

The supergiant Bep star CD – 42°11721 and its surrounding nebula [★]

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Abstract. We report here on new spectroscopic and direct imagery observations of the supergiant Bep star CD–42°11721 and its surrounding nebula.

The spectrum of the star essentially consists of Balmer and Fe II emission lines. He I emission lines are also observed, confirming the presence of spectral variations on long timescales.

The clumpy arc-shaped structure of the nebula as well as the presence of motions relative to the central star highly suggest that it has been influenced by a variable mass-loss.

The nebula shows both the reflection and emission characteristics. Its spectrum displays the red [N II] and [S II] lines while no oxygen forbidden lines can be detected. It is tempting to interpret this situation by a N/O overabundance which may indicate the presence of processed material in the nebula and thus confirm the evolved nature of the star.

Key words: emission-line stars – Be supergiants – mass-loss – reflection + emission nebulae

authors consider CD–42°11721 as a very luminous star ($M_{\text{bol}} \simeq -8.3$) which may be comparable to the Magellanic B[e] supergiants discussed by Zickgraf et al. (1985).

In addition to possible spectral variations (Carlson and Henize, 1979), CD–42°11721 seems to undergo colour and light variations of $\Delta V \simeq 0.3$ mag (Herbst, 1975).

One of the most interesting characteristics of CD–42°11721 is its association with a small diffuse surrounding nebula found by Henize (1962). This nebulosity is included in the survey of reflection nebulae by van den Bergh and Herbst (1975) with the remark that it may be an emission nebula. Up to now, its exact nature is still unknown.

Since very few Be supergiants are known to be embedded in nebulosities, the study of CD–42°11721 may be particularly important for understanding the evolution of massive stars. In this paper, we report on new direct imagery and spectroscopic data collected for both the star and the nebula with the special aim of clarifying the nature of the nebula.

1. Introduction

Strong emission at H α and H β in the spectrum of CD–42°11721 (= MWC 865 = He 3-1300) was first discovered by Merrill and Burwell (1949) during the Mount Wilson H α survey. The Bep character of this star was confirmed by Carlson and Henize (1979) who described the emission spectrum as entirely consisting of strong Balmer lines and numerous weak to moderate Fe II lines, no absorption lines being detected. These authors also noticed the spectral similarity of CD–42°11721 with CPD–52°9243, a star known to be a B[e] supergiant (Swings, 1981; Winkler and Wolf, 1989). They suggested that CD–42°11721 may be a transition object between P Cygni and Be type stars.

The infrared spectrum of CD–42°11721 was studied by McGregor et al. (1988). They reported the presence of Brackett and Paschen hydrogen lines in emission as well as a large infrared excess interpreted as due to the presence of both hot and cool dust around the star. Besides, Shore et al. (1986, 1989) noticed the presence of strong C IV, Si IV and Fe II absorption lines in the ultraviolet spectrum of this star so that they can assign to CD–42°11721 an O9-B0 ultraviolet spectral type. All these

2. The observations

On August 24, 1989, we have obtained images of CD–42°11721 and its surrounding nebula using the direct camera attached to the 2.2 m telescope at the European Southern Observatory (ESO, La Silla). The detector was a high resolution 1024 × 640 pixel RCA CCD. Using the CCD in the 2 × 2 binning mode, the effective pixel size of 30 μm corresponds to 0".35 on the sky. The observations were performed using R and red continuum ($\lambda_c = 6026 \text{ \AA}$, FWHM = 261 \AA) filters with exposure times ranging from 5 to 120 s. The seeing was typically around 2" FWHM.

More images were collected on September 1, 1989 with the ESO New Technology Telescope (NTT). During this commissioning period, no field rotator was installed and good images could only be obtained during a relatively short exposure time generally less than 5 min. The telescope was equipped with the EFOSC 2 spectrograph and camera (Eckert et al., 1989). The detector was a low resolution 512 × 320 pixel RCA CCD with 30 μm pixels corresponding to 0".26 on the sky. We used R and H α ($\lambda_c = 6557 \text{ \AA}$, FWHM = 76 \AA) filters with exposure times ranging from 1 to 10 s. The seeing of the NTT frames was much better: typically 0".6 FWHM.

