CCD photometric study of the contact binary TX Cnc in the young open cluster NGC 2632

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ABSTRACT

TX Cnc is a member of the young open cluster NGC 2632. In the present paper, four CCD epochs of light minimum and a complete V light curve of TX Cnc are presented. A period investigation based on all available photoelectric or CCD data showed that it is found to be superimposed on a long-term increase ($dP/dt = +3.97 \times 10^{-8}$ days/year), and a weak evidence suggests that it includes a small-amplitude period oscillation ($A_3 = 0.0028$; $T_3 = 26.6$ years). The light curves in the V band obtained in 2004 were analyzed with the 2003 version of the W-D code. It was shown that TX Cnc is an overcontact binary system with a degree of contact factor $f = 24.8\% (\pm 0.9\%)$. The absolute parameters of the system were calculated: $M_1 = 1.319 \pm 0.007 M_\odot$, $M_2 = 0.600 \pm 0.01 M_\odot$; $R_1 = 1.28 \pm 0.19 R_\odot$, $R_2 = 0.91 \pm 0.13 R_\odot$. TX Cnc may be on the TRO-controlled stage of the evolutionary scheme proposed by Qian (2001a, b; 2003a), and may contains an invisible tertiary component ($m_3 \approx 0.097 M_\odot$). If this is true, the tertiary component has played an important role in the formation and evolution of TX Cnc by removing angular momentum from the central system (Pribulla & Rucinski, 2006). In this way the contact binary configuration can be formed in the short life time of a young open cluster via AML.

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1. Introduction

It is well known that W UMa-type binary stars have a high frequency in old open clusters (with age no less than 4Gyr). In NGC 188, at least 9 W UMa-type binaries were reported by Kaluzny & Shara (1987) and Zhang et al. (2002, 2004). Four and five W UMa-type stars were detected in the open clusters M67 and Tombaugh 2 respectively (Gilliland et al. 1991; Sandquist & Shetrone 2003; Kubiak et al. 1992), while the two old open clusters, Berkeley 39 and Cr261, were known to possess 12 and at least 28 contact binary systems, respectively (Kaluzny et al. 1993; Mazur et al. 1995). Mazur et al. (1995) obtained a lower limit for the frequency of W UMa binaries in cluster in the range of 1/100-1/60. A high incidence of W UMa-type binaries correlating with gradually increasing age in old open clusters is in agreement with the theory of the formation of contact binary stars via magnetic braking (Rucinski, 1998). According to this mechanism, a detached system forms a contact binary by angular momentum loss via magnetic stellar wind, in which the spin and orbital angular momentum are coupled through tides (e.g., Huang 1967; Vilhu 1982; Guinan & Bradstreet 1988). In this way, contact binary stars are not expected to present in young open clusters unless there are some other mechanisms in action.

The W UMa-type binary star, TX Cnc, which is the first contact binary found in the Praesepe (M44, NGC 2632) cluster, was discovered to be variable by Haffner (1937). Complete photoelectric light curves of the system were derived by Yamasaki & Kitamura (1972), Whelan et al. (1973), and Hilditch (1981). Radial velocity curves and spectroscopic elements were obtained by Popper (1948), Whelan et al. (1973), McLean & Hilditch (1983), and Pribulla et al. (2006). Photometric solutions of TX Cnc were given by several authors (e.g., Wilson & Biermann 1976; Hilditch 1981). It was shown that TX Cnc is a W-type contact binary system in which the hotter star is the less massive component. Praesepe is a young open cluster with an age of (3 − 5) × 10^8 years (e.g., Von Hoerner 1957; Maeder 1971). Bolte (1991) showed that Praesepe contains 10 binary systems, but only one (TX Cnc) is a contact binary. The presence of TX Cnc in the young open cluster Praesepe produced interest in it (Guinan & Bradstreet 1988; Rucinski 1994), because the fast formation of its contact configuration is not expected from the theory of angular momentum loss via magnetic braking. As pointed out by Hazlehurst (1970), ‘the occurrence in Praesepe of a W UMa system remains a paradox.’ In this paper, new CCD photometric observations are
presented and the period variations of TX Cnc are analyzed. Then the triplicity and the evolutionary state of the system are discussed. We show that TX Cnc may be a triple system with an invisible companion and thus this paradox can be removed.

