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A dusty nebula around the luminous blue variable candidate HD 168625*

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Abstract. On the basis of narrow-band visible and near-infrared imagery as well as high-resolution spectroscopy, we report the discovery of a new LBV-type nebula around the B supergiant HD 168625. We find that it essentially consists of a dusty expanding shell from which seems to emerge a bipolar emission nebula, the whole embedded in a reflection nebulosity. The inner shell is stratified: the continuum emission arises beyond the ionized gas, and is possibly due to scattering of stellar light by large dust grains or to non-equilibrium dust emission. The unexpected presence of unidentified infrared emission bands (UIRs) in the spectrum of this object is also discussed.

We finally report the non-detection of a comparable nebula around the nearby LBV HD 168607.

Key words: luminous blue variable stars – circumstellar matter – emission nebulae – dust – HD 168625 – HD 168607

1. Introduction

Luminous blue variables (LBVs) are extreme supergiant stars located in the Hertzsprung-Russell (HR) diagram near the Humphreys-Davidson limit. They are generally thought to represent a short-lived intermediate stage in the evolution of massive stars from O to WR stars (cf. reviews by Humphreys 1989; Hillier 1992; Wolf 1992). About ten LBVs are presently known in our Galaxy.

One of the most remarkable characteristics of LBVs is that some of them are surrounded by a ring nebula apparently constituted of nuclear processed material ejected by the star (cf. reviews by Stahl 1989; Chu 1991; Smith 1993). In order to see if the association with a nebula is a generic property of these stars, we have searched for nebulosities around galactic LBV candidates using CCD imaging through narrow-band filters which isolate nebular lines. In addition to the previously known nebulae surrounding η Car, AG Car, and He3-519, nebulae have been found around HR Car and WRA751 (Hutsemékers & Van Drom 1991a, 1991b). The present paper is devoted to the study of a new case of LBV-type ring nebula, detected around HD 168625.

HD 168625 (= He3-1681 = SAO161375) is a very luminous B-type star which has been recently studied by Chentsov & Luud (1989) and van Genderen et al. (1992). We adopt the stellar parameters used by van Genderen et al. (1992), i.e. a distance d = 2.2 kpc, a bolometric magnitude $M_{\rm bol} = -8.6$, and an effective temperature $T_{\rm eff}$ = 12 000 K. While located in the same part of the HR diagram as HR Car and HD 168607, two bona fide LBVs (e.g. van Genderen et al. 1992), HD 168625 was not recognized as a LBV due to the weakness of its emission lines and to the low amplitude of its photometric variations. But, HR Car itself would be discarded from the LBV class if only classified using its position in the "Maximum light amplitude – Effective temperature" diagram of van Genderen et al. (1992). Also P Cyg and η Car would not be recognized as LBVs without the historical evidence for outbursts which occurred centuries ago. The photometric behavior is therefore not sufficient to invalidate the classification of HD 168625 as a LBV, especially if we note that spectral variations have possibly been observed: the spectral type of HD 168625 quoted in the literature varies between B2 (Popper & Seyfert 1940), B8 (Morgan et al. 1955), and B5.6 (Chentsov & Luud 1989), while the spectral type of HD 168607, located only $\sim 1'$ apart and described by the same authors, always remained between B8 and B9.4. Further, although weak, Hα is clearly seen on our high resolution spectrograms with a P Cygni line profile indicating a wind terminal velocity of $\sim$ 250 km s^{-1}, typical of LBVs. Also, like most LBVs known to be associated with a nebula, HD 168625 is surrounded by cool dust detected by the Infrared Astronomical Satellite IRAS (Chentsov & Luud 1989; Hutsemékers 1994, hereafter Paper I). With the discovery of an optical nebula around it, we consider that HD 168625 is a good LBV candidate.

The present paper is divided as follows: in Sect. 2, we present the imaging and spectroscopic observations. The characteristics

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Table 1. Visible imaging observations

Date	Instrument	Filter (ESO n^o)	λ_c/FWHM	Seeing
11/03/91	2.2m + CCD#5	Hα + [NII] (#436)	6560/63 Å	1.″5
22/04/91	3.6m + EFOSC1 + CCD#8	Hα + [NII] (#691)	6566/61 Å	1.″7
23/04/91	3.6m + EFOSC1 + CCD#8	Hα + [NII] (#691)	6566/61 Å	1.″1
23/04/91	3.6m + EFOSC1 + CCD#8	Continuum (#695)	6645/63 Å	0.″9
15/05/91	3.6m + EFOSC1 + CCD#8	Hα + [NII] (#691)	6566/61 Å	1.″7
15/05/91	3.6m + EFOSC1 + CCD#8	Continuum (#695)	6645/63 Å	1.″7
30/04/92	3.6m + EFOSC1 + CCD#26	Hα + [NII] (#691)	6566/61 Å	1.″2
30/04/92	3.6m + EFOSC1 + CCD#26	Continuum (#695)	6645/63 Å	1.″2
13/05/93	3.6m + EFOSC1 + CCD#26	Gunn z (#615)	8382/bb Å	1.″0
15/05/93	2.2m + EFOSC2 + CCD#19	Gunn z (#619)	8420/bb Å	1.″0

Table 2. Near-infrared imaging observations

Date	Filter	$\lambda_c/\Delta\lambda$	Seeing
10/05/93	H_2	2.121/0.039 μm	1.″6
10/05/93	Brγ	2.164/0.037 μm	1.″4
10/05/93	Continuum	2.177/0.038 μm	1.″4
10/05/93	CO	2.365/0.088 μm	1.″5
12/05/93	Continuum	2.177/0.038 μm	1.″6

of the nebula are described in Sect. 3. A few comments on the circumstellar environment of the nearby LBV HD 168607 are given in Sect. 4, while discussion and conclusions form the last section.

