Astron. Astrophys. 303, 766–772 (1995)

ASTRONOMY AND ASTROPHYSICS

Variability of the extreme P Cygni star HDE 326823*

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Received 8 March 1995 / Accepted 4 April 1995

Abstract. On the basis of *uvby* and visual photometry, and spectrography in the optical region collected over a time span of 10 years, we report large amplitude photometric and spectroscopic variations, and the onset of a sudden brightening event in the system of the extreme supergiant HDE 326823. The event fits the picture that the H-deficient N-rich star is on its way towards becoming a WN star.

Key words: stars: supergiants – stars: Wolf-Rayet – stars: individual: HDE 326823 – stars: variable

1. Introduction

HDE 326823 (CD-42°11834, He3-1330) belongs to an aggregate of distant OB supergiants in the galactic centre region (l^{II} = 344.3, b^{II}= -1.2) at a distance R $\sim$ 2 kpc. Feast et al. (1961) labelled the star as "peculiar emission object", with emission of H, He I, Fe II and Mg II, strong interstellar Ca II lines, and a strong sharp central reversed He Iλ3888 shell line. Allen (1973) determined its near-infrared (KL) colours. Sanduleak & Stephenson (1973) obtained low-dispersion (580 Å mm^{-1} at Hγ) spectra of the entire southern Milky Way, and, on the basis of the strong intensity of the hydrogen emission lines, they assigned the spectral category Be!pec to HD 326823; in addition they see strong emission in the He I lines at $\lambda\lambda$ 3889, 4120, 4471, 4713, 5016 and 5876. Stephenson (1974) reports the presence of H and K emission "somewhat like a nova near maximum", an interpretation supported by the saddle-shaped profiles of emission lines seen before. Stephenson (1974) calls attention to the great strength of the He I emission, a fact that he attributes rather to helium overabundance and H deficiency than to extreme temperature. McGregor et al. (1988) found the 1–2 μm spectral region dominated by He I emission lines, but H I emission lines are not seen, contrary to what is seen in the spectra of the other stars they investigated (viz. AG Car, HR Car, η Car, etc.). Lopes et al. (1992) confirm the double-structure He I emission lines, as well as similar "two-peak" structures in the red Ca II triplet and also in Fe IIλ9997.

In the ultraviolet, HDE 326823 shows a strong B-type absorption spectrum consistent with B1.5, see Shore et al. (1990), who point out the similarity in spectrum to the LBV R 127 in the LMC. Table 1 is a compilation of the star's most important photometric indices.

The star was put on the list of targets for monitoring in the Long-Term Photometry of Variables (LTPV) project at ESO (Sterken 1983, 1994), in addition it was monitored spectroscopically, and also visually, for several years.

2. The observations

2.1. Photometry

From 1988 on, the star was monitored on a night-to-night base in the framework of the LTPV project. Part of the resulting data were published by Sterken et al. (1993) and by Manfroid et al. (1994), remaining data will be published in forthcoming catalogues. Measurements consisted of simultaneous *uvby* observations with the Strömgren Automatic Telescope (SAT) at La Silla, Chile. HD 155051 (V = 7.88, B0.5II) was used as the sole comparison star (every measurement of HD 326823 was bracketed between two measurements of HD 155051). Similar measurements were additionally obtained by C.S. In addition, one of us (A.J.) carried out visual magnitude estimates of HDE 326823 using a private 12$''$.5 $f/5$ reflector with respect to two comparison stars (one being brighter, one being fainter than HDE 326823).

An analysis of the comparison star photometry reveals that HD 155051 is constant. 158 measurements are available in photometric configuration 7, and 36 measurements in configura-

* based on observations collected at the European Southern Observatory, La Silla, Chile.
** Belgian Fund for Scientific Research (NFWO)

Table 1. Photometric parameters of HDE 326823

$V = 9.00, B-V = 0.86$	Feast et al. (1961)
$K = 5.43, L = 4.33$	Allen (1973)
$V = 9.06, B-V = 0.87, U-B = -0.25, E_{B-V} = 1.12, Mv = -6.09$	Kozok (1985)
$V = 9.082 \pm 0.006, b-y = 0.740 \pm 0.001, m1 = -.210 \pm .007, c_1 = 0.048 \pm 0.005$	This work, JD < 2448600
$V = 9.031 \pm 0.008, b-y = 0.723 \pm 0.001, m1 = -.208 \pm .002, c_1 = -0.066 \pm 0.002$	This work, JD > 2449300

