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ASTRONOMY AND ASTROPHYSICS

Light Variations of Extreme Galactic B- and A Supergiants

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Summary. Twelve extreme B- and A supergiants of the Southern Hemisphere were photometrically monitored in 1973 and 1974. The observations were carried out in a differential way in the Strömgren *uvby* system. Eleven of these objects were found to be variable over medium and long time intervals. It was also found that the very extreme object HD 160529 exhibits small-amplitude light variations over a time scale of several hours, and there are, furthermore, indications that similar short term fluctuations are also present in HD 168607. The appreciable differences between the 1973 and 1974 yearly mean values indicate that the amplitudes over very long time intervals can be much bigger. All variations show the highest fluctuation in y and $u-v$, whereas only small or even no variations in $b-y$ and $v-b$ were found. Characteristic times of the variations in v were determined using a least squares method. These semi-periods range between 5 days and 100 days, and show an indication of being correlated with the absolute visual magnitude.

Key words: supergiants — photometric variations — pulsation

I. Introduction

From a number of spectrographic investigations it seems that variability in radial velocity and line strength is frequently present in early-type supergiants. Abt (1957), in an extended spectrographic study of supergiants, found different radial velocities for lines of different elements: the radial velocity curves of the metallic lines were similar, but had a phase lag with respect to each other, while the Balmer lines showed another kind of variation. All investigated objects seemed to be mainly velocity variables, while only few of them were known to be small-amplitude light variables. The amplitude of the radial-velocity curves was of the order of 4 to 8 km s^{-1}, and the amplitude of the light variation was only a few hundredths of a magnitude. Exact simple periodicities were not present, but sometimes semi-periods, increasing with luminosity and spectral type could be recognised. One of the most characteristic objects of this type is α Cygni, which at the end of the 19th century was already known as a velocity variable. Because the light- and velocity curves for this star were in phase, Abt (1957) concluded that the variations which he detected in the investigated objects were caused by irregular pulsations in the interior.

Struve and Elvey (1934) remarked that luminous stars had higher microturbulent velocities than less luminous ones, and Rosendhal and Wegner (1970) found a correlation between absolute magnitude and the *mean* microturbulent velocity in *A* supergiants. The microturbulent velocities obtained by them are between 10 and 15 km s^{-1}, and the explanation of these high velocities in supergiants is up to now unknown. Rosendhal (1973a) investigated a number of early-type supergiants and found that more than half of them showed variations of the Hα profile.

The Hα profiles are often of the P Cygni type, with emission strength increasing with luminosity.

Because the mentioned variations are generally increasing with luminosity, a number of extreme luminous southern early-type supergiants were selected for photometric monitoring in 1972 (Wolf et al., 1974), 1973 and 1974. The visual magnitudes of the objects are all between 5^m and 8^m and the absolute visual magnitudes probably lie between -5^m and -9^m. All stars are situated in the "Sagittarius-" and "Carinae" arms of the Galaxy (Fig. 1). Table 1 lists HD number, equatorial coordinates for the epoch 1900.0, spectral types, absolute visual magnitudes and mean *uvby* data for the investigated objects.

II. The Observations

All photoelectric observations were obtained with the Danish National Telescope and the ESO 50 cm Telescope of the European Southern Observatory at La Silla, Chile, during different observing runs in 1973 and

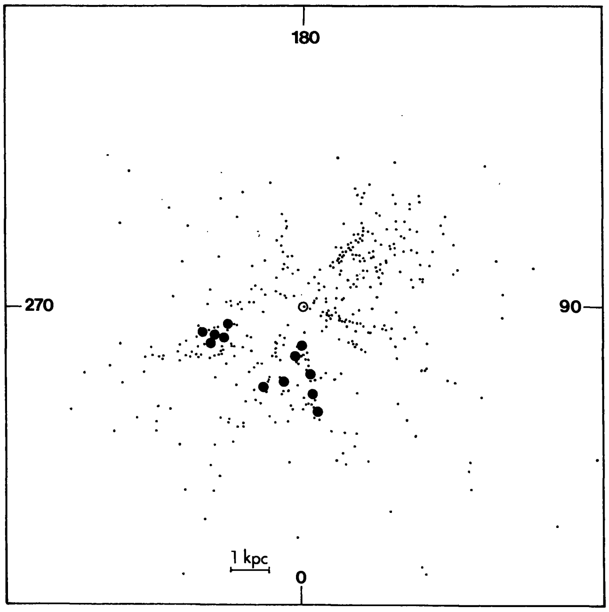

Fig. 1. Space distribution of all O9-A2 supergiants from the catalogue of Humphreys (1970). The Sun is indicated by ⊙ and the investigated objects are marked by ●

1974. All measurements were made in the Strömgren *uvby* system.

For the observations with the Danish National 50 cm Telescope the *uvby* photometer of the University of Copenhagen was used. Four uncooled EMI 6256 photomultipliers allow simultaneous pulse-counted measurements in all colours. All measurements were made through a focal-plane diaphragm of 30″. The other measurements were made with the ESO sequential photoelectric photometer, equipped with a set of *uvby* filters and a cooled EMI 6256 photomultiplier. A 15 or 30″ focal plane diaphragm was used. The observations were made with a DC Amplifier and a computer-controlled Data Acquisition System.

During each observing night of good quality, all program stars were observed at least twice. One differential measurement consisted of the sequence of integrations

$$C1\, H\, S\, H\, C2\,,$$

where the symbols $C1$, S and $C2$ represent consecutive integrations of respectively the first comparison star, the program star and the second comparison star. The symbol H denotes an integration over the sky background. During each night with the ESO 50 cm Telescope, special care was taken that the gain steps in the different colours for the comparison stars and for the program star were the same. The DC amplifier was calibrated at least twice each night using bright stars near the meridian. Except for one step, the amplifier proved to be very stable. Two extinction stars were monitored regularly each night, and a nightly sequence of at least eight standard stars was observed in order to determine the transformation coefficients into the standard *uvby* system.

