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Study of magnetic activity and period variations of TZ Bootis system

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Abstract. The possibility that the orbital period variation is connected with the light curve changes has been investigated for the contact binary solar–like system TZ Boo. The O'Connell effect and the minimum depth variation have been studied. The results may be through a light on the magnetic activity of the system. The system possesses the O'Connell effect with a cycle of 4.6 years while the depths variation has an 8.1 year cycle. The $(O - C)$ residual variations may be caused by a magnetic activity cycle mechanism, but it remains speculative.

Key words: contact binaries – period variation – O'Connell effect – magnetic activity – TZ Boo

1. Introduction

1.1. Previous photometric studies of TZ Boo

The star TZ Boo was found to be an eclipsing binary of the W UMa type by Guthnick & Prager (1926). In 1927 they obtained a light curve and light elements for the system. The system was observed photoelectrically by Binnendijk (1969) and the totality in the secondary minimum was found; Carr (1971) found the totality in the deeper minimum and cycle–to–cycle variations in the depths of minima. Hoffmann (1978) presented spectroscopic and photoelectric observations of the system. He detected strong light curve changes and explained them by occurrence of both solar–like star spots and circumstellar matter. Hoffmann (1980a, b) re–observed the system photoelectrically. He found that the magnitude differences of the transit and occultation minima vary with a period of 1260 days (Hoffmann 1980a). Awadalla (1989) observed TZ Boo in years 1983 and 1986, and confirmed the solar–like activity phenomenon for the system, but with a period of 1500 days. The system was also observed photoelectrically by Güdür et al. (1976) and Al–Naimiy (1982). Some authors had analyzed the light curves of TZ Boo and obtained the orbital geometric elements for the system. Using Fourier series truncated technique, Binnendijk (1969) found an orbital solution for the normal points of his yellow light curve observations, but he could not found a consistent solution for the blue light curve, because it was more distorted than the yellow one. Jabbar et al. (1986) used the normal points in *B*&*V* light curves of Binnendijk (1969) and found the orbital elements using Kopal's method of Fourier technique in the frequency domain. Al–Naimiy and Jabbar (1987), also using Fourier technique, analyzed six selected *B*&*V* light curves of different observers and found mean geometric orbital elements for the system. They, also, with the help of the spectroscopic data of Mclean and Hilditch (1983), calculated the absolute parameters of the system. These parameters were calculated theoretically by Brancewicz and Dworak (1980), as well as by Kaluzny (1985). TZ Boo system was found to be an X–ray source by Geyer and Hoffmann (1983 a, b) using the HEAO B Einstein satellite. They estimated the luminosity ratio L_x/L_v, of the system, to be about $10^{-3.8}$, which indicated that it was in a transition phase between the A & W subtype of W UMa type systems.

1.2. Previous spectroscopic studies and radial velocity curve analysis of TZ Boo

The spectroscopic observations of TZ Boo were carried out by Chang (1948). He found the radial velocity for the mass center of the system of about 58 km/s, with no variation with time. He also mentioned that in the system the double spectral lines at quadrature do not appear. Binnendijk (1969), using the corrected colour indices found by Eggen (1967), noted that the spectral type of the system was G9. Hoffmann (1978) noticed that TZ Boo has the largest ultraviolet excess among the 62 possible contact systems listed by Eggen (1967). Hoffmann (1978) also found that the spectra of the system are rather diffuse and that there was no indication of emission cores in the H and K lines of CaII. He found the semi–amplitude of the radial velocity between phases 0.7 and 1.0 of about ± 50 km/s, and the mass ratio q about 0.2. In order to interpret the radial velocities, Hoffmann (1978) postulated a third body with an orbital period of about 10 days.

Spectroscopic plates for the system TZ Boo were obtained by McLean & Hilditch (1983). They found that if the measurements between phase 0.7 and 1.0 are discarded, a semi–amplitude of the radial velocity curve is about ± 50 km/s. They calculated the spectroscopic parameters for the system. The spectral type of the primary component was given as G2 Vn in Kreiner et al. (2001) atlas.

