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A Photometric Study of the W UMa-Type Contact Binary RZ Com *

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Abstract We present results of CCD photometric observations of the short-period W UMa-type contact binary system, RZ Com. The light curve of the binary has changed from W-subtype to A-subtype from 1998 to 2003, then back to W-subtype in 2004. An analysis was carried out using the 2003 version of the Wilson-Devinney code. It is confirmed that RZ Com is a low-degree, overcontact $f = 20.1\%$ ($\pm 7.4\%$) binary system with a high inclination of $i = 81.^\circ 40$ ($\pm 0.^\circ 40$), and a mass ratio $q = 2.351$ (± 0.031). Combining four newly determined times of light minimum with others in the literature, the variations in orbital period is examined. A small-amplitude oscillation (A=0.0065d), with a period of 41.5 year, is discovered superimposed on a long-term increase at rate $dP/dt = +3.97 \times 10^{-8}$d yr^{-1}. The period oscillation can be explained either by the light-time effect due to the presence of an unseen third body, or by cycles of magnetic activity on the components. Combining our photometric solution with the spectroscopic elements obtained by Mclean & Hilditch, the absolute dimensions of RZ Com are: $M_1 = 1.14$ $(\pm 0.19) M_\odot$, $M_2 = 0.50$ $(\pm 0.09) M_\odot$, $R_1 = 1.12$ $(\pm 0.01) R_\odot$, $R_2 = 0.78$ $(\pm 0.01) R_\odot$ and $A = 2.41$ $(\pm 0.02) R_\odot$.

Key words: stars: binaries: close — stars: binaries: eclipsing — stars: individual: RZ Com

1 INTRODUCTION

RZ Com is a short-period W UMa-type overcontact binary system ($P = 0.3385$ d, m_v=10.55 mag). The first photometric observations of RZ Com were obtained by Broglia (1960), 2 to 3 months apart, who found that the light curves observed at slightly different epochs are significantly different. He attributed this temporal behavior to the existence of a bright area on the outer facing hemisphere of the smaller star in the period HJD2436310–341. Binnendijk (1964) re-discussed these observations and pointed out that a somewhat more consistent explanation can be given in terms of a dark area on the inner hemisphere of the larger star in the period HJD2436220–285. Later, Wilson & Devinney (1973) fitted these light curves using the Wilson-Devinney code and found the mass ratio of RZ Com to be $q = m_2/m_1 = 2.292$ in HJD2436220–285, and $q = m_2/m_1 = 2.394$ in HJD2436310–341. They concluded that RZ Com seems to have a larger gravity effect and is only marginally in contact. Jabbar & Kopal (1983) analyzed the observations obtained by Binnendijk (1964) and Struve & Gratton (1948) using Kopal's method. They obtained the mass ratio to be $q = m_1/m_2 = 0.24$ ($q = m_2/m_1 = 4.17$). The first radial velocity observations were published by Mclean & Hilditch (1983), and the mass ratio was found to be $q = m_2/m_1 = 2.33$. A CCD light curve in the B band was recently published by Xiang & Zhou (2004), and they derived the mass ratio to be

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$q = m_2/m_1 = 2.226$. As pointed out by Rovithis-Livaniou et al. (2002), the spectral type of RZ Com is not clear. Struve & Gratton (1948) classified its spectral type as K0. Wood & Austin (1980) gave F7 and G0 for the primary and secondary components, respectively. Mclean & Hilditch (1983) classified its spectral type again as K0. On the other hand, in the Eighth Catalogue of the Orbital Elements of Spectroscopic Binary Systems compiled by Batten et al. (1989), it is referred to as G2 Vn, while in the Hipparcos Catalogue, as G0 Vn. The orbital period change of the system was investigated by Qian & He (2005), who found a small-amplitude oscillation (A=0.0058d), with a period of 44.8 yr superimposed on a long-term variation at a rate of $dP/dt = +4.12 \times 10^{-8}$ d yr^{-1}.

Photoelectric results obtained by Broglia (1960), Rovithis & Rovithis-Livaniou (1984) and CCD photometric light curves obtained by Xiang & Zhou (2004), all revealed that they belong to a W-subtype in the classification of Binnendijk (1970). While Qian & He (2005) found that the light curve of RZ Com changed from W-subtype to A-subtype.

