Chin. J. Astron. Astrophys. Vol. 7 (2007), No. 2, 258–264
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

TZ Lyrae: an Algol-type Eclipsing Binary with Mass Transfer

Yuan-Gui Yang and Xin-Guo Yin

Physics Department of Huaibei Coal Industry Teachers College, Huaibei 235000; *yygcn@163.com*

Received 2006 July 20; accepted 2006 October 20

Abstract We present a detailed investigation of the Algol-type binary TZ Lyrae, based on 55 light minimum timings spanning 90 years. It is found that the orbital period shows a long-term increase with a cyclic variation superimposed. The rate of the secular increase is $dP/dt = +7.18 \times 10^{-8}\mathrm{d\ yr^{-1}}$, indicating that a mass transfer from the less massive component to the more massive one at a rate of $dm = +2.21 \times 10^{-8}\mathrm{M_\odot\ yr^{-1}}$. The cyclic component, with a period of $P_3 = 45.5\,\mathrm{yr}$ and an amplitude of $A = 0^{\mathrm{d}}.0040$, may be interpreted as either the light-time effect in the presence of a third body or magnetic activity cycles in the components. Using the latest version Wilson-Devinney code, a revised photometric solution was deduced from B and V observations. The results show that TZ Lyr is an Algol-type eclipsing binary with a mass ratio of $q = 0.297(\pm 0.003)$. The semidetached configuration with a lobe-filling secondary suggests a mass transfer from the secondary to the primary, which is in agreement with the long-term period increase of the binary system.

Key words: stars: binaries: close — stars: binaries: eclipsing — stars: individual: TZ Lyrae

1 INTRODUCTION

TZ Lyrae (=BD+41 3021=GSC 3107–0578, $V = 10^{\mathrm{m}}.87 - 11^{\mathrm{m}}.85$) was discovered as an Algol-type variable by D'Esterre (1914). Its spectral type is F5 and its color index is $B - V = 0^{\mathrm{m}}.3$ (Kreiner et al. 2001). Hoffmeister (1916) determined the light elements of TZ Lyr for a period of $0^{\mathrm{d}}.528854$. Later, Ustinov & Odynaskaja (1951) corrected its orbital period to $P = 0^{\mathrm{d}}.52882388$, while Szafraniec (1972) determined the value of $P = 0^{\mathrm{d}}.52882338$. Wood & Forbes (1963) obtained a quadratic ephemeris with a period increasing at a rate of $dP/dt = +4.90 \times 10^{-8}\mathrm{d\ yr^{-1}}$. Based on 16 light minimum times including one photoelectric one, Binnendijk (1972) gave a linear ephemeris with a period of $0^{\mathrm{d}}.52882613$ and clearly stated that its orbital period is variable. Rafert (1982) subsequently gave two upward parabolic ephemerides, one of which was superimposed with a cyclic oscillation with an amplitude of $A = 0^{\mathrm{d}}.0137$ and a period of 15.1 yrs. The photographic light curve given by Jordan (1929), was used by Krat (1935) for a determination of the orbital elements for this binary. Binnendijk (1972) published photometric light curves, which contain a total of 581 observations in yellow light and 581 ones in blue light. The orbital elements were derived with Fourier analysis technique. Based on the normal light curves of Binnendijk (1972), Kałużny (1985) obtained the photometric solution with a mass ratio of $q = 0.80$ at the minimum residuals, while Brancewicz & Dworak (1980) presented a mass ratio of $q = 0.68$ and a total mass of $M_{12} = 1.50\mathrm{M_\odot}$. Therefore, it is necessary to revise the photometric mass ratio and to analyze its orbital period change in more detail.