1.3. Previous period variation studies of TZ Boo

Many authors published times of minima for TZ Boo (e.g., Guthnick and Prager, 1926 & 1927; Koch, 1956; Szafraniec, 1953 & 1957; Dueball and Lehmann, 1965; Binnendijk, 1969; Akinci et al., 1974; Pohl & Gülmen, 1981 and Pohl et al., 1985). Gröbel (1989) found that the period changes were obscured by fictitious fluctuations caused by changes in the shape of the light curves. These fluctuations show a scatter in the $(O-C)$ diagram up to ±10 minutes. Wolfschmit et al. (1979) found a U–shaped $(O-C)$ curve with a continuous period change. However, Hoffmann (1980b) suggested a V-shaped curve with an abrupt period change. Lipari and Sistero (1987) showed a sinusoidal period variation (i.e. light–time effect) in order of 30 years with a 0.04 day amplitude for the photoelectric data. Qian and Liu (2000) showed that the period variations of TZ Boo were not continuous. They found three jumps superposed on a secular decrease of the period of the system in an interval of 47 years, between the middle of 1948 and early of 1995. They suggested that the secular decrease in the period of the system might be the result of mass transfer from the more massive to the less massive component. They concluded that the orbital period of the system showed a secular decrease via AML (angular momentum loss). When magnetic fields are variable, or the magnetic coupling is variable, the jumps in the orbital period take place (Qian and Liu, 2000).

In the present work the variation of orbital period of TZ Boo system, and its probable connection with the light curve variations, have been investigated. A different phenomenon, such as the O'Connell effect, and the minima depth variation for available light curves of the system have also been studied.

2. The (O-C) variations

2.1. Time of minima and new light elements

To study the variations in the orbital period and the possible connection with the light curve changes (such as the O'Connell effect and minima depth variations) of the contact binary TZ Boo, we first compiled and critically examined the photoelectric and CCD available published times of minima. The $(O-C)$ residual values have been calculated using the light elements:

$$\mathrm{JD\,Hel.\,(Min.\,I)} = 2\,443\,655.4984 + 0^{d}.29715954 \cdot E \tag{1}$$

given by Kreiner et al. (2001).

The residuals have been listed in a table (available electronically) and presented graphically against epoch numbers in Fig. 1 as $(O-C)$. The eight times of minima (see Al Naimiy, 1982), denoted in Fig. 1 as crosses, are scattered and do not contribute to the general trend of the $(O-C)$ diagram.

A brief inspection of the scattering points shown in Fig. 1 shows that the scatter may be due to the uncertainty in the determination of times of minima. This uncertainty comes from the non–symmetry and variability of TZ Boo light curves from cycle to cycle. However, the scattered points, for both primary and secondary times of minima, follow the same trend of the $(O-C)$ variation.

Any mean light elements derived by the linear best fit for all the residual points are not suitable to estimate the minima times in future. So, we are going to divide the $(O-C)$ variation into three sections $E_i - E_{i-1},\ i = 1, 2, 3$ as shown in Fig. 1. The determination of the extreme points, the intervals and the best