2 PHOTOMETRIC OBSERVATIONS

Observations of RZ Com in B and V bands were carried out on 2004 March 18 with a PI1024 TKB CCD photometric system attached to the 1.0 m reflecting telescope of the Yunnan Astronomical Observatory, NAOC. The B and V colors used were close to the standard Johnson UBV system. The effective field of view is 6.5×6.5 square arcmin at the Cassegrain focus and the CCD resolution is 0.38 arcsec per pixel. The integration time for each image is 120 s. The comparison star and check star are in the same field of view of the CCD camera. The aperture photometry package of IRAF, PHOT was used to reduce the observed images. The magnitude differences (variable minus comparison) and the Heliocentric Julian dates are listed in Tables 1 and 2, in which the phases were computed with the formula of Qian & He (2005):

$$\mathrm{Min.}I = 2443967.9440(\pm 0.0005) + 0.^{\mathrm{d}}33850673(\pm 0.00000003). \tag{1}$$

The light curve (magnitude versus orbital phase) is shown in Figure 1. As can be seen, the light curve is a typical EW-type. The transit eclipse appears to be shallower than the occultation eclipse, which makes it a W-subtype light curve according to the classification of Binnendijk (1970). A typical O'Connell effect, with Max II (phase 0.75) brighter than Max I (phase 0.25), is also visible in Figure 1. The transit eclipse minimum is shallower than the occultation eclipse by 0.035 mag in V and by 0.050 mag in B, and Max II is higher than Max I by 0.025 mag in V and by 0.025 mag in B.

The light curves of RZ Com published by Broglia (1960), Rovithis & Rovithis-Livaniou (1984) and the CCD photometric light curves obtained by Xiang & Zhou (2004) all showed a W-subtype (occultation

Table 1 B-Band CCD Observations of RZ Com

HJD 245308+	Δm	HJD 245308+	Δm	HJD 245308+	Δm	HJD 245308+	Δm	HJD 245308+	Δm
3.0888	–1.287	3.1555	–1.720	3.2304	–1.648	3.2964	–1.411	3.3613	–1.787
3.0924	–1.231	3.1590	–1.745	3.2340	–1.621	3.2998	–1.470	3.3648	–1.809
3.0960	–1.172	3.1625	–1.753	3.2374	–1.590	3.3033	–1.512	3.3683	–1.787
3.0995	–1.190	3.1659	–1.784	3.2409	–1.542	3.3068	–1.539	3.3718	–1.794
3.1030	–1.130	3.1694	–1.774	3.2444	–1.486	3.3102	–1.590	3.3753	–1.788
3.1066	–1.167	3.1728	–1.808	3.2479	–1.448	3.3137	–1.629	3.3824	–1.763
3.1100	–1.177	3.1762	–1.781	3.2513	–1.388	3.3172	–1.635	3.3858	–1.746
3.1135	–1.233	3.1797	–1.805	3.2548	–1.301	3.3208	–1.652	3.3892	–1.705
3.1170	–1.267	3.1831	–1.813	3.2583	–1.257	3.3243	–1.675	3.3927	–1.678
3.1204	–1.355	3.1866	–1.824	3.2617	–1.178	3.3279	–1.714	3.3965	–1.656
3.1239	–1.387	3.1900	–1.805	3.2652	–1.092	3.3297	–1.742	3.4002	–1.672
3.1275	–1.456	3.1934	–1.799	3.2687	–1.104	3.3334	–1.744	3.4037	–1.631
3.1310	–1.527	3.1969	–1.805	3.2721	–1.110	3.3370	–1.754	3.4073	–1.573
3.1345	–1.558	3.2096	–1.773	3.2756	–1.102	3.3405	–1.761	3.4109	–1.487
3.1380	–1.620	3.2131	–1.747	3.2790	–1.103	3.3440	–1.780	3.4144	–1.449
3.1415	–1.632	3.2166	–1.714	3.2825	–1.161	3.3474	–1.805	3.4180	–1.393
3.1451	–1.662	3.2201	–1.714	3.2859	–1.212	3.3509	–1.785	3.4216	–1.361
3.1486	–1.693	3.2235	–1.699	3.2894	–1.283	3.3544	–1.792	3.4251	–1.293
3.1520	–1.686	3.2270	–1.673	3.2929	–1.359	3.3578	–1.793	3.4287	–1.290

