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The First Photometric Investigation of the Neglected Contact Binary LP Comae

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Abstract

In this paper, we present the first complete photometric light curves in the B, V, and R passbands of the neglected contact binary LP Com. Based on the Wilson–Devinney code, it has been found that the LP Com is a W-type W UMa binary with a mass ratio of $q = m_2/m_1 = 4.36$ and a contact degree of $f = 21.3 \pm 0.3\%$. By using our new times of minimum light together with those collected from the literature, we found that the observed calculated $(O - C)$ curve shows an upward parabolic variation that corresponds to a long-term increase in the orbital period at a rate of $dP/dt = +2.59 \times 10^{-7}$ days yr^{-1}. Such a long–term increase in its orbital period may be caused by a mass transfer from the less massive component to the more massive one. This indicates that LP Com is in the thermal relaxation oscillation controlled evolution stage. The presence of two dark spots on both companions was used to fit the asymmetry of the light curves. When the upward parabolic change was subtracted, the $(O - C)_2$ curve reveals a cyclic variation with a period of 10.09 yr and a small amplitude of 0.0028 days. The cyclic variation was investigated by the light-time effect due to the presence of an extremely cool stellar companion.

Key words: (stars:) binaries (including multiple): close – (stars:) binaries: eclipsing – stars: evolution – stars: individual (..., ...)

Online material: color figures

1. Introduction

The most common feature of the W Ursae Majoris (W UMa) binaries is that both components are filling the critical Roche lobes and sharing a common convective envelope, and their eclipsing light curves have nearly equal depth. Such a system is not only an important source for testing the angular momentum evolution of binaries (Rucinski 2000), but also is an excellent object for testing the model of thermal relaxation oscillation (TRO, Lucy 1976; Flannery 1976; Robertson & Eggleton 1977; Lucy & Wilson 1979). Additionally, W Uma stars play an important role in the investigation of stellar evolution, as they are the possible progenitors of some objects (e.g., Chen & Han 2008; Jiang et al. 2013).

LP Com (GSC 0991 1633) was first discovered by Blattler & Diethelm (2001) and classified as an EW-type eclipsing binary. The investigation of this system has been ignored for a long time, even though the light curves were observed by Blattler & Diethelm (2001). So far, a complete photometric analysis of LP Com is not well known. Therefore, we show the first new complete charge-coupled device (CCD) light curves in the B, V, and R passbands for LP Com in Section 2. Then the analysis of the orbital period and the photometric solution with the Wilson–Devinney (WD) program are presented in Sections 3 and 4, respectively. Finally, according to the photometric solution and the orbital period variation, the discussion of the photometric and orbital solutions are given in Section 5.

2. Observations

We observed LP Com in the Johnson-Cousins BVR filters from 2015 March 22 to 24 with the Nanshan One-meter Wide-field Telescope (NOWT) at the Nanshan station of the Xinjiang Astronomical Observatory, China. The NOWT is equipped with a 4 K $\times$ 4 K CCD camera that shows a $1.3° \times 1.3°$ field of view (FOV) and a pixel scale of $1.13''$ pixel^{-1}. The details of NOWT can be found in Liu et al. (2014). Twilight sky flats, the bias, and the dark frames were taken in each observing night. The effective subframe of FOV is $15' \times 15'$. The standard aperture photometry routine of IRAF[3] was used to reduce the observed images.

The complete light curves in the BVR passbands are presented in the top panel of Figure 1. The orbital phases of those observations can be obtained by

$$\mathrm{Min.I} = 2457105.443 + 0\overset{\mathrm{d}}{.}3379335 \times E, \quad (1)$$