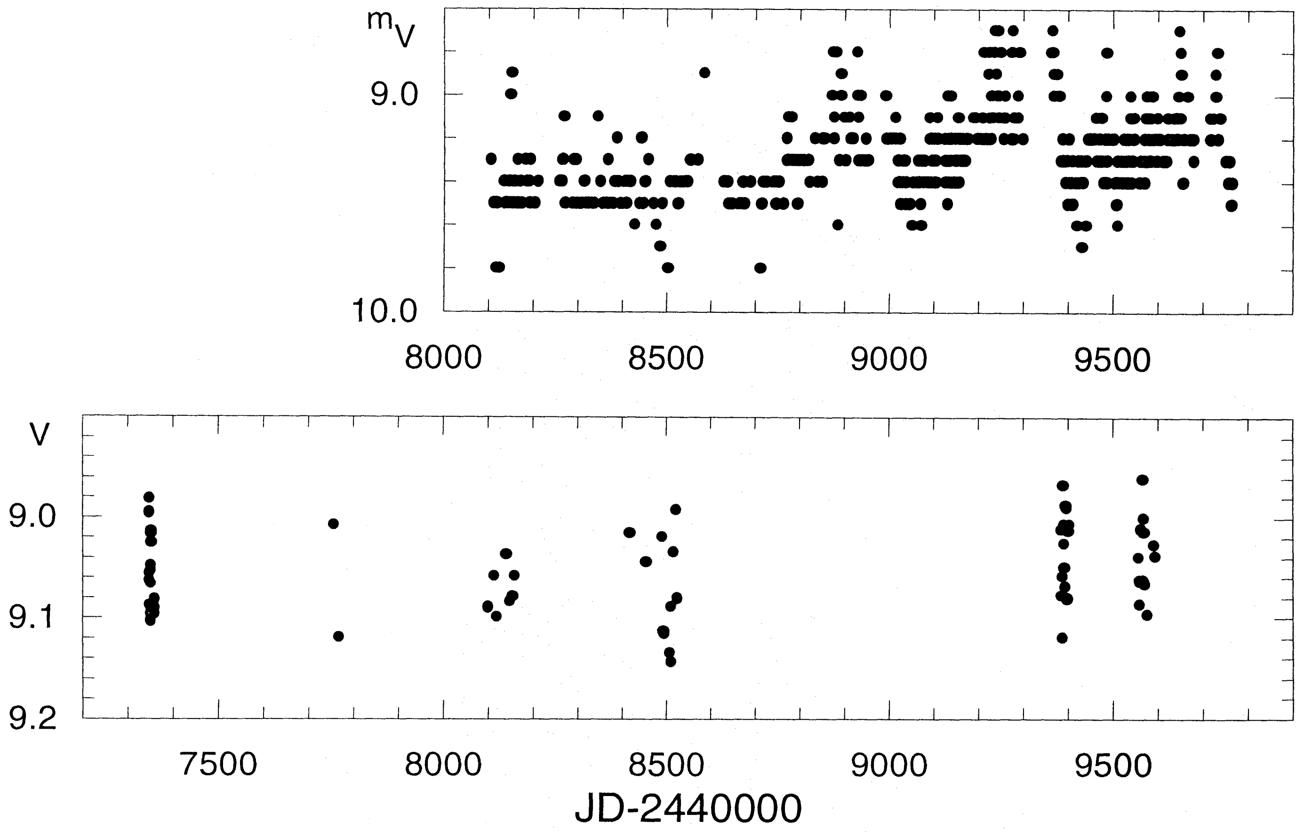

Fig. 1. Photoelectric V light curve (bottom) and visual light curve (top) of HDE 326823

tion 8 (for more details on these systems, see Manfroid et al. 1993). Data from one system are not transformable to another for stars which do not belong to the photometric-index space of the standard stars: for HD 326823, with its peculiar spectrum, this is obvious; for HD 155051 both data sets yield systematic differences up to $0^m.01$ in c_1 and even $0^m.05$ in m_1. We have, therefore, excluded all data of group 8 from the further analysis. The resulting mean indices for HD 155051 are $V = 7.893 \pm 0.001, b-y = 0.422 \pm 0.001, m_1 = -.091 \pm 0.001$ and $c_1 = 0.067 \pm 0.004$. For the construction of the light curves, the magnitude and colour indices of the program star minus the mean of the corresponding data for the preceding and following comparison star measurement was added to the above values in order to be able to plot the absolute values of the magnitude and colour index for HD 326823.

