Contrib. Astron. Obs. Skalnaté Pleso **38**, 538 – 544, (2008)

Asynchronous rotation of the mass gaining component in the Algol-type binary TX UMa

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Received: March 20, 2008; Accepted: June 3, 2008

Abstract.
High-dispersion spectrograms of the interacting close binary TX UMa taken in 1969-73 around the primary minima were used to display the rotational effect of the mass gaining component. The resulting rotational velocity of the gainer is 70.8 ± 2.9 km s^{-1}. The magnitude of the effect points to considerable over-synchronous rotation of the gainer due to direct impact of the gas flow from the loser component onto the surface of the gainer. Some aspects of the secular decrease of the orbital period of the system relevant to this finding are discussed, too.

Key words: stars: close binaries – rotational effect – asynchronous rotation – TX UMa

1. Introduction

The close binary TX UMa (HD 93033, BD +46°1659, SAO 43460 mag (V) =7.06 – 8.7, spectral type B8 V + G0 III-IV) was observed in 1925 by Pearce (1932) who discovered its radial velocity variations. Independently, the eclipsing nature of the system was detected by Růgemer (1931) and Schneller (1931). Its orbital period of 3.063 days is rather inconvenient for good phase coverage by photometry and spectroscopy. In spite of this difficulty it was soon discovered that TX UMa reveals period variations as well as considerable intrinsic scatter in radial velocities, indicating variations in the mass transfer and other activities of this interacting close binary.

A review of older photometric and spectroscopic investigations can be found in the introduction to the paper by Qian (2001). He has made the most thorough analysis of the period changes in the course of 11 400 orbital periods (∼ 96 years). Apart from the secular decrease of the period at a rate dp/dt = -7.13×10^{-7} d/yr, he identified 6 period jumps (alternating decreases and increases of the orbital period) between 1903–1966. The absolute values of ΔP during a jump amounts to $(2.2 - 4.6) \times 10^{-5}$ days. The author suggested that these jumps could be explained by the interplay between the variable magnetic coupling and variable spin-orbit coupling.

Maxted et al. (1995) used their own high-dispersion spectroscopy taken in the years 1985-1992 and BV photometry of Koch (1961), taken in 1956-7, to derive the absolute parameters of the binary TX UMa as follows: $M_1 = 4.76 \pm 0.16$ $\mathrm{M}_\odot$, $M_2 = 1.18 \pm 0.04$ $\mathrm{M}_\odot$, $R_1 = 2.82 \pm 0.04$ $\mathrm{R}_\odot$, $R_2 = 4.24 \pm 0.07$ $\mathrm{R}_\odot$, $\log(L_1/L_\odot) = 2.30 \pm 0.04$, $\log(L_2/L_\odot) = 1.17 \pm 0.06$. Although small orbital eccentricity was found from the photometry of the system, the authors claimed that the eccentricity is zero and the inclination of the orbit is close to 90°.

The system TX UMa was also included into a survey of 37 Algol-type binaries by Vesper et al. (2001), who studied mass transfer in semi-detached binaries with orbital periods of less than 5 days in the course of five years. Their analysis is based on the study of the behavior of the H_α line and its vicinity (640 – 670 nm). In all 49 spectra they found some degree of mass transfer activity in the system, displaying always emissions from the region between the two stars due to star-stream interaction. However, no features attributed to the existence of a permanent accretion disk were seen.

Peters and Polidan (1999) have used their UV spectra shortward of 117 nm for the confirmation of the spectral type of the gainer (primary component). They also remark that due to the small size of the system the gas stream from the loser (secondary component) directly impacts the photosphere of the gainer which prevents formation of a permanent disk.

This notion was corroborated by Richards (2004) who showed that all Algol-like binaries with the orbital period shorter than 6 days do not display accretion disks. In these cases the gas flow from the L1 point is not deflected enough by the Coriolis force exerted on the gas stream that hits therefore directly the surface of the gainer. The star-stream impact leads then to the formation of variable accretion structures that might be observed either by the photometry or by spectroscopy. She also noted persistent chromospheric activity of the loser following the contour of the Roche lobe and some evidence of its magnetic activity based on radio and X-ray data.

