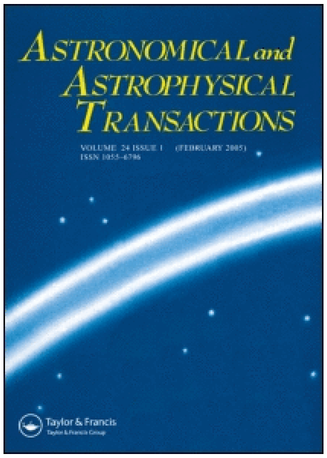

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η CARINAE: A PULSATING LUMINOUS BLUE VARIABLE

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We present and analyse two seasons of intense photometric monitoring of η Carinae (October, 1992 – August, 1994). The luminous blue variable (LBV) in the core did not show much S Dor-type activity. This situation was very favourable for studying its optical microvariations. It appears that the central LBV pulsates like other massive evolved stars, presumably in a non-radial mode. The quasi-period is 58.56 d. From photometric data collected since 1975 it is shown that this pulsation period is stable during the entire 20 yr period. Thus, η Carinae is the first LBV for which such a stable period can be recognized. There is also some evidence for a secondary period which beats with the main period on a time-scale of more than 20 years.

KEY WORDS Stars, individual, η Car – Stars, variables – Stars, oscillations – Stars, supergiants

1 OBSERVATIONS

Between October, 1992, and August, 1994, 270 *uvby* and 99 Hβ observations of η Carinae were obtained with the 50-cm Danish Strömgren Automatic Telescope at ESO, La Silla, using a 35 arcsec diaphragm. The *uvby* measurements have mean errors $\leq$ 1.5 millimag. Light curves, relative to the comparison star and in log intensity, are presented in Figure 1 where each data point represents a nightly average.

2 OBSERVATIONAL RESULTS

The following types of brightness variation are exhibited by η Car.

(1) *S* Dor-type variations of variable amplitude and recurrence time, but mostly with $\Delta V \sim 0.2$ and a time-scale of 1–3 yr.