Figure 1 shows the photoelectric V and visual light curves of HDE 326823. The photoelectric data reveal a large-amplitude ($\pm 0^m.15$) variation; the average V for the data collected after JD 2448600 is about $0^m.05$ brighter than the average V from the data taken before. The visual light curve displays a similar behaviour for the data preceding JD 2448600, but from then on, the light curve changes to a wavy pattern with a characteristic time scale of 300–400 days—a decrease in m$_V$ is also visible. The reason why that onset of brightening was missed by the photoelectric observers was because the measurements of HDE 326823 had been suspended because the observing time

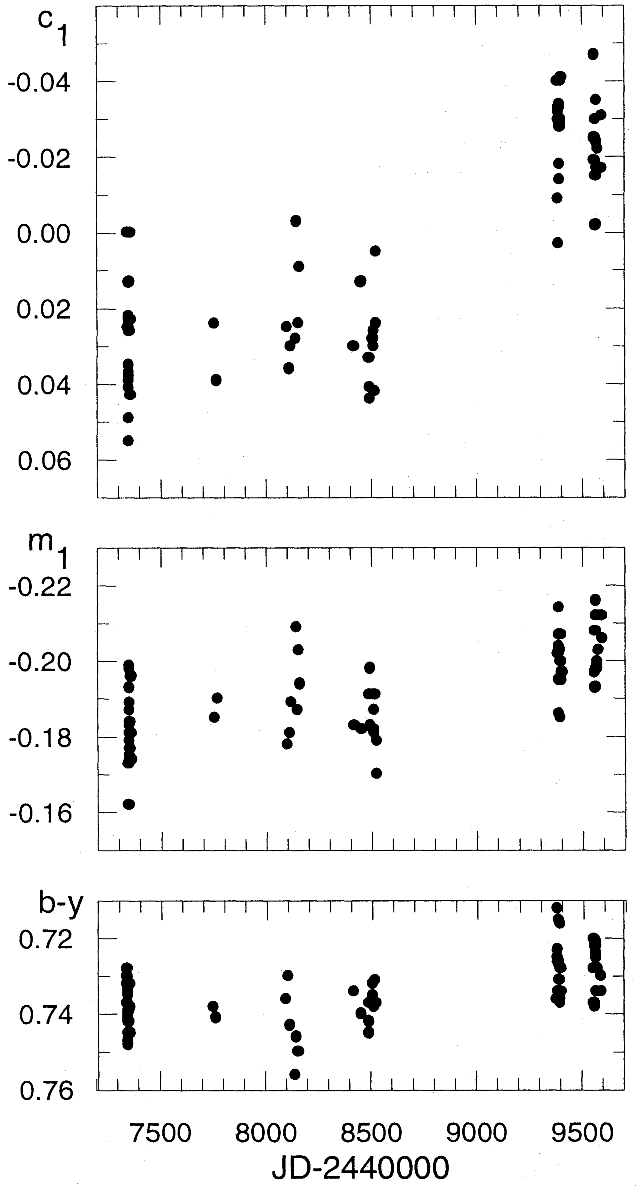

Fig. 2. $b - y, m_1, c_1$ colour curves of HDE 326823

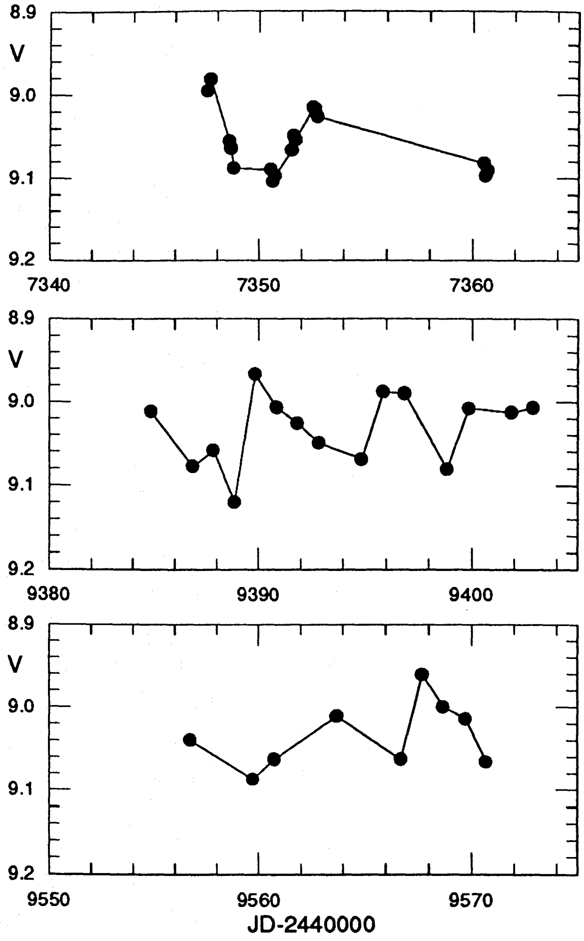

Fig. 3. Three samples of short-term V variations of HDE 326823 (time is HJD – 2,440,000)

was needed for "more interesting" objects. It was the visual observer's alert that made us to observe the star again.

