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DETECTION OF THE SECONDARY MINIMA IN TX UMa

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TX UMa (HD 93033) is a well known bright ($V_{\rm max} = 7.0$, $V_{\rm min} = 8.7$) Algol-like eclipsing binary (B8V+F6IV) discovered independently by Rügemer (1931) and Schneller (1931). However, the photographic times of minima are available since 1903. The $O-C$ diagram (Kreiner et al., 2001) shows that the system exhibits rather peculiar orbital period variability that is not easy to explain by a single cause.

The observations of the system are complicated by its orbital period ($P \approx 3\overset{\rm d}{.}063$) which prevents quick coverage of the whole light curve. Due to the extreme shallowness of the secondary minimum ($\Delta V = 0.06$) and its long duration (9.7 h), the only available reliable minimum is at HJD 2444616.7811 (Oh & Chen, 1984). Its position relative to the primary minimum is important for the discussion of possible apsidal motion in the system suggested by Pearce (1940) and Payne-Gaposchkin (1942).

We present new primary minima times obtained between 1992 and 1998 ($UBVR$), the observations of the secondary minima taken in 1994 (JHK) and in 2001 (VR) and discuss the likelihood of proposed apsidal motion eventually present in the system.

Photoelectric $UBVR$ observations of TX UMa were obtained in 1992-8 and 2001 at the Skalnaté Pleso (SP) and Stará Lesná (SL) observatories of the Astronomical Institute of the Slovak Academy of Sciences. In both cases the 0.6-m Cassegrain telescope equipped with a single-channel photoelectric photometer was used. The stars HD 92764 = SAO 43442 ($V = 9.05$, $B = 9.27$, $U = 9.39$, sp. type A7) and HD 93213 = SAO 43467 ($V = 7.95$, $B = 8.44$, $U = 8.39$, sp. type F5) served as a comparison and check star, respectively.

Standard data reduction, atmospheric extinction correction and transformation to the UBV international system were carried out. Observations in the R passband and observation of the secondary minimum on February 15/16, 2001 were not transformed to the international system.

Photoelectric JHK observations of the secondary minimum in 1994 were obtained with the CVF instrument on the 1.5-m Carlos Sánchez IR telescope at the Observatorio del Teide (TO) in Tenerife, operated by the Instituto de Astrofísica de Canarias (IAC). Standard data reduction was performed using software available at the IAC.

Our new SP observations of TX UMa consist of 13 different primary minima (presented in Table 1), giving 40 individual minima times for $UBVR$ passbands. The minima times were determined by parabolic fits as well as by employing Kwee & Van Woerden (1956) method. The times obtained for our secondary minima as determined by the former method are given in Table 2.

Table 1: New mean times of the primary photoelectric minima determined from the $UBVR$ SP observations. The epochs were calculated using ephemeris (1). The errors are given in parentheses

Epoch	$\mathrm{JD}^{\mathrm{mean}}_{\mathrm{hel}}$	Epoch	$\mathrm{JD}^{\mathrm{mean}}_{\mathrm{hel}}$	Epoch	$\mathrm{JD}^{\mathrm{mean}}_{\mathrm{hel}}$
1038	2 448 643.4919(1)	1152	2 448 992.710(1)	1513	2 450 098.5640(5)
1039	2 448 646.5555(4)	1165	2 449 032.5337(4)	1527	2 450 141.4450(4)
1053	2 448 689.4419(6)	1194	2 449 121.3700(4)	1636	2 450 475.3497(2)
1150	2 448 986.5840(1)	1399	2 449 749.3480(7)	1637	2 450 478.4137(7)
				1795	2 450 962.4149(1)