2. New observations for TX Cnc

TX Cnc was observed on five nights (December 30, 2003; March 16 and December 18, 19, 2004; March 29, 2006) with the PI1024 TKB CCD photometric system attached to the 1.0-m reflecting telescope at the Yunnan Observatory in China. The B and V color systems used are close to the standard Johnson UBV system. The effective field of view of the photometric system is $6.5 \times 6.5$ arc min at the Cassegrain focus. The integration time for each image before March 2004 is 100 s, and after that is 50 s. PHOT (measure magnitudes for a list of stars) of the aperture photometry package of IRAF was used to reduce the observed images. The observations obtained on December 18 & 19, 2004 are complete in the V band. By calculating the phase of the observations with Equation 2, the light curves are plotted (Figure 1) and the original data in the V band are listed in Table 1. It is shown in this figure that the data are high quality and the light variation is typical of EW type. Since the light minimum is symmetric, a parabolic fitting was used to determine the times of minimum light with a least square method. In all, four epochs of light minimum were obtained and are listed in Table 2.

3. Orbital period variations for TX Cnc

The orbital period of TX Cnc was first reported to be variable by Yamasaki & Kitamura (1972). They collected 20 light minima and pointed out that a sudden period increase occurred around 1959. Pribulla et al. (2002) suggested that the period of TX Cnc is increasing. Qian (2001a) derived a quadratic ephemeris

$$\text{Min. I} = 2434426.4761 + 0.38288070 \times E + 2.94 \times 10^{-11} \times E^2,$$

and a continuous period increase rate of $dP/dt = +5.61 \times 10^{-8}\text{days/year}$. In order to investigate the period change of TX Cnc in detail, all available photoelectric and CCD observations at times of light minimum were compiled and listed in Table 3. Based on all collected eclipse times, a new linear ephemeris was obtained:

$$\text{Min. I} = 2434426.4601(\pm0.0013)$$
Table 1: Photometric Data in the V band for TX Cnc observed with the 1.0 meter telescope at Yunnan observatory

