

Two O2 If*/WN6 stars possibly ejected from the massive young Galactic cluster Westerlund 2

A. Roman-Lopes,¹★ R. H. Barba^{1,2} and N. I. Morrell³

¹*Department of Physics, Universidad de La Serena, Benavente 980, La Serena, Chile*

²*Instituto de Ciencias Astronómicas, de la Tierra, y del Espacio (ICATE-CONICET), Av. España 1512 Sur, J54202DSP San Juan, Argentina*

³*Las Campanas Observatory, Carnegie Observatories, Casilla 601, La Serena, Chile*

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ABSTRACT

In this paper we report the identification of two new Galactic O2 If*/WN6 stars (WR20aa and WR20c), on the outskirts of the massive young stellar cluster Westerlund 2. The morphological similarity between the near-infrared spectra of the new stars with that of WR20a and WR21a (two of the most massive binaries known to date) is remarkable, indicating that probably they are also very massive stars. New optical spectroscopic observations of WR20aa suggest an intermediate O2 If*/WN6 spectral type. Based on a mosaic made from the 3.6 μm *Spitzer* IRAC images of the region including part of the RCW49 complex, we studied the spatial location of the new emission line stars, finding that WR20aa and WR20c are well displaced from the centre of Westerlund 2, being placed at ≈ 36 pc (15.7 arcmin) and ≈ 58 pc (25.0 arcmin), respectively, for an assumed heliocentric distance of 8 kpc. Also, very remarkably, a radius vector connecting the two stars would intercept the Westerlund 2 cluster exactly at the place where its stellar density reaches a maximum. We consequently postulate a scenario in which WR20aa and WR20c had a common origin somewhere in the cluster core, being ejected from their birthplace by dynamical interaction with some other very massive objects, perhaps during some earlier stage of the cluster evolution.

Key words: stars: individual: WR20aa – stars: individual: WR20c – stars: Wolf–Rayet – open clusters and associations: individual: Westerlund 2 – infrared: stars.

1 INTRODUCTION

Westerlund 2 (Wd2, Westerlund 1961; Moffat & Vogt 1975) is a young massive stellar cluster placed in the core of the H II region RCW49, which is located in the fourth Galactic quadrant, projected in the area of the Carina constellation. This cluster hosts one of the most massive binaries known: the star WR20a, comprised of two WN6ha-type stars with absolute masses of 83 and 82 M_{\odot} (Bonanos et al. 2004; Rauw et al. 2005). Another massive star of the same spectral type, WR20b (Shara et al. 1991), appears about 4 arcmin south-east of the cluster core. A second massive WR binary, WR21a (that is located 16 arcmin east of the Wd2 core), has a primary component of spectral type WN6ha with an estimated minimum mass of 87 M_{\odot} , and an early O-type secondary with a minimum mass of 53 M_{\odot} (Niemela et al. 2008). However, the membership of WR21a to Wd2 is still uncertain. Such WR stars are members of the WNH type, a subset of very luminous and massive hydrogen core burning WN objects (see definition in Smith & Conti 2008 and references therein).

With empirical masses exceeding 80 M_{\odot} , WNH stars are probably among the most massive stars known, being in the top-end of the mass distribution in young clusters and OB associations. This assumption is supported by results obtained from several studies of WNH stars in massive clusters such as R145 in 30 Doradus (Schnurr et al. 2009), WR25 (Gamen et al. 2006) and WR22 (Rauw, Vreux & Gosset 1996) in the Carina Nebula region, and NGC 3603-A1 in NGC 3603 (Schnurr et al. 2008).

More recently, Crowther et al. (2010) from the spectroscopic analyses of four WN stars located within R136 (the core of 30 Doradus Nebula in the Large Magellanic Cloud – LMC) and three WN stars of HD 97950 (the core of NGC 3603 in the Milky Way), computed initial masses in the range of 165–320 M_{\odot} , and 105–170 M_{\odot} , for the stars in R 136 and NGC 3603, respectively. The authors point out that due to their proximity to the Eddington limit, the very high mass progenitors would possess an emission-line spectrum at the beginning of their main-sequence evolution, mimicking the spectral appearance of classical WR stars.

