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Indirect evidence for short period magnetic cycles in overcontact binary stars

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Abstract
Complex period variations of five W UMa type binaries (AB And, OO Aql, DK Cyg, V566 Oph, U Peg) were investigated by the analysis of their O–C diagrams, and several common features were found. Four of the five systems show secular period variations at a constant rate in the order of $|\dot{P}_{\rm sec}/P| \sim 10^{-7}$ y^{-1}. In the case of AB And, OO Aql and U Peg a high-amplitude, nearly one-century long quasi-sinusoidal pattern was also found. It might be explained as light-time effect, or by some magnetic phenomena. The most interesting feature of the studied O–C diagrams is a low amplitude ($\sim 2 - 4 \times 10^{-3}$ d) modulation with a period around 18–20 yr in four of the five cases. This phenomenon might be an indirect evidence of some magnetic cycle in late-type overcontact binaries as an analog to the observed activity cycles in RS CVn systems.
Keywords: *binaries: close, binaries: eclipsing, stars: activity*

1 Introduction

The moments of minima are one of the most fundamental observables of eclipsing binary systems and, due to their relatively easy measurement, a huge pile of data of this type was collected by observers during the last century. However, so far there is no a commonly accepted and straightforward interpretation of the O–C diagrams constructed from them.

These observed variations can be classified into two subsets: (i) in the first part are the apparent period variations due to light-time effect (LITE) caused by a distant third or further body, or apsidal motion in eccentric systems, and (ii) the second part comprises the inherent physical period variations.

The latter may also be of various types, e. g. caused by the evolution of the system, mechanical and/or thermodynamical effects, or due to variable magnetic activity. Of course, a mixture of the different sources can be active at the same time, generating a very complex variation of the orbital period.

With respect to the involved time scales we can distinguish the long-term variations (on a nuclear or thermal time scale) from the short-term variations characterised by a decade long cycle length. In our recent study we are focusing onto the short–term orbital period variations of several W UMa systems, because the real O–C observations can reveal these effects only, while the long–term ones require a different (statistical) approach.

2 General remarks on the analysis

We concentrated mainly on systems whose observations cover more than half, or even a complete century. As in several cases the earlier observations are photographic or more frequently less accurate patrol measurements or visual observations, they were taken into account as well (at least at the first step of our analysis), but with different weights. We used four different weights: 1: visually observed minima; 2: plate minima; 5: photographic normal minima; and 10: photoelectric observations (both photomultiplier tube and CCD). The data series were analysed in a similar manner was described e.g. in Borkovits et al. (2002), i. e. after the calculation of the O–C curve with a preliminary linear ephemeris, the final representation of the O–C was searched for by a weighted linear least-squares fit in the form:

$$f = c_0 + c_1 E + c_2 E^2 + \sum_{i,j} a_{ij} \sin j\nu_i E + b_{ij} \cos j\nu_i E, \tag{1}$$

where $0 \leq i \leq 5$, $1 \leq j \leq 4$. The frequencies ν_i were kept fixed during the individual LSQ runs but an interval of frequencies was scanned and the best parameter set was selected according to the smallest χ^2 test. Then the astrophysical parameters were calculated from the corresponding coefficients of the equation above by the use of well-known physical relations.

Table 1: *Main parameters of the investigated stars. (The spectral types are taken from SIMBAD.)*

Name	Sp	P	T	M_1	M_2	R_1	R_2	T_1	T_2	A	refs
		d		$M_\odot$	$M_\odot$	$R_\odot$	$R_\odot$	K	K	$R_\odot$	
AB And	$G5V^a$	0.33	W	0.60	1.04	0.78	1.03	5450	5798	2.37	1
OO Aql	$G5V$	0.51	A	1.04	0.88	1.39	1.29	5700	5560	3.33	2
DK Cyg	$A6V$	0.47	A	1.74	0.53	1.71	0.99	7351	7200	3.34	1
V566 Oph	$F4V$	0.41	A	1.56	0.41	1.51	0.86	6700	6618	2.91	3
U Peg	$G2V$	0.37	W	1.15	0.38	1.22	0.74	5860	5785	2.52	4

1: Baran et al. (2004); 2: Hrivnak (1989); 3: Niarchos et al. (1993); 4: Pribulla & Vaňko (2002)
a: More recently Pych et al. (2004) found a mean spectral type of G8V

3 Discussion

The five investigated systems are distributed in the range of effective temperatures from $T_{\text{eff}} = 7400$ down to $T_{\text{eff}} = 5400$, which is the transition region where a convection zone develops in the envelope of the stars toward the lower temperatures. The most important parameters are listed in Table 1. The analysis of the O–C diagrams of the systems has revealed in four cases different periodic variations beside the secular development of the orbital period.

3.1 Secular period changes

Four of the five O–C curves show evidence of continuous orbital period change with a constant rate during the total observing interval. The only exception was OO Aql, although it is possible that in this system only one (or two) abrupt period jump(s) obscure this behaviour.

