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Light variations of the blue hypergiants HD 168607 and HD 168625 (1973–1999)*

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Abstract. Strömgren differential photometry of HD 168607 and HD 168625 collected during the previous 27 years is analysed. We bring to an end our quarter of a century monitoring of these objects and conclude that HD 168607 shows typical variability of an uneventful LBV, whereas HD 168625 remains to be classified as a variable hypergiant, or a marginally-dormant LBV. The long-term light- and colour behaviour of HD 168607 indicates the possible presence of a very slowly-developing S Dor phase – that is, a bright phase that coincides with redder colours. Besides the α Cygni-type microvariability, no other signs of ultrashort-periodic variability has been observed.

Key words: stars: early-type – stars: individual: HD 168607 – stars: individual: HD 168625 – stars: oscillations – stars: variables: general

1. Introduction

HD 168607 (B9 Ia) and HD 168625 (B8 Ia) are galactic supergiants of which the α Cygni-type variability was discovered by Sterken (1977). For HD 186607, the light curves revealed V light ranges over $0\overset{m}{.}25$–$0\overset{m}{.}30$ with a characteristic time of about 64 days. In the case of HD 168625, the range in V was smaller ($\sim 0\overset{m}{.}10$), with a similar pseudo-period. Sterken (1976a) also found very-short-term variability of HD 168607 in $u-v$ during one single night (as well as in the case of HD 160529, Sterken 1976b, such variations were later also found in the y band, see Sterken 1981).

Van Genderen et al. (1992) presented Walraven photometry for both stars, and found quasi-periodicities of the order of 58 and 33–37 days for HD 168607 and HD 168605, respectively. Van Leeuwen et al. (1998) confirmed these findings on the basis of Hipparcos photometry. Both stars have very mild LBV characteristics: no "eruptions" – not even outspoken S Doradus phases – have been reported (although HD 168625 has a surrounding nebula and is considered to be a true LBV, see Nota et al. 1996). These two stars share about the same location in the HR diagram (see Fig. 1), their initial masses must have been in the 25–30 M$\odot$ range though their current masses may be not more than half as much. Their celestial position being roughly 1 arcmin apart, they are excellent targets for photometric monitoring – either by photomultiplier photometry (using common comparison stars) or by CCD imaging (both stars and some comparison stars on a same CCD frame).

This paper discusses all new and published photometry of these stars over a time baseline of 27 years. Throughout this paper we discuss differential photometry, in the sense that the variability of both stars is discussed in terms of their differential magnitude relatively to a comparison star.

2. The data

2.1. The discovery data

The discovery data have been described by Sterken (1977) and consist of about 30 $uvby$ measurements of both stars, with an additional 5-hour time series of each object (Sterken 1976a). Because of significant changes in equipment (photomultipliers and, especially, u and v filters), only the y- and b-band data can be directly compared with data taken since the 1980s.

2.2. LTPV $uvby$ photoelectric photometry

The $uvby$ data were obtained at ESO in the framework of the "Long-term Photometry of Variables" (LTPV) project which was initiated more than a decade ago (Sterken 1983, 1994). A total of 172 datapoints (i.e. nightly averages of 1–3 measurements) have been collected for HD 168607, and 165 such observations for HD 168625. Table 1 gives the most important results for each variable and comparison star, as well as the overall averages in $y(V)$, $b-y$, m_1 and c_1, together with the corresponding standard deviations of individual measurements. The data in Table 1 are based on results from "System 7" (see Sterken 1993) only, and they give a general impression of the photometric accuracy of the LTPV program. The standard deviations of the program stars by far exceed those of the comparison stars. Both program stars have also been observed during several observing runs in 1995–96 using the ESO 50 cm telescope (mostly in y and b only). A total of 57 such measurements have

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* Based on observations obtained at the European Southern Observatory at La Silla, Chile (applications ESO 56D-0249, 58D-0118, 60D-0148, 61D-0128 and 62H-0110)

Table 1. Program stars (P) and comparison stars (A, B): average $y(V), b-y, m_1, c_1$ and standard deviations σ (in millimag). N denotes the total number of observations of each star. Note that these data are based solely on results from System 7 (Sterken et al. 1993, see also Sterken 1993)

