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Light variations of massive stars (α Cyg variables)*

XVI. The LMC supergiants R 85 (LBV) and R 110 (LBV) and the SMC supergiants R 42 and R 45

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Abstract. Multi-colour photometry of four variable supergiants in the LMC and SMC, viz. R 85, R 110, R 42 and R 45, is searched for periods, studied and discussed. The suspected LBV R 85 is undoubtedly an active LBV, though not as spectacular as R 110. Their microvariations superimposed on the S Dor-activity are analyzed as well as those exhibited by R 42 and R 45. Often, a period search is difficult because of the very complicated micro-variability. We suggest that this is caused by an intricate multi-cyclic behaviour combined with stochastic processes. The length of the strongest cyclicity in the power spectrum of R 42 (128 d) is of the order of the rotation periods of BA-type supergiants.

In connection with our findings described in the present paper and the previous ones, we discuss various competing theoretical models on the instability of α Cyg variables, including the LBVs.

Key words: stars: variables – stars: supergiants – stars: individual R 42 = HD 7099, R 45 = HD 7583, R 85 = HDE 269321, R 110 = HDE 269662

1. Introduction

For a proper introduction to this paper dealing with the photometric variability of evolved massive stars, the α Cyg variables, we refer the reader to our previous paper (van Genderen et al. 1998, hereafter Paper I). In the present paper we discuss $VBLUW$ photometry (Walraven system) and $uvby$ photometry (Strömgren system) of R 85 and R 110 (two emission-line supergiants and LBVs in the LMC) and $VBLUW$ photometry of the supergiant R 42 and the hypergiant R 45 (both in the SMC).

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Table 1. Aperture used (Ap, in arcseconds) and the average standard deviation (σ) per data point (in units of 0.001 $\log$ intensity) for the four programme stars

Star	Ap	V	$V-B$	$B-U$	$U-W$	$B-L$
R 85	23	3	2	3	7	3
R 110	16	3	3	7	17	4
R 42	16	3	3	4	8	4
R 45	16	3	2	3	7	3

2. Observations and reductions

The four objects were observed with the 90-cm Dutch telescope equipped with the simultaneous $VBLUW$ photometer, at the ESO in Chile. Further particulars on the observing procedure can be found in Paper I. Observations in the LMC were made for R 85 from 1988 to 1991, for R 110 from 1989 to 1991, both with respect to the comparison star HD 33486 (B9, $7\overset{m}{.}9$).

Both objects were also observed in the $uvby$ system by the LTPV (Long-Term Photometry of Variables) group (Sterken 1983). R 85 was observed between 1983 and 1994 (136 data points) with respect to the comparison stars HD 35293 (A1, $9\overset{m}{.}2$) and HD 35294 (G2 IV, $8\overset{m}{.}4$). R 110 was observed between 1989 and 1994 (72 data points) with respect to the comparison stars HD 37722 (A1 V, $8\overset{m}{.}9$) and HD 35294 (G2 IV, $8\overset{m}{.}4$).

The observations of R 42 were made between 1987 and 1990 and of R 45 between 1986 and 1989 with respect to the common comparison star HD 10747 (B3 V, $8\overset{m}{.}2$), which is also a standard star of the $VBLUW$ system. Table 1 lists the four programme stars as observed in the $VBLUW$ system, the aperture used and average standard deviation (σ) per datapoint relative to the comparison star, all in $\log$ intensity scale. Average mean errors are of course smaller, in these cases by about a factor two or three. The σ's for $B-U$ and $U-W$ of R 110 are relatively large because of its late spectral type due to the (temporary) evolution to the red (this long-term trend has been discussed by van Genderen et al. 1997b).

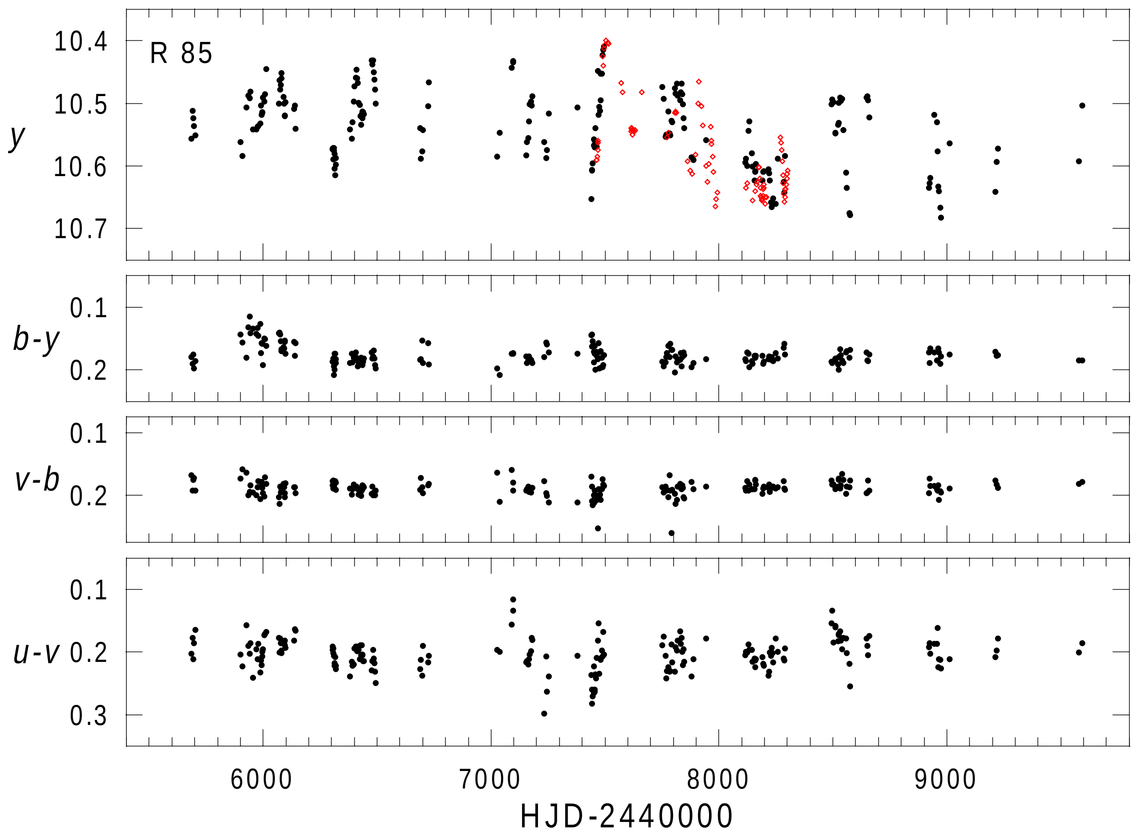

Fig. 1. The complete light curve $y \equiv V_J$ of R 85 (◇ for the Walraven system) and colour curves for the interval 1983–1994.