Spectroscopic observations of both the star and the nebula were carried out on July 12, 1989 at the ESO 1.52 m telescope equipped with a Boller and Chivens spectrograph and a high resolution 1024 × 640 pixel RCA CCD (see Heydari-Malayeri et al., 1989; Jarvis and Hutsemékers, 1989). The nebular spectrum

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[★] Based on observations collected at the European Southern Observatory, ESO, La Silla

was isolated by positioning the east-west oriented slit 7" north of the star i.e. more or less through a nebular condensation and above the star located 5" north (see Sect. 4). The slit was 1".7 wide. Using the ESO grating #15, we obtained spectrograms covering the spectral range $\lambda\lambda$ 3500–7250 Å with a resolution of 7.6 Å. Typical exposure times of 30 s to 30 min characterize the stellar and nebular spectra respectively.

Additional spectrograms of the star and the nebula have also been obtained during the NTT+EFOSC 2 run. For the nebula, the 1".1 slit was positioned in order to cross the W condensation (see Sect. 4) i.e. at about 6" from the star and with an orientation of +13 deg. relative to the north-south direction. With a grating giving a reciprocal dispersion of 153 Å/mm, the spectrograms cover the spectral range $\lambda\lambda$ 4670–6960 Å. Unfortunately, due to the lack of calibration lamps and the "too good" seeing compared to the available slit widths, these spectrograms are only useful for line identifications. The relatively short exposure times (from typically 2 s for the star to 5 min for the nebula) have prevented us against problems due to the field rotation.

Using the usual calibration frames (darks, dome flat-fields, and HeAr spectra) we have reduced our data 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.

3. The spectrum of the star

The spectrum of CD–42°11721, illustrated in Fig. 1, may be considered as entirely made up of emission lines, the few observed absorption features being interpreted as due to diffuse atmospheric and interstellar bands. The diffuse λ 4430 Å interstellar band is quite strong in our spectra. Balmer emission lines are detected up to H η . While more than thirty Fe II lines can be identified, no [Fe II] lines have been detected. The spectrum also displays a few Si II lines, never reported before, as well as the $\lambda\lambda$ 5876, 6678, and 7065 Å He I lines. The identified features are

present in the spectra obtained during both spectroscopic observing runs.

The presence of the He I line at λ 5876 Å in the spectrum of CD–42°11721 is particularly interesting: after analysing spectroscopic data recorded in 1945–48, Merrill and Burwell (1949) reported the possible detection of this He I line which is absent from spectra obtained later, in 1949–51 and 1962 (Carlson and Henize, 1979). The observation of this line as a relatively strong feature in our 1989 spectra definitely proves the spectral variability of CD–42°11721 on long timescales. We should remark that we have measured no significant radial velocity difference between the He I lines and the other ones. We also note that the presence of He I lines in the spectrum of CD–42°11721 is in agreement with the quite early O9–B0 spectral type determined from ultraviolet observations by Shore et al. (1986, 1989), especially if we compare with the spectral types that these authors have derived for Be supergiants in the spectrum of which no He I lines were detected.

4. Optical morphology of the nebula

As seen on the ESO/SRC R plate No. 277 (Fig. 2), the interstellar environment of CD–42°11721 is quite complex. About 10" north is an elongated region of obscuration where the number of stars is especially low. Nearer to CD–42°11721 are several smaller and less dense pockets and streaks. By analysing neighbouring stars, Glass and Allen (1975) conclude that there may be an extremely thick dark cloud to the north of CD–42°11721. A quite remarkable feature is the thin emission arc seen at about 1'.5 west of CD–42°11721 and separated from it by a region almost completely devoid of stars.