LTPV	HD	MK type	$y(V)$	$b-y$	m_1	c_1	N	σ_y	σ_{b-y}	σ_{m_1}	σ_{c_1}
P5012	168607	B4 Iae	8.223	1.218	-0.273	0.002	172	76	102	30	36
P5013	168625	B2/5 Iae	8.407	1.099	-0.223	0.129	165	25	10	12	15
A5012	168552	B2–3 Ib/II	8.080	0.292	0.000	0.099	382	9	4	5	7
B5012	168896	A3 III	8.477	0.134	0.190	0.974	303	8	5	6	7

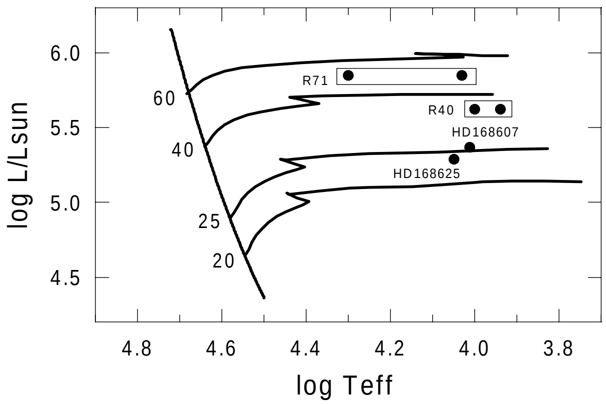

Fig. 1. HR diagram (evolutionary tracks for models with $Z = 0.001$ from Schaller et al. (1992) with the location of HD 168607 and HD 168625 (based on stellar parameters given by Leitherer & Wolf 1984). The horizontal boxes around the positions of the LBVs R 71 and R 40 correspond to the extreme positions observed for these objects

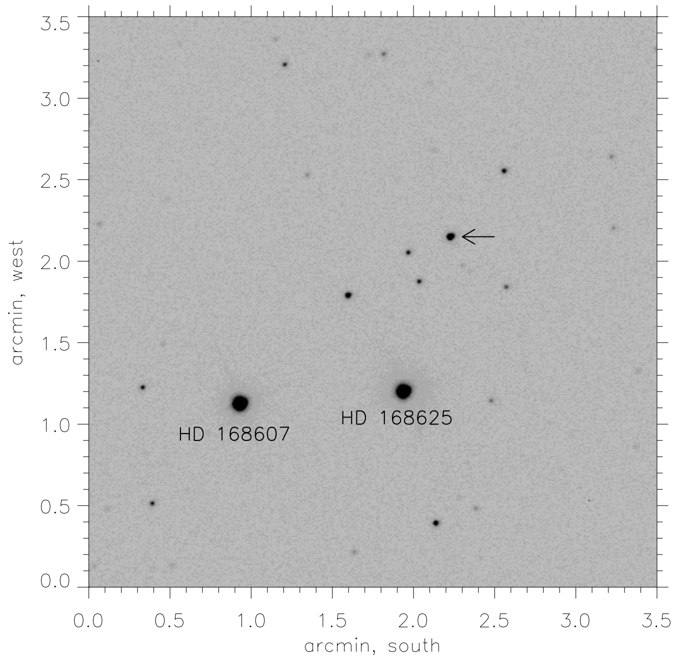

Fig. 2. CCD frame, field of view 3.′6. (N is up, E is right), the comparison star is indicated by an arrow

been obtained by A. Bruch, H. Duerbeck, A. Kelz, H. Melief, M. Nolte, C. Sterken and A. Visser.

Both comparison stars can be regarded as constant, (Hipparcos photometry of the first comparison star HD 168552 = HIP 89933 indeed confirms the constant character) but because the c_1 index of star B (HD168896) is so red, we prefer to work with HD 168552 (B2-3 Ib/II) as sole comparison.

A note is in place here concerning spurious variability seen in the u and v bands as a consequence of the use of different photometric passbands. A straight plot of all data irrespective of passband characteristics would show strong variability in $u-v$ and $v-b$ which can almost entirely be ascribed to transformation problems from one photometric setup to the other, while such detrimental effects are not present in the y and b bands. The same comment applies to Sterken's 1973–74 data, and also to the new data based on CCD-uv bands. Therefore, we have plotted in Figs. 3 and 4 only the $u-v$ and $v-b$ data belonging to one single photometric setup (System 7). All our figures are based on data in the instrumental photometric system. Part of the data have been published by Manfroid et al. (1991, 1994) and Sterken et al. (1993, 1995).

