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ORBITAL EFFECTS ON THE LIGHT CURVES OF η Car, BP Cru, AND OTHER ECCENTRIC BINARIES

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The very eccentric and massive binary η Carinae shows at each periastron passage a light peak ($0^{\rm m}_{\cdot}1$–$0^{\rm m}_{\cdot}2$) in the optical as well as in the near-infrared. Thereafter, a short lasting eclipse-like dip occurs, followed by a so-called 'egress-maximum' that subsequently fades away (see Fig. 1). Van Genderen et al. (2006, 2007) suggested that the peaks may well be the result of an enhancement of the deformation by tidal forces on the primary, and that the egress-maximum is the continuation of the peak (after interruption by the dip, which has another cause) until it disappears some months after the periastron passage.

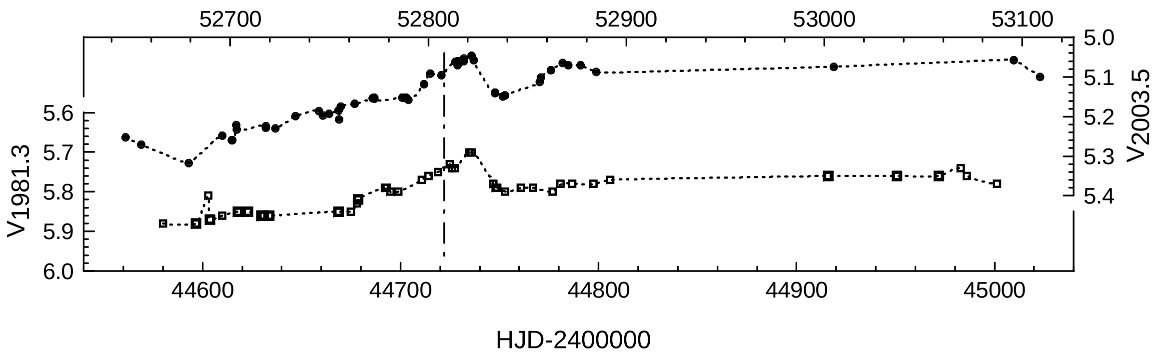

Figure 1. *V* light curves of the events of 2003.5 (•; magnitudes on the right, JD axis at the top) and 1981.3 (squares; magnitude scale on the left, JD axis at the bottom). Vertical dash-dotted line: periastron passages. The dotted lines are spline fits. Based on Fig. 1 of van Genderen et al. (2006).

The first aim of this paper is to provide additional support for these two suggestions. Therefore, the literature on photometrically well-observed eccentric detached binaries was surveyed. Among the dozens of suitable eccentric binaries, five show a clear bump, in the literature called the periastron effect (Table 1). One of these is BP Cru = WRA 977, a B-type hypergiant with an X-ray pulsar (GX301-2), in which the effect was first noticed by Pakull (1982). The second purpose of this note is to supplement Pakull's light curve with more photometric evidence.

It should be noted that eccentric detached binaries are important for the study of the internal structure of stars. Tidal distortion depends on the internal structure (though modified by stellar rotation), i.e. the density concentration. The more evolved a star is, the larger the effect of the tidal pull during the periastron passages will be. Due to tidal distortion – together with rotational flattening – these binaries show an apsidal motion, mostly in advance of the orbital motion. General Relativity also predicts a certain amount of secular apsidal motion, usually of a much smaller, though often non-negligible quantity.

Apart from the observable periastron effect in the light curves, the periodic variability of the tidal pull can also modulate the pulsational behaviour when one of the components is a pulsating star. Examples are the β Cep primaries of Spica (α Vir = HD 116658, Dukes 1974; Smith 1985; Claret & Giménez 1993) and σ Sco (= HD 142669, Chapellier & Valtier 1992). The S Dor-phases of η Car (which are a kind of slow pulsation) appear to reach maximum light during most of the periastron passages (van Genderen et al. 2001; Whitelock et al. 2004), and the quasi-period of the α Cyg-type variations of the primary of BP Cru (van Genderen & Sterken 1996) is about a quarter of the orbital revolution (Kaper et al. 2006). Something similar seems to be the case for the eccentric X-ray binary Vela X-1 (= HD 77581, Quaintrell et al. 2003).

