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The short-period low-mass binary system CC Com revisited

O. Köse[1], **B. Kalomeni**[1,2], **V. Keskin**[1], **B. Ulaş**[1], and **K. Yakut**[1,⋆]

[1] Department of Astronomy and Space Sciences, University of Ege, 35100, İzmir, Turkey
[2] Department of Physics, İzmir Institute of Technology, 35430, İzmir, Turkey

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In this study we determined precise orbital and physical parameters of the very short-period low-mass contact binary system CC Com. The parameters are obtained by analysis of new CCD data combined with archival spectroscopic data. The physical parameters of the cool and hot components are derived as $M_{\rm c}$ = 0.717(14) $M_\odot$, $M_{\rm h}$ = 0.378(8) $M_\odot$, $R_{\rm c}$ = 0.708(12) $R_\odot$, $R_{\rm h}$ = 0.530(10) $R_\odot$, $L_{\rm c}$ = 0.138(12) $L_\odot$, and $L_{\rm h}$ = 0.085(7) $L_\odot$, respectively, and the distance of the system is estimated as 64(4) pc. The times of minima obtained in this study and with those published before enable us to calculate the mass transfer rate between the components which is 1.6×10^{-8} $M_\odot$ yr^{-1}. Finally, we discuss the possible evolutionary scenario of CC Com.

1 Introduction

One of the crucial parameter that determines the evolutionary stages of a binary is its orbital parameter. Because of their unusual behaviour, short period systems like CC Com, GSC 1387-0475 (Yang et al. 2009) and V523 Cas (Köse et al. 2009) are important in evolutionary studies.

CC Com was discovered by Hoffmeister (1964) and has been intensively studied photometrically by Ruciński (1976), Breinhorst & Hoffmann (1982), Bradstreet (1985), Zhou (1988), Linnell & Olson (1989), and Zola et al. (2010). Over the last four decades intense spectroscopic studies were made by Ruciński et al. (1977), McLean & Hilditch (1983), and Pribulla et al. (2007). In these studies spectroscopic mass ratios were found as 0.52(3), 0.47(4), and 0.53(1), respectively. The photometric mass ratio, on the other hand, was given as 0.59 by Zhou (1988) and 0.51 by Linnell & Olson (1989). The physical parameters of the components have not been measured so far by a simultaneous analysis of spectroscopic and photometric data.

The orbital period of the weakly contact binary CC Com has been the subject of many papers. These studies indicate a systematic period decrease. In the literature the period variation ($\mathrm{d}P/\mathrm{d}t$) of CC Com is given as -4.4×10^{-8} d yr^{-1}, -4.0×10^{-8} d yr^{-1}, and -2.0×10^{-8} d yr^{-1} by Qian (2001a), Yang & Liu (2003), and Yang et al. (2009), respectively. Yang et al. (2009) presented cyclic variations superimposed on a parabolic period variation and discussed this feature as an indication of a third body or stellar activity.

A contact model solution has been suggested by Ruciński (1976), and related UBV parameters have been given in that study. Breinhorst & Hoffmann (1982) studied the effects that can cause variations in minima depths assuming no period change. The filling factor variation has been discussed by Linnell & Olson (1989) based on their u, y, and I photometry. Recently, Zola et al. (2010) gave the photometric elements of the system by using the Wilson-Devinney code.

In this paper, we present a photometric analysis and orbital period study of the short-period eclipsing binary system CC Com. First, the new observations with new linear ephemeris are presented. Then the mass transfer rate between the components is estimated by a period study. Next, the light curve of the system is modeled by comparing our results with those of previous works. Finally, the obtained results are presented with a discussion of possible evolutionary stages of CC Com.

2 New observations

We observed CC Com in the Bessel V and R filters in 2007 on six nights by using the 40-cm telescope with an Apogee U47 CCD at TÜBİTAK National Observatory (TUG) and on one night in 2011 at Ege University Observatory with the 40-cm telescope equipped with the Apogee CCD camera. GSC 01986 01673 and GSC 01444 00106 are chosen as comparison and check stars, respectively. The integration times were 30 s in V and 25 s in R. The IRAF (DIGIPHOT/APPHOT) packages were used to reduce the CCD data. The errors are 0.011 mag in V and 0.008 mag in R. The light-curve of the binary which shows a total eclipse is displayed in Fig. 1. In Table 1 our newly obtained times of minima are listed together with those published in the literature.