The most usual explanation of this kind of secular period variation is mass exchange in the system. The widely used approximating formulae for the calculation of the mass exchange rate is as follows:

$$\dot{m} = -m_{12}\frac{q}{1-q^2}\frac{\dot{P}}{3P} \approx -m_{12}\frac{q}{1-q^2}\frac{2}{3}\frac{c_2}{c_1^2}, \tag{2}$$

Table 2: *Derived parameters from the period variations*

Name	$\dot{P}_{\rm sec}/P$	$\lvert\dot{m}\rvert$	$P_{\rm mod}$	$A_{\rm mod}$
	$\times 10^{-7}$ (y^{-1})	$\times 10^{-7}$ (M$_\odot$ y^{-1})	(d)	(d)
AB And	2.65	1.25	6 695	0.0020
OO Aql	–	–	7 467	0.0036
DK Cyg	1.93	0.49	–	–
V566 Oph	6.76	1.25	7 250	0.0035
U Peg	−1.88	0.36	6 544	0.0016

where c_1, c_2 directly come from the O–C ephemerides in the form of Eq. (1). Note that the equation requires constancy of the total mass, as well as of the total angular momentum. The rate of the secular period change, as well as the calculated mass exchange rate are tabulated in Table 2.

Nevertheless, it is necessary to note that in the case of AB And and U Peg the coefficients of the quadratic terms, and the period and amplitude of the longer period quasi-sinusoidal period variations are not independent from each other as we will see later.

3.2 Longer period cyclic variations

In three cases (AB And, OO Aql, U Peg) the simultaneous fitting gave longer as well as shorter period cycles. These longer scale variations are roughly 62, 75 and 85 years long, respectively, and naturally might be identified as a LITE, i. e. effect due to the presence of a third body. The corresponding LITE solution parameters are listed in Borkovits et al. (2005). However, we have to note that e. g. in the case of OO Aql the calculated minimal mass of the tertiary component seems to be unrealistically large. Hence, the identification of these periods as LITE solution can be considered only as a simple designation and their real origin should require yet a careful analysis in all cases. It should also be emphasised that these periods are in the same order as the total interval of the observations and the separation of the different effects in the analysis are doubtful.

3.3 Shorter period cyclic variations - manifestation of magnetic activity cycles?

It is an interesting fact that four of our five systems show small amplitude cyclic fluctuations with very similar periods (see Cols. 4-5 in Table 2). The only exception is DK Cyg, the hottest in the sample, with A8 spectral-type components, whilst the other four are later than F0 down to G5 in the case of AB And.

These modulation periods range from 6 500 to 7 500 days (18–20 years) that are quite similar to those one observed in other types of stars showing magnetic activity. The startling resemblance of orbital period variations in these more or less similar systems suggests some parallelism in their origin and makes likely some common physical explanations. According to our opinion this feature might be an indirect evidence of similar magnetic cycles in the investigated binaries and the detected variations might caused by it. We mainly refer to Lanza & Rodonó (1999) who found a relation between the orbital period of a binary system and the magnetic activity cycle assuming synchronisation between the orbital motion and rotation of the member stars:

$$\log P_{\mathrm{mod}}\ [\mathrm{yr}] = 0.018 - 0.36(\pm 0.10) \log \frac{2\pi}{P_{\mathrm{orb}}} [\mathrm{sec}]. \tag{3}$$

For the binaries studied here, this formula predicts $P_{\mathrm{mod}} \approx 7\,900$, $9\,200$, $8\,500$, and $8\,200$ days, respectively. (Note that these values are very close to the length of the Sun's magnetic cycle). These values are in the same order of magnitude as the observed ones. This supports our conjecture that magnetic activity cycles are able to explain the observed short term orbital period variations.

From the period of the modulation (P_{mod}) and the amplitude of the O–C ($A_{\mathrm{O-C}}$) the rate of the period variation can be expressed easily. Using this the variation of the gravitational quadrupole momentum is (Applegate, 1992):

$$\Delta Q = -\frac{2\pi}{9} M R^2 \left(R/a\right)^{-2} \frac{A_{\mathrm{O-C}}}{P_{\mathrm{mod}}} \tag{4}$$

where M is the mass of the active star, R is the radius of the active star and $a = 2A$, the separation between the components. (A is the semi-major axis and note that in contact binaries the orbit is circular.) A calculation with the parameters of the primary and the secondary (see Table 1) gives $\Delta Q_1 = 4.02 \times 10^{42}\mathrm{kgm}^2$, and $\Delta Q_2 = 6.97 \times 10^{42}\mathrm{kgm}^2$, respectively. These values correspond to the typical values in active binary stars (Lanza & Rodonó, 1999). Due to the similar absolute dimensions of the other investigated binaries, the same calculations give physically realistic results for them as well.

As it was mentioned already, the spectral type of the systems showing short period variations in the O–C diagrams is later than F0, while the earlier type DK Cyg does not show this feature. This type of behaviour is pretty similar to the observed one among the Algol-type RS CVn systems (see Hall, 1989) that the magnetic activity can be observed only in systems later than F5, as the magnetic dynamo theories are based on a strong connection with the presence of a convection zone in the outer envelope predicting magnetic activity for them. Since the convection zones in the envelope appear in lower mass MS and cooler stars, this type of relation is a trivial requirement but, of course, the strict border lines can be different. Although our sample is not a systematic one, however, it indicates the existence of a separation border somewhere around the spectral type F0.

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