Of particular interest is the small ($\sim 40'' \times 80''$) diffuse nebulosity in which CD–42°11721 is embedded. CCD pictures of this nebula are shown in Figs. 3 and 4. The structure of the nebula is essentially identical in the three filters we have used (*R*, red continuum and H α), suggesting that the nebular emission may be due to the reflected stellar light. The compact object located at

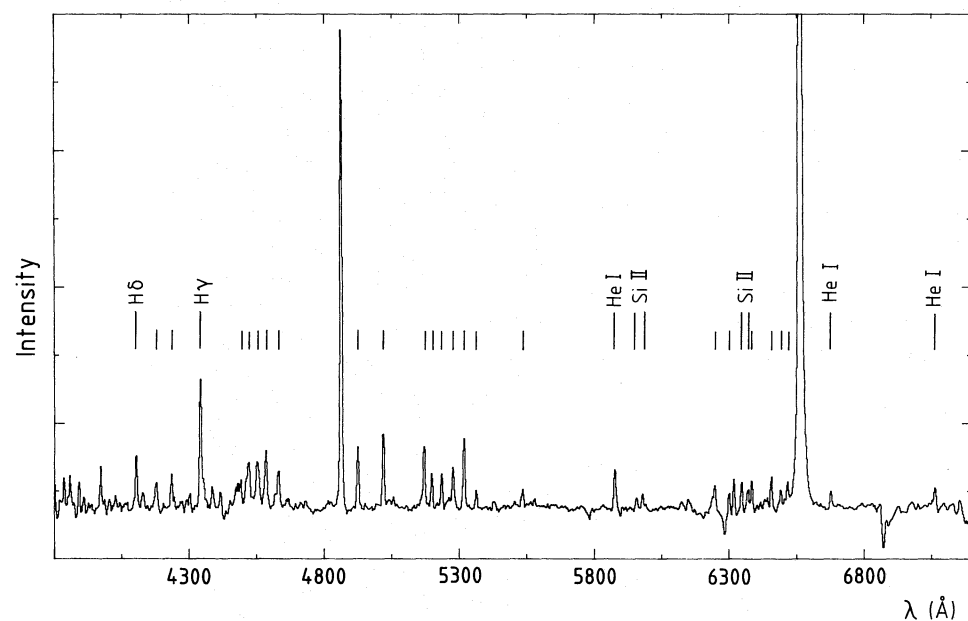


Fig. 1. The normalized spectrum of CD–42°11721 obtained at the 1.52 m telescope. Some of the most important spectral lines are indicated. The non-labeled marks correspond to the numerous Fe II lines