Table 2 lists the photometric results in the $VBLUW$ system for the comparison stars and the programme stars. The photometric parameters V and $B - V$ of the UBV system (with subscript J) were transformed with the aid of formulae given by Pel (1987), see van Genderen et al. (1992).

The $uvby$ data of R 85 and R 110 can be found in the four data catalogues by Manfroid et al. (1991, 1994) and Sterken et al. (1993, 1995). The $VBLUW$ differential intensities and colours relative to the comparison stars will be published in a data paper which also includes Walraven photometry of other, previously studied α Cygni variables (to be submitted to the Journal of Astronomical Data).

The variable R 85 was simultaneously (i.e. within a few days) observed in both photometric systems, so that a comparison could be made of the V_J magnitudes. It appeared that in three time intervals (JD 244 7462–7496, JD 244 7772–7943 and JD 244 8119–8290) the average differences V_J ($VBLUW$) minus V_J ($uvby$) showed a slight trend from -0$^{\rm m}_{.}$031 to -0$^{\rm m}_{.}$020 to -0$^{\rm m}_{.}$016. Whether the trend is significant is difficult to say, but the effect could be the result of systematic different centering techniques in a star-crowded field by different observers. Anyway, the V_J values derived from the $VBLUW$ system and used in the light curves were corrected for these differences to get a better match with results in the $uvby$ system.

All figures depicting the $VBLUW$ light- and colour curves are given in log intensity scale.

3. The light- and colour curves, the period analysis

In the following subsections we present a description of the light- and colour curves of the selected objects. It is very well known that the light variability of α Cygni variables, including hypergiants and LBVs, consists of several components, viz. the pseudo-periodical microvariations, the S Dor phases, and the ever present stochastic noise (for a detailed discussion, see Sterken et al. 1997). The stochastic-noise component—but also the occurrence of numerous gaps in the long-term light curve—sometimes hinders the graphical rendering, especially when all data points of the light curve are being connected by lines. However, our experience from previous studies indicates that it is extremely convenient to present parts of the light curves by full lines to help the eye see the variations clearly. We have, therefore, drafted lines representing the best polynomial fit (polynomials have the property to follow smooth minima and maxima without enforcing a harmonic function to the data). As to the pseudo-periodic character of the light curves (revealed, in the first place, by their visual effect) we prefer to use the term *cycle* instead of *period* since the latter term somehow involves a much higher degree of regularity than the former.

3.1. R 85 = HDE 269321, B5 Iae

During the $uvby$ and $VBLUW$ photometric campaigns R 85 appeared to be variable with a total range of 0$^{\rm m}_{.}$31, which is

Table 2. The average photometric parameters of the common comparison stars and the four programme stars (in log intensity scale for the $VBLUW$ system and in magnitudes for the transformed UBV parameters [with subscript J]). N is the number of measurements.

		Sp	V	$V-B$	$B-U$	$U-W$	$B-L$	V_J	$(B-V)_J$	N
	HD 33486	B9 V	-0.390	-0.010	0.330	0.078	0.112	7.86	-0.04	
R 85	HDE 269321	B5 Iae[1]	-1.440	0.075	0.038	0.113	0.017	10.48	0.18	86
R 110[2]	HDE 269662[2]	B9:eq[1]-G[3]	-1.225	0.25	0.11	0.24	0.10	9.93	0.57	82
	HD 10747[4]	B3 V	-0.510	-0.044	0.079	-0.001	0.026	8.17	-0.13	
R 42	HD 7099	B2.5 I[1]	-1.645	-0.005	-0.021	0.025	-0.020	11.00	-0.02	126
R 45	HD 7583	A0 Ia+[1]	-1.315	0.073	0.195	0.189	0.046	10.17	0.17	90

Notes to Table 2:
[1] Feast et al. (1960)
[2] Close to the maximum of an S Dor phase, the colours are still growing red. The photometric parameters are averages from October 1989 until February 1991 (JD 244 7777–8301)
[3] Zickgraf (quoted by Wolf 1992)
[4] Photometric parameters from Pel (1989)

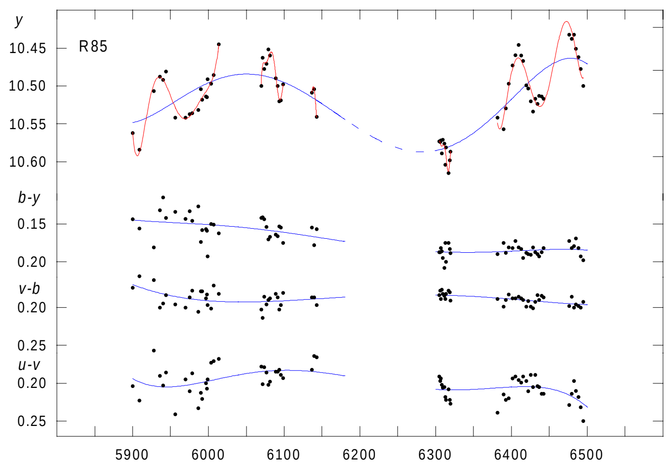

Fig. 2. A portion of the light and colour curves of R 85 as a function of JD-244 0000, based on $uvby$ photometry (in magnitudes) showing an oscillation (probably a "normal SD phase") of $\sim$ 400 d (upper, partially broken curve). Bright and blue are up. The solid lines that illustrate the long-term trend are polynomial fits to all data ($6^{\rm th}$ degree in V_J and $5^{\rm th}$ in the colour indices, see text). The short-term microvariations in V_J are also represented by $6^{\rm th}$ degree polynomials.