| JD.Hel. | Δm | JD.Hel. | Δm | JD.Hel. | Δm | JD.Hel. | Δm | JD.Hel. | Δm |
|---------|----|---------|----|---------|----|---------|----|---------|----|
| 2453300+ |    | 2453300+ |    | 2453300+ |    | 2453300+ |    | 2453300+ |    |
| 58.1519  | .068 | 58.2340  | .183 | 58.3215  | .143 | 58.4047  | .118 | 59.2586  | .245 |
| 58.1539  | .054 | 58.2363  | .197 | 58.3236  | .133 | 58.4078  | .134 | 59.2606  | .232 |
| 58.1558  | .047 | 58.2383  | .201 | 58.3258  | .116 | 58.4099  | .132 | 59.2626  | .222 |
| 58.1579  | .042 | 58.2406  | .205 | 58.3278  | .104 | 58.4120  | .143 | 59.2646  | .208 |
| 58.1599  | .036 | 58.2427  | .210 | 58.3298  | .106 | 58.4142  | .151 | 59.2666  | .197 |
| 58.1618  | .036 | 58.2448  | .223 | 58.3320  | .095 | 58.4165  | .160 | 59.2686  | .190 |
| 58.1639  | .036 | 58.2468  | .233 | 58.3340  | .094 | 58.4188  | .173 | 59.2706  | .179 |
| 58.1659  | .034 | 58.2489  | .243 | 58.3361  | .081 | 58.4209  | .179 | 59.2726  | .165 |
| 58.1678  | .039 | 58.2511  | .260 | 58.3383  | .075 | 58.4231  | .194 | 59.2747  | .157 |
| 58.1698  | .030 | 58.2531  | .267 | 58.3403  | .067 | 58.4250  | .203 | 59.2767  | .147 |
| 58.1718  | .024 | 58.2551  | .282 | 58.3425  | .066 | 58.4272  | .212 | 59.2787  | .142 |
| 58.1739  | .030 | 58.2573  | .292 | 58.3446  | .060 | 58.4297  | .222 | 59.2808  | .135 |
| 58.1759  | .029 | 58.2621  | .315 | 58.3468  | .055 | 58.4320  | .232 | 59.2828  | .124 |
| 58.1780  | .020 | 58.2641  | .321 | 58.3490  | .050 | 58.4343  | .245 | 59.2849  | .113 |
| 58.1800  | .030 | 58.2662  | .324 | 58.3511  | .052 | 58.4365  | .262 | 59.2870  | .109 |
| 58.1821  | .027 | 58.2683  | .330 | 58.3533  | .050 | 58.4385  | .265 | 59.2891  | .105 |
| 58.1841  | .033 | 58.2703  | .337 | 58.3553  | .051 | 58.4405  | .286 | 59.2911  | .098 |
| 58.1861  | .039 | 58.2726  | .337 | 58.3575  | .045 | 59.2123  | .314 | 59.2931  | .095 |
| 58.1884  | .043 | 58.2747  | .332 | 58.3596  | .043 | 59.2143  | .320 |
| 58.1904  | .038 | 58.2769  | .332 | 58.3617  | .041 | 59.2164  | .338 |
| 58.1923  | .050 | 58.2789  | .322 | 58.3637  | .037 | 59.2184  | .344 |
| 58.1944  | .051 | 58.2810  | .322 | 58.3658  | .036 | 59.2205  | .355 |
| 58.1964  | .053 | 58.2832  | .309 | 58.3679  | .037 | 59.2225  | .358 |
| 58.1985  | .050 | 58.2852  | .305 | 58.3700  | .035 | 59.2246  | .361 |
| 58.2006  | .053 | 58.2873  | .292 | 58.3720  | .038 | 59.2265  | .355 |
| 58.2028  | .064 | 58.2893  | .284 | 58.3743  | .041 | 59.2285  | .363 |
| 58.2047  | .072 | 58.2914  | .273 | 58.3764  | .045 | 59.2305  | .362 |
| 58.2068  | .074 | 58.2935  | .265 | 58.3782  | .049 | 59.2324  | .362 |
| 58.2089  | .081 | 58.2955  | .253 | 58.3802  | .044 | 59.2344  | .361 |
| 58.2109  | .089 | 58.2975  | .246 | 58.3822  | .053 | 59.2364  | .349 |
| 58.2130  | .098 | 58.2996  | .235 | 58.3843  | .061 | 59.2384  | .350 |
| 58.2151  | .102 | 58.3018  | .222 | 58.3864  | .070 | 59.2404  | .337 |
| 58.2172  | .116 | 58.3040  | .213 | 58.3886  | .073 | 59.2424  | .337 |
| 58.2192  | .119 | 58.3064  | .205 | 58.3905  | .076 | 59.2444  | .329 |
| 58.2213  | .125 | 58.3087  | .197 | 58.3925  | .083 | 59.2465  | .310 |
| 58.2235  | .138 | 58.3109  | .186 | 58.3944  | .086 | 59.2485  | .302 |
| 58.2255  | .148 | 58.3130  | .178 | 58.3965  | .098 | 59.2506  | .286 |
| 58.2275  | .157 | 58.3151  | .165 | 58.3984  | .097 | 59.2526  | .283 |
| 58.2296  | .168 | 58.3172  | .159 | 58.4005  | 110 | 59.2546  | .271 |
Table 2: New CCD times of light minimum for TX Cnc.

| JD (Hel.)  | Error (days) | Method | Min. | Filters |
|------------|--------------|--------|------|---------|
| 2453004.2995 | ±0.0003 | CCD | I | V |
| 2453081.0629  | ±0.0006 | CCD | II | V |
| 2453081.0631  | ±0.0006 | CCD | II | B |
| 2453358.2724  | ±0.0002 | CCD | II | V |
| 2453358.2725  | ±0.0003 | CCD | II | B |
| 2453824.0495  | ±0.0002 | CCD | I | V |

Fig. 1.— CCD data in the V band of TX Cnc observed on 18 and 19 December, 2004.
Fig. 2.— $(O - C)_1$ diagram of TX Cnc formed by all available photoelectric and CCD observations. The $(O - C)_1$ values were computed by using a newly determined linear ephemeris. Solid cycles refer to the primary minimum and open squares to the secondary minimum; Solid line represents a combination of a quadratic ephemeris and a cyclic variation. Also given in dashed line is the quadratic fit.
The \((O-C)_{1}\) values with respect to the linear ephemeris are listed in the fifth column of Table 3. The corresponding \((O-C)_{1}\) diagram is displayed in Figure 2.