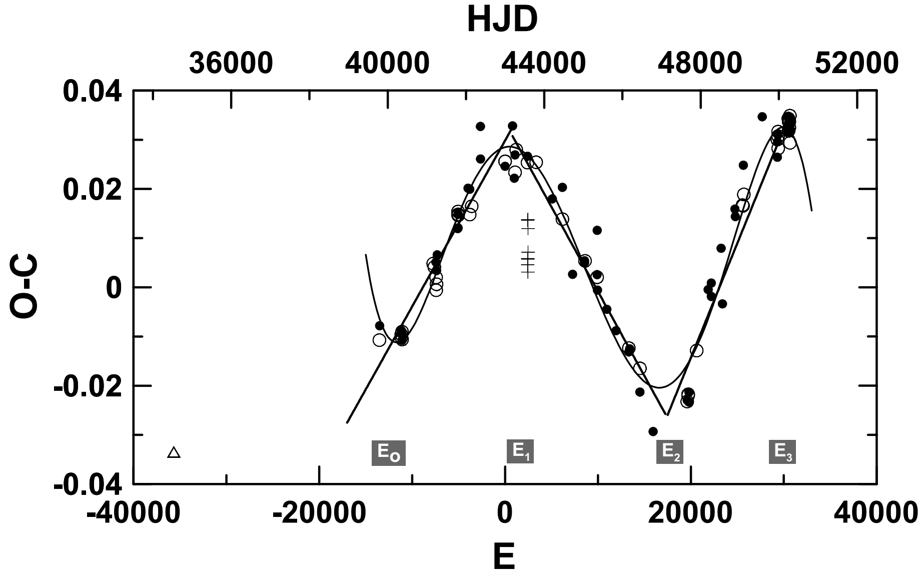

Figure 1. The $(O-C)$ vs epoch diagram for TZ Bootis. The three straight lines represent the linear best fits of the three sections $(E_i - E_{i-1},\ i = 1, 2$ and $3)$. The solid curve represents the polynomial fit. Open and full circles represent secondary and primary minima respectively. Crosses represent the photoelectric times of minima given by Al–Naimi (1996). The triangle (excluded) represents the first photoelectric data given by Blitzstein (cf., Koch 1956).

fit data with standard deviations SD, correlation coefficients r and the residual sum of squares are summarized in Table 1. The values of time intervals ΔE and the corresponding changes in the period ΔP, for each section according to the best fit of the $(O-C)$ residuals, are also listed in the table.

We also attempt to represent the $O-C$ data by a polynomial of the fifth degree in cycles (E) that is represented by solid curve in Fig. 1. The fifth degree best polynomial fit with a residual sum of squares equals 0.000152, yields the following:

$$\begin{aligned}\text{JD Hel. (Min. I)} &= 2\,443\,655.52686 + 0^d.297159998 \cdot E \\ &\quad -4.869 \cdot 10^{-10} \cdot E^2 + 1.677 \cdot 10^{-15} E^3 \\ &\quad +1.478 \cdot 10^{-18} E^4 - 3.349 \cdot 10^{-23} \cdot E^5 \qquad (2)\end{aligned}$$

The light elements from the polynomial can be used to estimate minimum times for the next few years. Comparing roughly this curve with Irwin's (1959) standard light time effect curves, one may estimate the eccentricity to be $e =$

Table 1. The three linear fit sections, the intervals, and the rate of changes of the period and mass of TZ Boo.

E	E_o to E_1	E_1 to E_2	E_2 to E_3
Interval (JD:2400000+)	40357 to 43893	43893 to 49153	49153 to 52767
Epoch	43655.52968	43655.53200	43655.37654
Period (days)	0.297163157	0.297156095	0.297164857
SD	0.004	0.005	0.005
r	0.954	0.962	0.966
Residual sum of squares	0.000474	0.000497	0.000557
ΔE(day)	3536	5260	3614
ΔP(day)	3.617×10^{-6}	-3.444×10^{-6}	6.989×10^{-6}
$\Delta P/P$	1.22×10^{-5}	-1.16×10^{-5}	2.35×10^{-5}
$\Delta P/\Delta E$ (d/cycle)	3.04×10^{-10}	-1.95×10^{-10}	5.75×10^{-10}
$\Delta M_1(M_\odot)$	4.209×10^{-7}	4.002×10^{-7}	8.107×10^{-7}
$dM/dt(M_\odot/\mathrm{yr})$	4.35×10^{-8}	-2.78×10^{-8}	8.19×10^{-8}

Notes: 1) From Pribulla et al. (2003) Catalogue; $\Delta P/P = -2.45 \times 10^{-5}$ around 1979 and $\Delta P/P = +3.27 \times 10^{-5}$ around 1992.

2) From Qian and Liu (2000), a secular decrease $\Delta P/\Delta E = -9.6 \times 10^{-11} day/cycle = -1.18 \times 10^{-7}$ day/year and transfer of mass (conservative) $dM/dt = 1.4 \times 10^{-8} M_\odot/year$.

