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# A kinematic and morphological investigation of the asymmetric nebula around the LBV candidate WRA 751

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**Abstract.** WRA 751 is an evolved massive star in our Galaxy closely resembling Luminous Blue Variable stars (LBVs). It is surrounded by a nitrogen enriched nebula of about 23″ diameter. A comparative study of the nebula's morphology and kinematics is presented, it supports—together with spectroscopical evidence—the classification of WRA 751 as a LBV. Images show that the nebula consists of a nearly spherical shell as well as a bipolar-like structure north and south of its main body, the Northern and Southern Caps.

In contrast to the almost spherical appearance of the main body of the nebula, the kinematics shows a deviation even of this part from a classical spherical expansion pattern. From the present data it can be concluded that the main body expands asymmetrically (central expansion velocity $\sim 26\,\mathrm{km\,s^{-1}}$), with a thicker shell at the back side. A bump-like structure can be found to the west of the central star. In addition to the main body, bipolar kinematic components can be identified with the morphologically classified Caps. These results put WRA 751 into the class of LBVs which are surrounded by a nebula with bipolar components, albeit considerably less pronounced than, for instance, in the classical bipolar LBVs $\eta$ Car and HR Car.

**Key words:** Stars: evolution – Stars: individual: WRA 751 – Stars: mass-loss – ISM: bubbles: jets and outflows

## 1. Introduction

With today's initial mass function, stars with masses of $M \sim 50-100\,\mathrm{M_\odot}$ and luminosities of $L \sim 10^{5-6}\,\mathrm{L_\odot}$ top the *Hertzsprung-Russell diagram* (HRD) and represent the most massive stars known. These massive stars show a remarkable evolutionary behavior (e.g., Schaller et al. 1992, Stothers & Chin 1996). After spending a 'normal' life as O stars on the main sequence they evolve towards cooler temperatures while entering a phase with very high mass loss (up to $10^{-4}\mathrm{M_\odot\,yr^{-1}}$), they become *Luminous Blue Variables* (LBVs). This phase starts when the stars reach the *Humphreys-Davidson limit* (Humphreys & Davidson 1979, 1994, Langer 1994) in the HRD. Analyzing HRDs of the Galaxy and the LMC, Humphreys (1978, 1979) and Humphreys & Davidson (1979) found a lack of very luminous red supergiants. Apperently the most massive stars do not evolve into red supergiants but instead their evolution is reversed towards the blue supergiant part in the HRD. The turning points form the empirical Humphreys-Davidson limit. Around this Humphreys-Davidson limit in the HRD LBVs are found. One of the most prominent characteristics of the unstable LBV phase are strong stellar winds and possible giant eruptions, which lead to the peeling off of parts of the stellar envelope and the formation of small circumstellar nebulae, the so-called *LBV nebulae* (LBVN, e.g. Nota et al. 1995).

Only very few LBVs are known in our Galaxy (8 classified and candidate objects) and a few in other galaxies, for instance in the LMC, SMC, M31, and M33 (Humphreys & Davidson 1994). Altogether nearly 40 LBVs and good candidates are currently known. Not all of them, but many show circumstellar nebulae. In this paper we analyze the LBVN around the galactic star WRA 751 and put it into context with the well known and better studied LBVs $\eta$ Carinae and HR Carinae.

WRA 751 (= He 3-591) was first identified as a possible Wolf-Rayet star by Henize (see Roberts 1962) and then appeared in the Carlson and Henize (1979) sample of southern peculiar emission-line stars, where the authors already recognized the strong [Fe II] lines and classified it as Bep. In addition they proposed a similarity between WRA 751 and HR Car (which in the meantime is known to be a LBV). Using spectroscopic and photometric observations Hu et al. (1990) noted for the first time that WRA 751 is a good LBV candidate. In addition to the characteristically strong [Fe II] lines this star shows an irregular light variation typical for LBVs. In their analysis the star was classified as O9.5 with $M_{\mathrm{bol}} = -9.6^{\mathrm{m}}$. They derived $T_{\mathrm{eff}} = 30\,000\,\mathrm{K}$, $E(\mathrm{B-V}) = 1.8$, $M = 50\,\mathrm{M_\odot}$, and a distance of about 5 kpc.

