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# HR Carinae: a luminous blue variable surrounded by an arc-shaped nebula ⋆

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**Abstract.** We present new, high and medium dispersion spectroscopic observations of the luminous blue variable (LBV) star HR Car, showing that this star has a multiple shell expanding atmosphere and undergoes spectral variations apparently correlated with the light variations similarly to the other LBVs. Most striking are the very broad emission wings (FWZI $\sim 3000\,\mathrm{km\,s^{-1}}$) of the Balmer lines, reminiscent from the broad lines observed in the spectra of Of and WR stars.

We also derive a kinematic distance of 5.4 kpc and a bolometric magnitude of $-9^{m}.4$, putting HR Car among the most luminous stars of the Galaxy.

From the analysis of narrow band filter imagery, we report on the discovery of an arc-shaped jet-like nebula associated with HR Car.

Spectroscopic observations of this nebula reveal an emission nature with very low excitation. As the star itself, the nebula is characterized by a significant N/O overabundance, probably due to the presence of nuclear processed material ejected by the star.

**Key words:** luminous blue variable stars – mass-loss – emission nebulae – HR Car

## 1. Introduction

HR Car is one of the few luminous blue variables (LBVs) known in our Galaxy. These stars are very luminous evolved supergiants characterized by irregular outbursts or eruptions. Although no more than ten LBVs have been observed in the Galaxy and the Large Magellanic Cloud, they are generally considered as a short but important stage in massive star evolution towards the WR stage. They constitute a quite unique group for understanding the physics of the stars near the Humphreys-Davidson stability limit (Humphreys 1989).

One of the most interesting characteristics of the LBVs is certainly that some of them are surrounded by a small nebula apparently formed of matter ejected by the star and giving evidence for enrichment by nuclear processed material. These nebulae therefore constitute an important clue for understanding the LBV phenomenon and the evolutionary status of these stars. Such nebulae are well-known around $\eta$ Car and AG Car, which are, with P Cyg and HR Car, the 4 confirmed galactic LBVs. If the presence of a circumstellar nebula around P Cyg is possible but doubtful, nothing was ever detected around HR Car (Stahl 1989).

Since HR Car is by far the less studied of the galactic LBVs, the goal of this paper is to present new observations of this star and more particularly the discovery of a nebulosity around it.

HR Car (= HD 90177 = CPD −58°2145 = MWC 202 = He 3-407) is known to be a B2I P Cygni-type star with [Fe II] and Fe II emission lines, undergoing irregular slow light variations of approximately 1.5 mag as well as spectral variations on a period of a few months (Carlson & Henize 1979). It has a very high luminosity which is comparable to that of AG Car and P Cyg (Viotti 1971). From the photometric study of the light variations, van Genderen et al. (1990) clearly show that HR Car suffers S Dor type variations similar to those reported for AG Car and P Cyg.

A detailed infrared spectroscopic investigation has been performed by McGregor et al. (1988) who reported the presence of cool dust around HR Car and a variable spectrum characterized by strong [Fe II] emission lines and weak CO first overtone emission. They also found that HR Car is losing mass at a variable rate with an average value of $6\ 10^{-7}\,M_{\odot}\,\mathrm{yr}^{-1}$. Ultraviolet observations were recently analysed by Shore et al. (1990) who assign to HR Car an ultraviolet spectral type B4–5 and confirm its very high luminosity. They find that the Si IV and C IV resonance lines are weak as in the spectrum of other P Cygni type stars.

In the remainder, we present medium and high dispersion spectroscopic observations of HR Car as well as imaging and spectroscopic observations of the nebula found in its surroundings.

## 2. The observations

The observations of HR Car were carried out at the European Southern Observatory (ESO) during the period December 1988–June 1990. For all the observations, spectroscopy and imaging, the detectors were high resolution CCD chips of type RCA SID 503, 1024 × 640 pixels, each 15 µm$^2$.

The usual calibration frames (bias, darks, flat-fields as well as spectra of HeAr, ThAr and spectrophotometric standard stars) have been obtained. The reduction was done with the standard IHAP and MIDAS packages available at ESO.

In most cases, we have obtained more than one frame for a given spectroscopic or imaging configuration. All these frames were reduced individually before their eventual comparison and/or addition.

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⋆ Based on observations collected at the European Southern Observatory (ESO, La Silla)

**Table 1.** Imaging observations of HR Car

| Date | Instrument | Filter | $\lambda_c$/FWHM (Å) | Exposure time | Seeing |
|---|---|---|---|---|---|
| 16/12/88 | 2.2 m + DC | [N II] | 6595/23 | 10 s | 0″.8 |
| | | Continuum | 6026/261 | 1 s | 0″.9 |
| 29/03/89 | 2.2 m + DC | Hα + [N II] | 6554/20 | 5 s + 10 s | 0″.9 |
| | | [N II] | 6595/23 | 2 × 10 s | 0″.9 |
| | | [N II] | 6595/23 | 5 min + 10 min | 1″.3 |
| | | Continuum | 6026/261 | 2 × 1 s | 0″.7 |
| 23/06/89 | 2.2 m + DC | Hα + [N II] | 6572/40 | 1 min + 5 min | 2″.0 |
| | | [N II] | 6593/36 | 5 min | 2″.5 |
| | | [O III] | 5006/66 | 2 × 5 min | 2″.2 |
| 27/04/90 | 2.2 m + DC | Hα + [N II] | 6572/40 | 2 × 5 min | 1″.4 |
| | | [N II] | 6580/20 | 4 × 10 min | 1″.3 |
| | | [S II] | 6735/26 | 15 min | 1″.4 |
| | | [O III] | 5007/27 | 10 min | 1″.5 |
| 29/04/90 | 2.2 m + DC | [N II] | 6580/20 | 30 s + 10 min | 1″.0 |
| 30/04/90 | 2.2 m + DC | Continuum | 6450/61 | 1 min | 1″.2 |
| 28/06/90 | 3.6 m + EFOSC | Hα + [N II] | 6548/63 | 4 × 2 min + 2 × 6 min | 1″.4 |
| | | [O III] | 5006/66 | 3 min | 2″.0 |