2 ORBITAL PERIOD CHANGE

In order to analyze changes in the orbital period, we collected available published times of light minimum, comprising 27 visual, 4 photographic, 15 photoelectric and 9 CCD ones. A total of 55 compiled light minimum times, spreading over 90 years from 1915 to 2005, should provide some new information about

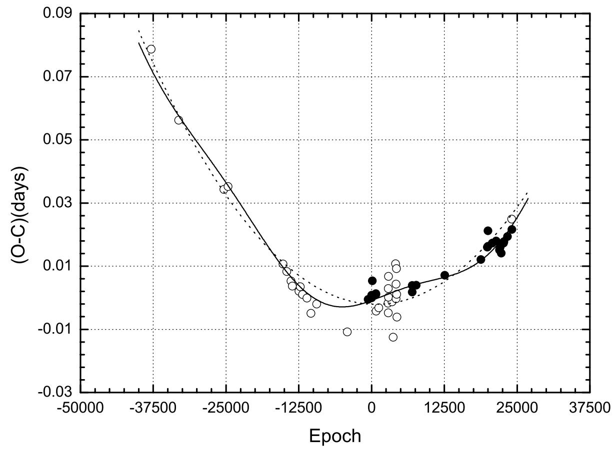

Fig. 1 $(O-C)$ curve of the eclipsing binary TZ Lyr. The open circles represent the photographic or visual observations, while the solid ones, the photoelectric or CCD data. The solid and dotted lines correspond to Equation (2) and its quadratic term.

the changes in the orbital period. The $(O-C)$ values of those eclipse timings were calculated according to the linear ephemeris (Binnendijk 1972),

$$\text{Min.I} = \text{HJD}2440737.8285 + 0.52882613 \times E. \tag{1}$$

The residuals are listed in the fifth column of Table 1 and shown graphically in Figure 1. The open circles refer to the photographic observations, the filled circles, to photoelectric or CCD ones.

As shown in Figure 1, the trend of the $(O-C)$ curve can be described by an upward parabolic curve with some smaller fluctuations, indicating that the orbital period appears to undergo a secular increase with a cyclic variation superimposed, which was identified by one of Rafert's (1982) ephemerides. The widely accepted weights (i.e., weight 3 for photographic or visual data, weight 10 for photoelectric and CCD observations) were assigned to all the minimum timings. A least-squares fitting yields the following equation,

$$\begin{aligned}(O-C) \;=\; & -0.0021(\pm0.0006) - 8.0(\pm4.0) \times 10^{-8} \times E \\ & +5.2(\pm0.2) \times 10^{-11} \times E^2 + 0.0040(\pm0.0010) \\ & \times \sin[0.0002 \times E + 0.3003(\pm0.2595)]. \end{aligned} \tag{2}$$

The corresponding residuals $(O-C)_1$ are listed in the sixth column of Table 1 and plotted in Figure 2. The parabolic and sinusoidal components give a good fit to the $(O-C)$ curve (solid line in Figure 1), the parabolic part alone corresponds to the dotted line. Using the coefficient of the quadratic term, we can derive a continuous period increase rate of $dP/dt = +7.18 \times 10^{-8}\,\text{d yr}^{-1}$ (i.e., 0.62 second century^{-1}), indicating that mass is transferred from the less massive component to the more massive one. The sinusoidal term reveals a periodic oscillation with an amplitude of $A = 0.^{\rm d}0040$, which is much smaller than the value of $0.^{\rm d}0137$ obtained by Rafert (1982). Using the relation $P_3 = 2\pi P/\omega$ with $\omega = 2.0 \times 10^{-4}$, the period of the cyclic variation can be estimated to be $P_3 = 45.5\,\text{yr}$.

Based on residuals $(O-C)$ of 24 photometric and CCD minimum times, a linear least-squares analysis gave the new ephemeris,

$$\text{Min.I} = \text{HJD}2453477.2718(\pm0.0009) + 0.52882690(\pm0.00000005) \times E. \tag{3}$$

The new revised period of $P = 0.^{\rm d}52882690$ is larger than the value $P = 0.^{\rm d}52882613$ in Binnendijk (1972), indicating that the orbital period increase of TZ Lyr may be identified indirectly. It is necessary to obtain a linear ephemeris for future observations.

