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A spectroscopic analysis of the Luminous Blue Variable candidate WRA 751*

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Abstract. We present spectroscopic observations of the LBV candidate WRA 751 taken at different epochs during the period 1989−1995. These observations are used to monitor the temporal evolution of the spectrum over the last few years. In addition, we identify most of the emission and absorption features in the spectral range 4100−9250 Å and obtain a new determination of the extinction towards this source of E(B−V) = 1.5 based on the relative intensities of the [Ni II] lines.

Our data suggest that the star is an evolved LBV star now in a relative quiescent state. No significant changes are found over the years in the emission line spectrum, although the continuum brightness seems to be globally fading. A high density and dusty circumstellar core is found to be surrounded by a low density nebula characterized by a significant [N/O] overabundance ($\sim 3\pm^{3.0}_{1.5}$). Using the photoionization-shock code MAPPINGS we estimate an effective temperature for the central star of T_{eff} = 25000 K. Most of the spectral features observed in the core, like the strong [Ni II] emission and the permitted emission lines of O, Fe, Si and Mg appear to be originated by continuum fluorescence.

The complex profile observed in Hα is explained as the result of a strong density discontinuity in the shell which might have been originated as a consequence of a recent episode of enhanced mass loss. From the observed profile we estimate a terminal velocity of the wind of ~ 175 km s^{-1}, typical of LBVs.

If we assume the previously reported distance of 4−5 kpc, from the apparent size of the nebular emission (22") and the expansion velocity deduced from the double-peaked [N II] lines (24 km s^{-1}) the kinematic age of the nebula is found to be ∼10,000 years, consistent with the predicted LBV lifetimes.

Key words: stars: supergiants – stars: emission line, Be – stars: mass loss – stars: individual: WRA 751

1. Introduction

Luminous Blue Variables (LBVs, hereafter) are evolved massive supergiant stars characterized by their enormous luminosities ($M_{bol} \leq -8$) and strong instability. Humphreys & Davidson (1994) described them as *astrophysical geysers*, since they undergo sporadic violent eruptions of variable duration and intensity whose origin is not yet well understood followed by long periods of relative quiescence when only small luminosity fluctuations are detected and which can usually be described by quasiperiods of a month or longer. Their spectra show H I, He I, Fe II and [Fe II] emission lines and variable P-cygni profiles in some of the permitted emission lines.

Although LBVs are extremely bright objects, their galactic population is very small and, thus, only a few galactic candidates are known. Classical LBVs are associated to large luminosities ($L \geq 10^6\ L_\odot$) and masses greater than 50 $M_\odot$, like P-Cygni or η Carinae. These two specific cases are very well known because they experienced giant eruptions in the recent past leading to a temporary increase of several magnitudes in their bolometric luminosity. A few, more recently discovered, show lower luminosities ($L \leq 10^6\ L_\odot$) and more modest eruptions in which the total luminosity remains constant while the star's photosphere expands and the apparent temperature decreases. It has been suggested that low luminosity LBVs, with $M_{bol} \approx -8$ to -9 might be the result of the evolution of red supergiants in their way to become Wolf-Rayet (WR, hereafter) stars.

WRA 751 (= IRAS 11065−6026 = Hen 3−591) was first identified as one of the members of this ultraluminous family by Hu et al. (1990) because of its suspected high luminosity, the photometric variability and the ultraviolet and optical spectra, which resemble those of the LBV star AG Car in its quiescent state (Hu et al. 1990; de Winter et al. 1992). However, some authors considered in the past that WRA 751 might be a massive post-AGB star in the short transition phase which precedes the formation of a PN, and not an LBV (Parthasarathy & Pottasch 1989; Riera et al. 1995). This was based on the fact that the far infrared IRAS colours of WRA 751 are identical to those usually observed in post-AGB stars and proto-planetary neb-

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* Based on observations collected at the European Southern Observatory (La Silla, Chile)

Table 1. Optical spectroscopy of WRA 751: log-in of the observations

Telescope	Date	Spectral Range	Resolution	Comments
1.52m ESO	February 1989	4270–6810 Å	2.5 Å/pix	
1.52m ESO	February 1990	4040–6940 Å	2.8 Å/pix	
1.4m CAT	February 1990	6530–6600 Å	0.05 Å/pix	
1.52m ESO	March 1993	3300-11000 Å	3.8 Å/pix	
1.52m ESO	February 1995	3500–11200 Å	3.8 Å/pix	p.a.= 282°

ula (Parthasarathy & Pottasch 1989). In addition, Hutsemékers and Van Drom (1991a, hereafter HVD) detected the presence of an extended nebular component with kinematic properties resembling those of planetary nebulae (PNe, hereafter).

The rich emission line spectrum has previously been studied in some aspects by several authors (Hu et al. 1990; de Winter et al. 1992), who also provide estimations of the distance and extinction towards WRA 751 from several independent methods, leading to values ranging from 4 to 5 kpc and E(B−V) = 1.4 − 2.1, which imply luminosities well beyond those expected for a PN.