Table 2 V-Band CCD Observations of RZ Com

HJD 245308+	Δm	HJD 245308+	Δm	HJD 245308+	Δm	HJD 245308+	Δm	HJD 245308+	Δm
3.0869	–1.302	3.1538	–1.682	3.2287	–1.630	3.2947	–1.369	3.3631	–1.765
3.0907	–1.246	3.1572	–1.710	3.2322	–1.604	3.2981	–1.434	3.3665	–1.759
3.0943	–1.179	3.1608	–1.721	3.2357	–1.582	3.3015	–1.474	3.3700	–1.767
3.0978	–1.109	3.1642	–1.733	3.2392	–1.549	3.3050	–1.534	3.3736	–1.739
3.1013	–1.133	3.1677	–1.747	3.2427	–1.501	3.3085	–1.568	3.3770	–1.731
3.1048	–1.121	3.1711	–1.769	3.2462	–1.445	3.3120	–1.611	3.3841	–1.699
3.1083	–1.145	3.1745	–1.775	3.2496	–1.384	3.3155	–1.617	3.3875	–1.674
3.1117	–1.155	3.1779	–1.764	3.2531	–1.330	3.3190	–1.629	3.3909	–1.650
3.1152	–1.220	3.1814	–1.784	3.2566	–1.253	3.3225	–1.654	3.3947	–1.628
3.1187	–1.278	3.1849	–1.792	3.2600	–1.184	3.3262	–1.663	3.3984	–1.641
3.1222	–1.376	3.1883	–1.778	3.2635	–1.120	3.3315	–1.708	3.4020	–1.595
3.1257	–1.425	3.1917	–1.797	3.2669	–1.100	3.3351	–1.722	3.4056	–1.563
3.1293	–1.474	3.1951	–1.788	3.2704	–1.096	3.3387	–1.746	3.4091	–1.507
3.1328	–1.512	3.2077	–1.753	3.2739	–1.099	3.3422	–1.725	3.4127	–1.511
3.1362	–1.555	3.2114	–1.725	3.2773	–1.103	3.3457	–1.748	3.4162	–1.440
3.1398	–1.577	3.2149	–1.717	3.2808	–1.120	3.3492	–1.753	3.4197	–1.396
3.1432	–1.618	3.2183	–1.704	3.2842	–1.163	3.3527	–1.774	3.4233	–1.319
3.1469	–1.630	3.2218	–1.677	3.2877	–1.231	3.3561	–1.780	3.4269	–1.261
3.1503	–1.666	3.2252	–1.652	3.2912	–1.302	3.3596	–1.769	3.4305	–1.184

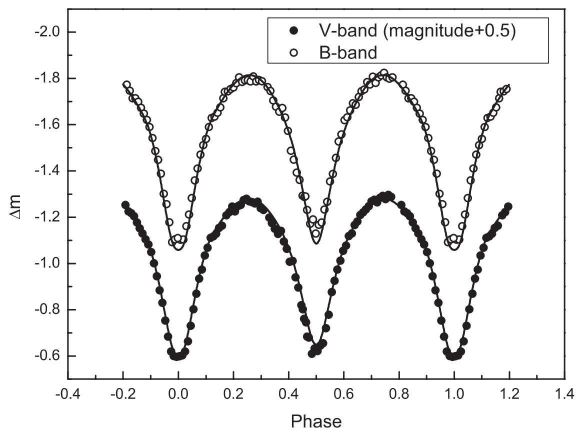

Fig. 1 Light curves of RZ Com in 2004. Open circles show the B-band observations, filled circles, the V-band observations. The solid lines are the theoretical light curves.

eclipse deeper than transit eclispe). However, the CCD photometric light curves obtained by Qian & He (2005) showed an A-subtype (transit minimum deeper than occultation minimum). Now, the light curve showed a W-subtype again. This suggests that the light curve of RZ Com has changed from W-subtype to A-subtype and back to W-subtype again in the past few years.