Table 1 All Published Times of Minimum Light for TZ Lyrae

JD (Hel.)	Epoch	Method	Type	$(O-C)$	$(O-C)_1$	Ref.
2420713.377	−37866.0	vi	I	+0.0787	+0.0063	(1)
2423205.712	−33153.0	pg	I	+0.0562	−0.0015	(1)
2427327.361	−25359.0	vi	I	+0.0343	−0.0031	(1)
2427710.232	−24635.0	vi	I	+0.0352	−0.0002	(1)
2432687.519	−15223.0	vi	I	+0.0107	+0.0010	(1)
2433042.359	−14552.0	vi	I	+0.0083	+0.0002	(1)
2433419.409	−13839.0	vi	I	+0.0053	−0.0012	(1)
2433536.278	−13618.0	vi	I	+0.0037	−0.0024	(1)
2434136.494	−12483.0	vi	I	+0.0021	−0.0017	(1)
2434265.529	−12239.0	vi	I	+0.0035	+0.0001	(1)
2434458.548	−11874.0	vi	I	+0.0010	−0.0018	(1)
2434868.916	−11098.0	pg	I	−0.0001	−0.0016	(1)
2435228.513	−10418.0	vi	I	−0.0049	−0.0055	(1)
2435748.352	−9435.0	vi	I	−0.0020	−0.0014	(1)
2438522.565	−4189.0	vi	I	−0.0108	−0.0080	(1)
2440418.4170	−604.0	pe	I	−0.0005	+0.0008	(1)
2440737.8285	+0.0	pe	I	+0.0000	+0.0009	(1)
2440749.4635	+22.0	pe	I	+0.0008	+0.0017	(2)
2440813.4560	+143.0	pe	I	+0.0054	+0.0062	(2)
2441126.5167	+735.0	pe	I	+0.0010	+0.0014	(3)
2441135.5070	+752.0	pe	I	+0.0013	+0.0017	(3)
2441152.424	+784.0	vi	I	−0.0042	−0.0038	(4)
2441392.512	+1238.0	vi	I	−0.0032	−0.0032	(5)
2442239.693	+2840.0	vi	I	−0.0017	−0.0028	(6)
2442247.630	+2855.0	vi	I	+0.0029	+0.0017	(6)
2442248.680	+2857.0	vi	I	−0.0048	−0.0060	(6)
2442265.614	+2889.0	vi	I	+0.0068	+0.0056	(6)
2442266.665	+2891.0	vi	I	+0.0002	−0.0010	(6)
2442596.651	+3515.0	vi	I	−0.0013	−0.0029	(8)
2442696.588	+3704.0	vi	I	−0.0125	−0.0143	(8)
2442922.420	+4131.0	pg	I	+0.0108	+0.0087	(7)
2442960.489	+4203.0	pg	I	+0.0043	+0.0022	(7)
2442964.715	+4211.0	vi	I	−0.0003	−0.0024	(8)
2442990.637	+4260.0	vi	I	+0.0092	+0.0070	(8)
2443008.609	+4294.0	vi	I	+0.0011	−0.0011	(8)
2443044.562	+4362.0	vi	I	−0.0061	−0.0083	(8)
2444426.3926	+6975.0	pe	I	+0.0018	−0.0021	(9)
2444435.3847	+6992.0	pe	I	+0.0039	+0.0000	(9)
2444784.4100	+7652.0	pe	I	+0.0040	−0.0002	(10)
2447384.3868	+12568.5	pe	II	+0.0071	+0.0006	(11)
2450657.5611	+18758.0	ccd	I	+0.0121	+0.0003	(12)
2451258.8404	+19895.0	ccd	I	+0.0160	+0.0025	(13)
2451306.7043	+19985.5	ccd	II	+0.0212	+0.0075	(13)
2451316.4827	+20004.0	ccd	I	+0.0163	+0.0026	(14)
2451698.8250	+20727.0	ccd	I	+0.0173	+0.0023	(15)
2452059.4851	+21409.0	pe	I	+0.0180	+0.0017	(16)
2452363.5572	+21984.0	pe	I	+0.0151	−0.0024	(17)
2452416.4408	+22084.0	pe	I	+0.0160	−0.0018	(17)
2452526.4347	+22292.0	pe	I	+0.0141	−0.0042	(17)
2452720.5171	+22659.0	pe	I	+0.0173	−0.0018	(17)
2452722.6325	+22663.0	ccd	I	+0.0174	−0.0017	(18)
2452761.7660	+22737.0	ccd	I	+0.0178	−0.0015	(19)
2453084.8804	+23348.0	ccd	I	+0.0194	−0.0014	(20)
2453464.583	+24066.0	vi	I	+0.0249	+0.0022	(21)
2453477.2716	+24090.0	ccd	I	+0.0216	−0.0012	(22)

