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TX Cnc AS A MEMBER OF THE PRAESEPE OPEN CLUSTER

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ABSTRACT

We present *B*-, *V*-, and *I*-band CCD photometry of the W UMa-type binary system TX Cnc, which is a member star of the Praesepe open cluster. Based on the observations, new ephemeris and a revised photometric solution of the binary system were derived. Combined with the results of the radial velocity solution contributed by Pribulla et al., the absolute parameters of the system were determined. The mass, radius, and luminosity of the primary component are derived to be $1.35 \pm 0.02\ M_{\odot}$, $1.27 \pm 0.04\ R_{\odot}$, and $2.13 \pm 0.11\ L_{\odot}$. Those for the secondary star are computed as $0.61 \pm 0.01\ M_{\odot}$, $0.89 \pm 0.03\ R_{\odot}$, and $1.26 \pm 0.07\ L_{\odot}$, respectively. Based on these results, a distance modulus of $(m - M)_V = 6.34 \pm 0.05$ is determined for the star. It confirms the membership of TX Cnc to the Praesepe open cluster. The evolutionary status and the physical nature of the binary system are discussed compared with the theoretical model.

Key words: binaries: eclipsing – open clusters and associations: individual (NGC 2632) – stars: activity – stars: individual (TX Cnc) – stars: late-type

Online-only material: color figures, machine-readable and VO table

1. INTRODUCTION

W UMa-type systems are a group of contact binaries consisting of solar-type stars. Because of the peculiar observational properties, such as the so-called light-curve paradox, W UMa stars have been a challenge to the current theory of stellar structure and evolution since the 1960s (Lucy 1968a, 1968b; Mochnacki 1981; Rucinski 1993; Eggleton 1996). How these systems formed and evolved is still an open issue, although W UMa stars are the most common kind of close binaries in the solar neighborhood. During the past two decades, more and more W UMa stars were discovered in star clusters (Kaluzny & Shara 1987; Gilliland et al. 1991; Kaluzny et al. 1993; Zhang et al. 2002, 2004). As members of the star population, the distance, age, and metallicity of these stars could be precisely determined. Taking advantage of this, studies of W UMa stars in star clusters could therefore provide more new information and help people to understand the formation and evolution of W UMa systems.

TX Cnc is a well-known W UMa system in the Praesepe open cluster. The host star cluster Praesepe (NGC 2632, M44) is a nearby open cluster located at a distance of about 180 pc (Robichon et al. 1999; van Leeuwen 1999), and has roughly a solar metallicity (Hambly et al. 1995). With a mean age around 600 Myr, it is one of the youngest open clusters containing a W UMa system (Rucinski 1998). These facts make TX Cnc a very interesting object for studying the structure and evolution of W UMa systems.

Since the discovery by Haffner (1937), TX Cnc has been observed and discussed by various authors. Lenouvel & Daguillon (1956) made the first photoelectric observation. Yamasaki & Kitamura (1972) performed a long-term photoelectric photometry and published a set of complete *U*, *B*, *V*, and narrowband light curves of this star. Further photometric observations were contributed by Whelan et al. (1973), who were the first to compute the simultaneous solution with photometric and spectroscopic data based on the Roche model. They derived a mass ratio of 0.62 for the system. McLean & Hilditch (1983) published another radial velocity solution which gave a mass ratio of 0.52. Both solutions were derived based on photographic spectra. Very recently, Pribulla et al. (2006) contributed a precise radial velocity observation of the star. Based on this, they obtained a smaller mass ratio, 0.455 ± 0.011. It shows that there could be large uncertainties in the physical parameters previously derived for the system. Therefore, revised high-precision photometry is needed to improve those parameters through simultaneous solution along with the radial velocity data.

We have therefore carried out new multi-color CCD photometry of TX Cnc. Complete *B*-, *V*-, and *I*-band light curves and a number of times of minima of the system were obtained. These allow us to investigate the star in detail. In this paper, we present the observations as well as the results of period and photometric analyses of TX Cnc.

2. OBSERVATIONS AND DATA REDUCTION

The star was observed on four nights from 2008 February 25 to 2008 February 28 using the 85 cm reflector at the Xinglong Station of the National Astronomical Observatories, Chinese Academy of Sciences. Data were collected with a PI MicroMAX 1024 BFT CCD camera, which provides a field of view of about $16'.5 \times 16'.5$ with a scale of 0.96 arcsec pixel^{-1}. Three standard Johnson–Cousin–Bessell filters in the *B*, *V*, and *I* bands were used. The exposure time was set at 8–10 s for *B*, 5–6 s for *V*, and 3–5 s for *I* measurements, respectively, depending on the weather conditions. In total, 1546 useful images in *B*, 1494 in *V*, and 1485 frames in the *I* band were obtained.