### *2.1. Imaging*

The images of HR Car and its nebula were obtained using the 2.2 m telescope equipped with the Direct Camera (DC) and the 3.6 m telescope equipped with the EFOSC camera (Melnick et al. 1989). At the 2.2 m and 3.6 m telescopes, the RCA CCD pixel size of 15 μm corresponds to 0″.175 and 0″.337 on the sky, respectively. We essentially used narrow-band interference filters centered on the spectral lines of Hα, [N II], [S II], [O III] and a red continuum. In order to avoid saturation effects, some frames were also obtained at the 3.6 m telescope by positioning on the stellar image the 8″.0 occulting spot of the EFOSC coronographic mode. A summary of these imaging observations is given in Table 1, together with the filter characteristics.

The search for faint nebulosities near bright objects is always a difficult task: the image of the star is generally saturated while filters of lower quality may produce some ghosts, both effects contaminating the direct surroundings of the stellar image. In order to be sure that the observed nebulosity is not due to such a contamination, we have repeated our imaging observations with various filters and CCDs, also moving the object at different positions on the CCD. When detected, the features discussed in Sect. 4 are present on all the frames obtained with a given filter.

### *2.2. Spectroscopy*

Low dispersion spectrograms of HR Car and its nebula were obtained at the 1.52 m and 2.2 m telescopes equipped with a Boller and Chivens spectrograph (Heydari-Malayeri et al. 1989). They cover the 3500–6800 Å spectral range. They were obtained at different epochs with the aim of detecting spectral variations. Each time a nebular spectrum was recorded, a stellar one was taken with the same setting in order to allow a comparison independent of the calibration. In most cases the Hα line did not reach the saturation level, the signal to noise ratio being increased by repeated exposures. Higher dispersion spectrograms were obtained with the same equipment in the 4430–4920 Å spectral range, an important region for the spectral classification of luminous early-type stars.

HR Car was also observed at high dispersion with the CASPEC spectrograph attached to the 3.6 m telescope (Pasquini & D'Odorico 1989). The 31.6 lines mm$^{-1}$ grating was used with a 300 lines mm$^{-1}$ cross dispersion grating and a *f*/1.5 camera. The high resolution RCA CCD was used in the 2 × 2 binned mode. The spectra were centered on the Hα and Hγ-Hβ spectral regions, the first one being slightly underexposed in the continuum.

Higher dispersion spectrograms were obtained more or less one year later with the CES spectrograph attached to the CAT telescope (Lindgren & Gilliotte 1989). Two regions were considered, centered on the Hα and the He I λ5876 – Na I D spectral lines. We should note that a ghost is present in the flat-fields at the He I λ5876 position hampering a good reduction at this wavelength. In order to derive precise radial velocities from these spectra, we have also observed two radial velocity standard stars: HD 168454 and HD 186791.

Finally, a spectrum of the nebula around HR Car was also obtained with the EFOSC spectrograph attached to the 3.6 m telescope (Melnick et al. 1989).

For the nebular spectra obtained at the 1.5 m telescope, the 2″.0 wide slit was positionned at a distance of ~16″ from the star and with a PA ≃ 60°, in order to cross the SE arcs (see Sect. 4). At the 3.6 m telescope, the 0″.75 wide slit was oriented E-W and positionned 15″ S of the star. We should note that the spectra are partially contaminated by the light from the bright star. But, since this contamination is spatially well defined on the nebular spectrum, it can be quite easily removed during the reduction procedure.

All the spectra have been sky-subtracted, this substraction taking also into account the eventual contamination by the faint ambient nebula in which HR Car is embedded and seen on the ESO/SRC sky survey R plates.

Table 2 gives a summary of the spectroscopic observations.

**Table 2.** Spectroscopic observations of HR Car and its nebula

| Date | Instrument | Spectral range (Å) | Resolution (Å) | Exposure time | Object |
|---|---|---|---|---|---|
| 14/04/89 | 1.5 m + B&C | 4430–4920 | 0.98 | 10 + 20 min | Star |
| 18/06/89 | 3.6 m + CASPEC | 4050–5120 | ~0.3 | 1 min + 5 min | Star |
| 18/06/89 | 3.6 m + CASPEC | 6050–7140 | ~0.4 | 1 min | Star |
| 14/02/90 | 1.5 m + B&C | 3500–5430 | 3.8 | 2 min + 4 × 60 s | Star |
| 15/02/90 | 2.2 m + B&C | 5100–6850 | 3.4 | 2 min + 3 × 30 s | Star |
| 10/05/90 | CAT + CES | 6535–6592 | 0.12 | 1 min + 2 × 5 min | Star |
| 12/05/90 | CAT + CES | 5860–5910 | 0.11 | 2 × 30 min | Star |
| 13/05/90 | CAT + CES | 5860–5910 | 0.11 | 30 min | Star |
| 15/05/90 | 1.5 m + B&C | 4820–6800 | 4.7 | 60 s | Star |
| 15/05/90 | 1.5 m + B&C | 4820–6800 | 4.7 | 2 × 30 min + 60 min | Nebula |
| 17/05/90 | 1.5 m + B&C | 3570–5510 | 4.9 | 90 s + 180 s | Star |
| 17/05/90 | 1.5 m + B&C | 3570–5510 | 4.9 | 2 × 60 min | Nebula |
| 19/05/90 | 1.5 m + B&C | 4820–6800 | 4.7 | 60 min | Nebula |
| 28/06/90 | 3.6 m + EFOSC | 3600–7000 | 6.4 | 10 min | Nebula |