In this paper we further discuss the evolutionary stage of this star and present additional low and high resolution optical spectroscopy, which is used to identify most of the emission lines detected and monitor the evolution of the optical spectrum in the period 1989−1995. In addition, we study the excitation mechanisms responsible for some of the emission lines observed in the spectrum of the core and obtain new determinations of the extinction and the effective temperature of the central star, as well as an estimate of the [N/O] ratio in the envelope.

2. Observations and data reduction

Low resolution optical spectra were taken at the 1.52m ESO telescope (La Silla, Chile) using a Boller & Chivens Spectrograph at several epochs during the period 1989−1995. In addition, a single high resolution spectrum centered around Hα was taken at the the 1.4m CAT telescope using the Coudé Echelle Spectrograph in February 1990 at the same observatory. The journal of these observations is given in Table 1. The position angle of 282 degrees chosen in February 1995 was intented to study the nature of an apparent knot of emission within the nebula which turned out to be a field star.

CCD images in the light of Hα and [N II] λ6584 Å (not shown in this Paper) were taken at the ESO 3.60m telescope using EFOSC, where a round extended nebular component is clearly visible with an extension of 9”. A deeper Hα image obtained by HVD shows a more extended roughly circular emission with a diameter of 22”.

In all cases, the CCD images were reduced using standard IRAF routines. The data reduction process includes bias and flat-field corrections, as well as wavelength calibration and sky subtraction for the spectroscopic observations. Absolute flux calibration was performed only for the low resolution spectra.

3. Analysis of the optical spectra

The low dispersion spectrum of WRA 751 (Fig. 1) is dominated by the emission from the central core and it is characterized by the presence of strong Balmer emission overimposed on a reddened early-type stellar continuum together with permitted emission lines of O I, Si II, Mg II and Fe II, unusually strong forbidden [Ni II] (2F) emission and many forbidden emission lines of [Fe II] corresponding to different multiplet transitions. In addition, strong diffuse interstellar bands (DIBs) are detected, suggesting a high interstellar extinction, together with a faint and slightly extended nebular component with low excitation characteristics. The extracted nebular emission between 6000 and 7000 Å is presented in Fig. 2, while in Fig. 3 we show the global (core + nebula) high dispersion spectrum between 6530 and 6600 Å. The high resolution spectrum is dominated by a strong Hα emission with a very complex P-Cygni profile, probably originated in the dense wind very close to the central star. In the same figure, faint double-peaked nebular [NII] $\lambda\lambda$ 6548, 6584 Å emission lines are also observed, confirming the presence of a low density expanding shell.

The complete list of features identified in the spectrum of WRA 751 in the range 4100−9250 Å is given in Table 2 together with their individual fluxes relative to Hβ. Typical associated errors are estimated to be around 20%.

3.1. Extinction

The measurement of the extinction in WRA 751 from the Balmer decrement in the core is not possible because the Balmer lines are strongly affected by the presence of strong P-Cygni profiles and also because self-absorption effects can be important in high density regions. HVD tried to derive the extinction from the observed Hα / Hβ nebular ratio, but Hβ was detected in the nebula with a very low S/N ratio, as it is also the case in our spectra. They estimated a reddening of E(B-V)= 2.1.

A similar extinction of E(B−V) = 1.8 was derived by Hu et al. (1990) from the comparison of the energy distribution predicted by a model atmosphere analysis with the observed data. The best fit they obtained assumes that the central star has an

