ASTRONOMY
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The long-term behaviour of the Be star HD 163868 *

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Abstract. In this paper we discuss the light variations of HD 163868 on the basis of all available photometric data originating from photometric monitoring during the last two decades. We suggest that one explanation of the on-and-off type variability can be a binary configuration with a compact companion and a period of the order of 850 days, though the observed effects could also be seen in the context of positive interference of NRPs. The bright stages are associated with strong reddening consistent with an increase in circumstellar material. We draw the attention to the similarity with cyclically-recurrent mild S Dor phases of LBVs.

Key words: stars: individual: HD 163868, HD 164152, HD 164270 – stars: emission-line, Be – stars: variables: other

1. Introduction

In this paper we discuss the light variations of HD 163868 (V=7.4, B5Ve) on the basis of all available photometric data originating from photometric monitoring during the last 23 years.

1.1. Strömgren $uvby$ data

HD 163868 was used for some time as one of the comparison stars for monitoring WR 103 (HD 164270, see Veen et al. 1997) in the framework of the "Long-term Photometry of Variables" (LTPV) project (Sterken 1983, 1994). During the analysis of the WR 103 data, strong variability of HD 163868 in all bands was noticed. Though Massey et al. (1984) found the star constant "to a few hundreths of a magnitude" (during a time interval of 10 days in June 1980), the discovery of the variability of HD 163868 was already announced by Woodward (1975). This author assigned a lower limit of 20 days as a possible period of variation, and pointed out that the star is possibly variable on a time scale of several hours.

About 150 $uvby$ measurements have been collected at ESO; the photometric magnitudes and colour indices in the standard photometric system were published by Manfroid et al. (1994) and by Sterken et al. (1993, 1995), and we refer to these papers for more details on the observing strategy and on the reduction procedure. Fig. 1 displays the $y \equiv V$ light curve together with the V light curve from data of Woodward (1975). Table 1 gives the average magnitudes and colour indices for HD 163868 and the (constant) comparison star B9007 = HD 164152. The data in Table 1 are based on data from "System 7" (see Sterken 1993) only, and the B star mean errors give a general impression of the photometric accuracy of the LTPV program. The standard deviations of A9007=HD 163868 by large exceed those of the comparison star.

1.2. Geneva $UBB_1B_2V_1G$ data

HD 163868 has been observed in the Geneva photometric system at two occasions in 1989 and once in 1991. The Geneva data being non-differential, the homogeneisation of Geneva m_V and y photometry is not always guaranteed. Sheer fortune provided us with four measurements of our comparison star HD 164152 obtained during one single night in 1983 when one Geneva observer erroneously measured HD 164152 by misidentification. This average value, $m_V = 8.873 \pm 0.004$–thanks to the high photometric fidelity of the Geneva photometric system–allows us to bring the more recent measurements of HD 163868 to a common scale with the LTPV data. Table 1 gives the Geneva visual magnitude m_V and the colour indices U, V, B_1, B_2, V_1, G. It is obvious that the scatter of the measured quantities plainly confirms the variability in the visual magnitude and the visual colour indices, with even stronger variability in the U index due to the larger amplitude of the variations in the ultraviolet. The index β_c is the Geneva emission-free β index calculated from the photometric data (see Cramer 1994). The deviance by $0\overset{m}{.}1$ of β_c from the observed Strömgren β index (β = 2.523, Klare

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Table 1. HD 163868 and comparison star HD 164152: 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 the results are solely based on data belonging to System 7 (Sterken et al. 1993, see also Sterken 1993). Geneva photometry: m_V is the visual magnitude, U, V, B_1, B_2, V_1, G are the colour indices with respect to the B band. The index β_c is the Geneva emission-free β index calculated from the colour indices. The first column gives HJD−2440000

LTPV	HD	MK type	$y(V)$	$b-y$	m_1	c_1	N	σ_y	σ_{b-y}	σ_{m_1}	σ_{c_1}
A9007	163868	B5Ve	7.365	0.056	0.045	0.140	153	45	12	7	43
B9007	164152	B9V	8.892	0.060	0.126	0.950	150	8	4	6	8

HJD	m_V	U	V	B_1	B_2	V_1	G	β_c
7672.820	7.268	0.496	0.955	0.817	1.550	1.655	2.116	2.625
7756.594	7.319	0.505	0.971	0.819	1.556	1.667	2.138	2.630
8494.585	7.332	0.532	0.966	0.814	1.554	1.666	2.146	2.634