Kang and Oh (1993) made the first attempt to determine the rotational velocity of the gainer in TX UMa using the RV curve of Hiltner (1945) observed in 1944 with the quartz spectrograph of the MacDonald Observatory (dispersion 4 $\mathrm{nm\,mm^{-1}}$ at 393 nm). The simultaneous solution of this RV curve together with photometric data by the WD method revealed the rotational velocity of the gainer (1.768 ± 0.140)-of the synchronous velocity.

It is well known that in the case of conservation of the mass and angular momentum of the binary, the mass transfer from the loser to the gainer should cause the orbital period to increase. Thus the overall behavior of the TX UMa close interacting binary is at variance with this textbook case. We wish to contribute towards solving this discrepancy by a re-examination of the spectra of TX UMa taken by JG in the years 1969-1980 at the DAO and Ondřejov observatories, mainly with the aim of detecting the spectrum of the loser during the primary minima as well as seeing the signature of the gas stream around the quadratures.

These spectrograms were analyzed for the first time by Komžík (1998). The rotational effect computed there was used as an illustration of the asynchronous rotation of accretors in interacting binaries by Skopal et al. (2005).

2. Spectroscopic observations

Our spectroscopy of TX UMa consist of:

- 96 spectra taken by JG with the Cassegrain spectrograph of the 1.8 m telescope at the DAO Observatory in the period December 1969 – July 1970. The Kodak photographic plates with II aO(B) emulsion were used. The dispersion 0.6, 1 and 1.5 nm mm^{-1} enabled the exposures of about 21 mins around the primary minima;
- 52 spectra taken by JG in 1972-80 and 7 spectra taken by RK in 1992-93 with the coudé spectrograph of the 2.0 m telescope at the Ondřejov Observatory. The Kodak plates with II aO(B) or 103AF emulsions were used. The dispersions 0.8 and 1.8 nm mm^{-1} required exposures of about 100 mins around quadratures. These spectra helped to cover all other orbital phases of TX UMa.

A list of all our spectrograms of TX UMa can be found at Komžík (1998).

The line positions were measured visually with the TV-Abbe comparator (Minarovjech, 1992) and later the same set was digitized and re-measured by the SPEFO programme (Horn et al., 1996; Škoda, 1996). No systematic differences between these two sets of measurements were found: the resulting radial velocities from some spectrograms differ from each other not more than 3 km s^{-1}. Digital data were a bit more accurate allowing measurement of more lines but the improvement of the accuracy was only slight. Altogether 155 spectra were measured and used in this study. As the primary component of TX UMa is about six times more luminous than the secondary one, only its spectral lines are seen, except for the primary eclipse phases. The radial velocities of the primary component were determined using the lines $H_\beta - H_{14}$, He I, Mg II and Ca II (K).

3. Rotational effect

An important proof of the star rotation is the Rossiter–McLaughlin rotational effect (Rossiter, 1924). The effect is detected in spectra of eclipsing binaries during primary eclipses. The observed radial velocity excess of the primary component with respect to the velocity coming from the orbital motion is caused by blocking either the red- or blue-shifted light from the rotating primary by the secondary component.

Table 1. A list of spectrograms taken during the primary eclipse of TX UMa, their radial velocities, excesses of radial velocities and computed rotational factors.