3 ORBITAL PERIOD CHANGES IN RZ COM

Using the observed data, two primary and two secondary light minimum times are determined using a parabola fit. The results are listed in Table 3, together with the errors in these times. Several light minima have been compiled by Agerer (2003, private communication), and some eclipse times were compiled at the Eclipsing Binaries Minimum Database. The $(O-C)$ values of all the available times, based on the ephemeris (Aslan & Herczeg 1984),

$$\mathrm{Min.}I = 2443967.9371 + 0.^{\mathrm{d}}33850604 \times E\,, \tag{2}$$

Table 3 $(O-C)$ Values of Photoelectric and CCD Eclipse Times for RZ Com

HJD(Hel.)	Error (d)	Method	Min	Filter	$(O-C)_1$	$(O-C)_2$	Residual	Source
2453083.1031	±0.0004	CCD	II	B	+0.0446	+0.0071	+0.0007	The present paper
2453083.2728	±0.0003	CCD	I	B	+0.0451	+0.0076	+0.0012	The present paper
2453083.1034	±0.0003	CCD	II	V	+0.0449	+0.0074	+0.0010	The present paper
2453083.2726	±0.0002	CCD	I	V	+0.0449	+0.0074	+0.0010	The present paper
2453410.6102	±0.0033			IR	+0.0471	+0.0080	+0.0018	Hübscher (2005)
2453462.4004	±0.0002			IR	+0.0459	+0.0065	+0.0003	Hübscher (2005)
2453462.5695	±0.0018			IR	+0.0457	+0.0063	+0.0001	Hübscher (2005)
2453485.4181	±0.0034			IR	+0.0452	+0.0057	–0.0005	Hübscher (2005)
2453806.8301	±0.0001	CCD	II	R	+0.0457	+0.0045	–0.0013	Nelson (2007)
2453845.4203	±0.0001	CCD	II		+0.0462	+0.0048	–0.0010	Parimucha (2007)
2453849.4809	±0.0006	CCD	II	Clear	+0.0447	+0.0033	–0.0025	Doğru (2006)
2453863.3564	±0.0002	CCD	II	Clear	+0.0451	+0.0001	–0.0057	Doğru (2006)

were calculated. We use the same equation as Qian & He (2005) to calculate the $(O-C)$s, so Table 3 lists the data that are not included in Qian & He (2005). The $(O-C)$ curves are shown in Figure 2 (solid dots for photoelectric/CCD observations, open circles for visual and photographic (VP) data). With weight 100 for photoelectric/CCD data and 1 for VP data, the weighted least-squares solution yields the following ephemeris:

$$\begin{aligned} \mathrm{Min.}I = 2443967.9429(\pm 0.0008) + 0.33850672(\pm 0.00000003) \times E + 1.84(\pm 0.10) \times 10^{-11} \times E^2 \\ +0.0065(\pm 0.0001) \times \sin[0.^\circ 0074(\pm 0.^\circ 0001) \cdot E + 278.^\circ 21(\pm 6.^\circ 59)]\,, \end{aligned} \tag{3}$$

which is close to that obtained by Qian & He (2005):

$$\begin{aligned} \mathrm{Min.}I = 2443967.9440(\pm 0.0005) + 0.33850673(\pm 0.00000003) \times E + 1.91(\pm 0.09) \times 10^{-11} \times E^2 \\ +0.0058(\pm 0.0005) \times \sin[0.^\circ 0074(\pm 0.^\circ 0001) \cdot E + 260.^\circ 21(\pm 6.^\circ 9)]\,. \end{aligned} \tag{4}$$

With the quadratic term in Equation (3), a continuous period, increases at a rate of $dP/dt = +3.97 \times 10^{-8}$ d yr^{-1}, is determined, which is close to the value $dP/dt = +4.12 \times 10^{-8}$ d yr^{-1} obtained by Qian & He (2005). The sinusoidal term in Equation (3) reveals a small-amplitude oscillation with an amplitude of 0.0065d. The $(O-C)_2$ values listed in Table 3 with respect to the quadratic part of Equation (3) are plotted. With $\omega = 360^\circ P_e/T$, the period of this oscillation is determined to be 45.1 yr. The period oscillation can be explained either by the light-time effect due to the presence of an unseen third body, or by magnetic-activity cycles of the components. A detailed discussion has been carried out by Qian & He (2005).