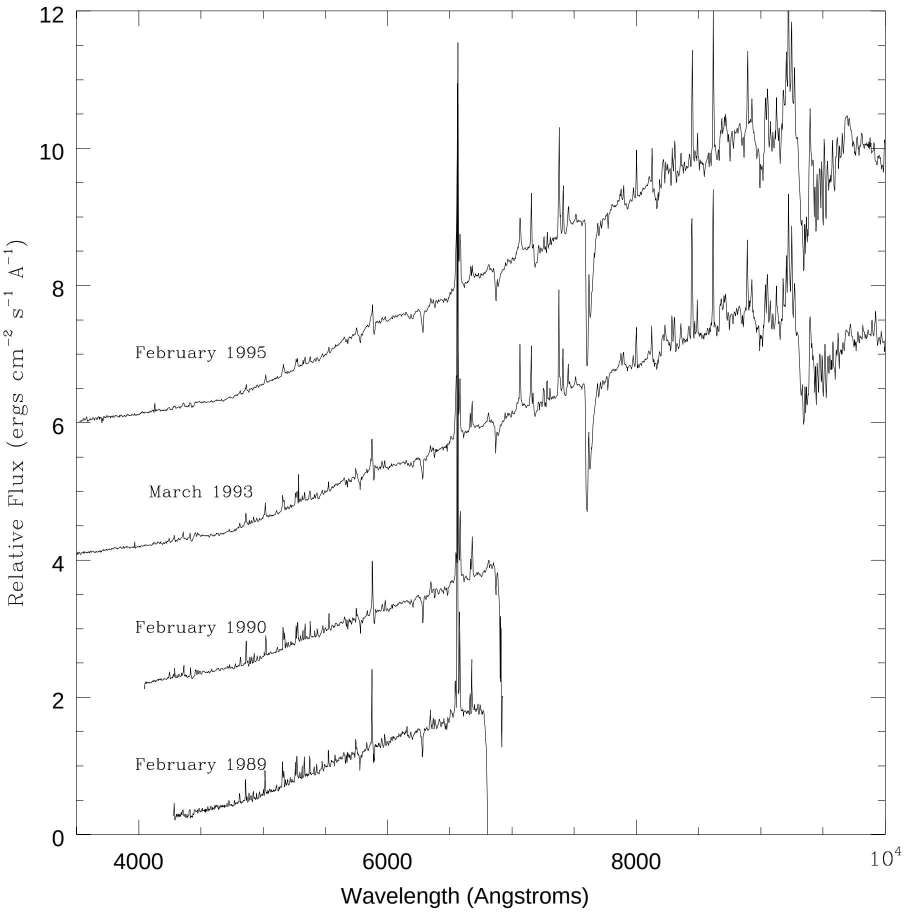

Fig. 1. Low resolution optical spectra of WRA 751 taken at the 1.52m ESO telescope in January 1989, February 1990, March 1993 and February 1995.

effective temperature T_{eff} = 30000 K and it is located at a distance D $\sim$ 5 kpc. An additional determination of the extinction is provided by van Genderen et al. (1992), who derived a value in the range 1.45−1.80 from VBLUW photometry of nearby field stars, applying the reddening-distance method which, at the same time, also provides a very similar estimation of the distance of 4−5 kpc.

We have computed the extinction using an alternative independent method based on the measurement of the [Ni II] (2F) (a^2D–a^2F) $\lambda\lambda$6667,7412 Å emission lines. Since both lines have a common upper level ($a^2F_{5/2}$), their ratio should be equal to the ratio of their A-values (which is 1.77). From the observed λ7412 Å / λ6667 Å ratio and assuming the standard interstellar extinction curve (Savage & Mathis 1979; Whittet 1992) we derive E(B−V) = 1.5.

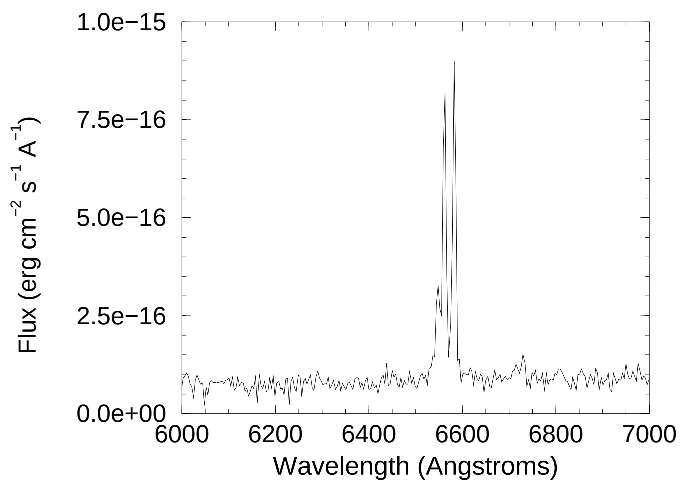

Fig. 2. Low resolution optical spectra of WRA 751 where the faint nebular component has been extracted

3.2. H I and He I emission lines variability

The observed Hβ fluxes and the HeI intensity ratios (relative to Hβ) taken during the years 1989, 1990, 1993 and 1995 are listed in Table 2. Comparison of the results obtained at these four epochs reveals that the He I and H I Balmer emission line intensities have apparently decreased from 1989 to 1995, although this effect might partially be an artifact produced by the different spectral resolution. In particular, the absolute Hβ flux decreased by a factor of 5 from 1990 to 1995, but flux calibration should always be considered uncertain when interpreting long slit spectroscopic data, since the amount of flux reaching the detector strongly depends on the seeing conditions. However, according to photometric measurements in the V band taken during the last decade (Hu et al. 1990) WRA 751 seems to be really fading, as it was observed $\sim$1.0−1.5 magnitudes brighter in the V band in 1980 than it was in 1989. The same conclusion is reached through the analysis of the near infrared emission, ∼0.5 magnitudes brighter in the K band when first observed by Hu et al. in 1984, compared to the more recent observations carried out by García-Lario et al. in 1989 and by Hu et al. in 1990, although with no significant colour changes (Hu et al. 1990; García-Lario et al. 1997).

The He I lines at λ5876, λ6678 and λ7065 Å (the latter only detected in the spectra taken in 1993 and 1995 because of the wider spectral coverage) have also apparently decreased in strength over the last few years. Unfortunately, with our low resolution, the Na ID $\lambda\lambda$5889,5895 Å absorption partially overlaps the He I λ5876 Å emission line and the decrease in intensity is not so clearly observed in this line. The effect is more evident in the He I λ6678 Å line, specially when comparing the strength of this line with the nearby [Ni II] λ6668 Å emission line (see Fig. 1). The He I λ6678 Å /[Ni II]λ6667 Å ratio declined from 2.6±0.1 in 1989 to a value of only 0.85±0.08 in 1995.