The preliminary processing of the CCD frames was performed with the standard routines of CCDPROC in the IRAF package. Photometry was extracted using the DAOPHOTII package (Stetson 1987). For the purpose of differential photometry, we first choose a number of relatively bright stars which were observed with good seeing in the program field as reference stars. The stars NGC 2632 WJJP 635 and NGC 2632 WJJP 667 were found to be constant within 0.01 mag on every night. They were finally employed as the comparison and check stars. We then extracted the differential measurements of the target in each frame. The CCD photometric data tabulated in the form of

Table 1
B-, *V*-, and *I*-Band Photometry of TX Cnc

HJD 2454000+	ΔB	HJD 2454000+	ΔV	HJD 2454000+	ΔI
521.99335	−0.426	521.99359	−0.617	521.99390	−0.838
521.99414	−0.431	521.99445	−0.608	521.99469	−0.847
521.99493	−0.420	521.99524	−0.602	521.99548	−0.833
521.99579	−0.425	521.99603	−0.599	521.99628	−0.827
521.99658	−0.425	521.99689	−0.592	521.99713	−0.827
521.99738	−0.410	521.99768	−0.605	521.99792	−0.825
521.99823	−0.417	521.99847	−0.596	521.99872	−0.816
521.99902	−0.410	521.99927	−0.586	521.99951	−0.813
521.99982	−0.403	522.00012	−0.588	522.00037	−0.816
522.00061	−0.402	522.00092	−0.575	522.00116	−0.804

Notes. This table gives *B*-, *V*-, and *I*-band differential measurements for TX Cnc described in the paper.
(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

HJD time versus differential magnitude (Table 1) are available in the online journal. The precision of the differential photometry in this run is computed to be better than 0.01 mag in all bands (*B*, *V*, and *I*).

In addition to this observation, the star TX Cnc has been observed previously on four nights from 2007 January 5 to 2007 January 8 just for the purpose of light minima determination. This observation was also performed at the Xinglong Station by using the 1 m telescope equipped with a VA1300B 1K × 1K CCD camera and a single *V* filter. A total of five epochs of light minima were detected. These data will be included in the period analysis in the next section.

3. PERIOD AND LIGHT CURVES

A total of 11 eclipses were recorded in our observations of TX Cnc. By using the K–W method (Kwee & van Woerden 1956), the epochs of these light minima were determined as given in Table 2. In addition, we have collected another 59 minimum times for the star from literature. The collected times of minima in Table 2 cover a time interval longer than 55 years, spanning more than 52,000 cycles. This enables us to discuss the long-term period variations of the system precisely.

By using the least-square method, the following new linear and quadratic ephemerides were calculated:

$$\mathrm{Min}\, I(\mathrm{HJD}) = 2454522.0432(4) + 0\overset{\mathrm{d}}{.}38288242(2) \times E \quad (1)$$

$$\mathrm{Min}\, I(\mathrm{HJD}) = 2454522.0456(3) + 0\overset{\mathrm{d}}{.}38288324(5) \times E + 1.95(8) \times 10^{-11} \times E^2. \quad (2)$$

The $O - C$ residuals for all the times of minimum light with respect to the linear and quadratic ephemerides are calculated as given in Table 2. Figure 1 plots the $O - C$ diagrams of the period analysis. The upper panel in Figure 1 illustrates the quadratic fit to the linear $O - C$ residuals from the second ephemeris. It is strongly suggested that the binary system was undergoing a strictly orbital period increase during the past few decades. The rate of period increase turns out to be $dP/dE = 3.9 \times 10^{-11}$d cycle^{-1} or $dP/dt = 3.7 \times 10^{-8}$d yr^{-1}. The long-term period decrease could be interpreted as probable mass transfer from the less-massive secondary to the primary component. In the lower panel of Figure 1, we plot the final