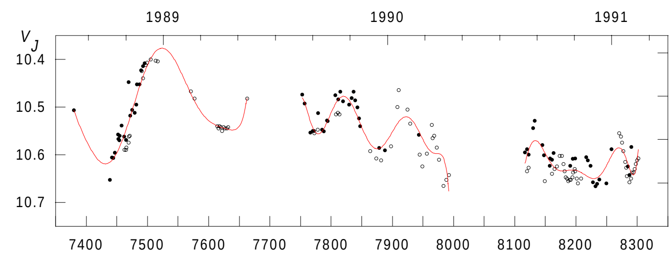

Fig. 3. A portion of the light curve V_J of R 85 as a function of JD-244 0000, based on $VBLUW$ (○) and $uvby$ (●) photometry. The fitted lines are $8^{\rm th}$ degree polynomial fits.

exceptionally large for an α Cyg variable of this spectral type (see Fig. 13 in van Genderen et al. 1992).

Fig. 1 shows the $y \equiv V_J$ light curve 1983–1994, including the V observations of the $VBLUW$ system transformed to V_J (◇) and the colour indices $b-y$, $v-b$ and $u-v$. The light curve (V_J) stretching over almost a dozen years shows a strongly oscillating trend of which the waves show a wide variety in duration (15–400 d) and amplitude ($0.^{\rm m}03$–$0.^{\rm m}20$). A small part, between JD 244 5900 and JD 244 6500 (1984–1986), is characterized by a long-term oscillation with two maxima with a time interval of roughly 400 d and an amplitude of $\sim 0.^{\rm m}12$ (partially dashed curve in Fig. 2, obtained by polynomial fits to all data). Colours tend to be red in the maxima and blue in the minima. Thus, this episode probably can be considered as a "normal S Dor phase", the shorter one of the two types of SD phases identified by van Genderen et al. (1997a). Short-term micro-oscillations with amplitudes of $\sim 0.^{\rm m}1$ are superimposed (fitted continuous curves in Fig. 2), and five approximate times of maximum can be recognised, which yield an average cycle length of $66.^{\rm d}9\pm0.^{\rm d}3$ (if we assume that the data span eight cycles).

During other time intervals the light curve looks completely different from this portion. The most surprising part, between 1987 and 1991, is shown in Fig. 3, incidentally including all $VBLUW$ datapoints. The 400 d oscillation is not visible. This part starts with a large-amplitude ascending branch ($\sim 0.^{\rm m}3$) lasting $\sim$ 70 d and showing a few small bumps. Then the oscillations tend to occur on a decreasing time scale and range till about JD 244 8240—that is, from 180 d to 15 d and $\sim 0.^{\rm m}3$ to $\sim 0.^{\rm m}01$—while the average brightness decreases. The stretches of solid line in Fig. 3 clearly illustrate that there is a change in the cyclic pattern. Note that the apparently-single wave (cycle length about 190 d) which is seen in 1988–1989 could very well be a double or triple wave (with cycle length ~ 140 d or ~ 90 d for the components).

Thereafter, in the time interval 1991–1994, the time scales and amplitudes of the oscillations, often only partly covered by

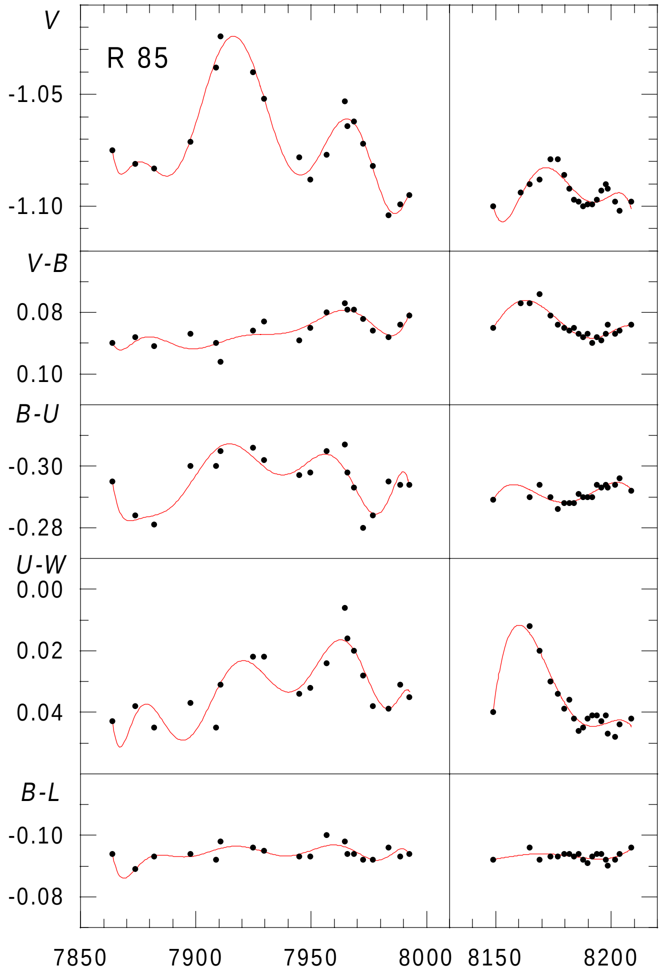

Fig. 4. A portion of the light and colour curves of R 85 in the $VBLUW$ system relative to the comparison star in log intensity scale as a function of JD-244 0000. Bright and blue are up.

observations (therefore the light curve is not shown), amount to 1–3 months and $\sim\ 0\overset{\rm m}{.}15$, respectively. Due to gaps in time and the relatively large scatter, the precise behaviour of the colour curves is unknown. So far, R 85 is the most peculiar α Cyg variable known. The possible reason for this peculiarity will be made clear below. Fig. 4 shows, as an example, the detailed colour variations in the $VBLUW$ system for four cycles.

A period search of the light-curve data shown in Fig. 1 was carried out using Fourier analysis in the frequency range 0–0.1 cd^{-1}, and the resulting spectral window and amplitude spectrum are given in Fig. 5. The spectral window shows the annual cycle at 0.002745 cd^{-1} ($P = 364.3$ d). An interesting peak in the amplitude spectrum occurs at $f_1 = 0.01199$ cd^{-1} ($P = 83$ d) with, at distances of $\pm$ 0.0027 cd^{-1}, the annual cycle aliases 0.01469 cd^{-1} and 0.00927 cd^{-1}, corresponding to $P = 68$ d and $P = 108$ d, respectively. The 400 d cycle (seen in Fig. 2, f_0 in Table 3) is also present (0.0025 cd^{-1}). A simultaneous sine fit with both frequencies yields a calculated light curve that looks like the one in Fig. 1 (see Fig. 6), but reduces the overall standard deviation by only 25% (the calculated curve

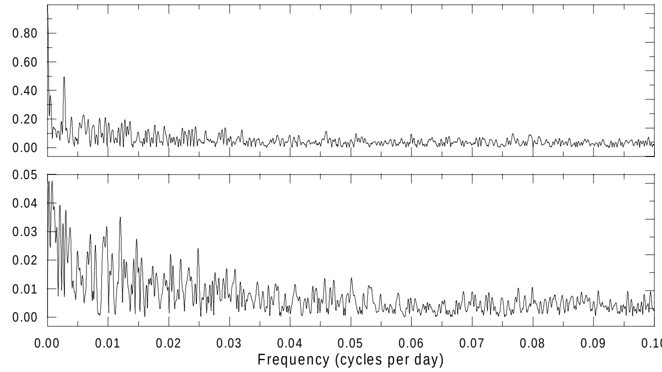

Fig. 5. Spectral window (top) and amplitude spectrum (bottom) for V measurements of R 85.

