Light variations of massive stars (alpha Cyg variables). XVIII. The B[e] supergiants S 18 in the SMC and R 66 = HDE 268835 and R 126 = HD 37974 in the LMC

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Light variations of massive stars (α Cyg variables)⋆

XVIII. The B[e] supergiants S 18 in the SMC and R 66 = HDE 268835 and R 126 = HD 37974 in the LMC

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Abstract. We discuss photometric monitoring ($VBLUW$ system) of three B[e] supergiants. All three objects appear to be variable. They are subject to two (R 66 and R 126 in the LMC) and three (S 18 in the SMC) types of light oscillations which range from a few days to years, and are probably due to pulsations. We argue that a classification as α Cyg variables is justified. Their classification as mixed B[e]/S Dor variables is less certain, though not impossible. Also based on other cases, a strong B[e]–S Dor variable connection seems to be present.

Key words. stars: variables – stars: supergiants – stars: individual S 18, R 66 = HDE 268835, R 126 = HD 37974

1. Introduction

This eighteenth paper in the series of photometric monitoring of massive stars deals with three B[e] supergiants in the Magellanic Clouds. It is generally believed that most of the B[e] supergiants are non-variable. We show that this is not the case for our three objects and that their classification as α Cyg variables is justified (see title).

B[e] supergiants are massive stars, the relatively high rotation of which is supposed to be responsible for the non-spherical wind (e.g. Zickgraf 1999). They can be either post-main sequence stars, or post-red supergiants. In the latter case their original rotation was too mild to develop a B[e] disk, but by moving to the left in the HR-diagram the rotation speeds up so that a B[e] disk could well be created (Lamers et al. 1999). The presence of P Cyg profiles indicates a very high luminosity and a mass-loss rate $\dot{M} \gtrsim 2 \times 10^{-6}\ M_{\odot}\ \mathrm{y}^{-1}$ (van Genderen et al. 1983).

Most of the B[e] supergiants are characterized by a two-component stellar wind consisting of a normal hot star wind from the polar zones and a slow dense disk-like wind from the equatorial regions. Therefore, they show hybrid spectra, i.e. narrow low-excitation lines and broad high-excitation absorption features (Zickgraf et al. 1985, 1986; Zickgraf 1999). Marked spectroscopic differences between individual B[e] supergiants are attributed to different inclination angles of the equatorial plane with respect to the line of sight.

Fundamental parameters of stars showing the B[e] phenomenon were recently derived by Cidale et al. (2001) based on a spectrophotometric study of the Balmer discontinuity. These authors demonstrate that the parameters of temperature, gravity and luminosity so obtained are model-independent.

We discuss Walraven $VBLUW$ photometry of the three objects. For the first object, S 18 in the SMC (perhaps a binary), a preliminary light curve showed its strong variability (van Genderen 2001). The other two objects, R 66 and R 126 in the LMC, also appear to be variable, but much less strong.

2. Observations and reductions

The three objects were observed with the 90-cm Dutch telescope equipped with the simultaneous $VBLUW$ photometer of Walraven at ESO, Chile. Further particulars on the observing procedure can be found in the previous papers of this series. Observations were made of S 18 (SMC) from 1987 to 1991 and of R 66 = HDE 268835 and R 126 = HD 37974 (LMC) from 1989 to 1991.

The precise effective wavelengths and the band widths of the five channels are given by de Ruyter & Lub (1986).

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⋆ Based on observations obtained at the European Southern Observatory at La Silla, Chile.

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Table 1. The average standard deviation (σ) per data point (in units of 0.001 log intensity scale) for the three programme stars relative to the comparison star. The aperture used is $16\farcs5$.

Star	Dates	V	$V-B$	$B-U$	$U-W$	$B-L$
S 18	1987–88	7	7	10	21	8
	1989–91	10	13	18	43	18
R 66	1989–91	3	2	4	7	3
R 126	1989–91	3	3	4	8	4

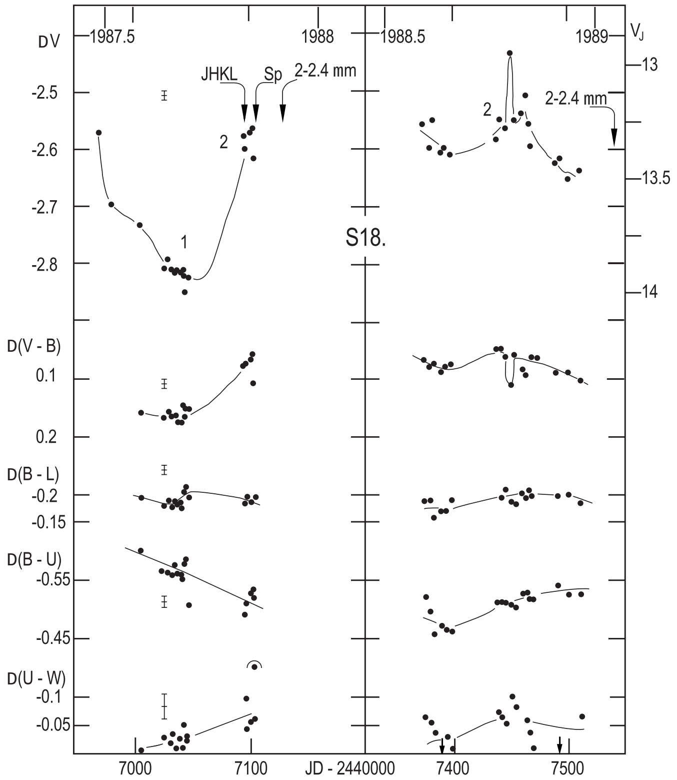

Fig. 1. The light and colour curves of S 18 in 1987 (panel at the left) and 1988 (panel at the right) in log intensity scale. Bright and blue are up. At the right hand side the V magnitude of the UBV system (with subscript J).

The L band (3840 Å) contains the Balmer limit and the U band (3620 Å) contains the Balmer jump and partly the Balmer continuum, while the W band (3230 Å) lies completely in the Balmer continuum. The photometric data in the $VBLUW$ system are given in log intensity (I) scale, as usual. Table 1 lists the programme stars, the aperture used and average standard deviations (σ) per data point (nightly averages) relative to the comparison star HD 3719 for S 18 and HD 33486 for R 66 and R 126 all in log intensity scale. For S 18 we list them for two different data sets. Average mean errors (used for the error bars in the figures) are smaller by about a factor of two to three.

