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Photometric behaviour of η Carinae, a celestial Chinese lantern: 1974–1998*

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Abstract. We discuss 24 y of optical photometry of η Carinae, among which new Geneva photometry made between 1994 and 1998. Various conclusions from our previous photometric studies are confirmed. The core hides a normal S Dor variable (or LBV): it shows light variations on a time scale of 1–4 y, with superimposed micro oscillations whose quasi-period indicates a temperature in the order of 22 000 K. Therefore, a more complicated model for η Car is necessary to explain its extraordinary appearance and phenomena exhibited in the past and at present.

An analysis of the brightness of η Car in the ultraviolet (UV) passbands of three photometric systems (Walraven, Strömgren and Geneva) reveals the presence of an important variable UV source, which appears to be modulated with the 5.52 y period of the spectroscopic events, related to the possible revolution of an excentric binary of the type proposed by Damineli et al. (1997).

Our new data support the luminous disk model suggested by van Genderen et al. (1994, 1995). A very hot companion of the LBV would be responsible for the excitation of the disk.

We suspect that the flare-like event in the X-ray flux and in the optical and near-infrared light around 1998.0 was the result of the encounter of the interface of the colliding winds of the binary with an arm-shaped density enhancement in a disk around the LBV (not necessarily "the" luminous disk). We suppose that this encounter created an intense X-ray/hot spot region. The subsequent steep decline of the flare is ascribed to an eclipse of the X-ray/hot spot by the wind interface.

The radio flux variation of the gas torus in the equatorial plane at a distance of $2''$ from the core, could be the result of the luminous disk becoming optically thin. This would, obviously, start abruptly near the time of periastron passage and would last for a few years thereafter, so that a hot star, normally enshrouded by the disk, is able to excite the outer gas torus. The creation of the X-ray/hot spot, with a life-time of at most a few months, could also be the cause of the instantanious physical change of the luminous disk mentioned above (and its 5.52 y modulation) visible in the UV, since both happen at the same time.

Apart from the 5.52 y period in the UV, we found a striking 200 d-oscillation, also in the UV, during the last orbital cycle beween 1992.5 and 1998.0. Its possible explanation depends on whether it is cyclic or truly periodic (in the latter case η Car could hide a triple star).

Key words: stars: individual: η Carinae – stars: oscillations – stars: supergiants – stars: variables: general – techniques: photometric

1. Introduction

From 1974 to 1994, η Car has been under photometric surveillance in the optical, on a more or less regular basis, with different telescopes, photometric systems and apertures (van Genderen & Thé 1984, 1987; van Genderen et al. 1994, 1995).

Although we have attempted to match various parts of the light curve obtained with different techniques (e.g. when they were made simultaneously), it was not always possible to obtain an accuracy as high as that of the data points themselves, especially for the colour indices. Table 4 in van Genderen et al. (1994) lists data points as homogeneous as possible for the interval 1974–1990 (aperture $16.''5$ in the Walraven $VBLUW$ system). Sterken et al. (1996a) show the light curve 1976–1994 with all V data transformed to V_J (the V of the UBV system of Johnson), including the $uvby$ observations discussed by van Genderen et al. (1995). These observations were obtained by the Long-Term Photometry of Variables (LTPV) Group of Sterken (1983). (That light curve still lacks a small group of observations around JD 244 8650, listed by Manfroid et al. 1994).

The photometric studies mentioned above confirmed unambigiously our earlier suspicion that the centre of η Car hides an S Dor variable, also called an LBV (Luminous Blue Variable). Yet, the method of observing was based on integrated optical photometry of the complete Homunculus, a pure bi-polar reflection nebula. Thus, in analogy with a "Chinese lantern", at optical wavelengths the whole nebula flickers with the star, thus

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Table 1. The mean photometric data of the three standard stars and their standard deviations. V = $V_{J,\mathrm{Geneva}}(22'')$

Star	V	$[U-B]$	$[V-B]$	$[B_1-B]$	$[B_2-B]$	$[V_1-B]$	$[G-B]$
HD 102350	4.102	1.808	−0.153	1.224	1.203	0.608	0.848
	0.006	0.014	0.010	0.007	0.013	0.010	0.013
HD 93548	5.318	0.829	1.076	0.822	1.556	1.765	2.281
	0.013	0.031	0.019	0.009	0.011	0.019	0.023
HD 94510	3.781	1.855	−0.207	1.252	1.185	0.559	0.776
	0.022	0.055	0.035	0.016	0.016	0.033	0.041

revealing detailed characteristics of the stellar oscillations as if the star was not rendered invisible by the circumstellar matter (provided that no other bright variable star is present in the centre). The central light source, the core, if at all visible, can be fainter than the integrated light of the Chinese lantern minus that of the core, depending on the amount of material in the line of sight. This is the case with η Car indeed (Thackeray 1953; van Genderen & Thé 1984).

According to the double-flask model of Currie et al. (1996a), to explain both the HST astrometric observations and the spectral observations of Hillier & Allen (1992), the wall of the SE lobe along the line of sight is responsible for occulting the core. Light-time durations could amount to a few weeks or months and might cause secondary features in the light curve. These effects must be small and are likely to be smoothed by the effects from various parts of the Homunculus. This is because the SE lobe, which is nearer to us than the NW lobe, points almost straight towards us, the angle between the symmetry axis of the two lobes and the line of sight being $\sim\ 33^\circ$ (Davidson 1997). Light reflected off the far back side of the SE lobe has to pass through the front side, which could cause a substantial amount of extinction. Indeed, according to Hillier (1997), the front side is denser than the back side and partially thick. Backward reflected light from the NW lobe has to pass a lot of material, amongst others the "skirt" or the extended equatorial disk (Currie et al. 1996b), before it reaches us. Besides, this lobe must be weaker anyway because backward scattered light is weaker than when scattered in the forward direction (e.g. Witt 1989). Nevertheless, we do not exclude the possibility that secondary features in the light curve are caused by such light-time effects.

New observations made in the interval 1994–1998 will be discussed in the present paper. They were made in the Geneva photometric system and are fitted to those of the previous monitoring campaigns 1992–1994 and 1974–1991, based on the Strömgren and Walraven photometric systems, respectively.

2. Observations and reductions

The monitoring campaign in the Geneva photometric system (Golay 1980; Rufener 1988) started in May 1994 at the time the then current monitoring campaign with the $uvby\beta$ system had to stop because of the decommissioning of the 50-cm Danish telescope at the end of 1994.

The purpose of starting a new campaign simultaneously with the current one was for calibration purposes. In this way a continuous light curve could be obtained right to the moment when, in March 1998, the Swiss telescope would stop its activities, too.

η Car was measured 120 times in the seven filters of the Geneva system from JD 244 9497 (May 1994) to JD 245 0891 (March 1998), with the 70-cm Swiss telescope at ESO La Silla (Chile), equipped with the P7 photoelectric photometer (Burnet & Rufener 1979). A diaphragm of aperture $22''$ was used for all measurements. It should be noted that the Walraven photometry was made with a $16.''5$ aperture, the Strömgren photometry with $17''$ and $35''$ apertures. The observations made with the last mentioned aperture were transformed into $17''$ aperture observations.

The definition of the seven Geneva passbands U, B, V, B_1, B_2, V_1, G was given by Rufener & Nicolet (1988). The photometric procedure was described by Rufener (1964, 1985) and the photometric data are collected in the General Catalogue (Rufener 1988) and its up-to-date database (Burki et al. 1998).

The observations have been organized as "all-sky absolute photometric measurements". However, because η Car was observed during the whole year, the airmass of the measurements was larger than 2.0 in August and September. In order to improve the accuracy of the photometric data, a second order "differential" correction has been applied in the reduction procedure. To do this, three nearby standard stars, HD 93540, HD 94510 and HD 102350, called hereafter A, B and C, respectively, have been measured together with η Car. Table 1 lists the mean photometric data of these three standard stars.

For each measurement of η Car, the magnitudes and colours relative to $(A+B+C)/3$ have been calculated (e.g. for the V magnitude):

$$\triangle V_{J,\mathrm{Geneva}}(22'') = V_{\eta\ \mathrm{Car}} - (V_A + V_B + V_C)/3$$

The subscript J means that the magnitude is identical to the V of the UBV system of Johnson. The observations in 1994 between JD 244 9497 and JD 244 9576 were made simultaneously in the Geneva and Strömgren systems (i.e. maximum 11 in van Genderen et al. 1995) and were used for calibration, especially for the observations in the $V_{J,\mathrm{Geneva}}$ and y passbands (see also Sterken et al. 1999).

In order to facilitate a comparison with light curves obtained in other photometric systems and with different apertures, and to transform relative magnitudes and colours into absolute ones, we list below the transformation relations (the constants are accompanied by standard deviations, but mean errors are much smaller).