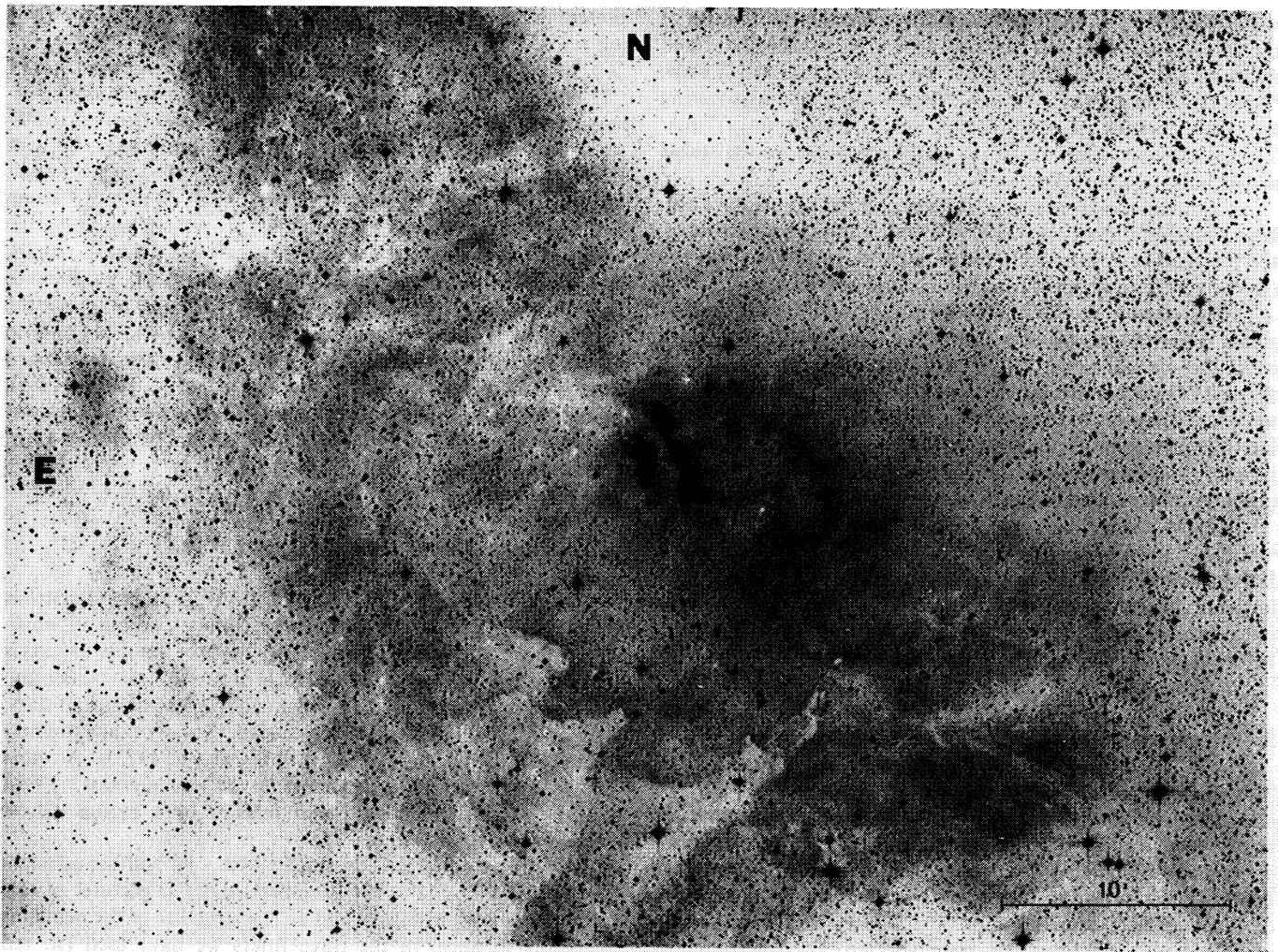


Fig. 2. Reproduction of a part of the ESO/SRC R plate No. 277, showing the complex interstellar environment of CD $-42^{\circ}11721$

about $5''$ north of CD $-42^{\circ}11721$ and definitely absent from the $H\alpha$ picture is most probably a star. The overall shaping of the nebula is influenced by obscuration zones like the one we can see between CD $-42^{\circ}11721$ and the nearby star located at about $35''$ SE (Fig. 3).

The most remarkable features of the nebula are certainly the arc-shaped filamentary condensations observed north and west of the star (Fig. 4). At least two of these structures can be identified: one clearly seen at about $6''$ from the star and another at about $14''$. Some additional condensations are probably present, namely closer to the star.

Since we can expect a relatively strong mass-loss from a Be supergiant, it is not unlikely that these arc-shaped condensations are stellar ejecta or due to mass-loss variations. In this simple morphological point of view, the arc seen $1.5''$ west of the star (Fig. 2) may be the front of a wind-blown shell.

5. The spectrum of the nebula

The two spots we have studied in the nebula (see Sect. 2) display similar spectra which are essentially identical to the spectrum of the star, in both the continuum and the spectral lines. This

confirms the reflection nature of the nebula surrounding CD $-42^{\circ}11721$.