2. The observations

The observations have been carried out at the European Southern Observatory (ESO, La Silla) from March 1991 to July 1993, using the 3.6m telescope equipped with the EFOSC1 spectrometer and camera (Melnick et al. 1989), the 2.2m telescope equipped with the direct camera, the EFOSC2 spectrometer and camera (Melnick 1993) and the infrared camera IRAC2 (Moorwood et al. 1992), the 1.4m CAT telescope feeding the CES spectrometer (Lindgren & Gilliotte 1989). More information on the telescopes, detectors and filters may be found in the ESO Users manual (Schwarz & Melnick 1993).

All the reductions were performed using standard procedures in the MIDAS application package developed at ESO.

2.1. Visible imagery

We have obtained CCD images of HD 168625 and its surrounding nebula using broad- and narrow-band filters, the latter centered on Hα and a nearby continuum. The journal of observations is given in Table 1. The numbers characterizing CCDs and filters are those currently in use at ESO.

In this paper, we mainly consider the EFOSC1 imaging observations of April 92 and May 93, obtained in better seeing conditions and with a cleaner CCD. The CCD#26 is a TEK 512×512 with 27×27 μm^2 pixels corresponding to 0.″61×0.″61 on the sky. The April 92 observations consist of 1^m and 5^m exposures obtained in both the Hα+[NII] and continuum filters. The 8″ coronographic spot of EFOSC1 was centered at best on the star to avoid effects due to saturation. Faint spikes nevertheless remain. For calibration purposes, 0.^{s}1 unsaturated exposures of the unmasked star were also secured in both filters, as well as 1^m exposures of the AG Car nebula in the Hα+[NII] filter with the same coronographic spot. The May 93 images consist of 20^s exposures obtained in a broad-band Gunn z filter with the 3″ coronographic spot centered on the star. Due to a better alignment of the Lyot stop, the faint contaminating spikes are no longer present. Dark-subtraction and flat-fielding were performed in the standard way.

It is important to note that the observations obtained in worse but different conditions essentially confirm the results presented in Sect. 3, within the limits fixed by their lower quality.

2.2. Near-infrared imagery

Near-infrared images of HD 168625 and its nebula were obtained in May 93 using the IRAC2 camera and narrow-band filters centered on various spectral lines (cf. Table 2). The detector was a Rockwell 256×256 pixel NICMOS3 array. With the B objective, the pixel size of 40 μm corresponds to 0.″27 on the sky.

For one image in a given filter, we have obtained 5 exposures of the object separated by 4 exposures of the sky successively sampling north, east, south and west of the object; one exposure consists of the average of 100 integrations of 1^s each. Even with this short integration time (the shortest possible), the images of HD 168625 are slightly saturated. Since the weather was cloudy, no calibration frames (standard stars,...) were obtained. Flat-fields were secured by taking difference images of the diffusing screen in the dome with a halogen lamp alternately on and off.

The reductions were performed as follows: after subtracting from each of the 5 object frames the median of the 4 sky

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Table 3. High-resolution spectroscopic observations

Date	UT (beginning)	Spectral range	Resolution	Exposure time	Position angle
12/07/93	$00^h 00^m$	6538–6593 Å	0.12 Å	60^m	267–279°
12/07/93	$02^h 53^m$	6538–6593 Å	0.12 Å	60^m	308–327°
12/07/93	$05^h 03^m$	6538–6593 Å	0.12 Å	$45^m \times 2$	354–34°
13/07/93	$23^h 52^m$	6698–6743 Å	0.12 Å	60^m	267–279°
14/07/93	$01^h 28^m$	6698–6743 Å	0.12 Å	60^m	287–303°
14/07/93	$06^h 40^m$	6538–6593 Å	0.12 Å	60^m	40–67°

frames, these frames were flat-fielded, cleaned for bad pixels, recentered, and finally averaged. After the reduction, faint features (spikes, ghosts, rings,...) are still present, contaminating the images (cf. Moorwood et al. 1992).

Several stars of comparable brightness have been observed and reduced similarly in order to construct a stellar profile which may eventually be subtracted. Useful mean stellar profiles without field stars have been obtained by taking the median of 4 frames centered on a given star and 90°-rotated.

2.3. High-resolution spectroscopy

High-resolution spectra of HD 168625 and its nebula were obtained in July 93 with the short camera of the CES spectrometer in wavelength ranges centered on the Hα+[NII] and [SII] $\lambda\lambda$6717–6731 emission lines. The journal of observations is given in Table 3. The seeing was typically 1.″6 and 1.″2 during the first and the second night, respectively. In spite of rather long exposure times, the nebular [SII] lines are underexposed. In order to estimate the shape of the continuum, two stars, HR6878 and HD 211998, were observed in similar conditions. The spectrum of a Th-Ar lamp has been recorded for the wavelength calibration.

The detector was a 1024×640 RCA CCD (ESO #9) with 15×15 μm^2 pixels corresponding to 0.″83 and 1.″02 along and across the slit respectively. The slit was approximately 20″ long; its width was 2.2″ for the Hα+[NII] spectral range and 2.3″ for the [SII] range. At the CAT, the position of the slit cannot be kept fixed on the sky: the field rotates around the star such that, during a given exposure, the slit sweeps a range of position angles. The position angles have been evaluated according to calculations by G. Artzner (private communication). They are given in Table 3, counted anti-clockwise from the N–S direction, north up, east to the left.

3. The characteristics of the nebula

3.1. The interstellar environment

HD 168625 and HD 168607 are twin bright stars located about 15′ southeast from the core of M17, the Omega nebula, and presumably at the same distance (cf. van Genderen et al. 1992, and references therein). Nice pictures of the Omega nebula obtained by T. Neckel with the ESO/MPI 2.2m telescope and R. West with the ESO 3.6m telescope are displayed in the atlases of Neckel & Vehrenberg (1987) and Laustsen et al. (1987), respectively. The diffuse aspect of HD 168625 may already be noticed.