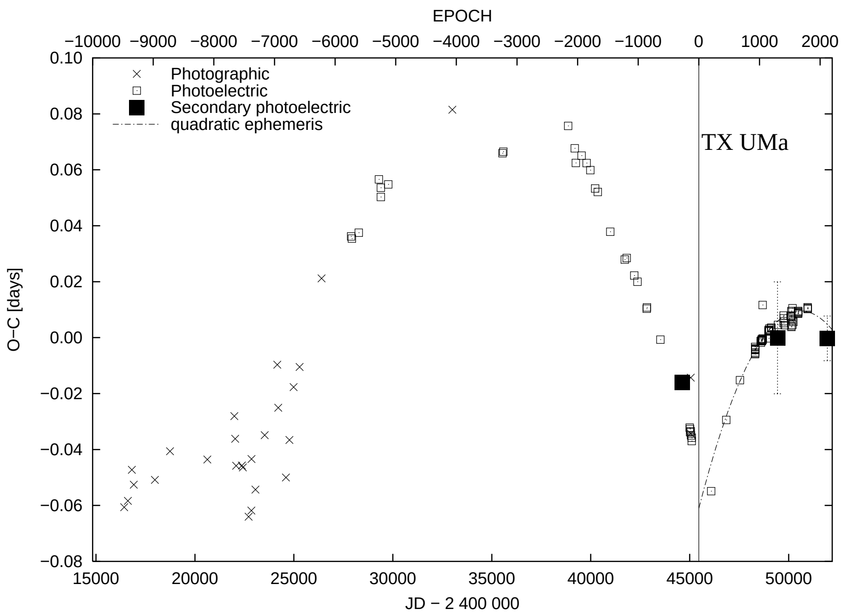

Figure 1. $O-C$ diagram for TX UMa

We combined our 40 primary minima times with other published 61 photoelectric and 27 photographic primary minima times (see e.g., Kreiner et al., 2001). The minima were weighted according to their standard errors (see Komžík, 1998). The least-square solution resulted in the following ephemeris:

$$\begin{array}{ll} \text{Min I} = \text{HJD } 2\,445\,463.797 + 3.063\,291 \times E. \\ \qquad\qquad\qquad\qquad \pm 2 \qquad\qquad\quad \pm 1 \end{array} \tag{1}$$

The corresponding $O-C$ diagram is presented in Fig. 1. It is clearly seen, that 69 primary photoelectric minima times after 1992 can be approximated well by a parabolic fit with the following ephemeris:

$$\begin{array}{ll} \text{Min I} = \text{HJD } 2\,445\,463.736 + 3.063\,375 \times E - 2.5 \times 10^{-8} \times E^2. \\ \qquad\qquad\qquad\qquad \pm 3 \qquad\qquad\quad \pm 5 \qquad\qquad \pm 2 \end{array} \tag{2}$$

Table 2: New times of the photoelectric secondary minima. The epochs were calculated using ephemeris (1). The errors are given in parentheses

Epoch	JD_{hel}	Filter	$JD_{hel}^{weighted\ mean}$	Obs.
1297.5	2 449 438.40(5)	J		TO
1297.5	2 449 438.42(3)	H		TO
1297.5	2 449 438.42(3)	K	2 449 438.417(20)	TO
2119.5	2 451 956.442(8)	V		SL
2119.5	2 451 956.445(40)	R	2 451 956.442(8)	SP

Our secondary minima observations performed on March 26/27, 1994 and February 15/16, 2001 are displayed on Figs. 2 and 3, respectively. The phases were calculated using the ephemeris given in Eq. (2).