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One year later Hutsemékers & Van Drom (1991a) found that WRA 751 was surrounded by a nebula roughly 22″ in diameter. They found the nebula to be nearly spherically symmetric and to show a diffuse structure. Their low-dispersion spectra revealed a nebula of low excitation with an electron temperature of $T_{\rm e,neb} < 15\,000$ K, an electron density of $n_{\rm e} \sim 400\,{\rm cm}^{-3}$, and an expansion velocity of $v_{\rm exp} = 26\,{\rm km\,s}^{-1}$. Assuming a distance of 7 kpc (derived from radial velocities and making use of the galactic rotation curve) their radius of the nebula is 0.38 pc.

Analysis of infrared data (see de Winter 1992) show a NIR excess from which an estimate for the mass loss of $\dot{M} \sim 10^{-5.5...-6}\,M_{\odot}\,{\rm yr}^{-1}$ with a velocity of $v_{\rm wind} = 500\,{\rm km\,s}^{-1}$ were derived. They found a cool dusty circumstellar shell with strong emission in the FIR to surround WRA 751. In 1992, from interstellar and circumstellar reddening, van Genderen measured a distance of $4-5$ kpc for WRA 751 as a lower limit. García-Lario et al. (1998) re-determined the characteristic parameters and found $T_{\rm eff} \sim 25\,000$ K, $v_{\rm exp} = 24\,{\rm km\,s}^{-1}$, and $n_{\rm e} \sim 200\,{\rm cm}^{-3}$.

In summary, the published observations and their interpretations point towards WRA 751 being a LBV star with a slowly expanding nebula.

## 2. Observation and data reduction

### *2.1. Imaging*

To compare kinematics and morphology we used images of the nebula around WRA 751 taken with the *Super Seeing Imager* (SUSI) on the *New Technology Telescope* (NTT) of the *European Southern Observatory* (ESO). The images were retrieved from the ESO NTT archive and reduced in a standard way, using flat-fields and bias frames from the same observing night. Besides of the emission-line images in $H_\alpha$ and [N II] a broad band red continuum filter image was used for the continuum subtraction in order to be able to distinguish the pure line emission from the continuum[1]. Fig. 1 shows a 1050 s exposure $H_\alpha$ image (not continuum subtracted) with a round field of view, about 50″ in diameter. From the image, we determined the seeing as 0.″8. As the image was taken using a coronograph, an occulting bar obscures the central star and some parts of the nebula. A non-occulted image of the nebula can be found in Hutsemékers & van Drom (1991a).

### *2.2. Long-slit echelle spectroscopy*

To analyze the nebula around WRA 751 in more detail we preformed high-resolution long-slit echelle spectroscopy. We used the echelle spectrograph on the 4 m telescope at the *Cerro Tololo Inter-American Observatory*. Inserting a post-slit $H_\alpha$ filter (6563/75 Å) and replacing the cross-disperser by a flat mirror we selected the $H_\alpha$ line and two [N II] lines at 6548 Å and 6583 Å. We picked the $79\,{\rm l\,mm}^{-1}$ echelle grating and a slit-width of 150 $\mu$ (corresponding to 1″), which lead to an instrumental FWHM at the $H_\alpha$ line of about $10\,{\rm km\,s}^{-1}$.

[1] Due to missing documentation in the NTT archive and especially the lack of information in the header of the images a more detailed specification of the filters can not be given here.

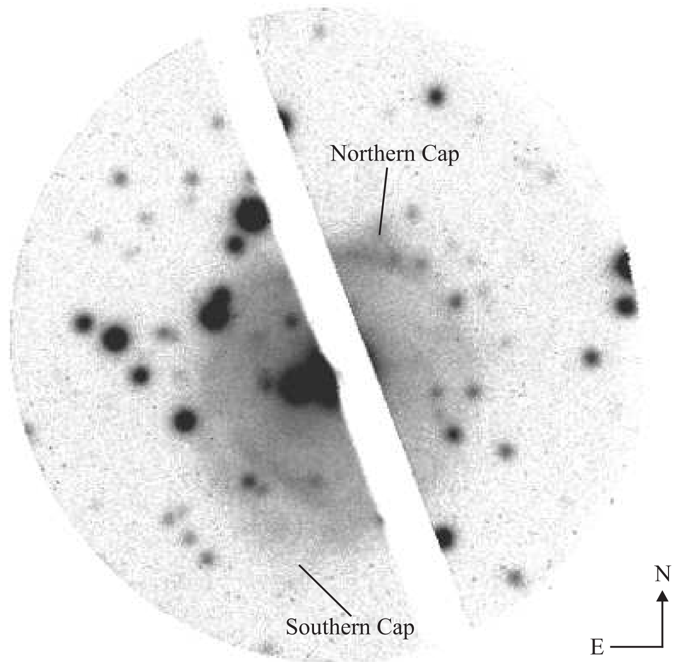


**Fig. 1.** ESO NTT archive image of the nebula around WRA 751, taken with SUSI using an $H_\alpha$ filter and a coronographic mask (see also Nota 1998). The diameter of the field of view is about 50″. The Northern and Southern Caps are indicated. A north-east vector marks the celestial orientation.