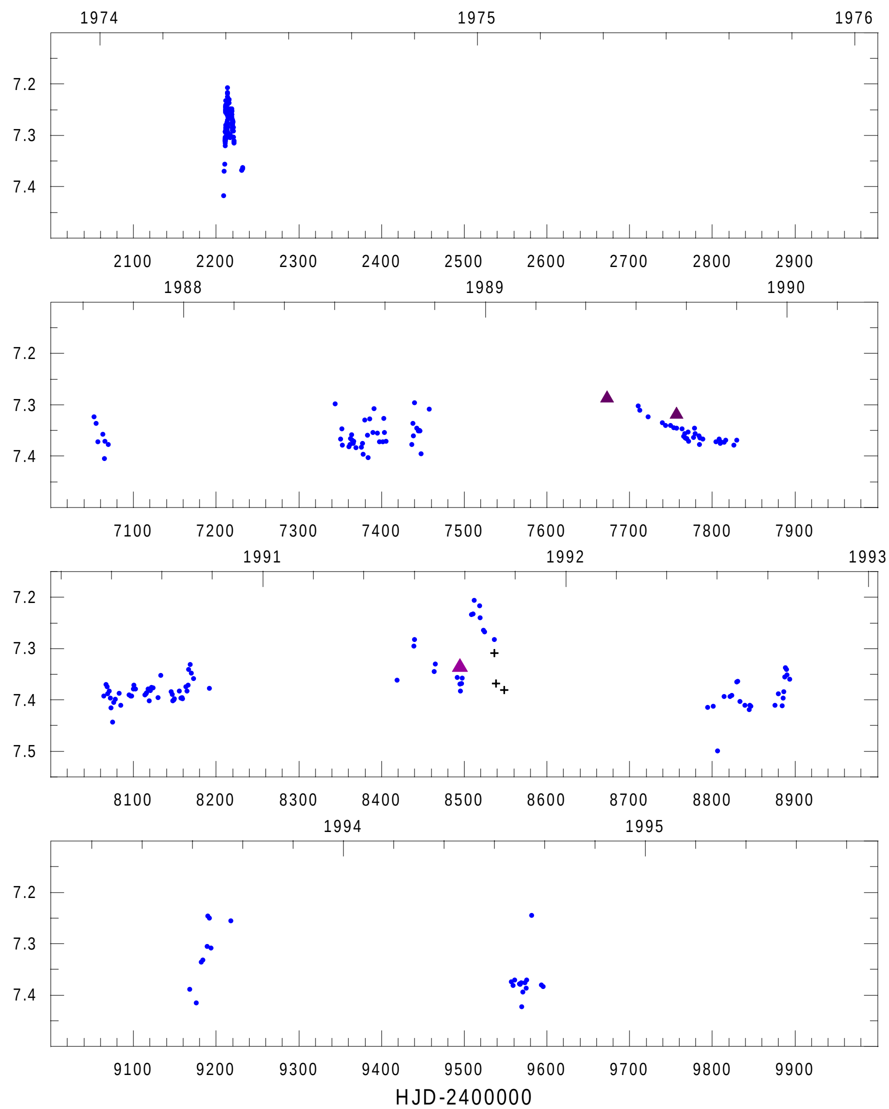

Fig. 1. All available V and y data. Top panel: V data from Woodward (1975), other panels: LTPV. The triangles represent Geneva visual magnitude data, the crosses indicate a few measurements of HD 163868 for which no comparison star measurements are available

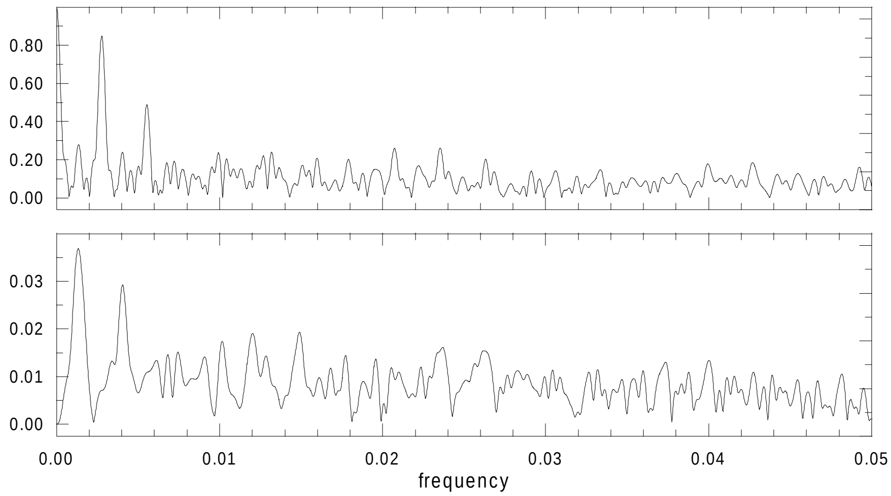

Fig. 2. Spectral window (top) and amplitude spectrum (bottom) of HD 163868 (y) in the frequency range 0.0-0.05 cd^{-1}

