OSCILLATIONS IN TW DRACONIS

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ABSTRACT. TW Draconis is one of the well-know known and studied Algol-like eclipsing binaries. The light variations of TW Dra are caused predominantly by eclipses of the hot main sequence star A8 V by the cooler and fainter giant component K0 III. The total primary minimum deep 2.3 mag in B takes 11.5 hours and repeats with the orbital period about 2.807 days. We target our analysis to the study of oscillations in the system of all kind. Combining all available timings of minima we found oscillations of orbital period manifesting in O-C values variations. We speculate they are caused by the mass and angular momentum transfer and the presence of the third body in the system. Our photometric observations confirm also previously revealed oscillations in the light curve. Delta Scuti-like oscillations of the primary component cannot be the only explanation of them, as we found these small light variations also in the bottom of the totality. The complete paper is to be published elsewhere.

Key words: Stars: binary: eclipsing; stars: individual: TW Dra.

1. Introduction

TW Draconis (also HD 139319, BD+64 1077, HIP 76196, $\alpha = 15^{\mathrm{h}}33^{\mathrm{m}}51\overset{\mathrm{s}}{.}1$, $\delta = 63°54'26''$, J2000.0). Eclipsing pair is also A-component of visual binary OΣ 299 = ADS 9706. The B-component is the 9.987 mag (VT) star HD 140512=TYC 4184 61 2 only 3.3" away from TW Dra. The eclipsing variability was discovered by Annie Cannon in 1910, however the older observations are noted in 1858. The star was studied both photometrically and spectroscopically in several campaigns, which revealed also some small changes of the light curve – small oscillations, irregularities, deformations. Furthermore it was also included in several surveys. Singh et al. (1995) obtained its first X-ray spectrum using the ASCA and ROSAT satellites and confirmed the results of White & Marshall (1983) revealing TW Dra as an X-ray source. Umana et al.(1991) found that radio-fluxes of Algols are generally comparable to those emitted from the RS CVn stars and that they are changing.

2. Time scales in TW Dra

It seems TW Dra is very complex system with large variety of phenomena found there. These physical phenomena caused variations of parameters on different time scales. However only some of them are well confirmed by observations and only a part of well observed variations are clearly explainable. The table 1 shows different time scales on which we can study different phenomena in TW Dra.

Table 1: Time scales found in TW Dra.

period	event(s)
0.01 d	small quasi-periodic oscillat. on LC
0.47 d	eclipse duration,
1.66 d	rotational period of the prim. star
2.81 d	orbital period P/period of the main light changes,
6.5 y	orbital period P_3 of the third body,
21.6 y	change of orbital period P/oscillations in O–C,
decades of years	(ir)regular small deformations of LC,
> 100 years	orb. period P_4 of visual companion

Although TW Dra is really a unique close binary system the photometric observations was done only several times in the history. Only Baglow (1952), Walter (1978), Papoušek et al. (1984) covered the whole light curve and built model of the system based on their own observations. So we decided in 2004 to start new campaign to obtain new photometric measurements of the system (see Tab. 2). In 83 nights (2001–2007) we collected 48 723 CCD or photoelectric measurements in *UBVRI* filters. The light curve is shown in Fig. 1.

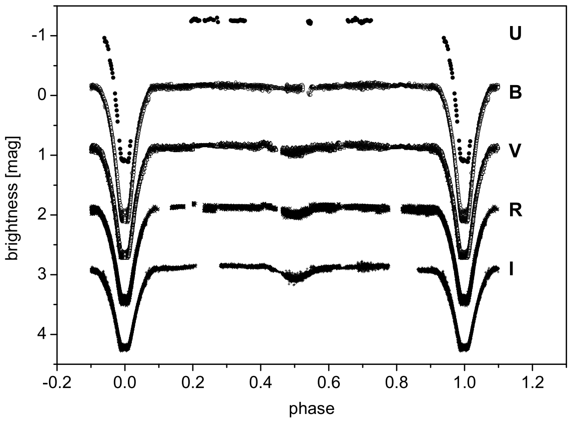

Figure 1: UBVRI light curves of TW Draconis .