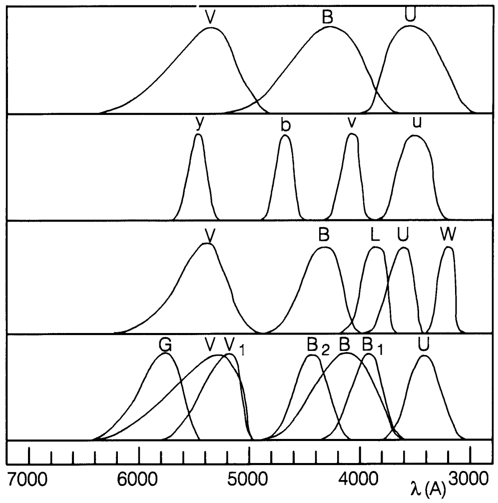

Fig. 1. The transmission curves of the passbands of four photometric systems. From top to bottom: the Johnson, Strömgren, Walraven and Geneva photometric system. The maxima are all normalized to unit transmission

$$V_{J,\mathrm{Geneva}}(22'') = \triangle V_{J,\mathrm{Geneva}}(22'') + 4.401\ (\pm 0.003)$$
$$[B-G] = \triangle[B-G] - 1.302\ (\pm 0.006)$$
$$[B-V] = \triangle[B-V] - 0.239\ (\pm 0.003)$$
$$[B-V_1] = \triangle[B-V_1] - 0.978\ (\pm 0.004)$$
$$[B-B_2] = \triangle[B-B_2] - 1.313\ (\pm 0.004)$$
$$[B_1-B] = \triangle[B_1-B] + 1.097\ (\pm 0.003)$$
$$[U-B] = \triangle[U-B] + 1.493\ (\pm 0.006)$$

The values of η Car's V magnitudes and Geneva colours, 1994–1998, are given in Table 2.[1]

$$y = V_J(uvby, 17'') = \triangle V_{\mathrm{Geneva}}(22'') + 4.614$$
$$\triangle y(17'', log_{\mathrm{int.scale}}) = 0.8044 - 0.4\triangle V_{J,\mathrm{Geneva}}(22'')$$
$$V_J(VBLUW, 16.5'') = V_J(uvby, 17") - 0.135(\pm 0.008)$$

Note that the last error is a mean error. The first part of the latter formula (we leave the bracketed information away) can be computed with the formula of Pel (1986):

$$V_J = 6.886 - 2.5[V + 0.033(V-B)]$$

in which V and $V-B$ are photometric parameters of the Walraven system.

Fig. 1 shows the passbands for the Johnson, Strömgren, Walraven and Geneva photometric systems.

3. The light and colour curves

Fig. 2 shows the relative light and colour curves for the 1994–1998 observations made in the Geneva system (dots). Long tick marks at the top indicate the beginning of the year (this holds for all subsequent figures). Smooth curves are hand-drawn. The crosses in the upper panel represent the best observations of maximum 11 of the 1992–1994 light curve (van Genderen et al. 1995) translated onto the Geneva magnitude scale $\triangle V_{J,\mathrm{Geneva}}(22'')$. The shape of the light maximum is equal in both systems. Thin arrows at the right top and above the light curve indicate the peaks in the steadily rising X-ray flux of which the average cycle length until the first half of 1997 equalled 85.1 d $\pm$ 5.4 d (Ishibashi et al. 1997; Corcoran et al. 1997a, b). Obviously, considering the decreasing distance between the peaks towards the end of 1997, this is no strictly periodic phenomenon. The arrow below the light curve indicates the steep decline in the X-ray flux (Corcoran et al. 1998a, b; Ishibashi et al. 1999) coinciding with the predicted and observed (Damineli et al. 1999) low-excitation event. It also coincides with a small, but significant, continuum light peak, or flare-like event.

There is no obvious relationship between the X-ray peaks and the secondary features in the light and colour curves, but the number of photometric observations is small; see however Sect. 4.3 where the optical light curve is combined with the light curve in the near-infrared passband J. The fat arrow at the top represents the spectroscopic low-excitation event computed with Damineli et al.'s (1997) formula (this holds for all other figures):

$$\mathrm{JD} = 244\,8800 + 2014E$$

The long time-scale oscillation amounts to at least ~ 3 y with a maximum in 1994 and one impending in the course of 1998. The striking flare starting shortly before the 1998.0 event (amplitude $0\overset{\mathrm{m}}{.}07$) is a feature different from the other microvariations. The reason is that it is the only one coincident with an equally prominent peak in $[U-B]$. Obviously the flare is largest in $[U]$ with an amplitude of $0\overset{\mathrm{m}}{.}12$, only half this amount in $[B_1]$, $[B]$ and $[B_2]$ and only a slight rise in the visual and red.

The six colour curves are ordered from top to bottom in such a way that the average wavelength shifts from red to blue. Further, all are drawn in such a way that in the figures blue is up and red is down, i.e. the colour $[V-B]$ has been written as $[B-V]$. The same has been done for $[G-B]$, $[V_1-B]$ and $[B_2-B]$. The scale for $[B-G]$ is twice as small as for the others. The framed parts in the $[B-V]$ and $[U-B]$ curves represent the observations simultaneously made in $uvby$ and which should be more or less comparable with the curves in the $v-y$ and $u-v$ colours, respectively (Fig. 3, see further).

With the exception of $[B-G]$, all colour indices tend to be bluer in the light minimum than in the ascending branch and the light maximum of the three-year stretch. This suggests that it represents part of an S Dor (SD) cycle of an LBV. Especially in $[U-B]$, the blueing is very pronounced, amounting to $\sim$ $0\overset{\mathrm{m}}{.}05$. This is one third of the amplitude of the light curve ($0\overset{\mathrm{m}}{.}15$). We believe that it is also partly caused by another variable light source (Sect. 4).

The time-scale of the microvariations in the light curve, superimposed on the SD cycle, appears to be of a different character than during the 1992–1994 interval, when the quasi-period amounted to 58.6 d. Some oscillations last about three months,

[1] Table 2 is only available in electronic form at the CDS via anonymous ftp do dcsarc.u-strsbg.fr (130.79.128.5)

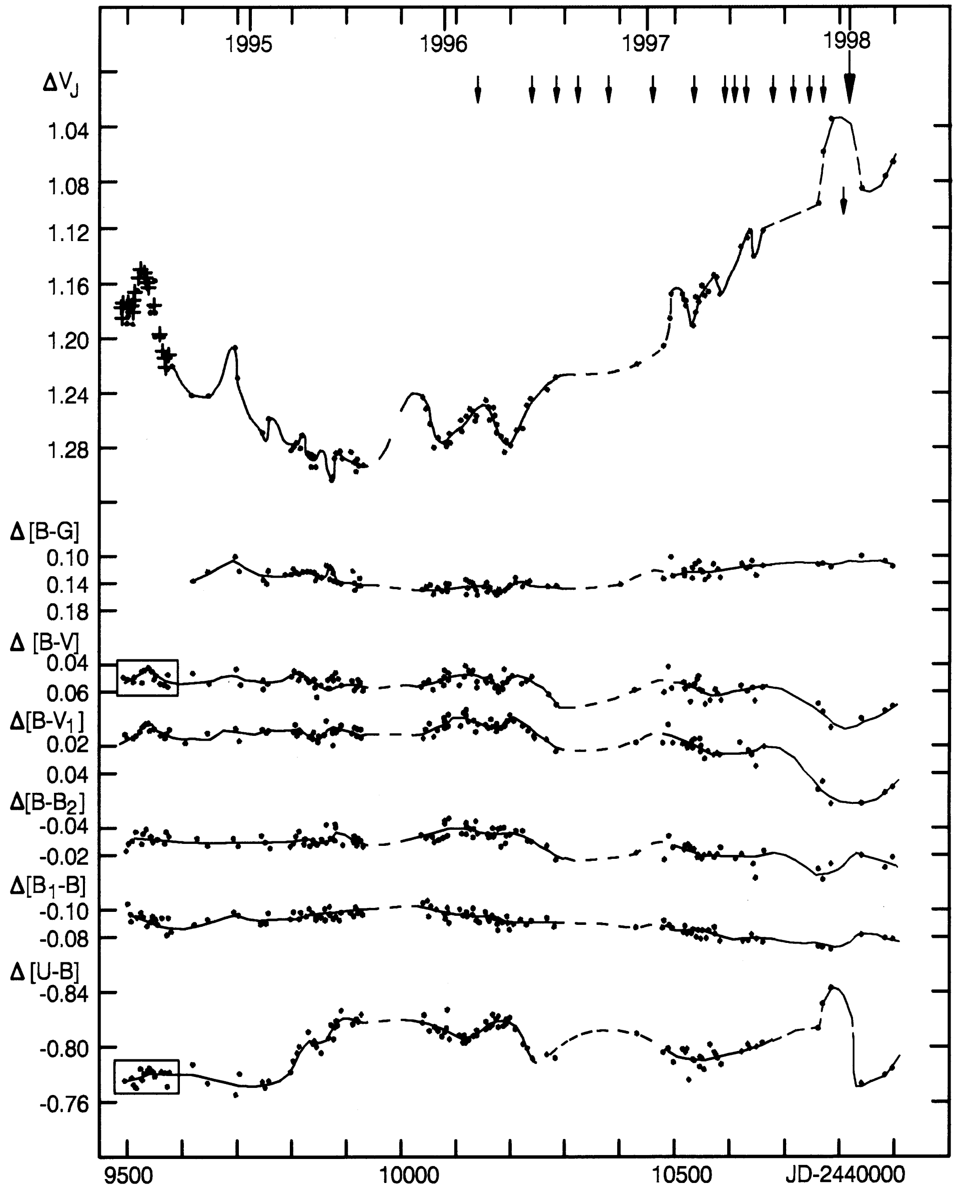

Fig. 2. The relative light curve $\triangle V_{J,\mathrm{Geneva}}(22'')$ and colour curves (in magnitudes) 1994–1998 in the Geneva system. Bright and blue are up. Thin arrows above the light curve represent the peaks in the steadily rising X-ray flux, the thin arrow below the light curve indicates the steep decline in the X-ray flux and the fat arrow indicates the spectroscopic low-excitation event 1998.0. The meaning of the framed parts is explained in Sect. 3

and sometimes they last only a few weeks. It is possible that multi-cyclicity is the reason; this aspect will be investigated in a subsequent paper when additional CCD photometry will be available.