The period variation study of CC Com was performed by using a total of 83 collected times of minima light ob-

⋆ Corresponding author: kadri.yakut@ege.edu.tr

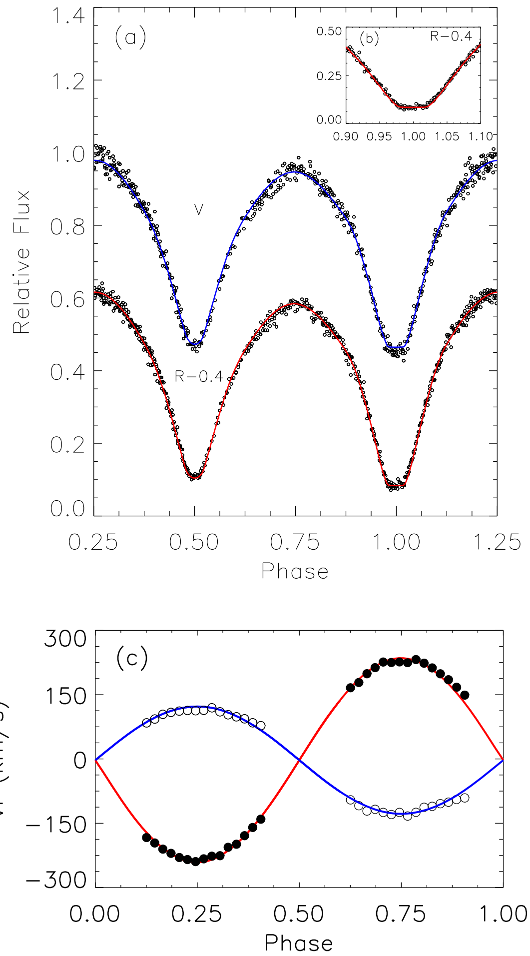

Fig. 1 (online colour at: www.an-journal.org) (*a*) The observed and computed (solid line) light curves of CC Com. The light curve in the R band is moved by a value of –0.4 in intensity; (*b*) minimum light is zoomed between phases 0.90 and 1.10 for a good visibility; (*c*) radial velocities of CC Com. The data obtained from Pribulla et al. (2007). The computed lines are estimated from a simultaneous solution.

tained by photometric/CCD observations. The new linear ephemeris derived in this study is

$$\mathrm{HJD(MinI)} = 2454151.6060(2) + 0.22068516(6) \times E. \quad (1)$$

3 Eclipse timings and period study

CC Com is a contact binary system in which continuous mass-transfer between the components is expected. A parabolic variation can be seen in the $O-C$ diagram due to the high mass transfer rate that can be derived by a period analysis. The period variation of CC Com has been discussed in some papers (Qian 2001a; Yang & Liu 2003; Yang et al. 2009). Qian (2001a), based on 35 photometric/CCD minima times, studied the parabola like variation and determined the quadratic term (Q) as $-1.323(3) \times 10^{-11}$. Yang & Liu (2003) analyzed 322 times of minima light including the visual data assuming a parabolic variation, and the Q value was obtained as $-1.2(4) \times 10^{-11}$. Recently, Yang et al. (2009), by using visual and photometric data, obtained a sine-like variation superimposed on a parabolic variation and found $Q = -0.59(5) \times 10^{-11}$. The period of the sine-like variation was calculated as 23.6 yr. This effect has been interpreted as an indication of either cyclic stellar activity or of the existence of a third body in the system.

Table 1 The times of minimum light of CC Com. The data obtained before 2001 were given in Qian (2001a).

HJD(Min) – 2400000	Ref.	HJD(Min) – 2400000	Ref.
52002.3484	1	53823.7849	11
52002.4592	1	53824.7758	11
52039.4238	1	53847.3921	7
52648.9580	2	53850.3695	12
52721.3429	3	54175.4396	10
52800.0165	4	54175.5505	10
53068.5921	5	54198.3907	13
53093.4195	5	54202.3634	10
53093.5298	5	54203.3558	14
53106.4436	6	54204.3531	10
53116.4819	6	54206.3358	10
53122.3280	5	54209.4245	10
53446.4060	7	54209.5347	10
53460.1993	4	54213.3979	13
53460.3101	4	54593.4190	14
53460.5312	6	54595.4049	14
53462.4063	6	54596.6184	15
53462.5169	6	55122.4751	16
53464.5030	6	55122.5856	16
53472.4471	6	55123.5786	16
53485.4677	6	55151.3853	16
53504.3365	8	55151.4958	16
53504.4465	8	55151.6054	16
53517.7983	9	55676.32502	16
53765.5180	10	55676.43554	16
53818.3717	7		

References: 1: Zejda (2004); 2: Nelson (2004); 3: Agerer & Hübscher (2003); 4: Kim (2006); 5: Hübscher (2005); 6: Hübscher et al. (2005); 7: Hübscher (2006); 8: Pribulla et al. (2005); 9: Nelson (2006); 10: Hübscher (2007); 11: Parimucha et al. (2007); 12: Doğru (2006); 13: Doğru (2007); 14: Hübscher et al. (2009); 15: Dvorak (2009); 16: present study.

