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Genderen, A.M. van

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An investigation of the micro-variations of highly luminous OBA type stars. V*

A.M. van Genderen

Leiden Observatory, Postbus 9513, NL-2300 RA Leiden, The Netherlands

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Summary. The optical micro variations of eight high luminous stars, five of type O, two of type B and one of type A are investigated. The *VBLUW* photometry is described in Paper IV (van Genderen et al., 1985c). Temperatures, gravities and reddenings are determined with the aid of theoretical colours. At least seven stars are variable, but only for three of them a characteristic period or characteristic time scale ($\bar{P}$) could be found in the light curve. A fourth $\bar{P}$ is suspect. Similar to the objects studied in Papers II and III, the scatter in the phase diagrams is analyzed with the aid of scatter diagrams.

The trend of the observed light amplitudes as a function of the wavelength (the amplitude/wavelength relation) is compared with the theoretical one, adopting that a temperature change is the only cause of the light variation. It appears that a difference exists, especially in the ultraviolet, in the sense that, compared with the visual amplitude, the observed ultraviolet amplitudes are usually smaller than the theoretical ones. These differences are small for the hottest stars and large for the cooler ones. By adopting a smaller temperature variation and an additional radius variation, the theoretical relations match the observed ones much better.

Key words: Early-type stars – supergiants – variable stars – photometry – oscillations

1. Introduction

This paper describes and discusses the photometric characteristics of eight high luminous OBA type stars of which most of them appear to be micro variables. This is the fifth paper in a series which deals with this type of variability. The scientific background is given mainly in Paper II (van Genderen, 1985a), the observational technique mainly described in Paper I (van Genderen et al., 1985a). The observations of the stars discussed here are presented in Paper IV (van Genderen et al., 1985c).

2. The reddenings and the physical parameters

In Paper II a description is given how reddenings, gravities and temperatures have been derived by means of the theoretical two-colour diagrams, with an uncertainty in E($V-B$) of ± 0.015; in $\log g$ of ± 0.5 and in T_{eff} of ± 1000 K for the late B type stars and of $\pm \lesssim 3000$ K for the O type stars. It should be remarked that these error estimates are relative with respect to the adopted grid of theoretical colours. For example the temperature derived by different methods may differ much more from each other than the relative errors: we find $T_{\mathrm{eff}} = 38000$ K for HD 46223 and Garmany et al. (1982) 50000 K (Table 1). Table 1 lists the reddenings (and also those transformed into the *UBV* system with subscript J: E$(B-V)_J$) and some physical parameters. The results for the gravities are not always satisfactory. For example, the $\log g$ values of HD 74194 and HD 120521 turned out to be too high for their luminosity classification (Ib) viz. $\log g = 4.0$. Obviously the error must be larger than ± 0.5; therefore we omitted them in Table 1. It is possible that the gravity for the Of star HD 91572 is also too high ($\log g = 4.5$), since according to Simon et al. (1983) Of stars have gravities somewhere between $\log g = 3.5 - 4.0$.

For the determination of the absolute magnitudes we often made use of the cluster distances of Humphreys (1978). Determinations of some of the parameters by other investigators are also given in Table 1. According to Leitherer and Wolf (1984) the star HD 148379 = QU Nor shows an ultraviolet excess in the E$(U-B)_J$/E$(B-V)_J$ diagram by $\sim 0^{\mathrm{m}}.2$ in $(U-B)_J$ (their Fig. 3a). However, in the two-colour diagrams of the *VBLUW* system, the star looks normal within $\sim 0^{\mathrm{m}}.1$ of the colour indices $B-L$, $B-U$ and $U-W$.

3. The search for the characteristic periods

The way in which we used the two methods for finding possible characteristic periods or characteristic time scales $\bar{P}$, is described in Paper II. (Some people would prefer to talk of characteristic *time scales* rather than of *periods*, especially if one deals with a variability like that of HD 102997 (Fig. 3).)

Unfortunately half of the stars have not been observed enough to find a possible $\bar{P}$. For three stars the search was more or less successful: two possible $\bar{P}$'s for HD 148379 (= QU Nor, B2 Iab), for HD 102997 (B5/7 Ia/ab) and HD 74194 (08.5 IbF) (Table 2). For a fourth star HD 46223 (O4 V), $\bar{P}$ is suspect. The corresponding correlation coefficient r (Sterken's method on the first line), the statistic θ and the significance (or probability that a given θ-value is due to random fluctuations) (Stellingwerf's method on the second line) are also listed. Both methods resulted into more or less similar results. Yet the phase diagrams constructed with the periods of Sterken's method are usually of a better quality than those obtained with Stellingwerf's method. This is also the

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* Observations collected at the ESO, La Silla, Chile

Table 1. Reddenings and some physical characteristics of the program stars. (Data without notes are from this paper)