On the plate shown by Laustsen et al. (1987), both stars seem to lie in some kind of cavity delimited to the north by a sharp arc in Omega nebula, to the east and to the west by faint diffuse clouds located about 8′ from the stars. The western nebulosity has a filamentary morphology reminiscent of wind-blown shells. This suggests that at least one of these stars (HD 168607, better centered on the cavity?) could be physically related to the Omega nebula.

A CCD picture of HD 168625 and its surroundings imaged with the Hα+[NII] filter is illustrated in Fig. 1. Apart from the small nebula seen immediately around HD 168625, many features are present, the most remarkable being a series of condensations within $\sim$ 1′ from HD 168625, and a dark lane immediately south. Similar condensations are also seen south of the darker region, suggesting that the nebular material is everywhere, most probably belonging to the Omega nebula. It is not clear whether these nebulosities are physically related to HD 168625 or not, but there is no indication from their morphology that they are. On the contrary, the small nebula seen around HD 168625 is clearly associated with the star, as discussed below.

3.2. Description and morphology

The nebula surrounding HD 168625 is best seen in Fig. 2 which illustrates a Hα+[NII] image, continuum subtracted. This picture is the difference of two 5^m exposure frames obtained in April 92 with the Hα+[NII] and λ6645 continuum filters. The seeing was similar during the two exposures. Before subtraction, the continuum frame was recentered and multiplied by 0.98, the ratio of the stellar fluxes in the Hα+[NII] and continuum filters measured on the frames where the image of the star is not saturated. Since the stellar intrinsic Hα emission line is faint and of P Cygni type, this ratio is mainly a continuum flux ratio and the field stars essentially disappear (when unsaturated). The instrumental spikes and stellar profile wings are also removed, therefore providing us with a rather clean image of the nebula.

The nebula surrounding HD 168625 is an emission nebula and its symmetry relative to the star indicates a physical asso-

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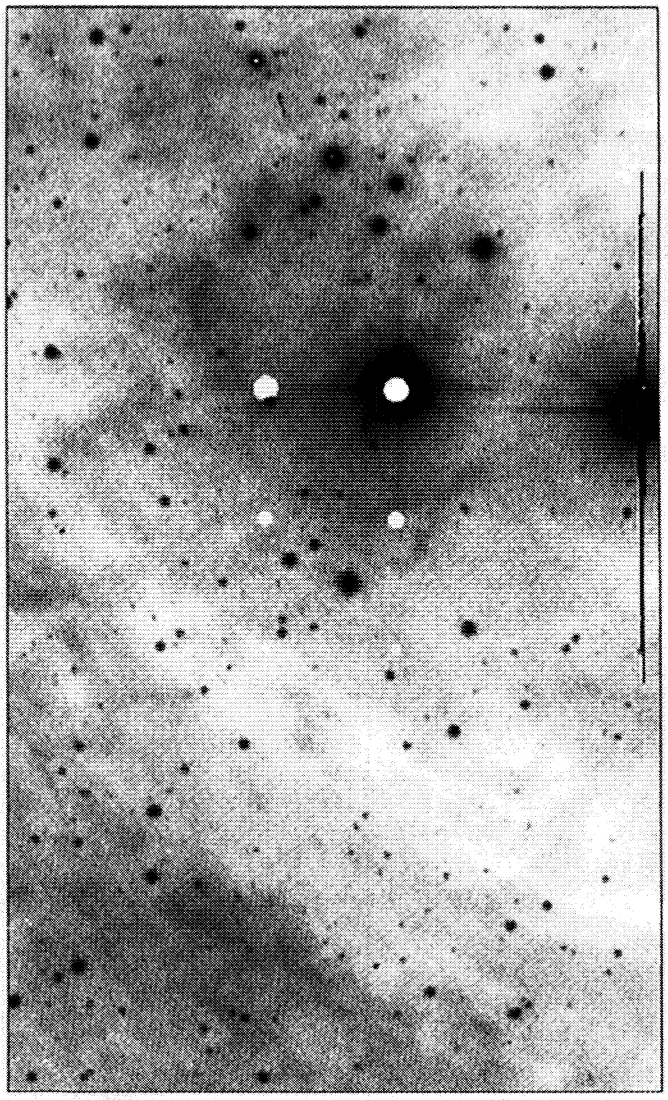

Fig. 1. An image of HD 168625 and its surroundings obtained with the Hα+[N II] filter. The field is 3′ × 5′. North is up and east to the left. This 5^{m} exposure frame has been obtained on April 92 with the 3.6m telescope and EFOSC1. The six coronographic spots are clearly seen, the largest being positioned on HD 168625. A small nebula may be identified around the star. The nebular features everywhere on the frame are due to the Omega nebula. The saturated star is HD 168607, which is comparable in brightness to HD 168625. The intensity scale is logarithmic

ciation. It seems constituted of two regions:
(1) An inner 10.″0 × 13.″5 elliptical ring detached from the star and with a major axis oriented SE–NW. The SW part of the ring is brighter with a sharply defined outer edge.
(2) An outer nebula on which the ring seems superimposed. Its size is ∼ 16″ × 21″. Its major axis is oriented NE–SW, perpendicular to that of the ring. The NE part is brighter and its edge well defined on the background. It appears horn- or ansa-shaped. A similar morphology is suspected for the fainter SW part, suggesting a bipolar morphology.

The inner ring may also be seen on the images obtained with the λ6645 continuum and Gunn z filters (cf. Fig. 3). In both filters, it is slightly but definitely larger than the Hα+[N II] ring, just surrounding the latter. The outer bipolar Hα+[N II] nebula is not detected in these continuum filters. In addition, a diffuse, quite symmetric but patchy nebulosity is observed all around the star up to ∼ 20″, contaminating the image of the ring (cf. Figs. 1 and 3). Its most remarkable feature is a clumpy elongation extending SE. This nebulosity is not seen on the difference image illustrated in Fig. 2 because it is equally present on the Hα+[N II] and λ6645 continuum frames. This, with a rough brightness decline with distance from the star, suggests that this nebulosity is mainly a reflection nebula which scatters the stellar light.

