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1965 Light Curves of BV Dra and BW Dra

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Abstract Differential *B*-band photometry of BV Dra and BW Dra, obtained in 1965, is presented. Times of primary and secondary minima are derived and combined with published times for a period study. Period variations are found in both binaries and magnetic cycles are proposed as an explanation. The cycle length is 19 years in BV Dra and 8 years in BW Dra.

Key words: eclipsing binaries, period variations—magnetic fields, cycles—stars, individual—W UMa binaries

1. Introduction

Shortly after the first author's death on December 19, 1989, a search of his files uncovered some photoelectric photometry which seemed valuable enough to publish. It comprised a complete light curve of both BV Dra and BW Dra, two W UMa-type eclipsing binaries which make up the visual binary ADS 9537AB, with A corresponding to the former and B to the latter. These are the original observations which led to the discovery that the two stars were variable. They were referred to in an abstract by Batten & Hardie (1965), although at that time the two variable star designations had not been assigned.

In the intervening years, this physical pair of(presumably coeval) W UMa binaries has attracted considerable attention and has been the subject of numerous papers. Two recent comprehensive treatments are those of Kaluzny & Rucinski (1986) and Batten & Lu (1986). Although good multi-bandpass light curves of both variables have now been published, and solved with physically realistic models, the Hardie light curves should be useful for times of minimum which extend the $O - C$ curve's baseline in time back towards earlier epochs.

According to Batten, Fletcher & McCarthy (1989) BV Dra has a spectral type of F9V+F8V and varies in V between 7.88 and 8.48 mag, while BW Dra has a spectral type of G3V + G0V and varies in V between 8.61 and 9.80 mag.

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2. Observations

The individual differential magnitudes have been sent to the I.A.U. Commission 27 Archive of Unpublished Observations of Variable Stars (Breger 1988) where they are available as file no. 159. Each value is a differential magnitude in the sense variable minus 121 Draconis, was corrected for differential atmospheric extinction, and was transformed to *B* of the standard *UBV* photometric system. The 24-inch Seyfert telescope at Dyer Observatory was used with a 1P21 photomultiplier, a DC amplifier, and a strip-chart recorder. A diaphragm 10 arcsec in diameter was used, small enough to handle the small angular separation between BV Dra and BW Dra, which is about 16 arcsec.

The data, 214 for BV Dra and 197 for BW Dra, are plotted as light curves in Fig. 1. Phases have been computed with the ephemerides given by Kaluzny & Rucinski (1986), namely, their Equation (1) for the former and their Equation (2) for the latter.

3. Times of minimum

Times of mid-eclipse were derived from the data using the method of bisected chords. These are presented in Table 1. The two entries marked with a colon are relatively uncertain; for them there was not very good overlap between the rising and falling eclipse branches. It turns out that four were times of primary minimum and seven were times of secondary; primary and secondary eclipses are comparably deep in both systems.

4. The $O - C$ curves and improved ephemerides

In addition to the times of minimum presented here for the first time, other, more recent times have been published since Kaluzny and Rucinski prepared their $O - C$ curves of BV Dra and BW Dra.

Fig. 2(a) is the $0 - C$ curve of BV Dra including the times in Table 1, those used by Kaluzny and Rucinski (1986, Table 1), those of Gorda (1986), those of Dapergolas, Kontizas & Kontizas (1989a), and the time of conjuction of Batten & Lu (1986), which should correspond to a time of mid-eclipse. $O - C$ residuals in Fig. 2(a) are computed with respect to the ephemeris

$$JD(\text{hel.})\ \text{pri. min.} = 2{,}440,\ \underset{\pm 4}{362.7927} + \underset{\pm 4}{0.35006660}\, n, \tag{1}$$

which is the result of a linear fit by least squares giving each time equal weight. Both the epoch and the period differ somewhat from the corresponding values of Kaluzny & Rucinski (1986, Equation 1).

Fig. 2(b) is the $O - C$ curve of BW Dra including the times in Table 1, those used by Kaluzny & Rucinski (1986, Table 2), those of Gorda (1986), those of Dapergolas, Kontizas & Kontizas (1989b), and the time of conjuction of Batten & Lu (1986). The first three times of Rovithis & Rovithis-Livaniou (1982, Table 1), which Kaluzny & Rucinski (1986) had concluded were systematically in error, were not included. The five new times presented by Rovithis & Rovithis-Livaniou (1987, Table 3) seem to be