HD	E($V-B$) (log int)	E($B-V$)$_J$ (mag)	M_{VJ}	T_{eff}	log T_{eff}	M_{bol}	log $L/L_\odot$	log g	$R/R_\odot$	Remarks
46223	0.213	0.50	-5.4	38000	4.580	-9.1	5.55	4.5	14	
		0.52$^{\mathrm{d}}$		50000$^{\mathrm{a}}$	4.699$^{\mathrm{a}}$	-9.8^{a}	5.83$^{\mathrm{a}}$			
74194	0.211	0.50	-6.1	33000	4.519	-9.3	5.63		17	
		0.52$^{\mathrm{d}}$		33500$^{\mathrm{a}}$	4.525$^{\mathrm{a}}$	-8.6^{a}	5.35$^{\mathrm{a}}$			
91572	0.141	0.33	-4.8	34500	4.538	-8.2	5.19	4.5	12	
		0.36$^{\mathrm{d}}$								
92693	0.46	1.06	-7.7	10000:	4.000:	-8.0	5.11	$\lesssim 1.5$	140	
		0.99$^{\mathrm{d}}$								
102997	0.16	0.38	-7.0	12500:	4.097:	-7.8	5.03	1.7	75	
		0.39$^{\mathrm{d}}$								
120521	0.211	0.54	-6.2^{b}	34000	4.531	-9.4	5.67		20	
148379	0.298	0.69	-7.5	18000	4.255	-9.0	5.51	2.2	65	HR 6131 = QU Nor
		0.70$^{\mathrm{d}}$		17800$^{\mathrm{f}}$					94$^{\mathrm{f}}$	
151804$^{\mathrm{e}}$	0.150	0.39	-6.9	34000	4.531	-10.1	5.95		30	HR 6245
		0.36$^{\mathrm{c}}$		34200$^{\mathrm{c}}$	4.534$^{\mathrm{c}}$	-10.7^{c}	6.19$^{\mathrm{c}}$	3.1$^{\mathrm{c}}$	35$^{\mathrm{c}}$	$M/M_\odot = 90^{\mathrm{c}}$
		0.37$^{\mathrm{d}}$								

[a] Garmany et al. (1982); [b] Average brightness for this type of supergiant; [c] Leitherer and Wolf (1984); [d] Humphreys (1978); [e] Parameters derived from *VBLUW* photometry in the 1970/1978 system given by van Genderen et al. (1984); [f] Underhill (1984)

Table 2. Characteristic periods and average amplitudes of cyclic curves (similar to those of Table 2 in Paper II)

HD	Sp$^{\mathrm{a}}$	$\bar{P}$ (d)	r θ	Sign.	Ampl. V (log int.)	Ampl. V_J (mag)	Remarks
46223	dO4	(1.06)	0.67		(0.0050)	(0.013)	$v \sin i = 95^{\mathrm{b}}, 143^{\mathrm{c}}$
		(1.06)	0.63	0.18			
91572	O6.0V (F)						
151804	O8.0IaF						$v \sin i = 50^{\mathrm{b}}, 124^{\mathrm{c}}$
120521	O8.0Ib (F)						$v \sin i = 109^{\mathrm{c}}$
74194	O8.5Ib (F)	0.26/3.20	0.67/0.56		0.0075	0.019	$v \sin i = 170^{\mathrm{b}}, 159^{\mathrm{c}}$
		0.58/3.16	0.54/0.67	0.12/0.30			Velocity variable$^{\mathrm{c}}$
148379	B2Iab	13.57	0.69		0.0190	0.048	$v \sin i = 66^{\mathrm{c}}$
		13.56	0.66	0.10			
102997	B5/7Ia/ab	84.2/49.6	0.64/0.60		0.0105	0.026	
		84.5/49.6	0.58/0.66	0.01/0.05			
92693	A2Ia						

[a] If more spectral classifications are known (Paper IV), then only one of them is given; [b] Conti and Ebbets, 1977; [c] Uesugi, 1976

case with the stars of Paper II. Therefore we conclude that for non-strict periodic variable stars the first method is best.

A few remarks on the results of individual stars follow here:

- For HD 46223 both period-search programs resulted into $\bar{P} = 1^{\mathrm{d}}.06$. Because of its proximity to 1^{d}, this $\bar{P}$ may be suspect. Indeed, this suspicion is confirmed by R. van Gent from the Observatory at Utrecht. At our request he applied his computer program for the search of periods based on the algorithm of Scargle (1982) on the *V, B, L, U* and *W* data of HD 46223. The analysis was complicated, since the number of observatons is actually much too low. Nevertheless there are strong indications that $\bar{P}$ found above is highly suspect and likely not real at all. Therefore the $\bar{P}$ is bracketed in Table 2.
- For HD 74194 three candidate characteristic periods were found (only those found with Sterken's method will be quoted): the two shortest ones are $0^{\mathrm{d}}.26$ ($f = 3.846\,\mathrm{cd}^{-1}$) and $3^{\mathrm{d}}.20$ ($f = 0.313\,\mathrm{cd}^{-1}$). Although the first one has a higher r value (and a lower θ value for the equivalent period according to Stellingwerf's method) this is not yet a guarentee that this one can be more trusted than the second one. This conclusion is based on an eye inspection of the spread in both phase diagrams, which appears to be nearly of the same order. Figure 1 shows the result for $\bar{P} = 0^{\mathrm{d}}.26$. Obviously more observerations are needed to settle the problem.

A third much longer period fitted also: $\bar{P} = 10^{\mathrm{d}}.78$ ($f = 0.093\,\mathrm{cd}^{-1}$) with $r = 0.69$. However since a few observations made in subsequent nights differ by the maximum light amplitude, the $\bar{P}$ must be much shorter. This star thus illustrates the danger of too few observations.