All data were recorded with the long focus red camera and a $2048 \times 2048$ Tek2 CCD.The pixel size was $0.08\,{\rm Å\,pixel}^{-1}$ along the dispersion and $0.\!''26\,{\rm pixel}^{-1}$ on the spatial axis. Vignetting limited the slit length to $\sim 4'$ . Seeing was $\sim 2''$ during the observations and the weather was not photometric. Thorium-Argon comparison lamp frames were taken for wavelength calibration and geometric distortion correction.

The slit was oriented in two different position angles (PA) perpendicular to each other (Fig. 2). We observed 5 positions with ${\rm PA} = 140°$. One position was centered on the star (in our nomenclature *Slit center*), two positions were offset to the north by 8″ and 12″ from the central star (*Slit 8N* and *Slit 12N*) and two positions were offset by 8″ and 16″ south of the central star (*Slit 8S* and *Slit 16S*). For ${\rm PA} = 50°$ we observed at two positions offset from the star by 9″ to the north and south, respectively (*Slit 9N* and *Slit 9S*). The left column of Fig. 3 shows the echellograms of the slits at ${\rm PA} = 140°$, Fig. 4 those at ${\rm PA} = 50°$. All echellograms cover a spectral range of 75 Å centered on $H_\alpha$ and extend about 2′ in the spatial direction, centered on the projected position of the central star. The top of each echellogram in Fig. 3 points to the north-west, and in Fig. 4 to the south-west. Some telluric lines are visible and were used to improve the absolute wavelength calibration.

## 3. Morphology of the nebula around WRA 751

The first image taken of the nebula around WRA 751 was published by Hutsemékers & van Drom (1991a). They discovered a spherical diffuse nebula about 22″ in size. We retrieved and re-analyzed [N II] and $H_\alpha$ images retrieved from the ESO NTT archive in order to compare the morphology and the kinematics of the nebula. Figure 1 shows that the nebula around WRA 751 indeed appears nearly round and almost spherically symmetric (see also Nota 1998). We measure a diameter of the main body of the nebula of 22.″8, which corresponds to 0.50 pc assuming the lower limit distance by van Genderen et al. (1992; $\sim 4.5$ kpc). Appearing rather homogeneous in its surface density and closely attached to the central star, it resembles very much a Stromgren sphere. However, this is in contrast to the morphological appearance of most other LBV nebulae like that of AG Car or HR Car (e.g. Hutsemékers & van Drom 1991b, Nota et al. 1995, Smith et al. 1997) which show a more intense detached ring structure, or as in the case of HR Car at least parts of a bipolar shell (Weis et al. 1997, Nota et al. 1997). This is mainly due to an increased matter density along the line of sight when looking through the edge of a shell.

A closer inspection of the images allows us to locate spatial variations in the surface density of the nebula around WRA 751: a brighter circular half-shell shows up in the eastern part, while—in comparison—in the western part the brightness decreases by about a factor of two. Even more remarkable are two extensions of the spherical shell, one nearly exactly to the north at a position angle of 340° which we will call the *Northern Cap* (Fig. 1) and the other to the south (*Southern Cap*) at $\mathrm{PA} = 165°$. This means that the Caps are almost along an axis through the star. Morphologically both appear roughly triangular in shape. The surface brightness of the Northern Cap is somewhat larger, that of the Southern Cap somewhat smaller than the low surface part (the west side) of the central spherical nebula. The Northern Cap extends by 2.″6 beyond the main body of the nebula, the Southern Cap by 4.″7.

## 4. Kinematic indication of a bipolar structure

Using high-resolution long-slit echelle spectra an analysis of the kinematics of the LBVN around WRA 751 was performed. With the 7 slit positions our mapping covers the entire nebula. The right columns of both, Figs. 3 and 4, show the position-velocity diagrams ($pv$-diagrams) corresponding to the echellograms in the same line. For the $pv$-diagrams we used the stronger [NII] line at 6583Å which is less contaminated by background emission. Additionally all measurements were compared to those of $H_\alpha$ to ensure that no kinematic difference exists between the two lines. All velocities were corrected to the *Local Standard of Rest* (LSR) system. The 0″ position in all $pv$-diagrams corresponds to the projected position of the central star (WRA 751) onto the slit, from there positive offsets are to the north-west for the $\mathrm{PA} = 140°$ slits (or south-west for $\mathrm{PA} = 50°$) and negative to the south-east (or north-east, respectively). All spectra (except Slit 16S) clearly resolve the