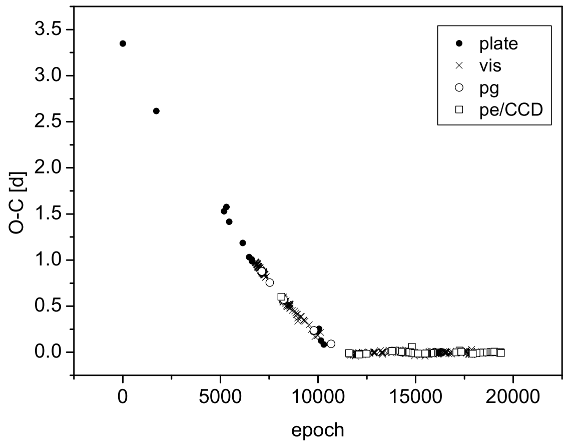

Figure 2: O–C diagram of TW Dra in 1858–2007.

Table 2: Review of photometric observations.

year(s)	observer(s)
1950–1	Baglow, Baker (DDO, Steward Observ.)
1964–5	Walter (Osserv. Astrofisico di Catania)
1969–72	Walter (University of Tübingen)
1976–9	Tremko (Tatranska Lomnica)
1967–80	Papoušek, Vetešník (Masaryk Univ., Brno)
2001	Kusakin et al. (Tien-Shan Astr. Obs.)
2001–2	Kim et al. (Sobaeksan Optical Astr. Observatory)
2004–6	Zejda (N. Copernicus Observatory and Planetarium Brno – CCD)
2005	Zejda, Janík, Božić (Hvar Observ.)
2005–7	Svoboda, Szász, Chrastina, Hroch, Brát (different observatories – CCD)
2006	Zejda, Janík (Mt. Suhora Observatory)

3. O–C oscillations

Studying the binary stars one can have a different views of the system:

macro-view – we can understand as a study of long-term global characteristics e.g. O–C diagram;

simple/basic-view – means a finding of basic characteristics during a campaign, e.g. determination of inclinations, radii, luminosities...;

micro-view – detailed study of the second order characteristics e.g. small variations on the light curve during a campaign or several observational runs.

This paper is only the first parts of the detailed study of TW Dra. It is necessary to start with a macro-view of the system. The basic time–scale in eclipsing binaries is that determined by orbital period. However one must know if this period is stable or changing and if it is changing it is necessary to describe all this changes. Only then one can for example construct the phased light curve! We concentrated in this paper on the change or let say oscillations in orbital period of the system. Summary of used observational data is given in the Tab. 3. There are only 8 secondary minima observed and furthermore the first one is wrong. We decided to use only primary minima for the study of O–C diagram.

Table 3: Review of timings of minima.

since	type	subtype	number
1858	photographic	plates	12
1913		series	6
1910	visual		419
1947	photometry	photoelectric	58
1996		CCD	66
1858	primary		553
1972	secondary		8
1858	totally		561

There are two gaps in the O–C data (see Fig. 2), which correspond the World War I and II, respectively. Unfortunately, especially during the 40's years of the last century the great change of orbital period happened. Thus we divided all data in two intervals splitting them in 1942.

The first interval contain 141 observations (9 plate faintenings, 125 visual timings, 7 pep/pg minima). Till the discovery in 1905 there are only 9 the less precise plate faintenings. For this part we used the simplest model - linear function sharing one point with the quadratic function which is suitable for the second

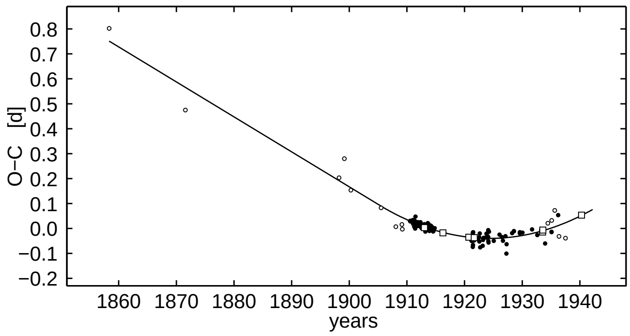

Figure 3: O–C diagram of TW Dra in 1858–1942. Plate faintening are drawn by small dots, visual observations by circles and sets of photographic or photoelectric measurements by squares.