Figure 1 also shows the colour curves $V-B$ and $V-W$ relative to the comparison star. The purpose is to illustrate the difference in intrinsic spread (caused by the difference between the *V*, *B* and *W* light amplitudes) between two parts of the spectral

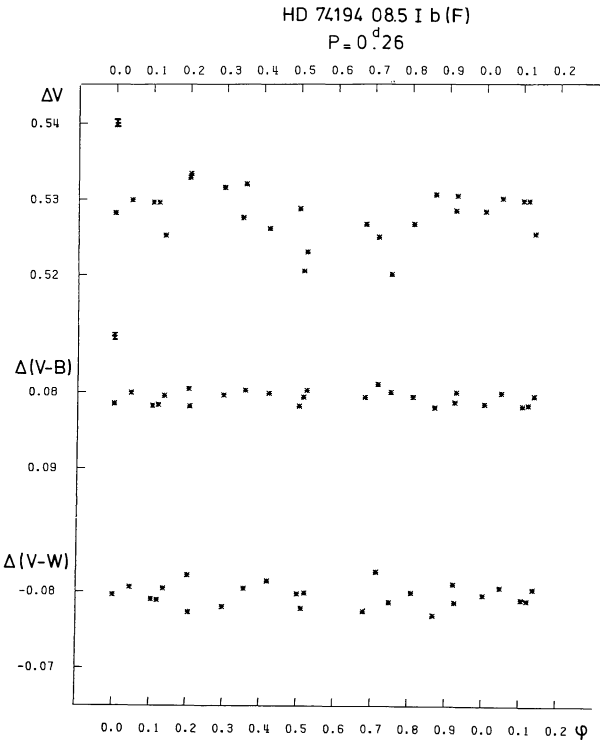

Fig. 1. The phase diagrams for V, $V-B$ and $V-W$ relative to the comparison star, of HD 74194 (08.5Ib(F)). The mean error bars are shown in the top left hand corners

energy distribution close to each other (V and B) and far apart (V and W). We shall return to this aspect in Sect. 5.

– For HD 148379 (= QU Nor) $\bar{P} = 13^{\mathrm{d}}.57$ and the phase diagram is shown in Fig. 2. The individual light curves (brightness against time) support the cyclic behaviour, but the cycles differ strongly from each other in amplitude and time scale. The star has already been independently discovered as a variable by Feinstein (1968), Cousins (1972), Campusano (1977), Ott (1981) and Schild et al. (1983). Underhill's (1984) far ultraviolet observations with the IUE satellite also suggested that small variations occur.

– For HD 102997 two candidate characteristic time-scales were found viz. $84^{\mathrm{d}}.2$ ($f = 0.0119\,\mathrm{cd}^{-1}$) and $49^{\mathrm{d}}.6$ ($f = 0.0202\,\mathrm{cd}^{-1}$) of which the first one is slightly more significant than the second one. A search for a secondary period (P_1) with Stellingwerf's method by adopting a principal period $P_0 = 84^{\mathrm{d}}.5$ (Table 2), resulted into a very weak signal for $P_1 = 49^{\mathrm{d}}.95$ with $\theta = 0.84$. Thus the significance is very doubtful.

R. van Gent also applied his computer program for the search of periods, based on the algorithm of Scargle (1982) on the data of HD 102997. He used the five brightnesses V, B, L, U and W. The result is that for all observations made in 1981–1984, the most dominant time-scale is $\bar{P} \sim 84^{\mathrm{d}}$. If only the observations in 1984 are considered, $\bar{P} \sim 49^{\mathrm{d}}.5$ is the strongest oscillation. The highest sidelobe in the data window transform (DWT), which is the measure of the regularity in the observing intervals, appeared to be $\sim 61^{\mathrm{d}}$. This deviates sufficiently from both characteristic time-scales to consider them as real.

From Fig. 3a, b, showing the observations of HD 102997 as a function of the date, it follows that the star varies in a complicated manner indeed. Numerous short time scale variations in the order of a few days and with relative large light amplitudes are superimposed on a longer time scale wavy pattern. According to its position in the theoretical HR diagram (Fig. 8) with respect to theoretical and empirical P = cont lines, such a short period would agree better. Figure 4 shows the phase diagram for $\bar{P} = 84^{\mathrm{d}}.2$.

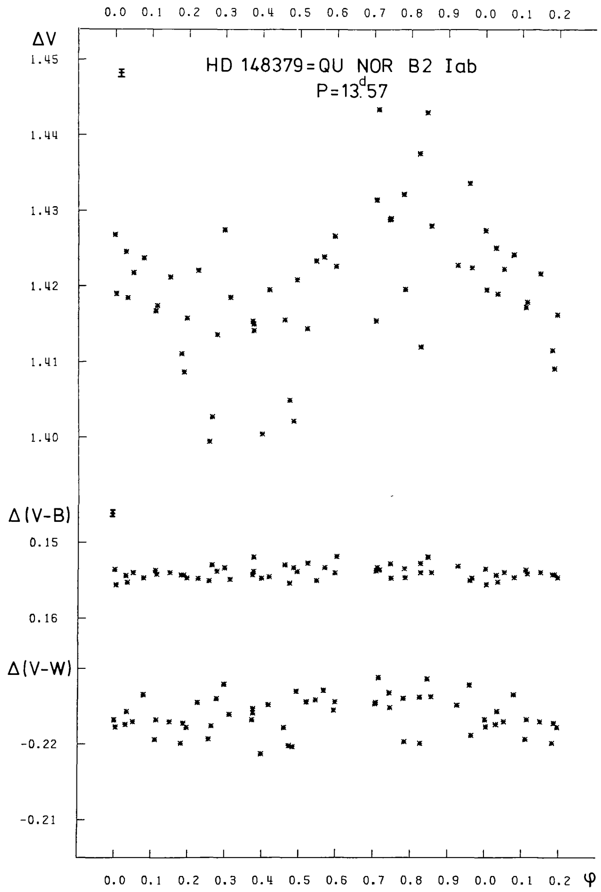

Fig. 2. The phase diagram for V, $V-B$ and $V-W$ relative to the comparison star, of HD 148379 = QU Nor (B2Iab). The mean error bars are shown in the top left hand corners

4. The scatter in the light- and colour curves

In Papers II and III we discussed the scatter of the average brightness- and colour curves in the phase diagrams. The main causes are presumably the short time scale fluctuations superimposed on the cyclic variations (mainly for the O type stars and to a lesser degree for the B type stars) and the strongly varying shapes of individual cycles (mainly for the B type stars). Our impression is here confirmed as far as the latter stars are concerned. These so called δ variations were analyzed in different kind of diagrams such as diagrams δ colour versus δ colour or in case no cyclic behaviour is evident: Δ colour versus Δ colour. In the latter case it is thus sufficient to plot the observed colours relative to the comparison star. Apart from the combinations already used in Paper II and III, we also used the colour index $V-W$ and $L-U$. They all give information on the differential behaviour of the fluxes in the five pass bands.