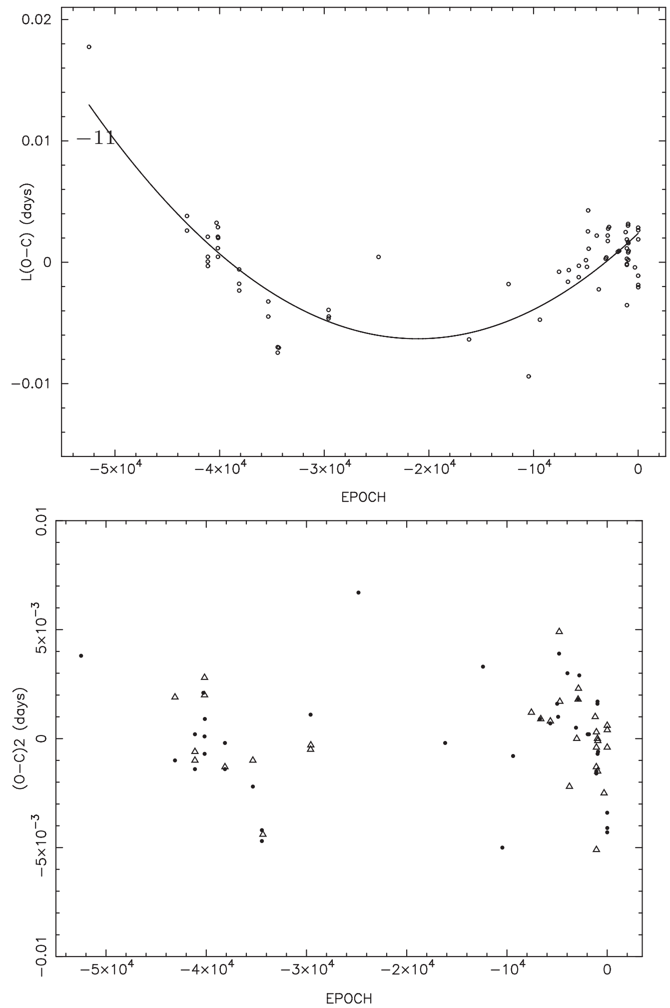

Figure 1. Period analysis of TX Cnc.

$O - C$ residuals computed from the quadratic ephemeris, where the solid circles represent the data of the primary minima and the open triangles denote the secondary minima. It shows no periodic variations as reported by Liu et al. (2007) but very large noise-like scattering. Moreover, there is no strict difference of behavior between the two types of data points in the diagram. Therefore, we would like to account for this large scatter of the minimum times to the influence of the probable spot activity which might be caused by the mass transfer mentioned above.

By using the newly derived linear ephemeris, phases of all the measurements were computed. The phased light curves are plotted in Figure 2. With the standard magnitudes known for the check star ($B = 12.17$, $V = 11.46$, and $I = 10.47$; Morel & Magnenat 1978), a brief magnitude calibration was performed. Table 3 lists the main feature parameters for the light curves of TX Cnc. The color indices of the star were measured to be $B - V = 0.63$ and $V - I = 0.86$. Considering the interstellar extinction of $E(B - V) = 0.029$ estimated for Praesepe corresponding to $A_V = 0.09$ for the average radial velocity of 3.1 km s^{-1} according to Schlegel et al. (1998), the intrinsic color index of the star could be about $(B - V)_0 = 0.60$, which suggests a spectral type nearly G0-1V for the binary system. This is in good agreement with Yamasaki & Kitamura (1972) and close to the results determined from spectroscopy (Popper 1948; Pribulla et al. 2006).

The general feature of the light curves is typical of W UMa systems with unequal minima. The primary eclipse is deeper

Table 2
Photoelectric and CCD Times of Minima of TX Cnc and the Residuals Computed from the Ephemerides