The general \((O-C)_{1}\) trend of TX Cnc, shown in Figure 2, indicates the continuous period increase reported by Pribulla et al. (2002) and Qian (2001a). However, a long-term period increase alone (dashed line in Figure 2) cannot describe the \((O-C)_{1}\) curve very well, and there is possibly very weak evidence that there may be a small-amplitude period oscillation. Assuming that the period oscillation is cyclic, then, based on a least-square method, a sinusoidal term is added to a quadratic ephemeris to give a better fit to the \((O-C)_{1}\) curve (solid line in Figure 2). The result is

\[
\text{Min. I } = 2434426.4740(\pm 0.0001) \\
+ 0.43828813(\pm 0.0000001) \times E \\
+ 2.08(\pm 0.22) \times 10^{-11} \times E^2 \\
+ 0.0028(\pm 0.0006) \sin[0.0142 \times E \\
+ 32.6(\pm 0.4)].
\]  

(3)

With the quadratic term in this equation, a secular period increase rate is determined, \(dP/dt = +3.97 \times 10^{-8} \) days/year, which is close to the value derived by Qian (2001a).

The \((O-C)_{2}\) values with respect to the quadratic ephemeris in Eq.(3) are shown in Figure 3. Although the data after \(E=27500\) show large scatters, a small-amplitude oscillation is disputably seen in this figure. However, as we will see, there are a lot of scattered data points, especially around \(E=27500\). In spite of this, by using this relation,

\[
\omega = 360^\circ P_e/T,
\]

(4)

where \(P_e\) is the ephemeris period \((0.4382888238)\), the period of the orbital period oscillation is determined to be \(T=26.6\) years. Nevertheless, it is not reliable to rely on just a few points, so further observations and studies will be needed.

### 4. Photometric Solution

Photometric parameters of TX Cancri have been derived by several authors, e.g., Whelan et al. (1973), Wilson & Biermann (1976) and Hilditch (1981). All of them found the mass ratio is near 0.6 (Whelan et al. 1973; Wilson & Biermann, 1976), while Pribulla & Rucinschi et al. (2006) obtained the spectroscopic mass ratio, \(q_{sp} = 0.455 \pm 0.011\). To check this value,
Table 3: Photoelectric and CCD times of light minimum for TX Cnc.