Since the H I and He I emission lines are formed in the high density wind, as suggested by the detection of strong P-Cygni profiles at Hα (Fig. 3) and HeI λ 4471 Å (Wolf, private communication), the apparent decrease in strength observed in these lines can simply be due to variations in the P-Cygni profiles as a consequence of the variable stellar wind.

The Hα emission profile (see Fig. 3) shows a primary component very broad and strong with a blue edge from which we deduce, taking as a reference the systemic velocity derived from the [N II] nebular emission (see Sect. 3.4), a terminal velocity of the stellar wind of $v_\infty \sim -175$ km s^{-1}. The center of the much narrower and weaker secondary absorption is blueshifted only -49 km s^{-1} with respect to the same reference, with a blue edge at -67 km s^{-1}. This complex profile can be explained by the presence of a density discontinuity in the shell, which would be an indirect evidence of a recent abrupt enhancement of the mass loss, as one would expect during an LBV eruption, with the subsequent formation of a double expanding shell. A similar profile has been observed in the LBV candidate HR Car, for which a multiple shell expansion model has also been suggested to explain the observations (Hutsemékers & van Drom 1991b).

3.3. Fluorescence excited emission lines

The O I, Fe II, Si II, Mg II and [Ni II] lines arising from the core have all them the commom property that their upper levels either are directly pumped by absorption of UV stellar photons or fed by downward transitions. They are probably fluorescence excited and formed in high density regions of the envelope ($n_e \geq 10^6$ cm^{-3}), very close to the central star. The same fluorescence mechanism has previously been proposed to explain the rich Fe^+ spectrum, which consists of both permitted and forbidden emission lines, by de Winter et al. (1992).

As an example, the remarkable strength of the O I λ8446 Å emission arising from the core of WRA 751 cannot be explained in terms of pure recombination since we do not detect the O I λ7773 Å quintet which, if this were the case, should be stronger than the emission observed at λ 8446 Å. Other mechanisms proposed for the formation of this line are: direct excitation by radiation coming from the central star (starlight or continuum fluorescence) and Lyβ fluorescence. In the Lyβ fluorescence mechanism (Grandi 1975), upper O I levels are excited because of a coincidence in the wavelengths of the H I Lyβ λ1025.72 Å and the O I λ1025.76 Å transitions. The subsequent cascade emits at λ11287, λ8446 and λ1302 Å. On the other hand, if the origin of the emission is continuum fluorescence, additional emission lines at λ7002, λ7254, and λ13164 Å would appear. The expected ratios of these lines to λ8446 Å depend on the assumed form of the exciting stellar continuum.

In the spectra available, no emission at λ7002 Å is detected but a faint emission line is found at λ7254 Å which could be identified either as O I or [Ni II] (7F). Assuming that the whole emission line is due to the O I transition, we obtain an O I λ7254 / λ8446 ratio of $\sim$ 0.22 which is consistent with the continuum fluorescence mechanism, but not enough to rule out the possibility of a partial contribution from Lyβ fluorescence.

Strong [Ni II] (2F) λ6667, λ7378 and λ7412 Å and weaker (8F) λ6365, λ6813 Å and (7F) λ7256, λ7308 Å transitions are also detected in the spectrum of the core. In the past, anomalous high [Ni II] emission was interpreted as a genuine Ni–enrichment. Recently, however, Lucy (1995) has shown that the strong [Ni II] emission lines observed in a wide variety of astronomical objects can also be explained by fluorescence. The starlight fluorescence excitation mechanism predicts the enhancement of these lines and peculiar relative intensities. In particular, the models predict the increase of the [Ni II] λ7412 Å / λ7378 Å ratio, which is only 1/11.0 when the emission is collisionally excited. P–Cygni, for instance, also recognized as a strong [Ni II] emitter, shows a [Ni II] λ7412 Å / λ7378 Å ratio of 1/3.7 (Johnson et al. 1992). In the case of WRA 751, the observed [Ni II] λ7412 Å / λ7378 Å ratio is 1/2.0, which suggests that starlight fluorescence may be responsible for the emission. This was confirmed through detailed calculations provided by Lucy (private communication), making use of his transfer code. As a first approach, the emergent flux of the star was assumed to be a blackbody with a luminosity of 10^6 $L_\odot$ and a grid of temperatures ranging from 20000 K to 35000 K were considered. The nebula was characterized by a dilution factor $\sim 10^{-11}$, an electron density of 200 cm^{-3} (see below) and, for the unknown electron temperature, a value of 8000 K was assumed. Under the above assumptions the predicted 7412:7378:6667 ratios are 1.00:3.23:0.58, with only 4% variations when increasing the blackbody temperature from 20000 K to 35000 K. The computed [Ni II] λ7412 Å / λ7378 Å ratio is similar to the one derived from our spectra, but still somewhat lower. A lower luminosity of the central star would favour a higher ratio. Alternatively, dust grains present in the circumstellar shell can absorb the stellar photons and produce a similar effect. We estimate that a visual extinction in the region between the star and the Ni^+ emitting region of $\sim$ 1.5 to 2.0 mag would be enough to increase the [Ni II] λ7412 Å / λ7378 Å ratio up to 1.00/2.38, quite consistent within the errors with our observations.