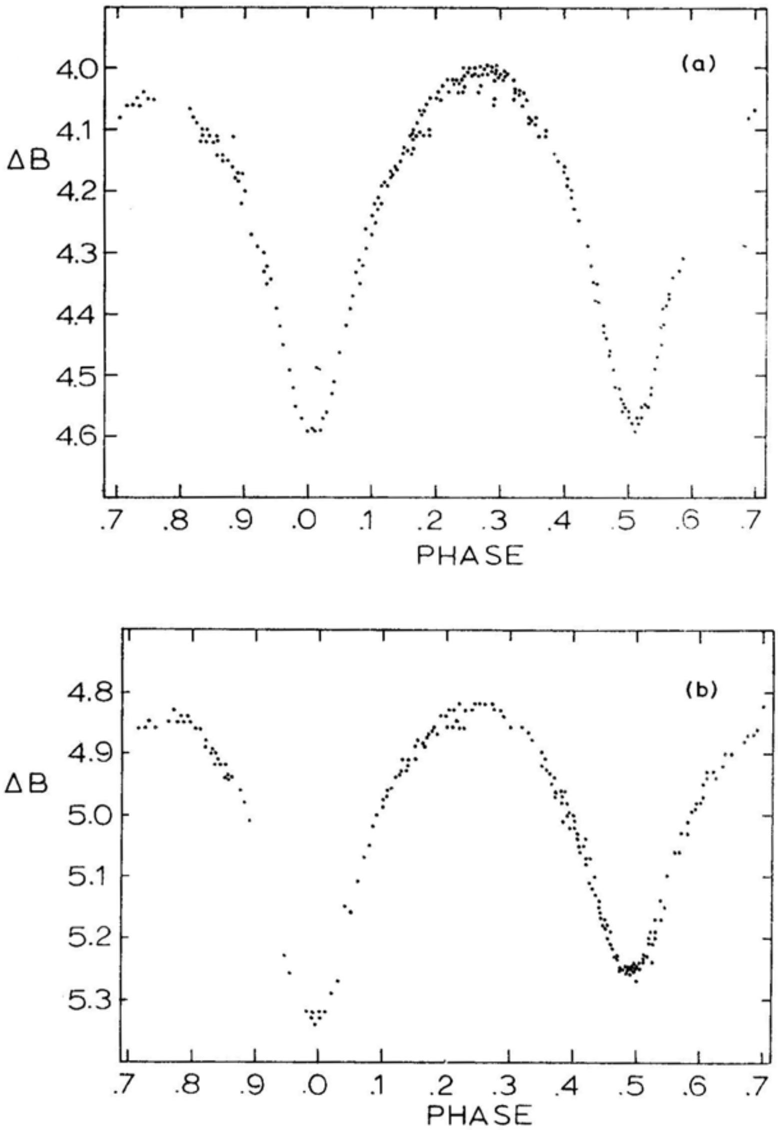

Figure 1. Light curve of (a) BV Dra and (b) BW Dra in 1965. Ordinate is differential *B* magnitude in the sense variable minus comparison. Abscissa is phase computed with the ephemerides in Kaluzny & Rucinski (1986).

affected by perhaps the same systematic error and, for the same reason, were not included. $O - C$ residuals in Fig. 2(b) are computed with respect to the ephemeris

$$\begin{aligned} \boldsymbol{JD}(\textbf{hel.})\ \textbf{pri. min.} = \mathbf{2{,}442{,}572.5405} &+ \mathbf{0.29216707}\,\boldsymbol{n}, \\ \pm 3 \qquad\qquad & \qquad \pm 3 \end{aligned} \tag{2}$$

which is the result of a linear fit by least squares giving each time equal weight. Neither the epoch nor the period differs very much from the corresponding values of Kaluzny & Rucinski (1986, Equation 2).

Table 1. Times of Minimum.

Star	*JD* (hel.) 2438000+	Type
BV Dra	882.8857	sec
	883.7604	pri
	884.8104	pri
	941.6969	sec
BW Dra	881.7370	sec
	882.907:	sec
	883.7825	sec
	886.8523	pri
	888.753:	sec
	939.7343	pri
	941.6328	sec