| JD.Hel.  | Min. | Method | E     | \((O-C)_1\)  | \((O-C)_2\)  | Ref. |
|----------|------|--------|-------|---------------|---------------|------|
| 2400000+ |      |        |       |               |               |      |
| 34426.4773 | I    | pe     | 0     | +0.01719      | +0.00225      | (1)  |
| 38011.2000 | II   | pe     | 9362.5| +0.00357      | +0.00020      | (2)  |
| 38012.1560 | I    | pe     | 9365  | +0.00236      | -0.00099      | (2)  |
| 38774.0915 | I    | pe     | 11355 | +0.00192      | +0.00046      | (2)  |
| 38774.2809 | II   | pe     | 11355.5| -0.00011      | -0.00156      | (2)  |
| 38775.0463 | II   | pe     | 11357.5| -0.00048      | -0.00193      | (2)  |
| 38775.2385 | I    | pe     | 11358 | +0.00027      | -0.00118      | (2)  |
| 39095.3310 | I    | pe     | 12194 | +0.00310      | +0.00238      | (2)  |
| 39141.0843 | II   | pe     | 12313.5| +0.00196      | +0.00134      | (2)  |
| 39141.2748 | I    | pe     | 12314 | +0.00101      | +0.00039      | (2)  |
| 39142.9995 | II   | pe     | 12318.5| +0.00274      | +0.00212      | (2)  |
| 39143.1885 | I    | pe     | 12319 | +0.00030      | -0.00031      | (2)  |
| 39153.1450 | I    | pe     | 12345 | +0.00186      | +0.00127      | (2)  |
| 39920.0547 | I    | pe     | 14348 | -0.00184      | -0.00081      | (2)  |
| 39921.9703 | I    | pe     | 14353 | -0.00066      | +0.00037      | (2)  |
| 39922.1600 | II   | pe     | 14353.5| -0.00240      | -0.00136      | (2)  |
| 40986.9551 | II   | pe     | 17134.5| -0.00321      | -0.00026      | (2)  |
| 40987.1453 | I    | pe     | 17135 | -0.00445      | -0.00150      | (2)  |
| 41331.7365 | I    | pe     | 18035 | -0.00739      | -0.00390      | (3)  |
| 41332.8856 | I    | pe     | 18038 | -0.00694      | -0.00345      | (3)  |
| 41372.1310 | II   | pe     | 18140.5| -0.00698      | -0.00343      | (2)  |
| 43191.7828 | I    | pe     | 22893 | -0.00371      | +0.00197      | (4)  |
| 43192.7393 | II   | pe     | 22895.5| -0.00442      | +0.00127      | (4)  |
| 43200.7800 | II   | pe     | 22916.5| -0.00425      | +0.00144      | (4)  |
| 45022.3480 | I    | pe     | 27674 | +0.00080      | +0.00752      | (5)  |
| 48332.3597 | I    | pe     | 36319 | -0.00570      | +0.00001      | (6)  |
| 49777.3625 | I    | pe     | 40093 | -0.00101      | +0.00309      | (7)  |
| 50515.5522 | I    | CCD    | 42021 | -0.00855      | -0.00553      | (8)  |
| 50926.3897 | I    | CCD    | 43094 | -0.00385      | -0.00151      | (9)  |
| 51952.5177 | I    | CCD    | 45774 | -0.00063      | -0.00026      | (10) |
| 52348.4185 | I    | pe     | 46808 | -0.00022      | -0.00070      | (11) |
| 52352.4397 | II   | pe     | 46818.5| +0.00071      | +0.00021      | (11) |
| 52611.8430 | I    | CCD    | 47496 | +0.00119      | +0.00010      | (12) |
| 52647.8334 | I    | CCD    | 47590 | +0.00065      | -0.00051      | (13) |
| 52685.3588 | I    | CCD    | 47688 | +0.00357      | +0.00231      | (14) |
| 52691.2952 | II   | CCD    | 47703.5| +0.00530      | +0.00403      | (15) |
| 52711.9677 | II   | CCD    | 47757.5| +0.00215      | +0.00083      | (16) |
| 53004.2995 | I    | CCD    | 48521 | +0.00325      | +0.00123      | (18) |
| 53081.0630 | II   | CCD    | 48721.5| -0.00116      | -0.00336      | (18) |
| 53358.2725 | II   | CCD    | 49445.5| +0.00148      | -0.00141      | (18) |
| 53410.5373 | I    | CCD    | 49582 | +0.00284      | -0.00019      | (17) |
| 53480.8920 | II   | CCD    | 49614.5| +0.00026      | -0.00079      | (16) |
Fig. 3.— \((O-C)_2\) values for TX Cnc with respect to the quadratic ephemeris in Eq. (3). The symbols are the same as figure 2. Solid line refers to the theoretical orbit of an assumed third body.
a q-search method with the 2003 version of the W-D program (Wilson & Devinney, 1971; Wilson, 1990, 1994; Wilson & Van Hamme, 2003) was used (Figure 4). Firstly, we fixed \( q \) to 0.2, 0.3, 0.4 and so on, as figure 4 (the left one) shows. It can be seen that the best result is obtained with a value of \( q = 2 \). Secondly, we performed additional solutions around this value, and found that the best mass ratio is \( q = 2.3 \), which agrees very well with the results of Pribulla et al. (2006).