Small but important differences between the nebular and stellar spectra nevertheless exist: the [N II] lines at $\lambda\lambda$ 6548, 6584 Å as well as the [S II] doublet at $\lambda\lambda$ 6717, 6731 Å are definitely present in the spectrum of the nebula with intensities comparable to those of the Fe II lines (Figs. 5 and 6). We have searched for the oxygen forbidden lines [O I] λ 6300 Å, [O II] λ 3727 Å and [O III] $\lambda\lambda$ 4959, 5007 Å, but without any success. We should nevertheless note that the [O II] doublet lies in the CCD low sensitivity region while [O I] is blended with a reflected stellar Fe II line at λ 6305 Å and with the strong oxygen sky line so that their detection is difficult. In any case, these lines are certainly much weaker than the [N II] and [S II] lines. Pure nebular $H\alpha$ emission, if present, should also be very small: in both our stellar and nebular spectrograms, this line has the same equivalent width. This is what we expect from a reflection.

Using the relative intensities of the two [S II] lines we can estimate the electron density n_e . In the two considered parts of the nebula we measure $I_{6731}/I_{6717} = 1.6$ which, on the basis of the curves given by Aller (1984), leads to $n_e \simeq 2.6 \pm 0.6 \cdot 10^3 \text{ cm}^{-3}$, the uncertainty being due to the unknown temperature. This electron density is comparable to that of the densest planetary nebulae. We

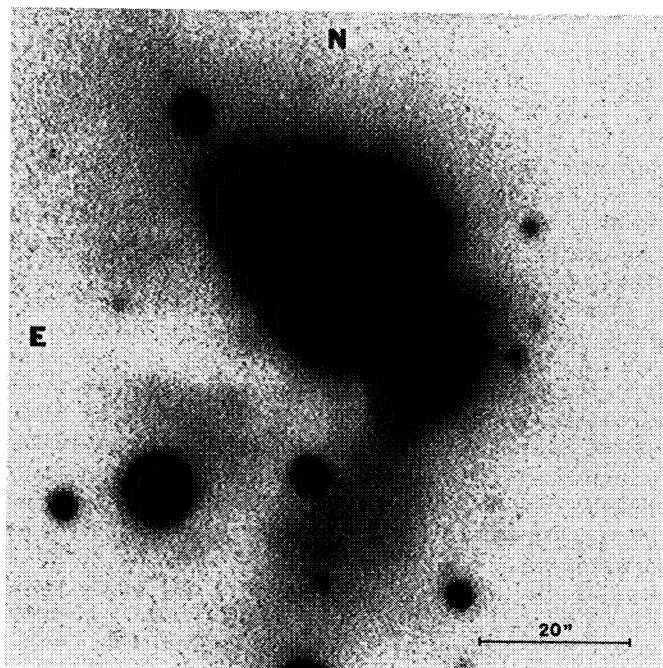


Fig. 3. A CCD R picture of the nebula surrounding CD-42°11721. This frame, obtained at the 2.2 m telescope with a seeing of 2" FWHM, emphasizes the overall structure of the nebula, namely the obscuring regions

