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CHANGES IN THE PERIOD AND LIGHT CURVE OF W CORVI

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The close eclipsing binary star W Corvi (EB or Beta Lyrae type; BD-12 3563, GSC5525-00352) became famous as a candidate for the 'broken-contact' phase of the Thermal Relaxation Oscillation (TRO) theory for how contact binary stars come into and maintain contact. Its light curve shows substantially different eclipse depths, indicating the two stars have significantly different temperatures, yet the short period of just 9.33 hours implies a contact configuration. Yang and Liu (2002) list about a dozen systems that exhibit this behavior, but W Corvi is the coolest case (spectral type G2), where the stars are both convective near the surface, which should wipe out any temperature difference.

Odell (1996) fit a linear ephemeris to 17 minima between 1935 and 1993 after finding no strong evidence for a period change. That paper also analyzed light curves from 1981 and 1988 using the Wilson-Devinney (Wilson, 1998) code including starspots, and concluded that photometry alone leaves three ambiguities: the mass ratio, the temperature distribution on the secondary star (concomitant with an ambiguity in degree of contact), and the cause and location of the "O'Connell" effect (fainter at phase 0.75 than 0.25). Rucinski and Lu (2000) obtained spectra of W Crv, and determined a mass ratio of 0.682 ± 0.016, thus removing the first ambiguity, while the second and third still stand.

Rucinski and Lu (2000) suggest, based on their 1997 radial velocity curve, that the period of W Crv is increasing slowly. They also conclude that variations of the light curve at all phases except primary eclipse indicate that mass exchange and accretion processes are operating between the stars, rather than cool dark spots. One purpose of this paper is to confirm the quadratic ephemeris. The other purpose is to point out that between 1999 and 2003 there has again been a large (10%) change in the light curve in that the two maxima are again equal in brightness (the O'Connell effect has again disappeared), and that the seasonal variation of the phase 0.25 maximum may be due to the comparison star "c" being slightly variable on a long timescale by 0.02 or 0.03 magnitudes.

The first timing of a minimum of W Crv was made by Lange in 1935, reported in Tsesevich (1954) as Min I HJD 2427861.361, apparently based on photographic discovery plates. Tsesevich also published visual (Nikolai Samus, priv. comm.) measurements made in 1944 and 1945, including the original brightness estimates. The 1944 data are of prime concern here because Tsesevich makes the point that the time of Min II is at phase 0.57, indicating an eccentric orbit. In fact, that timing yields a large residual for any reasonable ephemeris, so we re-analyzed that year's data in light of the current best period, and no such shift of secondary minimum could be found. Thus, for 1944, we used two newly-determined timings of Min I at HJD 2431180.2328 and Min II HJD 2431180.4299, different by +0.0018 days and −0.0201 days respectively. The 1945 timings were used as published, Min I HJD 2431562.106 and Min II HJD 1431562.305. Soloviev (1947) reported timings based on 84 visual measurements of Min I HJD 2432309.548 and Min II HJD 2432309.742; there was no evidence of an offset in the secondary minimum.

Dycus (1968) published the first photoelectric light curve, but his work was hampered by the small size of his telescope and the star being low in the western sky. We have re-analyzed his data to determine a timing of Min II at HJD 2439648.7357.

G. Samolyk (priv. comm.) kindly provided a total of 108 visual and 6 CCD timings made from 1971 to 2002 by members of the American Association of Variable Star Observers (AAVSO). These are available at `www.aavso.org/committees/eb/ebmono.stm` on the web and from the references to Baldwin (1976, 1977, and 1978) and Baldwin and Samolyk (1993, 1997, and 2002). The visual measurements made during each season were averaged by shifting each minimum by the well-known period and averaging to get one time for the season. In three cases, where only one or two measures were made and the residual from the ephemeris was more than ten minutes, the season was eliminated (1980, 1983, and 1989).

We used the 31" Cassegrain telescope at Lowell Observatory with the NURO CCD (LN2 cooled, 512 × 512 pixels) in 1999, and with Marc Buie's Photometrics CCD (thermoelectric cooling, TH7883 chip, 384 × 576 pixels) in 2001, 2002, and 2003 to obtain light curves. In 2003, one additional timing was made with University of Tasmania's Mt. Canopus 1-m telescope and the PLANET program CCD camera. All of these timings are listed here in Table I.