part of the data in 1905-1942 (see Fig. 3). Then the relevant light ephemeris in 1858–1905 are

$$\text{Pri.Min.} = M_0 + P_1\,(E - E_1)$$
$$= 24\,17065.3683(29) + 2\overset{d}{.}806513(9)\cdot(E - 6140) \quad (1)$$

where $E = 0$ corresponds to the time of the first faintening in our data in 1858.
The proper light ephemeris in 1905–1942 are given by following quadratic orthogonal form (see Mikulášek, these proceedings)

$$\text{Pri.Min.} = M_0 + \overline{P}\,E' + \frac{\dot{P}\,\overline{P}}{2}\left(E'^2 - \frac{\overline{E'^3}}{\overline{E'^2}}\,E' - \overline{E'^2}\right), \quad (2)$$

where basic minimum for the centre of gravity of data is $M_0 = 2\,422\,032.9979(7)$, the mean period $\overline{P} = 2\overset{d}{.}8066209(6)$ d, time derivation of the period $\dot{P} = 1.53(5)\times10^{-8} = 5.69\times10^{-8}$ d/year, where numbers in brackets here and hereafter mean standard error of found values of parameters. Furthermore epoch $E' = E - \overline{E}$, where $\overline{E} = 7910$, $\overline{E'^3}/\overline{E'^2} = 1360$ and $\overline{E'^2} = 1.39\times10^6$. The entering data had different quality, so we calculate for then the correct weights as s^{-2}, where s is standard error for the group of data in the model used. After several iterations we found following weights:

- plate faintening $w_1 = 1$,
- visual data 1920-1942 $w_2 = 4$,
- visual data 1905-1920 $w_3 = 28$,
- photoel./photogr. series $w_4 = 266(!)$.

The period increased by 1.94×10^{-4} day during whole epoch 1858–1942. Using the well–known formula (Kwee & van Woerden, 1958)

$$\frac{1}{M}\frac{\mathrm{d}M}{\mathrm{d}t} = \frac{q}{3P(q^2-1)}\frac{\mathrm{d}P}{\mathrm{d}t}, \quad (3)$$

where $M = M_1 + M_2$ is a mass of the binary system (in $M_\odot$) and $q = M_2/M_1$, we can estimate the rate of mass exchange in the system by prediction of conservative mass transfer and no exchange between rotational and orbital angular momentum. Assuming component masses $M_1 = 1.9\ M_\odot$ and $M_2 = 0.82\ M_\odot$ (Al-Naimiy & Al-Sikab, 1984) we found mass exchange rate of $3.9\times10^{-7}\ M_\odot$/year. This short epoch of very high mass transfer was followed by the period supposedly called "relaxation epoch".

The second time interval 1942–2007 is better covered by the data and the data are in majority better quality than in the previous interval. The O–C diagram (see Fig. 4) shows cyclic variations of O–C values. However it is also seen from this figure that the amplitude as well as the period of the cycle is diminishing. To describe such run of the O–C values we built the following mathematical model. The periodicity of the O–C values variations can be described simply by a function $\cos(2\pi\vartheta)$, where ϑ is time expressed by the number of passed cycles and phase in the actual cycle. The duration Θ of each further cycle is shortened by the same relative part

$$\dot{\Theta} = \frac{\mathrm{d}\,\Theta}{\mathrm{d}\,\vartheta}\frac{1}{\Theta} = \text{const.} \quad (4)$$

For the chosen reference timing T_0 of the O–C curve extremum is $\Theta = \Theta_0$ and $\dot{\Theta} = \dot{\Theta}_0$ and then

$$\Theta = \frac{\mathrm{d}t}{\mathrm{d}\vartheta} = \Theta_0 e^{\dot{\Theta}_0\vartheta}, \quad (5)$$

where t is flowing time. Solving the equation (5) we obtain

$$\vartheta = \frac{1}{\dot{\Theta}_0}\ln\left[1 + \frac{\dot{\Theta}_0}{\Theta_0}(t - T_0)\right], \quad (6)$$