JD(Hel) (2400000+)	E	$(O-C)_1$ (d)	$(O-C)_2$ (d)	Ref.	JD(Hel) (2400000+)	E	$(O-C)_1$ (d)	$(O-C)_2$ (d)	Ref.
34426.4773	−52485.0	0.0177	0.0048	1	52647.8334	−4895.0	−0.0004	0.0008	13
38011.2000	−43122.5	0.0038	0.0006	1	52685.3588	−4797.0	0.0025	0.0037	14
38012.1560	−43120.0	0.0026	−0.0006	1	52691.2952	−4781.5	0.0043	0.0054	15
38774.0915	−41130.0	0.0021	0.0005	1	52711.9677	−4727.5	0.0011	0.0022	16
38774.2809	−41129.5	0.0001	−0.0015	1	53004.2995	−3964.0	0.0022	0.0028	17
38775.0463	−41127.5	−0.0003	−0.0019	1	53081.0630	−3763.5	−0.0022	−0.0018	17
38775.2385	−41127.0	0.0005	−0.0011	1	53330.8963	−3111.0	0.0003	0.0003	18
39095.3310	−40291.0	0.0033	0.0023	1	53358.2725	−3039.5	0.0004	0.0003	17
39141.0843	−40171.5	0.0021	0.0013	1	53408.4319	−2908.5	0.0022	0.0021	19
39141.2748	−40171.0	0.0012	0.0003	1	53410.5373	−2903.0	0.0017	0.0016	20
39142.9995	−40166.5	0.0029	0.0021	1	53422.9820	−2870.5	0.0028	0.0026	16
39143.1885	−40166.0	0.0004	−0.0004	1	53455.3357	−2786.0	0.0029	0.0027	20
39153.1450	−40140.0	0.0020	0.0012	1	53776.5720	−1947.0	0.0009	0.0000	21
39920.0547	−38137.0	−0.0018	−0.0012	1	53824.0495	−1823.0	0.0009	0.0000	17
39921.9703	−38132.0	−0.0006	0.0000	1	54063.5440	−1197.5	0.0025	0.0011	22
39922.1600	−38131.5	−0.0023	−0.0017	1	54107.1904	−1083.5	0.0003	−0.0012	23
40986.9551	−35350.5	−0.0032	−0.0009	1	54107.3814	−1083.0	−0.0002	−0.0017	23
40987.1453	−35350.0	−0.0045	−0.0022	1	54108.1471	−1081.0	−0.0002	−0.0017	23
41331.7365	−34450.0	−0.0074	−0.0046	2	54108.3399	−1080.5	0.0011	−0.0004	23
41332.8856	−34447.0	−0.0070	−0.0042	2	54109.1064	−1078.5	0.0019	0.0004	23
41372.1310	−34344.5	−0.0070	−0.0042	1	54111.0154	−1073.5	−0.0035	−0.0051	24
43191.7828	−29592.0	−0.0039	0.0010	3	54150.2674	−971.0	0.0030	0.0014	25
43192.7393	−29589.5	−0.0046	0.0002	3	54150.4575	−970.5	0.0017	0.0001	26
43200.7800	−29568.5	−0.0045	0.0004	3	54153.3306	−963.0	0.0032	0.0016	26
45022.3480	−24811.0	0.0004	0.0065	4	54154.4769	−960.0	0.0008	−0.0008	26
48332.3597	−16166.0	−0.0064	−0.0005	5	54157.3479	−952.5	0.0002	−0.0014	26
49777.3625	−12392.0	−0.0018	0.0030	6	54163.4754	−936.5	0.0016	0.0000	26
50515.5522	−10464.0	−0.0094	−0.0053	7	54172.4725	−913.0	0.0009	−0.0007	25
50926.3897	−9391.0	−0.0047	−0.0011	8	54403.1578	−310.5	−0.0004	−0.0025	24
51625.3455	−7565.5	−0.0008	0.0019	9	54522.0421	0.0	−0.0011	−0.0035	23
51952.5177	−6711.0	−0.0016	0.0007	10	54522.2375	0.5	0.0029	0.0005	23
51983.3407	−6630.5	−0.0006	0.0016	9	54523.0023	2.5	0.0019	−0.0005	23
52348.4185	−5677.0	−0.0012	0.0004	11	54523.1898	3.0	−0.0021	−0.0044	23
52352.4397	−5666.5	−0.0003	0.0014	11	54524.1517	5.5	0.0026	0.0003	23
52611.8430	−4989.0	0.0002	0.0014	12	54525.1044	8.0	−0.0019	−0.0043	23

Notes. 1, Yamasaki & Kitamura 1972; 2, Whelan et al. 1973; 3, Hilditch 1981; 4, Diethelm 1982; 5, Diethelm 1990; 6, Diethelm 1995; 7, Krobusek 1997; 8, Diethelm 1998; 9, Agerer & Hubscher 2002; 10, Diethelm 2001; 11, Pribulla et al. 2002; 12, Dvorak 2003; 13, Nelson 2004; 14, Hubscher 2005; 15, Diethelm 2003; 16, Kim et al. 2006; 17, Liu et al. 2007; 18, Dvorak 2005; 19, Hubscher et al. 2006; 20, Hubscher et al. 2005; 21, Dvorak 2008; 22, Senavci et al. 2007; 23, present study; 24, Nagai 2008; 25, Hubscher 2007; 26, Arranz & Sanchez-Bajo 2007.

than the secondary by about 0.04, 0.03, and 0.03 mag in the B, V, and I bands, respectively. In comparison to the light curves published before, the asymmetry of the light curves outside the eclipses proves to be more obvious. The maximum at the first quadrature, Max I (at phase 0.25), is measured to be brighter than the secondary maximum (at phase 0.75) by 0.05 mag in B, 0.04 mag in V, and 0.03 mag in I, respectively. It shows that the light asymmetry seems to vary depending on the bandpass. The largest light excess at Max I appears in the B-band light curve, and the smallest appears in the I band. The distortion of the light curves might be caused by a hot spot on the massive primary component due to the probable mass transfer.