The scattering in visual data is about 0.03 days, which makes it difficult to study any low amplitude variation. Hence, visual data points are excluded in the period analysis. Times of mid-eclipses with those obtained in this study are given in Table 1.

The residuals shown in Fig. 2a indicate a quadratic solution with a binary period decreasing with time. In order to obtain the light elements given in Eq. (2) the differential correction method is used. By applying this equation to the times of minima given in Table 1 and by using a weighted least squares solution we obtain

$$\begin{aligned}\mathrm{HJD(MinI)} &= 2454151.60676(7)\\ &+ 0.22068573(9) \times E - 4.04(18) \times 10^{-12} \times E^2.\end{aligned} \quad (2)$$

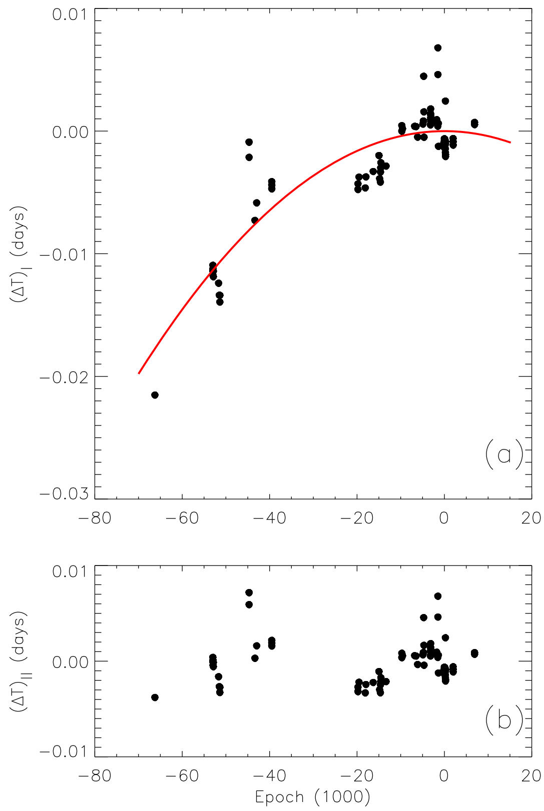

Fig. 2 (online colour at: www.an-journal.org) (*a*) Residuals for the times of minimum light of CC Com. The solid line is obtained with the quadratic terms in the ephemeris of Eq. 2. (*b*) The difference between the observations and the quadratic ephemeris.

The observed $O - C$ values given in Fig. 2 are derived by using the linear elements T_0 and P_0 given in Eq. (1). The solid line in Fig. 2a shows a secular period decrease of $\mathrm{d}P/\mathrm{d}t = -1.34 \times 10^{-8}\,\mathrm{d\,yr^{-1}}$ which has been determined by using Eq. (2). The difference between our result and the results of previous studies is mainly because of the less scattered data set used in this study. Figure 2b shows the residuals of a parabolic variation. These residuals may be assigned to a sine-like variation that can be interpreted as a consequence of a third body or stellar magnetic activity of the components as was discussed by Yang et al. (2009). At this point, however, we should emphasize that because of the absence of the data it is hard to confirm definitely any sine-like variation.

4 Simultaneous light and radial velocity curve analysis

The light variation of CC Com has been studied by many researchers. Ruciński (1976) analyzed the UBV light curve and determined the photometric parameters of the system and indicated the necessity of studying the system spectroscopically. Maceroni et al. (1982) re-analyzed Ruciński's data assuming an unspotted stellar model and a temperature of 4500 K for the hotter component. Apart from the study of Maceroni et al. (1982), however, almost all of the previous studies assumed a surface temperature of the hotter component of 4300 K. Bradstreet (1985) analyzed the B and I light curves and determined the absolute elements of the system. Bradstreet applied a spotted solution and also discussed that the spotted model light curve solution can be replaced by a model with a circumbinary gas stream. Zhou (1988), by making use of Ruciński's UBV data, derived the parameters of the binary system. In addition the author discussed the insignificance of any third light in the system. Recently, Zola et al. (2010) studied the $BVRI$ light variations over three days assuming a fixed mass ratios. Light curve variations with time have been indicated in some papers (e.g. Linnell & Olson 1989; Quian 2001a; Yang & Liu 2003).