The decreasing amplitude of the change of O–C values in time could be expressed by a multiplicative term $B\left(\frac{\Theta}{\Theta_0}\right)^2$, where B is semi-amplitude of O–C value change in time T_0. Then we are able describe the O–C value variations by the following wavy quadratic function

$$\text{Pri.Min.} = M_0 + \overline{P}\,E' + \frac{\overline{P}\dot{P}}{2}\left(E'^2 - \frac{\overline{E'^3}}{\overline{E'^2}}\,E' - \overline{E'^2}\right)$$
$$+B\left(\frac{\Theta}{\Theta_0}\right)^2\cos(2\pi\vartheta), \quad (7)$$

where E' means centre of gravity of the data in selected period as mentioned above ($E' = E - \overline{E} = E - 16634$). After some modifications

$$\text{Pri.Min.} = M_0 + \overline{P}\,E' + \frac{\dot{P}\,\overline{P}}{2}\left(E'^2 - \frac{\overline{E'^3}}{\overline{E'^2}}\,E' - \overline{E'^2}\right) \quad (8)$$

$$+B\left[1+\dot{\Theta}_0\frac{E'-E_0}{\Theta_0}\right]^2\cos\left[\frac{2\pi}{\dot{\Theta}_0}\ln\left(1+\dot{\Theta}_0\frac{E'-E_0}{\Theta_0}\right)\right],$$

where E_0 is the epoch of a basic extremum, Θ is expressed in orbital periods.

Applying the robust nonlinear regression we found out that we can neglect the quadratic for this epoch. However, the O–C residual diagram is showing another periodic term (see Fig. 5). Thus, finally we excluded the quadratic term and included the new term as well, yielding the following equation

$$\text{Pri.Min.} = M_0 + \overline{P}\,E' \quad (9)$$

$$+B_1\left[1+\dot{\Theta}_0\frac{E'-E_{01}}{\Theta_0}\right]^2\cos\left[\frac{2\pi}{\dot{\Theta}_0}\ln\left(1+\dot{\Theta}_0\frac{E'-E_{01}}{\Theta_0}\right)\right]$$

$$+B_2\cos\left[\frac{2\pi\,(E'-E_{02})}{P_2}\right]$$

$$+B_2\,b_2\left\{\sin\left[\frac{2\pi\,(E'-E_{02})}{P_2}\right]-\frac{1}{2}\sin\left[\frac{4\pi\,(E'-E_{02})}{P_2}\right]\right\}.$$

Applying the robust nonlinear regression we found following basic light ephemeris:

$M_0 = 2\,446\,519.31969(18)$, $\overline{P} = 2.^{\rm d}80685567(9)$

and the values of the coefficients

$B_1 = -0.01135(24)$ days,
$\dot{\Theta}_0 = -0.257(7)$,
$\Theta_0 = 2816(16)\overline{P} = 21.64(12)$ years,
$E_{01} = -1247(13)$; $T_{01} = 2\,443\,019(33) \sim 1976.7$,
$B_2 = 0.00279(24)$ days,
$b_2 = 0.51(13)$,
$P_2 = 847(4)\overline{P} = 2377$ days $= 6.51(3)$ years,
$E_{02} = -162(15)$; $T_{02} = 2\,446\,065(42) \sim 1985.0$,

where indices 1 and 2 indicate the parameters of the major oscillation and the small oscillations caused probably by the third body, respectively. Also in the second interval we calculated the weight of the used data according to the chosen mathematical model. There are only two group of data - less precise visual timings of minima with the weight $w_1 = 1$ and photoelectric or CCD minima with the weight $w_2 = 35$.

Regarding to the resulting coefficients, we conclude that the major oscillations in O–C diagram will disappear in 2051 ± 9. We predict the closest extrema in 2010.5 ± 1.5 and 2021.9 ± 2.2, respectively. The hypothetic third body causes more or less cyclic undulation of main O–C course with the period of 6.51 years and an amplitude of 0.0065 days. The final fit according to eq. (9) is shown in Fig. 4.

The cyclic O–C variations could be explained by several ways. Apsidal motion is generally an inviable explanation for such period changes because the orbital

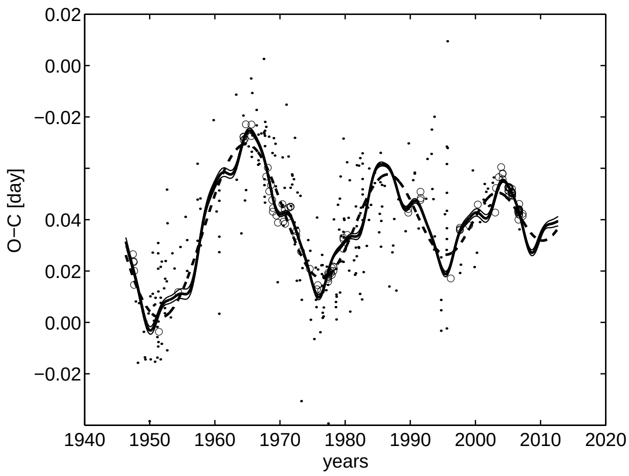

Figure 4: The O–C diagram of TW Dra in 1942–2007. Visual observations are drawn by points and CCD or photoelectric ones by empty circles. The dashed line shows the fit of the major period changes according to eq. (8) without quadratic term and the full line shows the fit including changes caused by the third body.