The colour variations during these oscillations are usually small and of a mixed behaviour. Sometimes they are even absent, just as in the 1992–1994 interval. With the exception of $[U-B]$, all colour curves are relatively smooth with secondary features $< 0\overset{\mathrm{m}}{.}02$. Van Genderen et al. (1995) suggested that their small amplitudes were caused by the possible presence of a non-negligible second light source in the centre of η Car (especially since the LBV is not so hot: see Sect. 5; the cooler a variable supergiant, the larger the intrinsic scatter in the colour curves ought to be). Light-time effects should not be excluded; they might result in a smoothing of short time-scale variations, especially when the original amplitudes are small (Sect. 1).

The sudden transition, when going along the sequence of near constant colour indices from top to bottom in Fig. 2, to a very variable $[U-B]$ curve is most remarkable and obviously only due to the light in $[U]$ ($\lambda \sim 3460$ Å). This curve shows a relatively long-lasting blueing during the light minimum. We presume that not all of this blueing is due to the SD cycle of the LBV alone (Sect. 4). Further, it shows a superimposed wavy pattern with a repetition time of 200 d (see below).

In order to make the comparison with the previous monitoring campaign easier, we present in Figs. 3 and 4 the $uvby$ light and colour curves (in magnitudes). The $v-y$ curve is also shown because it should be closer to $[B-V]$ than $b-y$ is. The dashed curve sketched by hand as an average trend through the microvariations and with maxima at 1992.5 and 1994.0, shows a cycle with a duration of 1.5 yr. That at the first mentioned date a maximum is most likely present, follows from the inspection

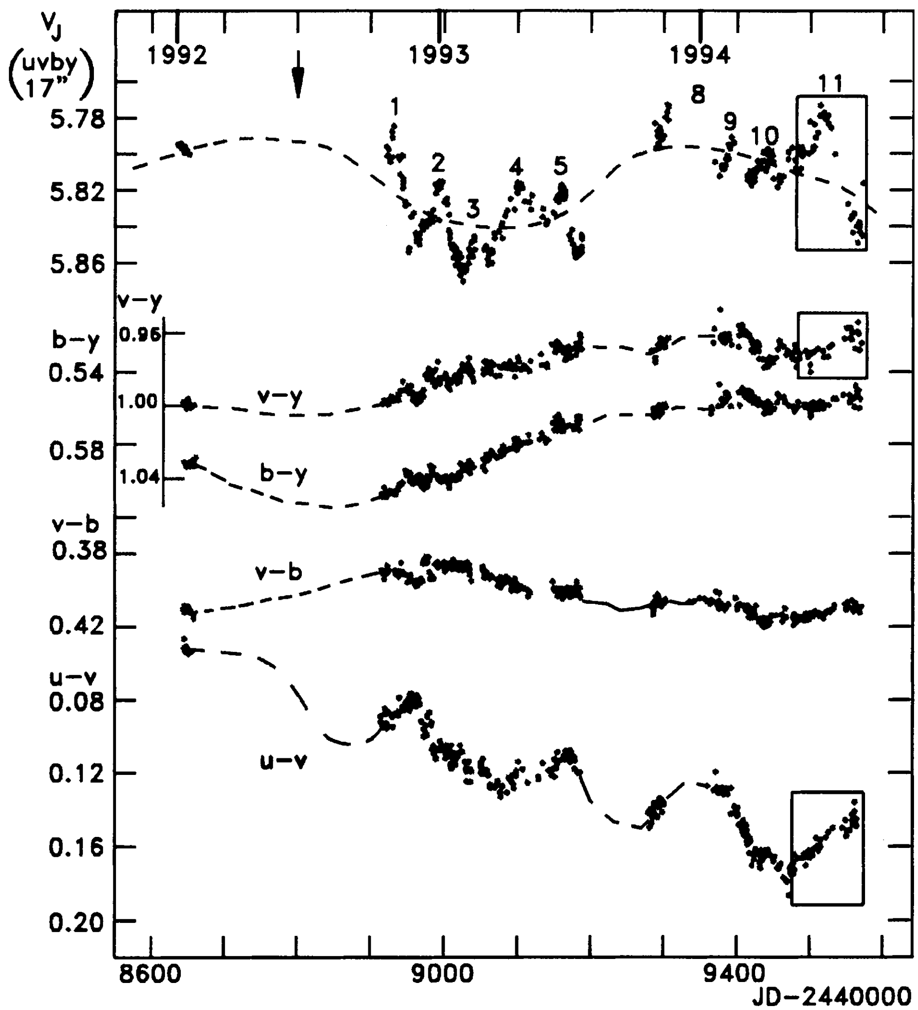

Fig. 3. The light ($y = V_J$) and colour curves (in magnitudes) 1992 – 1994 in the Strömgren system. Bright and blue are up

of the last panel of Fig. 5 in van Genderen et al. (1994), showing a few preceding observations in 1990 and 1991 which have a lower brightness.

The framed parts in the curves for $V_J(uvby, 17")$, $v-y$ and $u-v$ represent the observations made simultaneously with those made in the Geneva system. The supposed similarity between $u-v$ and $[U-B]$ is not quite true: $u-v$ shows a rise by $0\overset{m}{.}04$ and $[U-B]$ at most by $0\overset{m}{.}01$. Obviously, even a slight shift in effective wavelength ($\lambda_{\rm eff}$ in $u \sim$ 3500 Å and in $[U]$ $\sim$ 3460 Å, see Fig. 1), is able to introduce some difference in colour variation.

Although, the morphology of this light curve points to an ordinary SD cycle with superimposed microvariations, the colour curves are not all in quite agreement with that assumption (compare for example with Fig. 2 and the light curves of the LBVs studied by van Genderen et al. 1997a, b). The curves in Fig. 3 behave only partly as expected, e.g. while $v-y$ and $b-y$ become bluer (by $0\overset{m}{.}04$ and $0\overset{m}{.}05$, respectively), $u-v$ becomes redder (by $0\overset{m}{.}12$). Against the expectation, the latter shows no anti-correlation with the trend of the light curve. Van Genderen et al. (1995) suggested that the anti-correlation, which is so typical for SD phases, seems seriously disturbed by a second variable source (though not by a normal stellar photosphere), say by a luminous disk/bright spot system. The behaviour of $u-v$ on a time-scale of a few years points to a light source exclusively variable in the ultraviolet (UV) continuum (thus in u). A possible explanation will be given in Sect. 4.1. Marked variations in emission lines, but then in the far UV, were noted before by various researchers e.g. Zanella et al. (1984), Viotti et al. (1989), Damineli (1996) and Damineli et al. (1997).

Apart from that, the $u-v$ curve shows a most remarkable 200 d-oscillation with an amplitude of $\sim$ $0\overset{m}{.}04$ that appears to be caused exclusively by the light in the u passband also, since it is absent in the other colour curves. The oscillations in the $[U-B]$ curve of Fig. 2 are likely of the same type. We inspected the U and W curves of the $VBLUW$ system ($\lambda_{\rm eff}$ $\sim$ 3620 Å and $\sim$ 3240 Å, respectively) in van Genderen et al. (1994) discussing the observations between 1974 and 1990, but we could not find much evidence for this type of oscillation, perhaps because of the lower sampling rate (however, see Fig. 7 discussed later). The 200 d-oscillation will be discussed in detail in Sect. 4.2.