We analyzed simultaneously the two light curves of CC Com in V and R by means of the PHOEBE code (Prša & Zwitter 2005), which is based on the Wilson-Devinney-code (Wilson & Devinney 1971; Wilson 1994). During the solution the light and radial velocity data points were weighted ($1/\sigma^2$) according to their individual standard errors (σ). On the other hand, we used 613 R and 570 V photometric data points but only 60 data points for radial velocity. Hence, a higher weight was assigned to the radial velocity data to avoid domination of the photometric data and to construct an equilibrium between the data. The temperature of the primary star was adopted from Linnell & Olson (1989) as 4300 K. Gravity darkening coefficients and albedos are obtained from Lucy (1967) as $g_1 = g_2 = 0.32$ and from Ruciński (1969) as $A_1 = A_2 = 0.5$. The logarithmic limb darkening coefficients are adopted from van Hamme (1993) for solar composition and assumed to be equal for both stars for a given filter ($x_{1V} = x_{2V} = 0.798$, $x_{1R} = x_{2R} = 0.796$).

In addition, the radial velocities obtained by Pribulla et al. (2007) have been analysed simultaneously with the two colour photometric data. Orbital inclination (i), mass ratio (q), temperature of the secondary component (T_2), separation of the components (a), velocity of the center of gravity (V_γ), the monochromatic luminosity of star 1, L_1 and potential of the common surface (Ω) were adjustable parameters. The phase shift parameter was treated as a free parameter, and almost no shift has been detected.

Some previous studies of CC Com revealed an asymmetry in the maximum light. This effect is also apparent in the light curves obtained in this study (Fig. 1). In addition, similar variations, resulting from stellar spots, are also detected during the minimum light. Almost all of the light curves of the system presented in the literature are different from each other. Therefore, the light-curve solutions have been done by assuming spotted models (Zola et al. 2010; Linnell & Olson 1989; Yakut et al. 2009).

The presence of a spot on the primary component is also assumed in our analysis. The PHOEBE code does not give accurate results for simultaneous solutions where the spot

Table 2 The photometric elements of CC Com with their formal 1σ errors and the comparison with the solutions of Ruciński (1976) [R76], Maceroni et al. (1982) [M82], Bradstreet (1985) [B85], Zhou (1988) [Z88], Linnell & Olson (1989) [L89], and Zola et al. (2010) [Z10].

Parameter	R76	M82 ($B; V$)	B85	Z88	L89	Z10	This Study
Geometric parameters:							
i (°)	90	87.92; 87.92	90.0	87.7	85.2	84.8	89.8(6)
$\Omega_1 = \Omega_2$	4.997	5.045; 5.029	5.047	2.779	5.168	2.873	5.017(36)
q	1.919	1.930; 1.934	1.926	1.70	1.960	1.89	1.90(1)
Filling factor f (%)	23.5	18; 21.6	16.7	24	4.4	18	17
Fractional radius of primary	0.3395	0.3345; 0.3369	0.3337	0.4014	0.3236	0.3294	0.3348(43)
Fractional radius of secondary	0.4526	0.4493; 0.4513	0.4480	0.4884	0.4415	0.4467	0.4469(40)
Radiative parameters:							
T_1 (K)	4300	4500; 4500	4300	4300	4300	4300	4300
T_2 (K)	4082	4317; 4288	4140	4265	4133	4263	4200(60)
Luminosity ratio $\frac{L_1}{L_1+L_2}$ (%)							
U				37			
B		43	43	38		34	
V		43		38		35	40
R						35	40
I			40			35	
Spot on primary component							
Colatitude (°)			80		90	170.5	90
Longitude (°)					-90	130.7	90
Spot radius (°)					12.5	50.6	20
Spot temperature ($T_{\rm spot}/T_{\rm star}$)			0.93		0.84(I)	0.737	0.92

parameter is regarded as a free parameter. In order to obtain the best spot parameters different solutions have been performed by changing the location, size, and the temperature of the spot. Among these solutions, the one with the smallest standard deviation is regarded as a best solution for the spot parameters (Table 2). Since the errors of spot parameters are not available, the errors given in Table 2 may be smaller than the real values. On the other hand, we should emphasize the point that the spot parameters obtained from the LC solutions do not represent a single spot at the related point but indicate the total active area on the stellar surface. The filling factor, $f = (\Omega_{\rm in} - \Omega)/(\Omega_{\rm in} - \Omega_{\rm out})$, from the inner ($\Omega_{\rm in}$) to the outer critical surface ($\Omega_{\rm out}$), is estimated as 0.17.

The results derived from the light curve analysis are summarized and compared with the previous ones in Table 2. In Fig. 1 we compare the observed data with model's prediction.