0.15 ± 0.02 and the longitude of periastron $\omega = 245° \pm 10°$ for a third body orbit with a period of 25.23 ± 0.03 years and an amplitude of $0.^d0512 \pm 0.002$, if such a body exists. Also $a\,sin\,i = 4.44 \pm 0.17$ and a third body mass of about 0.64 $M_\odot$ may be calculated.

3. The light curves variations

It is of interest to search for a possible connection between the light curve variations and the period changes of the eclipsing binary TZ Boo. The most of the available published data of B&V light curves for the system TZ Boo have been collected. All the collected light curves are plotted in the same scale and presented in Fig. 2. Subsequently, the relative light levels at maxima (O'Connell effect) and minima have been evaluated from all light curves since 1927 (Guthnick and Prager, 1927). The magnitude differences between both maxima D_{max} and minima D_{min} and the amplitudes (depths) of the primary A_p and secondary A_s minima for every light curve have been obtained, where

$D_{max} = mag(max_p - max_s)$
$D_{min} = mag(min_p - min_s)$, and
$A_{p,s} = mag(min_{p,s} - max_p)$.

The values of these parameters in B&V filters are listed in Table 2, with their corresponding observers, observational date in years and mean heliocentric Julian day.

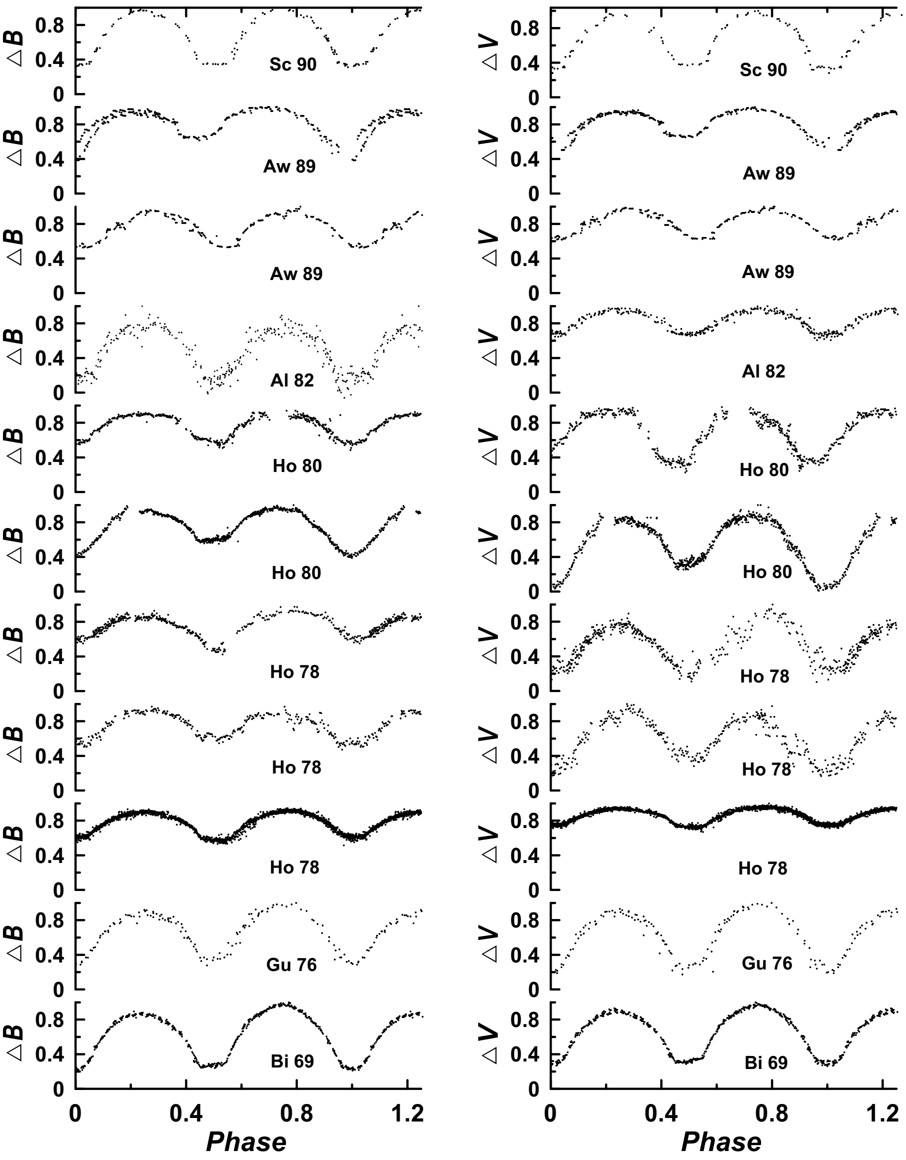

Figure 2. All light curves in B and V bands for the system TZ Bootis that were published. The abbreviations used under each light curve are identical with those of Table 2.

Table 2. The O'Connell effect, duration, primary and secondary amplitudes for different observed light curves of TZ Boo.

HJD 240000+	F	d_s min.	D_{min} mag.	D_{max} mag.	A_p mag.	A_s mag.	Ref.
25031	Sp	-	-0.05	+0.00	0.50	0.50	GP 27
39631	B	36.0	0.02	-0.06	0.34	0.40	Bi 69
	V	41.0	0.01	-0.04	0.32	0.36	
40372	B	27.5	-0.10	-0.03	0.33	0.36	Ca 70
41384	B	36.0	-0.04	-0.04	0.36	0.40	Gu 76
	V	36.8	-0.04	-0.03	0.34	0.37	
42153	B	41.2	0.03	-0.02	0.35	0.37	Ho 78