Table 2 lists the photometric results for the comparison stars and the three programme stars. The photometric parameters V and $B-V$ of the UBV system (with subscript J and in magnitude scale) were transformed using formulae given by Pel (1986, see van Genderen et al. 1992). The observations, the differential intensities and colours relative to the comparison stars will be published in the Journal of Astronomical Data. Due to the possible presence of emission lines in the V and B pass bands, the transformed values V_J and $(B-V)_J$ can be in error by at most $0\fm1$. The error for S 18 is likely larger than for the other two objects.

3. The light and colour curves. Time scales of the variability

All figures depicting the $VBLUW$ light and colour curves are in log intensity scale and the error bars represent twice the standard deviation (Figs. 1–3), or the mean error (in Fig. 4). The hand-drawn curves help the eye see the variations clearly.

3.1. S 18 = AzV 154, B[e]

S 18 is a very peculiar emission-line supergiant in the SMC, showing a number of outstanding spectral characteristics. Apart from the B[e] "phenomenon" (see for the nomenclature Lamers et al. 1998), thus showing the two-component stellar wind and the presence of hot circumstellar dust (Zickgraf et al. 1986), it shows variable high-excitation lines and a high N abundance (Shore et al. 1987), Fe II- and Fe I emission lines, a broad TiO emission band (Zickgraf et al. 1989), and an He II 4686 emission which is sometimes absent. Besides variability, the H emission lines sometimes show P Cyg profiles and sometimes do not (Sanduleak 1977; Azzopardi et al. 1981; Shore et al. 1987; Zickgraf et al. 1989; Massey & Duffey 2001).

Shore et al. (1987) and Zickgraf et al. (1989) favour the presence of an additional variable source of high-energy radiation in a binary system with an accretion disk. In this model the high temperature ionizing photons arise from an optically-thick shock due to accretion directly onto the companion of the supergiant, instead of accreting on its disk. The companion could be a neutron star, a He star, or a main-sequence star (Shore et al. 1987). The system is likely viewed more or less pole-on (Zickgraf et al. 1989).

An alternative origin of the strongly-variable He II 4686 emission could be a variable heating of the inner edge of the disk (or a single region) by a variable mass flow (Zickgraf et al. 1989).

A spectral study of S 18 between 3960 Å and 7800 Å and a number of related stars is presented by Nota et al. (1996). Morris et al. (1996) obtained IR spectra and noted a ^{12}CO overtone and He I 2.112–3 μm emission. They suggested that a binary model is not necessary: the He II 4686 emission is probably emitted inside the disk. Massey & Duffey (2001), comparing a spectrum of S 18 with that of S Dor in a "low state" in October 1996 (that is, on the rising branch to a new maximum after minimum No. 16, see Fig. 7 in van Genderen et al. 1997a), conclude that S 18 could well be an S Dor variable (LBV).

Table 2. The average photometric parameters of the comparison stars (taken from Pel 1993) and the three 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 data points.

Star		Sp	V	$V-B$	$B-U$	$U-W$	$B-L$	V_J	$(B-V)_J$	N
	HD 3719	A1m	0.004	0.052	0.452	0.136	0.203	6.87	0.12	
S 18		B[e]sg	−2.660	0.180	−0.100	0.090	0.010	13.50	0.42	142
	HD 33486	B9V	−0.390	−0.010	0.330	0.078	0.112	7.86	−0.04	
R 66	HDE 268835	B8p	−1.508	0.069	0.062	0.108	0.024	10.65	0.16	40
R 126[1]	HD 37974	B0.5 Ia$^+$	−1.632	0.088	−0.087	0.040	0.009	10.96	0.21	84

Notes:
[1] This object has practically the same photometric parameters as in 1966 (van Genderen 1970).

One of the supposed characteristics of B[e] stars is the absence of a significant photometric variation, but that is a misunderstanding as shown by a preliminary light curve (Fig. 19 in van Genderen 2001) and in the present paper.

Figure 1 shows the light and colour curves relative to the comparison star between 1987.5 and 1989. The dates of $JHKL$ photometry, optical spectroscopy (Zickgraf et al. 1989) and IR spectroscopy (McGregor et al. 1989) are indicated by arrows. The extrema are marked by a "1" (a minimum) and a "2" (two maxima).

Figure 2 shows the light (V) and colour curves between 1989 and 1991, and Fig. 3 the corresponding light curves in B and the three near-UV channels L, U and W. Since the measurements in the W band were seriously influenced by low photon numbers, the scatter is large and a number of data points had to be rejected. Therefore, only a schematic light curve has been sketched, revealing no significant short-time scale details. Six selected extrema in the V curve of Fig. 2 and in the B curve of Fig. 3 are marked by the letters "a" to "f".

Before analyzing the light and colour variations it is necessary to establish which emission lines contribute to the flux in the various pass bands. The B band contains – right at maximum response – the prominent Hγ line. Other lines are of much less importance. The famous He II 4686 line, which varies beteen total absence to a strength close to that of Hβ (Sanduleak 1978), lies close to the minimum of the B response curve, thus, is of no influence whatsoever.

The influence of the emission lines in the V band is less than in the B band, because, if they are prominent, like the He I 5875 line, then they are situated at a low response level.

Not much is known about emission lines and their behaviour in the three near-UV channels. The only IUE spectrum which covers our W band is that of Shore et al. (1987) made on 13 July 1981 (their Fig. 3). It shows many unidentified emission lines. We suppose that this will also be the case for the U band.

A careful inspection of Figs. 1 and 3 reveals three types of light variations:

1. A short-term variation on a time scale of days which appears as dips and peaks, in all channels. The range amounts to $0^{\mathrm{m}}.1$–$0^{\mathrm{m}}.2$ and is often largest in B, see for example at ~JD 2 448 200 (Fig. 3), showing a $0.25^{\log I}$ ($0^{\mathrm{m}}.5$) dip in B and much less in the other channels (note that due to an instrumental failure the L data point had to be rejected and the assumed dip is indicated by the dotted lines). Obviously, we are dealing with stellar-continuum variations, perhaps due to α Cyg-type pulsations of the supergiant, and a causally connected H emission-line variability due to fluctuations in mass-loss rate (note that the Hγ line lies at maximum response of the B band). Thus, somewhere in the system, there should be hot gas, such as a hot spot (in a disk or in a stellar atmosphere of a companion to the supergiant).