Reference: (1) Binnendijk 1972; (2) Kizilirmak & Pohl 1971; (3) Pohl & Kizilirmak 1972; (4) Flin 1971; (5) Klimek 1973; (6) Krobuser & Mallama 1975; (7) Ahnert 1976; (8) Mallama et al. 1977; (9) Aslan et al. 1981; (10) Derman et al. 1982; (11) Ogloza 1995; (12) Deeg et al. 2003; (13) Diethelm 2001; (14) Agerer et al. 2001; (15) Nelson 2001; (16) Agerer & Hübscher 2002; (17) Agerer & Hübscher 2003; (18) Kotkova & Wolf 2006; (19) Nelson 2004; (20) Dvorak 2005; (21) Locher 2005; (22) Kim et al. 2006.

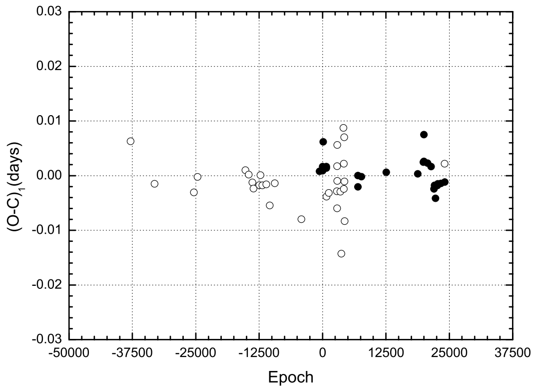

Fig. 2 Residuals $(O-C)_1$ diagram of the light minimum times for the eclipsing binary TZ Lyr. The symbols are the same as in Fig. 1.

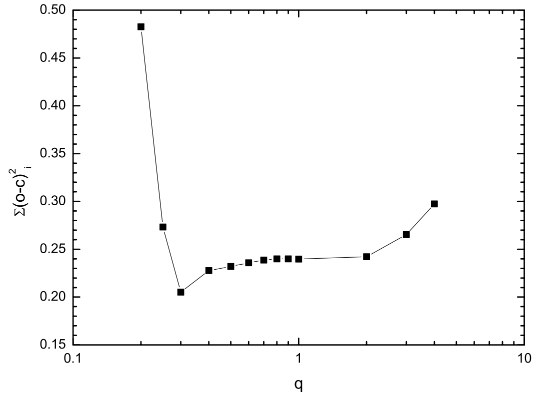

Fig. 3 Sum of residuals as a function of q for the eclipsing binary TZ Lyrae.

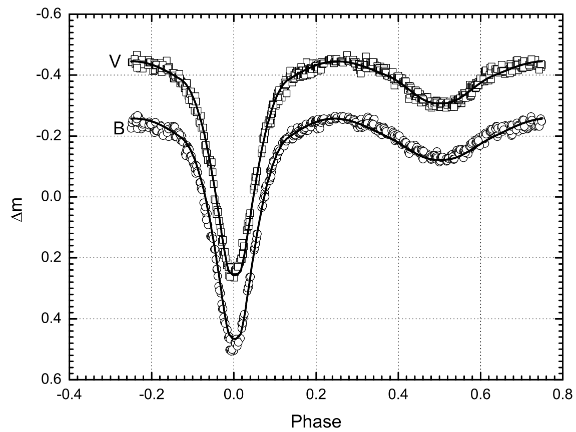

Fig. 4 Photoelectric light curves of the eclipsing binary TZ Lyrae, observed by Binnendijk (1972). The squares and circles respectively refer to observations in B and V bands. The solid lines are the theoretical light curves, calculated by the revised photometric solution.

3 THE PHOTOMETRIC SOLUTION

The 2003 version of the Wilson-Devinney program (Wilson 1990, 1994; Wilson & Devinney 1971) was applied to a total of 581 observations in B and V bands (Binnendijk 1972) for a reanalysis of the photometric solution. According to the color index $B - V = 0\overset{\text{m}}{.}3$ of TZ Lyr, we adopted an effective temperature of Star 1, $T_1 = 7216\,\text{K}$ (Flower 1996). The limb-darkening coefficients of $x_{1B} = 0.654$, $x_{2B} = 0.759$, $x_{1V} = 0.573$ and $x_{2V} = 0.688$ for B and V bands, were taken from the table of Díaz-Cordovés et al.(1995). The gravity-darkening coefficients $g_1 = 1.0$, $g_2 = 0.5$, and the bolometric albedo coefficients $A_1 = 1.0$, $A_2 = 0.5$ were assumed for the primary and the secondary, as usual. The adjustable parameters were: the mass ratio q, inclination i, temperature of Star 2 T_2, potentials of two components Ω_1 and Ω_2, the luminosity of Star 1 L_1.