Near-infrared images of HD 168625 and its nebula are shown in Figs. 4 and 5. We did not detect any significant morphological difference between the images obtained in the different near-infrared filters. This indicates that the near-infrared emission is dominated by the continuum. We therefore only consider an average of the images, which corresponds to an effective wavelength of ∼ 2.2 μm.

The ring is clearly seen in the 2.2 μm continuum. It is definitely larger (∼ 12″ × 15″) than the Hα+[N II] ring, and comparable in size to that observed in the visible continuum. It is however better resolved and less contaminated by the extended reflection nebulosity which is not seen at these near-infrared wavelengths. It appears inhomogeneous with a sharp SW edge and a fainter, more diffuse NE part. The ring is possibly linked to the star in its southern part; a bar-like feature oriented SE–NW and roughly crossing the star is also apparent. As in the visible continuum, the outer bipolar Hα+[N II] nebula is not seen in the 2.2 μm continuum.

The ring appears unusually bright in the continuum: after roughly subtracting a stellar profile, we find that its surface brightness in the λ6645 continuum filter is approximately 20 % that of the Hα+[N II] ring. While this estimate is uncertain, it is too large to be only explained in terms of thermal continuum emission processes which include bound-free, free-free and two-photon recombinations of hydrogen and helium. Scattering of stellar light may be invoked. However, if we compare the continuum surface brightness of the ring to that of the outer reflection nebulosity, we note that the ring is comparatively brighter with increasing wavelengths; for example, in the λ6645 continuum filter, the SE elongation of the outer nebulosity is as bright as the ring, while it is significantly fainter in the Gunn z filter, and undetected at near-infrared wavelengths. If this progressive disappearance of the outer reflection nebulosity with increasing wavelengths is naturally explained by scattering, the different wavelength dependence of the continuum emission from the ring would require scattering by much larger grains; this is a reasonable hypothesis since the presence of large grains has already been suggested for explaining the dust properties in other LBV nebulae, like those around AG Car and η Car (McGregor et al. 1988a, 1988b; Paresce & Nota 1989). On the other hand, this excess of continuum radiation may be similar to the non-thermal non-scattering dust

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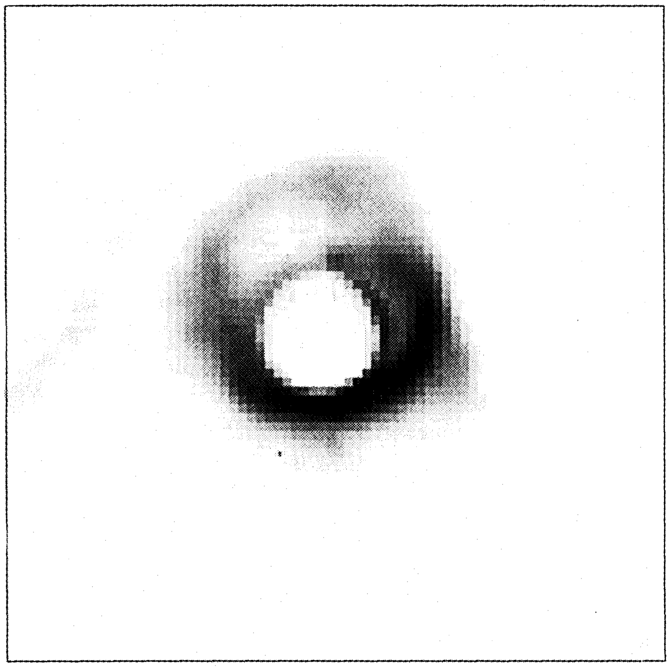

Fig. 2. A Hα+[N II] image of the nebula associated with HD 168625. This is the difference of frames obtained in April 92 with the Hα+[N II] and λ6645 continuum filters. The field is 74 pixels $\times$ 74 pixels i.e. $\sim$ 45″ $\times$ 45″; the star is at the center of the picture. North is up and east to the left. The coronographic spot is not exactly centered on the star but slightly east

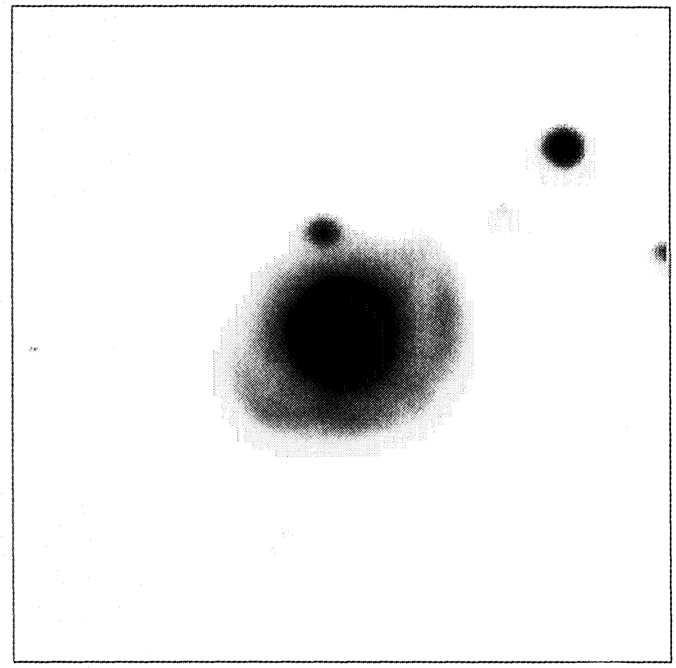

Fig. 4. A near-infrared continuum image of HD 168625 obtained in May 93. This is the average of frames obtained in different narrow-band filters. The mean effective wavelength is $\sim$ 2.2μm. The field is 167 pixels $\times$ 167 pixels i.e. $\sim$ 45″ $\times$ 45″; the star is at the center of the picture. North is up and east to the left