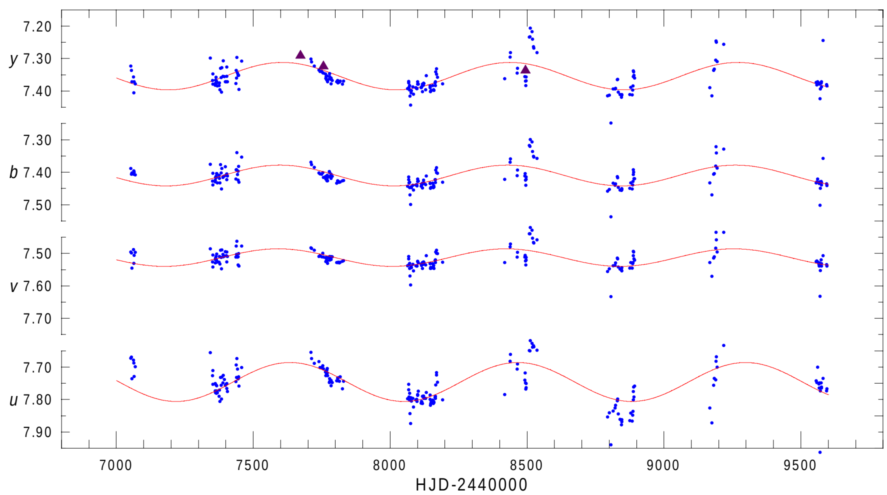

Fig. 3. LTPV $uvby$ light curves and least-squares sine fits. The triangles represent Geneva visual magnitude data

& Neckel 1977) is the signature of very strong emission in Hβ, an emission that also seems to be variable, as seen in column β_c in Table 1.

2. Periodicities

A period search was carried out using Fourier analysis on the differential A9007 *minus* B9007 $y \equiv V$ LTPV data in the frequency range 0.0-0.2 cd^{-1}. The spectral window (Fig. 2, top) is dominated by a strong peak at 0.00276 cycles per day (cd^{-1}), and a further 1 cycle per year alias at 0.005525 cd^{-1} due to the annual cycle of our observations. The amplitude spectrum (Fig. 2, bottom) shows the strongest peak at f = 0.0013 cd^{-1} with a weaker peak for the 1 cycle per year alias 0.00405 cd^{-1}. A least-squares sine fit with this frequency reduces the $O - C$ standard deviation by little more than $0\overset{\mathrm{m}}{.}01$ in all bands, leading to residuals that are still a factor of four larger than expected. A least-squares sine fit in each band leads to an average f = 0.00120 cd^{-1} (P = 833 d, for the LTPV data).

Besides the light curve published by Woodward (1975), the literature contains only one strongly deviant visual magnitude of HD 163868, that is, Kozok (1985) who reports V = 7.144 on HJD 2444025. Though we should not attach too much importance to this number in absolute terms, it is notwithstanding the brightest V-band measure ever reported, so we feel confident when identifying this bright phase with the maximum of a brightening event as the one seen by Woodward (1975). With our tentative period of the order of 830 days, we can construct a cycle-count scheme in which the maximum assigned to the measurement of Kozok (1985) occurs two cycles after the very first maximum. Then, four cycles would elapse till the supposed maximum around JD 2447600-7700 (no data available), after which brightness peaks around JD 2448500 and 2449200 each follow at one cycle interval. This scheme then leads to a preliminary linear ephemeris

$$
\begin{array}{rl} T_{\max} = & 244\,2244 + 884E \\ & \pm 71 \quad \pm 7 \end{array}
$$

We stress that this "period" should not be regarded as rigid in the true sense of the word, but that we rather deal with semi-periodic behaviour. As such, the mean errors quoted with the ephemeris only represent the uncertainties in the mathematical solution.