The long-term behaviour of the colours is very interesting. $b-y, m_1$ and c_1 display a similar pattern of variability as y. The range of variability in c_1 (also in $u - v$) is huge: almost $0\overset{m}{.}1$. It is clear that the whole system of HDE 326823 has become bluer, see also the last line of Table 1. Figure 2 shows the overall behaviour of the colour indices.

The short-term behaviour in V is illustrated in Fig. 3 which shows the three most contiguous sets of data. A semi-regularity is present on a time scale of 6 days. Indeed, a periodogram analysis yields a peak in the power spectrum at 0.16787 cycles per day. But the data are too scarce (period and amplitude are both variable) to allow a more accurate determination of a period.

2.2. *Spectroscopy*

Two red spectra were obtained at the CASPEC spectrograph (attached to the ESO 3.6m telescope) on Aug. 30, 1984, immediately after each other (UT 0.0 and UT 0.4). These spectra cover the spectral range from 5650 to 6700 Å. Blue CASPEC spectra were obtained on Aug. 31, 1984 (UT 1.1), Sep. 1, 1984 (UT 1.1), April 28, 1994 (UT 8.9) and Feb. 16, 1995 (UT 9.0). The blue spectra cover the spectral ranges from 3900 to 4950, 3650 to 4700, 3850 to 5200, and 3800 to 5100 Å, respectively. The spectral resolution ($\lambda/\Delta\lambda$) of the spectra is about 20 000.

Our spectra confirm the very peculiar nature of the star, viz. the weakness of the Balmer lines (the higher Balmer lines are probably filled in by emission, the lower Balmer lines are present as weak emission features), the extreme strength of the He I lines, e.g. the He I λ5876 line, and also the double structure of the