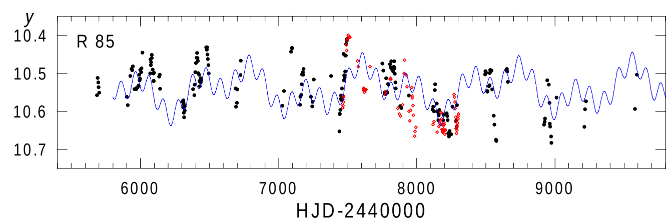

Fig. 6. Two-frequency fit with parameters from Table 3 (solution I).

does not follow the strong amplitude changes). Alternatively, we have performed a simultaneous sine fit using f_0 and the $P = 68$ d alias of f_1, which does not yield any improvement in terms of goodness of fit. The resulting parameters are given in Table 3. It is clear that the Fourier spectrum of R 85 cannot be unambiguously solved.

The changes in colour during the microvariations over the whole dataset and in the two photometric systems appear to be so diverse, that no systematic behaviour of the colours can be noticed: sometimes they are blue in the maxima, sometimes they are red. It is as if we are dealing here with a mix of the two types of microvariations. Indeed, if the individual cycles are scrutinized, we get the impression that both types of microvariations for LBVs, identified by van Genderen et al. (1997b), are operating here together, like in HR Car during a short time interval. The conclusion was that both types of microvariations are probably caused by different instability mechanisms. If the time scale amounts to $\gtrsim$100 d, the colours are red in the maxima, if $<<$100 d, the colours are blue in the maxima. They are called the "100 d-type" (for large range LBVs appearing at the upper half of the SD cycle) and "α Cyg-type" microvariations (for large range LBVs appearing at the lower half of the SD cycle), respectively.

The mix as exhibited by R 85 is no surprise since its temperature, according to its spectral type, is about 14 000 K and the estimated temperature boundary for the switch from one type of oscillation to the other presumably lies between 10 000 K and 15 000 K. The peculiarity of the overall light curve, noted above, is now understandable.

Also striking is the relatively large range of the colour variations, especially in $B-U$ and $U-W$ (Fig. 4). Quantitative

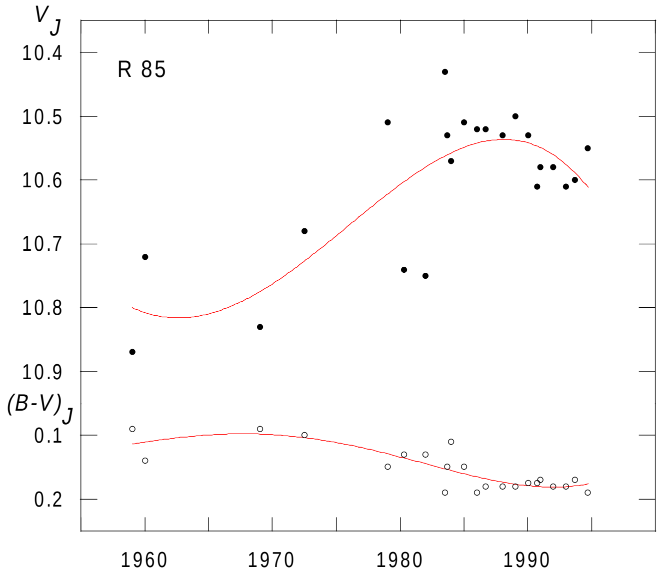

Fig. 7. The long-term light and colour variation of R 85.

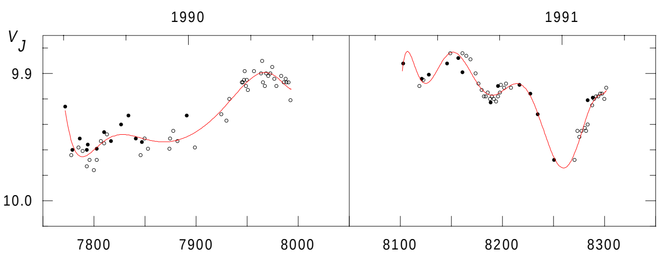

Fig. 8. The detailed light curve V_J of R 110 based on all available $VBLUW$ (○) and part of the $uvby$ (●) photometry made simultaneously. Dates mark the beginning of the year. Full lines are polynomial fits.