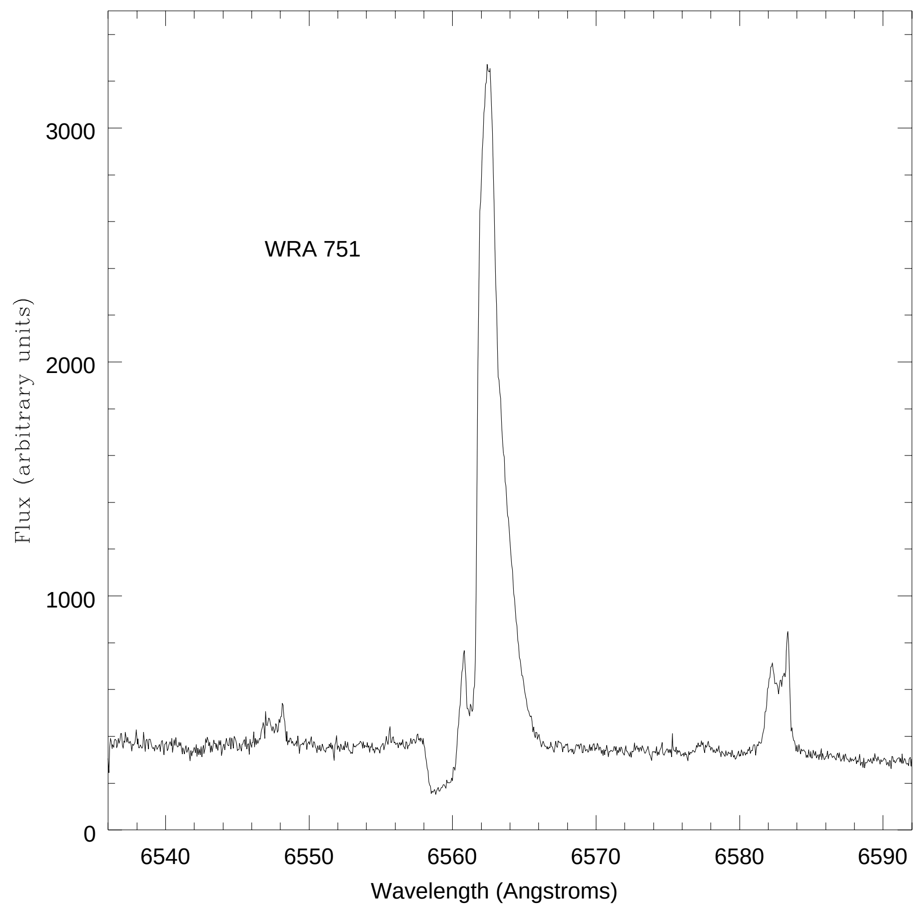

Fig. 3. High resolution spectrum of WRA 751 centered around Hα taken at the 1.4m CAT telescope in February 1990.

3.4. The low-density nebula

The faint nebular spectrum of WRA 751 extends over 9" and shows very low excitation characteristics, with strong [N II] emission at $\lambda\lambda$6548,6584 Å, a fainter Hα and the [S II] doublet at $\lambda\lambda$6717,6731 Å as the only emission features, as we can see in Fig. 2. From the observed [S II] λ6717 / λ6731 line ratio of 1.2$\pm$0.2, we derive an electron density of 200 cm^{-3}, somewhat lower than the value of 400 cm^{-3} quoted by HVD.

Using the photoionization-shock code MAPPINGS it is possible to estimate the effective temperature of the central star as well as the abundance ratios in the nebula surrounding WRA 751. The results derived in this way, however, should be carefully taken, since many unknown observational parameters are involved in our calculations.

Different tests were performed with the last version of this code, which includes the effect of dust on the ionized structure and on the thermal balance as well as the effect of dust scattering (Binette et al. 1993, and references therein). Dust plays an important role in the thermal balance since the heating by photoelectric emission from the dust is significant. In the photoionization code MAPPINGS, the dust content is scaled by the dimensionless parameter μ. We have adopted μ = 1.0, which corresponds to a dust-to-gas mass ratio of 6.4 10^{-3}. This value agrees with previous estimations by Hutsemékers (1994) of the dust mass in the nebula around WRA 751.

In our models we also assumed, as a first approach, a blackbody with a luminosity of 10^{6} L$_{\odot}$ as the ionizing source, a spherical symmetry for the nebula with a sharp inner radius, a constant density n$_H$ = 250 cm^{-3} and a filling factor of the unity. The best fit obtained corresponds to a central star temperature of 25000$\pm$5000 K.