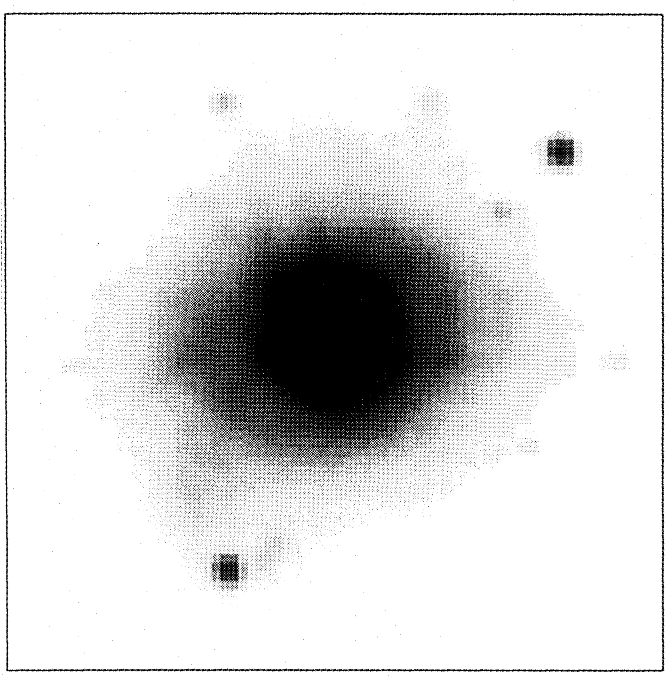

Fig. 3. A continuum image of the nebula obtained in May 93 with the Gunn z filter. The field is 74 pixels $\times$ 74 pixels i.e. $\sim$ 45″ $\times$ 45″; the star is at the center of the picture. North is up and east to the left

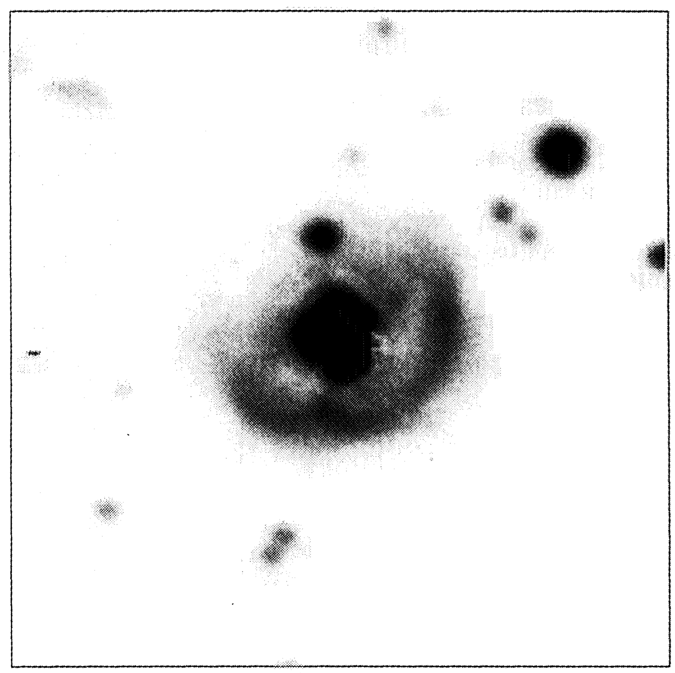

Fig. 5. Same as Fig. 4 but with a stellar profile subtracted. Since the subtraction is not perfect namely due to the saturation of the stellar images, the structure of the central part is not reliable

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continuum emission which has been observed in various types of nebulae. Indeed, an extended continuum emission is seen in the near-infrared spectrum of reflection nebulae (e.g. Sellgren 1989, and references therein) and young planetary nebulae (e.g. Hora et al. 1993; Likkel et al. 1994), while, at visible wavelengths, some of these objects show an extended red emission (e.g. Witt et al. 1984; Furton & Witt 1990). In some nebulae, the extended red and near-infrared continuum emissions have been mapped and shown to extend beyond the ionized gas (e.g. Furton & Witt 1990; Likkel et al. 1994), as observed in the case of the HD 168625 ring. These continuum emissions are generally attributed to non-equilibrium dust emission, and often associated with the so-called unidentified infrared emission bands (UIRs) (e.g. Sellgren 1989; Duley 1989). The presence of UIRs in the spectrum of HD 168625 (Cohen et al. 1986) therefore supports such an origin for the excess of continuum. Additional observations like spatially resolved polarization maps of the ring are needed to distinguish between this interpretation and the scattering one.

3.3. Kinematical and physical characteristics

Two-dimensional high-resolution Hα and [NII] emission line profiles are illustrated in Figs. 6 and 7 for different positions of the slit on the nebula. The two lines have rather similar profiles, Hα being more diffuse. The profiles essentially indicate that the ring is in fact a hollow ellipsoidal shell expanding at 20 $\pm$ 2 km s^{-1} along both its minor and major axes. At the distance of 2.2 kpc, the inner shell has a mean radius of 0.06 pc and a dynamic age of 3 10^3 years. The outer bipolar nebula is only barely seen on one frame (lower right in Figs. 6 and 7), such that nothing definite can be said about its kinematics. Its NE part seems nevertheless slightly blueshifted by $\sim$ 6 km s^{-1} with respect to the systemic velocity of the shell, possibly indicating that it is located closer to the observer.