III. The Reductions

All observations of the program stars and the comparison stars were reduced using the standard non-differential method for *uvby* measurements. For every single night of good quality the specific values of the extinction coefficients and the transformation coefficients were used. The y magnitudes were transformed to V magnitudes [standards from the Catalogue of Bright Stars, Hoffleit (1964)] and the transformation equations for $b-y$, $v-b$ and $u-v$ were determined using the values of Crawford et al. (1970). The results for the comparison stars were analysed in order to detect and remove variable comparison stars. Such variations were found in two cases. For every program star a non-variable comparison star was then selected and the differential measurements were obtained by calculating the differences of the corresponding quantities in the sense variable minus comparison star. Table 2 lists the selected comparison stars. These stars were consequently considered as primary comparison stars in later runs.

IV. Analysis and Results

1. Short Term Variations

In order to analyse the program stars for short term variability (nightly variations), first, for each program star and for each night, nightly means were calculated. The individual observations of each night were tested for statistically significant deviations from these nightly means. Using the fluctuations of the differences between consecutive comparison star observations, the statistical mean error in one observation was found to be $\lesssim 0.005$ in all colours for the brightest stars, and $\lesssim 0.008$ for the faintest objects.

For the detection of short term variations, only nights of good quality with at least five measurements were considered. Within the observational error limits, evidence for short-term variations in $u-v$ was present only in the stars HD 160529 and HD 168607. The other objects do not show significant deviations. The extensive nightly observations of HD 160529 were reported earlier (Sterken, 1976), and the $u-v$ fluctuations in HD 168607 on JD 2442168 are shown in Figure 2.

2. Intermediate Term Variations

For each star, averages of the nightly means were calculated, and the differences of the individual nightly means from their averages were tested for significant night to night variations. The standard deviation on one nightly mean in $y, b-y, v-b$ and $u-v$ is $\lesssim 0.005$ mag for the brightest stars and $\lesssim 0.007$ mag for the fainter ones.

Table 1. List of program stars

Object	α_{1900}	δ_{1900}	Spectral type	V	$b-y$	$v-b$	$u-v$
HD 91619	$10^h29^m.6$	−57°41′	B5Ia	6.11	0.340	0.302	0.516
HD 92207	10 33.6	−58 13	A0Ia	5.46	0.428	0.387	0.788
HD 96919	11 4.4	−61 24	B9Ia	5.14	0.225	0.228	0.605
HD 99953	11 24.8	−63 0	B2Ia	6.42	0.312	0.247	0.249
HD 100262	11 27.2	−58 58	A2Ia	5.13	0.396	0.364	1.252
HD 152236	16 47.0	−42 12	B1Ia+	4.70	0.441	0.336	0.269
HD 160529	17 35.3	−33 27	A2Ia+	6.49	0.997	0.786	1.508
HD 167264	18 9.3	−20 46	B0Ia	5.32	0.109	0.111	−0.002
HD 168607	18 15.5	−16 25	B9Ia+	8.15	1.270	0.917	1.032
HD 168625	18 15.6	−16 25	B8Ia	8.33	1.136	0.846	1.094
BD−14°5037	18 19.4	−14 42	B1.5Ia(+?)	8.18	1.092	0.797	0.827
HD 169454	18 19.6	−14 2	B1Ia+	6.57	0.738	0.556	0.524

Table 2. List of comparison stars

Identification	Comp. star for	Spectral type	V	$b-y$	$v-b$	$u-v$
HD 91943	HD 91619	B0	6.70	0.127	0.125	0.055
HD 92399	HD 92207	A0	6.48	−0.038	0.056	0.414
HD 96829	HD 96919	B8	7.29	0.256	0.199	0.248
HD 100126	HD 99953	B9	7.85	0.168	0.193	1.319
HD 100380	HD 100262	A2	6.76	0.107	0.258	1.385
HD 152234	HD 152236	B0	5.44	0.237	0.197	0.114
HD 160461	HD 160529	A0	7.47	0.110	0.225	1.385
HD 167263	HD 167264	B1	5.93	·0.092	0.099	−0.018
HD 168896	HD 168607 HD 168625	A2	8.43	0.151	0.301	1.310
HD 169313	BD−14°5037 HD 169454	B9	8.96	0.261	0.291	1.430

All nightly means obtained in 1973 and 1974 for the investigated objects are represented in Figure 3a–d. For the 1972 observations of HD 160529 we refer to Wolf et al. (1974).

The results of the analysis are given in Table 3. The first three columns give the identification, spectral type and absolute visual magnitudes. N denotes the number of nights during which the star was observed. The values $A(y)$, $A(b-y)$, $A(v-b)$ and $A(u-v)$ are the absolute maximum deviations of the nightly means from their corresponding averages. These values we will designate as *amplitudes of variation.* They are superpositions of the star's intrinsic light variations and the observational error, and in this way they are a slight overestimation of the real amplitude.

From Table 3 and from Figures 3a–d one can easily conclude that, except for HD 167264, *all investigated supergiants show detectable (i.e. larger than 3 standard deviations) irregular variations of small amplitude on a time scale of several days.*

3. Long Term Variations

Table 4 lists the differences between the average of the nightly means of 1973 and 1974 for each program star.