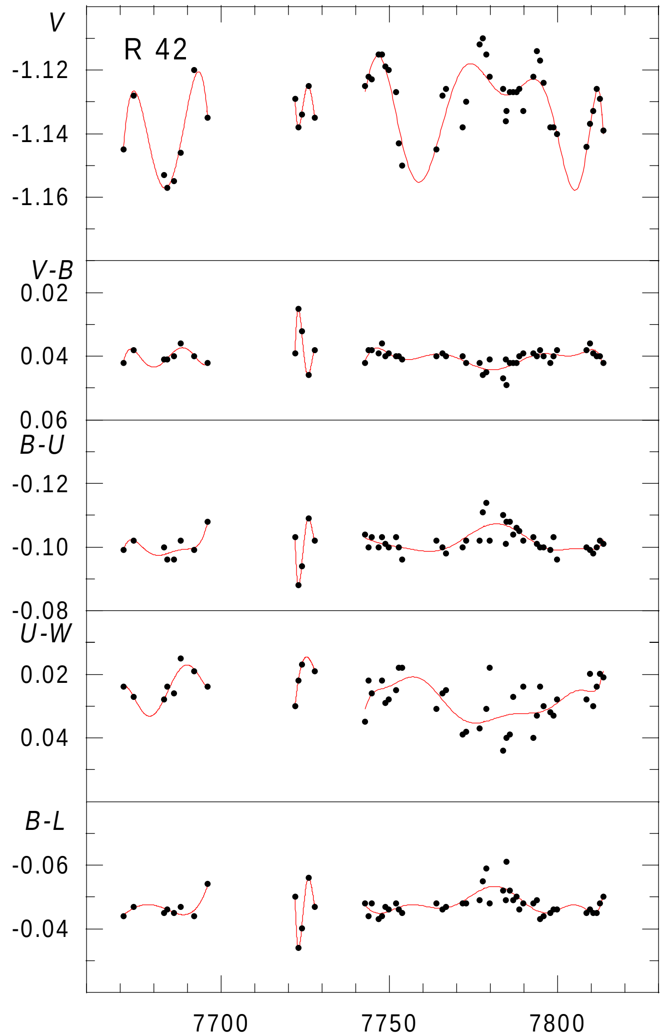

Fig. 9. A portion of the light and colour curves of R 42 in the $VBLUW$ system relative to the comparison star in log intensity scale as a function of JD−244 0000. Bright and blue are up.

parameters to characterize the size of the light and colour variations of α Cyg variables are the "maximum light amplitude" or MLA, and the "σ" for the four colour variations (for definitions, see van Genderen et al. 1989, 1990, 1992).

For R 85 they are too large for normal α Cyg stars, e.g. the MLA amounts to 0.122 in log intensity scale ($0\overset{m}{.}31$). They are of the same order as for the B9 Ia$^+$ LBV/hypergiant HD 168607 = V4029 Sgr (van Genderen et al. 1992). The relative lack of secondary features on top of the micro-oscillations is another characteristic shared with other LBVs.

A phenomenon which also strongly favours an LBV-classification is that R 85 shows a weak S Dor-activity on a time scale of decades if scattered observations during the last few decades are examined: colours are redder when the star is bright and bluer when faint. This has been convincingly established by Stahl et al. (1984) who made a compilation of values from the literature. Fig. 7 shows the plot of this compilation, completed with the data of the present paper by taking averages of sub-sets of observations. The $b-y$ indices were transformed to $V-B$ and then to $(B-V)_J$ by using the data sets where Walraven and Strömgren photometry was obtained simultaneously. The long-term variation has a time scale of more than 30 y with a light range of $0\overset{m}{.}3$, thus very similar to the LBV R 99 (Paper I). The colour $(B-V)_J$ behaves as it should for an SD-activity. We believe that this represents the longer one of the two types of SD phases identified by van Genderen et al. (1997a,b) in other LBVs, viz. the VLT (Very Long-Term)-SD phase. Part of the maximum and the subsequent decline of the VLT-SD cycle can be seen in more detail in the light curve of Fig. 1 (1983–1994). The colour index $u-v$ clearly shows the blueing trend during the decline.

3.2. R 110 = HDE 269662, B9 I:eq - G

The main results of the $VBLUW$ and $uvby$ monitoring campaigns have been discussed by van Genderen et al. (1997b) in combination with scattered observations dating back to 1957 and which were mainly collected for the study of the SD-activity on time scale of decades.

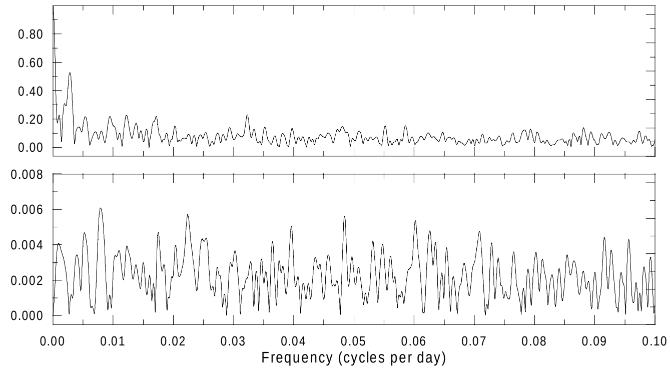

Fig. 10. Spectral window (top) and amplitude spectrum (bottom) for V measurements of R 42.

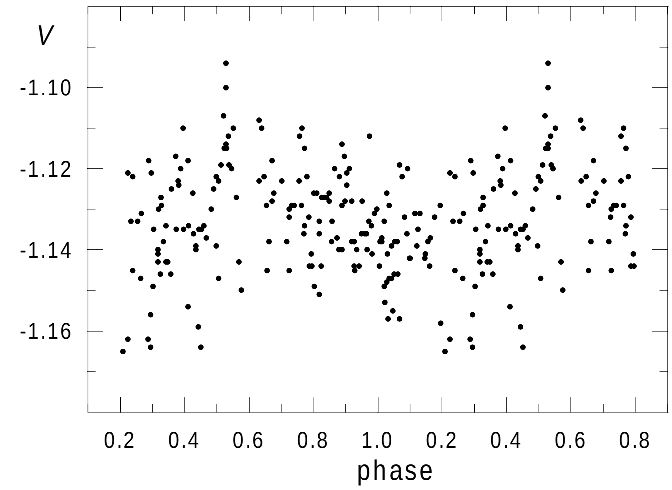

Fig. 11. The V (log intensity) phase diagram of R 42 with $P = 128$ d. Bright and blue are up.

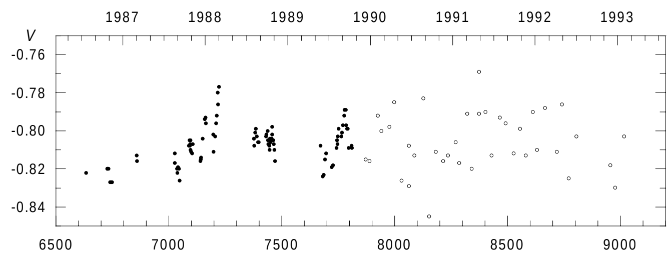

Fig. 12. The complete light curve in V of R 45 for 1986–1993 relative to the comparison star and in $\log$ intensity scale. Bright is up (Hipparcos data ○, our data ●).

We discuss here the detailed photometry related to the microvariations. The star is an LBV which reached a maximum early 1993 (JD 244 9000) with $V_J \sim 9.7$.