Fig. 4 shows as a comparison the light curves (in magnitude scale) in the b, v and u passbands during the 1992–1994 interval;

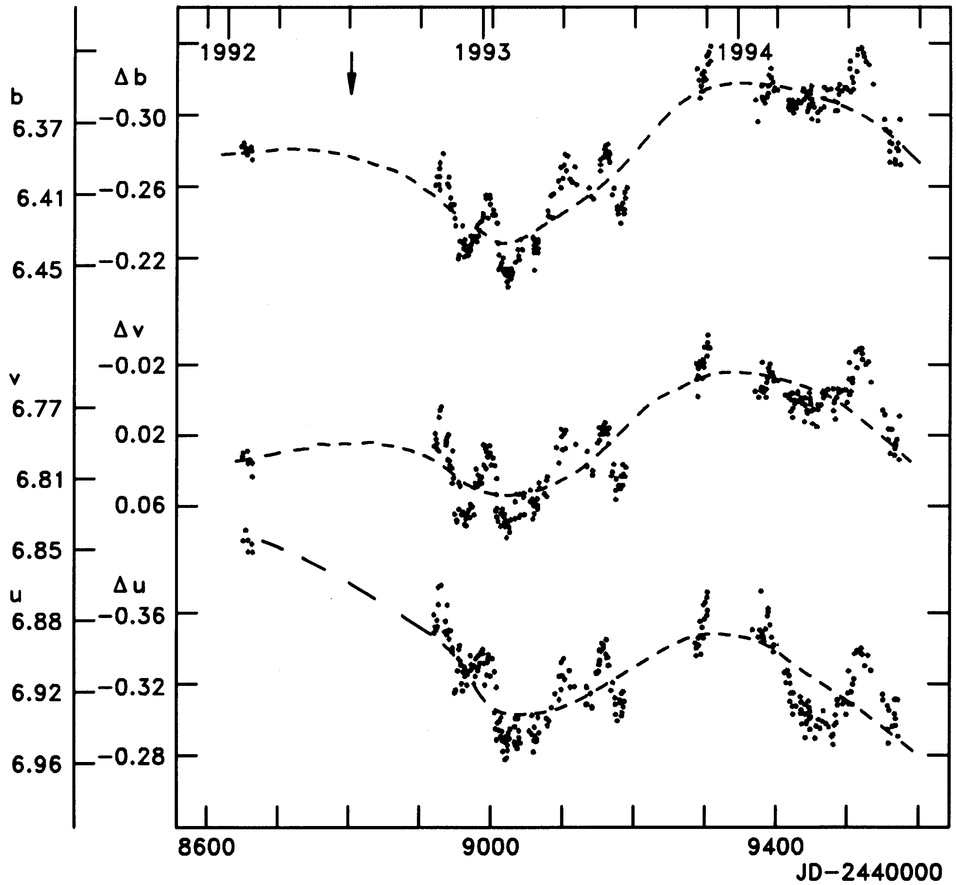

Fig. 4. The light curves b, v and u (in magnitudes) 1992–1994

see van Genderen et al. (1995) for the definition of the relative magnitudes of which the scales are also shown. The long-term trends of the colour curves in Fig. 3 are caused by the difference in height of the two maxima in Fig. 4.

The micro-oscillations in Fig. 3 (and Fig. 4) show small colour variations as those in Fig. 2. Sometimes they tend to be bluer in the maxima than in the minima as expected for this type of microvariation (quasi-period 58.6 d; as long as they are $<<$ 100 d, they are called α Cyg-type variations: van Genderen et al. 1997a, b). The reverse also occurs, e.g. maximum 11: some colours are redder in maximum than in the subsequent minimum.

Fig. 5 shows a compilation of the 1992–1994 and the 1994–1998 light curves $V_J(uvby, 17")$ by matching the data in maximum 11. The dashed curve has been sketched by eye to show the two SD cycles by averaging out the microvariations. Suggestive support for our claim that the SD cycles (which are mainly caused by a radius variation) are most likely caused by a genuine LBV inside the core of η Car, is shown in Fig. 6. This figure shows an SD cycle of the LMC LBV R 85 = HDE 269321 with a duration of $\sim$ 400 d (van Genderen et al. 1998). Dashed curves are sketched by eye and represent the main trend of the SD cycle. Colours tend to be redder in the light maxima and bluer in the light minima as expected. Full lines in Fig. 6 (in V_J) represent the trend of the microvariations. A large part of the scatter in the colour curves is intrinsic and caused by the microvariations with time scales of about 2 months. The morphological similarities of both light curves (and those of other LBVs) are striking.

To investigate the behaviour of the variable UV light source in the core of η Car, which we think is not caused by the LBV, we made $W-B$, $u-v$ and $[U-B]$ colour curves (in magnitude scale) for the time interval 1974–1998. The effective wavelengths for the UV passbands (lying in the Balmercontinuum) are 3235 Å for W, 3505 Å for u and 3464 Å for $[U]$. Especially the last two colour indices should be more or less similar (Fig. 1), but in view of the emission-line spectrum of η Car one must be careful. Thanks to a few overlapping observations made in the three photometric systems, the three colour curves could be fitted together, but one should realize that they are not completely identical (see above). Further, part of the possible differences could be caused by different apertures used in the three photometric systems (Sect. 2). The SD-type variability and the microvariations of the LBV are minimized in these colour curves.

Fig. 7, which we shall call the UV curve, shows the compilation of the three colour index curves (blue is up). The $W-B$ data were taken from Table 4 in van Genderen et al. (1994). The first three data points (at the left) are means of $\sim$ 10 nightly averages because the scatter was too large to show single points. The vertical error bars represent the mean error of the colour, the horizontal bars (if larger than the dot) represent the length of the time interval. The same is valid for the next three data points,

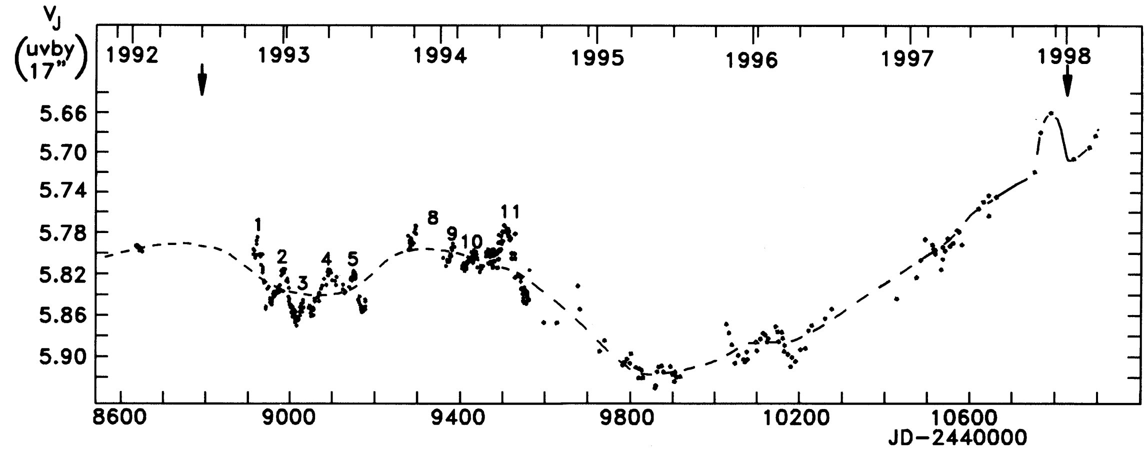

Fig. 5. The light curves $V_J(uvby, 17")$ 1992–1998 in the Strömgren and Geneva systems (the last one translated onto the first)

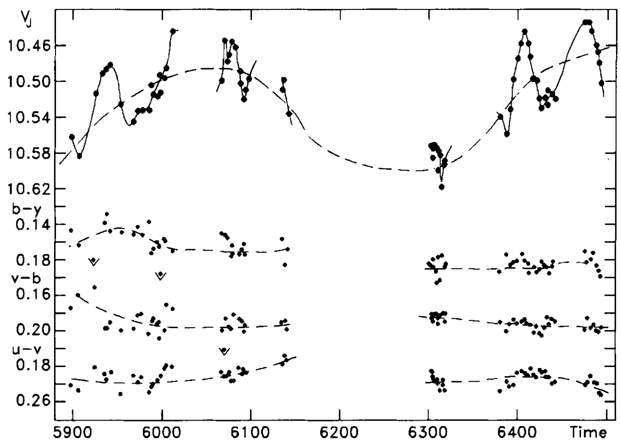

Fig. 6. The light and colour curves of the LBV R 85 = HDE 269321 (in the LMC) showing a "normal SD phase", one of the two types of S Dor phases (dashed curves) with superimposed microvariations (full curves). Time = JD - 2440000. A large part of the scatter in the colour curves is intrinsic and due to the microvariations

but the quality of the individual nightly averages is much better. Dots without error bars are single nightly averages; their error bar is shown at the left top (twice the mean error, or $0\overset{\mathrm{m}}{.}004$).

The $u - v$ data were taken largely from Table 1 in van Genderen et al. (1995). The relative data from that table have been corrected by adding the $u - v$ value of comparison star A from Table 3 of the same paper. In this way they are in the natural (instrumental) SAT system (Strömgren Automatic Telescope). These data and the few not listed in Table 1 mentioned above (those around JD 244 8650; i.e. in early 1992), are also listed in the LTPV data catalogues of Manfroid et al. (1991, 1994) and Sterken et al. (1993, 1995). All $u - v$ data points are plotted to the right of the $u - v$ axis in Fig. 7 with one exception: one data point has been plotted to its left (circle). This point is very important for the matching of the $u - v$ curve and the $W - B$ curve. It has been obtained in the same night as one nightly average in the $VBLUW$ system (JD 244 8290). Similar to the last mentioned data point, the former is based on a sequence of four measurements of the variable, alternated by the comparison star, yielding a very reliable nightly average with a very small internal scatter. (Before that date all η Car data points in the $uvby$ system were based on one measurement per night). The result is: $W - B$ = 0.390 and $u - v$ = 0.088.