2. A ~150 d continuum variation with a variable light amplitude: 0.1–$0.4^{\log I}$ ($0^{\mathrm{m}}.25$–1^{m}) which progressively increases from V to U (note that the W is not reliable). The colours are bluer in the maxima than in the minima. This could point to temperature variations (due to stellar pulsations?) on a cyclic basis with a superimposed strong variable influence of numerous metal lines in the near-UV.

A strict periodicity cannot be established, also not when combined with the light curve fragments of Fig. 1.

Important to note is the near-coincidence of the light maximum ($V \sim 13^{\mathrm{m}}.3$ around JD 2 447 100) in Fig. 1 (left panel) and an optical spectrum and $JHKL$ photometry by Zickgraf et al. (1989). It appears that then the He II 4686 line is absent altogether. It is also of interest to note that Zickgraf et al. (1989), in order to determine the continuum energy-distribution, assumed that the star is hardly variable, and therefore applied an $UBVRI$ data set of 13 August 1983 and the $JHKL$ set of 28 to 30 October 1987 (see Fig. 1). By a lucky coincidence, the V magnitude of the 1983 set ($13^{\mathrm{m}}.31$) was accidentally very close to the magnitude for the maximum of 1987 (with a transformed value $V_J = 13^{\mathrm{m}}.3$).

About a month after the last observations in Fig. 1, McGregor et al. (1989) obtained near-IR spectroscopy (2.0–2.4 μm), indicated by arrows in Fig. 1, but they did not mention the precise dates.

3. A long-term variation on which the ~150 d oscillation discussed in 2. is superimposed, with a time scale of ~2 y and a amplitude amounting to ~$0^{\mathrm{m}}.7$, see in Figs. 2 and 3 the dashed-dotted curves sketched as a lower

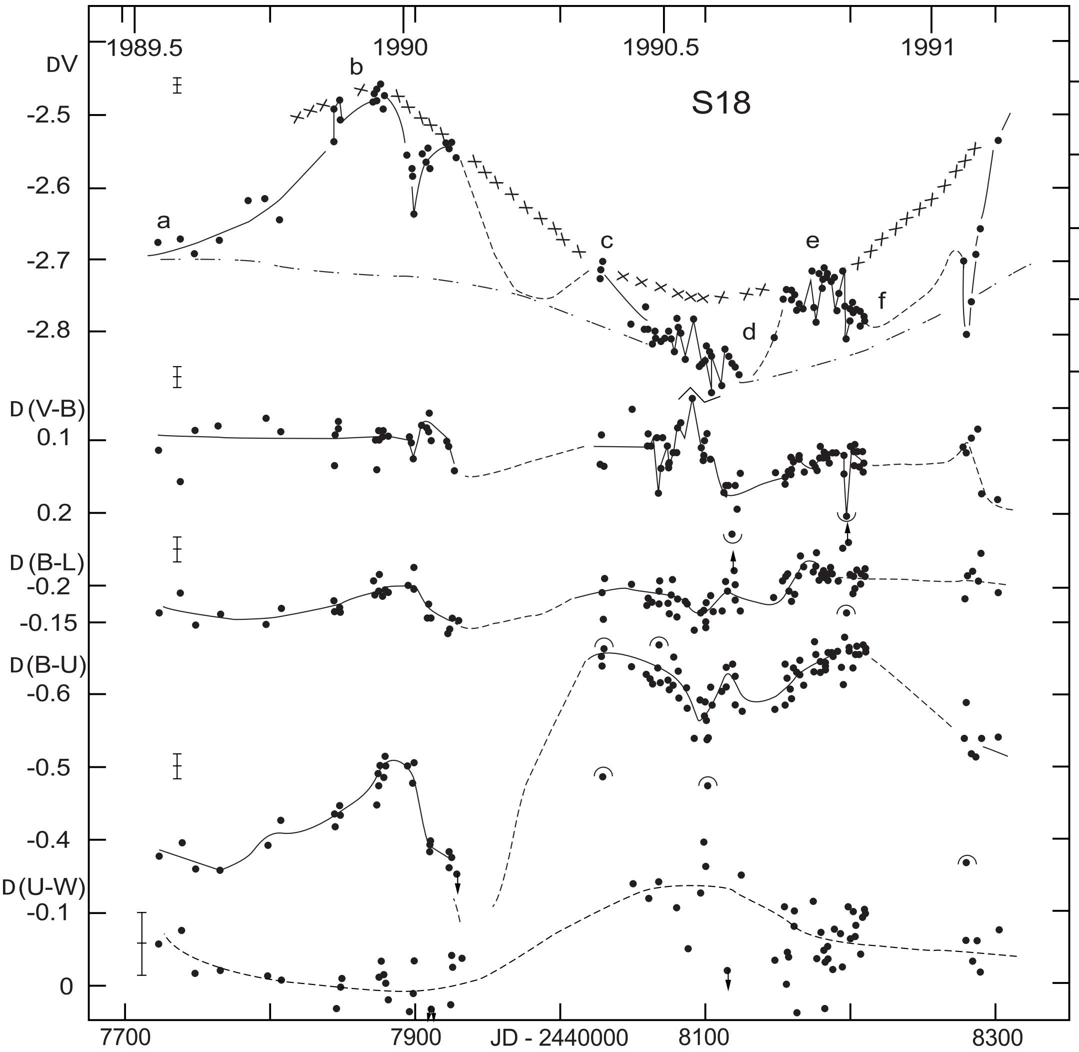

Fig. 2. The same as Fig. 1, but now for the time interval 1989.5–1991.1.

boundary line for the minima and the curve with crosses as an upper boundary line. The W curve is uncertain anyway.