The detailed light curves show a micro-oscillating behaviour on top of the ongoing SD-activity. These oscillations are smooth and have various amplitudes and time scales: $0\stackrel{\rm m}{.}02$ to $0\stackrel{\rm m}{.}10$ and 50 d to 100 d, respectively. Fig. 8 shows the light curve V_J based on part of the $uvby$ and all $VBLUW$ observations made more or less simultaneously. The colour behaviour for these oscillations is often blue in the maxima and red in the minima. Sometimes the colours behave in the opposite way, sometimes they stay constant. The remainder of the $uvby$ data show large gaps in the sequences which prevent a proper insight in time scales and colour behaviour (though a Fourier analysis does confirm the possible presence of a ~ 0.02 cd^{-1}frequency, see also the right panel of Fig. 8).

According to the time scales, the position close to or in the maximum of the SD cycle and the fact that the temperature is lower than 10 000 K, one would expect microvariations exclusively of the 100 d-type, which is obviously not the case.

3.3. R 42 = HD 7099, B2.5 I

During the $VBLUW$ photometric campaign R 42 appeared to be variable with a total amplitude of $0\stackrel{\rm m}{.}19$ (0.076 in $\log$ intensity scale), which is higher than for normal α Cyg variables of the same spectral type (see Fig. 13 in van Genderen et al. 1992) and more appropriate for LBVs.

There is a slight overlap with the Hipparcos photometry (1990–1993). During that time interval, the total amplitude amounted to $0\stackrel{\rm m}{.}11$ (van Leeuwen et al. 1998). There is no indication for a long-term trend within the last four decades: all magnitudes, starting with the one listed by Feast et al. (1960) until those obtained with Hipparcos, hover around V_J = 10.95 with an amplitude less than $0\stackrel{\rm m}{.}1$. So, in that respect, R 42 is not an LBV.

Fig. 9 shows as an example a portion of the light and colour curves in the $VBLUW$ system during five months in 1989. The colour variations are about twice as large as for other α Cyg variables of the same spectral type. The σ of the four colour indices (see Sect. 3.1) amount to 0.0026, 0.0035, 0.0058 and 0.0032, respectively (compare with Fig. 6 in van Genderen et al. 1990). In most cases the colours are blue in the maxima and red in the minima as expected. At first sight the time scales of the oscillations lie between 10 and 30 d, but it appears that longer time scale oscillations are hidden in the fluctuating brightness (see below).

A Fourier analysis in the frequency interval 0–0.10 cd^{-1} was carried out on both data sets together (in the V band; the Hp magnitudes were transformed to V applying a small correction Δm to the Hipparcos photometry [Table 2 of van Leeuwen et al. 1998]). Fig. 10 shows the resulting spectral window and amplitude spectrum. Weak amplitude peaks occur at 0.0078 cd^{-1} (128 d) and 0.0224 cd^{-1} (44.6 d), these frequencies could be real because they are present in both data sets separately, but they are embedded in strong noise.

The most surprising result is the duration of the longest cycle: if real, its length is unique among the early-type α Cyg variables (see Sect. 4.3). Fig. 11 is the phase diagram for 128 d and shows a visible cyclic behaviour in V (both data sets). The colour indices do not exhibit any significant cyclic behaviour.

A phase diagram folded with 44.6 d (the second best period for the V measurements) only shows a cyclic behaviour in $B - U$, but then in phase with V as it should. We must stress,

Table 3. Overview of the results of the period search. Amplitudes A (in mag) and phase φ (in degrees, phase zero corresponds to JD=2440000. Roman numbers indicate different possible solutions.).

Object	Frequency	Period (d)	A	φ
R 85 (I)	$f_0 = 0.00256$	390	0.026	18.9
	$f_1 = 0.01197$	83.5	0.030	54.5
R 85 (II)	$f_0 = 0.00255$	392	0.030	22.9
	$f_1 = 0.01469$	68.1	0.023	29.1

though, that the composite light curve based on the simultaneous fit of both periods does not reproduce the morphology of the light curve: the overall residual decreases by only 10%, and the resulting amplitudes are far too small (not exceeding $0\overset{m}{.}015$) to combine to any large amplitude variations. We have, therefore, not included these results in Table 3.

3.4. *R 45 = HD 7583,* A0 Ia$^+$

During the $VBLUW$ photometric campaign R 45 appeared to be variable with a total amplitude of $0\overset{m}{.}13$ (0.052 in log intensity scale) which is normal for an A-type hypergiant (see Fig. 13 in van Genderen et al. 1992). The Hipparcos observations were made directly after the campaign. The amplitude of the variations was of the same order (van Leeuwen et al. 1998). There is no significant long-term trend present when scattered observations within the last decades are considered.

Fig. 12 shows the complete light curve in V (1986–1993) for both data sets (○ for the Hipparcos data) relative to the comparison star and in log intensity scale. The mean errors per data point vary between 0.001 and 0.004 in log intensity scale. We applied a small correction to the Hipparcos data (Table 2 of van Leeuwen et al. 1998) and transformed them to the same scale as for the other set.

Fig. 13 shows a characteristic portion of the light and colour curves in the $VBLUW$ system during five months in 1989. The $U-W$ curve is omitted because of low readings in the W channel. Colours are blue in the maxima and red in the minima which is normal for α Cyg variables. Also the amplitude of the colour variations is normal for this spectral type. The time scales of the oscillations is difficult to estimate, but lies in the order of 1–2 months.

A Fourier analysis of the V data was carried out (both data sets together, the Hp magnitudes corrected by Δm [see Table 2 in van Leeuwen et al. 1998]) in the frequency range 0–0.10 cd^{-1}, and the resulting spectral window (top) and amplitude spectrum (bottom) are given in Fig. 14.