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

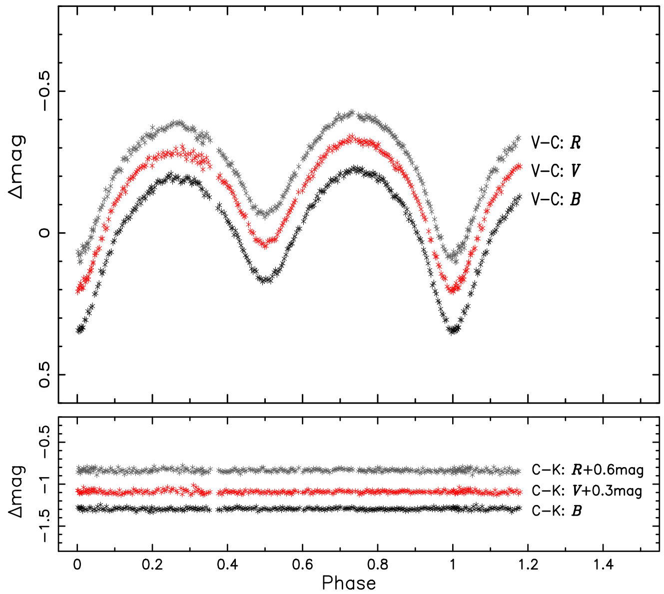

Figure 1. Upper panel shows the CCD photometric light curves in the *BVR* passbands for LP Com. The black, red and gray asterisks stand for *B*, *V* and *R* passbands, respectively. The magnitude difference between the comparison and check stars are shown in the bottom panel, in which a shift of +0.30 mag and +0.60 mag for the *V* and *R* passbands has been used.
(A color version of this figure is available in the online journal.)

where the vale of 2457105.443 is one of the new times of light minima obtained by these observations; the period is adopted by Blattler & Diethelm (2001). The bottom panel of Figure 1 displays the magnitude differences between the comparison and check stars in the *BVR* passbands. In Figure 1, it can be seen that LP Com has an typical EW-type light curve, which is symmetric in all passbands. We have checked the O'Connell effects (O'Connell 1951), and found obvious differences between the two maxima in the light curves (0.032 mag/0.042 mag/0.046 mag in the $B/V/R$ band, respectively). In these observations, three times of light minimum listed in Table 1 were obtained in each passband by the method developed by Kwee & van Woerden (1956).

3. Orbital Period Variation for LP Com

The change of the orbital period is one of the observational properties of binary stars. Blattler & Diethelm (2001) have given the ephemeris of LP Com, 2451967.4962(9)+0.3379351 (17) $\times E$. The investigation of the change of orbital period for LP Com has been neglected by earlier investigators. To investigate this property, we collected the light minimum times from the eclipsing binary (O-C) database Gateway[4], all of these minimum times are observed by photoelectric or CCD observations (listed in Table 2). Including the three new

Table 1
New Times of the Light Minimum for LP Com

HJD	Errors	Types	Filters
2457105.4440	0.0005	I	B
2457105.4430	0.0003	I	V
2457105.4420	0.0005	I	R
2457104.2600	0.0002	II	B
2457104.2609	0.0003	II	V
2457104.2618	0.0005	II	R
2457105.2748	0.0003	II	B
2457105.2745	0.0003	II	V
2457105.2738	0.0004	II	R

minimum times in this work, a total of 53 minimum times were studied, which span over 14 years. According to Equation (1), we modified the period of LP Com, and obtained a new corrected linear ephemeris as

$$\begin{aligned}\mathrm{Min.I} = {} & 2457105.4427(0.0029)\\ & + 0.33793547(0.00000078) \times E. \end{aligned} \quad (2)$$

The $(O-C)_1$ values are obtained by using this new linear ephemeris, and the corresponding $(O-C)_1$ diagram is shown in the top panel of Figure 2 (black dots).