During the solution, the mass ratio is fixed on the spectroscopic value 2.1978 that was obtained by Pribulla et al. (2006). The same value of temperature for star 1 (star eclipsed at secondary light minimum) as that used by Wilson & Biermann (1976) (\( T_1 = 6400 \)K) was chosen. The bolometric albedo \( A_1 = A_2 = 0.5 \) (Rucinski 1969) and the values of the gravity-darkening coefficient \( g_1 = g_2 = 0.32 \) (Lucy 1967) were used, which correspond to the common convective envelope of both components. A limb-darkening coefficient of 0.62 in V was used, according to Claret & Gimenez (1990). The adjustable parameters were: the orbital inclination \( i \); the mean temperature of star 2, \( T_2 \); the monochromatic luminosity of star 1, \( L_{1V} \); and the dimensionless potential of star 1 (\( \Omega_1 = \Omega_2 \), mode 3 for contact configuration). The O’Connell effect of the system is so obvious, and as TX Cnc’s spectral type is G0-G1V (Yamasaki & Kitamura, 1972), F8V (Popper 1948), or F6 (Haffner & Heckmann, 1937), (a later type), it seemed that chances were good that starspots will appear on the surface of the star. In that case, we add a dark spot on the more massive component (the cold one) as many researchers have done (e.g., Binnendijk, 1960, Mullan, 1975, Bell, et al., 1990, Linell & Olson, 1989). Mullan (1975) deemed that dark spots exist in contact binaries due to their deep convective envelopes. The photometric solutions are listed in Table 4 and the theoretical light curves computed with those photometric elements are plotted in Figure 5, meanwhile, the geometrical structure of TX Cnc is displayed in Figure 6.

5. Discussions and conclusion

Combining the results \((M_1 + M_2) \sin^3 i = 1.330 \pm 0.012 M_\odot \) and \( q_{sp} = 0.455 \pm 0.011 \) (Pribulla et al. 2006), absolute parameters about each component were calculated to be, \( M_1 = 1.319 \pm 0.007 M_\odot \), \( M_2 = 0.600 \pm 0.01 M_\odot \); \( R_1 = 1.28 \pm 0.19 R_\odot \), \( R_2 = 0.91 \pm 0.13 R_\odot \); \( L_1 = 1.253 L_\odot \), \( L_2 = 1.997 L_\odot \).

Based on all available photoelectric and CCD eclipse times, the period changes of the contact binary star were discussed in the previous section. The general O-C trend may reveal a long-term period increase at a rate of \( dP/dt = +3.97 \times 10^{-8} \) days/year. Meanwhile, a small-amplitude period oscillation \( (A_3 = 0.40026) \) was discovered superimposed on the
Fig. 4.— The relation between $q$ and $\Sigma$ for TX Cnc. The figure on the right shows more detail around the best mass ratio $q = 2$. 
Fig. 5.— Observed and theoretical light curves in the V band for TX Cnc with a spot on the more massive component.
Fig. 6.— Geometrical structure of the open cluster's contact binary TX Cnc with a dark spot on the more massive component at phase 0.00, 0.25, 0.50 and 0.75.
Table 4: Photometric Solutions for TX Cnc.

| Parameters | Photometric elements with dark spot | Photometric elements without dark spot |
|------------|-------------------------------------|---------------------------------------|
| $g_1 = g_2$ | 0.32 assumed                        | 0.32 assumed                          |
| $A_1 = A_2$ | 0.50 assumed                        | 0.50 assumed                          |
| $x_{1V} = x_{2V}$ | 0.62 assumed                        | 0.62 assumed                          |
| $T_1$       | 6400K assumed                       | 6400K assumed                         |
| $q$         | 2.1978 assumed                      | 2.1978 assumed                        |
| $\Omega_{in}$ | 5.5292 – 5.5292 –             | 5.5292 – 5.5292 – –                  |
| $\Omega_{out}$ | 4.9264 – 4.9264 –              | 4.9264 – 4.9264 – –                  |
| $T_2$       | 6058K ± 19K                        | 6058K ± 21K                           |
| $i$         | 62.241 ± 0.31                       | 62.015 ± 0.18                         |
| $L_1/(L_1 + L_2)(V)$ | 0.3853 ± 0.0435               | 0.3876 ± 0.0405                       |
| $\Omega_1 = \Omega_2$ | 5.3796 ± 0.0083               | 5.3929 ± 0.0066                       |
| $r_{1(pole)}$ | 0.3051 ± 0.0007                   | 0.3039 ± 0.0006                       |
| $r_{1(side)}$ | 0.3202 ± 0.0009                   | 0.3188 ± 0.0007                       |
| $r_{1(back)}$ | 0.3623 ± 0.0015                    | 0.3599 ± 0.0012                       |
| $r_{2(pole)}$ | 0.4342 ± 0.0007                   | 0.4331 ± 0.0005                       |
| $r_{2(side)}$ | 0.4650 ± 0.0009                    | 0.4636 ± 0.0007                       |
| $r_{2(back)}$ | 0.4975 ± 0.0012                   | 0.4956 ± 0.0010                       |
| $f$         | 24.8 % ± 0.9 %                     | 22.6 % ± 0.8 %                        |
| $\theta$ (°) | 28.86 –                             | –                                     |
| $\psi$ (°) | 268.85 –                             | –                                     |
| $\Omega$(sr) | 0.3920 –                             | –                                     |
| $T_1/T_*$  | 0.9690 –                             | –                                     |
| $\sum \omega_i (O - C)_i$ | 0.008574                             | 0.020054                             |
period increase. If this period increase is due to a conservative mass transfer from the less massive component to the more massive one, then with the absolute parameters derived by the present paper and by using the well-known equation,