2.3. Walraven $VBLUW$ photometry

Walraven $VBLUW$ photometric data of both stars were obtained by van Genderen et al. (1992) using the Walraven photometer at the Dutch 90-cm telescope at La Silla. We transformed the Walraven differential $\Delta V, \Delta(V-B)$ ($\log$ intensity scale, differential measurements with respect to HD 168663, F4 V) to Johnson-like V_J and $(B-V)_J$ using the transformation formulae given by Pel (1986). In order to homogenise the resulting Johnson magnitudes to the LTPV magnitude scale, we collected all LTPV magnitudes and van Genderen et al. (1992) data that were obtained within a time span of less than five hours from each other. 21 such measurements were found, they yield a correction $y_{\rm LTPV} - V_J = 0.029 \pm 0.^{\rm m}002$. This correction was then applied to the V_J magnitudes and thus enabled us to study all V-band variability on a commonly constructed V_J scale.

2.4. Hipparcos photometry

76 measurements of HD 168607 and 78 of HD 168625 are available in the Hipparcos photometric catalogue (ESA 1997). The Hipparcos passband embraces both the y and b passbands of the Strömgren system, thus a correction is needed. From simultaneously obtained H_p and y magnitudes, we derive the relation $y = H_p - 0.060$.

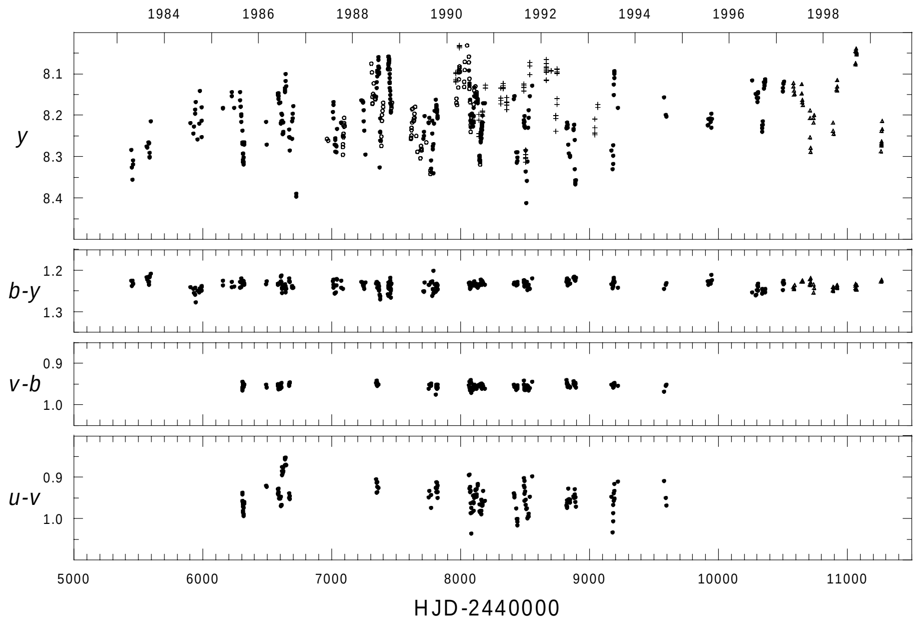

Fig. 3. LTPV $y, b-y, v-b, u-v$ data for HD 168607. ●: LTPV photomultiplier data, +: Hipparcos, ○: Walraven, △: LTPV-CCD