The spectral type O3If*/WN6-A was introduced almost 30 years ago by Walborn (1982) to classify the bright emission line star Sk-67 22 in the LMC, which shows an intermediate spectrum between those of HD93129A (O2 If*) and HD93162 (=WR25,

★E-mail: roman@dfuls.cl

Table 1. Coordinates and optical/NIR photometry of the newly identified O2 If*/WN6 stars on the outskirts of Westerlund 2.

Star	RA (J2000)	Dec. (J2000)	<i>B</i>	<i>V</i>	<i>J</i>	<i>H</i>	<i>Ks</i>	Other designation
WR20aa	10:23:23.49	−58:00:20.8	13.86 ± 0.02	12.69 ± 0.02	9.28 ± 0.02	8.73 ± 0.02	8.40 ± 0.02	SS215
WR20c	10:25:02.60	−57:21:47.3	20.10 ± 0.05	17.51 ± 0.03	10.51 ± 0.02	9.57 ± 0.02	9.04 ± 0.02	–

Table 2. Journal of the spectroscopic data used in this work.

Star	Programme ID	Date	Telescope	Instrument	Grism/disperser	Slit	<i>R</i>	Range (μm)
WR20a	075.D-0210	2005 June 21	NTT	Sofi	GR	0.6 × 290 arcsec ²	1000	1.53–2.52
	072.D-0082	2004 January 29	NTT	EMMI/2.3	GRAT#3	1 × 120 arcsec ²	1600	0.39–0.47
WR20b	075.D-0210	2005 June 20	NTT	Sofi	GR	0.6 × 290 arcsec ²	1000	1.53–2.52
WR21a	075.D-0210	2005 June 20	NTT	Sofi	GR	0.6 × 290 arcsec ²	1000	1.53–2.52
WR20aa	075.D-0210	2005 June 21	NTT	Sofi	GR	0.6 × 290 arcsec ²	1000	1.53–2.52
	GOSSS	2010 June 30	du Pont	Boller Chivens	1200 lines mm ^{−1}	1 × 270 arcsec ²	2500	0.39–0.55
WR20c	075.D-0210	2005 June 21	NTT	Sofi	GR	0.6 × 290 arcsec ²	1000	1.53–2.52
WR25	GOSSS	2008 May 20	du Pont	Boller Chivens	1200 lines mm ^{−1}	1 × 270 arcsec ²	2500	0.39–0.55
HD93129A	GOSSS	2010 June 30	du Pont	Boller Chivens	1200 lines mm ^{−1}	1 × 270 arcsec ²	2500	0.39–0.55

WN6ha). New examples of this intermediate spectral type were mainly found in the LMC, always consisting of bright massive objects (see for example, Melnick 1985; Walborn & Blades 1997; Crowther et al. 2010).

In this paper we report on the identification of two new Galactic O2 If*/WN6 stars (WR20aa and WR20c) on the outskirts of the massive young cluster Wd2. In Section 2 we describe the observational data we have used and the data reduction procedures, in Section 3 we present the results and discussion, and in Section 4 we present the summary of the work.

2 OBSERVATIONS AND DATA REDUCTION

2.1 Optical and near-infrared photometry of WR20aa and WR20c

Coordinates and photometric parameters for the new O2 If*/WN6 stars are shown in Table 1. The near-IR photometric data are from the Two-Micron All Sky Survey (2MASS, Skrutskie et al. 2006), and were retrieved using the NASA/IPAC¹ Infrared Science Archive. Bessell *B*- and *V*-band imaging of WR20aa and WR20c was obtained with the Swope 1-m telescope at Las Campanas Observatory (Chile) using the SITe 3 CCD detector, on 2010 April 20. The night was photometric, with a typical seeing of 1.2 arcsec. The data were reduced following standard IRAF² procedures. We then obtained aperture photometry for both the stars, and their instrumental magnitudes were transformed to the standard system using a set of photometric standard stars observed in the concerned night.