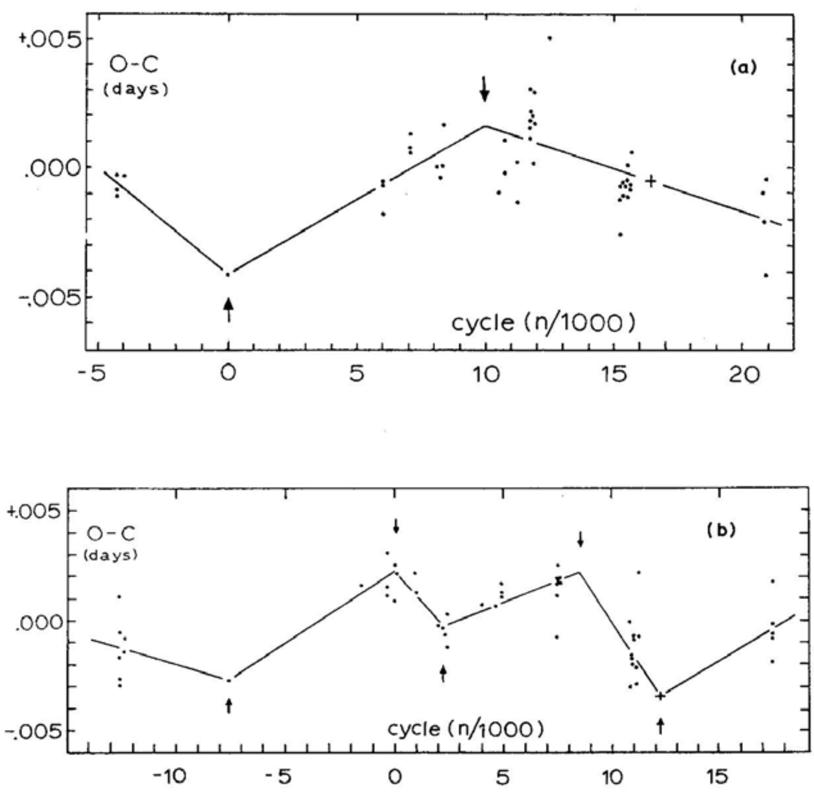

Figure 2. *O* – *C* curve for (a) BV Dra, with residuals and cycle numbers computed using Equation (1), and (b) BW Dra, with residuals and cycle numbers computed using Equation (2). The filled circles are photoelectrically determined times of primary or secondary minimum and the plus sign is a spectroscopically determined time of conjuction. Note the period increases and decreases marked with arrows, and also given in Table 2.

5. Possible magnetic cycles

The *O* – *C* curves for both BV Dra and BW Dra show systematic deviations which are larger than can be reasonably accounted for by uncertainties in the observed times of minimum. That means the orbital period is variable in some way, although Kaluzny and Rucinski did not come to that conclusion, probably because their *O* – *C* curves had shorter baselines in time.

The straight-line segments in each *0-C* curve (Figs 2(a) and (b)) are given as approximate representations of the period variation. In both cases the one time of Wood (1971) plays a critical role in the interpretation but the uncertainty of each one is probably quite small, because each represents a mean epoch for a series of observations including several different cycles. Note that the spectroscopically determined times of conjunction are not discordant in either star's *O* – *C* diagram. Batten & Lu had estimated an uncertainty of ±0.0007 day in the case of BV Dra and one can presume that it is similar in the case of BW Dra.

In the *O* — *C* curves times of both primary and secondary minima are included. Consideration of residuals from'the straight-line fits shows that there is no significant systematic difference between the two. For BV Dra the primary minima were systematically early by only $0^{\rm d}.000\,1 \pm 0^{\rm d}.0003$ and the secondaries were systematically late by only $0^{\rm d}.0003$ $+0^{\rm d}.0003$. For BW Dra primary was late by an insignificant amount ($+$ $0^{\rm d}.0001$ $\pm 0^{\rm d}.0002$) and secondary was on time ($0^{\rm d}.0000 \pm 0^{\rm d}.0002$). The rms deviation of the scatter is $0^{\rm d}.0013$ in Fig. 2(a) and $0^{\rm d}.0011$ in Fig. 2(b) and neither would have been lessened in the last decimal place by shifting times of secondary relative to primary.

In proposing a physical explanation for the observed period changes in these two W UMa binaries, it is not reasonable to consider apsidal motion nor orbital motion around a third body. The former mechanism requires an orbital eccentricity, which does not exist in contact binaries. The second mechanism would, in the case of ADS 9537AB, produce apparent period variations with a cycle approximately 20000 years long (Batten & Lu 1986).

The likelihood of magnetic cycles in late-type stars of various types has been reviewed by Hall (1990). One manifestation of such cycles is a cyclic (but not strictly periodic) variation in the orbital period of a binary. These cyclic variations are observed in several types of (eclipsing) binaries: Algol-type (Hall 1989), RS CVn-type (Hall & Kreiner 1980), and W UMa-type (Kreiner 1977). The physical mechanism for the period changes has been explored by Matese & Whitmire (1983), Applegate & Patterson (1987), Bolton (1989), and Hall (1990).

Both stars in a typical W-type W UMa system are of late spectral type and hence might be expected to have magnetic cycles, which probably would be different from each other. Rucinski (1985) points out, however, that dark spot activity occurs predominantly on the more massive component. This fact, though not necessarily understood theoretically, suggests that other magnetic phenomena (such as the cycles we are suggesting here) are similarly confined to the more massive component.

The time between one period decrease and the next decrease would be one full magnetic cycle. This suggests cycle lengths of about 19 years in BV Dra and 8 years in BW Dra, one longer and the other shorter than the sun's 11-year cycle. Hall (1990) had found similar cycles in 18 other W UMa binaries. The sizes of the period changes, indicated by arrows in Fig. 2, are listed in Table 2.

Table 2. Period Changes.

Star	Epoch	$\Delta P/P$
BV Dra	1969.4	$+4.0 \times 10^{-6}$
	1978.9	-2.6×10^{-6}
BW Dra	1969.4	$+3.2 \times 10^{-6}$
	1975.4	-6.0×10^{-6}
	1977.2	$+5.1 \times 10^{-6}$
	1982.2	-4.6×10^{-6}
	1985.2	$+7.2 \times 10^{-6}$

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