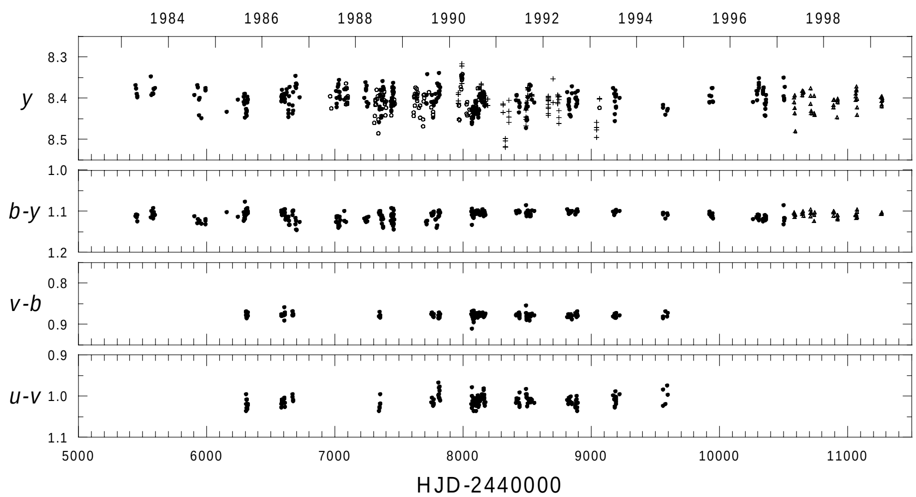

Fig. 4. LTPV $y, b-y, v-b, u-v$ data for HD 168625, symbols as in Fig. 3

Table 2. Standard deviations σ (in millimag) in the Strömgren bands obtained from CCD photometry. N denotes the number of nightly averages of each star.

HD	N_y	σ_y	N_b	σ_b	N_v	σ_v	N_u	σ_u
168607	44	78	42	76	9	25	9	29
168625	44	22	42	23	9	12	9	7

2.5. *LTPV $uvby$ CCD photometry*

CCD photometry at the Dutch 90 cm telescope at La Silla was obtained on about 40 nights in 1997–1999. Observers were C.S., T.A. and H.W.D. Time-series with ~ 40–150 frames were also obtained during ten nights between May 1997 and September 1998. The detector was ESO CCD 33 with 512×512 pixels. Data reduction was carried out with the MOMF package (Kjeldsen & Frandsen 1992). The zero-point offset was determined on the basis of a number of CCD frames of standard stars taken from the list of Jønch-Sørensen (1994). Fig. 2 shows the 3$'\!.$6 field around both stars: it is obvious that this field of view, with its paucity of bright comparison stars, will complicate the reliability of our results. The position of the brightest reference star is indicated, that object ($V = 11.9$) is about 3 magnitudes fainter than the program stars. We, therefore, use nightly averages in the light curves. Table 2, giving the number of nightly averages and the corresponding standard deviations in each band, has very similar entries as Table 1 for both variables, the estimated observational accuracy is ~ 0.008–0.009 mag in y, b, v and about $\sim 0\overset{\mathrm{m}}{.}12$ in u.

3. The light- and colour curves

3.1. *The character of the light variations*

Figs. 3 and 4 give the light (y and V corrected to the y scale) and colour curves of both stars. HD 168607 shows a larger amplitude than HD 168625 in y and also in $u-v$. A significant brightening in y occurs at a rate of $0\overset{\mathrm{m}}{.}0045 \pm 0\overset{\mathrm{m}}{.}0001\ \mathrm{y}^{-1}$, and there is an associated (though weak) reddening in $b-y$ at a rate

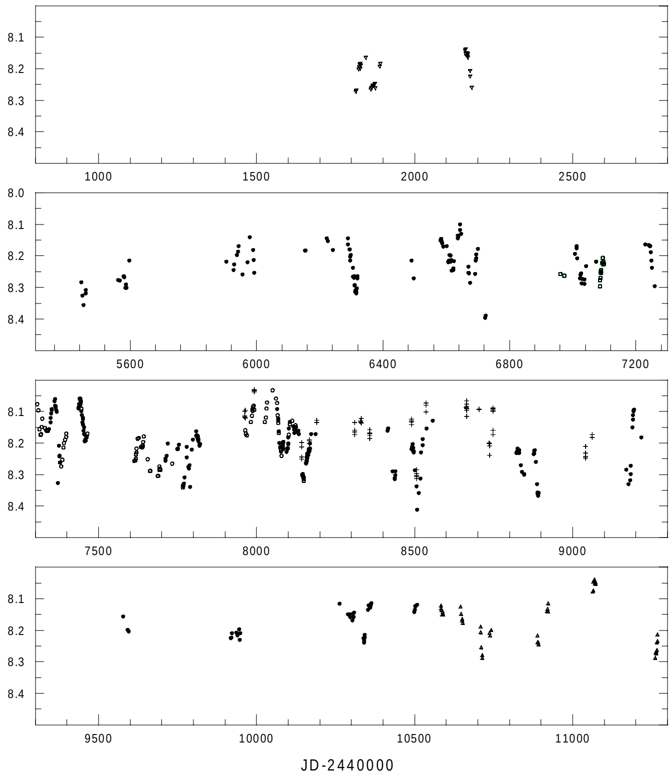

Fig. 5. Long-term V light curve for HD 168607. ●: LTPV data, +: Hipparcos, ○: Walraven, △: LTPV-CCD data, ▽: Sterken (1977)