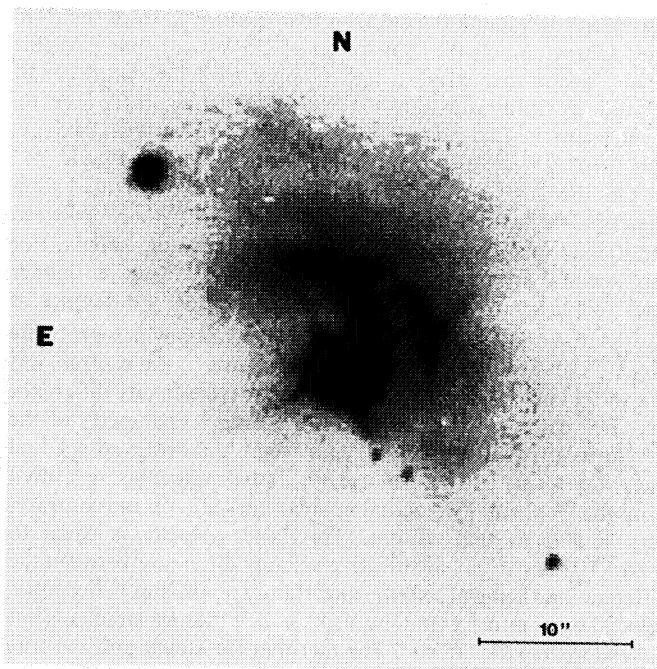


Fig. 4. A CCD R picture of the immediate surroundings of CD-42°11721. This frame, obtained at the NTT with a seeing of 0".6 FWHM, shows the arc-shaped filamentary condensations around CD-42°11721

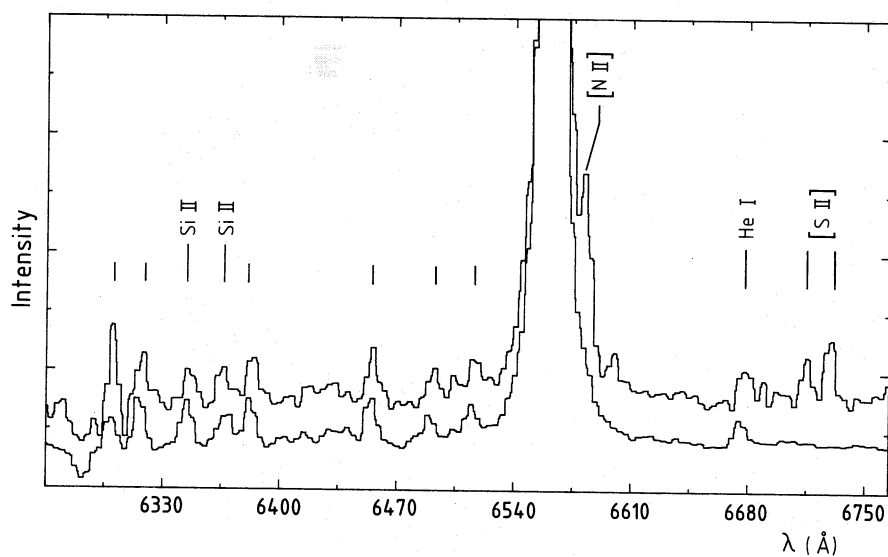


Fig. 5. Parts of the stellar and nebular spectra obtained at the 1.52 m telescope are compared, illustrating the reflection of the stellar features by the nebula as well as the presence of the [N II] and [S II] true nebular lines. The S/N ratio is lower for the nebular spectrum. The non-labeled marks correspond to the Fe II lines. The behavior of the $\lambda \sim 6305 \text{ \AA}$ feature is most probably due to an imperfect subtraction of the strong oxygen sky line

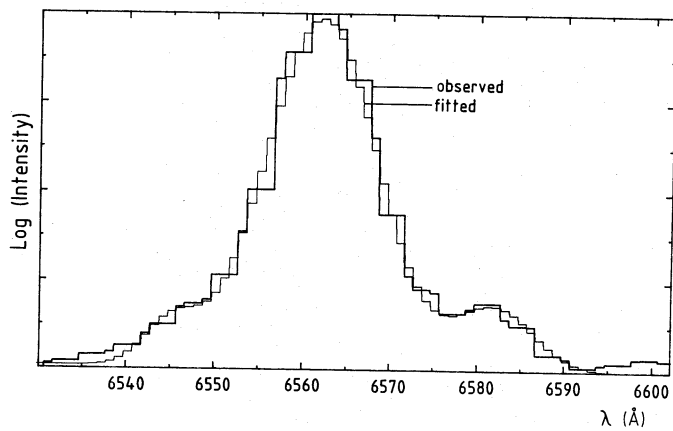


Fig. 6. Enlargement of the nebular $H\alpha + [N II]$ line profile. Both of the [N II] lines are clearly seen. The result of a 3 gaussian line profile fitting is also shown