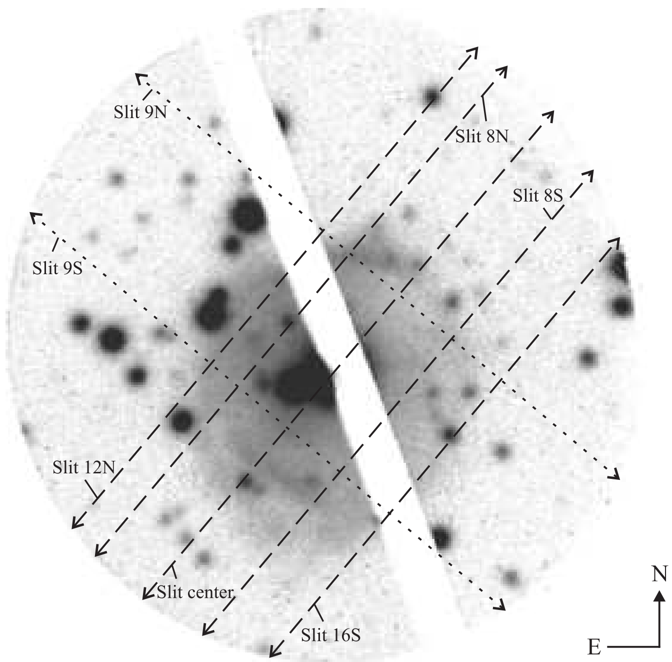


**Fig. 2.** Same image as in Fig. 1 with the slit positions overlayed: two slits (9N and 9S) are oriented at $\mathrm{PA} = 50°$, all others at $\mathrm{PA} = 140°$.

Doppler ellipse, and indicate a predominantly spherical expansion of the nebula. The largest radial expansion velocity $v_{\mathrm{exp}}$ was found in the central position (0″) of Slit 9S ($\mathrm{PA} = 50°$) with a value of 29.4 km s$^{-1}$± 2 km s$^{-1}$, the second largest in Slit 8N at 28.3 km s$^{-1}$± 2 km s$^{-1}$. A similar expansion velocity was derived at the same position in the central slit at 26.3 km s$^{-1}$± 2 km s$^{-1}$. Since this slit crosses the star in the center, the velocity measurements are less certain at the 0″ position. There $v_{\mathrm{exp}}$ might be even higher as can be estimated from interpolating for the missing data points in the $pv$-diagram of Fig. 3. If a nebula is spherically expanding, the largest expansion velocity should occur at the position projected onto the star. Even though this is not the case here, the difference of the expansion velocity between the central slit and the Slit 8N is not significant and within the errors.

However, a comparison with Slit 9S ($\mathrm{PA} = 50°$) shows an asymmetric shape of the expansion structure indicating that the nebula is most likely not perfectly round but perhaps a tilted ellipsoid with the maximum expansion off-centered to the east of WRA 751. There the largest expansion velocities are found. Another possibility is that the nebula is spherical with a bump at this point. This is best visible in the asymmetric shapes of the expansion ellipses in Slits 8N (Fig. 3) and Slit 9S ($\mathrm{PA} = 50°$; Fig. 4). While the largest negative velocity is found at the 0″ position, the largest positive velocity is located at $-2''$, i.e., the Doppler ellipse is asymmetric with respect to the projected position of the star. All derived global expansion velocities are in good agreement with expansion velocities found in the literature (Hutsemékers & van Drom 1991a, García-Lario et al. 1998).

In almost all spectra the redshifted line is more intense and broader than the blueshifted side. Since it is the redshifted component which is stronger, this brightness difference cannot be accounted by an absorption of the blueshifted component. It is either an intrinsic brightness difference or results from a thicker shell at the backside which leads to a higher emission measure. The FWHM of the redshifted wing of the expansion ellipse is resolved at $21\,\mathrm{km\,s^{-1}}$ (instrumental FWHM $\sim 10\,\mathrm{km\,s^{-1}}$) and supports the interpretation as a thicker shell. The widths itself is indicative of a stratification of the radial velocities along a line of sight, presumably with the inner parts of the nebula moving slower. A wider redshifted component can be explained as due to a thicker shell there.