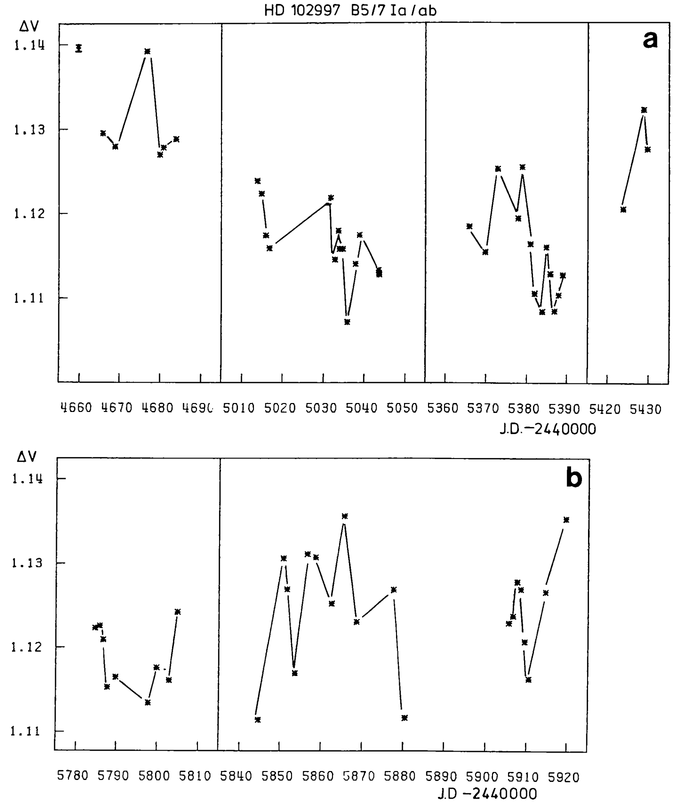

Fig. 3a and b. The V observations of HD 102997 (B5/7Ia/ab) relative to the comparison star, as a function of the Julian Date, showing the complicated manner of the variations. The mean error bar is shown in the top left hand corner

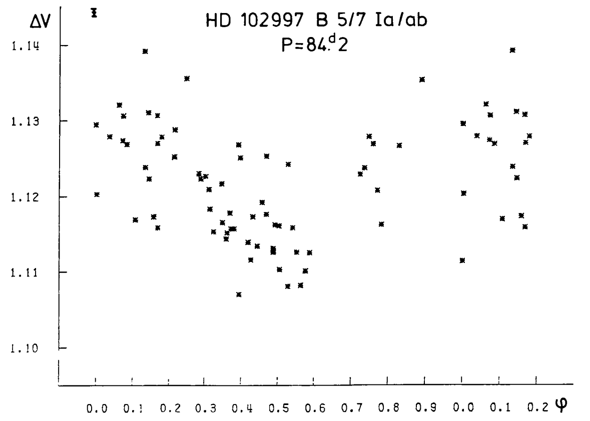

Fig. 4. The phase diagram for V relative to the comparison star, of HD 102997 (B5/7Ia/ab). The mean error bar is shown in the top left hand corner

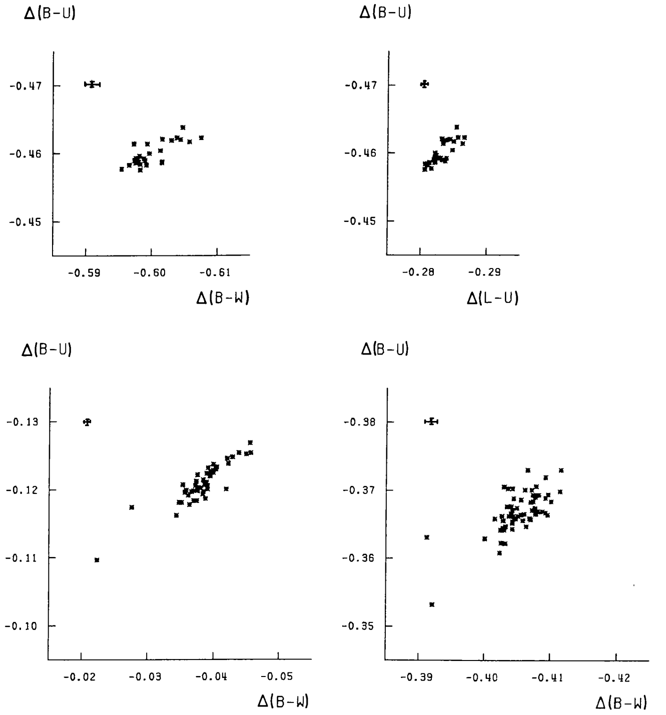

Fig. 5. At the top the scatter diagrams $\Delta(B-U)/\Delta(B-W)$ and $\Delta(B-U)/\Delta(L-U)$ of HD 46223 (O4/5VF) and below it at the left and right the scatter diagrams $\Delta(B-U)/\Delta(B-W)$ of HD 62150 (B3/5Iab) and HD 102997 (B5/7Ia/ab), respectively. The mean error bars are shown

Figure 5 (upper panels) shows the $\Delta(B-U)/\Delta(B-W)$ and $\Delta(B-U)/\Delta(L-U)$ diagrams for HD 46223 (blue is at the top and to the right). The correlations demonstrate that the scatter in the colour diagrams of Fig. 2 in Paper IV is mainly intrinsic. Both diagrams indicate that any light variation has a larger amplitude in W than in U (range $B-W >$ range $B-U$) and that both have a larger amplitude than in B and L.