also tried to evaluate the electron temperature T_e from the [N II] lines. Unfortunately the [N II] line at $\lambda 5755 \text{ \AA}$ is only barely visible on our spectra so that only a higher limit to the temperature can be derived. By fitting gaussians to the $H\alpha + [\text{N II}]$ line profile (Fig. 6), we measure the $I_{5755}/(I_{6548} + I_{6583})$ ratio to be less than 0.05, i.e. $T_e \leq 2 \cdot 10^4 \text{ K}$ if we use the formulae given by Kaler (1986).

On the basis of the spectrograms obtained at the 1.52 m telescope, we have searched for radial velocity differences between the stellar emission lines and those reflected by the nebula. For this, spectral lines of all ions were considered except the Balmer ones. We measured an average systematic velocity difference of $63 \pm 8 \text{ km s}^{-1}$ ($\sigma/\sqrt{n} = 8 \text{ km s}^{-1}$ for $n = 23$ lines) which probably indicates an expansion of the nebula relative to the central star. We should nevertheless keep in mind that this velocity difference may be due, at least partially, to an eventual asymmetry of the envelope surrounding the star and where the observed spectral lines are formed. The heliocentric radial velocities measured from the [N II] and [S II] actual nebular lines are, on the contrary, very similar to that of star. This latter velocity is equal to $-84 \pm 10 \text{ km s}^{-1}$, no significative velocity difference between the different ions being noted (the uncertainty on the star heliocentric velocity takes into account the dispersion of the measurements but not the systematic effects). The fact that the stellar and the true nebular velocities are nearly the same – and apparently different to that of the local interstellar medium which is equal to 6 km s^{-1} (Rickard, 1974)¹ – also suggests that the nebular condensations may be stellar ejecta.

6. Discussion and conclusions

From our observations, CD–42°11721 appears as an early Bep supergiant, spectroscopically variable on long timescales and embedded in a small reflection+emission nebula. The whole system lies in a young and complex interstellar environment. The arc-shaped morphology of the nebula as well as the presence of motions relative to the star and to the interstellar environment strongly suggest that the observed condensations may be due to the ejection of matter by the star, probably under the form of a variable dusty wind. Such an hypothesis is supported by the high mass-loss rate of CD–42°11721 as well as by the large amount of circumstellar dust (McGregor et al., 1988). The presence of high density and collisionnally excited regions, at the origin of the observed [S II] and [N II] spectral lines, is also compatible with our interpretation. Assuming that the nebular condensations expand at the constant velocity of 63 km s^{-1} and that CD–42°11721 is located at 2.5 kpc (McGregor et al., 1988), we can derive for these structures a kinematic age of about 2000 yr, which is comparable to the typical lifetime of stellar ejecta. If we adopt a similar expansion velocity for the greater arc seen in Fig. 2, we derive an age of more than 15 000 yr, a value which is certainly a lower limit. This thin arc is more probably some kind of wind-blown shell, as suggested by its morphology. Further studies of this arc are badly needed in order to understand its nature.

The stellar and nebular characteristics of CD–42°11721 are strikingly similar to those of HD 87643, which, as far as we know, is the only other Be supergiant embedded in a reflection nebula

(see Surdej et al., 1981; McGregor et al., 1988). However, strong P Cygni line profiles have been reported in the spectrum of HD 87643. This discrepancy between the two stars can be explained by adopting a disk-like envelope model like the one proposed by Zickgraf et al. (1985) for the Magellanic B[e] supergiants. In this model, the observation of P Cygni or pure emission line profiles essentially depends on the orientation of the expanding envelope relative to the observer. If this interpretation is correct, the study of the two stars may be an important clue for checking this kind of model.