Most of the images we used included on chip both the comparison star "c" (=GSC05525-00217), located 4^s west and $160''$ south of W Crv, and check star "d" (=GSC05525-00351), located 16^s east of W Crv and $55''$ south (Fig. 1). A finding chart is given also in Tsesevich (1954), and the 1855 coordinates are given in Dycus (1968). Star "c" seems to be variable by a few hundredth of a magnitude on long timescale, but appears to be constant during any one night. The photoelectric data are too inhomogeneous to correct for this effect, so absolute levels of early light curves should be used with caution. For instance, we believe this is the cause of Rucinski and Lu's (2000) finding a variation of W Crv around phase 0.25.

Table I. Times of Minimum of W Corvi, 1999-2003

HJD (2450000.+)	Type	Filters	HJD (2450000.+)	Type	Filters
1305.7230	Primary	*VRI*	2325.7983	Secondary	*BVRI*
1306.6938	Secondary	*VRI*	2325.9901	Primary	*BVRI*
1307.6639	Primary	*VRI*	2701.8486	Secondary	*BVRI*
2028.7212	Primary	*BVRI*	2704.1768	Secondary	*VI*
2029.6929	Secondary	*BVRI*	2704.7598	Primary	*BVRI*
2030.6619	Primary	*BVRI*	2704.9538	Secondary	*BVRI*
2320.9456	Primary	*BVRI*	2705.9240	Primary	*BVRI*

The complete list of timings used for the ephemeris and the residuals shown in Fig. 1 are available from the IBVS web site as 5514-t1.txt.

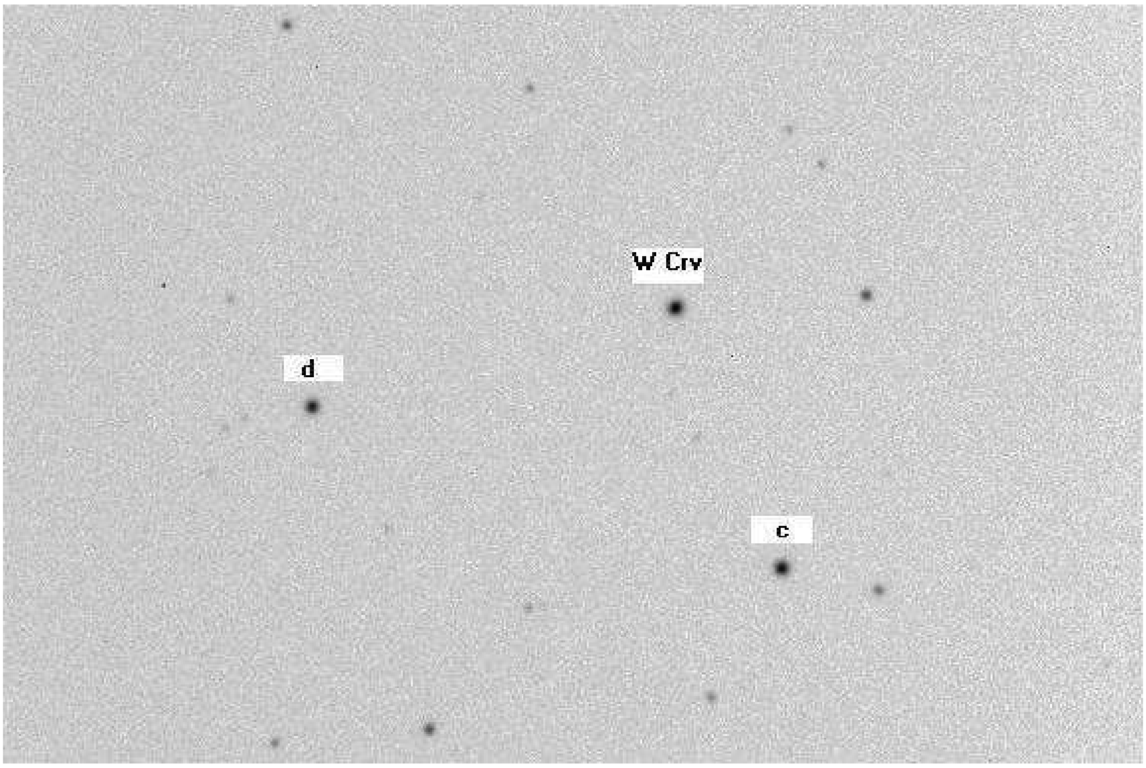

Figure 1. Finding chart

In order to test the increasing-period hypothesis, we used all timings starting in 1967 to derive a linear ephemeris, yielding a period of 0.38808134 days. We then looked at the residuals for evidence of curvature, and fitted a quadratic ephemeris. Fig. 2 shows the residuals from the linear fit, along with the quadratic residuals. The timings from the 1940's are clearly better fit by the quadratic, and the curvature in the later timings is noticeable. This confirms the suggestion of Rucinski and Lu (2000) that W Crv is increasing its period by about 0.25 sec/century. This corresponds to a value of $(d\ln P/dt)$ in the range of $7.5x10^{-8}$ year^{-1}.