It appears that the slopes and the spread of the relations differ from star to star. This spread is mainly caused by observational errors. In the colour indices the mean errors amount to ± 0.0003 on the average (Paper I). However if the comparison star is of a relative low brightness, viz. $V_J \gtrsim 9$ and of spectral type AO (thus ultra violet flux low), then these mean errors may amount to ± 0.0010 in colour indices containing the W for stars like HD 46223 and HD 102997. Partly, the spread is caused by variable ratios between the light amplitudes of the different passbands. Of course this second order variation also contributes to the δ variations in the phase diagrams. As an example of the second order variation we show in Fig. 5 (lower panels) the $\Delta(B-U)/\Delta(B-W)$ diagrams of HD 62150 (Papers I and II) and HD 102997. (Since the amplitudes of the cyclic colour curves in the phase diagrams are small compared with the total scatter, it would not make much difference for the spread in Fig. 5, to read off the precise scatter δ around these curves. However it makes the range in $B-U$ and $B-W$ somewhat smaller.) At constant $\Delta(B-W)$ for example, the spread in $\Delta(B-U)$ amounts to 0.0050–0.0100 for the NA of HD 102997, which is several times larger than the m.e. (see the error bars). Such variations occur much less in HD 62150 or HD 46223 (upper panel at the left) of which the m.e. in $B-W$ is of the same order as for HD 102997.

HD 91572 (06.0VF) is the second O type star with no detectable short time scale variations (Paper IV, Fig. 3). The first one is HD 37041[1] from Paper I. Whether HD 91572 is also stable on time scales of years should be settled by more observations.

5. The amplitudes

In Fig. 8 of Paper II the amplitudes of the cyclic or $\bar{P}$ variations and of the δ variations are plotted as a function of the stellar

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[1] See note added in proof

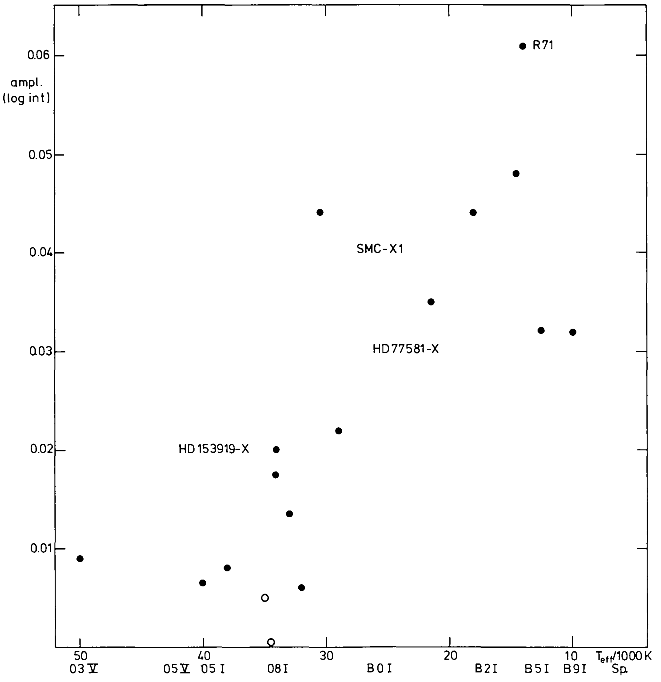

Fig. 6. The total light amplitudes in V of all stars from the previous papers and this one. The two stars with no cyclic variations are indicated by circles

temperature. They appear to increase with decreasing temperature. The same holds for the stars of this paper. The fact that, especially for the cooler stars, the δ variations increase with decreasing temperature, simply indicates that the magnitude of the instability and of the variability of the characteristics of each cycle, go hand in hand.

Figure 6 depicts a similar diagram for all stars of Paper II, III and this paper, but now only the maximum observed amplitude in V is plotted.

In order to study the trend of the maximum observed amplitude as a function of the wavelength, the so called amplitude-wavelength relation, we determined for the other four passbands the range between a few of the faintest and brightest observations in the same way. Then we derived for each temperature interval and depending on the gravity (taken from Table 1 or estimated on account of the luminosity), the trend of the Kurucz (1979) fluxes as a function of the temperature and the wavelength. It is then assumed temporarily that the V amplitudes are caused by a temperature change ($\Delta T_{\mathrm{eff}}(\mathrm{max})$) only. This is of course not true, since a radius change will also take part in the light variation (see further).

Usually $\Delta T_{\mathrm{eff}}(\mathrm{max})$ ranges between 400 and 1000 K. For HD 105056 (Paper II) it amounts to 2100 K. The five pseudo theoretical light amplitudes, called $\Delta \log F_\lambda(\mathrm{max})$, are thus at the same scale as the observed amplitudes.

Figures 7a, b show for the 15 stars the observed amplitudes (circles connected by dotted lines) and the theoretical ones (dots connected by continuous lines), the latter normalized to the observed V amplitude. HD 37041 and HD 91572 are not shown, the first star shows a slow secular variation, the second one is possibly not variable. An uncertainty in $\log g$ has usually little influence on the slope of the relation for the theoretical amplitudes. As a matter of interest we only show for R71 the theoretical relation for $\log g = 2.0$ and 2.5. (Notice that because of the large light amplitudes, the origin of the diagram starts at $\Delta \log F_\lambda(\mathrm{max}) = 0.055$).

