 \pm 0.29502416 \pm 0.0000034E$$  \hspace{1cm} (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. According to NOMAD, 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 is corresponding 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 are usually converged when both components fill their Roche lobes. So, the final iterations were made performed in mode 3, which corresponds to the contact configuration. The quantities that were varied 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 $\Omega_1$ ($\Omega_1 = \Omega_2$). As an obvious example of the O’Connell effect can be seen in the light curves of GSC 03517–00663, the solutions were calculated on 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 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.
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. Do you mean 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 \( f = (\Omega_{\text{in}} - \Omega)/(\Omega_{\text{in}} - \Omega_{\text{out}}) \), is \( f = 69.2\% \), as 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.\[1\]

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. Therefore, 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. Do you mean It may be the progenitor of a blue straggler/FK Com-type stars? Future observations are needed to determine the evolution of the binary and to analyze the orbital period variation.

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References

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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. Please remove the empty space outside the boundary in Figures 1–6.

Fig. 2  Relationship between the trial period and $V_{\text{2m}}$ using all the $V$ band data.
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, high fill-out overcontact binary GSC 03517–00663 at phase 0.25. Note: you do not mention “high fill-out” somewhere else in the article. Our editorial staff thinks this is confusing to the reader. Please either explain what you mean by “high fill-out” in the text of the article or remove “high fill-out” from this caption. We believe this would make the meaning in your article clearer to the reader.