Since the intrinsic variations of the hypergiant primary of BP Cru are relatively strong (showing a quasi-period of $11\overset{\mathrm{d}}{.}9$, van Genderen & Sterken 1996), the light curve is folded with the binary period. We used the data sets of Bord et al. (1976, UBV), Hammerschlag-Hensberge et al. (1976, $uvby$) and van Genderen (1977, $VBLUW$, also used by Pakull 1982), and a new larger $VBLUW$ data set (63 nightly averages). The latter was obtained in 1976, 1977 and 1978 (van Genderen & Sterken 1996). However, we could not get hold of the three other data sets used by Pakull (1982).

As three different photometric systems are involved, the V_{UBV} and $y(uvby)$ light curves were matched with the V_{VBLUW} light curve by shifting them along the magnitude scale, until a good fit was obtained. Then, the data points of the two first mentioned photometric systems were transformed to the relative magnitude scale of the V_{VBLUW} system. The comparison star is HD 109164 (B2 II). Averages in ten phase-bins were computed, yielding an average mean error of $0\overset{\mathrm{m}}{.}007$. Phases were computed with the ephemeris JD_0 = 2 443 451.55 + $41\overset{\mathrm{d}}{.}498$, where the period is from Kaper et al. (2006) and the zero point for the periastron is taken from Watson et al. (1984). This choice is justified because of the close proximity of JD_0 to all the data sets used by Pakull (1982), and to the new one in this paper.

Fig. 2 shows the phase diagram based on 169 nightly averages. The periastron effect – a small modulation ($\sim 3\%$) of the optical brightness around phase zero – is obvious as in the case of the Pakull (1982) curve, though obtained from a different combination of data sets. The amplitude of the periastron effect is of the order of $0\overset{\mathrm{m}}{.}03$, and the duration of the effect is about 6 days ($\sim 0.15 \times P$).

Table 1 lists six eccentric binaries (including η Car and BP Cru), and gives the spectral types, masses, eccentricities (e), orbital periods (P), the amplitude of the periastron effect in magnitudes, and its duration in phase units ($\triangle\phi$). The six binaries are listed in order of increasing eccentricity. It should be noted that spectral types, masses and eccentricity of η Car are uncertain and based on current estimates (Davidson 1999; Corcoran et al. 2001). The period, first discovered by Damineli (1996), is an average from various authors. The stellar parameters of the four other binaries are taken from the compilations by Claret & Giménez (1993) and Claret & Willems (2002), including the references to the original papers.

To illustrate the subtle character of the periastron effect, we show in Figs. 3 and 4 two examples of phase diagrams. The V 380 Cyg case (based on data from Guinan et al. 2000) shows a periastron effect near phase 0.15. For V 346 Cen (extracted from Giménez

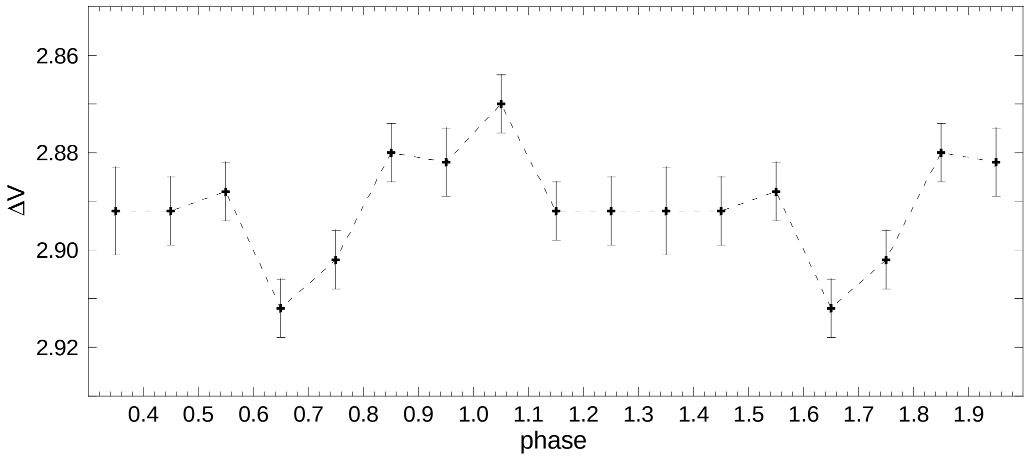

Figure 2. The differential orbital phase-diagram of BP Cru = WRA 977. Phase 0.0 corresponds to the periastron passage, and $P = 41\overset{d}{.}498$.

et al. 1986), the periastron effect is visible as a point-like maximum near phase -0.2. These authors point to *"a persistent, though small, discrepancy between the predicted and observed light curves around periastron"* that cannot be removed by changing the model parameters. Their Figure 5d clearly illustrates the very small amplitude of the associated colour variations, and implicitly underlines the fact that only high-quality and homogeneous data sets can reveal the presence of a periastron effect. The difficulty of detection is emphasised by the counter example of β Ari – one of the most eccentric orbits ($e \sim 0.9$, as for η Car) known among spectroscopic binaries – where Lovell and Hall (1971) found a very weak ($0\overset{m}{.}01$) effect, though Ogata (1973) subsequently reports no photometric evidence supporting an appreciable periastron effect.