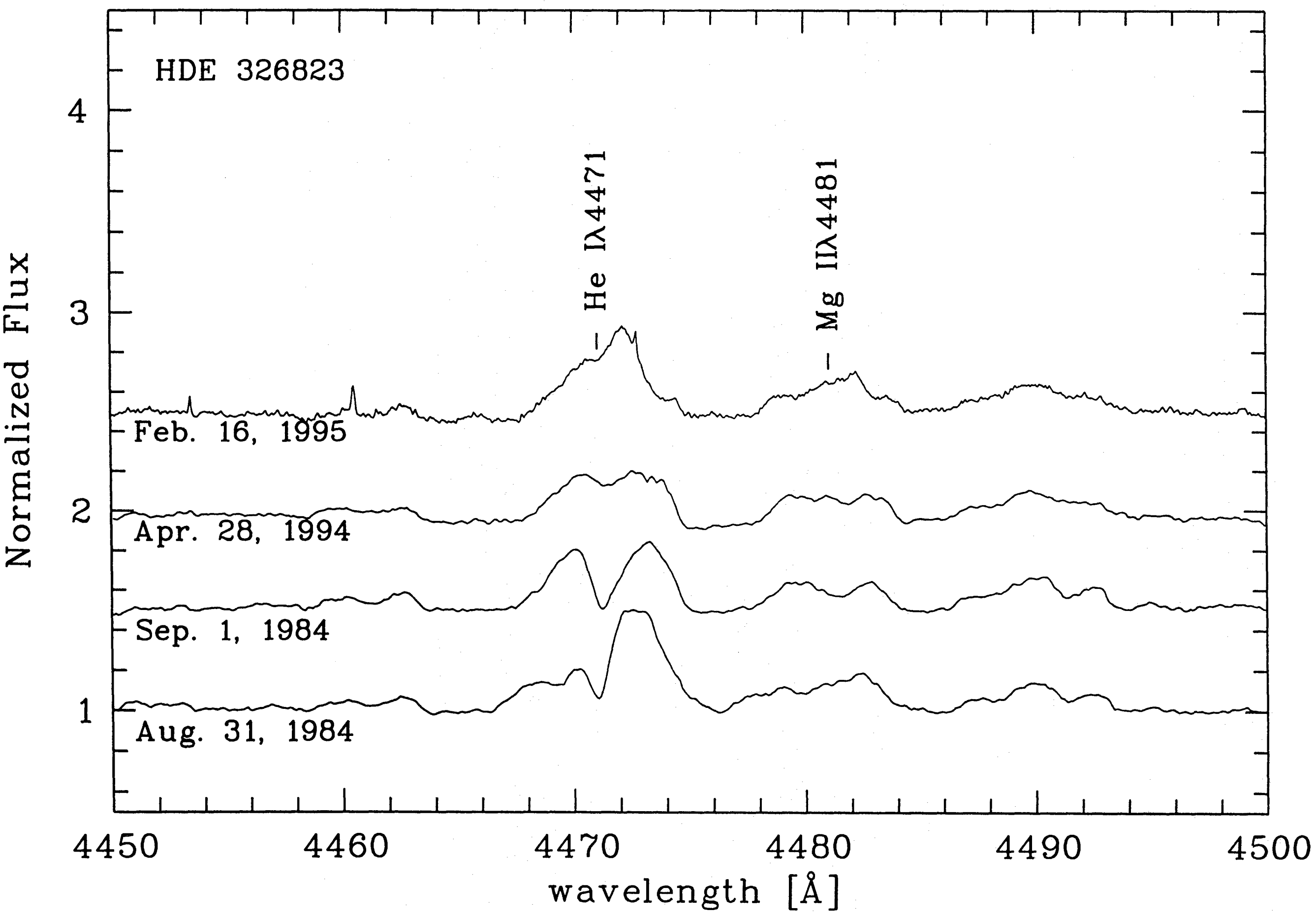

Fig. 4. Selected CASPEC line profiles of HDE 326823. Note the prominent He I λ4471 shell line and the strong night-to-night variations

He I lines. The high resolution of our data, compared to spectra reported in the literature, also reveals some new features, such as the interstellar CH^+ λ 4232 line and the forbidden [NII]-lines λλ5755, 6548 and 6583 (see Fig. 6). Figures 4, 5 and 6 show a few selected line profiles. Surprisingly strong night-to-night variations are seen (cf. Figs. 4, 5); they are of the same order of magnitude as the variations spanning a decade, thus confirming the emission-line variability on a time scale of a week observed by Stephenson (1984). These variations may be related to the short-term photometric variations (see Fig. 3). There is no pronounced difference between the spectra taken about 10 years apart which exceeds the level of the night-to-night variability. More observations, especially at shorter timescales, are needed to discuss possible long-term spectroscopic variations.

3. Discussion

McGregor et al. (1988) illustrate that He is overabundant (HDE 326823 has the largest He/H line strength ratios of all LBVs they observed), and that the 2 μm spectrum of HDE 326823 is dominated by He I emission, a situation that is very similar to the one in helium-rich LMC stars and also in η and AG Car, two notorious LBVs. HDE 326823 may thus be related to Ofpe/WN9 stars that are known to have circumstellar ejecta. Such ejecta are quite common for LBVs, see Stahl (1989): for several galactic LBVs and candidate LBVs such nebulae have been resolved; they are characterised by strong N emission lines and N/O and N/C overabundance. McGregor et al. (1988) fitted the spectral energy distribution of HDE 326823 with a model consisting of a reddened (Rayleigh-Jeans) photospheric energy distribution and a hot thermal emission (1550K) from dust originating at the inner edge of a circumstellar dust shell. Lopes et al. (1992) stress the unique character of HDE 326823 in comparison with other luminous peculiar B stars: the star is H deficient, He and N overabundant, and highly evolved. They derive $M_V \sim -8.0$ and $M_{bol} \sim -10$, an initial mass of 40 $M_\odot$ and an actual mass of 23 $M_\odot$ ($\dot{M} > 3\ 10^{-5}$ $M_\odot$ yr^{-1}, this is half as much as $\dot{M}$ for R 71 during maximum phase, see Wolf et al. 1981), supporting the picture of H and N enrichment by a factor of 2 and the interpretation that HDE 326823 is well on its way becoming a WR star.