Concerning abundances, we assumed [O/H] abundances of 1.0 10^{-4} and 1.5 10^{-4} for our models 1 and 2 respectively (see Tables 4 and 5), typical of nebulae around LBV (like AG Car and η Car) and galactic WR-ring nebulae. These values are consistent with the non-detection of [O I] emission at $\lambda\lambda$6300, 6363 Å and [O II] emission at λ3727 Å, from which we obtain an upper limit for the [O/H] abundance of 2 10^{-4}.

Both the theoretical and the observed dereddened emission line ratios of WRA 751 are listed in Table 3, together with the values observed in the WR ring nebula M1-67 (from Esteban et al. 1991) for comparison. If we accept that the oxygen abundance is in the range above cited, which seems a reasonable assumption, the observed [NII] / Hα ratio cannot be satisfactorily reproduced unless nitrogen is overabundant, while sulphur lines are found to be consistent with a solar abundance. Depending on the adopted [O/H] value we derive a [N/O] ratio $\sim 3\pm^{3.0}_{1.5}$.

Nitrogen enhancement and oxygen depletion, together with helium overabundance, are usually observed in other LBVs and in some WR ring nebulae, confirming their possible evolution-

Table 2. Line identifications in WRA 751 and relative intensities refered to Hβ = 100

λ_{obs}(Å)	Identification	1989	1990	1993	1995
4108	Hδ 4101	-	29	-	-
4175	[Fe II] (21F) 4177.2	-	9	10	-
4243	[Fe II] (21F) 4244.0,4244.8	-	31	45	37
4286	[Fe II] (7F) 4287.4	37	34	67	42
4318	[Fe II] (21F) 4319.6	-	9	11	-
4344	Hγ 4340, [FeII] (21F) 4346.8	22	15	15	-
4356	[Fe II] (7F) 4358.4,(21F) 4359.3, Fe II (27) 4352.8	43	49	84	59
4413	[Fe II] (6F) 4416.3, (7F) 4413.8	50	49	42	44
4470	He I 4471, [Fe II] (7F) 4475, (21F) 4474.9	-	17	27	ov.
4492	[Fe II] (6F) 4488.8	26	29	27	ov.
4585	Fe II (38) 4583.8	23	19	26	26
4716	[Fe II] (5F), He I 4713.2	10	9	-	13
4731	[Fe II] (3F) 4729.8, (4F) 4728.1	30	21	22	23
4777	[Fe II] (20F) 4774.7	17	17	20	-
4812	[Fe II] (20F) 4814.5	41	41	39	50
4861	Hβ 4861	100	100	100	100
4888	[Fe II] (4F) 4889.6, (3F) 4889.7	30	25	21	43
4903	[Fe II] (20F) 4905.4	23	22	17	43
4923	Fe II (42) 4923.9	26	33	26	-
4948	[Fe II] (20F) 4950.7	24	26	24	41
4970	[Fe II] (20F) 4973.4	27	18	16	-
5002+5020	[Fe II] (20F) 5005.5,5020.5, Fe II (42) 5018.4	23+103	14+110	21+104	129
5107	[Fe II] (18F) 5108.0, (19F) 5111.6	28	29	35	-
5158+5167	[Fe II] (18F) 5158.0, (19F) 5158.8, (35F) 5163.9, Fe II (42) 5169	116+82	108+85	100+56	194
5180	[Fe II] (18F) 5182.0	26	23	-	-
5196	Fe II (49) 5197.6	28	19	24	-
5217	[Fe II] (19F) 5220.1	21	14	21	-
5260	[Fe II] (18F) 5268.9, (19F) 5261.6	67	74	91	106
5272	Fe II (49) 5276.0, [Fe II] (18F) 5273.4	123	109	131	100
5294	[Fe II] (19F) 5296.8	23	20	-	-
5314	Fe II (49) 5316.6	42	45	24	34
5332	[Fe II] (19F) 5333.6	74	71	57	72
5374	[Fe II] (19F) 5376.5	75	73	73	71
5412	[Fe II] (16F) 5412.6	28	27	25	34
5431	[Fe II] (18F) 5433.0	35	49	39	50
5475	[Fe II] (34F) 5477.2	43	43	52	70

ary connection. Large [N/O] ratios have also been found, for instance, in LBVs like AG Car, ηCar and HR Car. The computed [N/O] ratio for AG Car varies from 2 to 7 (values provided by Mitra & Dufour 1990; and by de Freitas Pacheco et al. 1992, respectively), the most recent determination being 5.7±2.0 (Smith et al. 1997). A huge [N/O] abundance ratio has also been quoted for η Car, with a lower limit of 16 (Davidson et al. 1986) while for HR Car, Hutsemékers & Van Drom (1991b) estimated a lower limit of 0.4. Among the WR ring nebulae, M 1–67, NGC 6888 and S 308 show the highest [N/O], with similar values in the range 1.4 to 3.0 (Esteban et al. 1992).