3. Discussion

The light curve presented in Fig. 3 reveals several patterns of variability, viz.:

1. the long wave on a time scale of the order of 850 days. Fig. 4 gives the phase diagram for P = 833 d in y, b, v, u and in the colour index $b-y$; the system is visibly redder during maximum light, as was already remarked by Woodward (1975) and as is illustrated in Fig. 5
2. variability of a semi-regular or even irregular character on time scales of tens of days or more
3. burst-like events that occur around the maxima of the long wave. They rise the light level in each band by more than $0\overset{\text{m}}{.}1$ in Woodward's light curve, and on two occasions in our data. The well-covered event around JD2448400-8500 has a double structure (see also Fig. 5), and the dip preceding maximum light has been observed by two independent observers. We draw special attention to the fact that burst-like events of a smaller amplitude seem to occur at epochs of minima too, see Fig. 1 (JD 2448800-8900) and Fig. 4, where large error bars accompany data taken during minimum (phases 0.1-0.2)–we stress, though, that our data are not numerous enough to preclude the existence of flares at other phases in the 830-day variability cycle
4. during some time intervals (like JD 2448060-8160) the star is almost non-variable (confirming the statement by Massey et al. 1984).

The most prominent variability aspect, clearly, is the 830-day variability cycle. The interpretation of this on-and-off variability is not straightforward. HD 163868 may simply be an interacting binary including an emission disk, so that the $\sim$ 850 d cycle is due to changing aspects of a precessing envelope (like, e.g. HR 2142, which also shows rising/fading events as discussed by Mennickent et al. 1997).

But the variability of HD 163868 does also resemble the case of κ CMa, μ Cen and HR 2517, three Be stars showing recurrent flaring. Balona (1990) ascribes the flaring of κ CMa (a multiple-peak outburst amounting to $0\overset{\text{m}}{.}1$ suddenly appears, and fades in several days) to the abrupt appearance of a bright area–thus ruling out NRP to explain Be outbursts–but Rivinius et al. (1997) found in μ Cen a correlation between beat periods in NRP and the increases of Hα emission strength, thus giving new support to the notion of pulsationally driven outbursts of Be stars.

Sterken & Manfroid (1996) offer an alternative explanation for HR 2517 in the sense that this star may be an eccentric, massive close binary system, where the primary has lost a large amount of mass so that the secondary obtains an internal structure very similar to that of a single star of that mass. A subsequent supernova explosion makes a compact remnant orbit the mass gainer, and a high-mass X-ray binary (HMXB, see Kaper 1994) is observed. In HMXBs where the secondary star is a Be star, often a transient X-ray source is found, and this is explained by the fact that a detectable X-ray luminosity is only expected when the compact star crosses the dense equatorial disk of the Be star (Kaper 1994, van den Heuvel & Rappaport 1987). About

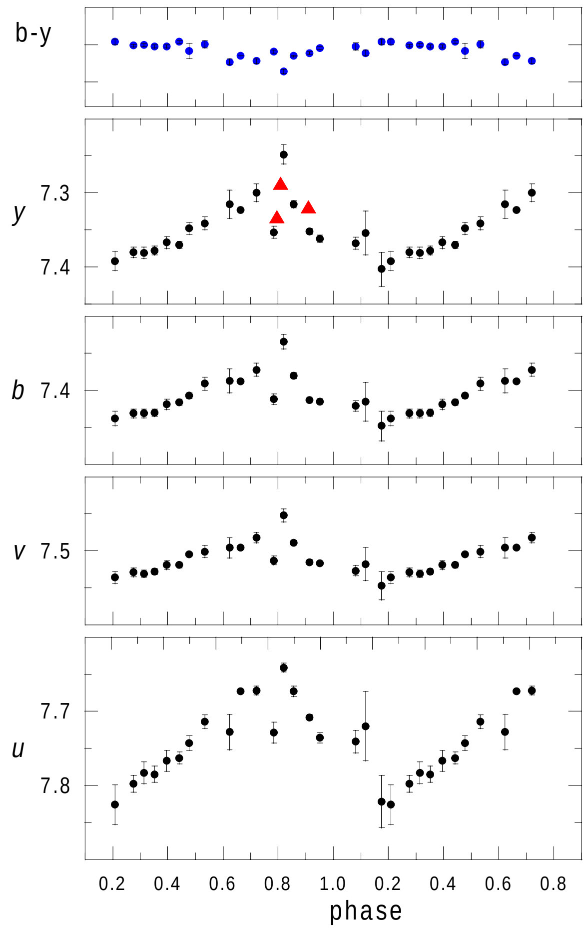

Fig. 4. LTPV $uvby$ magnitudes in function of phase in the P = 833 d period (f = 0.001201). Phase 0 (JD 2447000) was chosen arbitrarily, phase bins correspond to about 30 days. The diagram at the top is the phase diagram of the colour index $b-y$. The error bars represent m.e. Triangles in the y graph are based on Geneva m_V magnitudes