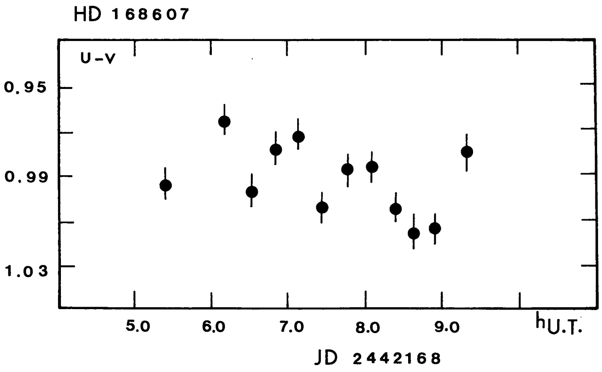

Fig. 2. $u-v$ fluctuations for HD 168607 on JD 2442168

The year-to-year differences are smallest for HD 167264 and are of the order expected from the statistical error.

V. Discussion

1. Night to Night Variations

From IV.2 we conclude that, except for the B star HD 167264, all stars show irregular variations on a time scale of several days. The amplitudes of these variations are different from star to star, but all stars have fluc-

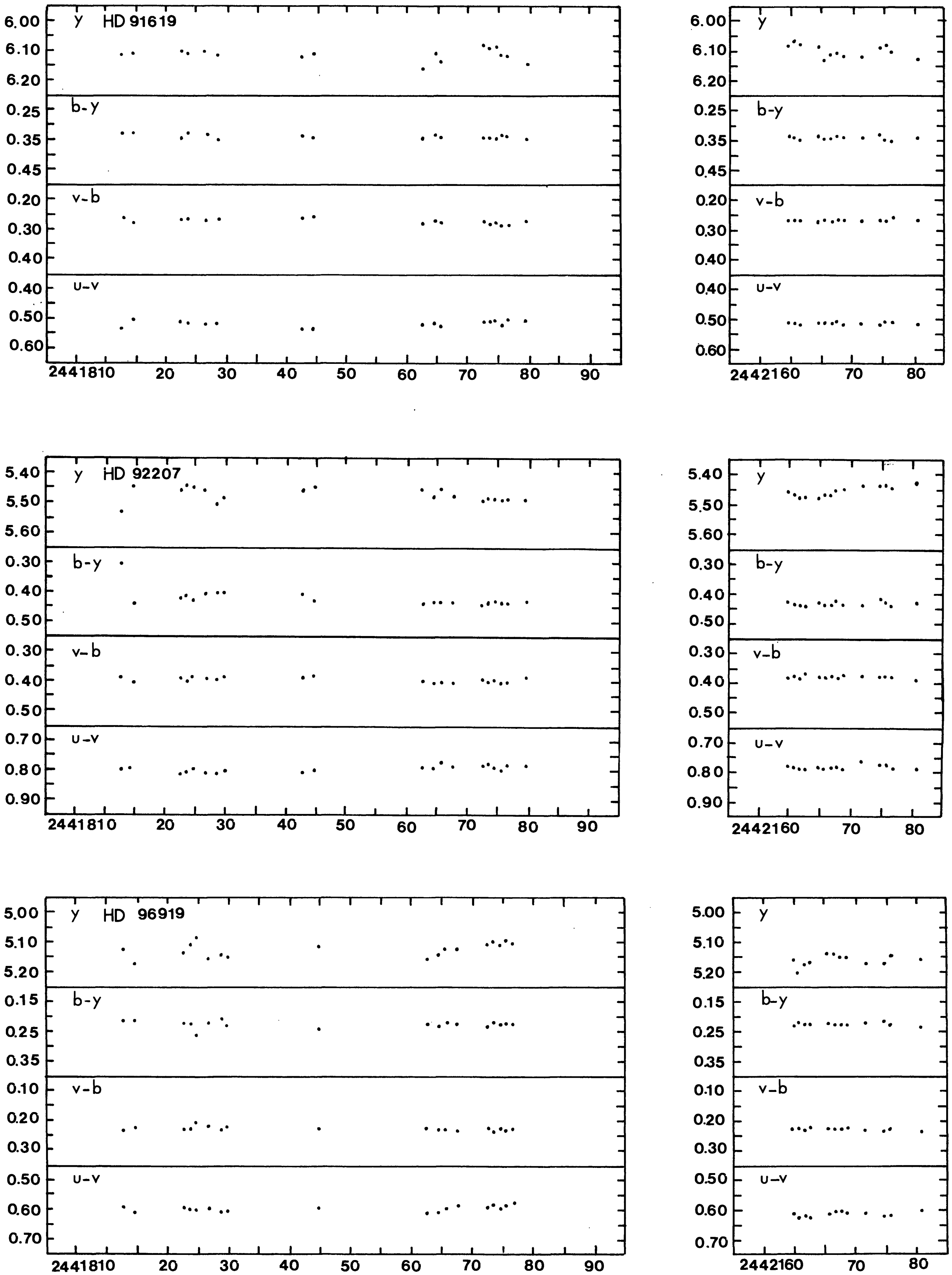