It is necessary to search for a reliable mass ratio q. We first carried out a series of solutions for fixed mass ratios, ranging from 0.2 to 4.0. For each assumed mass ratio, the calculation started at mode 2 (i.e.,

Table 2 Revised Photometric Solution for the Eclipsing Binary TZ Lyr

Parameters	Values
$i(^\circ)$	$83.32(\pm 0.29)$
$q = M_2/M_1$	$0.297(\pm 0.003)$
g_1	1.0
g_2	0.32
A_1	1.0
A_2	0.50
T_1 (K)	7216
T_2 (K)	$4160 \pm (34)$
Ω_1	$2.7445(\pm 0.0051)$
$\Omega_2 = \Omega_{\rm in}$	2.4596
$L_1/(L_1+L_2)_B$	$0.9896(\pm 0.0013)$
$L_1/(L_1+L_2)_V$	$0.9767(\pm 0.0017)$
r_1(pole)	$0.4050(\pm 0.0009)$
r_1(side)	$0.4248(\pm 0.0011)$
r_1(back)	$0.4379(\pm 0.0014)$
r_1(point)	$0.4543(\pm 0.0018)$
r_2(pole)	$0.2604(\pm 0.0007)$
r_2(side)	$0.2712(\pm 0.0007)$
r_2(back)	$0.3039(\pm 0.0007)$
r_2(point)	$0.3782(\pm 0.0068)$
$\sum(O-C)_i^2$	0.0329

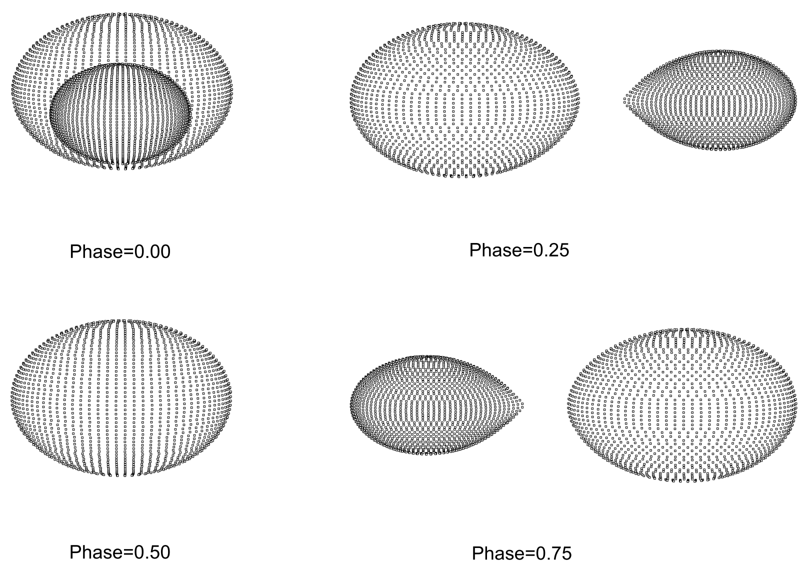

Fig. 5 Configurations of the eclipsing binary TZ Lyrae at the phases (0.00, 0.25, 0.50 and 0.75), which were described by the LC code of the 2003 version W-D program.

the detached mode). The solutions always converged to mode 5 (i.e., the semidetached mode with filled secondary). The curve of the resulting sum of residuals $\sum(O-C)_i^2$ as a function of the trial mass ratio q of Figure 3 shows a minimum value of $\sum(O-C)_i^2$ at $q = 0.3$. Then the list of adjustable parameters was extended to include the mass ratio q, and a final photometric solution derived. Its orbital elements are listed in Table 2. The corresponding theoretical light curves, shown in Figure 4, fit the observations fairly well. Finally, we used the LC code of the 2003 version W-D program to display the configurations of TZ Lyr at different phases with the secondary filling its Roche lobe. See Figure 5.