## 3. The star

### 3.1. Analysis of the spectrum

The spectrum of HR Car is dominated by strong Balmer emission lines showing P Cygni type profiles superimposed on very broad (FWZI $\simeq 3000\,\mathrm{km\,s^{-1}}$) emission features, the profiles of the upper members of the series being dominated by absorption. Moderately strong emission lines due to [Fe II] and Fe II are also observed, the latter ones with P Cygni type profiles. Spectral lines due to He I, N II, Si II, Si III, and Mg II are seen in absorption. Strong Ca II and Na I absorption lines are detected, most probably of circumstellar/interstellar origin, the diffuse interstellar bands being also very prominent.

Representative parts of the spectrograms recorded at the most separated epochs are illustrated in Figs. 1 and 2. Despite the unequal spectral dispersions, definite differences can be seen: the absorption lines of He I, N II, Si III as well as the [Fe II] emission lines are stronger in April 89 while the Fe II lines are stronger in May 90. According to their epoch of observation, the other spectra show intermediate characteristics, the CASPEC spectrograms obtained in June 89 being not too different from the April 89 spectrum. On the basis of the Si II, Si III, Mg II, and He I absorption lines, we have determined an equivalent spectral type B3I in April 90 and B9I in May 90. The He I $\lambda$4471/Mg II $\lambda$4481 line ratio is quite illustrative of this variation (Fig. 2).

It is particularly interesting to remark that between these two epochs, HR Car has apparently brightened (see Fig. 3) so that the spectral variations are most probably linked to the light variations. This behavior is quite common in LBVs (see for example the well-documented and similar behavior of S Dor, R127 or R71 reported by Leitherer et al. 1985; Stahl et al. 1983; or Wolf et al.

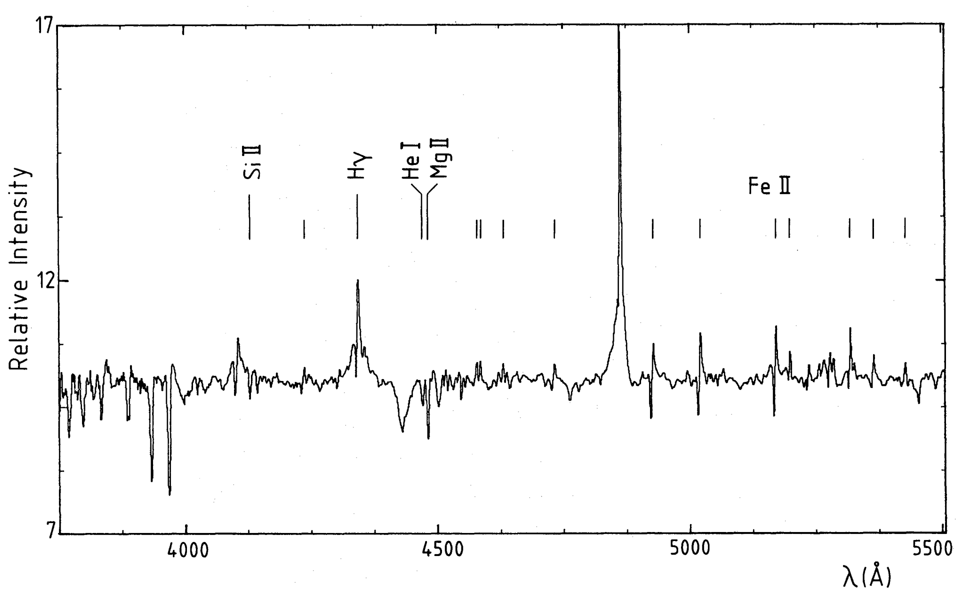


**Fig. 1.** The normalized blue spectrum of HR Car observed with the 1.52 m telescope in May 90. A few lines of interest are indicated. The non-labeled marks indicate Fe II lines

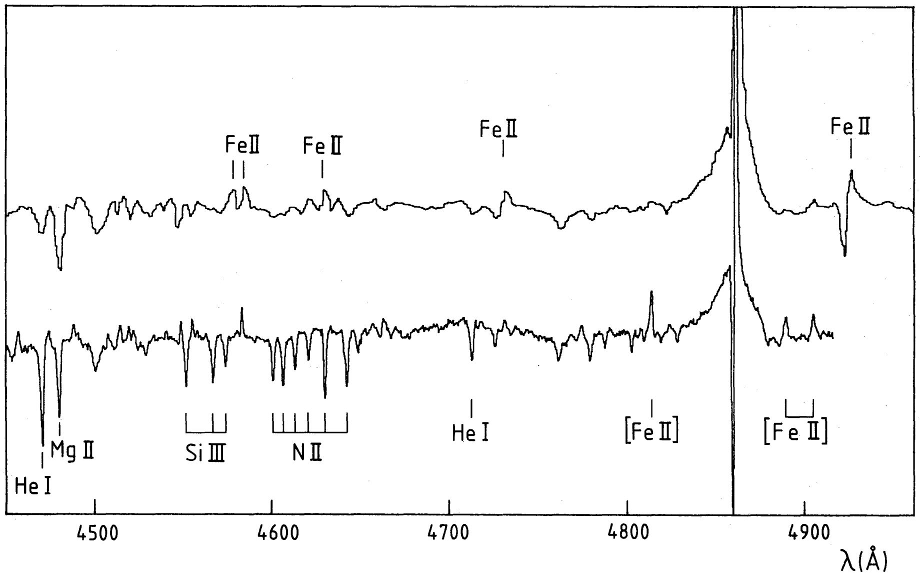


**Fig. 2.** Comparison of two spectrograms of HR Car recorded at the 1.52 m telescope in April 89 (*lower*) and May 90 (*upper*)