In order that this ∼2 y variation can be identified as an S Dor (SD)-phase (thus, whether the supergiant is also to be classified an S Dor variable), the minimum should be bluer than the maximum. The colour curves in Fig. 2 show hardly any significant blueing in $V-B$ and $B-L$, while the blueing in $B-U \sim 0.2^{\log I}$ ($0\overset{\mathrm{m}}{.}5$), and $U-W \sim 0.12^{\log I}$ ($0\overset{\mathrm{m}}{.}3$), is much too big. The global impression is that this wave does not represent a typical SD-phase. However, one should realize that the colours could very well be seriously disturbed by emission-line variations, especially in the near-UV. After all, in a minimum of an SD-phase the star is smaller and hotter, thus better able to ionize circumstellar material.

To be more quantitative about the excessive UV radiation in the visual minimum: S 18 rises in the U band (3400–3800 Å) by $\sim 0\overset{\mathrm{m}}{.}5$ relative to the light in the V and B bands and even relative to that in the L band (3700–4000 Å). The rise in the W band (3100–3300 Å) amounts to $\sim 0\overset{\mathrm{m}}{.}75$ relative to V and B. In other words: in the near-UV the long-term variation has a very low amplitude, see dashed-dotted curve in Fig. 3.

3.2. R 66 = HDE 268835, B8p

R 66 has a dense, rather cool expanding circumstellar dust shell, and has many characteristics in common with S Dor variables in maximum light (Stahl et al. 1983). The excessive free-free radiation in the red and IR is negligible in the V band (van Genderen et al. 1983). No light variation of any importance has ever been detected, apart from the Hipparcos photometry (1989–1993) which indicated a possible variability amounting to $\sim 0\overset{\mathrm{m}}{.}05$, but the noise is large (HIP 22989, ESA 1997).

The results of our photometry, largely made simultaneously with that of the Hipparcos satellite, are depicted in Fig. 4, upper panel. It shows the V light curve ($VBLUW$ system) relative to the comparison star. Indeed, R 66 is definitively variable. The nightly averages in V of the comparison star (HD 33486) with respect to standard stars (in the natural scale of the $VBLUW$ system) are shown in the bottom panel of Fig. 4. It is obvious

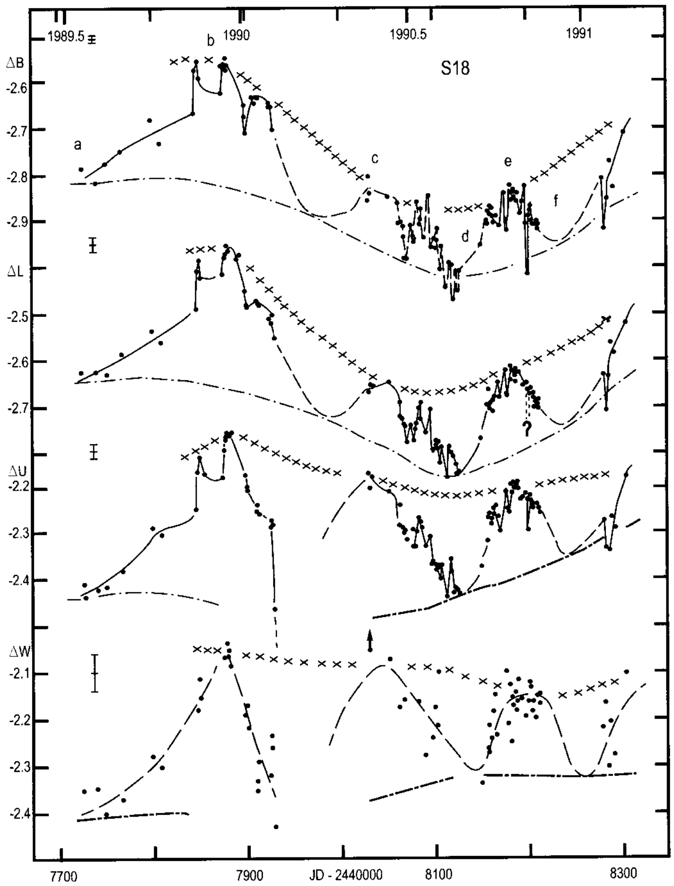

Fig. 3. The same as Fig. 2, but now only for the light curves in B, L, U and W.

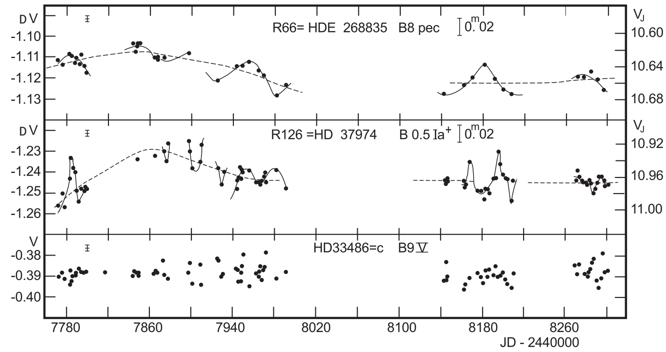

Fig. 4. The light curves (V of the $VBLUW$ system, in log intensity scale) of R 66 (first panel) and R 126 (second panel) relative to the comparison star HD 33486 in the interval 1989–1991. Error bars represent twice the mean errors of the nightly averages. The third panel at the bottom depicts the nightly averages of the brightness of the comparison star HD 33486.

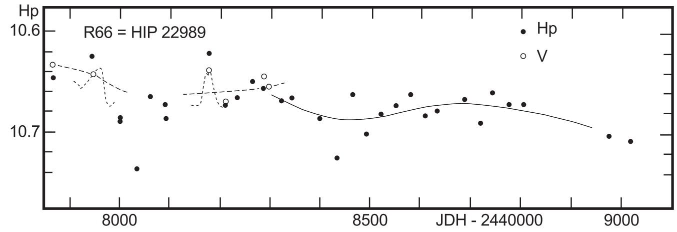

Fig. 5. The light curve of R 66 in the magnitude scale of the Hipparcos satellite (Hp) in the interval 1989–1993 (dots). Part of the V light curve in Fig. 4 is represented by the dashed curve (1989–1991) and two peaks of the short time scale variations are dotted. The six circles are observations from Fig. 4 made close to the dates of the Hipparcos photometry.

that HD 33468 is stable, while R 66 shows a long-term wave with a possible time-scale of hundreds of days and an amplitude of $\sim 0\overset{\mathrm{m}}{.}06$ (dashed curve). A short time-scale oscillation is superimposed (full curves) with a possible cyclicity of two months and an amplitude of up to $0\overset{\mathrm{m}}{.}03$.