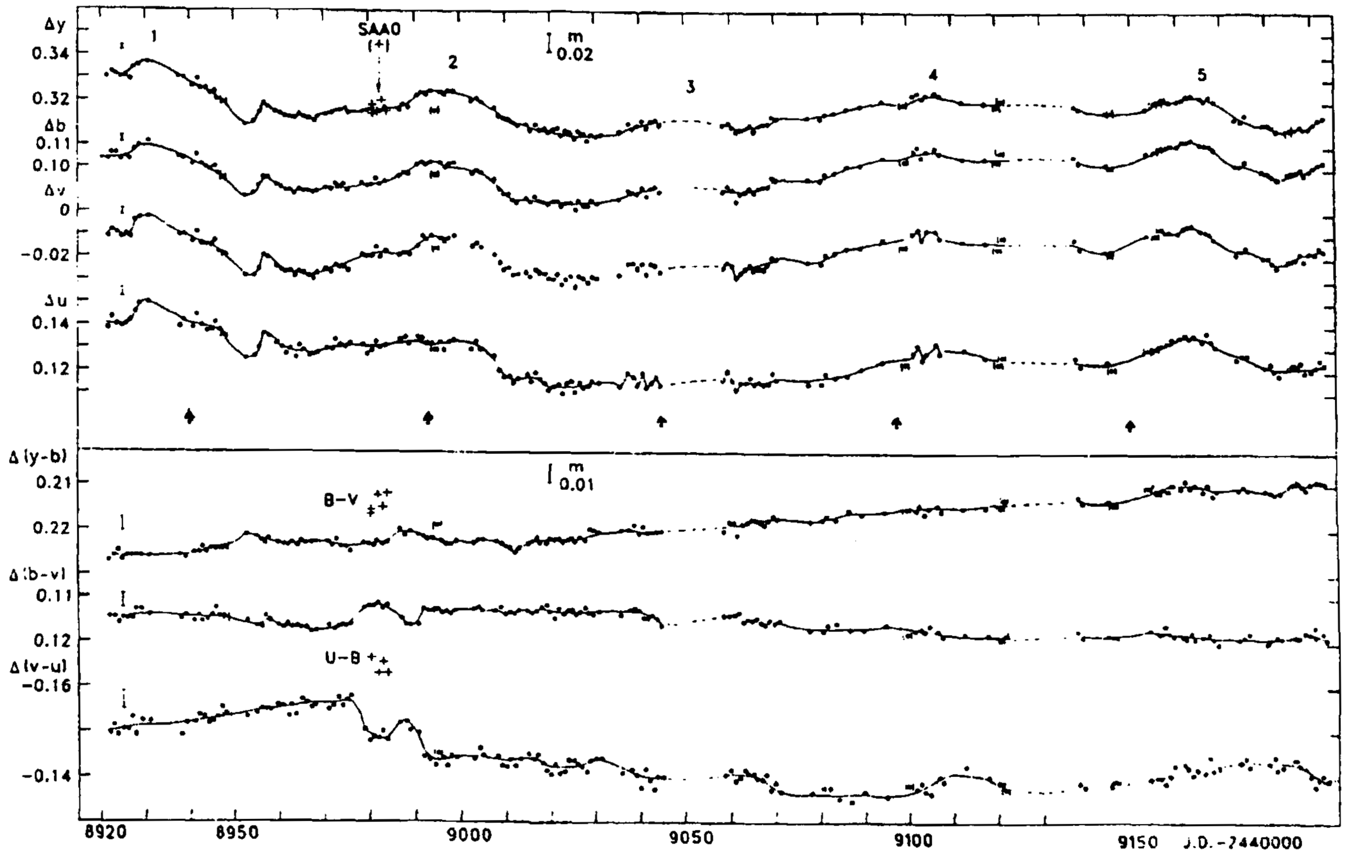

Figure 1 The light and colour curves of η Car relative to the comparison star in log intensity scale (for the light curves bright is up; for the colour curves blue is up) for the interval October, 1992 – August, 1994. The scale for the colour curves is twice as large as for the light curves. Data points based on one observation only, and those made at high airmasses and/or in bad nights are bracketed.