Other $u - v$ observations (34) made in the same configuration and before the night mentioned above (between JD 244 6422 and JD 244 8084, see Manfroid et al. 1991 and Sterken et al. 1993) were not used for the reason explained below (more observations were made with slightly different Strömgren filter systems, so that they cannot be used because of the emission-line spectrum of η Car). The $u - v$ values of these 34 data points are systematically too red by $\sim 0\overset{\mathrm{m}}{.}1$ compared to JD 244 8290 and the later ones. The jump happened somewhere between JD 244 8084 and JD 244 8290. The observations in the $VBLUW$ system, made in the same time interval do not show such a jump in the same wavelength interval. Yet, there exists a linear relationship between the (too red) $u - v$ and the $W - B$ values, pointing to an internal consistency, as far as the number of simultaneously obtained data in both photometric systems allows the comparison (11 data points obtained within a 2-day interval). Therefore, we believe that the jump is caused by some peculiarity in the observational, instrumental, or reduction technique (which in the case of an emission-line object can have serious consequences) and, therefore, we omitted these data in Fig. 7.

The very first Geneva measurements made simultaneously with the $uvby$ data (around JD 244 9500, framed in Fig. 7) are matched with the minimum in the $u - v$ curve. The result is: $u - v$ = 0.164 and $[U - B]$ = 0.720. In this way the three colour curves are joined together, but nevertheless the comparibility of the variations is uncertain and should be considered with some caution.

A dashed curve has been sketched by eye through those parts thinly populated with data points. The scatter in the last part of the $W - B$ curve (1988–1991) is larger than the mean error. The largest deviations downwards of the sketched curve are caused by the "dimples" (van Genderen et al. 1994, 1995 and Sect. 4 of the present paper) and were ignored when sketching the dashed curve. The remaining scatter could be caused by the same type of variability as in $u - v$ and $[U - B]$, viz. the 200 d-oscillation.

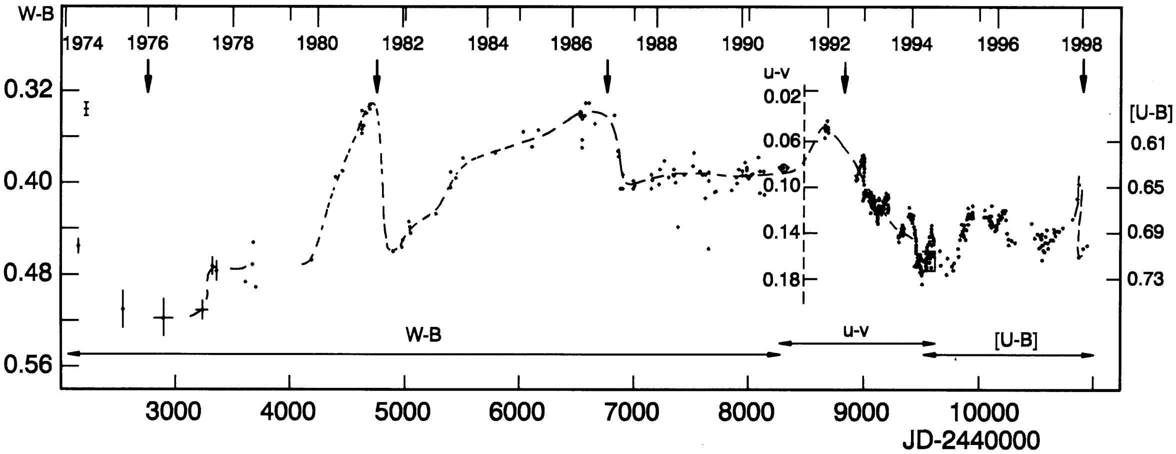

Fig. 7. The UV curve (in magnitudes) for the three photometric systems. Blue is up. For the explanation see Sect. 3.

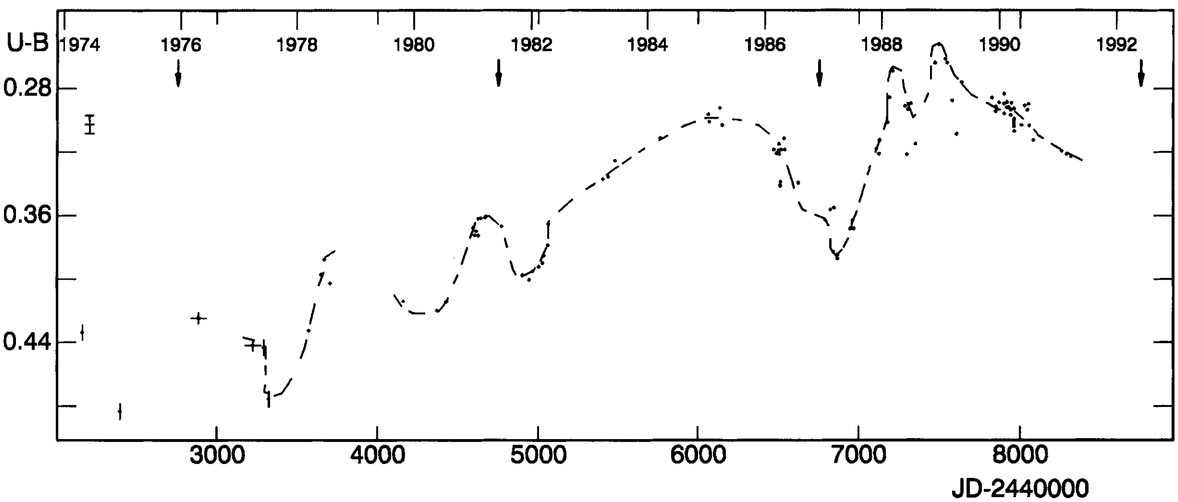

Fig. 8. The Balmer jump curve, or $U - B$ curve (Walraven system, in magnitudes). For the explanation see Sect. 3

The description for $W - B$ also holds for the $U - B$ curve in Fig. 8 (in magnitude scale) and is also based on the observations made in the $VBLUW$ system. This curve we call the Balmerjump curve.

There is a long-term trend of blueing in $W - B$ and $U - B$ amounting to $\sim 0\overset{\mathrm{m}}{.}08$ and $\sim 0\overset{\mathrm{m}}{.}11$, respectively, interpreted as part of a decrease of the extinction by the expanding Homunculus (van Genderen et al. 1994, 1995). Again, the fat arrows at the top mark the expected times of the spectroscopic low-excitation events.

4. Discussion

4.1. General results

Damineli (1996) found a 5.52 y periodicity from a study of spectroscopic events that showed a stable cycle over the last 50 y. The claim that fading of the high-excitation lines is coincident with the maxima in the near-infrared light curves of Whitelock et al. (1994) and with optical light maxima, is only partially true. For example, the predicted maximum at 1986.9 is coincident with a minimum in the optical as well as in the near-infrared (van Genderen et al. 1997a). The 1992.5 maximum in the light curve fits the ephemeris of Damineli et al. (1997) and according to their model should be coincident with the periastron passage of a highly excentric massive binary. However, there is an extra light maximum in 1994 (Figs. 2, 5) which does not agree with that explanation. (The adopted radial velocity curves of Damineli et al. (1997) and Davidson (1997) may need correction in view of the results of radial-velocity measurements obtained by de Groot & Henderson 1998, pr. comm.). They were unable to match the radial velocities given by Damineli et al. (1997) between June 1992 and July 1994 and suspect that the discrepancies are due to asymmetries in the He I $\lambda\lambda$ 5875 and 6678 lines used in the investigation, see Sect. 5.). Further, the light curve in Fig. 2 suggests that at the computed epoch, 1998.0, an SD maximum is impending, but not yet reached. The near-infrared (NIR) light curve in the J-passband of Whitelock (1999) supports that. So, only some of the V-maxima coincide with a low-excitation event. We return to this subject later in this section. However, the small, though very significant peak in the continuum light and twice as large in $[U]$ might point to a causal connection (Sect. 4.3).

Our analysis from 1974 onwards reveals that the time scale of the SD phases generally lies between 1 and 3 y (van Genderen et al. 1994, 1997a) and the two time scales found in the interval 1992–1998 (1.5 and > 3 y) agree with that. Stothers & Chin (1997) made a list of light maxima back to 1827 and found a time scale of 4 y, which is of the same order.

It should be noted that we doubt whether all the light maxima, especially those in the early days, are genuine SD phases. The presence of explosive events of a different kind, perhaps seated in an active accretion disk (van Genderen et al. 1994; Aitken et al. 1995), or in a companion star, are not ruled out. The five peaks in the 1827–1857 interval (Innes 1903, see also Fig. 2 of Damineli 1996), suggest explosive events rather than SD phases, because of the high energy involved to surpass such a high luminosity by $\sim$ 1 mag. In the interval 1827–1857 there are three parts lasting 4–7 y without any observation, thus, more explosions could have occurred. Stothers & Chin (1997) interpreted η Car as a hydrogen burning star in its core and repeatedly encountering ionization-induced dynamical instability within its outer envelope resulting in cycles of mass loss with a time scale of $\sim$4 y.

Very strongly related to the 5.52 y cycle in the spectroscopic features is the X-ray flux (Corcoran et al. 1997b, 1998a; Ishibashi et al. 1999; Viotti et al. 1998). These observations support the proposed periodicity because the X-radiation reached minimum intensity at the predicted and postulated periastron passage of 1998.0, while the high-excitation lines did indeed disappear around that time (Damineli et al. 1999; Jablonski et al. 1998). On the other hand, the radio flux (3–6 cm) had a minimum at the low-excitation event of 1992.5 (Duncan et al. 1995), but reached maximum around 1996.0 rather than around 1995.0 (Duncan et al. 1997, 1999), the supposed apastron passage. Thus, it seems that the extrema of the 3–6 cm radio flux are not quite in phase with the 5.52 y periodicity and are delayed (see Sect. 4.3 for a possible explanation). The trend of the 1.3 mm and 2.9 mm radiation between 1991 and 1992 (Cox et al. 1995) shows the expected decline and a subsequent rise until the last observation in 1994.