Figure 5 shows the light curve for the Hipparcos magnitude scale Hp (nightly averages). Statistical aspects of the use of these photometric data in variability research have been described by van Leeuwen et al. (1997) and in vol. 3 of ESA (1997). A variabilty study of a selected sample of massive evolved stars has been undertaken by van Leeuwen et al. (1998). They show that the Hp scale is $\lesssim 0\overset{\mathrm{m}}{.}1$ fainter than the V of the UBV system. Observations in V ($VBLUW$ system) and transformed to the V of the UBV system (with subscript J) made within a few days from the Hipparcos photometry, or even at the same day, are plotted as circles. The differences are not more than $\sim 0\overset{\mathrm{m}}{.}03$. The dashed curve is part of the long cycle in Fig. 4 (assuming that the transformed V equals Hp). The Hp data seem to support this long-term cycle. A second cycle in the Hp data is suggested by the full curve (sketched by eye) after our photometry came to an end. The time scale of these two cycles amounts to $\sim$400 d. Two of the short cycles from Fig. 4 are sketched as dotted curves.

A Fourier analysis was carried out in the frequency interval 0.002–0.3 d^{-1}. In order to avoid the effects of the long-term variability, the data obtained before JD 2 448 000 were corrected for the slow trend indicated by the dashed line in Fig. 4. The amplitude spectrum and spectral window are shown in Fig. 6. The strongest frequency peak occurs at $f_1 = 0.018$ d^{-1} with an amplitude of $0\overset{\mathrm{m}}{.}0036$. After prewhitening with this frequency, a secondary possible frequency appears at 0.009 d^{-1} $\sim \frac{1}{2} f_1$. The combination of both frequencies yields a residual of $0\overset{\mathrm{m}}{.}002$. f_1 is not in contradiction with the time scale of the microvariations amounting to $\sim$2 months in Fig. 4.

R 66 was also observed in the $uvby$ system by the LTPV (Long-Term Photometry of Variables) group organized by Sterken (1983) in 1982 and 1983 during 19 nights (Manfroid et al. 1991) and discussed by Zickgraf et al. (1986). Figure 7 shows the y light curve (magnitude scale) indicating two descending branches $\sim$300 d apart. The average magnitude, the amplitude and the time scale are of the same order as those in the years 1989–1993 (Figs. 4 and 5). A rough estimation for the average cycle length between 1982 and 1993 reveals $\sim$380 d (nine cycles).

The colour variations are small, but significant (the curves are not shown). For the long wave (hundreds of days) the $V - B$ and $U - W$ are bluest in the descending

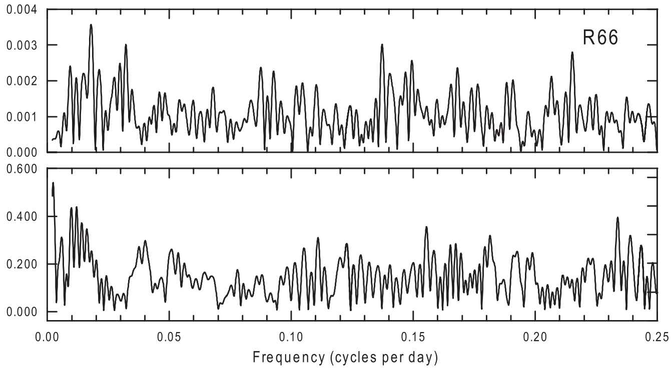

Fig. 6. Amplitude spectrum (top) and spectral window (bottom) for R 66.

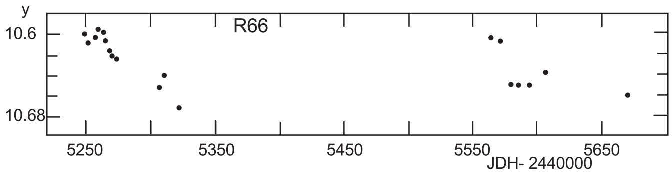

Fig. 7. The light curve of R 66 in $y = V_J$ of the Strömgren system, in 1982 and 1983.

branch of the light curves (amplitudes $0.005^{\log I}$ ($0\overset{\mathrm{m}}{.}013$) and $0.01^{\log I}$ ($0\overset{\mathrm{m}}{.}025$), respectively), while the $B - L$ and $B - U$ are bluest in the light maximum (amplitudes $0.005^{\log I}$ ($0\overset{\mathrm{m}}{.}013$) and $0.008^{\log I}$ ($0\overset{\mathrm{m}}{.}020$), respectively). It is not unlikely that emission-line variations add to the continuum variations. These emission-line variations may be caused by a variable mass-loss rate, induced by the stellar oscillations. No significant colour variations are present during the short cycles (with a time scale of two months).

3.3. R 126 = HD 37974, B0.5Ia$^+$

R 126 is a peculiar hypergiant (spectral type from Zickgraf et al. 1985) with a hybrid spectrum: broad UV absorption lines and sharp emission lines, indicating the existence of a two-component stellar wind leading to a disk-like outer configuration (Zickgraf et al. 1985). These authors show that the disk is also responsible for an IR excess. Considering the characteristics of similar types of stars like R 66 (Sect. 3.2), no significant flux to the V band by the free-free emission is to be expected (van Genderen et al. 1983). This has been confirmed by the continuum energy contribution (Zickgraf et al. 1985). No significant light variation has ever been detected since the first photometry by Smith (1957) in January 1954 ($m_v = 11.03$). Our accurate photometry proofs that R 126 is variable. Figure 4 (middle panel) shows the V light curve relative to the comparison star (bottom panel). Similar to S 18 (Sect. 3.1) and R 66 (Sect. 3.2) there is a long-term oscillation, probably with a time scale of hundreds of days and an amplitude amounting to $\sim 0.02^{\log I}$ ($0\overset{\mathrm{m}}{.}05$) and a superimposed short-term variation in the order of 10–30 d and also with an amplitude amounting to $\sim 0.02^{\log I}$ ($0\overset{\mathrm{m}}{.}05$).