Plate	Date UT	JD_{hel} − 2 440 000.0	Phase	Exp min	n	rv	RMS	rv′	*F*
DAO 68253	1969/12/19 09:19	0574.8908	0.0194	43	12	-51.6	4.8	-34.0	-0.44693
DAO 68254	1969/12/19 10:56	0574.9582	0.0413	31	14	-45.8	2.9	-21.0	-0.27194
DAO 68255	1969/12/19 11:25	0574.9783	0.0479	25	13	-42.4	3.5	-15.5	-0.18311
DAO 68256	1969/12/19 11:49	0574.9950	0.0534	22	11	-31.7	2.8	-3.0	-0.11278
DAO 68257	1969/12/19 12:10	0575.0096	0.0581	21	7	-34.7	3.8	-4.6	-0.06001
DAO 68258	1969/12/19 12:33	0575.0256	0.0633	24	8	-15.9	1.6	15.9	-0.01560
DAO 68368	1970/02/03 10:29	0620.9414	0.0527	25	9	-45.0	4.4	-16.6	-0.12133
DAO 68413	1970/02/09 13:49	0627.0804	0.0567	24	12	-36.6	3.2	-6.9	-0.07475
DAO 68414	1970/02/09 14:06	0627.0922	0.0606	12	14	-39.8	2.8	-8.9	-0.03632
DAO 5408	1970/02/21 11:45	0638.9942	0.9460	61	18	14.3	1.7	7.6	0.10557
DAO 5409	1970/02/21 12:59	0639.0456	0.9628	81	11	8.0	2.7	6.7	0.32544
DAO 68799	1970/03/24 04:43	0669.7002	0.9700	34	10	27.5	4.2	28.6	0.40578
DAO 68800	1970/03/24 05:28	0669.7314	0.9802	51	9	22.5	5.1	27.0	0.44810
DAO 68807	1970/03/24 09:38	0669.9050	0.0369	10	15	-45.3	2.4	-21.9	-0.32921
DAO 68808	1970/03/24 09:50	0669.9133	0.0396	10	13	-44.3	2.0	-20.1	-0.29450
DAO 68809	1970/03/24 10:03	0669.9224	0.0426	11	14	-50.6	3.0	-25.4	-0.25448
DAO 68810	1970/03/24 10:16	0669.9314	0.0455	10	8	-33.7	3.7	-7.6	-0.21530
DAO 68811	1970/03/24 10:26	0669.9383	0.0478	7	11	-41.5	3.6	-14.6	-0.18444
DAO 68812	1970/03/24 10:36	0669.9453	0.0501	6	10	-39.0	3.9	-11.4	-0.15422
DAO 68813	1970/03/24 10:46	0669.9522	0.0523	8	9	-34.7	3.3	-6.4	-0.12628
DAO 68814	1970/03/24 10:56	0669.9592	0.0546	7	10	-39.6	2.9	-10.6	-0.09848
DAO 68845	1970/03/27 04:08	0672.6757	0.9414	12	11	14.9	2.3	6.8	0.05498
DAO 68846	1970/03/27 04:24	0672.6868	0.9450	17	11	21.6	2.3	14.6	0.09383
DAO 68847	1970/03/27 04:41	0672.6986	0.9489	13	8	18.2	2.0	12.4	0.14138
DAO 68848	1970/03/27 04:55	0672.7083	0.9521	11	11	20.2	1.9	15.5	0.18311
DAO 68849	1970/03/27 05:12	0672.7201	0.9559	12	11	18.9	2.4	15.4	0.23422
DAO 68850	1970/03/27 05:27	0672.7306	0.9593	13	11	22.7	3.2	20.3	0.27995
DAO 68851	1970/03/27 05:44	0672.7424	0.9632	15	9	19.6	4.1	18.5	0.33046
DAO 68852	1970/03/27 06:01	0672.7542	0.9670	14	13	16.0	2.3	16.1	0.37533
DAO 68868	1970/03/27 10:47	0672.9528	0.0319	9	12	-44.6	4.0	-22.9	-0.38711
DAO 68869	1970/03/27 10:58	0672.9604	0.0344	9	15	-53.5	1.4	-31.0	-0.35948
DAO 68870	1970/03/27 11:08	0672.9674	0.0366	9	13	-49.0	2.4	-25.7	-0.33296
DAO 68871	1970/03/27 11:19	0672.9750	0.0391	8	16	-45.0	2.4	-20.9	-0.30105
DAO 68872	1970/03/27 11:27	0672.9805	0.0409	7	15	-44.2	3.1	-19.5	-0.27728
DAO 69108	1970/05/06 06:42	0712.7798	0.0335	198	16	-42.0	3.4	-19.8	-0.36977
DAO 69118	1970/05/09 06:06	0715.7546	0.0046	64	8	-22.7	4.5	-10.1	-0.16806
DAO 69119	1970/05/09 06:53	0715.7872	0.0153	23	15	-56.3	4.8	-40.1	-0.41768
DAO 69120	1970/05/09 07:17	0715.8039	0.0207	23	13	-58.3	5.1	-40.3	-0.44977
DAO 69121	1970/05/09 07:41	0715.8205	0.0261	21	4	-44.2	6.9	-24.4	-0.43558
OND 1471	1973/03/30 22:29	1772.4401	0.9616	422	11	10.0	2.4	8.3	0.31013
LWR 8903	1980/09/28 09:41	4510.8999	0.9371	30	12	3.7	5.2	-5.8	0.01829
LWP 5840	1985/04/28 00:33	6183.5242	0.9584	34	10	21.6	3.9	18.9	0.26793