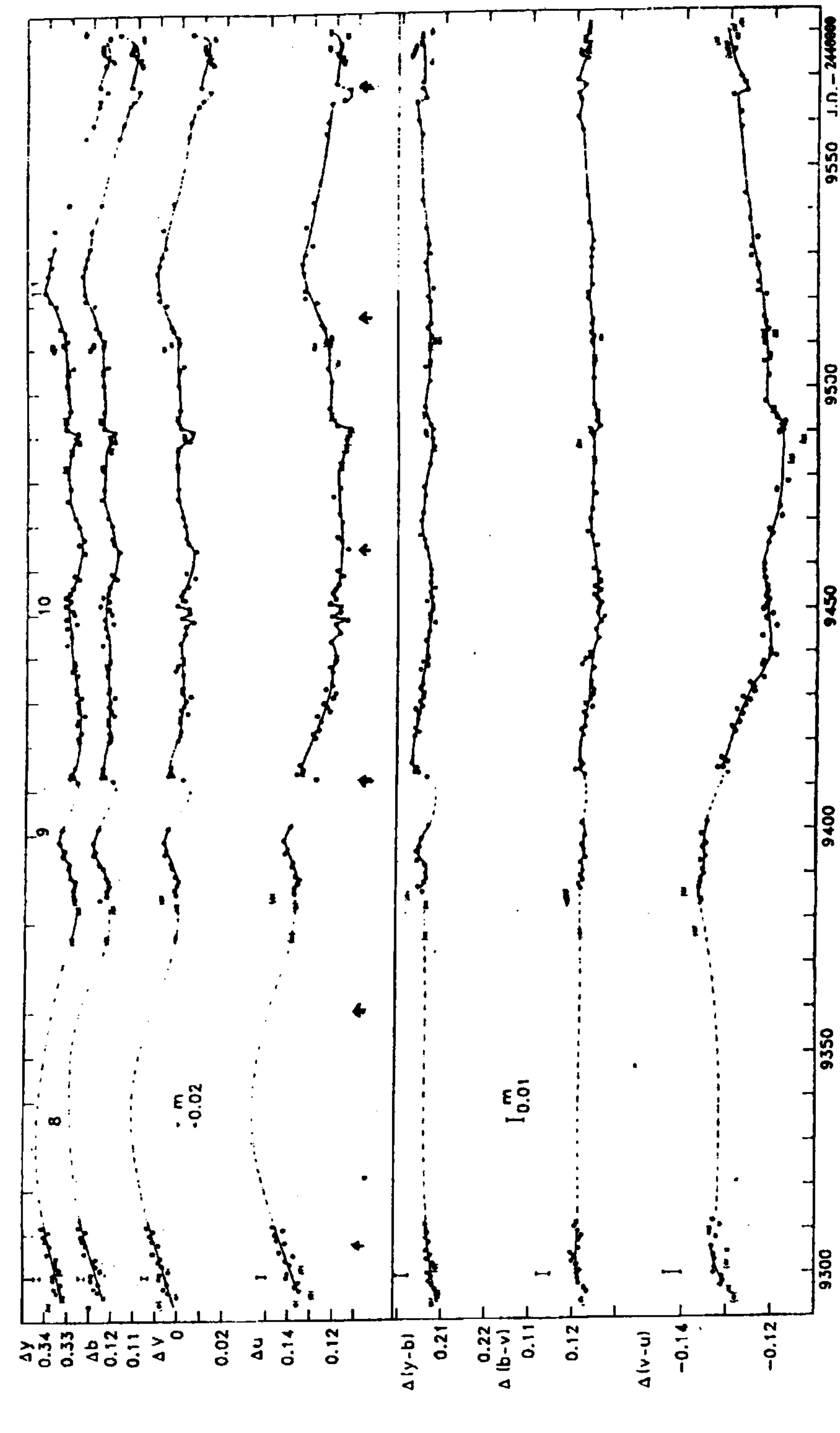

Figure 1 Continued.

(2) Some evidence for eclipse-like features with a period of 52.4 d. These are marked with arrows below the light curve of Figure 1 (See also van Genderen *et al.*, 1994).

(3) Brightness variations of the Balmer continuum possibly indicative of a luminous disk with variable accretion rate (van Genderen *et al.*, 1994).

(4) A quasi-cyclic variation with amplitude between 0.02 and 0.05 mag and a period of ~ 60 dy. The maxima of this variation are indicated by the numbers 1 to 11 in Figure 1.

3 DISCUSSION

Here we limit our discussion to the cyclic variations mentioned under point (4) above. Maxima numbered 3 and 8 in Figure 1 are not well observed, while maxima 6 and 7 occurred during a period when no observations at all were obtained. Thus, these four maxima are exluded from Table 1.

A linear least-squares fit of the maxima in Table 1 with E_1 between 1 and 11 yields:

$$JD_{\max} = 2\,448\,875.0 + 58\overset{\mathrm{d}}{.}56E. \tag{1}$$

Table 1. Heliocentric times of maximum light of η Car, cycle number E_1 or E_2, and $(O\text{–}C)_1$ are according to Ephemeris (1). The quantity ε indicates the number of cycles to be added to the time of maximum on the same line in order to obtain the next listed $T_{\max}$

T_{max}	E_1	$(O\text{–}C)_1$	E_2	ε
3250	–96	0.1	–95	6.0
3600	–90	–1.4	–89	11.0
4245	–79	–0.8	–78	13.1
5010	–66	2.7	–65	7.1
5423	–59	5.6	–58	11.6
6100	–47	–20.3	–47	8.0
6570	–39	–18.0	–39	5.1
6870	–34	–11.9	–34	8.1
7345	–26	–5.5	–26	9.0
7875	–17	–2.7	–17	2.0
7987.2	–15	–7.7	–15	1.9
8110	–13	–2.1	–13	14.1
8933.1	1	0.9	1	1.1
8997.4	2	6.6	2	1.9
9106.8	4	–1.1	4	1.0
9165.1	5	–1.4	5	4.0
9400.8	9	–0.0	9	0.9
9454.5	10	–4.9	10	1.2
9527.1	11	9.1	11	