The long-term variation in V, B and L has an amplitude twice as large as in the near-UV (U and W), leading to a redder colour during the light maximum, especially in $B - U$. This is also a characteristic of S Dor variables during their long-term variations, known as SD-phases (van Genderen et al. 1997a, 1997b).

The short-term light variations show, apart from a few exceptions, a slight progressively-increasing amplitude to the shorter wavelengths suggesting pulsations with temperature effects. The exceptions are represented by the prominent peaks around JD 2 447 780, JD 2 448 165 and JD 2 448 195. Here, B definitively shows the highest amplitudes for which the explanation should probably be sought in the prominent influence of the Hγ emission line (Sect. 3.1). Just like in the case of S 18 one can speculate that some of the short-term oscillations are accompanied by an increased mass-loss rate to the disk or bright spot.

A Fourier analysis using PERIOD98 (Sperl 1998) was carried out in the frequency interval 0.002–0.6 d^{-1}. In order to avoid the effects of the long-term variability, the data obtained before JD 2 448 000 were corrected for the slow trend indicated by the dashed line in Fig. 4. The amplitude spectrum and spectral window are shown in Fig. 8. The strongest frequency peak occurs at $f_1 = 0.041$ d^{-1} with an amplitude of $0\overset{\mathrm{m}}{.}003$. After prewhitening with this frequency, a secondary peak appears at 0.024 d^{-1} $\sim \frac{1}{2} f_1$, but the combination of both frequencies does not yield a satisfactory representation of the light curve.

4. Discussion

4.1. S 18

4.1.1. The UV excess, interpretation of the system

The position of S 18 in the two-colour diagrams of Fig. 7 emphasizes its UV excess due to the emission lines of metals. The number 1 indicates the light minimum of 1987 and the number 2 the average of the two maxima of 1987 and 1989 (Fig. 1). The letters "a"–"f" indicate the position of the extrema of the 150 d oscillation (Fig. 2): maxima are encircled. There is no systematic clustering of maxima and minima of the 150 d oscillation (assuming that the extrema 1 and 2 in Fig. 1 are also due to this oscillation). On the contrary, the increasing UV excess from maximum to minimum light of the ∼2 y oscillation is obvious from the wide distance between extrema "a" and "d" in the two lower panels. The colours of the extrema "a" and "d" should be independent of the 150 d oscillation because they are chosen in its minima.

In case the possible S Dor variable in the system of S 18 has a very hot companion as suggested by Shore et al. (1987), one would expect a progressively increasing UV excess from U to W for all extrema. This is not the case considering the location of the extrema of S 18 in the bottom panel of Fig. 7: they should then lie above the reddening line for O-type stars (arrow). One would also expect progressively decreasing light amplitudes for the 150 d oscillation from the visual to the UV, while the opposite is

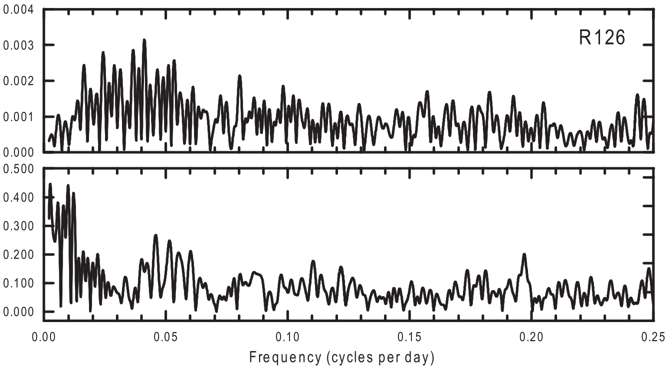

Fig. 8. Amplitude spectrum (top) and spectral window (bottom) for R 126.

observed (Fig. 3). Thus, the presence of a hot companion is not likely unless the companion has a temperature not so much different from the primary (~25 000 K, Zickgraf et al. 1989) and/or much fainter.

What could be the origin of the 150 d oscillation? No hot main-sequence stars, or hot He stars are known with a comparable variability (e.g. a light amplitude in the UV by ~1^{m}. S Dor variables do show oscillations on a time scale of 50 d–150 d if they are in maximum stage (the so-called 100 d-type light variations), but their amplitudes are at most $0\overset{\mathrm{m}}{.}2$ and the colours are usually red in the maxima (van Genderen et al. 1997a, 1997b; van Genderen 2001) and not blue (Sect. 3.1, point 2).

We tentatively conclude that the system of S 18 contains a star at least closely related to S Dor variables (it has been classified as a "possible candidate S Dor variable" by van Genderen 2001), which should be responsible for the ~2 y oscillation. A plausible explanation for the 150 d oscillation is lacking, thus the source is unknown. If there is a companion, it should be of a comparable temperature as the supergiant and/or much fainter.

4.1.2. A possible relation between He II 4686 Å and the light variation

Massey & Duffey (2001) reported that the visual magnitude in the Smith system changed from 13.59 on 25 October 1999 to 13.79 on 27 October 1999, thus, within three days only. This must be a short-term variation of the type shown in Figs. 2 and 3. Assuming that the Smith and Johnson V magnitudes are not so much different from each other, then S 18 was at the time of Massey & Duffey's observations (~JD 2 451 478) close to a deep minimum (compare with the magnitude scale at the right of Fig. 2). No spectra were made at this occasion. A year later (October 2000, ~JD 2 451 830), both authors (same publication) obtained spectra, but no photometry. It appeared that the HeII 4686 emission line was absent despite numerous other emission lines.