Fig. 3a. Night-to-night variations for HD 91619, HD 92207, HD 96919

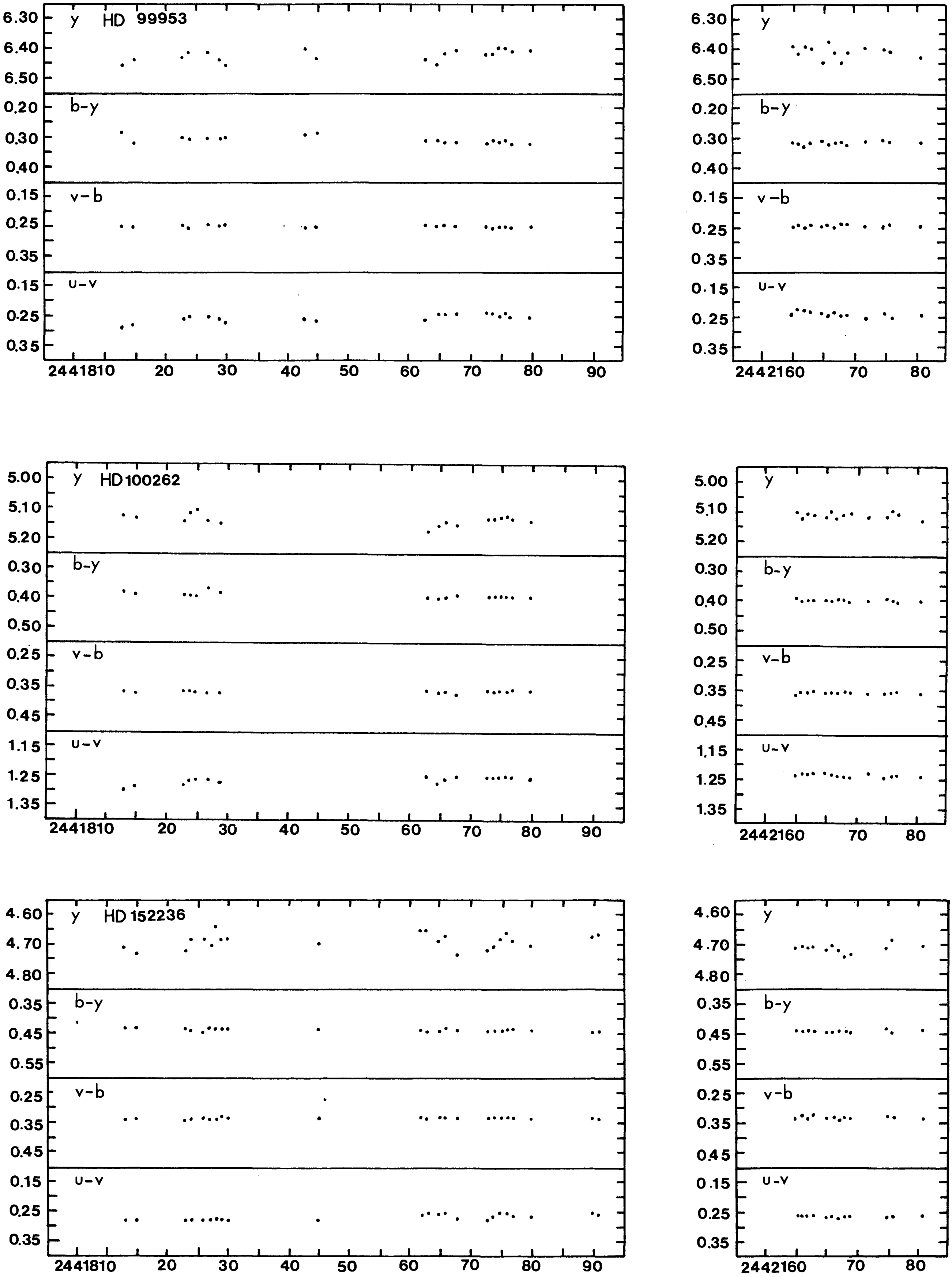

Fig. 3b. Night-to-night variations for HD 99953, HD 100262, HD 152236

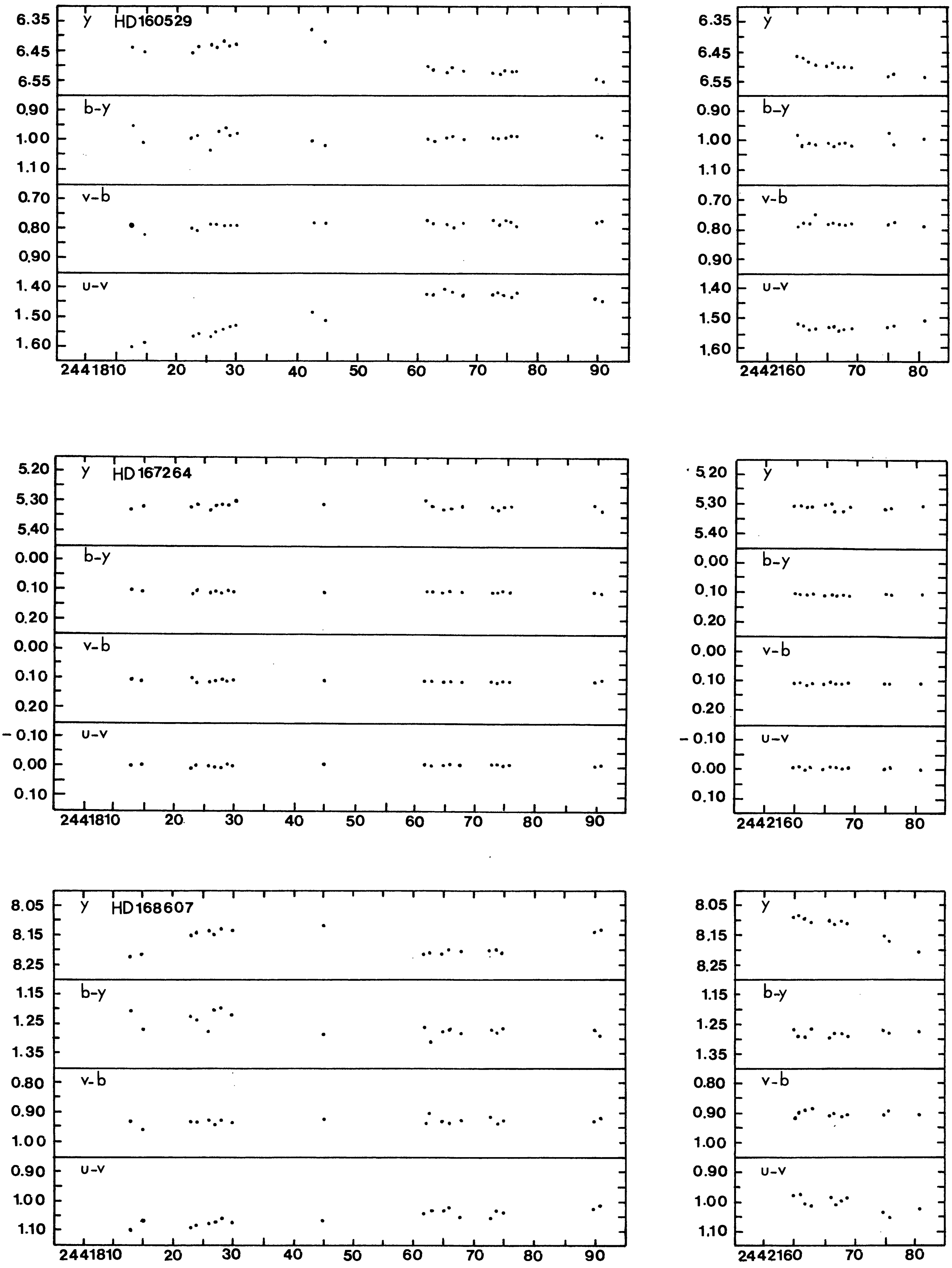

Fig. 3c. Night-to-night variations for HD 160529, HD 167264, HD 168607

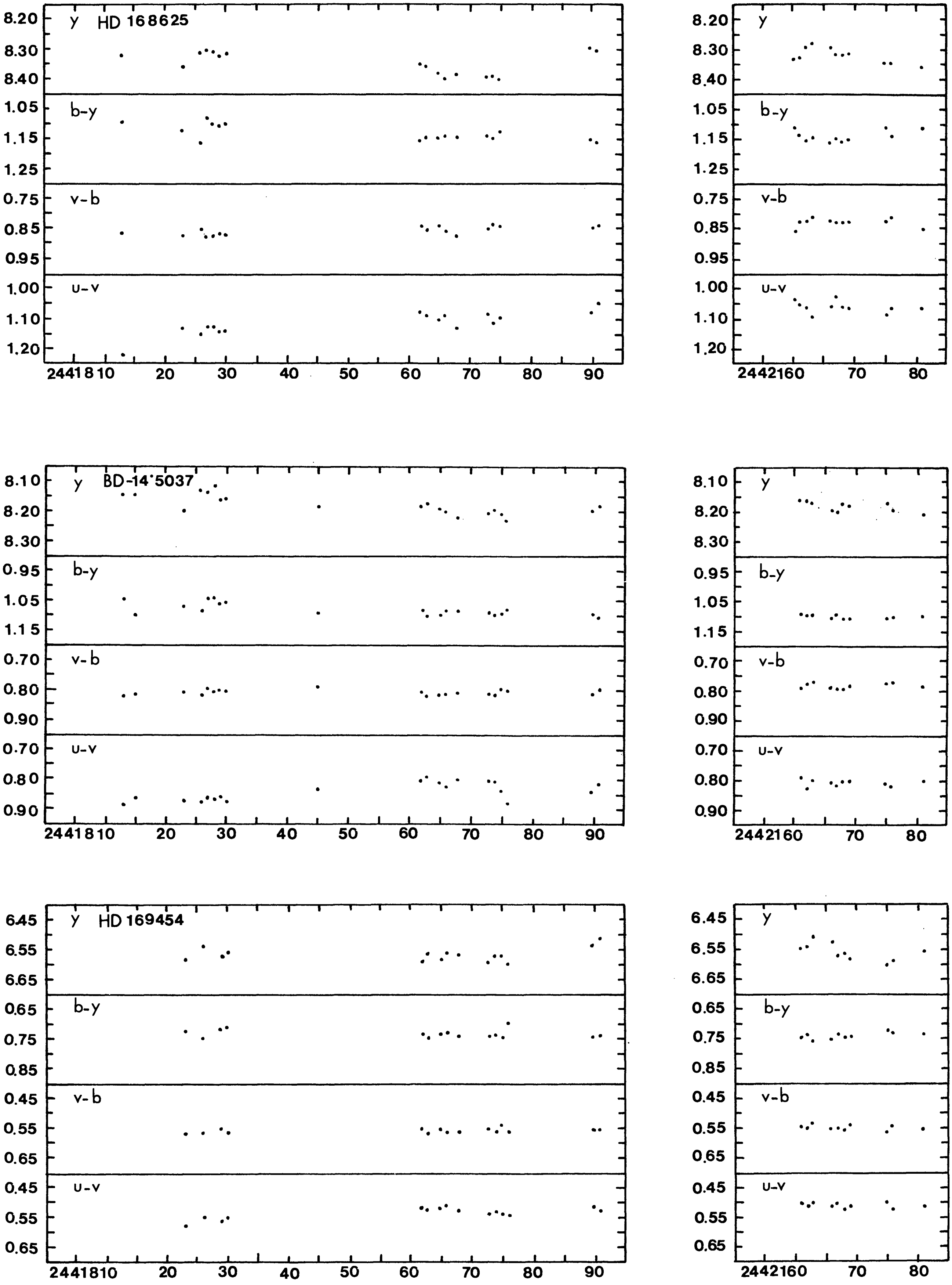

Fig. 3d. Night-to-night variations for HD 16825, BD−14°5037, HD 169454

Table 3. Amplitudes for the intermediate term variations

Identification	Spectral type	*N*	*A*(*y*)	*A*(*b*−*y*)	*A*(*v*−*b*)	*A*(*u*−*v*)
HD 91619	B5Ia	30	0.047	0.013	0.015	0.015
HD 92207	A0Ia	34	0.035	0.020	0.018	0.020
HD 96919	B9Ia	30	0.055	0.016	0.015	0.025
HD 99953	B2Ia	32	0.042	0.020	0.007	0.030
HD 100262	A2Ia	32	0.038	0.012	0.009	0.031
HD 152236	B1Ia+	35	0.048	0.007	0.007	0.014
HD 160529	A2Ia+	35	0.067	0.040	0.035	0.096
HD 167264	B0Ia	33	0.014	0.009	0.005	0.009
HD 168607	B9Ia+	30	0.067	0.047	0.034	0.060
HD 168625	B8Ia	28	0.054	0.042	0.031	0.095
BD−14°5037	B1.5Ia(+?)	30	0.055	0.030	0.025	0.052
HD 169454	B1Ia+	25	0.044	0.021	0.018	0.041