A clear long-term increase of the orbital period was shown in the top panel of Figure 2 (the red dashed line). A small-amplitude cyclic variation is displayed in the middle panel of Figure 2 (the red solid line). Therefore we use a combination of an upward parabolic and a sinusoidal variation to describe the general trend of $(O-C)_1$ (the blue solid line in the top panel of Figure 2). So a least–square calculation result is given as

$$\begin{aligned}\mathrm{Min.I} = {} & 2457105.4394(\pm 0.0021)\\ & + 0.33793723(\pm 0.00000005) \times E\\ & + 1.20(\pm 0.03) \times 10^{-10} \times E^2\\ & + 0.0028(\pm 0.0007)\sin[0\overset{\circ}{.}033(\pm 0.0020) \times E\\ & + 110\overset{\circ}{.}8(\pm 2\overset{\circ}{.}1)]. \end{aligned} \quad (3)$$

The quadratic term in Equation (3) indicates that the orbital period of LP Com increases secularly at a rate of $dP/dt = +2.59 \times 10^{-7}$ days yr^{-1}. The residuals from Equation (3) are shown in the bottom panel of Figure 2.

Once the continuous upward increase has been subtracted, the $(O-C)_2$ values of all minimum times are displayed in the middle panel of Figure 2. It shows that the orbital period of LP Com underlies a periodic oscillation with a small-amplitude. This periodic oscillation is also found in other contact binaries, such as the PY Virgins (Zhu et al. 2013), AL Cas (Qian et al. 2014), and V345 Gem (Yang et al. 2009). From Equation (3), we can see that the amplitude is only about 0.0028 days, and the oscillation period is estimated as $T = 10.09$ yr with $\Omega = 2\pi P/T$, where P is the period of LP Com.

[4] http://var.astro.cz/ocgate/

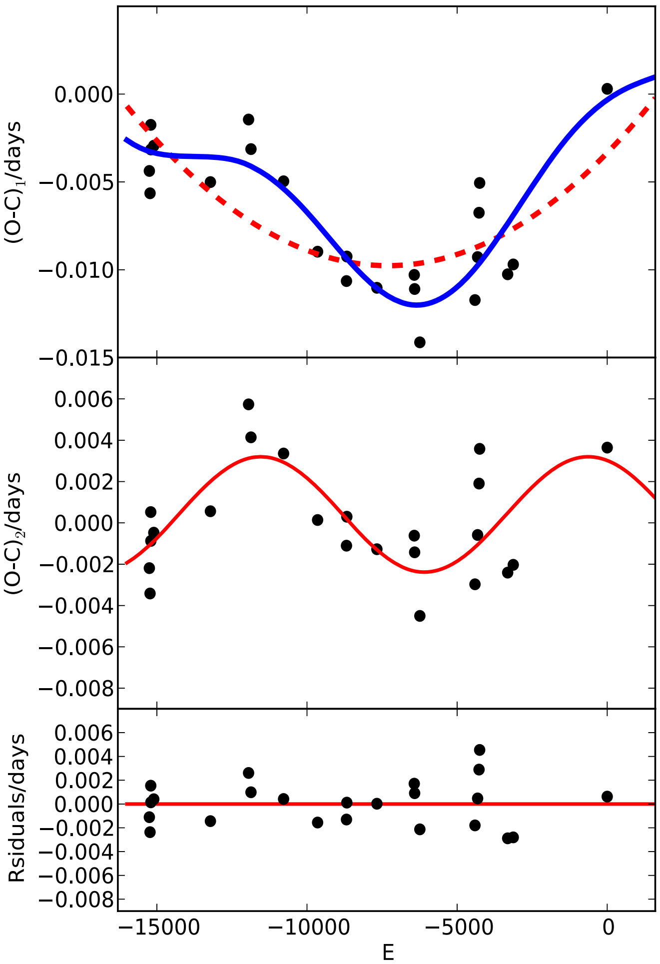

Figure 2. Top panel: the $(O-C)_1$ diagram for all minimum times for LP Com. The black dots are obtained from the linear ephemeris in Equation (1).The blue solid line stands for the general trend of these data. The red dashed line represents a long-term increase. Middle panel: the $(O-C)_2$ curve with respect to the quadratic ephemeris in Equation (3). The red solid line shows a cyclic variation. The residuals are shown in the bottom panel.

(A color version of this figure is available in the online journal.)