5 Summary and conclusion

Period variations and light curves of the low temperature contact binary (LTCB) system CC Com have been studied. The physical parameters of the system have been determined with the simultaneous solution of our two light curves (V, R) and the spectroscopic study of Pribulla et al. (2007).

The physical parameters of CC Com are presented in Table 3 with their errors. It seems that there is a good agreement between the derived physical parameters of CC Com and other LTCBs (Yakut & Eggleton 2005). We estimated the distance to CC Com by using the results obtained from a radial velocity and light curve analysis. For that purpose the total brightness ($V = 11\overset{\rm m}{.}30$) and light ratio of the components have been used. The results indicate a distance of 65 pc and 63 pc for the hot and cool components, respectively. The mean of these estimates gives the distance of the system as 64(4) pc. This value is 20 % smaller than the value given in the SIMBAD database.

We have collected and analyzed the times of minima for CC Com. The $O - C$ diagram shows a downward parabola. This property can be explained by a mass transfer from the more massive component to the less massive one. The quadratic term of Eq. (2) shows that the orbital period of the system decreases at a rate of $\mathrm{d}P/\mathrm{d}t = 1.34 \times 10^{-8}$ d yr^{-1} as a result of mass transfer rate of 1.6×10^{-8} M$_\odot$ yr^{-1}. In this study, the residuals of the period variation do not show any reliable sine-like variation (Fig. 2b). Assuming the existence of a third body we solved the data, however, because of their poor quality it is hard to find any evidence for a third body in the system. On the other hand, Yang et al. (2009), by assuming a third body in the system, solved for the residuals and determined the orbit parameters of this third body.

Most of the contact binaries show the O'Connell effect in their light curves. This effect is due to large cool starspots (see, for details, Kalomeni et al. 2007). The variation seen in Fig. 2b can also be explained by stellar activity. Similar residuals have been observed in many contact binary systems (e.g., XY Leo, Yakut et al. 2003). The light curve solution indicates that 6 % of the primary star's surface is cov-

Table 3 Absolute parameters of CC Com. The standard errors 1σ in the last digit are given in parentheses. HC denotes the hot component and CC stand for the cool component.

Parameter	Unit	CC	HC
M	$M_\odot$	0.717(14)	0.377(8)
R	$R_\odot$	0.708(12)	0.530(10)
$T_{\rm eff}$	K	4300	4200(180)
L	$L_\odot$	0.138(12)	0.085(7)
$\log g$	cgs	4.59	4.57
$M_{\rm bol}$	mag	6.90(14)	7.43(18)
M_V	mag	7.86(16)	8.25(20)
$\dot{P}$	d yr^{-1}	-1.34×10^{-8}	
$\dot{M}$	$M_\odot$ yr^{-1}	$-1.6\ \times10^{-8}$	
d	pc	64(4)	

ered by a cold spot. In this case, the Applegate mechanism (Applegate 1992) can be responsible from the variation in the orbital period and the occurrence of the non-periodic change.

Different scenarios have been proposed for the evolution and structure of contact binaries. The prevailing theory among them is the thermal relaxation oscillation (TRO) theory, proposed by Lucy (1976), Flannery (1976), Robertson & Eggleton (1977), and Yakut & Eggleton (2005). The TRO model can explain successfully the evolution, structure and the observed properties of contact binary systems (Wang 1994; Qian 2001b; Van Hamme 2001; Webbing 2003; Paczyński et al. 2006; Zhu et al. 2010).

Stępień (2006) also proposed a scenario explaining the evolution of contact binary systems. In short period binaries like CC Com, angular momentum loss plays a crucial role in their evolution. For a close detached binary system with initial parameters 1.19 $M_\odot$ + 0.94 $M_\odot$ and a period of 0.75 days, the mass of the system is estimated to decrease by $\sim$15 % (0.97 $M_\odot$ + 0.83 $M_\odot$) until RLOF at $P = 0.31$ d, and it reaches the contact phase at 0.88 $M_\odot$ + 0.91 $M_\odot$, $P = 0.28$ d. This scenario can explain the evolutionary stages of CC Com with TRO mode like the other LTCBs that are discussed in detail in Yakut & Eggleton (2005).

Additionally, the evolution of short period binaries is also important for measuring gravitational waves. Binary systems with very short periods can create gravitational waves in detectable strength (Ju et al. 2000; Köse & Yakut 2011). We have estimated the amplitude of the gravitational wave in the CC Com binary system as $\log h = -20.6$. Hence, the system CC Com is an important source for interferometers and its amplitude is within the detection limit of detectors such like LISA. The relatively close distance of the system makes it an important target for gravitational wave studies.

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