Table 3
Main Feature Parameters of the Light Curves of TX Cnc

Phase	B (mag)	V (mag)	I (mag)	$B-V$ (mag)	$V-I$ (mag)
0.00	10.95	10.31	9.44	0.64	0.87
0.25	10.59	9.96	9.11	0.63	0.85
0.50	10.91	10.28	9.41	0.63	0.87
0.75	10.64	10.00	9.14	0.64	0.86

4. PHOTOMETRIC SOLUTION

With the completely covered B, V, and I light curves, a revised photometric solution of the binary system was carried out. The numerical light curve analysis was done by using the 2003 version of the Wilson–Devinney code with the Kurucz atmospheres (Wilson & Devinney 1971; Wilson 1979, 1990; Kallrath et al. 1998). A nonlinear limb-darkening law with the logarithmic form was applied in the light-curve synthesis. Considering the probable close distance between the components, the effect of reflection was taken into account.

TX Cnc has been argued to be a W-subtype W UMa system with the less-massive component hotter than the massive primary star. To check this hypothesis, we reformed the radial velocity curve contributed by Pribulla et al. (2006) with the newly derived ephemeris and computed the radial velocity solution at the outset. The reformed radial velocity curve along with the

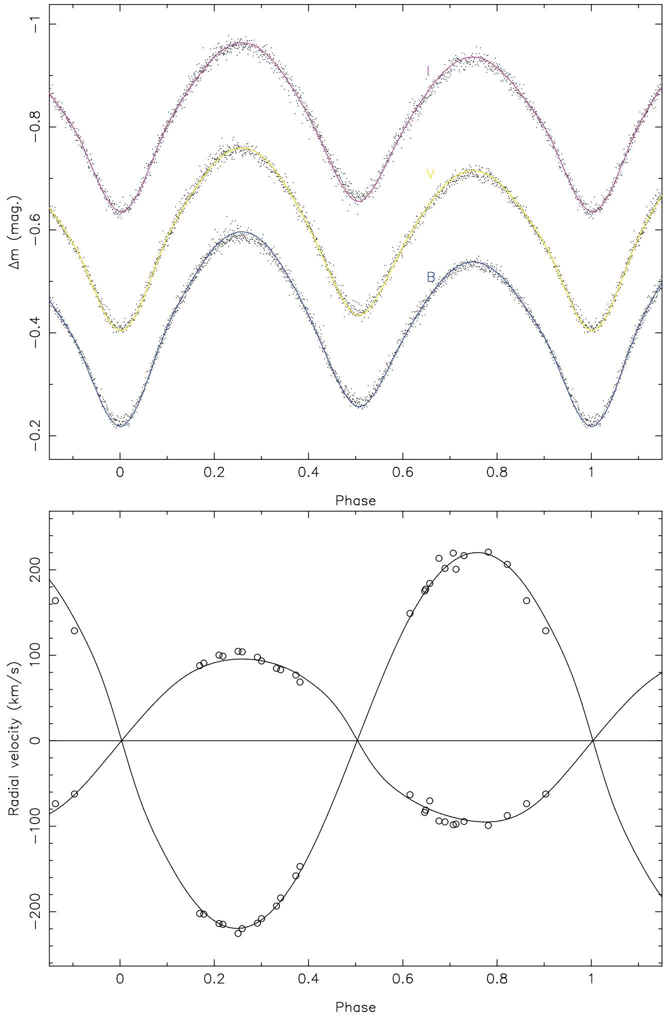

Figure 2. Observed B, V, I light and radial velocity curves of TX Cnc and their theoretical synthesis.