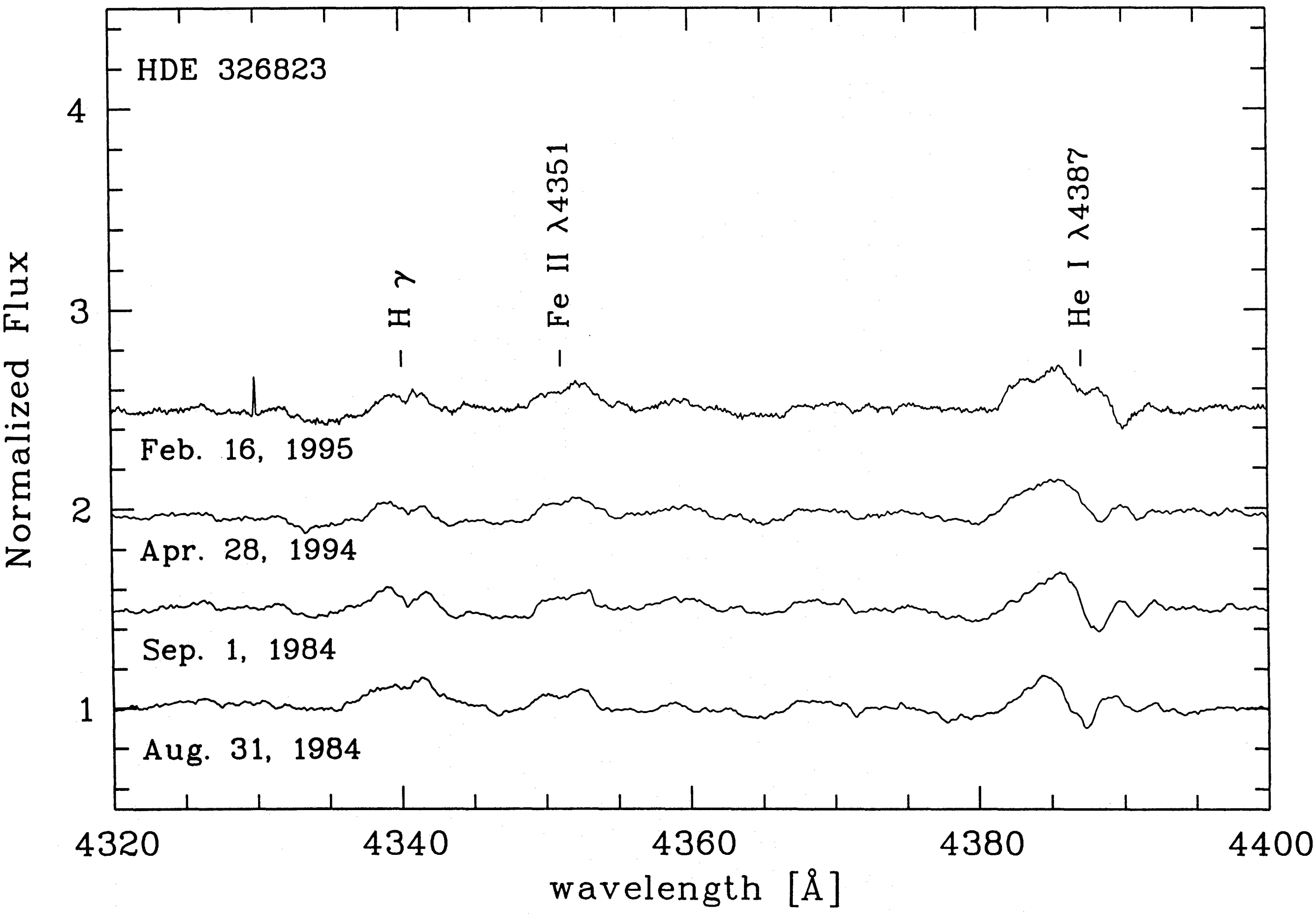

Fig. 5. Selected CASPEC line profiles of HDE 326823. Note the very weak Hγ line, compared to the He Iλ4387 line