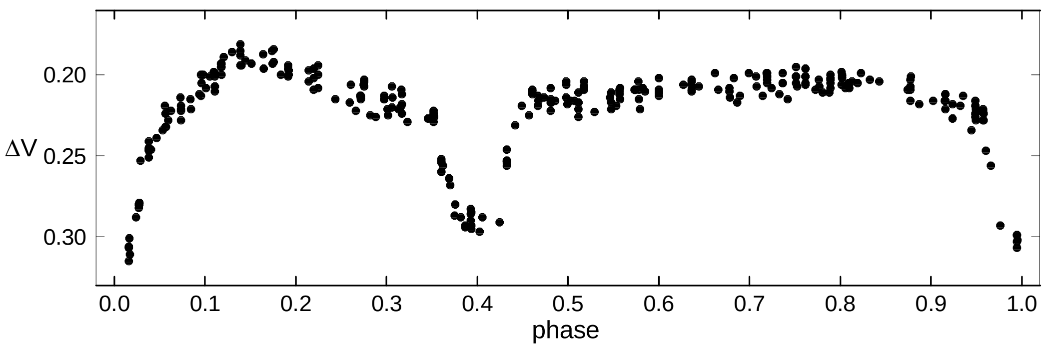

Figure 3. Phase diagram of V 380 Cyg (based on differential V data from Guinan et al. (2000).

The $\triangle\phi$ of η Car and BP Cru are uncertain because the effect occurs on top of cyclic, or quasi-periodic light oscillations. It should be noted that in most cases a small part of the periastron effect can be attributed to reflection and/or ellipticity (distortion by rotation). Furthermore, the amplitude of the periastron effect possibly depends on the viewing angle to the tidally distorted star, thus on how much of the distortion is seen.

It is perhaps not surprising that η Car shows the strongest periastron effect, amongst

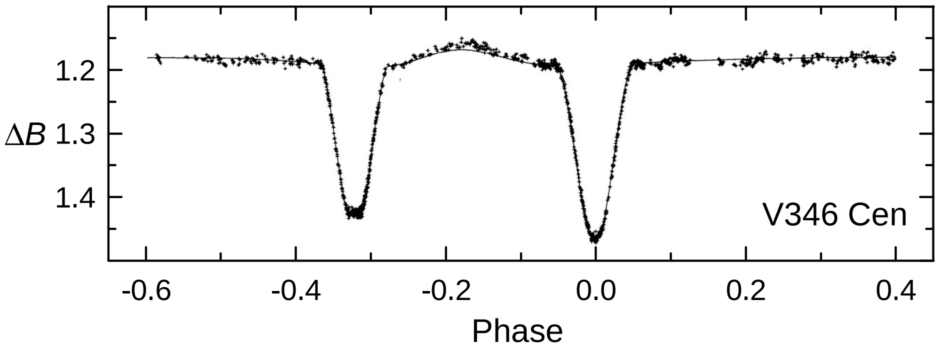

Figure 4. Phase diagram of V 346 Cen (differential B, extracted from Giménez et al. (1986).

Table 1: The six eccentric binaries showing the periastron effect

Object	Sp	$M_1 + M_2$ ($M_\odot$)	e	P (d)	peri.eff. (mag)	$\triangle\phi$	Ref. l.c.
V 380 Cyg (= HD 187879)	B1.5II–III + B2V	14.3 + 8.0	0.23	12.4	0.03	0.15	1
V 346 Cen (= HD 101837)	B0.5-1V + B0.5-1V	11.8 + 8.4	0.29	6.3	0.03	0.2	2
V 1647 Sgr (= HD 163708)	A1V + A2V	2.2 + 2.0	0.41	3.3	0.015	0.1	3
V 560 Car (= HD 93205)	O3V + O8V	45 + 20	0.46	6.08	0.02	0.15	4
BP Cru (=WRA 977)	B1.5Ia$^+$ + NS	43 + 1.85	0.46	41.5	0.03	0.15	5
η Car (= HD 93308)	B + O	80 + 30	0.9	2023	0.1–0.2	0.1	6