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

theoretical fitting is presented in the lower panel in Figure 2. The solution reveals a mass ratio of about 2.20, which is just the inverse value of 0.455 as given by Pribulla et al. (2006). It implies that the primary minima of the light curves at phase 0.0 must correspond to the eclipses of the secondary component by the massive companion and confirms directly that the less-massive component indeed possesses a higher surface temperature than massive primary. In this case, we designated star 1 as the less massive, and star 2 as the massive component. In computing the photometric solutions, the temperature of star 2 was assigned to be $T_2 = 6250$ K according the spectral type of F8V through the calibration of Cox (2000), and the mass ratio of the system was fixed at $q = M_2/M_1 = 2.20$. The initial bolometric (X_1, X_2, Y_1, Y_2) and monochromatic (x_1, y_1, x_2, y_2) limb-darkening coefficients of the components were taken from Van Hamme (1993). The gravity darkening exponents were set to be $g_1 = g_2 = 0.32$ according to Lucy (1967), and bolometric albedos were given as $A_1 = A_2 = 0.5$ following Rucinski (1969). The adjustable parameters are the orbital inclination i, the mean temperature of the first star T_1, the potentials Ω_1, Ω_2, and the nondimensional luminosity L_1 and L_2.

For the marked asymmetry in the light curves, we could not obtain a satisfactory fit to both the quadratures of the light curves with the unspotted synthesis. To solve this problem, we set the weights of the measurements with phases between 0.2 and 0.4 to be zero and fit the second quadratures of the light curves only. In this way, we derived the proper geometry system parameters through the unspotted light-curve synthesis. After that the weights for all the measurements were reset to 1, and the star-spot model was employed to perform a further analysis. A hot spot was placed on the massive component (star 2). The spot parameters are the spot temperature T_s (given as a fraction of the surrounding photospheric temperature), the spot radius r_s, co-latitude and longitude. The preliminary spot longitude could be found approximately from the phases of spot distortion in the light curves. The other three parameters were calculated by adjusting the theoretical light curve to approximately fit the observed distorted light curve. The spot parameters were then adjusted along with the adjustable system parameters. Finally, we obtained the photometric solution with the best fit. Table 4 gives the results from the best-fit solution. The light-curve synthesis was illustrated by Figure 2. In Figure 3, a geometric presentation of the system along with the hot spot based on the solutions is displayed.

Table 4
Photometric Solutions for TX Cnc

Parameters	Best-Fit Value	Formal Error
i (deg)	62.10	±0.06
$q = m_2/m_1$	2.2198[a]	
T_1 (K)	6537	±9
T_2 (K)	6250[a]	
$g_1 = g_2$	0.32[a]	
$A_1 = A_2$	0.50[a]	
$\Omega_1 = \Omega_2$	5.4526	±0.0028
$X_1 = X_2$(bolo)	0.640[a]	
$Y_1 = Y_2$(bolo)	0.232[a]	
$x_2 = x_2$ (B)	0.815[a]	
$x_1 = x_2$ (V)	0.725[a]	
$x_1 = x_2$ (I)	0.540[a]	
$y_1 = y_2$ (B)	0.206[a]	
$y_1 = y_2$ (V)	0.266[a]	
$y_1 = y_2$ (I)	0.266[a]	
$L_1/(L_1 + L_2)$ (B)	0.386	±0.002
$L_1/(L_1 + L_2)$ (V)	0.372	±0.001
$L_1/(L_1 + L_2)$ (I)	0.356	±0.001
r_1 (pole)	0.2988	±0.0002
r_1 (side)	0.3126	±0.0003
r_1 (back)	0.3496	±0.0004
r_2 (pole)	0.4282	±0.0002
r_2 (side)	0.4571	±0.0003
r_2 (back)	0.4870	±0.0004
$\mathrm{Latitude_{spot}}$ (deg)	112.6	±2.2
$\mathrm{Longitude_{spot}}$ (deg)	91.4	±3.4
$\mathrm{Radius_{spot}}$ (deg)	48.1	±1.1
T_{spot}/T_2	1.045	±0.002

Notes. [a] Assumed.

5. RESULTS AND DISCUSSION

The photometric solution reveals a contact configuration for the system with a filling factor computed to be 0.21. With an inclination of about 62.1 degrees, it is in partial eclipse. The difference of the mean temperature between the components was derived to be 287 K. With the less massive component hotter than the primary companion, TX Cnc is confirmed to be a typical W-type W UMa system. Combining the results of our photometric solution with the spectroscopic solution given by Pribulla et al. (2006), the absolute parameters (mass, radius, and luminosity) for each of the components were computed as given in Table 5.