In the Dong & Hu (1991) catalogue of early-type emission stars with $V - [25] \geq 8$, the position of HDE 326823 in the $\log(F_{60}/F_{25})$, $\log(F_{25}/F_{12})$ diagram is in a region which is exclusively populated by massive stars, and by Herbig Ae/Be stars, but it is uncertain whether the star is a pre- or a post main sequence star. The distribution of $V - [25] \geq 8$ stars in l and b (see Fig. 4 of Dong & Hu 1991) indicates that, at the galactic position of HDE 326823, 90% of the stars are WR stars. Though it would be very interesting to have such a massive HAeBe star, the odds are in favour of classifying HDE 326823 as a WN-precursor. With $\log T_{\rm eff} = 4.3$ from McGregor et al. (1988), the position of HDE 326823 in the "instability strip" (the inclined hatched area in Fig. 5 of Wolf 1989), using $M_{\rm bol} \sim -10$ from Lopes et al. (1992), is more or less on the ridge line of the strip. It should be noted here that the absolute magnitude derived by Lopes et al. (1992) is about two magnitudes brighter than the values given by Kozok (1985)—see Table 1—or McGregor et al. (1988). The former value is based on a value $E_{B-V} \sim 1.8$ mag derived from the strength of the Na I interstellar lines, whereas the latter is based on $E_{B-V} \sim 1.1$ derived from $U - B, B - V$ colour indices (assuming a normal reddening law and neglecting all envelope emission effects). From our $uvby$ photometry (JD < 2448600) we obtain, applying the iterative procedure of Crawford & Barnes (1974), $E_{b-y} = 0.868$ and $V_0 = 6.010$; using $A_V = 3.13\, E_{B-V}$ (Leitherer & Wolf 1984) yields $E_{B-V} = 1.2$, fully supporting the values quoted above (though with a slightly smaller difference from the spectroscopically-determined value than what is obtained using broad-band photometric indices). The large discrepancy between the spectrographic E_{B-V} and the $uvby$-photometric value must be attributed to the large uncertainties involved using the highly-saturated Na I line profiles in combination with a not well-defined relation between line strength and E_{B-V}, but also due to the fact that the u, v and b magnitudes (which contribute to the colour indices $b-y, m_1$ and c_1) are contaminated by emission lines at λ 4130 and 4233, and definitely by the strong and double emission of He Iλ4713 (in the b band)—this is even more so for the U, B, V magnitudes.

The interpretation of the $uvby$ photometry (due to the emission lines) is not a straightforward issue—we note, by the way, that this problem is also a problem of all intermediate-band photometry of WR stars. The blueing and brightening of the system points to a rather sudden event of which the outcome is sustained