The heliocentric systemic velocity of the nebula is 14 $\pm$ 3 km s^{-1}, greater or equal to the mean velocity of the Omega nebula, 5.2 $\pm$ 5 km s^{-1} (Georgelin et al. 1973). According to the galactic rotation curve in this region (e.g. Georgelin et al. 1973), this means that the distance to HD 168625 is at least as large as the distance to the Omega nebula.

From these spectroscopic observations, we measure the following line ratios, uncorrected for reddening: Hα/[NII]6584 $\simeq$ 2.6 and [SII]6717/[SII]6731 $\simeq$ 0.9. The [SII] line ratio provides us with an estimate of the electron density n_e in the nebula: $n_e \simeq 630 \pm 300$ cm^{-3}.

Taking into account the Hα/[NII] ratio and the transmission curve of the filters, we may evaluate the total Hα flux by integrating over the whole nebula (ring + outer bipolar nebula) the light received in the Hα+[NII] filter, continuum subtracted (i.e. using the image displayed in Fig. 2). The flux from the region masked by the coronographic spot has been extrapolated using the nebula mean surface brightness. The total Hα flux has been subsequently calibrated using the Hα flux of the AG Car nebula, available from the literature (e.g. Stahl 1987; de Freitas Pacheco et al. 1992; Nota et al. 1992) and measured on frames obtained during the same observing run (cf. Sect. 2.1). The Hα flux from the HD 168625 nebula finally amounts to 4.6 $\pm$ 0.7 10^{-13} erg cm^{-2} s^{-1}, uncorrected for reddening. The uncertainty mainly accounts for errors in evaluating the contribution due to the part of the nebula masked by the coronographic spot. In order to estimate the nebular $E(B-V)$, we used a low-resolution (also low-quality) nebular spectrum, obtained in April 92 with EFOSC1. The slit was oriented N–S and positioned $\sim$ 17$''$ east from the star, crossing a faint arc-like feature (cf. Fig. 2). From the Hα/Hβ ratio, we derive $E(B-V) = 0.75 \pm 0.1$. This value is smaller than the stellar $E(B-V) = 1.46 \pm 0.12$ (e.g. van Genderen et al. 1992). This may indicate that there is a significant circumstellar reddening. On the other hand, this nebular feature, probably a condensation in the Omega nebula, is not clearly associated with HD 168625, and the difference of reddenings may suggest that HD 168625 and its nebula are located beyond the Omega nebula, or on its far side. Spectroscopy of the ring around HD 168625 is needed to estimate the actual nebular $E(B-V)$. With $E(B-V) \simeq 0.75$, the de-reddened Hα flux amounts to $F_{\mathrm{H}\alpha}$ = 2.5 $\pm$ 0.9 10^{-12} erg cm^{-2} s^{-1}; this was the value used in Paper I. With $E(B-V) \simeq 1.46$, we have $F_{\mathrm{H}\alpha}$ = 1.2 $\pm$ 0.4 10^{-11} erg cm^{-2} s^{-1}.

From the Hα flux, the electron density and the distance, we can evaluate M_{i}, the mass of the ionized gas. Using formulae given in e.g. Aller (1984), and $F_{\mathrm{H}\alpha} \simeq 2.5\ 10^{-12}$ erg cm^{-2} s^{-1}, we find $M_{\mathrm{i}} \simeq 7\ 10^{-3}\ M_\odot$ (Paper I). With $F_{\mathrm{H}\alpha} \simeq 1.2\ 10^{-11}$ erg cm^{-2} s^{-1}, we have $M_{\mathrm{i}} \simeq 3\ 10^{-2}\ M_\odot$. From the IRAS fluxes, we also found that cool ($T_{\mathrm{d}} \simeq 124$ K) dust is present in the nebula, and that its mass M_{d} amounts to $\sim 3\ 10^{-4}\ M_\odot$ (Paper I). It is interesting to note that with the largest value for the ionized gas mass in the nebula around HD 168625, the slope of the LBV nebula "$\log M_{\mathrm{i}} - \log L$" relation found in Paper I is in better agreement with the slope of the "$\log M_{\mathrm{d}} - \log L$" relation.

4. The nebular environment of the nearby LBV HD 168607

Since the nearby star HD 168607 is also a LBV, we have similarly searched for a nebulosity around it. While observed in the same conditions as HD 168625, including with EFOSC1 and IRAC2, nothing has been detected in the vicinity of this star. Also, no nebular line may be seen on high-resolution CAT+CES spectra obtained with exposure times as long as those for HD 168625. Finally, IRAS did not detect any cool dust around HD 168607. We can therefore safely conclude that HD 168607 is not associated with a LBV-type nebula.

On the other hand, HD 168607 is possibly at the origin of a wind-blown shell in the Omega nebula, as suggested by its position almost at the center of a cavity (cf. Sect. 3.1). Its heliocentric velocity (4–10 km s^{-1}, Chentsov 1980) is in quite good agreement with that of the Omega nebula, 5.2 $\pm$ 5 km s^{-1} (Georgelin et al. 1973).

5. Discussion and conclusions

Our observations confirm that HD 168625 is at least as distant as the Omega nebula and the nearby LBV HD 168607. Further