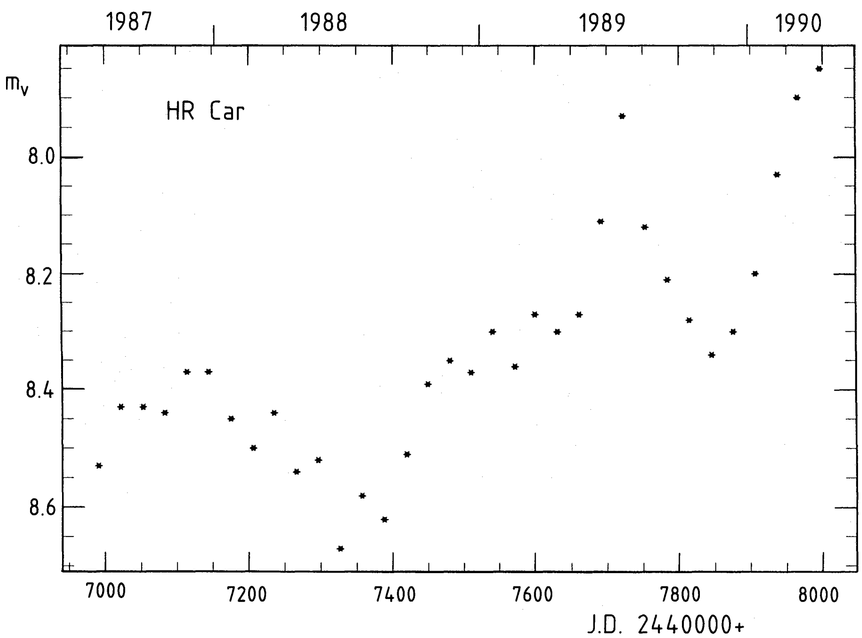


**Fig. 3.** The visual light curve of HR Car from the observers of the Royal Astronomical Society of New Zealand (Bateson 1987–1990)

1981, respectively): during brightening, these stars are surrounded by a cool dense envelope which hampers the observation of the true stellar features observed at minimum.

The spectrum of HR Car obtained in April 89 is quite remarkable in the sense that the N II lines are well seen while no O II can be detected contrary to normal B supergiants or P Cygni itself where O II is at least as intense as N II (see for example the atlas by Walborn & Fitzpatrick 1990, and Yamashita et al. 1977). This fact, already noticed by Carlson & Henize (1979), probably indicates a N/O overabundance in the atmosphere of HR Car. A similar deficiency of oxygen lines has been reported for the galactic LBV AG Car (Caputo & Viotti 1970; see also Hutsemékers & Kohoutek 1988).

Radial velocities have been measured for most lines on the high dispersion CASPEC spectrograms recorded in June 89. They are given in Table 3 while a few line profiles of interest are illustrated in Fig. 4. We should note that similar velocities were measured for the less numerous lines observed in the April 89 spectrum. The heliocentric systemic velocity of HR Car was measured from the [Fe II] emission lines: $+22\,\mathrm{km\,s^{-1}}$ ($\sigma/\sqrt{n}=4\,\mathrm{km\,s^{-1}}$ for $n=9$ lines). The lines of He I, Mg II, Si II, Si III, N II are only slightly blueshifted by typically $15\,\mathrm{km\,s^{-1}}$ with respect to the star, such motions being quite common in the atmospheres of supergiants. The He I lines have in addition a weak blue wing extending up to $\sim -102\,\mathrm{km\,s^{-1}}$. Very different are the P Cygni type profiles of the Balmer and Fe II lines which show two absorption components significantly displaced to the shorter wavelengths. These components probably reveal the presence of two extended shells in the atmosphere of HR Car. Compared to the most blueshifted absorption component, the less blueshifted one is stronger for the upper Balmer lines than for the lower members of the series. If the excitation is higher near the star, this suggests that the less blueshifted component is formed nearer to the star.

**Table 3.** Mean radial velocities ($km\,s^{-1}$) relative to the star of the absorption lines of the different ions observed in the CASPEC spectrograms of HR Car

| Ion | Velocity |
|---|---|
| H I | −105 |
| | − 36 |
| Fe II | −104 |
| | − 31 |
| He I | − 1 |
| N II | − 10 |
| Mg II | − 16 |
| Si II | − 15 |
| Si III | − 14 |

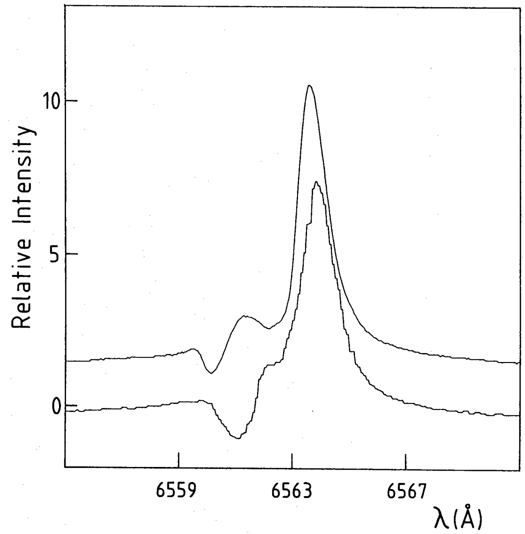


**Fig. 5.** Comparison of the Hα line profiles obtained in June 89 with CASPEC (*lower*) and May 90 with the CAT+CES (*upper*). The spectra have been rebinned in wavelength to take into account the difference in the motion of the earth between these two epochs