Fig. 5 shows a composite $pv$-diagram of all slits with $\mathrm{PA} = 140°$. It shows the trend of the expansion velocities across the nebula:

– The split of the Doppler ellipse decreases as we move away from the geometric center of the bubble. The decrease, however, is not in agreement with a purely spherical expansion. While the redshifted part of the expansion ellipse decreases more like that of a spherical expansion, the blueshifted component stays nearly at a constant velocity for a given position along the slit.
– For a spherical expansion not only the width of the expansion ellipse in velocity space shrinks, but it also becomes narrower in spatial extent. In the WRA 751 nebula, however, we find that the convergence points at positive positions migrate to smaller values as one proceeds to slits farther away from the star while they are at approximately the same location for negative values.

Both points are in agreement with an asymmetry within the nebula and indicate deviations from a spherical expansion.

Besides the—asymmetric—expansion of the shell, the spectra show additional kinematic components. At slit position 8N the redshifted side converges with the blueshifted side in the north-west, at the position of about $10''$ as expected at this position for an expanding bubble. At the same point, however, a component which is more redshifted as the nebula appears, and extends to a position of $13''$. The redshift of this component increases to $32\,\mathrm{km\,s^{-1}}$above the central expansion velocity as one moves away from the nebula. In Fig. 3 a dashed line in the $pv$-diagrams for Slits 8N, center, and 8S indicates the rest velocity of the kinematic center of the expansion at $10\,\mathrm{km\,s^{-1}}$, $14\,\mathrm{km\,s^{-1}}$, and $12\,\mathrm{km\,s^{-1}}$, respectively.

A similar kinematic behavior can be found in Slits central and 8S, but this time at the south-eastern rim of the nebula. At about the position $-12''$ in both spectra an additional blueshifted component appears with maximum velocities of 12 and $18\,\mathrm{km\,s^{-1}}$ below the respective central expansion velocities. Again the velocities of these components reach their maximum at the location most distant from the star.

The position of the two kinematic extensions is very symmetric with respect to the central star and thus indicative of a bipolar kinematic structure. At Slit 8N material at the rim of the inner (nearly) spherical nebula moves away from us while

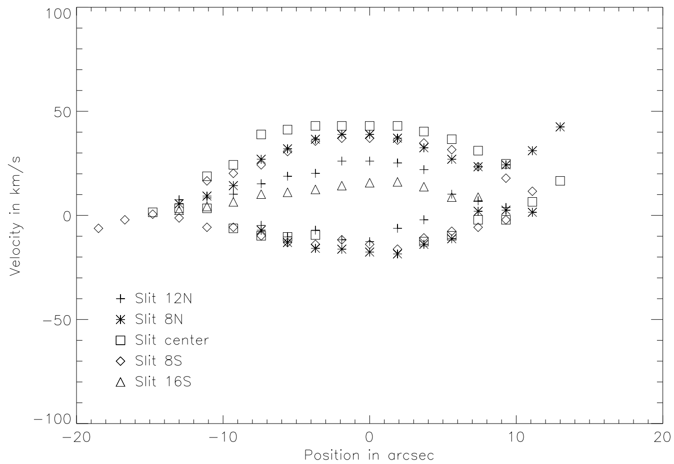


**Fig. 5.** Overlay of all position velocity diagrams at $\mathrm{PA} = 140°$.

in Slit 8S material at the corresponding positions, namely the edge of the nebula, approaches us. With respect to the center of expansion of the central spherically expanding nebula these kinematic components are bipolar.

The spatial distribution of the velocity field corresponds well to the morphology discussed above: The main part of the expansion (between the two convergence points of the expansion ellipse) measures $23''$ in diameter and thus agrees with the diameter of the main body of the nebula as determined from the image to be $22\overset{''}{.}8$. Moreover, it is noteworthy that the sizes of the kinematic extensions as measured from the spectra and of the Northern and Southern Caps as determined from the images agree equally well.

To ensure that the Caps are part of the nebula around WRA 751 and not just a background object onto which the nebula is projected, we have determined the line ratio [N II] 6583Å/$\mathrm{H}_\alpha$ after subtracting contributions of the telluric $\mathrm{H}_\alpha$ line. Within the accuracy of our measurements, the entire nebula, including both Caps, shows a constant value of [N II] 6583Å/$\mathrm{H}_\alpha = 1.2 \pm 0.1$, in contrast with the value for the background material of 0.3. The background line ratio is compatible with the value for a galactic H II region (Shaver et al. 1983). This difference ensures that we can disentangle source and background contributions.