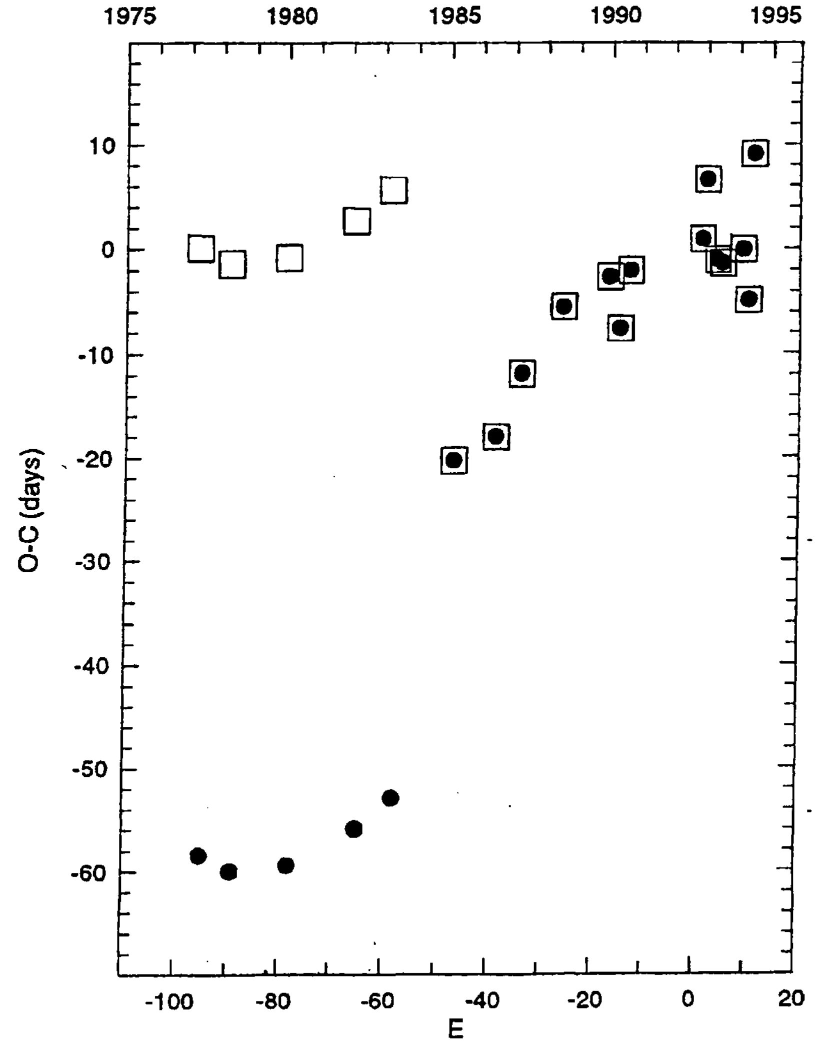

Figure 2 O–C diagram for all T_{max} data listed in Table 1. The open symbols correspond to the cycle-count scheme in which JD 2 445 423 corresponds to $E_1 = -59$ (Table 1); the filled symbols to $E_2 = -58$ for JD 2 445 423.

In order to study these variations further, we extended our search for periodicities over all observations of η Car back to 1974 (van Genderen and Thé, 1984; van Genderen *et al.*, 1994, 1996). Visual inspection of the complete light curve yields the list of well-observed maxima and their cycle numbers presented in Table 1 which includes the maxima numbered 1–11 mentioned under point (4) above. The longer term variations due to η Car's S Dor phases and its secular brightening (van Genderen *et al.*, 1994, 1996) were duly accounted for. It turns out that more than 75% of these maxima can be assigned an unambiguous value of E by working our way back from $E = 1$ to the first observed maximum. The values are given in Table 1 and lead to the new ephemeris:

$$HJD_{\max} = 2\,448\,873.6 + 58.^{\mathrm{d}}58E. \quad (2)$$

The only ambiguity arises with the cycle number of the maximum at JD 2 445 423. Depending on whether one chooses $E_1 = -59$ or $E_2 = -58$ one obtains a different shape of the O–C diagram (see Figure 2). In the case of E_1 (upper part of Figure 2) one gets the impression of a reasonably constant pulsation period with some erratic changes in the intervals 1985–1987 and 1992–1994. The case of E_2 (lower part of Figure 2) evokes a completely different picture. Here the O–C curve could be better represented by a periodic function of 20–30 years' period and an amplitude of $\sim$ 30 days.

One possible interpretation of the cyclic variation of P would be the motion of the pulsating star in a wide binary system. With $P = 20$ yr and orbital radius of 30 light-days, the secondary needs to be at a distance $d \sim 5000$ au, corresponding to 1.8 arcsec. However, no companion was seen by the HST WEPC (Hester, 1994) nor through speckle-interferometry (Weigelt and Ebersberger, 1986; Hofman and Weigelt, 1988). Any such secondary would yield a totally unrealistic radial-velocity variation of 16 000 km s^1.

The only remaining interpretation (besides discontinuous period changes) is in terms of two interacting pulsation modes. With $P_1 = 58.6$ d and a beat period of 20 yr, one finds $P_2 = 59.1$ d. This conclusion is supported by theoretical work by Gautschy and Saio (1993) and Dziembowski (1994) who showed that the β Cep instability strip widens into the supergiant region. With its $T_{\mathrm{eff}} \leq 30,000$ (Davidson, 1971; Hillier and Allen, 1992) the position of η Car fits the extension of the β Cep instability strip to higher luminosities. This also supports the conclusion that an effective temperature as low as 22 000 K is impossible; T_{eff} must be between 28 000 and 30 000 K in agreement with the position of η Car in an extrapolation of Figure 6 of Maeder (1980).

Full details of this investigation are published in two papers (Sterken *et al.*, 1996; Genderen *et al.*, 1996).

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