The expansion velocity of the nebula surrounding the central star of WRA 751 can easily be derived from the double-peaked emission observed in the [N II] $\lambda\lambda$6548,6584 Å lines, as well as the systemic velocity, which is derived from the center wavelength of this emission. Our estimation of v_{exp} = 24±2 km s^{-1} is in agreement with the value reported by HDV. Similar expansion velocities (20 $-$ 30 km s^{-1}) have been reported for other LBVs, like R 127, S 119 and HD 168625 (= SAO 161375), while Hen 3$-$519, HR Car and AG Car show larger expansion velocities, from 60 to 70 km s^{-1} (Nota et al. 1995).

On the other hand, the systemic LSR velocity is found to be v_{LSR} = $-$24±2 km s^{-1}, from which we cannot derive a kinematic distance for WRA 751, since this value is not compatible with the galactic rotation curve. However, as already cited, different authors have previously determined the distance to WRA 751 using several independent methods and they all conclude that the distance must be somewhere in the range from 4 to 5 kpc, with the exception of the value reported by HDV of 7 kpc, based on a probably wrong radial velocity determination.

Table 2. (continued)

λ_{obs}(Å)	Identification	1989	1990	1993	1995
5526	[Fe II] (17F) 5527.3,(34F) 5527.6	57	71	58	83
5745+5753	[Fe II] (34F) 5747.0, [N II] 5754.8	90:	59+27	102:	107:
5876	He I 5875.7 + NaID absorption	309:	288:	279:	333:
5956	Si II (4) 5957.6	70	50	58	79
5977	Si II (4) 5978.9	70	57	65	73
6346	Si II (2) 6347.0	120	78	68	94
6368	[NiII] (8F) 6365, Si II (2) 6371.2	19+38:	45:	35+33:	70:
6562	Hα 6562.8	2553	2671	2701	2666
6668	[Ni II] (2F) 6668.2	86	107	116	136
6678	He I 6678.1	221	217	177	115
6813	[Ni II] (8F) 6813.7		60	82	75
7065	He I 7065.3			442	371
7154	[Fe II] (14F) 7155.1			398	517
7255	O I (20) 7254.0, [Ni II] (7F) 7256.2			117	129
7281	[Fe II] (30F) 7281.7, He I 7281.0			125	128
7308	[Ni II] (7F) 7307.8			52	84
7378+ 7388	[Ni II] (2F) 7379.6 + [Fe II] (14F) 7388.2			769+96	1009+146
7412	[Ni II] (2F) 7413.3			313	477
7452	[Fe II] (14F) 7452.5			160	185
7875	Mg II (4d^{2}D-4p^{2}P^o) 7877			141	132
7896	Mg II (4d^{2}D-4p^{2}P^o) 7896.4			108	136
8000	[Fe II] (1F) 7999.5, [CrII] (1F) 8000.2			271	419
8124	MgII (6p^{2}P° - 4d^{2}D) 8115, 8120, [Cr II] (1F)			265	309
8214	MgII (5s^{2}S - 4p^{2}P°) 8214			510	720
8234	MgII (5s^{2}S - 4p^{2}P°) 8234			229	240
8287	Fe II (5p^{6}F - e^{6}D) 8287.6, 8287.9			279	317
8306	[Ni II] (2F) 8303.6			442	625
8358	[Cr II] (1F) 8357.8, Fe II 8357.2			250	267
8421	Fe II(5p^{6}F - e^{6}D) 8423.9			124	173
8446	O I (4) 8446			1068	1046
8617	[Fe II] (13F) 8617.0			1106	1346
8893	[Fe II] (13F) 8891.9			614	867
9222	H I Pa9, Mg II (4p^{2}P^o-4s^{2}S) 9217			886	1517
9248	Mg II (4p^{2}P^o-4s^{2}S) 9244.3			617	830

Notes:
1989: F(Hβ) = (7.70±0.25) 10^{-14}
1990: F(Hβ) = (11.0±0.10) 10^{-14}
1993: F(Hβ) = (4.60±0.30) 10^{-14}
1995: F(Hβ) = (2.20±0.25) 10^{-14}

units: erg s^{-1} cm^{-2}

Table 3. Nebular spectrum: observed and predicted emission line ratios

Line ratio	WRA 751	M1–67^a	WRA 751 model 1	WRA 751 model 2
$[NII]$ 6583/Hα	1.1±0.1	1.06±0.02	1.19	0.96
$[SII]$ (6717+6731)/Hα	0.13±0.02	0.100±0.002	0.13	0.13
$[OII]$ 3727/Hβ	–	0.15±0.01	0.23	0.18
$[NII]$ 5755/6583	–	0.0035±0.0010	0.0038	0.0026

Table 4. Nebular abundances

	M1–67[a]	WRA 751 model 1	WRA 751 model 2
N/H	2.8 10^{-4}	3.0 10^{-4}	3.5 10^{-4}
O/H	9.5 10^{-5}	1.0 10^{-4}	1.4 10^{-4}

[(a)] Esteban et al. (1991)

Thus, we will assume a distance of 4.5 kpc for the rest of the discussion.