	V	36.4	0.00	-0.03	0.36	0.39	
42525	B	40.7	-0.09	0.05	0.47	0.42	Ho 78
	V	38.5	-0.10	0.04	0.44	0.40	
42867:	B	-	-	-0.06:	0.31	0.37	Ho 78
	V	-	-	-0.08:	0.33	0.41	
43655:	B	38.2	-0.17	-0.02	0.49	0.51	Ho 80a
	V	32.0	-0.18	-0.02	0.48	0.50	
43973	B	46.7	-0.05	-0.03	0.37	0.40	Ho 80a
	V	36.0	-	0.00	0.36	0.36	
44372	B	37.4	0.01	-0.02	0.37	0.39	Ho 80b
	V	35.7	0.00	0.00	0.36	0.36	
44375	B	23.0:	0.00	0.00	0.37	0.37	Al 82
	V	25.0:	-0.02	0.00	0.35	0.35	
45485	B	30.0	-0.02	0.00	0.45	0.45	Aw 89
	V	34.0	0.00	0.01	0.40	0.39	
46597	B	34.5	-0.20	-0.04	0.57	0.61	Aw 89
	V	34.5	-0.15	-0.04	0.51	0.55	
47616	B	35.6	-0.01	0.00	0.34	0.34	Sc 90
	V	34.2	-0.02	0.00	0.34	0.34	

Notes: 1) : uncertain; 2) GP 27=Guthnick and Prager (1927), Bi 69=Binnindijk (1969), Ca 70=Carr (1970), Gu 70=Güdür et al. (1976), Ho 78=Hoffmann (1978), Ho 80a=Hoffman(1980a), Ho 80b=Hoffmann (1980b), Al 82=Al-Naimiy (1982), Aw 89=Awadalla (1989), and Sc 90=Schaub (1990).

A brief inspection of all the light curves of Fig. 2 and the values of the parameters of Table 2 leads to a conclusion that there is a wave–like character (or oscillatory behavior) for these parameters, such as a $P(E)$ function. This may be modulated by a periodic action of some physical mechanism.

(i) The variations of amplitudes $A_{p,s}$ in $B\&V$ filters, as a function of time, are displayed in Fig. 3 a, b, c, d. The figures show mostly two peaks around the

years 1978 and 1986 which suggest a cycle of about 8.08 years.
(ii) The Data Compensated Discrete Fourier Transform (DCDFT) technique is used to obtain the power spectrum of a time series of $D_{max}(t)$ (O'Connell effect) and $D_{min}(t)$ (the difference between the two minima) functions. In order to find a periodicity, we used the function (Ferraz-Mello, 1981):

$$F(\omega) = \sum_{i=1}^{N} \; f(t) \; exp\,(2\pi \, i\omega \, t_j),$$

which leads to a significant highest peak and corresponds to a true periodicity.