4. Photometric Solution for LP Com

The spectral type and temperature of LP Com can be measured from the spectral data or color indices. Three spectra of LP Com were obtained by the Large Sky Area Multi-Object Fiber Spectrpscopic Telescope (LAMOST, also called Guo Shoujing telescope), one of them was observed on 2012 January 1, and is displayed in Figure 3. The LAMOST pipeline is used to derive the stellar atmospheric parameters (including the effective temperature T_{eff}, gravitational acceleration log g, metallicity [Fe/H] and radial velocity V_r) for late A and FGK type stellar observations (Luo et al. 2015) when their spectra have higher signal-to-noise (S/N). Two spectra have high S/N, and their stellar atmospheric parameters were automatically derived via ULySS (Universite de Lyon Spectroscopic analysis Software Koleva et al. 2009; Wu et al. 2011). The ULySS package is employed to fit the full observed spectra with the model spectrum that is generated by an interpolator by the ELODIE library as reference (Prugniel & Soubiran 2001; Prugniel et al. 2007). The standard deviations are 110 K, 0.19 dex, and 0.11 dex for T_{eff}, log g and [Fe/H], respectively, with $T_{eff} < 8000$ K, and 4.91 km s^{-1} for V_r when $T_{eff} < 8000$ K (Gao et al. 2015). The derived spectral type and temperature of LP Com were G9 and 5247 K.

It has been shown that the light curves displayed in this work are symmetric and the eclipses are complete. These are very useful for determining a reliable photometric solution for LP Com. The photometric solutions of this system have been ignored for a long time. To investigate its geometrical structure and evolution stage, the 2010 version of the WD program (Wilson & Devinney 1971; Wilson 1979, 1990; Van Hamme & Wilson 2007; Wilson 2008) was adopted to analyze the multi-color light curve. During this procedure, the effective temperature of the star 1 (the star eclipsed at the primary light minimum) was fixed as $T_1 = 5247$ K. The gravity-darkening coefficients $g_1 = g_2 = 0.32$ (Lucy 1967), and the bolometric albedos $A_1 = A_2 = 0.5$ (Rucinski 1969) for stars with a convective envelope were adopted. For the limb darkening, we chose the logarithmic functions. These assumed parameters of the photometric solution are displayed in Table 3. During this solution, a contact configuration (model 3) was adopted for the EW-type light curve. The adjust parameters are: the orbital inclination (i); the temperature of star 2 (T_2); the dimensionless surface potential (Ω_1 and Ω_2); as well as the monochromatic luminosities of the star 1 (L_{1B}, L_{1V}, and L_{1R}).

So far, no photometric and spectroscopic solutions of LP Com have been studied, and meanwhile no reliable mass ratios were given. To obtain a guaranteed mass ratio by using the WD program, we adopted a mass ratio search (q-search) method. We fixed a series of values of mass ratio q in the range of 0.1–6.0 by steps of 0.01. The relation between the resulting Σ of weighted square residuals and the assumed q is shown in Figure 4. It can be seen that the Σ has a minimal value at $q = 4.04$. Hence, we chose 4.04 as the initial value of q and took it as an adjustable parameter in subsequent calculations until a convergent solution was obtained. Here, we need to note that there exist uncertainties for mass ratio q based only on photometric observations, and Rucinski (2015) have also pointed out this phenomenon. Zhang et al. (2017) investigated this uncertainty and they found that an estimate of mass ratio uncertainty based only on photometric observations might be up to 10%. They also concluded that the degree of symmetry of the light curves and the degree of sharpness of the q-search curve bottom could be used to investigate the mass ratios reliability for photometric observations. For LP Com, we can see that q-search bottom is sharp around 4.04 in Figure 4 and the light curves are symmetric with a typical O'Connell effect. Therefore, it is believed that the mass ratio solution of LP Com