Table 4. Differences between the annual means for 1973 and 1974

Object	*Δ*(*y*)	*Δ*(*b*−*y*)	*Δ*(*v*−*b*)	*Δ*(*u*−*v*)
HD 91619	0.014	−0.003	0.004	0.001
HD 92207	0.016	−0.016	0.015	0.008
HD 96919	−0.038	0.000	−0.003	−0.021
HD 99953	0.011	−0.007	0.002	0.013
HD 100262	0.027	−0.007	0.006	0.026
HD 152236	−0.024	−0.002	0.006	0.004
HD 160529	−0.023	−0.011	0.007	−0.048
HD 167264	−0.006	0.000	0.002	0.002
HD 168607	0.053	−0.026	0.026	0.045
HD 168625	0.021	0.014	0.022	0.050
BD −14°5037	−0.004	−0.020	−0.023	0.029
HD 169454	0.010	−0.005	0.012	0.028

tuations with more or less the same characteristics: the highest amplitudes appear in the visual and in $u-v$, while smaller or even no variations were found in $b-y$ and $v-b$. The most striking case is HD 160529, where the range in the y-variation amounted to 0.13 mag and in $u-v$ to 0.20. A general uniform correlation between the y and $u-v$ fluctuations is not present.

2. *Nightly Variations*

Within the accuracy of these measurements, significant deviations on a short time scale in $u-v$ are only present in HD 160529 and in HD 168607. The other stars do not show significant fluctuations in the measured magnitudes or indices. If short-term variations are present in these stars, their amplitudes will certainly be smaller than 0.015 mag.

Though deciding about the presence of this kind of variability is very difficult on this limited observational material (HD 168607 was monitored only during one observing night), it is remarkable that these small variations are just present in these two stars for which the amplitudes of the night to night variations are the largest, so that *nightly variations with small amplitudes are probably only present in the most luminous stars.* These short-term variations look like irregular drifts, with no indication of periodicity. The amplitudes change from night to night, while during some nights no observable fluctuations were present [see Sterken (1976) for a detailed description of the nightly variations of HD 160529]. It is also very interesting to note that these two stars have just the same P Cygni type structure of Hα, showing a very broad overall emission of more than 20 or 30 Å. They are exactly the same type of profiles as one finds in S Dor and HDE 269006 of the LMC (Wolf, 1975a). Appenzeller (1974) also detected short-term variability in S Dor and recently Wolf (1975b) found significant short-term variations on a time scale of a few hours in HDE 269006.

3. *Long-term Variations*

Table 4 shows clearly that, except for the non-variable supergiant HD 167264, all objects show appreciable differences from one year to the other in magnitudes or indices. More systematic observations over much longer periods will be needed to see whether this is due to a statistical effect, or whether some of these stars are variables with a very long time base.

Similar variations over short, medium or long terms were already reported by other investigators:

— α Cygni was already known in 1896 as a spectrum variable. Paddock (1935) found a semi-periodic radial velocity variation with a period of about 12 days. The observations were obtained during a period of five years, and the variations were often almost periodic, with considerable variation in amplitude. Fath (1935) also found light variations which were in phase with the radial-velocity variations, and he also remarked that, besides light variation in periods of days, there was evidence of irregular variations during one single night amounting to 0.03 or 0.04 mag. This means that similar short term variations such as those seen in HD 160529 and eventually in HD 168607 have never been found in α Cygni.

— P Cygni is known since long to be a very irregular variable star. Old chronicles mention enormous light variations whereby the star was visible at intervals to the naked eye. Present photoelectric investigations report irregular variations with a maximum amplitude of

0.2 mag (de Groot, 1969). Magalashvili and Kharadze (1967) found that the lightcurves were not completely irregular, but had a period of about 0.5 days. Alexander and Wallerstein (1967) on the other hand found no variation during five observing nights.

— In 1953 Hubble and Sandage discovered five very luminous irregular variables in the extragalactic Nebulae M31 and M33. The variations cover the period between 1916 and 1953, and these variations were later confirmed and extended by Rosino and Bianchini (1973).

— Rosendhal and Snowden (1971) found light variations in five supergiants of the LMC: the maximum amplitudes of eventual nightly variations are smaller than 0.015 mag in all colours, and the night to night variations have a range between 0.02 and 0.07 mag.

Table 5. Semi-periods T and correlation coefficient r for the optimal least squares fit to the light-curve

Object	T	r
HD 91619	15.2	0.68
HD 92207	22.1	0.65
HD 96919	17.2	0.57
HD 99953	17.7	0.50
HD 100262	46.3	0.70
HD 152236	16.5	0.57
HD 160529	100.9	0.95
HD 168607	63.9	0.97
HD 168625	64.8	0.84
BD − 14°5037	7.3	0.64
HD 169454	19.6	0.71
HD 33579	104.5	0.70

4. Semi-periods

Precisely similar periods for the variability of supergiants have never been found, but there are several indications which point to the presence of semi-periods (often called characteristic times). Beside Abt's data, two LMC supergiants were found to exhibit semi-periodic light fluctuations: HD 33579 ($P = 90\,d$, van Genderen, 1974) and HD 268907 ($P = 55\,d$, Maeder and Rufener, 1972). An inspection of the lightcurves in Figures 3a–d shows that the time scale of variation of the highly luminous stars HD 160529, HD 168607 and HD 168625 is much larger than the time scale of variation of the fainter stars. We have tried to determine the optimal characteristic time T by a harmonical analysis of the data.