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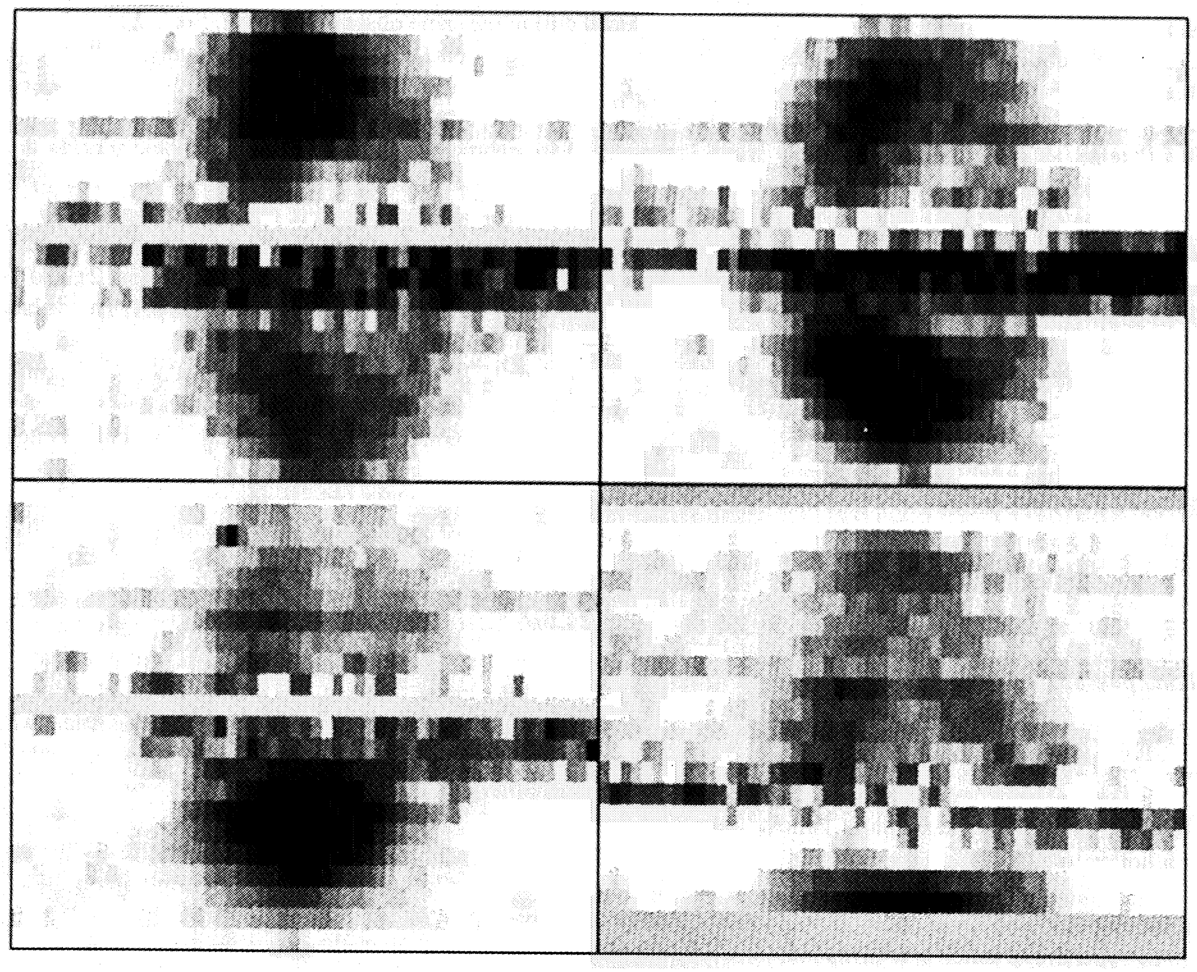

Fig. 6. Two-dimensional Hα emission line profiles from the nebula surrounding HD 168625. The four frames correspond to different position angles of the slit (cf. Table 3): ~ 273° (upper left), ~ 318° (upper right), ~ 14° (lower left), and ~ 54° (lower right). The size of each frame is 2.75 Å × 22 pixels, i.e. ~ 125 km s^{-1} × 18″. The spectrum of the star has been subtracted from the two-dimensional spectra, after its replication using the spatial profile of the continuum on each side of the line. This subtraction is not perfect and a noisy strip is still present. On the last frame the star is not at the center of the slit

support to this result comes from high-resolution observations of the NaI D line profiles obtained by one of us (E.G.), and showing that interstellar absorption occurs at higher positive velocities in the spectrum of HD 168625 than in the spectrum of HD 168607. HD 168625 is therefore a very luminous star, possibly a LBV. The nebula found around HD 168625 cannot be considered as a planetary nebula: it is better classified as a LBV-type nebula.

While our observations are not sufficient to build a detailed model, the following picture may be sketched: the nebula essentially consists of a dusty expanding shell from which seems to emerge a bipolar emission nebula, the whole embedded in a reflection nebulosity whose relation with the star is unclear. The shell is stratified: the dust continuum emission (either due to dust scattering or to non-equilibrium dust emission) arises beyond the ionized gas.

Although this kind of morphology is more typical of young planetary nebulae, it may be observed in some other LBV nebulae. The nebula around η Car is constituted of a dusty inner part –the homunculus– and outer emission nebulosities (Walborn 1976). On our images of the nebula around AG Car (often considered as the prototype of the class), we can clearly see a small and faint loop north of the ring: it has a N–S symmetry axis, an opening angle of ~ 50°, and peaks 28″ north from the star. This structure probably corresponds to the northern part of the bipolar outflow spectroscopically detected by Smith (1991), giving evidence that a faint bipolar nebula is also associated with AG Car in addition to the bright ring. Further, on the near-infrared images of HD 168625 described in Sect. 3.2, we note the presence of elongations inside the continuum-emitting ring: these are reminiscent of the dusty jet-like condensations around AG Car which also extend beyond the region where the Hα ring peaks (cf. Paresce & Nota 1989).