Table 2
The CCD Times of Minimum Light of LP Com

HJD+240 0000	Min.	HJD+240 0000	Min.	HJD+240 0000	Min.
51951.44090	s	51951.61380	p	51959.38500	p
51967.32850	s	51967.49930	p	51968.51170	p
51984.56090	s	52001.46010	s	52001.62940	p
52027.47940	s	52363.38670	s	52638.97000	p
52691.51820	s	53068.31270	s	53068.48710	p
53095.52010	p	53462.34530	s	53462.51410	p
53464.37490	s	53476.53940	s	53788.45210	s
53811.76790	s	53845.38880	p	53863.46410	s
54097.32170	s	54149.70130	s	54170.47920	p
54174.53580	p	54200.39100	s	54512.80550	p
54564.33860	s	54874.90800	s	54933.36590	s
54933.53350	p	54937.42050	s	54937.58790	p
54955.66820	s	54996.38530	p	55276.71030	s
55310.50250	s	55616.83370	p	55646.57430	p
55646.74510	s	55662.45970	p	55669.38500	s
55669.55800	p	55675.47280	s	55984.84480	p
56047.70100	p	56061.39350	s	57104.26090	p
57105.27440	p	57105.44300	p		

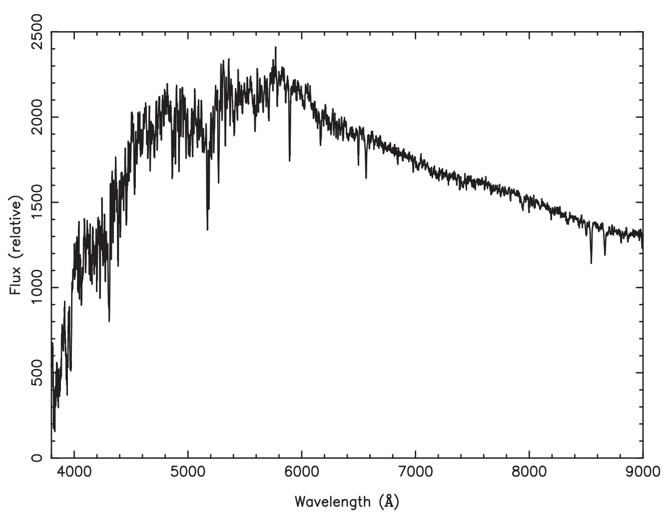

Figure 3. Spectrum of LP Com from LAMOST.

Table 3
Assumed Parameters During Photometric Solution

Parameters	Values
$g_1 = g_2$	0.32
$A_1 = A_2$	0.50
$x_{1bolo} = x_{2bolo}$	0.082
$y_{1bolo} = y_{2bolo}$	0.646
$x_{1B} = x_{2B}$	0.778
$y_{1B} = y_{2B}$	0.301
$x_{1V} = x_{2V}$	0.680
$y_{1V} = y_{2V}$	0.297
$x_{1R} = x_{2R}$	0.582
$y_{1R} = Y_{2R}$	0.295
T1 (K)	5247

is generally reliable only depending on the light curves with the uncertainty of 10%.

Both components of LP Com are cool stars and they share a common convective envelope. This deep convective envelope can produce strong dynamo and solar like magnetic activities (e.g., photospheric dark spots). An obvious O'Connell effect can be found in Figure 1. The different heights of the two light maxima between phase 0.25 and 0.75 in the top panel of Figure 1 could be caused by the existence of dark spots on the common convective envelope. These models of dark spots were used earlier by some studies (e.g., Bell et al. 1990; Samec et al. 2010; Zhu et al. 2012). To explain the O'Connell effect, the presence of dark spot activity on the photospheric surface of two components is displayed in this work. Four parameters of each spot are needed to give the best fitting results in the photometric solutions. Through fitting three band data, we obtain the best photometric solution. The results of this corresponding photometric solution are listed in Table 4. The parameters of these two spots are listed in Table 5, so the theoretical light curves were obtained by using the light curve program in WD code. In Figure 5, it can be seen that the theoretical light curves fit to the observed data very well. The geometrical structures of LP Com at four (0.00, 0.25, 0.50 and 0.75) different orbital phases are displayed in Figure 6.