In the light of these new discoveries, Figs. 7 and 8 are of importance. These diagrams deliver a good impression of the variability of the UV light source separated from that of the LBV whose variability dominates at the longer wavelengths. The near-coincidence of four out of five spectroscopic low-excitation events during the last 18 y with four maxima in the UV curve of Fig. 7 (for the time being, we consider the small peak at 1998.0 to be a maximum also) suggests that a causal connection exists between the two phenomena. We neglect the very first event (1976.0) which coincides with an unreliable and poorly covered part of the light curve, especially in the UV. Each of the four cycles in Fig. 7 is different and each is highly asymmetric. The descending branch occupies about 0.1 of the cycle only, pointing to a strong asymmetry in the effect. The largest amplitude in Fig. 7 amounts to $0^{\mathrm{m}}_{.}12$.

Thanks to 24 years of photometry, this is the first indication that the 5.52 y periodicity is present in the optical continuum region, albeit that the correlation happens mainly in the UV. We attribute this variable light underlying the emission-line spectrum, to a luminous disk with a radiation peak lying alternatingly in the Balmer continuum and in the Balmer jump part of the spectrum. Thus, the switch from the one to the other appears to be modulated by the same period as the spectroscopic events identified by Damineli (1996). Such a luminous accretion disk/bright spot system has been proposed by us before (van Genderen et al. 1994, 1995).

An optically thick disk radiates more in the Balmer and Paschen continua than in the lines. As soon as the disk becomes optically thin it will radiate more in the lines. Thus, in our case one expects that the modulation in the brightness in W should be roughly half a cycle out of phase with that in L (which includes the Balmer limit) and U (which includes the Balmer jump *and* the Balmer limit) if the phenomenon is caused by a modulation of a disk's physics by a binary revolution in an excentric orbit with P = 5.52 y. Indeed, Fig. 8, in which $U - B$ of the Walraven system is plotted versus time, demonstrates this very clearly (since $L - B$ shows more or less the same curve, it is not shown). In 1978 there is an ascending branch indeed with an unobserved extrapolated maximum likely in early 1979 around the postulated apastron. The unexpected small U maximum just before the next periastron passage (1981.4) coincides with the very high peak in W (Fig. 7) and indicates that the hypothetical disk is of a "mixed" structure. Then, between the three periastron passages of 1981.4, 1986.9 and 1992.5 two prominent maxima in U emerge, while in W the brightness is still relatively low (Fig. 7) and reaches maximum brightness only some years later, just before the postulated periastron. Fig. 8 only shows the Walraven colour index $U - B$. The Strömgren system has no equivalent of the Walraven $U - B$ or $L - B$ indices, so we cannot check whether in 1992–1994 the Balmerjump area and Balmercontinuum were in anti-phase.

As mentioned at the beginning of this section, most, but not all, light maxima (1994, see Fig. 5) coincide with, or lie at least close to (1986.9), the low-excitation events (see Fig. 4a, b in van Genderen et al. 1994). This could point to an additional light contribution in the Paschen continuum superimposed on the ongoing SD cycles when the luminous disk becomes optically thick. Although the second SD cycle in Figs. 2 and 5 has apparently not yet reached maximum light at 1998.0, two months ahead of it one finds the marked, but short lasting flare in the whole spectral range of the Geneva system (Sect. 3). Unfortunately, the number of observations (6) is too small to give more details on this very important feature, however, see Sect. 4.3!

It seems that much material from the disk is lost in some way just after the supposed periastron passage. Why the circumstances for mass loss would be favourable during the years immediately after the passage is not clear, but a possible cause is suggested in Sect. 4.3 where we present a qualitative model. Anyway, the disk becomes optically thin and has to be built up in the course of the rest of the cycle, presumably by gaining mass from its parent star and/or from the LBV.

We do not know which star possesses the luminous disk, the LBV, the secondary, or a third, but close companion to the LBV like in the model of Bath (1979). Anyway, the disk must be ionized by a nearby very hot star. Only single, fast rotating B-type stars showing non-radial pulsations (Be stars) are able to build up a disk (see, e.g., Osaki 1986 and Ando 1986). However, we know now that η Car is a complicated, multi-component object and that, therefore, the presence of a disk is a real possibility.

Damineli et al. (1997) and Corcoran et al. (1997a, b; 1998a) attribute the gradual rise of the X-ray radiation to the increased collissional effects between the two winds. In their view the dense interface is supposed to block the X-rays from our view around periastron and is, thus, responsible for the steep decline observed by Corcoran et al. (1998a, b; 1999). The flaring X-ray radiation on top of the steady rising X-ray output is not periodic (Sect. 3). This could be explained by density fluctuations met by the orbiting interface, say by a structured, or clumpy disk around the LBV and in the orbital plane (this is not necessarily "the" luminous disk). These inhomogeneities could be shaped like arms analogous to pulsating Be stars which show global arm oscillations.

When the secondary, also called the wide companion, approaches the periastron and thus the LBV, the interface collides with denser disk and arm material. The flares should then show increasing amplitudes and shorter repetition times, which is observed. After periastron, when the X-ray flux recovers quickly from a deep minimum, peaks should be observable again, presumably with a relative short repetition time in the beginning. Corcoran et al.'s (1998b, 1999) observations support that. See Fig. 9 for the sketch of our model, discussed in Sect. 4.3. It should be noted that Davidson et al. (1998) predict in a broad class of other models also a decreasing recurrency before the periastron, and a drastic lengthening of the recurrence interval just after it. Long runs of new X-ray observations are needed to check that.

The explanation for the dramatic increase in radio flux at 3–6 cm between 1992 and 1996 proposed by Duncan et al. (1995, 1997), is an outburst of the UV luminosity in the core by a factor of three. This causes ionization of circumstellar gas clouds in a torus lying in the equatorial plane of the wide binary and at a distance of $2''$ ($\sim$ 5000 AU). This UV outburst should then also be responsible for the increased thermal emission at 1.3 and 2.9 mm (Cox et al. 1995). The origin of the UV outbursts can hardly be the LBV. Whithin the framework of our model it could be caused by a decreased extinction for UV photons around a very hot star normally embedded in its disk. Whether this is the secondary, or a third star–the hypothetical close companion to the LBV–is unknown.

As soon as the disk becomes optically thin, around the periastron and lasting for some years thereafter, the screening of UV photons decreases, so that excitation of the outer gas torus is possible (apparently the decrease in the UV radiation amounts to slightly more than $1^{\rm m}$ in order to explain the rise in the radio flux by a factor of three in 1996.0). However, then one would expect an anti-phase relationship between the UV curve in Fig. 7 and the radio curve of Duncan et al. (1999). While the UV radiation shows a minimum around 1996 (the bump in that minimum is in our view partly caused by the minimum of the 1994–1998 SD cycle) and the radio flux does indeed show a maximum, the steady decline in the 3–6 cm radiation is not accompanied by a steady rise in $[U-B]$ apart from the peak at 1998.0. It is possible that the ongoing rise in the SD cycle to a maximum somewhere after 1998.0 suppresses a possible rise in the UV. Thus, we cannot yet speak of a close correlation between the two curves. It is uncertain whether they will be precisely correlated and it cannot be checked for the previous 5.52 y cycles, because no radio monitoring was ever done at that time.

In the new data set, 1994–1998, no traces of new "dimples" were found. For these depressions in the light curve, occurring especially in the UV, at most $0\overset{\rm m}{.}1$ deep, and lasting for a few days, a very tentative period was computed (52.4 d or 104.8 d) and attributed very cautiously to occasional atmospheric-type eclipses of a close companion star, or bright spot in a disk around this companion. (We emphasize that this periodicity is of a quite different nature than that of the stellar micro-pulsations amounting to 58.6 d). Their presence was striking in the 1972–1992 data set (van Genderen et al. 1994). During the intensive monitoring campaign 1992–1994 only a few shallow ones were detected, more or less at the predicted dates (van Genderen et al. 1995). None were found in the new data set 1994–1998, probably because our data density is too low to detect them if they occurred at all.

4.2. The 200 d-oscillation in the UV

The 200 d-oscillation in the UV, as evident from the $u-v$ and $[U-B]$ curves in Fig. 7, points to an additional variation of the flux exclusively in the Balmer continuum superimposed on its steady decline after the low-excitation event of 1992.5. It is absent in v and, as far we can judge, hardly visible in $[B_1]$. Thus, it is most likely of non-stellar origin, possibly caused by the luminous disk. Obviously, the steady decline in the UV curve of Fig. 7 and the subsequent minimum lasting until 1997, could point to a long-lasting thinning process of the disk material, but the oscillations with an amplitude of $0\overset{\rm m}{.}04$ are difficult to explain within the framework of this model.