4 DISCUSSION AND CONCLUSIONS

The revised photometric solution indicates that TZ Lyrae is a semidetached binary with a mass ratio of $q = 0.297(\pm0.003)$, which is very different from the value of 0.80 (Kałużny 1985). This shows that the obtained parameters and configurations are sensitive to the choice of the gravity darkening coefficient in temperatures from $6700\,\mathrm{K}$ to $8000\,\mathrm{K}$. Following Lucy (1967) and Rafert & Tigg (1980), the gravity darkening exponent g is assumed to be 1.00 for a radiative envelope or 0.32 for a convective envelope according to the switch temperature at $7200\,\mathrm{K}$. Kałużny (1985) adopted the gravity darkening exponent of $g_1 = 0.32$, without, however, making a complete grid of solutions with $g_1 = 1.0$. In our analysis, the effective temperature of Star 1, $T_1 = 7216\,\mathrm{K}$, is just above the limit (i.e., $7200\,\mathrm{K}$) generally assumed to be the switch from radiative to convective envelope. Although this limit as a rough value denotes a transition region, a radiative primary is in accordance with a lobe-filling secondary, with mass transfer from the secondary to the primary. Therefore, it is reasonable that the gravity darkening exponent for TZ Lyrae is $g_1 = 1.0$, rather than the 0.32 in (Kałużny 1985). This situation occurs also in some other semidetached binaries, such as BL And (Zhu et al. 2006), TT Her (Milano et al. 1989) and SS Cet (Narasaki & Etzel 1994). After the q-search, the obtained mass ratio of $q = 0.297(\pm0.003)$ for TZ Lyrae is a typical value for Algol-type binaries. Therefore, the revised photometric solution with a radiative primary component is reliable.

According to the well-known relation given by Eggleton (1983),

$$\frac{R_L}{A} = \frac{0.49q^{\frac{2}{3}}}{0.6q^{\frac{2}{3}} + \ln(1 + q^{\frac{1}{3}})}, \tag{4}$$

the volume radius of the Roche lobe R_L of the primary in units of the distance between the components can be estimated to be $R_{L1}/A = 0.4863$. Comparing with the mean relative radius of the primary component $r_1/A = 0.4319$, the filling factor (i.e., $f = \frac{r}{R_L}$) of the primary is 88.8%, indicating that the primary has not filled its Roche lobe, but has nearly done so.

The orbital period of TZ Lyrae shows a secular increase superimposed with a cyclic oscillation of a low amplitude of $A = 0^{\mathrm{d}}.0040$. The long-term period increase at a rate of $dP/dt = +7.18 \times 10^{-8}\,\mathrm{d\ yr^{-1}}$ can be interpreted by a mass transfer from the less massive component to the more massive one. In the case of the conserved mass transfer, the mass transfer rate can be estimated by the well-known formula,

$$\frac{\dot{P}}{P} = 3\frac{1-q^2}{q}\frac{\dot{M}_1}{M_{12}}. \tag{5}$$

In Equation (5), the units of M_{12} and $\dot{M}_1$ are $\mathrm{M_\odot}$ and $\mathrm{M_\odot\ yr^{-1}}$, those of P and $\dot{P}$ are day and $\mathrm{d\ yr^{-1}}$. Combining the revised photometric ratio of $q = 0.297$ and the total mass of $M_{12} = 1.50\mathrm{M_\odot}$ (Brancewicz & Dworak 1980), the mass transfer rate can be easily calculated to be $dm = dM_1/dt = +2.21 \times 10^{-8}\mathrm{M_\odot\ yr^{-1}}$. Therefore, the secular mass transfer from the less massive component to the more massive one, may result from the less massive one filling its Roche lobe. Long-term period increases also occur in many other Algol-type binaries, including TW Dra (Qian et al. 2002a), WW Cyg (Zavala et al. 2002), SW Cyg and RR Dra (Qian et al. 2002b). The cyclic oscillation of the orbital period may be interpreted as either the presence of a third body or as magnetic activity cycles in the components. For TZ Lyrae, the period of the cyclic variation is $P_3 = 45.5\,\mathrm{yr}$. This kind of periodic oscillation also appears in other Algol-type binaries, such as TT Del ($P_3 = 43.7\,\mathrm{yr}$) (Qian 2001a) and RT Per ($P_3 = 41.9\,\mathrm{yr}$)(Qian 2001b). Thus, the period of the cyclic variation in TZ Lyr is typical for this kind of semi-detached binary. It is desirable to verify the period change and to obtain the absolute parameters by further high-precision spectroscopic and photometric observations.