From the apparent size of the nebular shell, equivalent to a physical size of 0.23 pc at 4.5 kpc, and the expansion velocity we derive a kinematic age for the nebula of 9600 years, consistent with the expected LBV lifetimes ($\sim$ 25000 yrs) derived from the assumption that they are the progenitors of massive WR stars and considering the relative population of both type of stars in the Galaxy and in the Magellanic Clouds (Humphreys & Davidson 1994).

4. Infrared emission

Another remarkable characteristic observed in WRA 751 as an LBV candidate is the strong far infrared excess detected by IRAS (see Fig. 2 in Hu et al. 1990). The infrared colours are well fitted by blackbody emission at $\sim$140$-$175 K, depending on the IRAS bands used, and are similar to those observed in detached dust shells surrounding post-AGB stars and PNe (García-Lario et al. 1997). Only a few other LBV candidates: AG Car, HR Car, and HD 168625 (= SAO 161375) in our Galaxy (Hutsemékers et al. 1994) and R71 in the LMC (Wolf and Zickgraf 1986) show similar far infrared colours.

It is important to note that LBVs form a totally heterogeneous group from the infrared point of view (Humphreys & Davidson 1994). S Dor, for instance, does not show any far infrared excess and its global energy distribution is well fitted at quiescence by continuum emission from a star with 20000$-$25000 K and a small contribution from free-free emission in the near infrared. Neither η Car, which experienced a giant eruption in the last century and now shows an obscured stellar continuum, together with strong emission from hot dust still present in the circumstellar envelope peaking at $\sim$10 μm. In contrast, AG Car, HR Car, HD 168625 and R71, like WRA 751, are surrounded by cool circumstellar shells detected by IRAS with a very strong emission in the far infrared peaking beyond 25 μm, although they show stellar-like colours in the near infrared.

The absence of a significant far infrared excess in objects like P-Cygni, which underwent one of these giant eruptions 400 years ago, suggests that these eruptions are not the origin of the strong far infrared emission observed. It seems more likely that the presence or absence of cool circumstellar envelopes around LBV stars depends on the age of the LBV star. It seems that the eruptive mass loss rates for all but the very brightest LBVs are probably not much greater than the quiescent rates (Stothers & Chin 1996). Thus, the non-detection of a far infrared excess in S Dor, the prototypical low luminosity LBV in the LMC, would simply indicate that this star is still in a very early stage as LBV, while WRA 751, AG Car, HR Car and HD 168625 should be considered evolved stars of the LBV class. An even more evolved status is assigned by Davidson et al. (1993) and Smith et al. (1994) to Hen 3$-$519, an LBV star surrounded by a WR ring nebula, supporting the idea of an evolutionary connection between these two types of astronomical objects. Searching the IRAS Point Source Catalogue for a possible far infrared counterpart we found that the optical coordinates of Hen 3$-$519 are coincident with those of IRAS 10520$-$6010, a bright infrared source showing colours which correspond to a very cool circumstellar shell with only $\sim$125 K, in agreement with its possible post-LBV status.

5. Conclusions

Taken together, the observational data collected by different authors in the recent past and the results shown in this Paper indicate that WRA 751 is an evolved LBV star. The star shows a high density and dusty core surrounded by a much lower density expanding nebula with characteristics very similar to those observed in WR ring nebulae.

The photometric and spectroscopic variability, luminosity considerations and its similarity with other LBV candidates in quiescence support this identification. The evolutionary status of WRA 751 as an LBV star must be very similar to that of AG Car, HR Car and HD 168625, all them surrounded by cool circumstellar shells detected by IRAS.

The circumstellar material detected in the far infrared is interpreted as the result of the strong mass loss undergone by the central star of WRA 751 during the LBV phase. The infrared properties of the circumstellar shells surrounding these objects are probably reflecting the evolutionary status of the central stars.

An abrupt enhancement of the mass loss is deduced from the interpretation of the double P-Cygni profile observed in Hα as produced by a density discontinuity in the shell, which suggests that this star has probably undergone a relatively recent LBV-like eruption.

Most of the peculiar emission features observed in the core can be explained as formed by continuum fluorescence in a dusty environment. The possible nitrogen enhancement observed in the nebula surrounding WRA 751 is consistent with the suggested LBV nature.

The central star of WRA 751 seems to be currently fading, at least in the optical and in the near infrared since it was first observed several decades ago.

A detailed analysis of the time scale variability in this and other LBV stars is required to understand the physical mechanisms which are triggering the violent eruptions observed. It is still not clear whether these episodes affect all LBVs in the same way or whether the giant eruptions sometimes recorded are very rare events affecting only the most massive representatives.

It is clear that objects like WRA 751 deserve further monitoring in the near future, since the answers to these and many other open questions are essential to understand the stellar evolution of massive stars.

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