4 PHOTOMETRIC ANALYSIS

We carried out a photometric analysis of RZ Com using the 2003 version of the Wilson-Devinney program (Wilson et al. 2003). According to the spectral type K0 given by Mclean & Hiditch (1983), we adopted a temperature of 5000 K for star 1 (star eclipsed at Min.I) . Because RZ Com is a late-type system, we adopt gravity-darkening exponents, $g_1 = g_2 = 0.32$, and the bolometric albedo of the two components, $A_1 = A_2 = 0.5$. Linear limb darkening laws are used with the parameter values as given by Al-Naimiy (1978). The reflection effect is computed with the detailed model of Wilson (1990). The adopted adjustable parameters are: the orbital inclination (i), the mean temperature of star 2 (T_2), the dimensionless potentials of star 1 and star 2 (Ω_1 and Ω_2), and the monochromatic luminosity of star 1 (L_1). The relative brightness of the secondary star is calculated by the blackbody radiation model.

The Wilson-Devinney code is used in contact mode 3 , appropriate for dealing with a contact system. The spectroscopic mass ratio was found to be $q = m_2/m_1 = 0.43$ by Mclean & Hiditch (1983), while the photometric mass ratio was found to be $q = m_2/m_1 = 2.29$ by Wilson & Devinney (1973), 0.24 by Jabbar & Kopal (1983), and 2.226 by Xiang & Zhou (2004). To check the mass ratio we assumed a series of trial values of q (0.2, 0.3, 0.4, 0.5, 0.6,0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 4.0 and 5.0). The resulting sum, $\sum(\omega_i(o-c)_i)^2$, of the weighted square deviations of the converged solutions for each trial value is plotted in Figure 3.

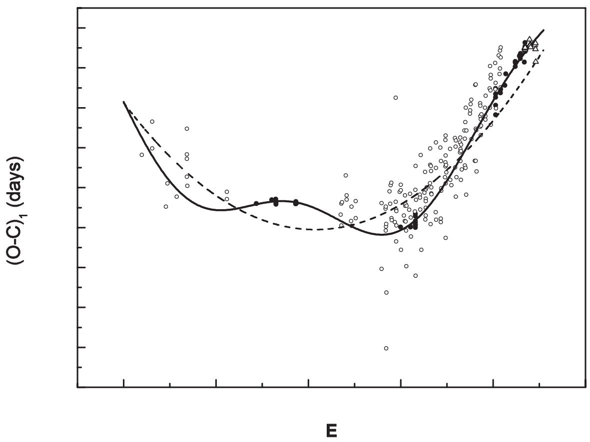

Fig. 2 $(O-C)_1$ plotted vs. observing date computed with Eq. (2). Circles refer to visual or photographic observations, dots to photoelectric data and triangle to the data after Qian & He (2005) listed in Table 3. The dashed line shows the quadratic fit, the solid line, a combination of the quadratic fit and the periodic component.

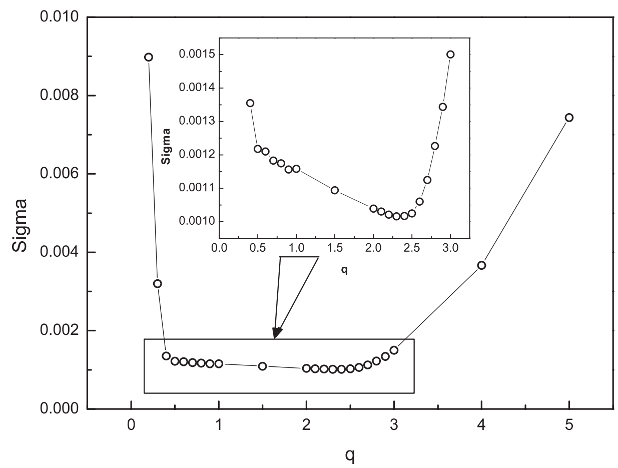

Fig. 3 Variance of the computed fit as function of the mass ratio q.