A strong peak in the window function at 0.0031 cd^{-1} (322 d) corresponds with a strong peak in the amplitude spectrum, most likely representing the nearly-annual cycle. A nearby peak in the latter diagram at 0.0053 cd^{-1} could be the half annual cycle. Other peaks lie at 0.0207 cd^{-1} (48 d) and 0.037 cd^{-1} (27 d), and

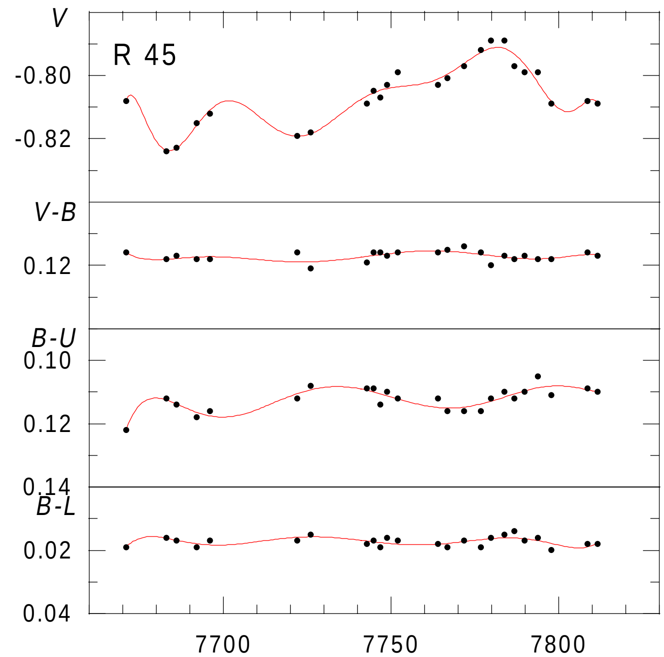

Fig. 13. A portion of the light and colour curves of R 45 in the $VBLUW$ system relative to the comparison star and in log intensity scale as a function of JD-244 0000. Bright and blue are up, full lines are polynomial fits.

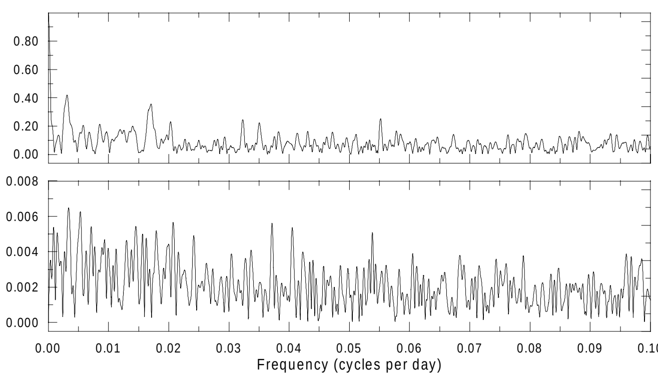

Fig. 14. Spectral window (top) and amplitude spectrum (bottom) for V measurements of R 45.

there are many others that are only slightly lower. We conclude that the period search does not give unambiguous results.

4. Discussion and conclusions

We have investigated the photometric characteristics of four α Cyg variables. Two of them belong to the LMC: R 85, an emission-line object and suspected LBV, and R 110 an active LBV. According to the photometry R 85 is a true and active LBV also, but not so spectacular. Two other stars are SMC members: R 42 and R 45. For both the search for a period was troublesome, which even becomes worse if the time base is made longer (say from 3 to 5 y). This could mean that the multi-cyclic oscillations are disturbed by strong stochastic noise (Sect. 4.5).

4.1. R 85 = HDE 269321

No detailed spectroscopic analysis exists for R 85. Its spectrum is B5 Iae (Feast et al. 1960). The suspicion that R 85 could be an S Dor variable with a small range was expressed by Stahl et al. (1984). Our new photometry confirms that classification and it appears that R 85 is subject to the two types of SD-phases defined by van Genderen et al. (1997a,b). Thus, there is a VLT (Very-Long Term)-SD phase with an estimated time scale of 4 decades and an amplitude of $0\overset{m}{.}3$, and, only occasionally, a normal SD phase with a time scale of 400 d and an amplitude of $0\overset{m}{.}12$.

The microvariations show a mix of the two types normal for active LBVs (van Genderen et al. 1997b): the α Cyg-type and the 100 d-type variation. Time scales lie between 15 and 180 d with an amplitude of $0\overset{m}{.}3$. There exists a preference for time scales of the order of 83 d, 67 d and 40 d. The ratio between the second and first amounts to 4/5 and between the third and second to 3/5. Such ratios, if not accidental, often occur among multi-mode pulsating stars.

The likely explanation for the mix of the two types of microvariations mentioned above is that, presumably R 85 just has the transition temperature somewhere between 10 000 K and 15 000 K ($\sim$ 14 000 K). Note that R 85 is the second LBV where both types were seen together; the other one is HR Car (van Genderen et al. 1997b).

4.2. R 110 = HDE 269662

This LBV had a spectacular behaviour during our photometric campaign 1989–1994: it showed a steep rising branch and a maximum (van Genderen et al. 1997b). The spectrum changed from late B to G. The microvariations have time scales of 50–100 d and their colour behaviour is mixed, while, considering the relatively long time scales, one expects them in general to be red in the maxima and blue in the minima. Probably, the star's position in the HR-diagram (extremely low temperature and luminosity) compared to other LBVs (Stahl et al. 1990) giving it a different structure, have something to do with the mixed colour behaviour. (It must be noted that the latter characteristic is roughly similar to that of S Dor's microvariations in maximum light: van Genderen et al. 1997a).

4.3. R 42 = HD 7099

R 42 is an abnormal α Cyg variable with a total light amplitude of $0\overset{m}{.}19$, which is even larger than for hypergiants and is often exhibited by LBVs in quiescence. Colours are usually blue in the maxima and red in the minima as they should, but the ranges of the colours are twice as large as for other variables of the same spectral type. The search for a period was troublesome, probably due to a complicated type of multi-cyclicity and the contribution of stochastic secondary processes. Most surprising is that the strongest cycle in the power spectrum is so long: $\sim$ 128 days. This is quite abnormal for such an early spectral type (B2.5 I)—that is, unless it represents the rotation period of the star which is of the same order as for a number of later BA-type supergiants investigated by Kaufer et al. (1996, 1997). These authors suggest the presence of co-rotating weak magnetic surface structures as the source for the rotationally modulated Hα line-profile variability originating in the lower wind region. If the 128 d period in the brightness of R 42 is indeed caused by rotational modulation, perhaps too long for such an early spectral type, it might mean that magnetic fields and star spots are present. Therefore, it is recommended that a detailed spectroscopic study should be made to establish the true nature of the variability of R 42.

4.4. R 45 = HD 7583

The A0 hypergiant R 45 is visually the brightest star of the SMC (after the maximum stage of the LBV R 40, van Genderen et al. 1997b). Wolf (1973) has done a model atmosphere analysis and derived physical parameters, showing that the atmosphere is near the limit of instability. There are striking similarities with HD 33579, the A3-hypergiant in the LMC. He also found strong indications that emitting material of the chromosphere is falling back to the star's surface. Stellar wind properties were derived by Stahl et al. (1991), and Humphreys et al. (1991) considered R 45 a "normal" A-type hypergiant as opposed to those with an enhanced He abundance due to their post-red supergiant evolutionary stage. R 45 should then be a post-main sequence star evolving to the red, similar to HD 33579 (Nieuwenhuijzen et al. 1998).