Figure 5 illustrates the variations of the Hα line profile between June 89 and May 90. The less blueshifted absorption component shows only little radial velocity variation (it even seems to be present in the spectra obtained in 1987 by Bandiera et al. 1989) while the high velocity one is significantly displaced to the blue. Since the radial velocity of the stable component is not too different from the radial velocity of some of the higher excitation lines (Table 3), we may think that this component is formed in more or less the same part of the atmosphere. If this is true and if the highest excitation lines are formed the deepest in the atmosphere, it indicates that, near the star, the envelope is slightly accelerated outwards. The other absorption component, whose radial velocity relative to the star changes from $-105\,km\,s^{-1}$ to $-140\,km\,s^{-1}$ between June 89 and May 90, is probably formed in a more extended and more rapidly expanding shell becoming less optically thick with time. We should remark that in the May 90 CAT+CES spectrum, the He I λ5876 line shows 2 absorption components at −38 and $-135\,km\,s^{-1}$ relative to the star. The peculiar behavior of this line was already noticed in the spectrum of R127 by Stahl et al. (1983).

From the blue wing of the Balmer and Fe II lines observed in the CASPEC spectra, we have measured the terminal velocity of the wind which is found equal to $\sim 145\,km\,s^{-1}$. Half the FWZI of the [Fe II] lines is somewhat lower than this value: $\sim 125\,km\,s^{-1}$. If the [Fe II] lines are formed outer than the region where the Balmer lines are formed, in lower density regions, this indicates that either the wind is decelerating at large distances from the star, probably because of its interaction with old remnants, or the material ejected before had a lower velocity. Let us finally note that the terminal velocity of the wind measured one year later from the Hα profile (Fig. 5) has increased to $\sim 170\,km\,s^{-1}$.

One of the most striking characteristics of the spectrum of HR Car is certainly the presence of very broad wings (FWZI $\sim 3000\,km\,s^{-1}$) superimposed on the Balmer emission lines. A faint broad emission of similar width may also be present around the He I λ4713 absorption lines, which, on our April 89 spectrum, is the only one sufficiently unblended to detect such a faint feature. Spectra of other stars have been obtained with the same instrumental setting and reduced on the same way with no equivalent bump at λ4713 so that it is reasonable to think that this feature is real. We should notice that broad He I emission lines have been reported in the spectrum of R127 (Stahl et al. 1983).

In the spectrum of P Cygni and AG Car, the broad wings of the Balmer lines have been interpreted as due to non-coherent scattering of the emission line photons by free electrons (Bernat & Lambert 1978; Wolf & Stahl 1982). In the case of HR Car, this interpretation does not seem very satisfactory: the equivalent width ratio of the broad to the narrow residual emission is rather high (about 10 for Hδ) and greater by a factor 5 for Hδ than for Hβ (see Fig. 1). In order to reproduce the broad wings of both Hδ and Hβ by electron scattering, we need quite different electron optical depths which means quite different loci of formation of

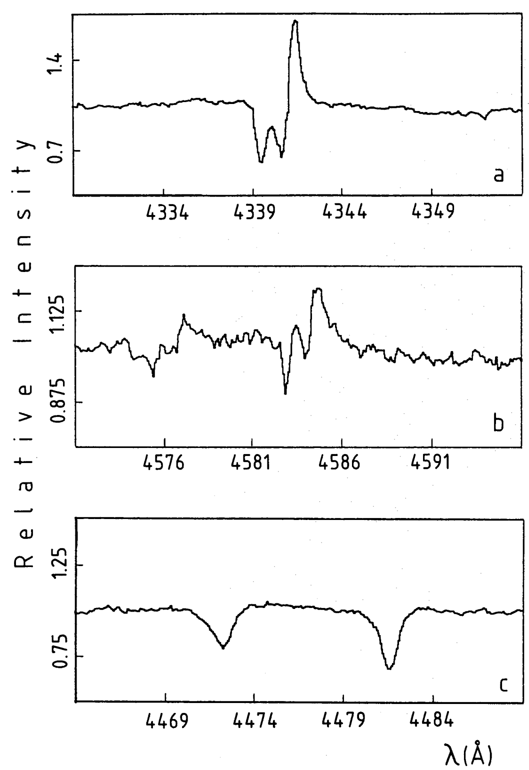


**Fig. 4a–c.** The line profiles of Hγ (**a**), Fe II λ4583 (**b**), He I λ4471 (**c**) and Mg II λ4481 (**c**) from the CASPEC spectrograms obtained in June 89

these lines, a situation which is not supported by net differences in the radial velocities. Also, with such high electron optical depths, we should detect broad emission lines associated with the brightest Fe II lines, these lines being as intense as H$\delta$ or H$\gamma$ (see Fig. 1) with nearly equal radial velocities (cf. Table 3). Finally, the H$\beta$ broad emission wings appear rather asymmetric, more extended to the blue, while scattering by electrons preferentially produces wings more extended to the red (Auer & Van Blerkom 1972). All these observational characteristics are significantly different from those described by Bernat & Lambert (1978) for the case of P Cygni. We therefore think that these broad lines more likely reveal the presence of high velocity motions in the atmosphere of HR Car, as the He I broad lines observed in the spectrum of R 127 (Stahl et al. 1983). Since emission lines with such a large Doppler broadening are only seen in the spectrum of WR stars and of some extreme Of stars – superimposed on narrower emission lines for these latter ones (Underhill et al. 1989) –, this may indicate that the atmosphere of HR Car has some properties in common with those of Of and WR stars, therefore supporting a possible evolutionary link.