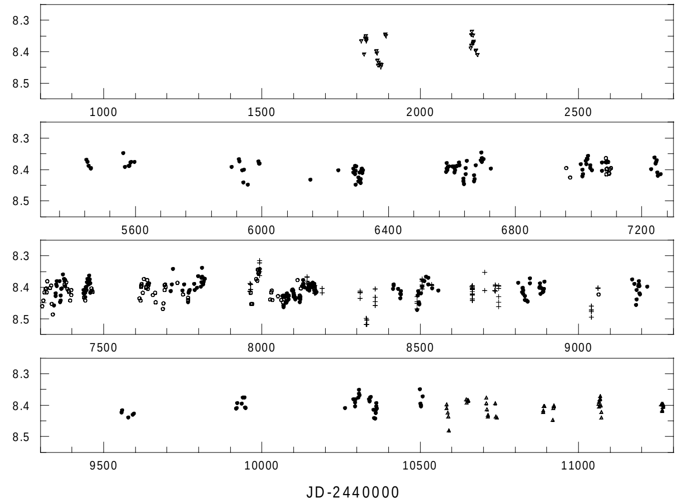

Fig. 6. Long-term V light curve for HD 168625, symbols as in Fig. 5

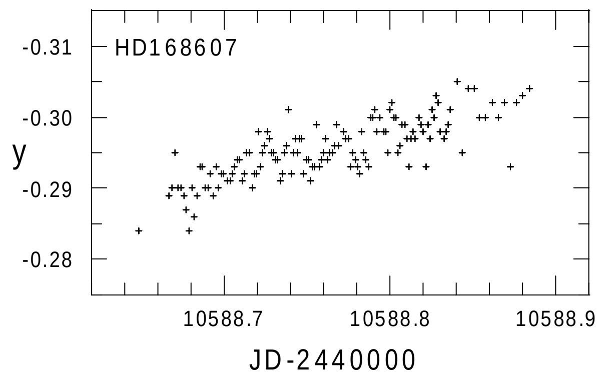

Fig. 7. Short-term y variability of HD 168607 on JD 2450588.

that is about ten times less. Microvariability is superimposed on the brightness increase, though no significant $b-y$ and $v-b$ colour variations are associated. There is, however, substantial additional variability in u, as one can infer from the large amplitude and the low-frequency trend in $u-v$. In the case of HD 168625, much lower trends are visible: a steady decrease in light by $0^{\mathrm{m}}_{\cdot}0025$ y^{-1}, without any associated significant colour trend. HD 168625 has little or no $b-y$ colour variation, and the $u-v$ index does vary, though not very conspicuously.

3.2. High-frequency variability

The presence of high-frequency variability in massive and luminous stars is rather uncommon. In order to check whether one of these stars displays brightness variations on short time scales (as were, for example found in the W-R star HD 5980, see Sterken & Breysacher 1997), we also intensively monitored the field during ~ 4–5 hours in about ten nights collecting 50–150 b, y frames each night. These frames cannot be analysed relatively to the fainter comparison star because the photon noise becomes a too important negative factor. We, therefore, analysed differential magnitudes of HD 168607 *minus* HD 168625 which, due to the less outspoken activity of the second LBV, mostly reflect the short-term variability of HD 168607. The conclusion of this monitoring is that

– no flare-like light variability is seen
– no regular variability (i.e. periodic, as in the case of HD 5980) on time scales of several hours has been detected

The sole manifestation of short-term variability that is evident was observed on JD 2450588 (20 May 1977, a night of good atmospheric conditions) as a smooth brightening superimposed on a descending branch in the cycle of microvariability, as is illustrated in Fig. 7.