## 5. Discussion and conclusions

A comparison of detailed kinematic data and the morphology of the LBVN around the galactic star WRA 751 indicates that the expansion is not as perfectly spherically symmetric as previously thought. The redshifted central part of the nebula expands nearly spherically while the blueshifted part appears stalled and moves at an almost constant radial velocity of about $-15\,\mathrm{km\,s^{-1}}$(Fig. 5). A natural reason may be that the front side of the nebula expands into a denser medium and that thus the expansion is decelerated. The maximum expansion velocity was found off-centered from the central star adding a further piece of evidence that the nebula is neither exactly spherical nor expanding accordingly. The off-centered maximum velocity is

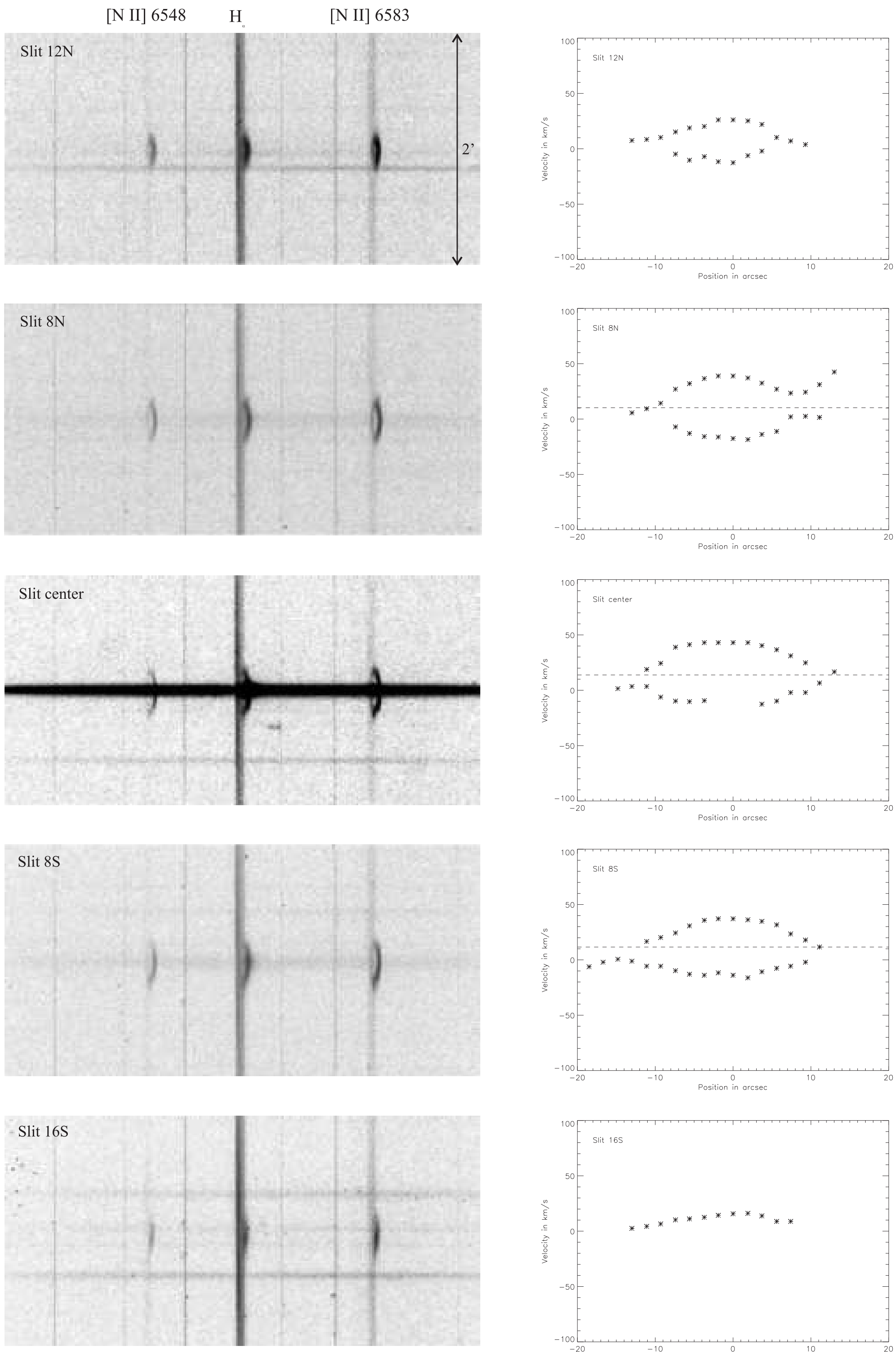


**Fig. 3.** Echellograms (left column) and corresponding position-velocity diagrams (right column) for the slits with $\mathrm{PA} = 140°$. The positions are centered on the projected location of the star, the velocities are with respect to the LSR. Dashed lines in the $pv$-diagrams mark the center of expansion velocities.