As noted by McGregor et al. (1988), both stars present many characteristics in common with the massive, almost certainly post-main sequence, B[e] supergiants. Some of their more luminous counterparts, like η Car and AG Car, are also known to be embedded in dusty nebulae probably ejected by the star (cf. Allen, 1989; Paresce and Nota, 1989). On the other side, the interstellar environment of CD–42°11721 and HD 87643 shares many properties with those associated to the Herbig Ae/Be stars (see Herbig, 1960) which are known to be almost certainly pre-main sequence objects; CD–42°11721 was even included in the list of Herbig Ae/Be star candidates by Finkenzeller and Mundt (1984). This common point emphasizes the strong similarities observed between these different types of stars (McGregor et al., 1988).

When compared to the observed [N II] lines, the absence or weakness of the forbidden oxygen lines in the nebular spectrum of CD–42°11721 is particularly striking and it is tempting to interpret this result by a N/O overabundance. If these nebular condensations are really due to the stellar mass-loss, this suggests the presence of processed material in the nebula, confirming the evolved nature of the star. This situation may be comparable to the abundance anomalies known in the nebulae surrounding other luminous supergiants (Walborn, 1988; Dufour, 1989).

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References

- Allen, D.A.: 1989, *Monthly Notices Roy. Astron. Soc.* **241**, 195
 Aller, L.H.: 1984, *Physics of thermal gaseous nebulae*, Reidel, Dordrecht
 Carlson, E.D., Henize, K.G.: 1979, *Vistas Astron.* **23**, 213
 Dufour, R.J.: 1989, *Rev. Mexicana Astron. Astrof.* **18**, 87
 Eckert, W., Hofstadt, D., Melnick, J.: 1989, *Messenger* **57**, 66
 Finkenzeller, U., Mundt, R.: 1984, *Astron. Astrophys. Suppl.* **55**, 109
 Glass, I.S., Allen, D.A.: 1975, *Observatory* **95**, 27
 Henize, K.G.: 1962, *Astron. J.* **67**, 612
 Herbig, G.H.: 1960, *Astrophys. J. Suppl.* **3**, 337
 Herbst, W.: 1975, *Astron. J.* **80**, 212
 Heydari-Malayeri, M., Jarvis, B., Gilliote, A.: 1989, ESO Operating Manual No. 9
 Jarvis, B., Hutsemékers, D.: 1989, *Messenger* **53**, 65
 Kaler, J.B.: 1986, *Astrophys. J.* **308**, 322
 McGregor, P.J., Hyland, A.R., Hillier, D.J.: 1988, *Astrophys. J.* **324**, 1071
 Merrill, P.W., Burwell, C.G.: 1949, *Astrophys. J.* **110**, 387
 Paresce, F., Nota, A.: 1989, *Astrophys. J.* **341**, L43
 Rickard, J.J.: 1974, *Astron. Astrophys.* **31**, 47

¹ More precisely, 6 km s^{-1} represents the radial velocity of the main interstellar cloud observed in this direction; turbulent motions at negative radial velocities are also observed.

- Shore, S.N.: 1989, *Physics of Luminous Blue Variables*, *IAU Coll.* **113**, p. 51
- Shore, S.N., Brown, D.N., Sanduleak, N.: 1986, *New Insight in Astrophysics*, ESA SP-263, p. 357
- Surdej, A., Surdej, J., Swings, J.-P., Wamsteker, W.: 1981, *Astron. Astrophys.* **93**, 285
- Swings, J.-P.: 1981, *Astron. Astrophys.* **98**, 112
- van den Bergh, S., Herbst, W.: 1975, *Astron. J.* **80**, 208
- Walborn, N.R.: 1988, *Atmospheric diagnostics of stellar evolution*, *IAU Coll.* **108**, p. 70
- Winkler, H., Wolf, B.: 1989, *Astron. Astrophys.* **219**, 151
- Zickgraf, F.-J., Wolf, B., Stahl, O., Leitherer, C., Klare, G.: 1985, *Astron. Astrophys.* **143**, 421