3.3. Frequencies in the light variation

Figs. 5 and 6 illustrate the microvariations seen in the (y) light of both stars. A frequency analysis of these data was carried out in the frequency range 0.0–0.05cd^{-1}using Fourier analysis. Figs. 8 and 9 show the resulting amplitude spectra and window functions. The highest peak in the amplitude spectrum of HD 168607 occurs at 0.00157cd^{-1}, corresponding to a cycle of 640 days, the second-highest peaks are at 0.016cd^{-1}(62 d) and 0.028cd^{-1}(35.7 d). The low frequency, probably, is an artifact, the 62 d pseudo-periodicity corresponds to the characteristic time scale found by Sterken (1977). For HD 168625, however, no outstanding peaks are apparent.

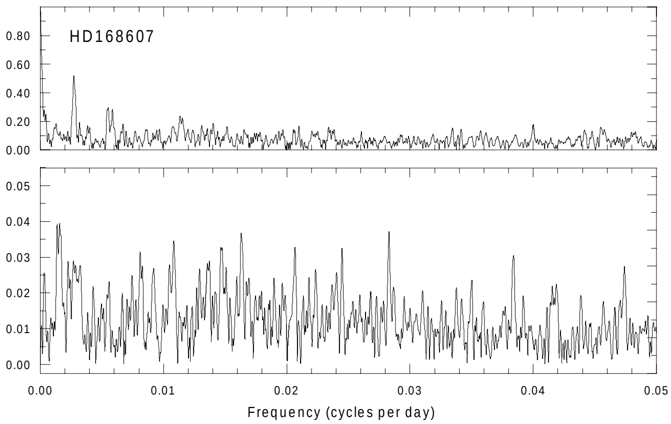

Fig. 8. Spectral window (top) and amplitude spectrum (bottom) for HD 168607

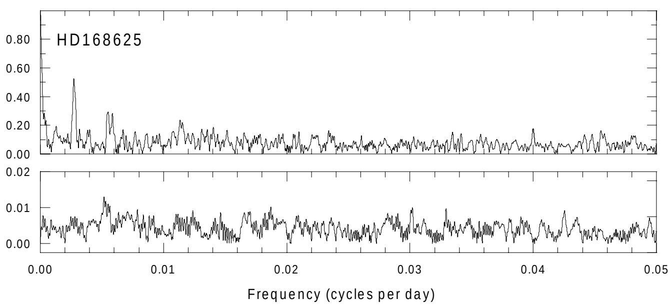

Fig. 9. Spectral window (top) and amplitude spectrum (bottom) for HD 168625

The light-and colour behaviour in 1982–1999 exactly confirms the effects observed by Sterken (1977), except for the fact that the periodicity seen in HD 168625 in 1972–73 (and by van Genderen et al. 1992 and van Leeuwen et al. 1998) does not seem to be a long-standing characteristic.

4. Discussion and conclusion

The colour behaviour described in Sect. 3.1 could indicate the presence of a very slowly-developing S Dor phase in HD 168607. This is illustrated in Fig. 10, which shows the $y, b-y$ diagram for both stars, and also for AG Car (data from van Genderen et al. 1997) and R 40 (data from Sterken et al. 1998): all y magnitudes are negatively correlated with $b-y$ – that is, bright phases coincide with redder colours. The effect is about a factor of ten stronger for the large-amplitude S Dor variables (R 40 and AG Car) than it is for HD 168607.

We bring to an end our quarter of a century monitoring of these objects and conclude that HD 168607 shows typical variability of an uneventful LBV, whereas HD 168625 remains to be classified as a variable hypergiant, or a marginally-dormant LBV. Besides the α Cygni-type microvariability, no other signs of ultrashort-periodic variability have been observed.

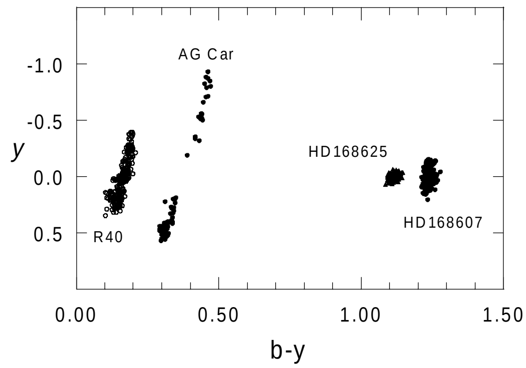

Fig. 10. $y, b-y$ diagram for both stars, and also for AG Car and R 40. (for the sake of clarity, the y scale is normalised to the average y for each star)

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