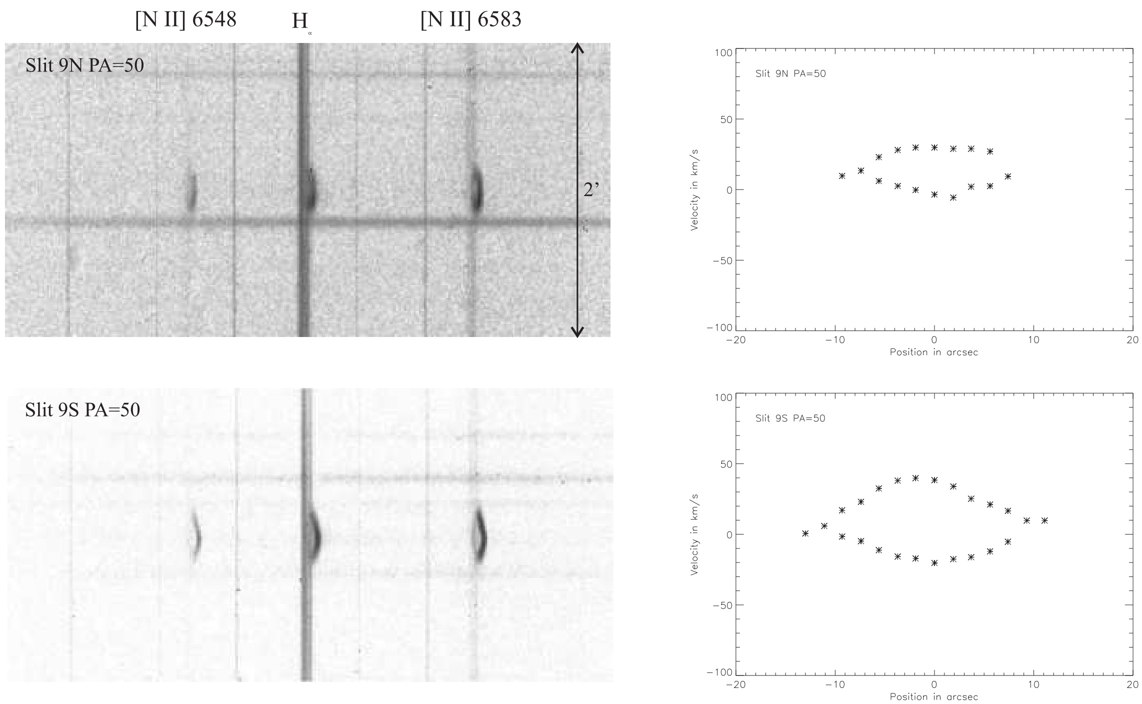


**Fig. 4.** Echellograms (left column) and corresponding position-velocity diagrams (right column) for the slits with $\mathrm{PA} = 50°$. The positions are centered on the projected location of the star, the velocities are with respect to the LSR.

either an evidence for an elongated (elliptical) shape and tilt or for a bump on the back side of the nebula.

Two kinematic extensions, one redshifted, one blueshifted appear attached to the ridge of the nebula. A comparison with the morphology of the nebula around WRA 751 allows to identify the redshifted extension (Slit 8N) with the Northern Cap and the blueshifted one (Slits center and 8S) with the Southern Cap (see Cap and Slit positions in Figs. 1 and 2). The Northern and the Southern Cap therefore indicate morphologically and kinematically bipolar components in the nebula around WRA 751. While one may speculate about a jet like structure or—similar to planetary nebulae (for a discussion of similarities between LBVs and planetary nebulae, see, e.g., Frank 1998)—wider funnels, or an altogether elliptical form of the nebula creating the bipolar appearance, due to the limited spatial resolutions of both the available kinematic data and the available images, higher resolution observations will be necessary to further constrain the structure of the nebula around WRA 751.

Nonetheless, from the data presented one can draw several conclusions:

- The LBVN around WRA 751 consists of an expanding shell of 23″ in diameter, with a thicker shell at the back side. The radial velocity distribution deviates from that of a simple spherical expansion pattern. We find bipolar contributions to the morphology as well as radial velocity distribution in approximately north-south direction (Northern and Southern Caps).
- The maximum expansion velocities are off-centered which most likely can be accounted for by a bump in the back side east of the central star.
- The [N II] 6583Å/$H_\alpha$ ratio is considerably larger than that of the background material. This is typical for CNO-processed material.