DAO - Dominion Astrophysical Observatory, OND - Ondřejov
LWR, LWP - IUE satellite, low dispersion
n - number of spectral lines used to determine the radial velocity
rv′ - radial velocity excess due to the rotational effect
Plate in italics - not used
Date is given in format YYYY/MM/DD HH:MM ; rv, RMS, rv′ in $\mathrm{km\,s^{-1}}$

We had 42 spectra (listed in Tab. 1) taken during the primary eclipse (phases 0.934–0.066), where the corresponding rotational effect can readily be seen and measured. The spectrograms dispersions are D = 1.5 $\mathrm{nm\,mm^{-1}}$, except for the spectra DAO 5408, (D = 1 $\mathrm{nm\,mm^{-1}}$), OND 1471 (D = 0.8 $\mathrm{nm\,mm^{-1}}$) and IUE spectra LWR 8903 and LWP 5840.

The rotational effect is described by the equation

$$v' = v_{\mathrm{rot}} \sin i_{\mathrm{rot}} \times F \ , \tag{1}$$

where v' is the radial velocities' excess (orbital radial velocities subtracted); v_{rot} - the equatorial rotational velocity of the eclipsed component; i_{rot} - the inclination of its rotational axis and F is a rotational factor. This factor is a function of the phase, limb darkening of the eclipsed component and the components' radii ratio. Equations for computations of rotational factors F are given by Kopal (1959).

Komžík (1998) used spectroscopic data presented in our paper and his own photometric data to determine the photometric and spectroscopic elements of TX UMa by the Wilson-Devinney method. The excess of radial velocities in primary minimum from calculated orbital radial velocities and parameters $i = 81\overset{\circ}{.}37$; $R_{\mathrm{P}} = 2.03\ \mathrm{R}_{\odot}$; $R_{\mathrm{S}} = 3.88\ \mathrm{R}_{\odot}$; $a = 13.709\ \mathrm{R}_{\odot}$, limb darkening coefficient $u = 0.525$ (an average for filters U and B) were used to compute the rotational factors F. The phases were computed using the ephemerides of Oh & Chen (1984) for JD < 2 445 111 and Komžík (1998) for the rest. Some simplifications were made in our computations: the stars are spherical, they rotate like rigid bodies, and the limb darkening law is linear.

However, some spectroscopic data had to be excluded from the computations. In DAO 68258 and DAO 5409 spectra a shift in the wavelength calibration was probably present. Therefore, the radial velocities determined from these two spectrograms are unreliable. The exposition time of OND 1471 spectrum was too long to offer a reliable radial velocity measurement. The IUE spectra LWR 8903 and LWP 5840 were taken 10 and 15 years later than our spectra. In such a long time span one may expect measurable variations in the rotational velocity of the gainer.

The results are given in the Tab. 1 and in an accompanying Fig. 1. The synchronous rotation case (33.5 $\mathrm{km\,s^{-1}}$) is depicted there as well. No eccentricity of the orbit was found by Komžík (1998). Since the circularization of the binary orbit takes more time than the rotational synchronization of the primary, the gainer should rotate synchronously in the conservative case.

The primary component resulting rotational velocity is **70.8 ± 2.9 $\mathbf{km\,s^{-1}}$**. As it is clearly seen from our data, the gainer rotates at least 2.1 times faster than what would be expected for a synchronous rotation. If the inclination of the rotational axis is smaller than 90°, then the true rotational velocity would be even higher.