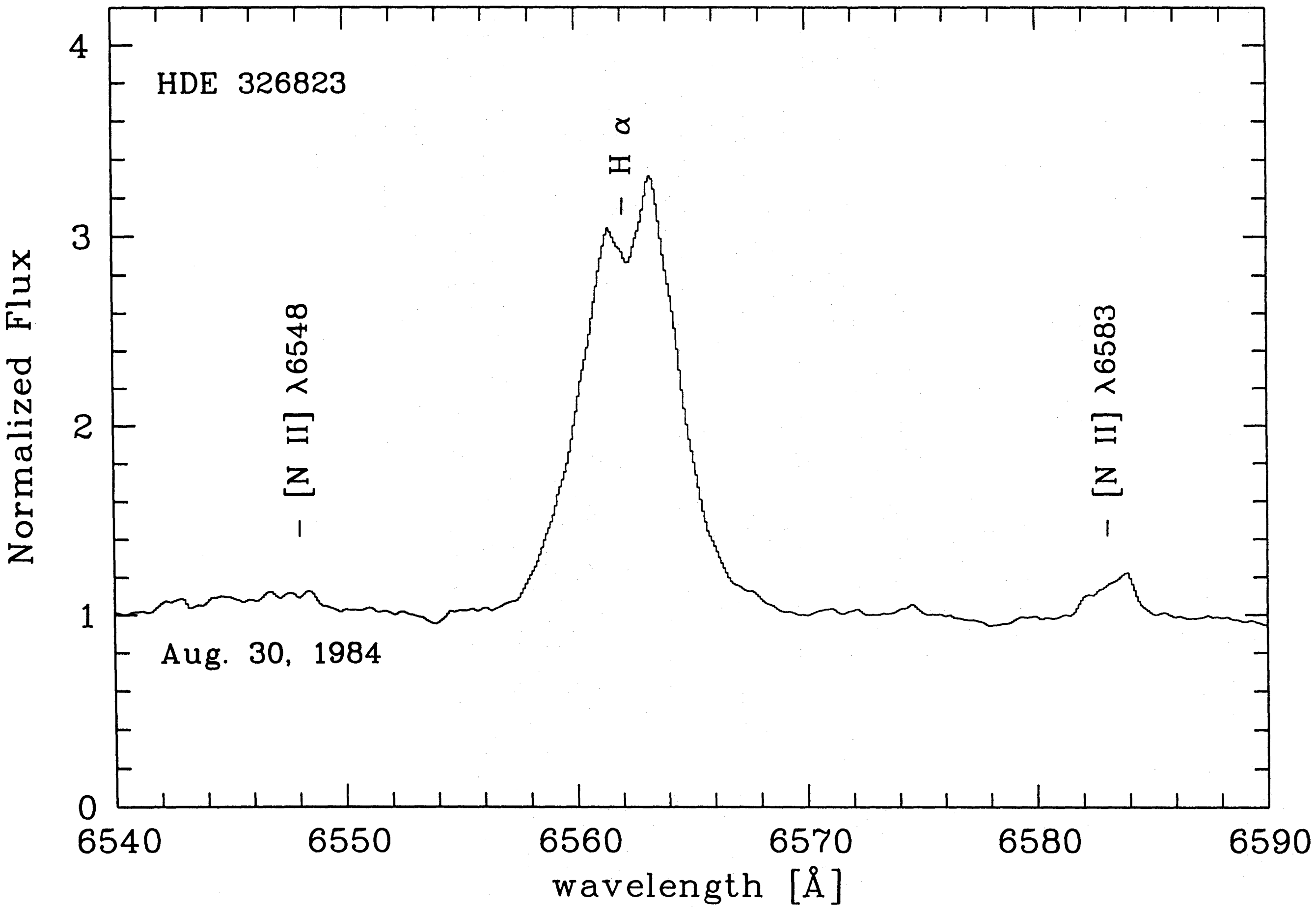

Fig. 6. CASPEC spectrum around the Hα line. Note the pronounced double-peak structure of Hα, and an indication of the presence of a double peak in the forbidden [NII] lines, which indicate a very extended shell. [NII]λ5755 is also present and even stronger than λ6583. This indicates a high density in the line-emitting region

for a time span of at least half a year (see Fig. 7). The exact time scale of the brightening is not known, but the gradient in V is not more than $0\overset{m}{.}1$ per year—note that the gradient of a moderate burst, for example in R 71, amounts to about $0\overset{m}{.}3$ yr^{-1}. The expected rise in $T_{\rm eff}$ associated with the $\sim 0\overset{m}{.}02$ jump in $b-y$ amounts to about 2000–3000 K. If the effect is not due to a change in the emission properties of the circumstellar shell, it points to a possible migration of HDE 326823 towards a hotter (and slightly brighter) region in the HR diagram. HDE 326823 may then be an LBV in quiescent state (of which we expect it to display small-amplitude variations, which is certainly not the case), having had S Dor eruptions in the past, and which is now possibly moving towards a WN configuration. Further systematic photometric and spectrographic observations will tell us whether the star continues its way outward the instability strip, and whether this motion is a continuous one, or will be accomplished in a sequence of sudden events.

Acknowledgements. The authors are indebted to A. Jorissen for carrying out some observations in the framework of the LTPV program, and to ESO and to the Copenhagen University Observatory for using the SAT telescope. C.S. acknowledges financial support from the Belgian Fund for Scientific Research (NFWO).

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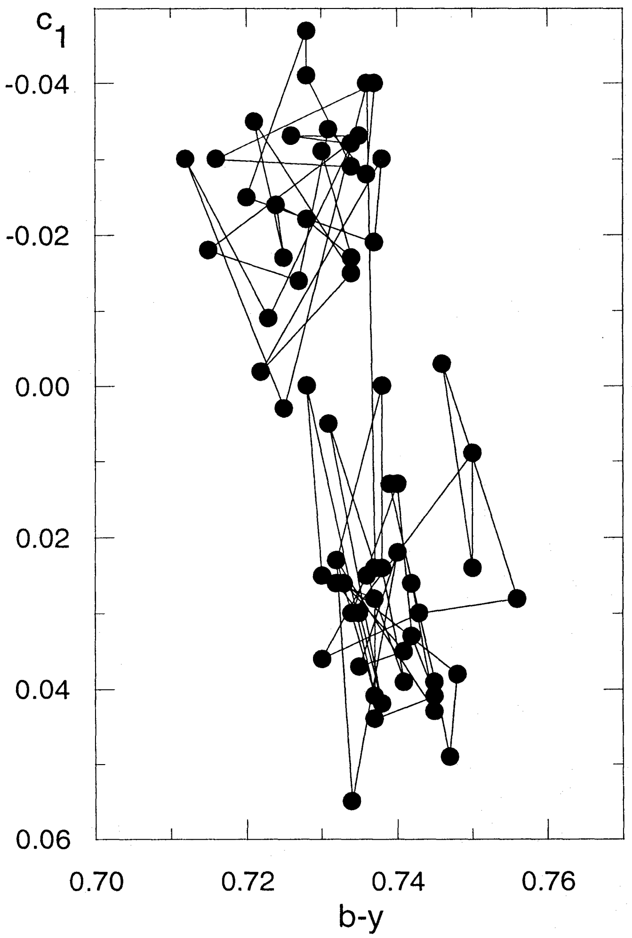

Fig. 7. $b - y$, c_1 diagram of the colour variations of HDE 326823. The lower cloud of measurements precedes the upper cloud in time

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