Its variability in light as well as in colour is normal with respect to other α Cyg variables (hypergiants) of roughly the same spectral type. The search for a period was troublesome, probably due to multi-cyclicity and the contribution of stochastic secondary processes.

4.5. Instabilities in theoretical models

Evidence is now accumulating that the intricate photometric variability of α Cyg variables, among which the LBVs, is caused by multi-cyclic oscillations combined with a stochastic component (van Genderen et al. 1997b; Sterken et al. 1997, 1998; Paper I and the present paper).

During the last few years, dynamical strange-mode and mode-coupling instabilities were found in theoretical models of massive stars (Glatzel & Kiriakidis 1993; Kiriakidis et al. 1993; Glatzel 1997). A strong non-adiabaticity in the stellar envelopes is necessary for strange modes to occur (Zalewski 1993). Essential for pulsational instability in α Cyg variables is also a sufficiently high L/M ratio (e.g. Gautschy 1992) on which depends the radiation pressure. The envelopes possess three opacity peaks: one by metals (the Z-bump) and two by the partial ionization zones of He and H, which cause density inversions and, consequently, acoustic cavities giving rise to a rich unstable oscillation spectrum (Gautschy & Glatzel 1990; Glatzel 1997; see also the excellent review papers on stellar pulsations by Gautschy & Saio 1995, 1996).

It is therefore not unrealistic to suppose that such phenomena might result in intricate light variations of evolved massive stars because of linear superposition of many excited modes. There are no direct objections against presuming that these multiple excited modes appear superimposed on top of the S Dor phases (which have annual-to-decadal time scales) whether they are caused by the relaxation oscillations in the outer layers of LBVs—as theoretically discovered by Stothers & Chin (1993, 1994, 1995)—or by the pulsation cycles leading to "outburst" in the models of Cox et al. (1997) and Guzik et al. (1997). It is then also conceivable that LBVs near minimum should show an oscillation spectrum of a different kind then near maximum. The reason is that the radius of the star/envelope is small in the first case and large in the second case. The size has a direct impact on the physical structure. However, the physics of strange modes and their consequences on the continuum light is still not well understood. Based on our various monitoring campaigns we have indeed observed different kinds of microvariations (often with a multi-periodic character) on top of the SD phases. Guzik et al. (1997) find in their models oscillations with periods of 5–40 d, indeed typical for the α Cyg-type microvariations which we have found in LBVs fainter than the median magnitude (van Genderen et al. 1997a, b).

The LBV models of Stothers and Chin have achieved many points of detailed agreement with the observations of SD phases (Stothers & Chin 1996, 1997)—despite Glatzel's (1997) criticism. A recently described fact in favour of these models is that LBV nebulae often represent H-rich envelopes of RSGs ejected before the "blue LBV phase" (Nota & Clampin 1997; Smith 1997).

However, it is still a matter of debate what exactly pulsates: the outer envelope, or the underlying star (or perhaps both). Stothers & Chin predict envelope pulsations during the "blue LBV phase" (thus after the RSG stage) and characterize the accompanying slow cyclic light variations as "eruptions" with the expectations that thick shells are then ejected, "while the star moves hardly at all on the H-R diagram, the observable changes being produced primarily by the optically thick ejected cloud" (Stothers & Chin 1996; actually, this is similar to the "classical" interpretation of the observed light- and colour variations of SD phases independently proposed by Martini 1969 and van Genderen 1979, and that $M_{\rm bol}$ stays more or less constant: Sect. 4.3 in the latter paper). While Stothers & Chin predict quasi-regular cycles of the annual-to-decadal time scales, which is the case indeed, we believe that ejections of that caliber do not occur because they have not been observed. We rather believe that after expansion the envelope contracts again wihout losing much of its mass. It is true that significant mass-loss variations exist in some LBVs, but no general correlation between mass loss and photospheric parameters has been found (Leitherer et al. 1992; de Koter et al. 1996) such as for the radius (Leitherer 1997). If during every SD cycle a thick shell were ejected, then e.g. AG Car and S Dor should have been enshrouded by conspicuous nearby clouds, caused by centuries, if not millennia, of SD phases with a time scale of 1–10 yr. That is also the reason not to call them "outbursts" (or "eruptions") as has been proposed by Lamers 1987, Leitherer et al. 1992 and van Genderen et al. 1997a. Guzik et al. (1997) define an "outburst" when the outward photospheric radial velocity suddenly becomes large, and the radii of outer zones monotonically increase during several "would-be pulsation periods". Quantitative information on the possible expelled mass is lacking; therefore, it is uncertain whether this definition is correct.

Others believe that the cyclic variations of LBVs, (with an annual-to-decadal time scale), the SD phases, are caused by the underlying stellar radius (Leitherer et al. 1989; de Koter et al. 1996; van Genderen et al. 1997a), although de Koter et al. (1996) conclude that they are induced by the combined effect of an increase of the stellar radius and a reduced effective gravity. A pseudo-photosphere in the wind is not likely to occur (de Koter 1997).

Perhaps, the truth on what pulsates, lies somewhere between these suppositions and depends also on the individual LBV.

However, considering the conspicious individuality of the photometric characteristics of LBVs, one is inclined to believe that most of the instability sources are seated in a somewhat less-bound outer envelope. (According to the models of Stothers and Chin the envelope is even nearly detached from the underlying star. Also in Maeder's (1992, 1997) "geyser model", the outer gaseous photospheric layers float upon a radiative layer, according to him a favourable situation for "giant outbursts").

After all, this could offer much freedom (intuitively) for the dynamical consequences and, thus, for the annual-to-decadal brightness variations and the significant mass-loss variations in some LBVs (see above).

On the other hand, spectroscopically as well as with regard to their morphology and physics of circumstellar or ring nebulae, LBVs show more homogeneity (e.g. Nota & Clampin 1997; Smith 1997; Hutsemékers 1997). Computations of the behaviour of circumstellar gas around such objects can be well modelled and predicted and provides a powerful tool for the investigation of the stellar mass-loss history (Garcia-Segura et al. 1996).

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