The uncertainty in the observed amplitudes is difficult to estimate: partly it depends on the amount of available data. More important for our purpose are the relative errors of the five amplitudes. Due to intrinsic variations of the amplitude differences and due to statistical effects (Sect. 4), the errors may amount to $\pm 0.0010 - \pm 0.0020$. The largest errors may occur at the short wavelengths, where often stronger variations in the relative ratios are present.

With the observed relations in Figs. 7a, b it is easy to explain why some of the scatter diagrams show no, other outspoken correlations (Papers II, III and this paper show a few examples). Whether or not a correlation exists, simply depends on the size of the amplitude difference between the various pass bands.

It further appears that for practically all stars the observed relation differs from the theoretical one, which is based on the assumption that a temperature change in the only cause. For the cool stars ($T_{\mathrm{eff}} \leqq 25000$ K) this difference increases strongly to the short wavelengths, in the sense that compared with the visual amplitude, the observed ultra violet amplitudes are much smaller than the theoretical ones. In the W band the difference amounts to 0.02–0.05 or $0^{\mathrm{m}}05 - 0^{\mathrm{m}}12$. For the hot stars ($T_{\mathrm{eff}} \geqq 25000$ K) the difference between both relations is much smaller. In one case a significant opposite difference exists viz. HD 46223 in Fig. 7b. This star showed a secular variation in U and W with respect to V, B and L (Fig. 2 in Paper IV), which is thus responsible for the abnormal deviation.

The difference discussed above is an indication that the light variation of highly luminous stars must be also caused by at least one other mechanism, such as a radius variation (ΔR). Presumably most of the luminous stars show non-radial pulsations (see Paper II and references therein). Thus part of the light variations may be caused by a change in the size of the visible surface, which can be expressed in terms of ΔR as if the pulsations were radial. This variation should not have a noticeable influence on the slope of the amplitude/wavelength relation, adopting that the gravity change is small.

By adopting a lower temperature change, thus $\Delta T_{\mathrm{eff}} < \Delta T_{\mathrm{eff}}(\mathrm{max})$, the theoretical relation in Figs. 7a, b can be transformed in such a way that it fits more or less the shape of the observed relation. ΔT_{eff} has been derived by decreasing the theoretical amplitude difference $\Delta W - \Delta V$ (or sometimes $\Delta U - \Delta V$) such that it equals the observed value. With the corresponding value $\Delta \log T_{\mathrm{eff}}$ and the observed value $\Delta \log L/L_\odot$ (usually the average of the five light amplitudes), $\Delta \log R/R_\odot$ follows from the relation: $\Delta \log R = 1/2\, \Delta \log L - 2 \Delta \log T_{\mathrm{eff}}$.

The fit described above, is however not always satisfactory, but in most cases the deviations are of the order of 0.0010–0.0030, thus they may be largely caused by the errors in the amplitudes. Sometimes the deviations amount to 0.0040 in one or two of the passbands, such as for HD 102997 and HD 105056. The reason may be sought in additional sources of light variation as is discussed in Paper II.

Because of the various uncertainties, no reliable values for ΔT_{eff} and ΔR can be obtained, apart from the fact of interpreting ΔR in terms of a change in the size of the visible surface because of possible non-radial pulsations. Yet it is of interest to discuss the results in short.

For six out of eight stars with $T_{\mathrm{eff}} > 30000$ K, ΔR turns out to be slightly negative: $\Delta R/R_\odot = -0.5 \pm 0.5$. This means that ΔT_{eff} is in fact still too high. Thus the observed amplitudes in the ultraviolet are apparently too high with respect to those in V and B of