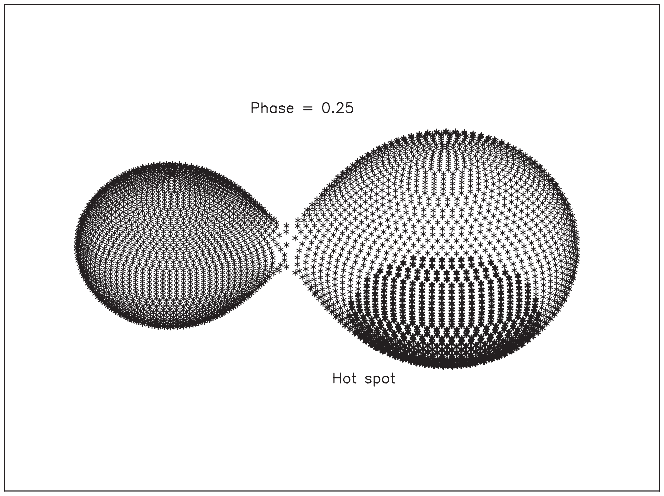

Figure 3. Geometric configuration and the spot distribution of TX Cnc.

Table 5
Absolute Parameters of TX Cnc

Parameter	Primary	Secondary
Mass ($M_\odot$)	1.35 ± 0.02	0.61 ± 0.01
Radius ($R_\odot$)	1.27 ± 0.04	0.89 ± 0.03
Luminosity ($L_\odot$)	2.13 ± 0.11	1.26 ± 0.07

With the derived luminosity for both components, the bolometric magnitude of the total binary system is then calculated to be $M_{\rm bol} = 3.41 \pm 0.03$. Taking the visual magnitude $V = 10.00$ at phase 0.75 (Table 3), a bolometric correction of BC $= -0.16$ according to the spectral type F8V, and the interstellar absorption $A_V = 0.09$, the distance modulus of the binary system is then computed to be $m - M = 6.34 \pm 0.05$. This is in perfect agreement with the distance modulus of 6.37 $\pm$ 0.15 or parallax of 5.32 $\pm$ 0.37 mas assigned for Praesepe by van Leeuwen (1999) based on the *Hipparcos* astrometry. We can therefore conclude that TX Cnc could be a certain member of the Praesepe cluster.

Being a member of the Praesepe cluster, TX Cnc could be one of the youngest W UMa systems with a known age, and becomes an important sample to test the theories of contact binary formation and evolution. In Figure 4, we plot the two components of the system on the mass–luminosity (M–L) and mass–radius (M–R) diagrams along with the 600 Myr theoretical isochrone from Girardi et al. (2000) for the Population I stars with $(X, Y, Z) = 0.708, 0.273, 0.019$. In comparison with the theoretical models, the primary component is obviously underluminous and slightly undersized. For the secondary star, its radius is about 70% larger, and the luminosity is 15 times higher than the theoretical model. Coincidentally, it is found that the total luminosity of the two stars is almost equal to the sum of the luminosities of the two stars with similar masses computed from theoretical models, or in other words, the absolute underluminosity of the primary component is almost equal to the overluminosity of the secondary. This seems to be direct evidence for the predicted energy transfer between the components according to the contact model (Lucy 1968a, 1968b).

According to the theory of the contact binary model, there also exists a mass exchange from the primary to the secondary component accompanying the energy transfer, which could cause the orbital period of the system to decrease. In the case of TX Cnc, however, the orbital period study presented above indicates that the system is undergoing an increase in the long-term period. It could be interpreted as the effect of mass transfer from the less massive to the massive component. Assuming that the total mass and orbital angular momentum of the binary system are both conserved, the rate of mass transfer turns out to be about $1.1 \times 10^{-7}\,M_\odot$ yr^{-1}. The mass transfer is taking place at a timescale of about 5.5×10^6 yr, which is comparable to the thermal timescale of the secondary star; the later value is estimated to be about 9.9×10^6 yr.

It shows that the energy transfer model could not match the situation of TX Cnc. In view of the formation and evolution of close binaries, most contact binaries could not be originally in contact but formed from detached or semidetached systems through mass exchange and mass-ratio reverse. For the case of TX Cnc, if we assume that the total mass and orbital angular momentum are both conservative during the mass transferring stage, the changing of the critical Roche radii for the donor depending on its mass could be traced as illustrated by the dotted curve on the M–R diagram in Figure 4. The radius of the donor always obeys the normal M–R relation before mass exchange, but is limited within the Roche lobe when the mass transfer begins. Thus, the intersection point between the critical Roche radius and the M–R relation denotes just the moment when the mass transfer begins. From this the initial mass of the present less massive star could be deduced as about 1.4 $M_\odot$, which for the companion is estimated to be about 0.56 $M_\odot$. It means that the donor has transported its mass to the gainer for about 0.8 $M_\odot$.