We represented the magnitudes m_i by a single periodical variation with period P and amplitude components a and b as follows

$$m_i = a_0 + a \sin 2\pi t_i/P + b \cos 2\pi t_i/P\,,$$

where a_0 is a constant. The corresponding values of a and b which lead to an optimum reduction, yield the amplitude A belonging to the vibration with period P:

$$A = (a^2 + b^2)^{1/2}\,.$$

For a certain value of P, a, b and a_0 are chosen in such a way that the sum of the squares for n observations

$$\sum_n v_i^2 = \sum_n \{m_i' - (c + a \sin 2\pi t_i/P + b \cos 2\pi t_i/P)\}^2$$

becomes as small as possible. m_i' is the deviation from the mean value $\bar{m}$, and

$$c = a_0 - \bar{m}\,.$$

Then

$$R = \sum_n m_i'^2 - \sum_n v_i^2$$

is a spectral function of P and the highest peaks of R yield the period P and the optimal values of a_0, a and b.

We have considered a region of P values ranging between 1 day and 120 days, and for discrete values of P in this region we determined the parameters. Phase diagrams were constructed with the P values yielding significant peaks of the spectral function R, and the characteristic time was selected by a visual inspection of the diagrams.

Table 5 lists the selected semi-periods T and the correlation coefficient r defined by

$$r^2 = \frac{R}{\sum_n m_i'^2}\,.$$

The low value of the correlation coefficient for some stars indicates that a large amount of scatter remains in the phase diagrams. This scatter is similar to the scatter present in the single-period phase diagrams constructed from Abt's data. A similar harmonic analysis of van Genderen's data yielded a T value of 104.5 days for HD 33579 which gives a much smoother phase diagram.

It is very likely that the resolution between the shortest characteristic times is illusory, since the obtained semi-period can only be recognised in some parts of the light-curve. This shows that periods deduced from one cycle are not identical with periods deduced from other cycles, so that we should think rather in terms of a mean period. The only way to obtain a consistent value for this mean period is to have continuous, equally distributed observations, covering a greater number of cycles. But increasing the number of cycles will increase the scatter in the phase diagrams, so that for some stars it will be very difficult to determine the exact period or semi-period. Another difficulty is the possible presence of selection effects, especially for the stars with the largest periods (the observations of HD 160529 cover less than one cycle). We plan further monitoring of these stars in the near future in order to find out whether the obtained periods are really significant or not.

5. Luminosities

The absolute magnitudes were calculated using our mean V values, the $B-V$ indices and colour excesses

Table 6. Visual magnitudes, distances from the sun in kpc, colour index, colour excess, calculated absolute visual magnitude and sources of information of the program stars

ID	V	r	$B-V$	E_{B-V}	M_v	Source
HD 91619	6.11	2.26	0.34	0.40	−6.94	1, 2, 7, 8, 9, 10, 15
HD 92207	5.46	1.68	0.47	0.39	−6.92	1, 7, 8, 9, 11, 15
HD 96919	5.14	2.05	0.21	0.17	−6.96	1, 2, 7, 8, 10, 11, 15
HD 99953	6.42	2.27	0.30	0.47	−6.85	2, 8, 9, 15
HD 100262	5.13	1.88	0.46	0.45	−7.68	1, 7, 8, 10, 11, 12, 16
HD 152236	4.70	2.16	0.43	0.59	−8.84	1, 7, 8, 13, 16
HD 160529	4.49	1.98	1.28	1.22	−8.91	8, 14, 15
HD 167264	5.32	1.29	0.07	0.16	−5.71	6, 7, 8, 16
HD 168607	8.15	2.36	1.60	1.66	−9.01	6, 8
HD 168625	8.33	2.81	1.46	1.55	−8.84	6, 8
BD − 14°5037	8.18	1.08	1.39	1.64	−7.15	6, 8
HD 169454	6.57	1.85	0.94	1.20	−8.54	5, 6, 8, 14

Sources:

1. Westerlund (1959)
2. Feinstein (1969)
3. Hoffleit (1956)
4. Schild et al. (1969)
5. Wallerstein (1970)
6. Hiltner (1956)
7. Hoffleit (1964)
8. Humphreys (1970)
9. Cousins et al. (1961)
10. Blanco et al. (1968)
11. Arp (1957)
12. Buscombe (1959)
13. Hiltner (1954)
14. Mendoza (1958)
15. Buscombe (1969)
16. Hiltner et al. (1969)

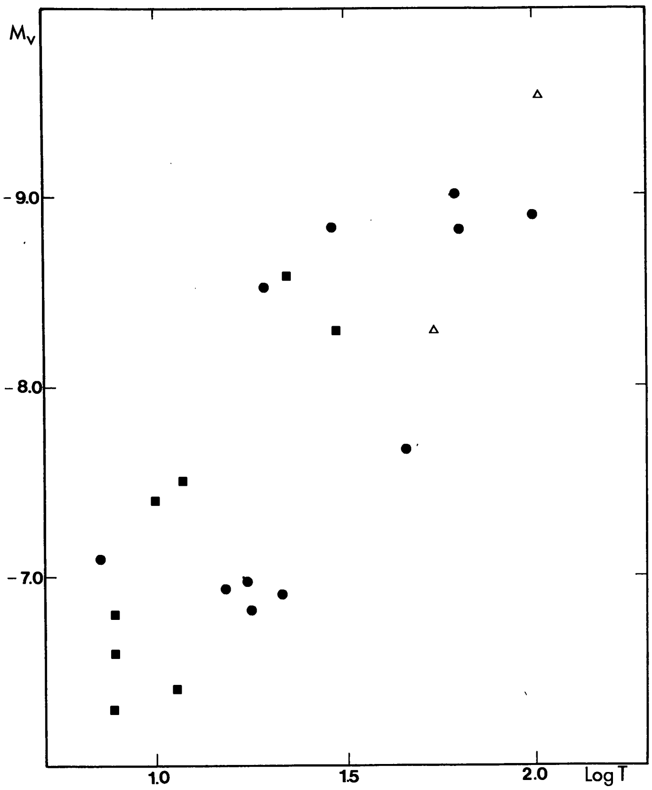

Fig. 4. Relation between the absolute visual magnitude and semi-period for the investigated supergiants ■: Abt's results; ●: this paper; △: HD 33579 and HD 268907