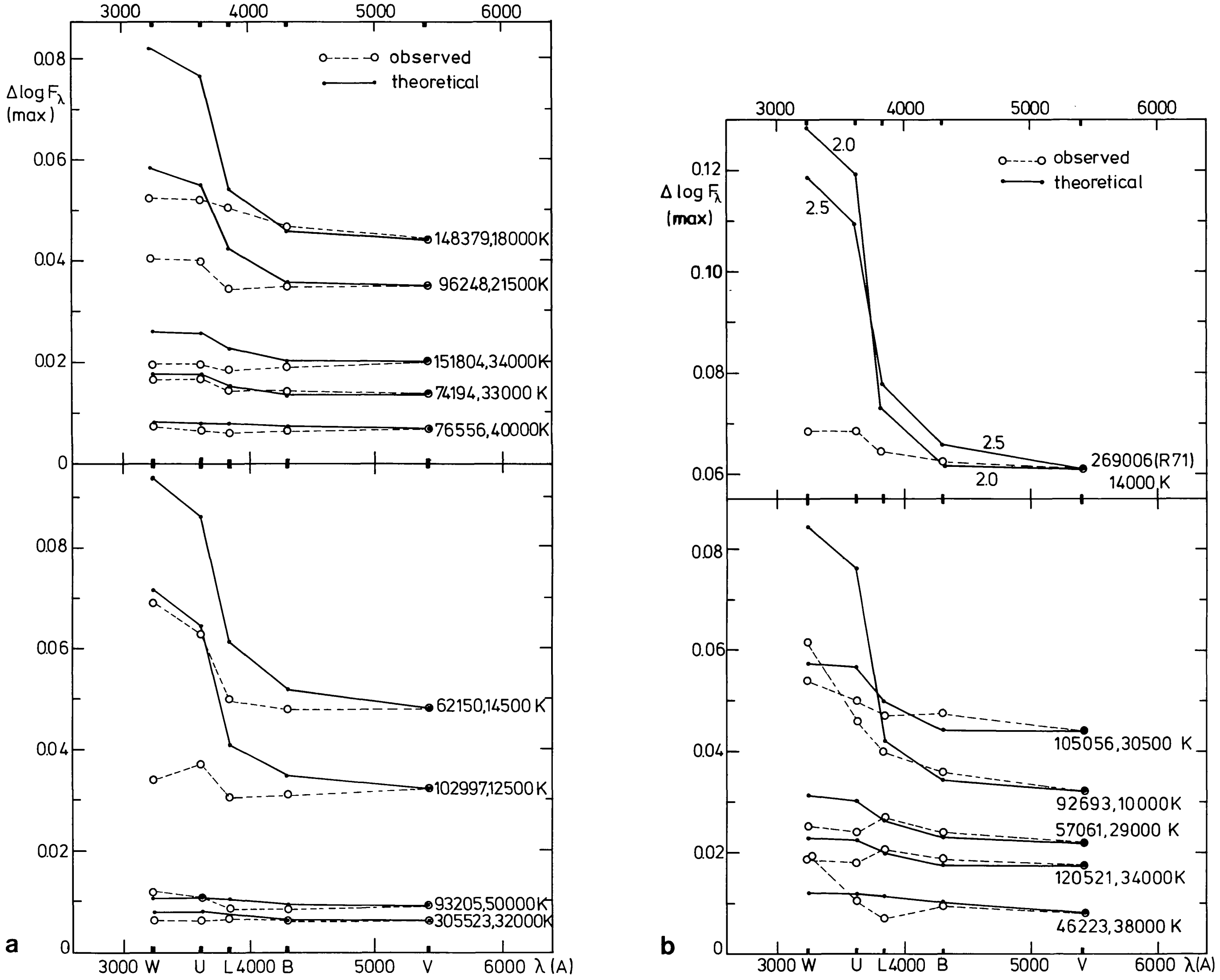

Fig. 7a and b. The approximate trend of the maximum observed light amplitudes (circles connected by dotted lines) and computed theoretical ones for $\Delta T_{\rm eff} = \Delta T_{\rm eff}({\rm max})$, normalized to the observed V amplitude (dots connected by continuous lines), as a function of the wavelength. All program stars are shown apart from HD 37041 and HD 91572

the order of a few ‰. With a smaller difference (thus a smaller slope) $\Delta T_{\rm eff}$ would become also smaller and ΔR would turn out positive. How this strange effect must be explained is not clear and should be further investigated. A possibility could be that at the brighter stages absorption lines are less intense than normal and at the fainter stages stronger than normal. A qualitative and quantitative confirmation by spectroscopy is however necessary.

For the nine other stars, most of them with $T_{\rm eff} < 30000$ K, $0 < \Delta R/R_\odot < 4$. The largest radius variation is found for R71 ($4 R_\odot$) of which $\Delta T_{\rm eff} \sim 200$ K. For most of the other stars $\Delta T_{\rm eff}$ is also in the order of a few hundred degrees.

6. The theoretical HR diagram

In Fig. 8 all program stars of the previous papers and this one are plotted in the theoretical HR diagram adapted from Lovey et al. (1984), thus similar to Fig. 9 of Paper II. The diagram shows evolutionary tracks, theoretical and empirical $P =$ const. lines. No proper empirical lines for shorter periods than $10^{\rm d}$ have been established so far. As shown in Paper II, the characteristic periods of the short time scale variables are much longer than the theoretical ones for the fundamental mode. The stars R71 ($20^{\rm d}$) and HD 148379 ($13^{\rm d}\!.6$) fit the empirical $P =$ const lines very well. The star HD 102997 with the longest time scale ($84^{\rm d}/50^{\rm d}$) lies on the empirical line for $\bar{P} \sim 10^{\rm d}$. As discussed in Sect. 3, its variability is very complicated. In fact the short period variations superimposed on the long time scale variation have the expected time scale of a few days to $10^{\rm d}$. Thus it is possible that the real pulsational characteristic time scale is so much disturbed by other semi-periodic mechanisms, that it cannot be detected by means of the period-search programs used.

The two stars HD 37041 and HD 91572 (slowly variable and presumably non-variable, respectively) are encircled and lie close to the ZAMS.