### 3.2. *Distance and stellar parameters*

From the heliocentric velocity of the star, we can estimate the kinematic distance of HR Car. Adopting $+22\pm4\,\mathrm{km\,s^{-1}}$ as the systemic velocity of HR Car, we derive its velocity relative to the local standard of rest, $v_{\mathrm{lsr}}=+9\,\mathrm{km\,s^{-1}}$. This value is equal to that reported by Humphreys et al. (1989) for AG Car which is located in the same region of the sky, so that a similar reasoning can be followed in order to derive the kinematic distance of HR Car. We find $5.4\pm0.4$ kpc which is greater than the value of 2.5 kpc generally adopted considering its belonging to the Carina OB association. Such a large distance for HR Car is in agreement with the very strong interstellar lines observed in its spectrum. The Na I D lines are illustrated in Fig. 6. At least five absorption components are clearly seen, with velocities up to $-86\,\mathrm{km\,s^{-1}}$. Such high velocity components seem quite common in the Carina nebula (Walborn 1982). The presence of an absorption component at an heliocentric velocity of $+22\,\mathrm{km\,s^{-1}}$, similar to that of the star, indicates that the light coming from HR Car crosses interstellar material moving at positive radial velocities, giving some support to the large distance we derived. We should remark that an absorption component of Na I is also detected with a similar velocity in the spectrum of a neighbouring star, He 3-519, in agreement with the suggestion that this component has an interstellar origin.

Using the magnitudes and parameters of HR Car determined by van Genderen et al. (1990): $V=8\overset{\mathrm{m}}{.}4$, $A_V=3\overset{\mathrm{m}}{.}1$, $T_{\mathrm{eff}}\simeq14000$ K, $BC\simeq-1$ as well as the new distance of 5.4 kpc, we find a bolometric magnitude of $M_{\mathrm{bol}}\simeq-9\overset{\mathrm{m}}{.}4$. If corrected for the distance, a similar value can be obtained from the data of Shore et al. (1990) which are derived from ultraviolet observations. As noted by van Genderen et al. (1990), such a value of the bolometric magnitude will be in better agreement with the LBV amplitude-luminosity relation found by Wolf (1989). With these values for the distance and bolometric magnitude, the average mass-loss rate of $6\;10^{-7}\,M_\odot\,\mathrm{yr}^{-1}$ determined by McGregor et al. (1988) amounts to $2\;10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$.

The stellar parameters that we just derived confirm the LBV nature of HR Car by putting it in the upper part of the HR diagram between S Dor and R 71 (see e.g. the HR diagram displayed by Wolf 1989). Also the higher mass-loss rate is more typical of that of other LBVs.

## 4. The nebula

### 4.1. *The optical morphology*

First, looking at the ESO/SRC sky survey plates, we can see that HR Car does not belong to a particular star cluster and is embedded in a faint extended nebula which is apparently not related to the star itself.

A CCD image in the H$\alpha$+[N II] filter of the direct surroundings of HR Car is illustrated by Fig. 7. Two nebular arcs are definitely seen in the SE direction. They are located at 13″ and 17″ from the star and are ~2″ wide. The stellar image also shows a diffuse aspect in the NW direction suggesting that the nebulosity is extended in this direction and therefore has a bipolar geometry with a SE-NW axis. Especially interesting is the condensation located 6″ SE from the star: it is diffuse and elongated in the direction of the nearest arc, looking like a jet originating from the

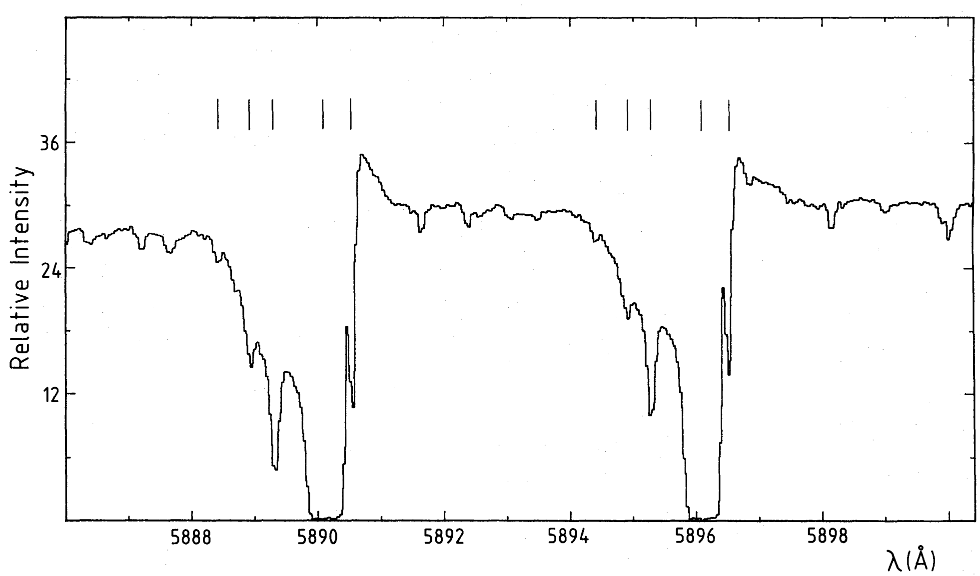


**Fig. 6.** The profiles of the Na I D lines observed with the CAT+CES in May 90. Five absorption components are indicated. They have heliocentric radial velocities of −86, −60, −41, +0.3 and $+22\,\mathrm{km\,s^{-1}}$