These three results are fully consistent with WRA 751 being a true member of the LBV class of stars. In many of the well investigated ones bipolar components to the morphological as well as kinematic structures of the nebula are found. $\eta$ Car (Duschl et al. 1995, Morse et al. 1998) and HR Car (Weis et al. 1997, Nota et al. 1997) are the most prominent examples. As stars in late phases of their evolution, LBVs quite naturally show CNO-processed material in their envelopes and ejecta (García-Segura et al. 1996, Smith et al. 1978). A large [N II] 6583Å/$H_\alpha$ ratio in a nebula is often used as one of the indicators for a star being a LBV. One finds, for instance, values of [N II] 6583Å/$H_\alpha = 3 \ \ldots \ 7$ for $\eta$ Car (Davidson et al. 1982, Meaburn et al. 1987, 1996, and Weis et al. 1999), $= 0.4 \ \ldots \ 0.9$ for HR Car (Hutsemékers & van Drom 1991b, and Weis et al. 1997), and $= 0.7$ for AG Car (Thackeray 1977 and Smith et al. 1997).

Combining our morphological, kinematic and spectroscopic results, we find mounting evidence that WRA 751 is a LBV, indeed. Moreover, there are bipolar components in its nebula, notably the two Caps. While the bipolarity in this object is less pronounced and less obvious than in other LBVs, it still strengthens our suspicion that bipolarity—albeit at different levels—is a genuine property of LBV nebulae. This makes it even more likely that modeling LBVNs as simple windblown spheres is an unjustified oversimplification.

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## References

Carlson E.D., Henize K.G., 1979, Vistas in Astron. 23, 213
Davidson K., Walborn N.R., Gull T.R., 1982, ApJ 254, L51
Duschl W.J., Hofmann K.-H., Rigaut F., Weigelt G., 1995, RevMexAA SdC 2, 17
Frank A., 1999, NewAstron. Reviews, 43, 31
García-Lario P., Riera A., Manchado A., 1998, A&A 334, 1007
García-Segura G., Mac Low M.-M., Langer N., 1996, A&A 305, 229
van Genderen A.M., Thé P.S., de Winter D., et al., 1992, A&A 258, 316
Hu J.Y., de Winter D., Thé P.S., Pérez M.R., 1990, A&A 227, L17
Hutsemékers D., Van Drom E., 1991a, A&A 251, 620
Hutsemékers D., Van Drom E., 1991b, A&A 248, 141
Humphreys R.M., 1978, ApJS 38, 309
Humphreys R.M., 1979, ApJS 39, 389
Humphreys R.M., Davidson K., 1979, ApJ 232, 409
Humphreys R.M., Davidson K., 1994, PASP 106, 1025
Langer N., Hamann W.-R., Lennon M., Najarro F., Pauldrach A.W.A., Puls J., 1994, A&A 290, 819
Meaburn J., Wolstencroft R.D., Walsh J.R., 1987, A&A 181, 333
Meaburn J., Boumis P., Walsh J.R. et al., 1996, MNRAS 282, 1313
Morse J.A., Davidson K., Bally J. et al., 1998, AJ 116, 2443
Nota A., 1998, IAU-Coll. 169, 62
Nota A., Livio M., Clampin M., 1995, ApJ 448, 788
Nota A., Smith L., Pasquali A., Clampin M., Stroud M., 1997, ApJ 486, 338
Roberts M.S., 1962, AJ 67, 79
Schaller G., Schaerer D., Meynet G., Maeder A., 1992, A&AS 96, 269
Shaver P.A., McGee R.X., Newton L.M., Danks A.C., Pottasch S.R., 1983, MNRAS 204, 53
Smith L.J., Nota A., Pasquali A., Leitherer C., Clampin M., Crowther P.A., 1998, ApJ 503, 278
Smith L.J., Stroud M.P., Esteban C., Vílchez J.M., 1997, MNRAS
Stothers R.B., Chin C.-W., 1996, ApJ 468, 842
Thackeray A.D., 1977, MNRAS, 180, 95
Weis K., Duschl W.J., Bomans D.J., Chu Y.-H., Joner M.D., 1997, A&A 320, 568
Weis K., Duschl W.J., Chu Y.-H., 1999, A&A, 349, 467
de Winter D., Pérez M.R., Hu J.Y., Thé P.S., 1992, A&A 257, 632