The kinematical and physical properties of the nebula are consistent with those commonly reported for LBV nebulae (cf. Smith 1993; Paper I and references therein). The size and the expansion velocity are smaller than in the representative AG Car nebula, but comparable to those of the η Car and WRA751

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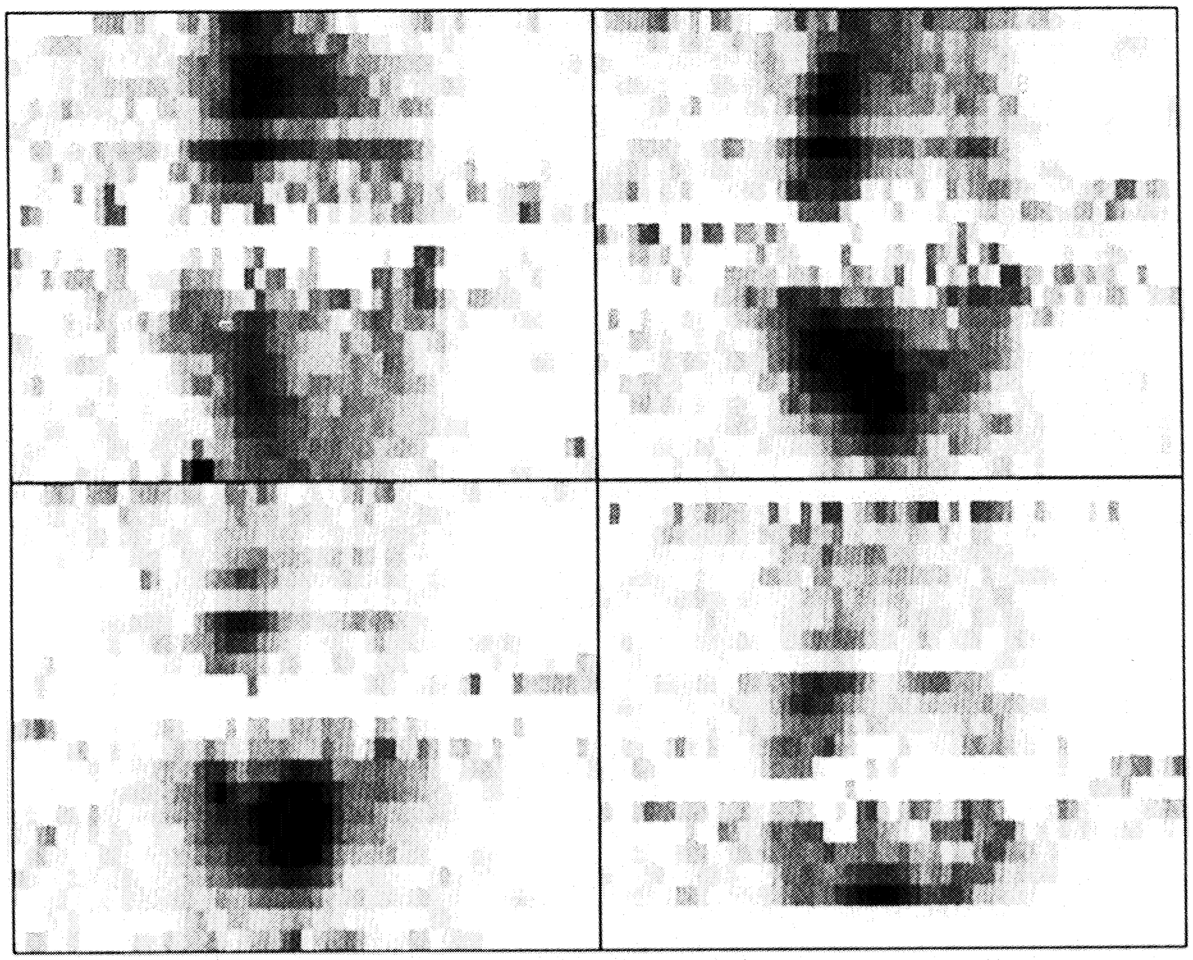

Fig. 7. Same as Fig. 6 but for the [N II] λ6584 emission line

nebulae, respectively. The nebular mass is smaller but nevertheless fitting the "nebular mass – stellar luminosity" relations of Paper I.

A peculiarity of HD 168625 is the presence in its spectrum of unidentified infrared emission bands (UIRs) which most probably arise in the nebular environment. Indeed, UIRs are detected in a variety of nebulae, including reflection nebulae, H II regions and planetary nebulae. These bands are generally attributed to polycyclic aromatic hydrocarbon molecules (PAHs); they are stronger in the spectrum of planetary nebulae where high C/O abundance ratios prevail (e.g. Cohen et al. 1986, 1989 and references therein). On the contrary, the nebula around HD 168625 is expected to contain CNO-synthesis products, as other LBV nebulae which are commonly N-rich. Furthermore, from the comparison of medium-resolution stellar spectra obtained in the λλ4050–4950 spectral range with spectra displayed in the atlas of Lennon et al. (1992), we confirm the classification of HD 168625 as a mid-B type supergiant with normal absorption lines of C II, N II, O II, and Si III (see also Chentsov & Luud 1989); it is therefore likely that the photospheric abundances of HD 168625 are modified by CNO processed material, as those of other galactic B-type supergiants (Lennon et al. 1993). The detection of relatively strong UIR bands in the spectrum of HD 168625 is unexpected, but may indicate that a large C/O abundance ratio is not essential for the formation of UIRs in this kind of nebulae, like, may be, in the case of pre-main sequence objects (e.g. Geballe et al. 1989). On the other hand, it is possible that the UIR emitting material has not been ejected by the star, but is of interstellar origin, possibly due to the nearby Omega nebula where UIR features are known to be enhanced

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relatively to the average interstellar medium (Giard et al. 1989). It is clear that a mapping of these UIRs would be worthwhile, as well as a detailed abundance analysis of the nebula. In this context, it is worth mentioning that diffuse absorption bands (DIBs) have been detected in the spectra of HD 168625 and HD 168607 (Herbig 1975), giving some support to the suggestion by Le Bertre & Lequeux (1993) that DIBs are commonly associated with LBV-type objects.

In conclusion, we find HD 168625 surrounded by a nebula whose characteristics are consistent with other LBV-type nebulae, although it has some peculiarities making it a rather unique object which certainly deserves further study. HD 168625, and the nearby LBV HD 168607 which is not associated with a comparable LBV-type nebula, constitute an important pair of supergiants for understanding the detailed processes of massive star evolution.

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