In connection with this phenomenon we want to mention the following peculiar fact. The Julian dates of the prominent maxima in $u-v$ and $[U-B]$ between the two low-excitation events of 1992.5 and 1998.0 and as a matter of interest including the Julian dates of these low-excitation events also (Figs. 2, 3 and 7), yield a repetition time of $\sim$ 200 d (we omit the two small bumps between JD 244 9800 and JD 244 9900 in Fig. 2). Table 3 lists the Julian dates of the nine observed maxima (O) with their estimated error. First, we derived the number of cycles E, elapsed since the maximum at JD 244 8970. They are listed in the second column. Obviously, two maxima did not turn up, viz. E = 4 and 8. Two least-squares solutions were made; one with equal weights (solution 1) and one with weights defined as the reciprocal of the estimated error squared (solution 2). The results are:

JD(UV max) = 2 448 977.1 + 198.6E (solution 1)

with mean errors: 7.5 d and 1.0 d, respectively, and

JD(UV max) = 2 448 970.3 + 201.2E (solution 2)

Table 3. Analysis of the maxima in the UV curve $u-v$ and $[U-B]$. O is the observed Julian date and the residuals $(O-C)$ are given in days

O	E	$(O-C)_1$	$(O-C)_2$
48800$\pm$50	-1	21.5	30.9
48970$\pm$10	0	-7.1	-0.3
49175$\pm$10	1	-0.7	3.5
49360$\pm$25	2	-14.3	-12.8
49575$\pm$20	3	2.0	1.0
	4		
49960$\pm$50	5	-10.0	-16.5
50175$\pm$10	6	6.1	-2.7
50350$\pm$50	7	-17.5	-29.0
	8		
50785$\pm$10	9	20.2	3.6

with mean errors: 0.8 d and 0.1 d, respectively.

The $(O-C)$ values for the first solution are small for the maxima between the low-excitation events and largest at the epochs (E = -1 and 9) of these events. Therefore, one could be tempted to consider this UV oscillation as periodic–rather than cyclic–but not related to the low-excitation events. Support for this non-relationship is the fact that the 198.6 d period fits about 10 times into the 2014 d period, with a very large deviation of 14%. For the second solution–P = 201.2 d–this deviation is only 1%, which is not surprising since the 1998.0 event has a large weight. Therefore, we conclude that the UV oscillation is at least cyclic, but that the relatively nice fit with the low-excitation events seems accidental.

If the oscillations are cyclic, they could have something to do with local rythmic enhancements of the luminous-disk density, say by cyclic shell ejections of the LBV. We suggest that, considering its presumed spectral type (Sect. 5), the rotation time of the LBV could be of the order of 200 d. If they are truly periodic, one could suggest that the 200 d represents the revolution time of a star with a permanent hot spot (in an accretion disk) around another star. If this other star is the LBV, it is also reasonable to expect that, in view of the viewing angle of $\sim 57^\circ$ to the orbital plane, the spot's UV radiation will be modulated by the extended atmosphere and clouds moving along the rotation axis. The fact that two maxima did not turn up would then point to a variable density of the intervening matter. After all, the physical state of the hot spot must be variable too, depending on the amount of infalling matter. At certain times the hot spot might even be absent altogether.

In connection with the average 85 d-recurrence interval of the X-ray flares, Livio and Pringle (1998) and Davidson et al. (1998) discussed the possible presence of a third component. The first mentioned authors conclude that a stable hierarchical system is possible, although perhaps only marginal if for the period of the third star 85 d is used. However, the stability increases for a period of 200 d, since the excentricity for the outer orbit then turns out to be $\lesssim 0.41$ (applying the formulae used by Livio and Pringle), while for stability $\lesssim 0.67$ is required. A long run of X-ray observations after periastron passage are necessary to investigate the trend of the recurrence interval, which is crucial for the models of Davidson et al. (1998).

4.3. The 1998.0 flare and subsequent eclipse-like event. A qualitative model

It appears that the light curves in V_J (Figs. 2, 5) and in the NIR passband J (Whitelock 1999) are almost identical with respect to the general trend, secondary features and amplitudes. Therefore, a combination of both reveals many more details, especially of the 1998.0 brightness jump, or flare, and the subsequent sharp decline to a minimum. This feature shows a fast brightness rise within $\sim$ 25 d with an amplitude of $0\overset{m}{.}07$ lasting for a month and coinciding with the last and most prominent X-ray flare observed by Ishibashi et al. (1999). (It is striking that some other secondary features in V_J and J also coincide with X-ray flares). After a steep decline of $0\overset{m}{.}12$ (in the combined V_J and J light curve), the brighness recovers quickly. The decline of the X-radiation to zero intensity lasts $\sim$ 25 d (counted from the level between the X-ray flares). The one in V_J and J is slow by $\sim$ 30 d (and also lasts $\sim$ 25 d).

The decline of the X-ray source strongly suggests an eclipse (also suspected by Ishibashi et al. 1999). Since the hot spot must be part of the X-ray spot but, obviously, more extended, we believe the hot spot is eclipsed at the same time. (Note that the amplitude of the optical flare in $[U]$ is twice as large as in the other passbands of the Geneva system, thus obviously, the flare is of a non-stellar origin; Sect. 3). The duration of zero X-ray flux is $\sim$ 20 d. Thus, the "size" of the eclipsing body amounts to 20 d + 25 d = 45 d, after which a slow recovery sets in. The recovery of V_J and J is much quicker, because of the ongoing rising branch of the SD cycle.

Since the viewing angle to the orbit equals $\sim 57^\circ$ and the major axis might point nearly into our direction according to the models of Damineli et al. (1997) and Davidson (1997), the eclipsing body is not likely to be a star; otherwise the X-ray source and hot spot would almost make contact with it. Besides, the X-ray eclipse is highly asymmetric and further the required size of that body deduced from the 45 d is much too large (at least a few hundred $R_\odot$). Therefore, we suspect that the eclipsing body is the interface of the colliding winds (bowl-shaped) of the secondary and the LBV, in accordance with the suspicion of Damineli et al. (1997), with mainly at one side a region where the X-rays and high-excitation lines are generated. An absorbing wake following the star that passes in front at periastron is not excluded.

Fig. 9 shows a sketch of a possible model, with the observer facing the binary from the bottom of the figure. It should be stressed that Fig. 9 only depicts the essence of what we believe could explain the various phenomena, independent of the precise orbital elements. Afterall, the last are unknown (Sect. 5), as well as the parent star of the disk and the orientation of the bowl-shaped interface. This orientation depends on the difference in momentum between the two stellar winds. In Fig. 9 it is assumed that the one of the secondary is largest. However, the reversed case will not alter the essence of our model.

To explain the X-ray flares, in Sect. 4.1 we suggested that the LBV could be surrounded by a disk (not necessarily "the" luminous disk) with high-density arms. It is thinkable that such a disk shows an elliptical shape caused by the compression of the secondary's wind when both stars approach each other (Fig. 9a). Therefore, the disk and its arms will be denser near periastron. In this way one can understand the increasingly stronger X-ray flares when periastron is approached. The strongest X-rays will be generated where the interface makes contact with the disk and its arms. In view of its obscuring capability the interface must be partly optically thick to X-rays to its backside, i.e. facing the star in front at periastron (unless the obscuration is caused by a dense wake following it).

We suggest that the first contact of the interface with a very dense arm near periastron created an intense X-ray spot and surrounding hot spot, which were subsequently eclipsed by the proceeding interface (Fig. 9b). Figs. 9b1 and 9b2 present the X-ray/hot spot with a time interval of about one month. It is most likely that transient X-ray/hot spots of a much lower intensity are the explanation for the other coinciding X-ray and optical/NIR flares.

In this very tentative qualitative model, the origin of the high-excitation lines must lie close against the bowl-shaped interface (in Fig. 9 facing the LBV) where also the X-rays are created. At apastron we look right into that area resulting in their maximum strength. While the stars revolve to periastron, these lines will gradually weaken by the intervening interface. The X-rays will be visible along the whole orbit, apart from the situation sketched in Fig. 9b. At apastron the X-ray intensity is relatively low because of the lower density of the disk and the larger distance of the interface to the stars, but the density, and subsequently the X-ray intensity, will increase as periastron is approached. Our explanation is basically in agreement with the synthetic curve of the X-ray emission modelled by Pittard et al. (1998) and which is based on two colliding winds.

It must be emphasized that the amplitude of the 1998.0 optical/NIR flare is only the relative contribution of the hot spot to the total optical/NIR light of η Car. Therefore, if the amplitude was about $0^{\rm m}_{.}1$ instead of the observed $0^{\rm m}_{.}07$, because the growth of the spot may have been interrupted by the ingress, its optical/NIR brightness was only $2^{\rm m}_{.}5$ fainter than that of η Car, which is considerable. Considering that only ~10% of the luminosity of η Car (for a distance of 2.3 kpc: $10^{6.64}\,L_{\odot}$) is received in the optical region (van Genderen & Thé 1984), the optical luminosity of the spot could lie between 10^4 and $10^5\,L_{\odot}$. The life-time of the spot is unknown, but may be less than 2 months.

With this model in mind, the conclusion lies at hand that the creation of the intense X-ray/hot spot has something to do with the sudden physical change of the luminous disk (whatever its location may be) at periastron, as demonstrated convincingly by the UV variation in Figs. 7 and 8 with a cycle of 5.52 y. Obviously, the 1998.0 X-ray/hot spot was no exception in view of the previous UV cycles.