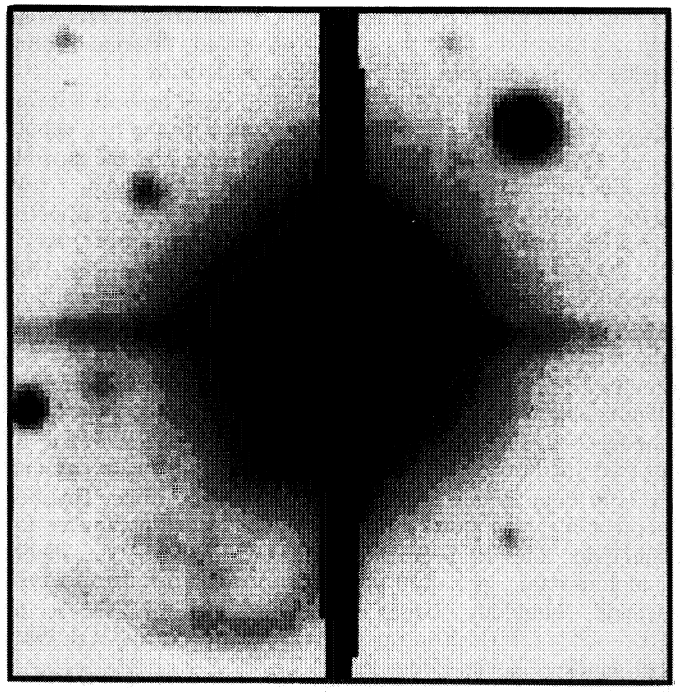

**Fig. 7.** Sum of the two best seeing (~1″.2 FWHM) images (2 min exposure each) obtained at the 3.6 m telescope + EFOSC with a good quality Hα + [N II] filter. The intensity scale is logarithmic. North is up, east to the left. The field is 35″ × 35″. The vertical and horizontal features are instrumental, due to the overexposition of the stellar image. The other features may be considered as real (see text)

stellar core. Despite some net differences, this kind of geometry is reminiscent from that of the nebula associated with AG Car where a jet has recently been found in addition to an overall bipolar geometry (Paresce & Nota 1989).

The nebular features discussed above are detected on all the images obtained in the [N II] and Hα + [N II] filters, including those obtained in the EFOSC coronographic mode which are unsaturated but of less good seeing. These features are nevertheless absent on the images obtained with the [O III] and continuum filters. This suggests that the nebula is not of reflective nature but of emission type.

On the good seeing and unsaturated images of HR Car, we can also see a faint star clearly resolved and located at 3″.7 E, 0″.2 S of HR Car. In the red continuum filter used on March 89, this companion is about $5^m$ fainter than HR Car and $0^m.4$ brighter than the star seen 15″ NW of HR Car.

### *4.2. The spectrum and physical characteristics*

The spectrum of the nebula, which essentially refers to the arcs, consists of the Balmer emission lines seen up to Hγ (Hδ is very faint but probably present) as well as the [N II] λλ6548–6583 and the [S II] λλ6716–6723 forbidden lines (Fig. 8). [N I] λ5199 is also probably present but faint. The spectrum is remarkable by the low excitation and the absence of oxygen lines, namely the [O I] λ6300, [O II] λλ3726–3729 and [O III] λλ4959–5007 lines. As from the spectrum of the star, this suggests a net N/O overabundance.

Despite some differences in the location of the slit, the spectra obtained at various epochs are essentially the same. Also, we have not detected any significant spatial variation of the nebular spectrum except radial velocity differences up to $\sim 50\,\mathrm{km\,s^{-1}}$ between small regions in the two arcs, the greatest arc being the most redshifted. This velocity difference was measured in the May 90 spectra from the spatial profile of the [N II] lines. It is rather high and may indicate that the arcs are strongly related to the stellar wind, as also suggested by the morphology.

With so few observed lines it is not easy to derive quantitative parameters for the nebula. We can nevertheless try to constrain some of them. Assuming case B recombination with $T_e = 10^4$ K, we derive from the observed Hα/Hβ and Hγ/Hβ ratios the logarithmic extinction coefficient: $c \simeq 1.4$. This extinction corresponds to $A_V \simeq 3$, a value which is nearly the same as the value derived from the stellar photometry (see Sect. 3.2) suggesting that no additional extinction occurs inside the nebula. Both the measured $F(\lambda)/F(\mathrm{H}\beta)$ and the corrected $I(\lambda)/I(\mathrm{H}\beta)$ emission line ratios are given in Table 4.

From the [N II] lines, we can estimate the electron temperature $T_e$. Since the [N II] λ5755 lines is not convincingly detected in our spectra, only an upper limit to the temperature can be obtained. With $I([\mathrm{N\,II}])/I(\mathrm{H}\beta) \leqq 0.03$, we find $T_e \leqq 12\,500$ K. We may therefore adopt in the following the electron temperature $T_e = 10^4$ K. From the [S II] line ratio, we derive the electron density: $n_e = 600\,\mathrm{cm^{-3}}$. These values are rather typical of H II regions and not too different from those obtained by Mitra & Dufour (1990) for the nebula associated with AG Car.

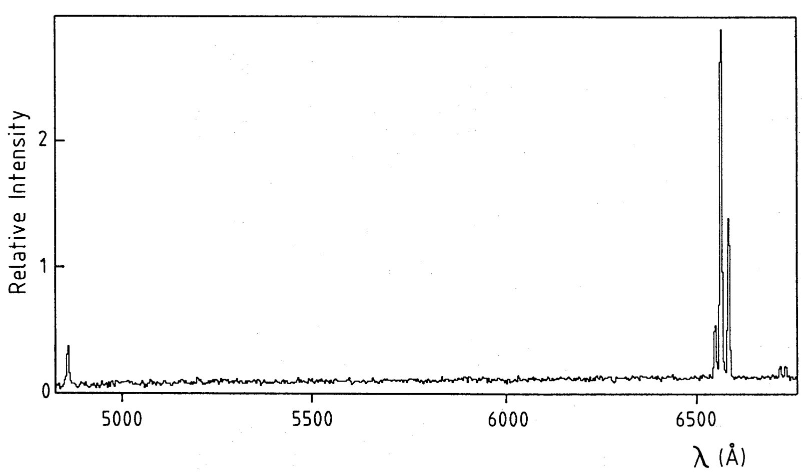


**Fig. 8.** The red part of the spectrum of the nebular arcs associated with HR Car. It was obtained in May 90 with the 1.52 m telescope. The Hβ, Hα, [N II] and [S II] lines are clearly identified