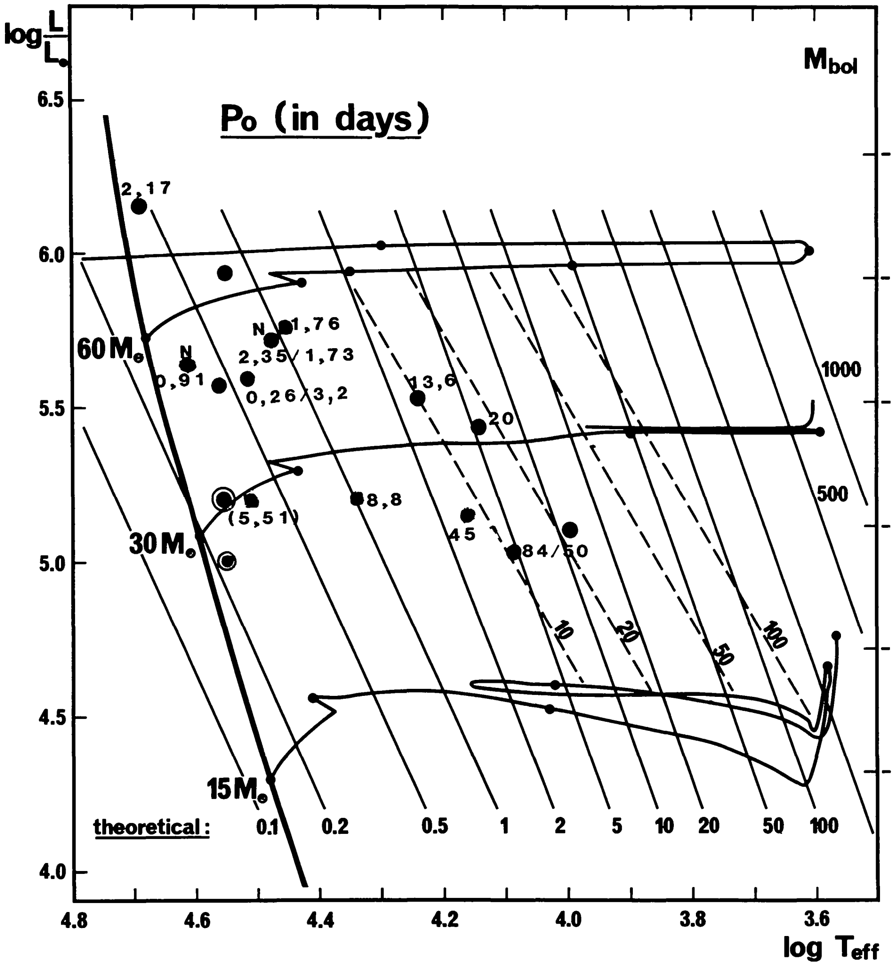

Fig. 8. The theoretical HR diagram with $P =$ const lines for the fundamental radial mode (continuous lines) and the empirical ones (dashed lines) adapted from Lovey et al. (1984). All program stars are shown by large dots, while HD 37041 and HD 91572 are encircled. Characteristic periods $\bar{P}$ are indicated

7. Discussion and conclusions

Similar to Papers I and II, seven of the eight program stars appear to be variable. Only for the three stars a characteristic period or time-scale ($\bar{P}$) could be found, but $\bar{P}$ for HD 102997 (B5/7Ia/ab) is very problematic. The $\bar{P}$ for a fourth star HD 46223 (O4V) is close to 1^d and therefore suspect. For three other stars the number of observations is too low to find a proper time scale. The eighth star HD 91572 (O6.0V(F)) is presumably non-variable, but this should be confirmed by more observations.

Generally speaking the observed amplitudes of the light variations are largest in the ultraviolet, especially for the BA type supergiants. For some O type stars there is little or no difference between the amplitudes at short and long wavelengths. All light amplitudes increase from O – to early A type stars.

The trend of the maximum observed light amplitudes as a function of the wavelengths, the so called amplitude/wavelength relation, has a smaller slope than the theoretical one assuming that a temperature change is the only cause of the light variation. The inconsistency can however be removed more or less by lowering the temperature variations, which are usually in the range of a few hundred degrees, and adopting an additional radius variation (ΔR). However, for the hottest stars ΔR is often slightly negative and for the cooler stars positive ($\Delta R/R_\odot < 4$). A tentative explanation for the negative values in terms of additional line strength variations in the ultra violet, causing flux variations in the order of a few ‰, is suggested.

A problem is how to explain the various photometric characteristics in terms of real pulsational effects, hot active regions, the effects of possible macro turbulent elements moving up and down in the atmosphere, etc. (see Sects. 8 and 9 in Paper II). Such elements can be large, at least for the very cool supergiants: they may be of the same order as the stellar radius (Schwarzschild, 1975; de Jager and Vermue, 1979). The forming of an extended atmosphere has been studied by Hillendahl (1970) theoretically. The momentum of shock waves formed by convective elements below the photosphere, causes the blow-off of parts of the surface upwards. Part of it may fall back, giving rise to dissipation of mechanical energy rising the temperature as has been concluded by Wolf (1972) from spectrograms of the hypergiant HD 33579 (A3Ia$^+$). It is of interest to note that this star, extensively observed photometrically by the author (van Genderen, 1979), showed some cycles ($\bar{P} \sim 100^d$) with an amplitude/wavelength relation (not shown here), with very much less obliquity than one should expect for such a type of star. Other cycles were more or less similar to those of the coolest stars of our sample.

Anyway, much more observations should be made of these type of stars, preferably in conjunction with spectroscopy.

The variety of the photometric characteristics of light- and colour variations of highly luminous stars (O-type main sequence stars, Of stars and BA type supergiants) is an indication that we are not dealing with one major type of instability mechanism only, but with a mixture of various partly stochastic processes. Presumably they are seated not only below or on top of the photosphere, but also in the atmosphere, where density and temperature fluctuations occur by moving clouds of matter, shock waves, etc., which influence the strength of spectral lines. For a short review on the various possible causes, different types of observations, references etc., the reader is referred to Paper II.

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Note added in proof: It appeared after a careful inspection of the coordinates, that the observers have systematically observed HD 37041 (O9.0 V) instead of the nearby star HD 37022 (O7.0 V). Thus in Papers I, II and IV one should read HD 37041 = HR 1897 = 43 Ori = θ^2 Ori instead of HD 37022 = HR 1895 = 41 Ori = θ^1 Ori. Both stars have practically equal magnitudes and colours.

In Table 1 of Paper II, the reddening given by Humphreys (1978) and the physical parameters of HD 37041 given by Garmany et al. (1982) should be as follows $E(B-V)_J = 0.20$, $M_{V_J} = -4.0$, $T_{\rm eff} = 34500$ K, $\log T_{\rm eff} = 4.538$, $M_{\rm bol} = -7.2$, $\log L/L_\odot = 4.79$. The agreement with the values derived form our photometry is now good. In Table 2 $v \sin i$ given by Conti en Ebbets (1977) and Uesugi (1976) should be 147 and 170 km s^{-1}, respectively.

It should be noted that the variable stars described in this series of papers likely belong to the class of *α Cygni variables* according to the definition of Kholopov et al.'s General Catalogue of Variable Stars I (1985).