The spectra obtained using the DCDFT technique for the parameters D_{max} and D_{min} in B&V filters have been shown in Fig. 4a, b, c, d, where the main spectral components (marked by ω_{max} and ω_{min}) correspond to periodicities of $D_{max_{B,V}} = 4.69$, & 4.52 years and $D_{min_{B,V}} = 8.06$, &8.06 years.

4. Interpretations and discussions

The orbital period of the eclipsing binary TZ Boo and the possible connection with the light curves variations are investigated. It is shown mostly by the above analysis that the orbital period of the contact system TZ Boo oscillates depending on the light curves asymmetries. However, there are different physical mechanisms which cause this phenomenon. So, the oscillatory behavior of the $(O - C)$ residuals as shown in Fig. 1 and the periodicity of O'Connell effect and the depth differences (Fig. 3a, b, c, d) as well as the amplitudes periodicity of TZ Boo light curves, may be interpreted in terms of: mass exchange and magnetic activity cycles.

The orbital period $P(E)$ of TZ Boo shows two main period jumps around HJD 244 3893, and 245 1233 (marked by E_1 and E_3 in Fig. 1) which are approximately 20 years apart. These two peaks are superposed on several decreases and increases of the system period. This may be a result of rapid mass exchange between the two components. Peaks have been found in the light curves, too: around HJD 244 6624 and 244 3673 (marked by 1 and 2 in Fig. 3) which yield a difference about 8 years. A similar cycle has been found for D_{min} as a function of time (Fig. 4c, d) to be about 8 years too, which may refer to streaming matter between the components. In addition to that, the system TZ Boo shows the O'Connell effect, D_{max} changing in cycles of about 4.5 years (Fig. 4a, b). One of the possible explanation of the O'Connell effect for close binary stars has been based on the hypothesis that the circumstellar material of a binary system is captured by its components (Liu and Yang, 2003). However, if a decrease or an increase of the orbital period is due to a conservative mass exchange between the components, then we can estimate from the well–known equation,

$$\Delta P/P = 3\,((M_1/M_2) - 1)\,\Delta\, M_1/M_1,$$

the mass transfer rate dM/dt. The values of these rates are listed in Table 1, according to the spectroscopic mass ratio $q_{sp} = 0.132$ and $M_1 = 0.691$ with spectral type G2V (Pribulla et al., 2003, catalogue with reference in).

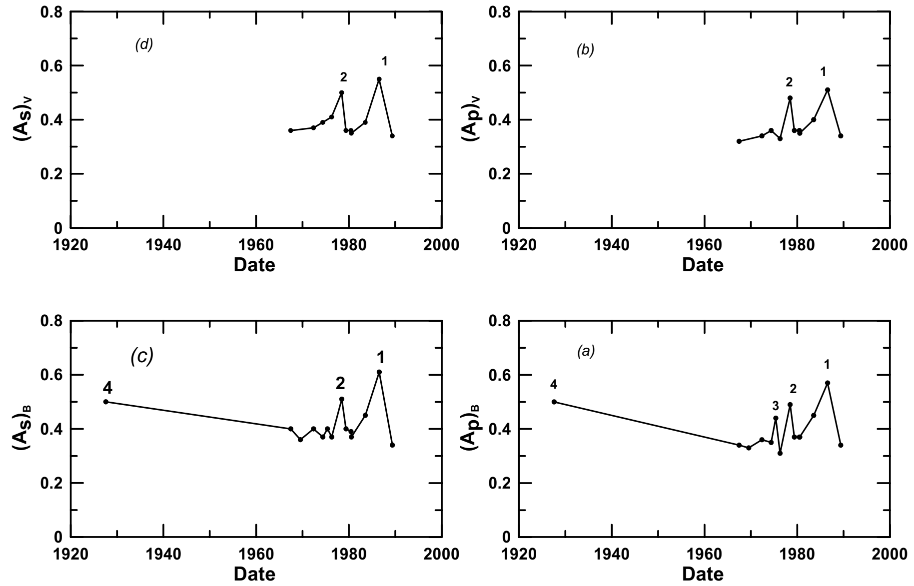

Figure 3. The variations of $A_{p,s}$ in B and V filters show two peaks around the years 1978.46 and 1986.54. Note that the numbers 1, 2, 3, and 4 correspond to the dates 1986.54, 1978.46, 1975.38, and 1927.58, respectively.