**Table 4.** Relative intensities of the emission lines observed in the spectrum of the nebular arcs surrounding HR Car

| Line | $F(\lambda)/F(\mathrm{H}\beta)$ | $I(\lambda)/I(\mathrm{H}\beta)$ |
|---|---|---|
| $\mathrm{H}\gamma$ | 30 | 48 |
| $\mathrm{H}\beta$ | 100 | 100 |
| $\mathrm{H}\alpha$ | 846 | 285 |
| [N II] $\lambda 6548$ | 126 | 42 |
| [N II] $\lambda 6583$ | 365 | 123 |
| [S II] $\lambda 6716$ | 25 | 7.7 |
| [S II] $\lambda 6731$ | 26 | 8.0 |

Using the approximation $N/O = N^+/O^+$, which seems reasonable for low excitation H II regions (Pagel 1990; see also Mitra & Dufour 1990), we may calculate a lower limit of this abundance ratio, the [O II] $\lambda 3727$ line being not detected in our spectra. Considering the [O II] lines due to the ambient nebula, which are well seen in our spectrograms, in order to fix the limit of visibility of the lines in this spectral region, we adopt $I([\mathrm{O\,II}])/I(\mathrm{H}\beta) \leqq 0.5$. We therefore obtain $N/O \geqq 0.4$, assuming for the nebula a simple one layer model in the low density limit. This value is significantly greater than the normal N/O abundance known in H II regions, 0.07 (Shaver et al. 1983), suggesting that the nebula contains nuclear processed material ejected by the star. We should remark that the presence of CO, detected by McGregor et al. (1988), could not easily explain this abundance anomaly since this CO is apparently formed in high density regions nearer the star.

Finally, adopting the distance of 5.4 kpc for HR Car, the projected distance of the arcs from the star is 0.34 and 0.45 pc while they are approximately 0.05 pc wide. If we assume that these arcs are confined in a cone originating from the star, we can roughly estimate their mass: $\sim 0.15\,M_\odot$, using the electron density determined above. With an expansion velocity of the order of a few $10\,\mathrm{km\,s^{-1}}$, the arcs have a kinematic age of the order of $10^4$ yr.

## 5. Discussion and conclusions

The present observations show that the characteristics of HR Car, including its variations, are very similar to those of other LBVs, belonging either to the Galaxy or to the LMC. This strengthens the view that these stars undergo the same kind of physical processes, essentially dominated by a variable mass-loss.

The presence in the spectrum of HR Car of broad emission lines indicative of high Doppler velocities suggests a link with the Of and WR stars which are the only stars known to display very broad lines in their spectra. The overabundance of N relative to O, in agreement with the predictions of the models of Maeder (1987) for massive stars, also supports the interpretation that HR Car is an evolved star in a transition stage towards WR stars.

The observations are also consistent with the view that the nebula surrounding HR Car is constituted, at least in part, of enriched material ejected by the star.

If we except the case of P Cygni which is still a matter of controversy (Stahl 1989), all the galactic LBVs are now shown to be surrounded by a nebula apparently related to the mass-loss of the star. Also the new LBV candidate WRA 751, recently discovered by Hu et al. (1990), is embedded in a faint emission nebula (de Winter 1990; Hutsemékers & Van Drom 1991) while many LBVs of the LMC have spectroscopically detected circumstellar shells (Walborn 1982b; Stahl & Wolf 1986).

It is particularly interesting that the nebula around HR Car has some common morphological features with the ring nebula associated with AG Car, namely the bipolarity and the possible jet. Since such a morphology is most naturally explained by a close binary hypothesis, it gives some support to this interpretation for the LBV phenomenon itself, as proposed by Gallagher (1989).

The nebula around HR Car shares other characteristics with the AG Car nebula like the low excitation, the physical conditions and the N/O overabundance (Mitra & Dufour 1990). However, the nebula surrounding AG Car looks more massive (Stahl 1987) and partly of reflective nature, especially the jet (McGregor et al. 1988b; Paresce & Nota 1989). This difference is in agreement with the fact that the amount of cool dust, which is assumed to be located in the visible nebula, has been found greater around AG Car than around HR Car (McGregor et al. 1988). The dust content may therefore constitute an important parameter for classifying the nebulosities associated with early-type highly luminous stars, especially if we compare with the nebulae observed around luminous Bep supergiants like HD 87643 or CD $-42°11721$ which are much more reflective (Surdej et al. 1981; Hutsemékers & Van Drom 1990).

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**Note added in proof:** On April 24 and 26, 1991, we have recorded the spectrum of HR Car at the 1.52 m + B&C telescope with a spectral resolution comparable to that of the April 89 observations. In addition to the Balmer emission lines, the April 91 spectrum essentially shows bright Fe II lines with P Cygni type profiles. These Fe II lines are stronger than in the May 90 spectrum, Fe II $\lambda$4583 being nearly as prominent as H$\gamma$. The He I lines are very faint while no [Fe II] is detected. The Balmer line profiles still consist of P Cygni type profiles superimposed on very broad wings. These observations show that the spectrum of HR Car is still evolving, following the trend noticed between the April 89 and the May 90 observations.