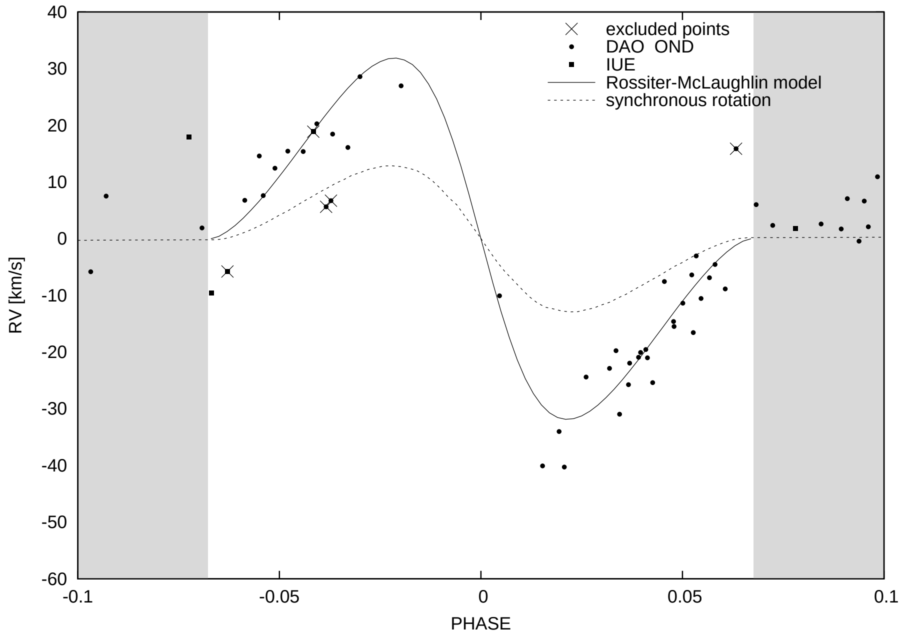

Figure 1. The rotational effect in TX UMa during the primary minimum (the white area).

4. Discussion

The fast over-synchronous rotation of the gainer is almost certainly due to the direct impact of the gas flow from the loser to the surface of the gainer. According to the calculations by Albright and Richards (1996) the impact velocities could be up to ten times higher than the (synchronous) rotational velocity of the gainer. If only surface layers of the primary rotate fast, one may expect dramatic changes in the observed rotational velocities in the course of time and particularly during the observed jumps of the orbital period. Therefore, it is advisable to combine rotational data from relatively short time intervals only. However, we are not aware of any dramatic changes of the orbital period during the interval covered by our spectrograms.

The observed secular decrease of the orbital period can be explained by non-conservative mass transfer in the system accompanied by the magnetic braking of the magnetized loser (Chen et al., 2006). Csatáryová and Skopal (2005) pointed out that a fast-rotating gainer could easily expell material from its surface during the outbursts, thus diminishing the angular momentum of the system. An alternative explanation through the presence of a massive third body in the system (Rovithis-Livaniou et al., 1998) is improbable because the photometric and spectroscopic observations of TX UMa have not shown any sign of such large massive component (Qian, 2001). Chen et al. (2006) invoked the formation of a circumbinary disk during the mass transfer as an additional mechanism for the extraction of orbital angular momentum from the binary through tidal torque. However, the existence of such circumbinary disk in TX UMa has not yet been confirmed by observations.

Acknowledgements. JG thanks NRC of Canada for a Post-Doctoral Fellowship and the staff of the Dominion Astrophysical Observatory in Victoria, B.C., for the hospitality during his stay there in the course of obtaining the spectra used in this investigation. He is also obliged to the Director of the Astronomical Institute in Tatranská Lomnica for his hospitality during the finalizing of the paper.

The authors thank Mgr. Vaňko who helped with some spectrograms digitization. Our thanks also go to an anonymous referee for a careful reading of the manuscript and valuable comments. This paper was supported by the VEGA grant 7010.

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