\[ \frac{\dot{P}}{P} = 3 \frac{M_2}{M_2} (1 - \frac{M_2}{M_1}), \]  

(5)

the mass transfer rate is estimated to be, \( dM_2/dt = 3.82 \times 10^{-8} M_\odot/\text{year} \). The timescale of mass transfer is \( \tau \sim M_2/\dot{M}_2 \sim 1.58 \times 10^7 \) years which is close to the thermal time scale of the secondary component.

As shown in Figures 2 and 3, both the primary and the secondary times of light minimum follow the same general trend of O-C variation indicating that the weak O-C oscillation cannot be explained as apsidal motion. The alternate period change of a close binary containing at least one solar-type component can be interpreted by the mechanism of magnetic activity (e.g., Applegate, 1992; Lanza et al. 1998). However, for contact binary stars, we do not know whether this mechanism can work how does it might work, because there is a common convective envelope. We think the period oscillation may be caused by the light-time effect of a tertiary component. As we can see from Figure 3, the data after E=27500 show large scatters, therefore details on the information of orbital eccentricity are unknown. In the previous section, by assuming a circular orbit, a theoretical solution of the orbit for the assumed tertiary star was calculated. By using this equation;

\[ f(m) = \frac{4\pi^2}{GT^2} \times (a'_{12} \sin i')^3, \]  

(6)

where \( a'_{12} \sin i' = A_3 \times c \) (where \( c \) is the speed of light), the mass function from the tertiary component is computed. Then, with the following equation;

\[ f(m) = \frac{(M_3 \sin i')^3}{(M_1 + M_2 + M_3)^2} \]  

(7)

and taking the physical parameters given by us, the masses and the orbital radii of the third companion are computed. The values of the masses and the orbital radii of the third component stars for several different orbital inclinations (\( i' \)) are shown in Table 5. As shown in this table, the assumed tertiary component is invisible unless the orbital inclination \( i' \) is very small (\( i' < 10^\circ \)). If the tertiary companion is coplanar to the eclipsing pair (i.e., with the same inclination as the eclipsing binary), its mass should be, \( m_3 = 0.097M_\odot \), which is too small to be detected. Actually, Pribulla et al. (2006) didn’t discover the third body, it maybe suspected or nondetected as they said. More evidence is needed to show the existence of the third body.
We estimated the orbital angular momentum and the spin angular momentum of the system with the absolute parameters. As a crude estimate, it assumes that the star is a rigid body rotator, using the formula $J_{\text{spin}} = M_i R_i^2 \omega$, where $\omega$ is the self-rotation velocity dependent on the period. Meanwhile the orbital momentum was calculated by;

$$J_{\text{orb}} = (GA)^{1/2} \frac{M_1 M_2}{(M_1 + M_2)^{1/2}},$$

and the results are $J_{\text{spin}} = 4.56 \times 10^{42} \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$, $J_{\text{orb}} = 5.78 \times 10^{44} \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$. $J_{\text{orb}}$ is much larger than $J_{\text{spin}}$. Hut (1980) pointed out a critical condition that if the orbital angular momentum is less than three times the total spin angular momentum, the system will become unstable and evolve into single rapid-rotating stars. This is another approach which is different from a period decrease system. But TX Cnc seems far from that condition. Consider with that TX Cnc is a member of the young cluster NGC2632 (with an age of $(3-5) \times 10^8$ years), the discussion above may indicate that TX Cnc just formed its contact configuration.