Though the data described above were originally obtained in order to improve the ephemeris, another important property of the system has emerged. From its earliest extant light curves in the 1940's, W Crv has shown a classic O'Connell effect, in that the sides of the stars visible after secondary eclipse are about 0.1 mag fainter than the other side. Between 1966 and 1981, the star was not observed, but Odell (1996) showed that in 1981 and 1982, the two maxima were of equal brightness. By 1988, the difference in brightness had returned (see Fig. 3, light curves from 1988 and 1993).

In 1999, the light curve looked very similar to 1993, but Fig. 4 shows that by 2001, the brightness at phase 0.70 had increased by about 0.05 mags. This CCD photometry is of considerably higher quality compared to the earlier photoelectric light curves. No other differences in the light curves are noticeable – the only change is in the phase interval 0.60 to 0.80.

Fig. 5 shows light curves from 2002 and 2003, where the two maxima are of the same brightness.

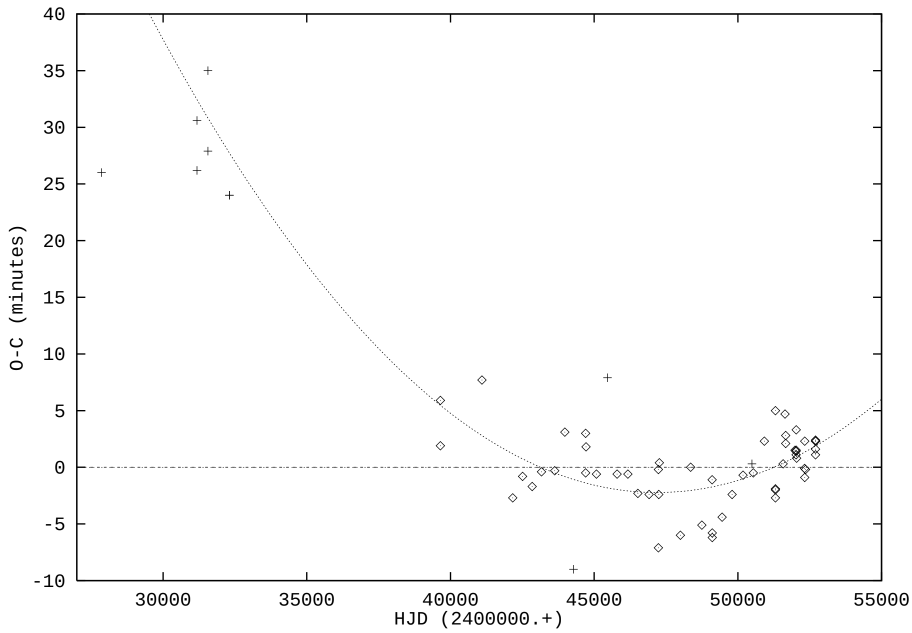

Figure 2. Residuals from linear ephemeris

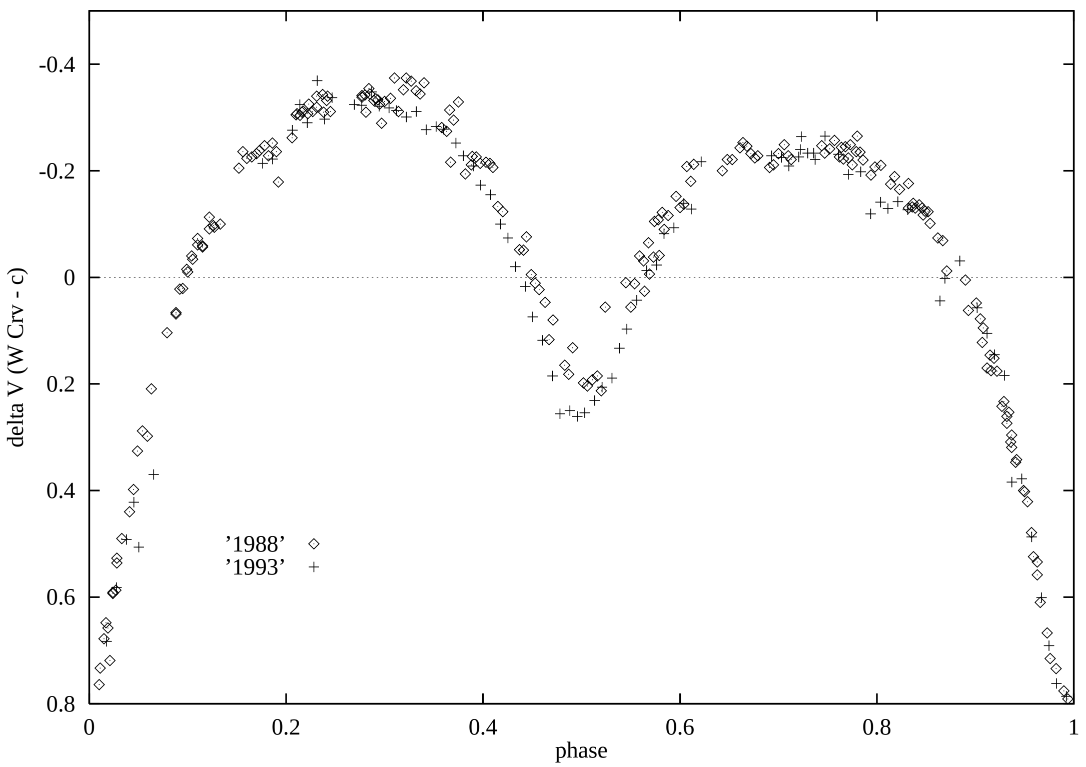

Figure 3. V light curves from 1988 and 1993.

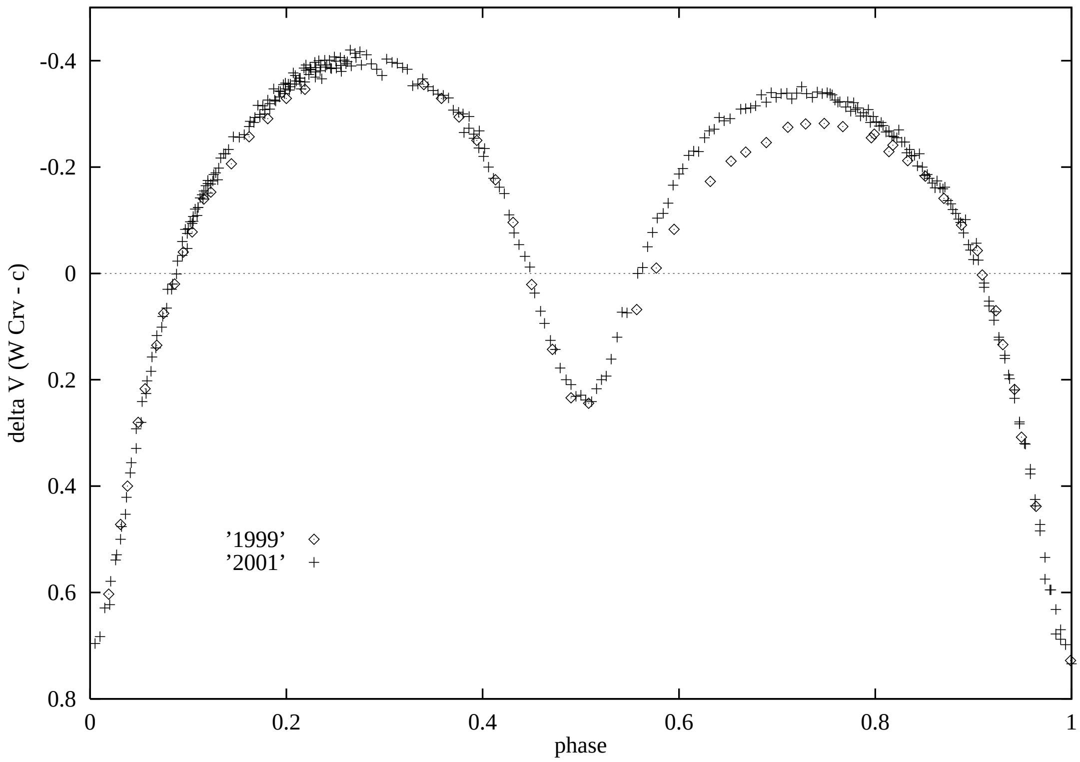

Figure 4. V light curves from 1999 and 2001.