E_{B-V} from different sources, and the distances given by Humphreys (1970). The distances mainly come from association memberships. Table 6 gives the visual magnitudes V, distances r from the sun in kpc, colour index $B-V$ and colour excess E_{B-V}, the calculated absolute magnitude M_v, and also the sources from which the photometry was taken. For the ratio of total to selective absorption the value

$$R = 3.20 + 0.21\,(B-V)_0$$

was used (Schmidt-Kaler, 1965).

The M_v magnitudes are considered to be reliable to ± 0.4 mag. The relation between absolute visual magnitudes and characteristic times is presented in Figure 4. The results from Abt (1957) and for HD 268907 and HD 33579 ($P = 104.5\,d$) are also indicated.

6. Discussion

A possible explanation of the remaining large scatter in the phase diagrams could be that in these stars probably only the lower layers are involved in pulsation-type motions, and that the outer layers of the atmosphere expand in an irregular way, so that the dynamical activity of these surface layers produces the stochastic variations which we see superimposed on the more regular variation caused by pulsation. Simultaneous photometric and spectrographic observations over long periods are necessary to get some insight into the processes causing the variations.

Lucy (1975) concluded from an analysis of the variable radial velocity of α Cygni that the semi-regular variability of early-type supergiants is due to simultaneous excitation of many discrete pulsation modes. Hence the origin of the large scatter in the single-period phase diagrams might be due to the presence of several periods, but the time base of the actually available photoelectric measurements is too short to identify discrete pulsation modes.

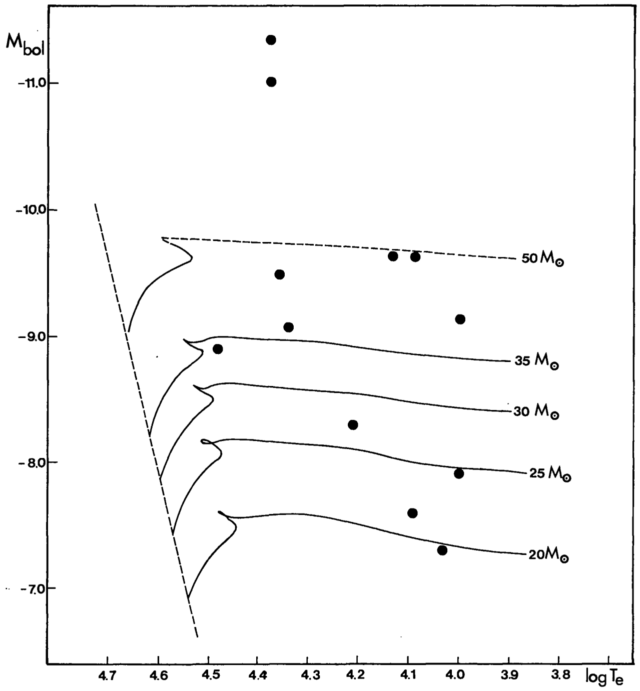

Fig. 5. Location of the investigated supergiants in the $M_{bol} - \log T_e$ plane. The bolometric magnitudes were calculated using the M_v-values from Table 6, and the bolometric corrections listed by Harris (1963). The evolutionary tracks calculated by de Loore and De Grève (1976) are indicated

7. Hα *Emission*

The most striking spectral feature of the stars studied here is the very pronounced emission in Hα which is often variable [Hα emission features for the bulk of these stars are presented by Wolf et al. (1974)]. The presence of time dependent emission in Hα is a very common feature in the spectra of luminous supergiants. Rosendhal (1973b) investigated 90% of all known O9-A5 supergiants with visual magnitude below 6.2 and which are easily observable from the northern hemisphere. He found that, from $M_v = -6.5$ on, strong luminosity dependent Hα emission is present.

Underhill (1966) already mentioned that Hα profiles of Ib supergiants show no emission. Rosendhal (1973b) found that in a sample of 28 B and A supergiants showing Hα in emission, twenty were definitely spectrum variables. Too few observations were available to draw valid conclusions for the other objects.

VI. Conclusion

Most of the stars included in this investigation were found to be variable. The time scales involved range from a few hours or a few days to annual variations. None of them, however, exhibits detectable short-period variations which were predicted by theoretical investigations of vibrationally unstable massive stars. The amplitudes (half ranges) reach 0.07 mag in V and 0.1 mag in $u-v$ for the medium-term variations, and increasing amplitudes are correlated with increasing luminosity. Characteristic times ranging between 5 and 100 days can be assigned to the variation in V. These semi-periods are linked to the absolute visual magnitudes by means of a reasonably well-defined characteristic time-luminosity relation.

The frequent presence of Hα emission, and also their locations in the theoretical HR-diagram (Fig. 5), reveals evidence for mass loss in these stars. Up to now the relation between mass loss and these variations is still unclear. The presence of depth-dependent and time-dependent velocity fields point to the fact that an oscillatory mechanism is probably present in the deeper layers. But the irregular type of some variations and the time scales involved (nightly to annual variations and the absence of short periods) supports the idea that vibrational instability does not seem to be a suitable mechanism to explain the detected light variations.

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