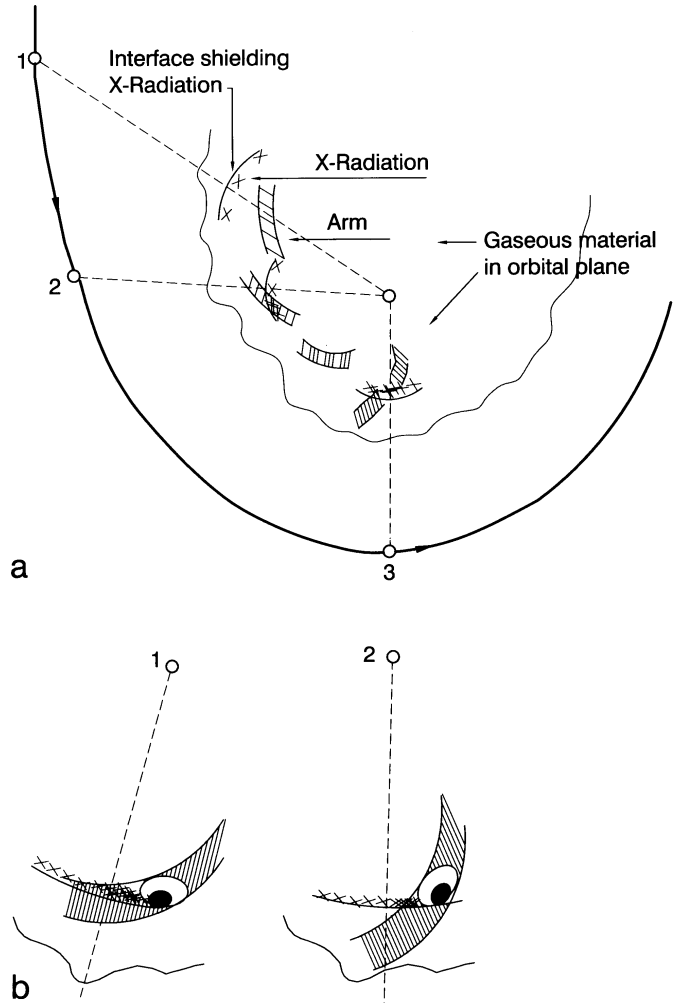

Fig. 9a and b. A sketch of the excentric binary viewed at right angles to the orbital plane. The periastron points more or less into the direction of the observer, but the angle between the orbital plane and the line of sight equals $\sim 57°$. We omitted a possible third companion. **a**1: the interface moves through the disk producing a curved X-ray field at the inside of the bowl. **a**2: The interface collides with an arm producing an X-ray/hot spot, resulting in an X-ray/optical/NIR flare. **a**3: The interface collides with an arm with a higher density than in **a**2, generating a stronger flare. **b**1: Just before the 1998.0 periastron passage the first contact of the interface with a high-density arm produces an intense X-ray spot (black oval) and surrounding hot spot (white oval). **b**2: At periastron the interface eclipses the X-ray spot and some time later the hot spot. Dashed lines point to the secondary

Within the framework of our model it is also understandable that the maximum radio flux from the outer gas torus at a distance of $\sim$ 5000 AU can be reached everywhere during the 5.52 y cycle and that it has nothing to do with the apastron passage (maximum radioflux was reached in 1996 instead of 1995, Sect. 4.1). The radio-flux rise only stops when the disk, enshrouding the exciting star, will become optically denser through mass gain, which is an arbitrary process dependent on the mass donor.

5. Conclusions

The importance of dedicated photometry of η Car and its contribution to the better understanding of pulsational characteristics of the LBV in the core of η Car cannot be overestimated.

We have shown, that integrated photometry of the circumstellar reflection nebula (the Homunculus) during the last 24 y, is capable of yielding important information on the brightness and colour variations and, consequently, on the pulsational characteristics of the LBV in the core of η Car. We may also extract important details on the variable UV light source.

Based on the integrated photometric characteristics, we suspect that the LBV is much cooler than 30 000 K (van Genderen et al. 1995). It seems that this temperature (Davidson 1971) refers to a very hot companion of the LBV. One of the considerations, amongst others, is that 22 000 K would not be unrealistic in view of the length of the quasi-period of the micro-oscillations (58.6 d between 1992 and 1994, van Genderen et al. 1995). Compare this with Damineli et al. (1995, 1998) and Ebbets et al. (1997) who suggested temperatures between 12 500 K and 22 000 K. Nevertheless, one should consider these spectroscopic temperatures with caution since they refer mainly to the dense stellar wind, so that a photospheric temperature cannot be estimated accurately in this way (Davidson 1997).

It should be stressed that the physical difference between the periodicity of the dimples (52.4 d, Sect. 4.1 and van Genderen et al. 1994) and that of the micro-pulsations of the LBV (58.6 d, van Genderen et al. 1995; Sterken et al. 1996) seems to be misunderstood by some researchers (Davidson & Humphreys 1997; Lamers et al. 1998).

The main variable object is most likely a garden-variety LBV, at least at present, exhibiting so-called “normal SD phases” which are mainly caused by a slow variation of the stellar radius (de Koter et al. 1996; van Genderen et al. 1997a; and should not be called “eruptions” or “outbursts”), time scale 1–4 y, with at times micro-oscillations superimposed on them like many other LBVs.

Again, we found support for the presence of a luminous disk somewhere in the system, responsible for the UV variation modulated with the 5.52 y periodicity (see below), and a striking 200 d-oscillation. The explanation for the latter depends on whether the 200 d is cyclic or truly periodic (Sect. 4.2). In the latter case η Car could be a triple system. We suspect that a very hot companion of the LBV causes the ionisation of the disk. This companion could be a Be-type star in a wide excentric orbit of 5.52 y of the type as proposed by Damineli et al. (1997), or a hot close second companion to the LBV. We have shown that the observed optical variations fall well within the ranges of Bath’s (1979) close-binary model computations (van Genderen et al. 1994).

The orbital parameters of the wide binary may perhaps be different from those of Damineli et al. (1997) and Davidson (1997) considering the radial velocities of -40 and -60 kms^{-1} for the He I emission lines at 5875 Å and 6678 Å at phases 0.13 and 0.34, respectively, obtained by de Groot & Henderson (1998, pr. comm.). These new results are based on spectroscopic observations of Stahl et al. (1995) made between June 1992 and July 1994. At these phases Damineli et al. find radial velocities of +40 and 0 kms^{-1} respectively for the Paschen γ emission lines.

The fact that most of the light maxima lie at or nearby the low-excitation events, if not accidental, could be explained by additional light from the luminous disk reaching the region of maximum optical density which is then superimposed on the ongoing SD activity. Apart from that we do not exclude the possibility of a triggering effect on the SD activity by gravitational forces, when the excentric wide companion approaches periastron.

The brightness contribution of the luminous disk may also be responsible for the relatively too low colour amplitudes of the stellar (the LBV) micro-pulsations we observe. The opposite behaviour of the continuum variations in blue light and in the Hβ index (van Genderen et al. 1995) is not in contradiction with the suggestion that a luminous disk is present. The physics of the disk (such as the optical density) and, consequently, its spectrum, especially in the UV, appears to be modulated by the 5.52 y period of the low-excitation events/periastron passages. A periastron passage seems to cause a sudden thinning of the luminous disk. In Sect. 4.3 we speculated that the intense X-ray/hot spot, created at that particular moment and visible as an X-ray/optical/NIR flare, is responsible for the thinning (by its wind?). The spot is subsequently eclipsed. During this phase it obviously fades away and during the rest of the orbital cycle the luminous disk recovers slowly through mass gain. In Sect. 4.3 (Fig. 9) we proposed a model which explains qualitatively most of the observed phenomena, such as those mentioned above and the peculiar pattern in the time scale and in the intensity of the X-ray flares.

The radio flux variation of the gas torus in the equatorial plane at a distance of 2” ($\sim$ 5000 AU) might be caused by the varying excitation capability of the very hot companion of the LBV, whether it is the wide secondary or a close companion. As soon as the disk becomes optically thin during and after periastron passage, the hot star’s UV photons are able to excite the outer gas torus. The moment of radio flux maximum is only dependent on when the disk’s density increases again and not depend on the apastron passage.

At first sight, the luminosity excess by $\sim$ $2\overset{\mathrm{m}}{.}5$ between 1827 and 1857, first noted by van Genderen & Thé (1984), the frequent explosions during the same time and those of previous centuries (Walborn et al. 1978), the existence of the bipolar nebula, and the various types of fast ejecta, can hardly be attributed to an ordinary and single LBV, albeit very luminous and massive. P Cyg also behaved extraordinarily with two outbursts in the 17th century, probably also exceeding its present bolometric luminosity (de Groot & Lamers 1992; Lamers & de Groot 1992), while no companion star is known. A bipolar nebula is then also missing. Accumulating observations point to a different status for η Car and a more intricate scenario is not unreasonable. Detailed spectroscopic studies support this too (e.g. Viotti et al. 1989; Hillier & Allen 1992; de Groot & Henderson 1998, pr. comm.).

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