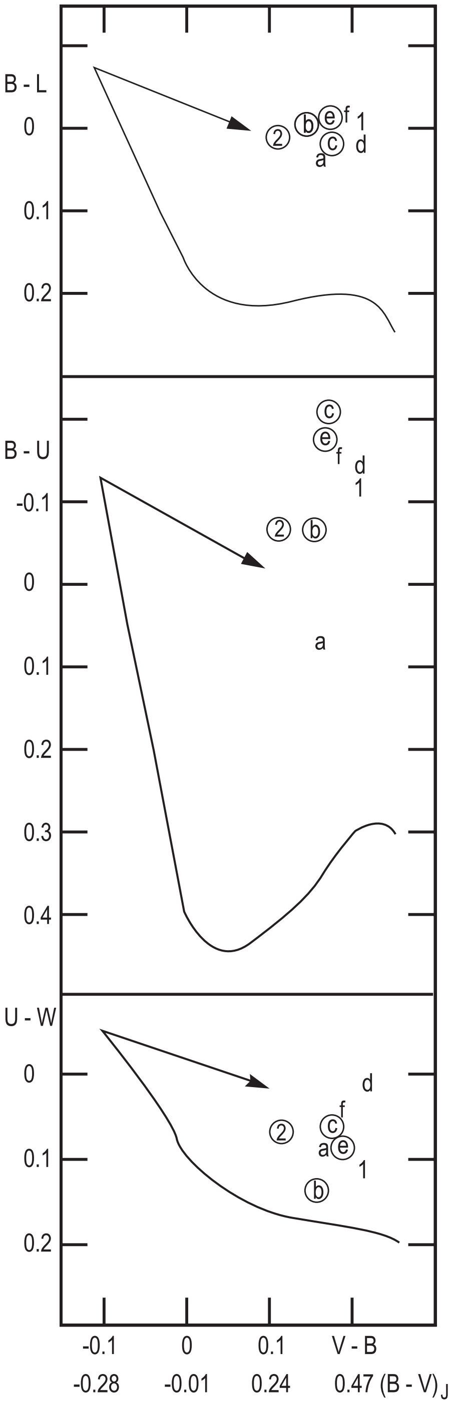

Fig. 9. The two-colour diagrams of the $VBLUW$ system (the horizontal axis also shows the $(B-V)_J$ scale) with the relation for main sequence stars (continuous line) and the position of the extrema of S 18 indicated with letters and numbers (see Sect. 3.1). Long arrow: the reddening line for O-type stars.

In Sect. 3.1, point 2, we noted that during the light maximum of 1987 (Fig. 1), this emission line was also absent in the nearly simultaneous spectra by Zickgraf et al. (1989). Speculating that this emission has something to do with the 150 d oscillation one could assume the following correlation: no He II 4686 emission if S 18 is in a maximum due to this cycle. This is not in contradiction with the Massey & Duffey (2001) result: since in their first night the star was near minimum brightness (photometry only), it could very well be near maximum in their second night (only spectroscopy: He II 4686 absent), because that was ~2.5 cycles later. Or, if the emission has something to do with the ~2 y cycle, the star should be in a maximum of this cycle as well during Massey & Duffey's second night, since that was roughly half a cycle later. This example stresses the need for simultaneous photometry and spectroscopy.

4.1.3. The reddening and luminosity of S 18

A reddening determination from Fig. 9 is troublesome because of the emission lines. At face value $E_{V-B} = 0.22$ (log intensity scale). The B band has probably a stronger contribution of emission lines than the V band, thus, the $V - B$ index (and the equivalent $(B-V)_J$) may be too blue. Based on experience, the excess in magnitude scale may be in the order of $0\overset{\text{m}}{.}1$. Transforming E_{V-B} into E_{B-V_J} by a formula of Pel (1986) and allowing for an estimated transformation error due to the emission lines, we find a total interstellar reddening amounting to $\sim 0\overset{\text{m}}{.}6 \pm 0\overset{\text{m}}{.}2$. Zickgraf et al. (1989) found $0\overset{\text{m}}{.}4$ based on a model fit to the energy distribution, but due to the emission line contribution, its reliability may be uncertain as well.

Since the galactic foreground reddening in the direction of S 18 amounts to ~0.1 (Fig. 7c in Schwering & Israel 1991), the internal reddening in the SMC amounts to $\sim 0\overset{\text{m}}{.}5 \pm 0\overset{\text{m}}{.}2$, part of which must be due to circumstellar dust (Zickgraf et al. 1989). The luminosity of S 18 is estimated to amount to $\log L/L_\odot = 5.58 \pm 0.20$ assuming a distance modulus 19.0 ± 0.10, and an extinction law of 3.1. With a temperature of $\log T_{\rm eff} = 4.40$ (Zickgraf et al. 1989), its position in the S Dor instability region is relatively low with respect to the "SD-minimum strip" obeyed by most S Dor variables (dashed line in Fig. 10), especially considering the possible presence of a companion, which would lower the intrinsic luminosity further.

4.2. R 66: Reddening and some physical parameters

Based on the position of R 66 in the two-colour diagrams the total interstellar reddening amounts to $E(V-B) = 0.11 \pm 0.03$ (log intensity scale) and transformed $E(B-V)_J = 0\overset{\text{m}}{.}26 \pm 0\overset{\text{m}}{.}07$. The estimated error includes the UV excess. Van Genderen et al. (1983) suggested $0\overset{\text{m}}{.}25$. Stahl et al. (1983) preferred $0\overset{\text{m}}{.}12$ because of various reasons, they also assumed a low foreground reddening amounting to $0\overset{\text{m}}{.}05$, while according to the foreground reddening map to the LMC of Schwering & Israel (1991) it should be $\sim 0\overset{\text{m}}{.}13$ in the direction of R 66. We shall adopt a total reddening of $0\overset{\text{m}}{.}26$ mentioned above, a distance modulus of 18.45 ± 0.10, an extinction law of 3.1. Then $M_v = -8.6 \pm 0.3$ and with $\log T_{\rm eff} = 4.08$ (Stahl et al. 1983), $M_{\rm bol} = -9.4 \pm 0.3$ (−8.9 according to Stahl et al. 1983), or $\log L/L_\odot = 5.64 \pm 0.14$. The position in Fig. 10 with respect to the dashed line is satisfactory.

If R 66 with a quasi-period of 55 d is plotted in the theoretical HR-diagram with respect to the $P =$ constant lines for α Cyg variables (van Genderen & Sterken 1996) its shows a too long period, but the deviation is roughly of the same order as the scatter shown by some other objects.