Finally, the photometric solution shows that LP Com has a contact degree of $f = 21.3\%$, and the derived $q = 4.36$. The spectral type of LP Com is G9, and its mass can be estimated as

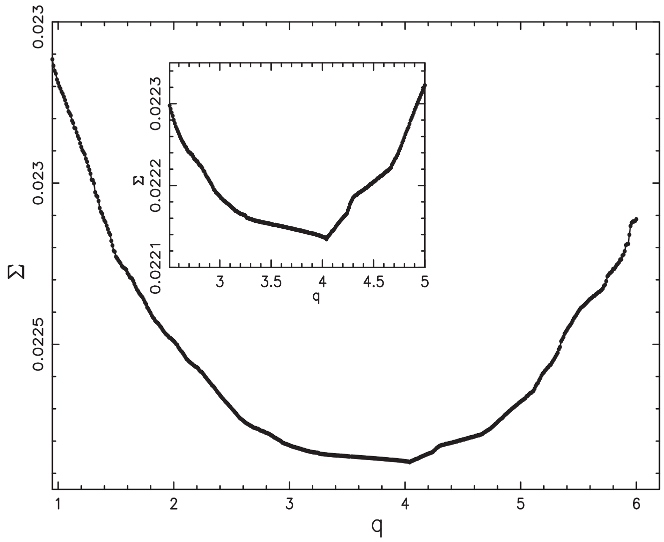

Figure 4. Relation between $\Sigma W(O-C)^2$ and q of LP Com.

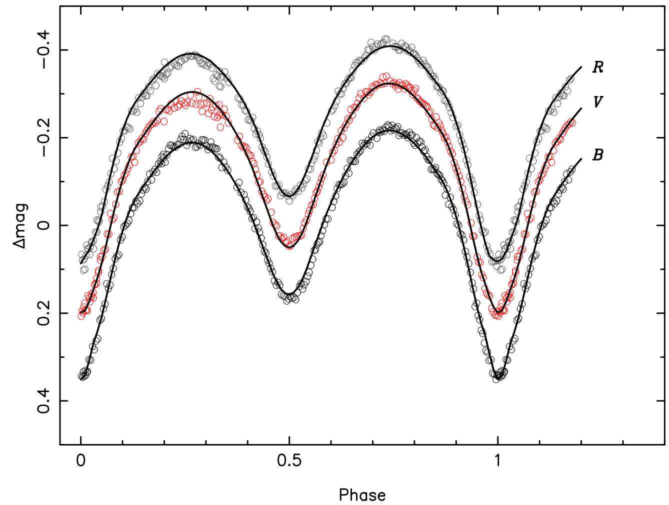

Figure 5. Observational (open circles) and fitted (solid lines) light curves of LP Com in the B, V and R passbands.
(A color version of this figure is available in the online journal.)

Table 4
Photometric Solution of LP Com

Parameters	Values
$i(°)$	73.061 ± 0.0241
T_2(K)	4852 ± 4
$\Omega_1 = \Omega_2$	8.2329 ± 0.0041
$q(M_2/M_1)$	4.3609 ± 0.0041
$L_1/(L_1+L_2)_B$	0.3232 ± 0.0031
$L_1/(L_1+L_2)_V$	0.2975 ± 0.0002
$L_1/(L_1+L_2)_R$	0.2776 ± 0.0002
r_1(pole)	0.2501 ± 0.0005
r_1(side)	0.2613 ± 0.0006
r_1(back)	0.3010 ± 0.0013
r_2(pole)	0.4839 ± 0.0014
r_2(side)	0.5264 ± 0.0020
r_2(back)	0.5521 ± 0.0026
f_{over}(%)	21.3 ± 0.3
$\sum W(O-C)^2$	0.016396

Table 5
Parameters of the Dark Spots on the Two Components

Parameters	Spot 1 on the Primary	Spot 1 on the Secondary
θ(radian)	0.03923	0.88638
ϕ(radian)	2.38157	2.50034
r(radian)	0.33631	0.18533
$T_f(T_d/T_0)$	1.65497	0.74566