Light levels for the four phases of quadrature are estimated in Table II - the reader is cautioned against attaching too much significance to any one value, as it seems the comparison star "c" may well be variable from night to night by several hundredth of a magnitude. But the difference between phase 0.25 and 0.75 (last column) between 1988-2001 is much larger than the variation of the comparison star, and hence is real.

Table II. Magnitude differences ($WCrv - c$) at various phases

Year	$\Phi = 0.00$	$\Phi = 0.25$	$\Phi = 0.50$	$\Phi = 0.75$	delta $(0.75 - 0.25)$
1988	0.79	-0.35	0.21	-0.24	0.11
1993	0.79	-0.32	0.27	-0.24	0.09
1999	0.73:	-0.38:	0.25	-0.28	0.10:
2001	0.74	-0.40	0.24	-0.34	0.07
2002	0.73	-0.36:	0.22	-0.32	0.04:
2003	0.78	-0.34	0.20	-0.34	0.00

Values marked with : are estimates due to sparse data.

We conclude that W Crv indeed does show a secular period increase, but that variations of the light curve at any but the second maximum (around phase 0.75) may well come from variation of the comparison star. We point out that from 1999 to 2003, the feature which causes the O'Connell effect has again disappeared. It is of utmost interest to continue to observe this star for period change, and even to search archival plates to see if earlier times of minimum light can be found. Complete light curves are important in the next few years in order to see how long the O'Connell effect will be missing, and the timescale for its eventual return.

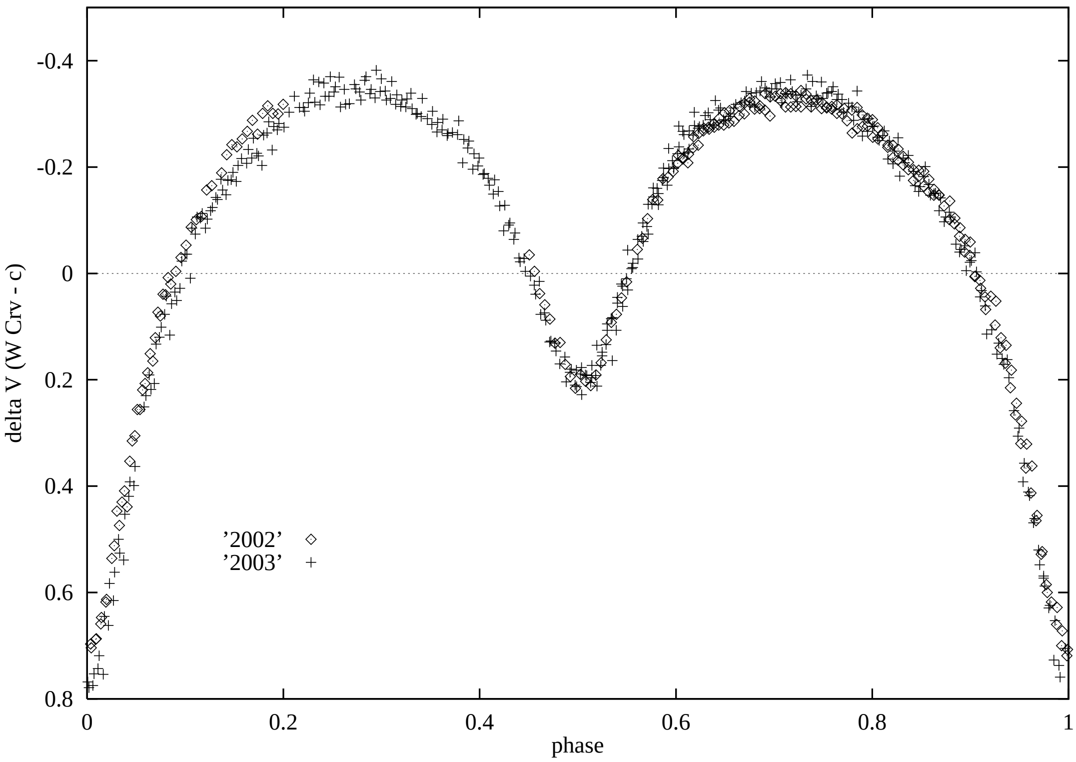

Figure 5. V light curves from 2002 and 2003.

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