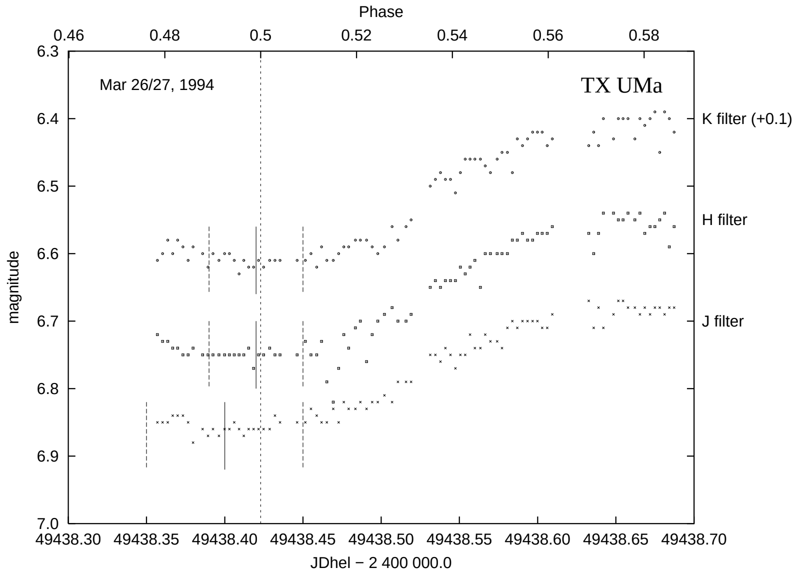

Figure 2. The secondary minimum in J, H, K (full vertical line: minimum, dashed: standard errors)

The $O-C$ diagram (Fig. 1) shows that the orbital period variations of this semi-detached binary are very complex. Long intervals of (almost) constant period were suddenly interrupted by period jumps, while recent times of minima suggest a continuous period decrease.

Plavec (1960) and Rovithis-Livaniou et al. (1998) found a 34 years periodicity in the $O-C$ residuals of the primary minima. The authors suggested apsidal motion as a likely explanation of the observed period changes. According to Todoran & Roman (1992) the observed period changes could be caused by the apsidal motion superimposed on a light-time effect or strong period variations due to mass exchange.

The reality and amplitude of the apsidal motion can be tested by the shifts of the secondary minima with respect to phase 0.5, as determined from the primary minima. Now we have at disposal three independent minima times obtained in 1981 (Oh & Chen, 1984), 1994 and 2001 (Table 1). The first one is shifted from phase 0.5 by $+0\overset{d}{.}0085$, the second and third one by $-0\overset{d}{.}006$ and $-0\overset{d}{.}005$, respectively.

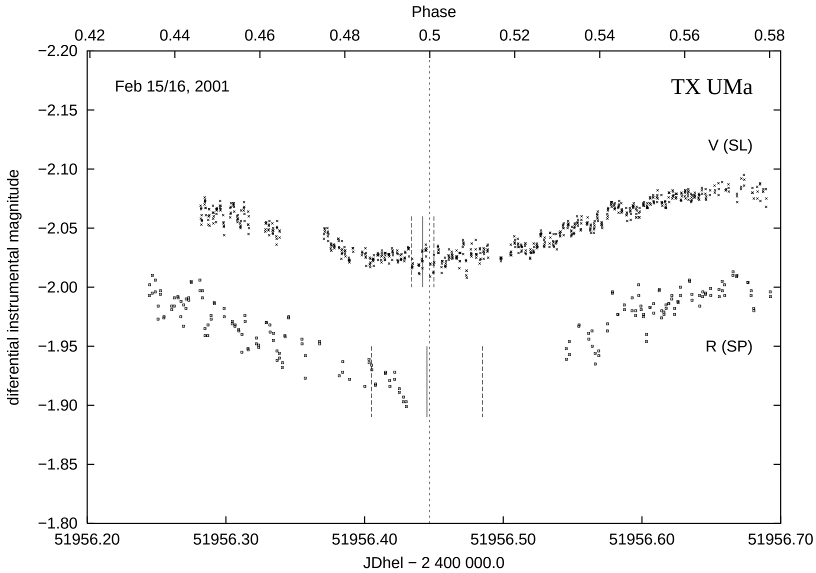

Figure 3. The secondary minimum in V, R (full vertical line: minimum, dashed: standard errors)

Thus, it is apparent that apsidal motion alone cannot explain the observed orbital period changes. Other explanations such as light-time effect, Applegate's mechanism and mass transfer are still viable.

Detailed photometric and spectroscopic analysis of all available data necessary to decipher the causes of such behaviour will be presented in a forthcoming paper.

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