1000 to 10000 such Be/X systems may exist in our own galaxy, but only about two dozen of them are observed, all close to the galactic plane (Giovanelli et al. 1992), and they have long orbital periods. HD 163868 and HR 2517 are on the galactic plane; the low observed X-ray luminosity of HR 2517 (Grillo et al. 1992) fits the explanation, but for HD 163868 no information on X-ray luminosity is available. Such systems need not go into outburst every orbital cycle, but can remain dormant for many orbital periods (Stevens 1988), a situation that may also apply to HR 2517, where the flaring has variable (even vanishing) amplitude, and does not contradict the fact that X-rays have not been detected in HD 163868. An objection against this interpretation remains with the spectral type B5Ve of HD 163868, a very unusual spectrum for such a system, and rather pointing to the possible existence of a white-dwarf companion.

We also draw the attention to the resemblance with the description by Roche et al. (1997) of X Per, a (BeXRB) massive X-ray binary. These authors describe an extended low state (ELS) bracketed by similar flare-like events as we ob-

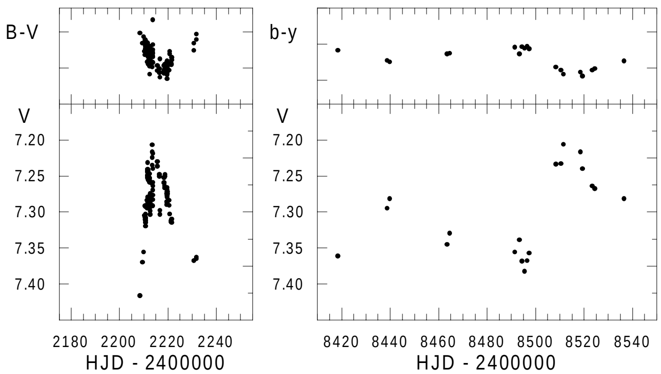

Fig. 5. Woodward's light and colour curve during the 1974 maximum, together with the flare event that occurred in 1991 (the $B-V$ and $b-y$ scales are the same as the $V \equiv y$ scale, but the colour indices are not calibrated)

served in HD 163868, including the reddening during light maximum consistent with an increase in circumstellar material. The HD 163868 system, though, shows interesting differences as compared to the behaviour of X Per. The evolution of the shape of the 1974 maximum, and the one covered in 1991 is remarkable: Fig. 5 shows both maxima and their colour variation on the same graphical scale, and illustrates that the 1974 event rises and falls much more steeply–and at the same time has a stronger reddening aspect–than does the more contemporaneous occurrence, thus pointing to a denser and less extended slab in the past. The double structure seen in the latter (and also during the following minimum) may be explained by a ring or disk of matter of non-uniform composition, though we must stress that Woodward's (1975) data do not exclude the existence of such a double peak. Another difference to be stressed is that our data indicate that the occurrence of an ELS is not a random, but a cyclic (or quasi-periodic) phenomenon.

One cannot help seeing a striking analogy between the shape of the light and colour curves of HD 163868, and the occurrences of S Dor phases (SD phases, see van Genderen et al. 1997) in Luminous Blue Variables (LBVs): except for the scale of events–that is, the magnitude of the brightening/reddening–the SD phases in LBVs are also cyclic, and display a similar reddening behaviour. Recently, Marlborough (1997) has outlined the evidence supporting the possible connection between the LBV variations of 1-2 magnitudes on time scales of tens of years (i.e. SD phases) and the shell phases of the Be star γ Cas. It is evident that the reported behaviour of HD 163868 is much gentler than that of γ Cas–where the events led to a complete disruption of the disk with a subsequent slow recovery–and that it is (so far) not at all certain that the long-term behaviour of HD 163868 is related to mild S Dor variability as seen in some LBVs (like ζ^1 Sco and R 40, see Sterken et al. 1997, 1998). It is clear that for a star like HD 163868 that was successively claimed to be variable on a short time scale, then constant and finally variable on a time scale of 2-3 years, continuous photometric and spectrographic monitoring is of urgent need.

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