One of the possible physical mechanism for explaining the period changes of the system TZ Boo may be the magnetic activity cycles. The (O-C) curve of the system shows two deep decreases around $E_o \simeq 244\,0357$ and $E_2 \simeq 244\,9153$. The time between one period decrease and the next decrease is about 24 years which would be referred to one full magnetic cycle. The likelihood of magnetic cycles in late–type stars of various types was reviewed by Hall (1990). One manifestation of such cycles is cyclic, but not strictly periodic, variation in the orbital period of a binary. Many investigators found similar cycles in other W UMa binaries (e.g., Kreiner, 1977; Hall, 1990 and Hardie and Hall, 1990). However, the changes of the light curves are not synchronous with the period changes, they do not confirm the presence of a magnetic effect i.e., the magnetic activity explanation remains speculative for the changes of the $O - C$ curve of the TZ Boo system.

5. Conclusion

The results of the present work show that the changes of the light curve of the system have been related to two phenomena:

1. The O'Connell effect $D_{max.}(t)$ with a cycle length of $\simeq 4.5$ years and,

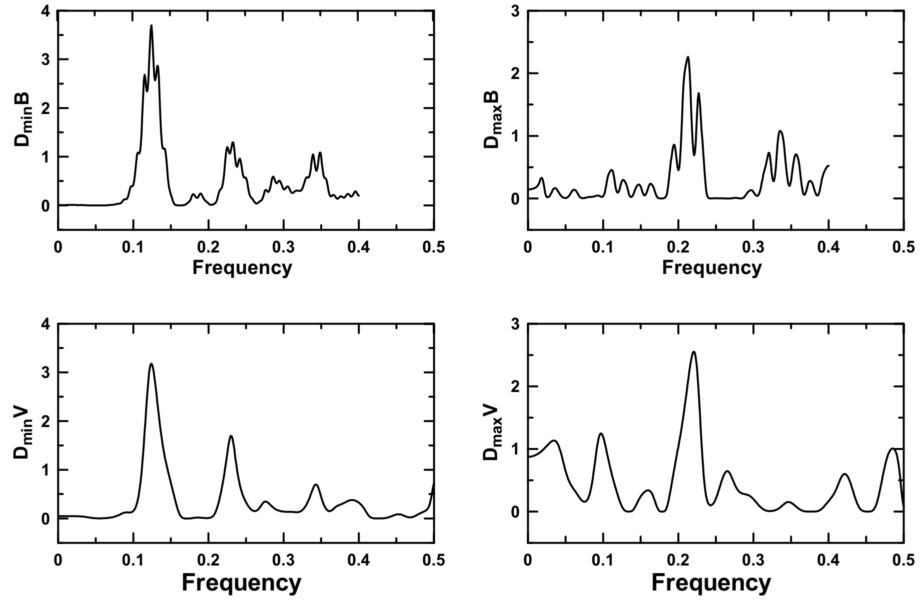

Figure 4. The spectrum of D_{max} (O'Connell effect data) and D_{min} (the deference in the two minima) in B and V filters for TZ Boo in an interval of 62 years (from 1927 to 1989).

2. The minima difference $D_{min}(t)$ with a cycle length of about $\simeq$ 8.0 years. Both could be explained by streaming of matter exchange between the components.

A correlation between the $(O-C)$ changes with the magnetic activity may be found, if it is studied quantitatively. Then the increase and decrease found in the $(O-C)$ curve may be due to two mechanisms, magnetic cycling and/or mass transfer.

Also, one cannot ignore the mass and angular momentum loss from the system, but this may not be the main cause for the period fluctuation of TZ Boo.

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