4.3. R 126: Reddening and some physical parameters

In the same way as for R 66, we found for R 126 a total reddening $E(B-V)_J = 0\overset{\text{m}}{.}28 \pm 0.07$, which agrees with that of Zickgraf et al. (1985): $0\overset{\text{m}}{.}25$. The galactic forground reddening in the direction of R 126 amounts to $\sim 0\overset{\text{m}}{.}09$ (Schwering & Israel 1991). Adopting our own reddening $M_v = -8.4 \pm 0.3$. With $\log T_{\rm eff} = 4.35$ (Zickgraf et al. 1985) $M_{\rm bol} = 10.6 \pm 0.3$ (−10.5 according to Zickgraf et al. 1985), or $\log L/L_\odot = 6.12 \pm 0.13$. The position in Fig. 10 with respect to the dashed line is satisfactory as well.

Similar to R 66, R 126 shows a too long quasi-period for its α Cyg-type variations (20 d–30 d) in the HR-diagram, but considering the deviation of some other objects, this is not quite abnormal.

5. The B[e]–S Dor variable connection

The question of whether B[e] supergiants and S Dor variables are related would be a theoretical problem, were it not that some objects share the characteristics of both. The continuous debate in the literature of a possible connection between the two groups is due to the spectroscopic similarities and their non-spherical winds (Stahl et al. 1983; Gummersbach et al. 1995; Miroshnichenko 1996; Stothers & Chin 1996; Zickgraf 1999). We presume that it also depends on the luminosity: bright B[e] supergiants (thus, within the same luminosity range of the S Dor variables) might once enter the S-Dor region, while this is not the case with the much fainter ones i.e. with $\log L/L_\odot \lesssim 5$ down to 4 (Gummersbach et al. 1995). It is now believed that only the brightest S Dor variables are post-main-sequence stars (Stothers 2002; Stothers & Chin 1996; Lamers et al. 2001). Consequently, they could be the natural descendants of the most luminous B[e] supergiants.

The faint S Dor variables are supposed to be post-RSG and the descendants of the yellow hypergiants (de Jager 1998; Nieuwenhuijzen & de Jager 2000; van Genderen 2001; Stothers & Chin 2001). That these objects will further evolve to the WR stage is almost certain, but whether this evolution is interrupted by a medium-bright B[e] stage ($\log L/L_\odot = 5$–5.5) like the following objects lying far below the SD-minimum strip is worth to consider (Fig. 10 of the present paper and Fig. 20 in van Genderen 2001): the binary R 4 (the B[e] companion is also a strong-active S Dor variable), R 149 (a Be star, but not a B[e] star), which is also a weak-active S Dor variable and HDE 326823 (a B1.5 Ie star which has been classified by van Genderen 2001 as an ex-/dormant S Dor variable), Various photometric studies have proven that a number of such medium-bright B[e] stars turned out to be genuine S Dor variables: the above-mentioned R 4 in the SMC (Zickgraf et al. 1996;

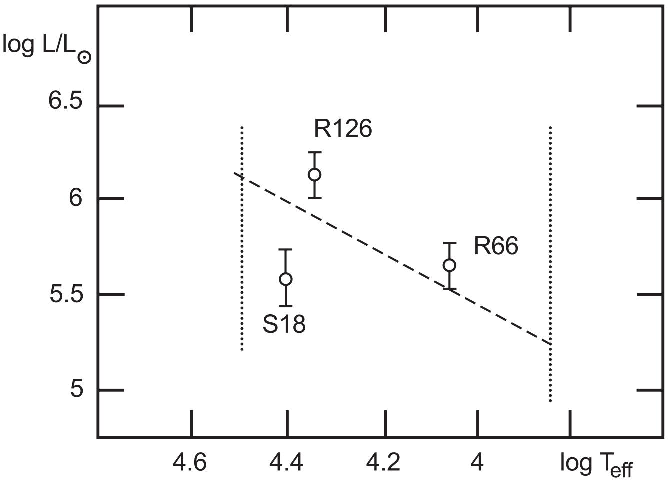

Fig. 10. The position of the three program stars in the S Dor (LBV) region (inside the vertical dotted lines). The SD-minimum strip is represented by the dashed line, the locus of most of the S Dor variables (van Genderen 2001).

van Genderen 2001) and the LMC objects HD 34664 = S 22 (van Genderen & Sterken 1999) and HD 38489 = S 134 (Stahl et al. 1984; van Genderen 2001).

Therefore, it is not unlikely that the brightest ($\log L/L_\odot \sim 6$) and medium-bright ($\log L/L_\odot = 5$–5.5) B[e] supergiants will turn out to show the low-amplitude α Cyg-type microvariations and some of them additionally the SD-phases with higher amplitudes (note that the S Dor variables are considered as a small subclass of the α Cyg variables), if long-term photometric observations are made. Because of this reason, the results of our photometric campaign of the three objects discussed here, are of importance.

6. Conclusions

Despite the general view that most of the B[e] supergiants are not variable, we have shown that the three arbitrarily selected objects each are subject to two (R 66 and R 126) and three (S 18) types of light oscillations. Most of these oscillations are probably pulsational. Considering the time scales they belong to three catagories:

1. A few years (all three objects).
2. ∼150 d (S 18).
3. Days to two months, the so-called α Cyg-type variations, viz. a few days (S 18), ∼25 d (R 126) and ∼55 d (R 66).

With respect to the last catagory we presume that these oscillations in the case of S 18 are accompanied by an enhancement of most emission lines (possibly by a bright spot/disk in the case we are dealing with a binary), due to an increase of the stellar mass loss. This presumption is based on the fact that the light amplitudes in our B band are often significantly the largest due to the Hγ emission line lying at maximum response.

There is a global correlation between the temperature and the time scale of the α Cyg-type variations: the hotter the star, the shorter the oscillations. Also because of this reason it seems justified to classify B[e] supergiants as α Cyg variables: a large group of unstable evolved massive stars.

It was impossible to establish unambiguously whether the variations of years are due to SD-phases, thus, whether the three objects can also be classified as S Dor variables like some other B[e] stars. Yet, they add further support to the suspicion that a strong B[e]–S Dor variable connection exists. Both groups seem to merge gradually into each other, since some individual cases show mixed characteristics.

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