From Figure 3, we can see that the minimum of $\sum(\omega_i(o-c)_i)^2$ is located at $q = m_2/m_1 = 2.3$. We then made another photometric solution with the mass ratio $q = m_2/m_1$ an adjustable parameter, using the Wilson-Devinney program. The results are listed in Table 4. We see that the parameters of RZ Com are close to those of GSC 0445-993 (Yang 2005).

5 DISCUSSION AND CONCLUSIONS

Our solutions indicate that the binary could be a W-type overcontact binary system with a mass ratio of $q = 2.351(\pm 0.031)$. The mass ratio $q = 2.351$ is close to the spectroscopic mass ratio $q = m_2/m_1 = 0.43$ (or $q = m_1/m_2 = 0.23$) obtained by Mclean & Hiditch (1983). It is a total-eclipse binary star with an orbital inclination of $i = 81^\circ.40(\pm 0^\circ.40)$. The less massive component has a temperature up to $\Delta T = 100\,\mathrm{K}$ higher than the more massive one, while contributes less light. The degree of geometrical contact, defined by $f = (\Omega_{\rm in} - \Omega)/(\Omega_{\rm in} - \Omega_{\rm out})$, is $20.1\%(\pm 7.4\%)$, indicating RZ Com is an overcontact binary system. Combining our photometric solutions with the spectroscopic elements obtained by Mclean & Hilditch (1983), the absolute dimensions of RZ Com are: $M_1 = 1.14\,(\pm 0.19) M_\odot$, $M_2 = 0.50\,(\pm 0.09) M_\odot$,

Table 4 Photometric Solutions of the Eclipsing Binary RZ Com

Parameters	Value
$g_1 = g_2$	0.32
$A_1 = A_2$	0.50
$x_{1\mathrm{bol}}$	0.296
$x_{2\mathrm{bol}}$	0.315
$y_{1\mathrm{bol}}$	0.401
$y_{2\mathrm{bol}}$	0.371
x_{1V}	0.562
x_{2V}	0.682
y_{1V}	0.271
y_{2V}	0.135
x_{1B}	0.892
x_{2B}	1.036
y_{1B}	-0.046
y_{2B}	-0.216
T_1(K)	5000
$i(^\circ)$	81.40($\pm$0.40)
$\Omega_1 = \Omega_2$	5.6201($\pm$0.0448)
Ω_{in}	5.7420
Ω_{out}	5.1353
f	20.1%($\pm$7.4%)
T_2(K)	4900($\pm$8)
$q = M_2/M_1$	2.351($\pm$0.031)
$(L_1/(L_1+L_2))_{\mathrm{V}}$	0.3470($\pm$0.0037)
$(L_1/(L_1+L_2))_{\mathrm{B}}$	0.3545($\pm$0.0041)
r_1(pole)	0.2971($\pm$0.0045)
r_1(side)	0.3113($\pm$0.0055)
r_1(back)	0.3512($\pm$0.0098)
r_2(pole)	0.4371($\pm$0.0037)
r_2(side)	0.4682($\pm$0.0049)
r_2(back)	0.4990($\pm$0.0067)
$\sum(\omega_i(o-c)_i)^2$	0.00101

$R_1 = 1.12\ (\pm 0.01) R_\odot$, $R_2 = 0.78\ (\pm 0.01) R_\odot$ and $A = 2.41\ (\pm 0.02) R_\odot$. It is found that the light curve of the binary star has changed from W-subtype (Wilson & Devinney 1973; Xiang & Zhou 2004) to A-subtype (Qian & He 2005) between 1998 and 2003, then in 2004 it changed back to W-subtype. We think that this variation can be explained by activity of some dark spot on the primary component, as pointed out by Binnendijk (1964). It is, of course, well-known that such phenomena appear in other W UMa binaries including FG Hya (Qian & Yang 2005), TZ Boo (Hoffman 1978, 1980; Awadalla 1989), AM Leo (Binnendijk 1969; Hoffman & Hopp 1982; Derman et al. 1991), SS Ari (Kim 2003), AC Boo and AH Cnc (Kurochkin 1960; Maceroni et al. 1984; Zhang et al. 2005; Qian et al. 2006). To further understand the properties of the variation of the light curve, long-term photometric monitoring is needed.

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