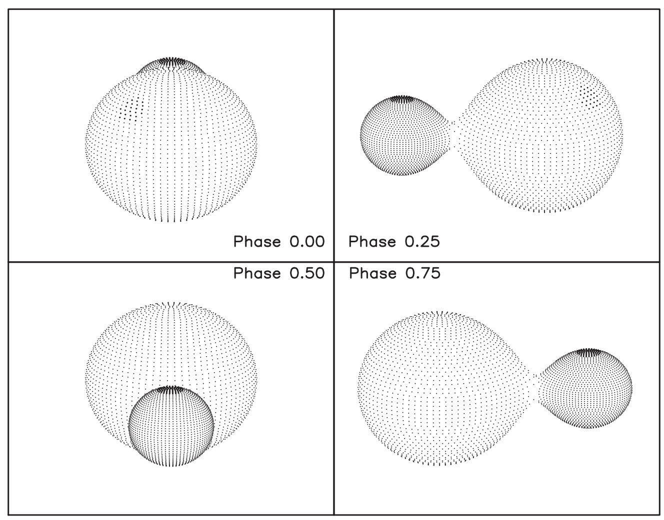

Figure 6. Configurations at the phases of 0.00, 0.25, 0.50 and 0.75, respectively.

$M_2 = 0.86\,M_\odot$ (Cox 2000). Then, the derived mass of secondary component is about $M_1 = 0.20\,M_\odot$.

5. Discussion and Conclusion

The first complete CCD photometry observations in the B, V, and R passbands of contact binary LP Com were studied in this paper. The photometric solutions show that this system is a contact binary system with a contact degree of $f = 21.3 \pm 0.3\%$. The mass ratio has been estimated as

Table 6
Parameters of Third Body in LP Com

Parameters	Values	Errors
$T\,(yrs)$	10.09	0.52
$A_3(days)$	0.0028	0.0007
$e'(Assumed)$	0	0.0
$a'_{12}(AU)$	0.48	0.033
$f\,(M_3)(M_\odot)$	0.0011	0.0004
$M_3 sin\, i'(M_\odot)$	0.115	0.05
$a_3(i' = 90°)(AU)$	4.45	0.32

$q = 4.36$. The orbital period changes were also investigated, and it was found that a cyclic variation with a small amplitude of 0.0028 days overlaps an upward increase at a rate of $dP/dt = +2.59 \times 10^{-7}$ days yr^{-1} in its orbital period. Qian (2001) proposed that the contact binary was undergoing the TRO stage (e.g., Flannery 1976; Eggleton 1996; Csizmadia & Klagyivik 2004; Li et al. 2004; Li et al. 2005) with an angular momentum loss (AML), when the period of the contact binary changes continuously.

The phenomenon of long-term increase in the orbital period can be explained by the mass transfer from the less massive component to the more massive component (Qian 2001, 2003), which agrees with the TRO theory. In the TRO evolution stage, the W UMa binaries oscillate around the status of contact and non-contact. According to a conservative mass transfer from the less massive component to the more massive component, by a calculation with the equation

$$\frac{\dot{P}}{P} = -3\dot{M}_1\left(\frac{1}{M_1} - \frac{1}{M_2}\right), \tag{4}$$

the mass transfer rate can be estimated to be $dM_1/dt = -0.67 \times 10^{-7}\, M_\odot\, yr^{-1}$. With the period increase, the contact degree becomes smaller, resulting a larger AML. The LP Com system becomes more active with more AML, and it will evolve into an AML controlled stage. Then the period decrease during the AML process and its degree of degree becomes larger, and induces a smaller AML. At the end, this system will evolve into a TRO stage again and the period will increase.

From the $(O\text{-}C)_2$ of Figure 2, a cyclic variation with a period of 10.09 yr found in the orbital period. This cyclic oscillation maybe caused by the light-travel time effect, which derives from the gravitational influence of a third body. The parameters of the third body are given in Table 6. The mass of the third companion is $M_3 sin\, i' = 0.007\, M_\odot$. To check the existence of the third component, we searched for the luminosity of third light (L_3) in the photometric solution. According to the calculation of WD code, it is shown that the total contribution of this third light L_3 is about 1%. This indicates that the third body is a cool and faint object.

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