Recent period studies by Qian (2001a, b; 2003a) have shown the long-term period variation of contact binary stars may correlate with the mass of the primary component ($M_1$) and with the mass ratio of the system ($q$). Systems with higher $M_1$ and $q$ usually display an increasing period, the secular period increase of TX Cnc is consistent with this conclusion. In order to interpret the secular period changes of contact binary stars, an evolutionary scenario was proposed by Qian (2001a, b, 2003a). According to this scenario, the evolution of a contact binary may be the combination of the thermal relaxation oscillation (TRO) and the variable angular momentum loss (AML) via the change of depth of contact. Systems (e.g., V417 Aql, see Qian 2003b) with a secular decreasing period are on the AML-controlled stage, while those (e.g., CE Leo, see Qian 2002) showing an increasing period are on the TRO-controlled stage. The long-term period increase of TX Cnc may suggest that it is on the TRO-controlled stage of this evolutionary scheme.

The high frequency of contact binaries in old open clusters have been reported by several investigators (e.g., Kaluzny & Shara 1987; Kubiak et al. 1992; Kaluzny et al. 1993; Mazur, et al. 1995; Rucinski 1998, Zhang et al. 2002). However, a survey made by Kaluzny & Shara (1988) of six open clusters with age no less than 4Gyr did not find a single W UMa-type binary star. These properties are in agreement with the formation of contact binary stars from detached binaries by angular momentum loss via magnetic braking. This mechanism was first proposed by Huang (1967) and was later investigated by Van’t Veer (1979); Rahunen (1981); Vilhu (1982); Guinan & Bradstreet (1988); Hilditch et al. (1988); Van’t Veer & Maceroni (1989) and others. Praesepe (M44) is a young open cluster with an age of $(3-5) \times 10^8$ years (e.g., Von Hoerner 1957; Maeder 1971). The W-type contact binary
star TX Cnc present in this cluster makes it a very interesting system (Guinan & Bradstreet 1988; Rucinski 1994). As discussed for AP Leo (Qian et al. 2007) and AH Cnc (Qian, et al. 2006), the tertiary component in TX Cnc, if it really exists, may play an important role in the formation and evolution of this binary star by removing a large amount of angular momentum from the central system (Pribulla & Rucinski, 2006). Thus the system may have a short initial orbital period or a collision path to fast evolution. Thus, the large disparity in age between TX Cnc and almost all other contact binaries in other open clusters can be interpreted.

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Table 5: The masses and orbital radii of the assumed third body in TX Cnc.

| Parameters      | TX Cnc        | Units         |
|-----------------|---------------|---------------|
| $A_3$           | 0.0028(±0.0006) | d             |
| $T_3$           | 26.6(assumed)  | yr            |
| $e'$            | 0(assumed)     | —             |
| $a'_12\sin i'$ | 0.48(±0.10)    | AU            |
| $f(m)$          | 1.56(±0.9) $\times 10^{-4}$ | $M_\odot$   |
| $m_3(i' = 90^\circ)$ | 0.086(±0.018) | $M_\odot$   |
| $m_3(i' = 70^\circ)$ | 0.091(±0.019) | $M_\odot$   |
| $m_3(i' = 50^\circ)$ | 0.113(±0.066) | $M_\odot$   |
| $m_3(i' = 30^\circ)$ | 0.176(±0.011) | $M_\odot$   |
| $m_3(i' = 10^\circ)$ | 0.569(±0.040) | $M_\odot$   |
| $a_3(i' = 90^\circ)$ | 10.7(±3.5)    | AU            |
| $a_3(i' = 70^\circ)$ | 10.8(±3.3)    | AU            |
| $a_3(i' = 50^\circ)$ | 10.6(±2.8)    | AU            |
| $a_3(i' = 30^\circ)$ | 10.5(±2.0)    | AU            |
| $a_3(i' = 10^\circ)$ | 9.3(±1.0)     | AU            |