Affected by such vast mass transfer, the structure of both the donor and the gainer could be strongly changed and each M–L relation may be quite different from the normal single

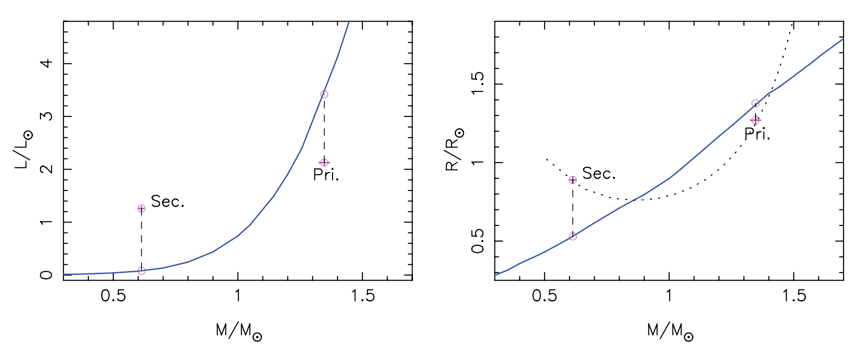

Figure 4. Locations of the components of TX Cnc on the mass–luminosity and mass–radius diagrams. The solid lines represent the 600 Myr isochrones from Girardi et al. (2000) with solar chemical composition.

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

Table 6
Evolutionary Timescales Estimated for the Components of TX Cnc

Timescales	Mass Trans. Begins	Present
τ_K (donor)	9.8×10^6 yr	9.9×10^6 yr
τ_K (gainer)	3.9×10^8 yr	2.0×10^7 yr
τ_{ff} (donor)	7.4×10^5 yr	5.4×10^5 yr
τ_{ff} (gainer)	2.0×10^5 yr	6.2×10^5 yr
τ (mass trans.)	More shorter	4.6×10^6 yr

stars. Moreover, when the mass transfer occurs, there is an evolutionary timescale issue. Once the mass transfer starts, it generally takes place at a thermal timescale of the donor if the stellar envelope is radiative. If the envelope is convective, it occurs even on a dynamical timescale. Both of these timescales are far shorter than the thermal timescale of the gainer. In this case, the hydrogen burning core of the gainer could not be enlarged efficiently corresponding to the increase in mass and thus generates less luminosity and remains a smaller radius in comparison to a normal single star. In contrast to the gainer, the core of the donor could not be reduced enough during the mass loss so that it emits more luminosity possessing a larger radius. Based on the parameters obtained above, we have estimated the related timescales for the two stars as given in Table 6. It shows that the mass exchange timescale is still shorter than the thermal timescales of both the components even at the present stage. We therefore suggest that the peculiar evolutionary status of the contact system as discussed above could be mainly due to the effect of mass transfer.

6. CONCLUSIONS

We have presented high-precision, multi-color CCD photometry of the W UMa-type binary system TX Cnc. Complete covered *B*-, *V*-, and *I*-band light curves and a number of times of minima were detected, based on which a comprehensive study of the contact binary system was carried out. It leads us to draw the following conclusions.

1. The orbital period of the binary system TX Cnc is indicated to be undergoing a long-term period increase during the past 60 years which may be caused by the continuous slow mass transfer from the secondary to the primary component. The period study did not provide any obvious evidence for the existence of a third body.
2. With a hot spot model, the light curves of the system were fairly synthesized. It indicates that TX Cnc is a typical W UMa system with marked surface activity. Moreover, the photometric solution confirms the W-type nature of the contact system. The mean temperature of the less massive component is about 287 K higher than the massive primary.
3. The physical parameters including the mass, radius, luminosity for each component, and the distance modulus of the binary system were determined. It confirms the membership of TX Cnc to the Praesepe open cluster. Based on this, the evolutionary status for each component was discussed in connection with the theoretical model. Both components show quite different properties in comparison with the single normal stars, which could not be interpreted satisfactorily by the current contact binary model. Finally, we suggest that the contact system might be formed from a detached or a semidetached binary through mass exchange and mass-ratio reverse. The peculiar property of the system might be due to the effect of the mass transfer.

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