eccentricity for active close binaries is negligible. The orbit of TW Dra is circular. Light–time effect (hereafter LITE) needs strictly periodic variations of O–C residuals and it is fulfilled only in small oscillations in residuals after subtracting the large oscillations (see Fig. 5). So these small oscillations could be explained by the presence of the third body with estimated minimum mass $M_{3,min} = 0.3$ M$_\odot$ with the assumption of a coplanar orbit and masses $M_1 = 1.9$ M$_\odot$ and $M_2 = 0.82$ M$_\odot$ (Al-Naimiy & Al-Sikab, 1984). We can also interpret the cyclic O–C variations by interrupted mass transfer when secondary component is close to the Roche limit or by the (ex)change of angular momentum of the system. However influence of magnetic field offers the most probably explanation of such O–C changes. If the secondary companion is spectral type F5 or later (here K0III), there is sizeable convective envelope, which together with rapid rotation provide conditions for development of strong dynamo action in star. Matese &Whitmire (1983), Applegate (1992), Lanza et al. (1998) showed that magnetic activity could lead to a cyclic change of gravitational quadrupole moment of active stars and as a result of it to cyclic change of period. This dependence is possible to express according to Applegate & Patterson (1987) as follows

$$\frac{\Delta P}{P} = -9\left(\frac{R_2}{a}\right)^2\frac{\Delta Q}{M_2 R_2^2}, \quad (10)$$

where ΔP is a period change, ΔQ a change in the quadrupole moment, M_2 and R_2 are mass and radius of the secondary star and a is orbital separation of components. We calculated ΔQ for six in-

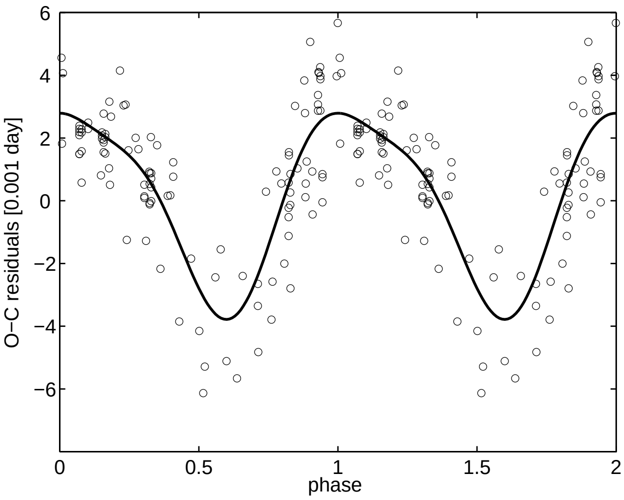

Figure 5: Residuals of O–C after subtracting the major oscillations phased with the period 6.51 year.

tervals with a good coverage of the period change.

Interval years	$\lvert\Delta P\rvert$ [10^{-5} day]	$\lvert\Delta Q\rvert$ [10^{50} g cm^2]
until 1942	19.4	88.6
1952-1965	1.98	9.0
1965-1976	1.75	8.0
1976-1987	1.52	6.9
1987-1996	1.34	6.1
1996-2003	1.18	5.4

These values corresponds to the typical values of the quadrupole moment in Algols and RS Canum Venaticorum systems (Lanza, 2006).

4. Conclusion

We made the detailed analysis of O–C values using different mathematical models for two parts of O–C diagram. The major oscillations found in more precise O–C values after 1942 are probably caused by the change of quadrupole moment as a result of the presence of magnetic field in the system. Subtracting this O–C changes we found also small oscillations. We suppose they are caused by the presence of the third body in the system with estimated mass 0.3 $M_\odot$. According to the used mathematical model we were able to predict the next development of the oscillations in the system. The further observations are desirable to confirm our prediction.

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