`References light curve`: 1. Guinan et al. (2000); 2. Giménez et al. (1986); 3. Clausen et al. (1977); 4. Antokhina et al. (2000), van Genderen (2003); 5. Pakull (1982), this paper; 6. van Genderen et al. (2006).

others because of its extreme eccentricity and its highly evolved state. There are spectroscopic indications for a shell ejection, or at least a mass-ejection event during the 2003.5 periastron passage (Stahl et al. 2005). Corcoran et al. (2001), moreover, needed a substantial increase of the mass-loss rate to properly explain the X-ray light curve of the 1997.9 periastron passage. It is quite well thinkable that η Car's primary exceeds its Roche Lobe during the periastron passage, enabling an increase of mass flow into the system.

The eclipse-like dip interrupting the periastron effect of η Car appears to be a short intermezzo and we speculate that it is due to some obscuration process of the emitting material associated with the secondary (van Genderen et al. 2006). A similar type of attenuation process was suggested earlier by Whitelock and Laney (1999) as an explanation for the dip. In the light of the evidence offered by the examples in Table 1, it seems to be justified to assume that in the case of η Car, the egress-maximum is also part of the periastron effect that finally fades away after a couple of months.

We conclude that η Car's optical and near-infrared 'light peak' around the periastron passages are in various respects similar to the periastron effects exhibited by other eccentric binaries, and therefore may well have the same physical cause.

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References:

Antokhina E.A., Moffat A.F.J., Antokhin I.I., et al., 2000, *ApJ*, **529**, 463
Bord, D.J. Mook, D.E. Petro, L. Hiltner W.A., 1976, *ApJ*, **203**, 689
Chapellier E., Valtier J.C., 1992, *A&A*, **257**, 587
Claret A., Giménez A., 1993, *A&A*, **277**, 487
Claret A., Willems B., 2002, *A&A*, **388**, 518
Clausen J.V., Gyldenkerne K., Grønbech B., 1977, *A&A*, **58**, 121
Corcoran M.F., Ishibashi K., Swank J.H., Petre R., 2001, *ApJ*, **547**, 1034
Damineli A., 1996, *ApJ*, **460**, L49
Davidson K., 1999, *ASPC*, **179**, 304, (eds. Morse J.A., Humphreys R.M., Damineli A.)
Dukes R.J., 1974, *ApJ*, **192**, 81
van Genderen A.M., 1977, *A&A*, **54**, 733
van Genderen A.M., 2003, *A&A*, **397**, 921
van Genderen A.M., Sterken C., 1996, *A&A*, **308**, 763
van Genderen A.M., de Groot M., Sterken C., 2001, *ASPC*, **233**, 59, (eds. de Groot M., Sterken C.)
van Genderen A.M., Sterken C., Allen W.H., Walker W.S.G., 2006, *J. Astron. Data*, **12**, 3
van Genderen A.M., Sterken C., Allen W.H., Walker W.S.G., 2007, *J. Astron. Data*, **13**, 1
Giménez A., Clausen J.V., Andersen J., 1986, *A&A*, **160**, 310
Guinan E.F., Ribas I., Fitzpatrick E.L., et al., 2000, *ApJ*, **544**, 409
Hammerschlag-Hensberge G., Zuiderwijk E.J., van den Heuvel E.P.J., 1976, *A&A*, **49**, 321
Kaper L., van der Meer A., Najarro F., 2006, *A&A*, **457**, 595
Lovell L.P., Hall, D.S., 1971, *PASP*, **83**, 360
Ogata H., 1973, *IBVS*, 784
Pakull M.W., 1982, in *Accreting Neutron Stars*, Proc. Workshop M. Planck Inst. 177, Garching, Brinkmann W., Trümper J., (eds), p. 53
Quaintrell H., Norton A.J., Ash T.D.C., et al., 2003, *A&A*, **401**, 313
Smith M.A., 1985, *ApJ*, **297**, 206
Stahl O., Weis K., Bomans D.J., et al., 2005, *A&A*, **435**, 303
Watson M.G., Warwick R.S., Corbet R.H.D., 1982, *MNRAS*, **199**, 915
Whitelock P., Feast M.W., Marang F., Breedt E., 2004, *MNRAS*, **352**, 447
Whitelock P., Laney D., 1999, *ASPC*, **179**, 258, (eds. Morse J.A., Humphreys R.M., Damineli A.)