Acknowledgements This work was supported partly by Huaibei Coal Industry Teachers College under the initial fund of the science and research for the doctorial degree, the Innovation Project of Science and Technology of Anhui Province (No. 2006KJ003TD) and Anhui Key Laboratory of Green Material Chemistry KLSF(I)04. Many thanks go to the anonymous referee for his valuable comments and suggestions.

References

Agerer F., Dahm M., Hübscher J., 2001, IBVS, 5017
Agerer F., Hübscher J., 2002, IBVS, 5296
Agerer F., Hübscher J., 2003, IBVS, 5484
Ahnert P., 1976, IBVS, 1190
Aslan Z., Asir A., Engin S. et al., 1981, IBVS, 1908
Binnendijk L., 1972, AJ, 77, 595
Brancewicz H. K., Dworak T. Z., 1980, Acta Astronomica, 30, 501
Deeg H. J., Doyle L. R., Béjar V. J. S. et al., 2003, IBVS, 5470
Derman E., Yilmaz N., Engin S. et al., 1982, IBVS, 2159
D'Esterre C. R., 1914, Astronomical Notes, 198, 163
Díaz-Cordovés J., Claret A., Giménez A., 1995, A&AS, 110, 329
Diethelm R., 2001, IBVS, 5027
Dvorak S. W., 2005, IBVS, 5603
Eggleton P. P., 1983, ApJL, 170, L199
Flin P., 1971, IBVS, 584
Flower P. J., 1996, ApJ, 469, 355
Hoffmeister C., 1916, AN, 202, 327
Jordan F. C., 1929, Publ. of the Allegheny Obs., 7, 146
Kałużny, J., 1985, Acta Astronomica, 35, 327
Kim C.-H., Lee C.-U., Yoon Y.-N. et al., 2006, IBVS, 5694
Kizilirmak E., Pohl E., 1971, IBVS, 530
Klimek Z., 1973, IBVS, 0779
Kotkova L., Wolf M., 2006, IBVS, 5676
Krat V., 1935, Russian A.J., 12, 21
Kreiner J. M., Kim C-H. Nha I.-S. 2001, An Atlas of O-C Diagrams of Eclipsing Binary Stars, (Kraków: Wydawnictwo Naukowe AP)
Krobusek B. A., Mallama A. D., 1975, IBVS, 954
Locher K., 2005, Open European Journal on Variable Stars, 3, 1
Lucy L. B., 1967, Zeitschrift für Astrophsik, 65, 89
Mallama A. D., Skillman D. R., Pinto P. A. et al., 1977, IBVS, 1249
Milano L., Barone F., Mancuso S. et al., 1989, A&A, 210, 181
Narasaki Y., Etzel P. B., 1994, ASPC, 56, 378
Nelson R. H., 2001, IBVS, 5040
Nelson R. H., 2004, IBVS, 5493
Ogloza W., 1995, IBVS, 4263
Pohl E., Kizilirmak E., 1972, IBVS, 647
Qian S.-B., 2001a, AJ, 121, 1614
Qian S.-B., 2001b, AJ, 122, 2686
Qian S.-B., Boonrucksar S., 2002a, NewA, 7, 435
Qian S.-B., Zhu L.-Y., Boonrucksar S., 2002b, A&A, 296, 609
Rafert J. B., 1982, PASP, 94, 485
Rafert J. B., Twigg L. W., 1980, MNRAS, 193, 79
Szafraniec R., 1972, Acta Astronomica, 22, 273
Usinov B. A., Odynaskaja O. K., 1951, Astr. Circ., 118, 8
Wilson R. E., 1990, ApJ, 356, 613
Wilson R. E., 1994, PASP, 106 921
Wilson R. E., Devinney E. J., 1971, ApJ, 166, 605
Zavala R. T., McNamara B. J., Harrison T. E. et al., 2002, AJ, 123, 450
Zhu L.-Y., Qian S.-B., 2006, MNRAS, 367, 423