The stars were named WR20aa and WR20c, following the common practice of giving the WR Galactic stars numbers according to their RA, with further additions between integers following van der Hucht (2001, 2006). Searching in SIMBAD,³ we found that WR20aa is catalogued as SS 215, an H α emission-line object discovered by Stephenson & Sanduleak (1977).

2.2 Spectroscopic observations

2.2.1 Near-infrared spectroscopy

Near-infrared (NIR) ESO⁴ archival spectra obtained with the Sofi instrument (Son of ISAAC – Moorwood, Cuby & Lidman 1998), coupled to the 3.5-m New Technology Telescope (NTT), are part of the data set used in this work. These spectra were taken as a part of the ESO programme 075.D-0210 (PI Marston), with the targets being selected according to near- to mid-IR colour criteria for stars possessing strong winds (Hadfield et al. 2007). The log file of the NIR spectroscopic data set is presented in Table 2.

The raw frames were reduced following the NIR reduction procedures presented by Roman-Lopes (2009), and briefly described here. The two-dimensional frames were sky-subtracted for each pair of images taken at the two nod positions A and B, followed by division of the resultant image by a master flat. The multiple exposures were combined, followed by one-dimensional extraction of the spectra. Thereafter, wavelength calibration was obtained using the IDENTIFY/DISPCOR IRAF tasks applied to a set of OH skyline spectra (each with about 35 skylines in the range of 15 500–23 000 Å). The typical error (1 σ) for this calibration process is estimated at ~ 20 Å which corresponds to half of the mean full width at half-maximum (FWHM) of the OH lines in the mentioned spectral range. Telluric atmospheric corrections were done using *H*- and *K*-band spectra of B-type stars obtained before or after the target observation. The photospheric absorption lines present in the high signal-to-noise ratio telluric spectra, were subtracted from a careful fitting (through the use of Voigt and Lorentz profiles) to the hydrogen and helium absorption lines (He absorption lines are sometimes seen at 1.70 and 2.11 μm in the earliest B-type stars), and respective adjacent continuum.

2.2.2 Optical spectroscopy

Optical spectroscopic CCD observations were performed with the Boller & Chivens spectrograph attached to the 2.5-m du Pont telescope at Las Campanas Observatory (Chile) in 2010 June. The

¹ <http://irsa.ipac.caltech.edu/applications/BabyGator/>

² <http://iraf.noao.edu/>

³ <http://simbad.u-strasbg.fr/simbad/>

⁴ http://archive.eso.org/eso/eso_archive_main.html

spectrum was obtained in the framework of the Galactic O-stars Spectroscopic Survey (GOSSS, Maíz Apellániz et al. 2010), and therefore using its instrumental set-up. A spectrum of HD 93129A was also obtained in 2010 June, and a spectrum of HD 93162 (WR25) in 2008 May, during the first GOSSS southern campaign. Additionally, two optical spectra of WR20a were retrieved from the ESO Archive under the programme 072.D-0082 (PI Rauw). These spectra were obtained with EMMI instrument attached to the ESO NTT at La Silla (Chile) in 2004 February, and they belong to the same data set analysed and published by Rauw et al. (2005). Data were reduced and normalized using ONEDSPEC IRAF routines. A journal of the optical spectroscopic observations is presented in Table 2.

3 RESULTS AND DISCUSSION

3.1 NIR spectra of WR20aa and WR20c

In Fig. 1 we present the telluric-corrected (continuum normalized) *H*- and *K*-band spectra of the WR20aa and WR20c stars, together with those of WR20a, WR20b and WR21a. The strongest features are the blends of H I and He II emission lines at 1.736 and 2.167 μm , as well as the He I+N III and He II emission lines at 2.115 and

2.189 μm , respectively. A list with the main emission lines and corresponding equivalent linewidths is presented in Table 3.

The similarity between the NIR spectra of the known WN6ha stars with that of WR20aa and WR20c (Fig. 1) is remarkable, indicating that the latter may also belong to the WN6ha spectral type. The validity of this assumption is reinforced by the close morphological match of the WR20aa *H*- and *K*-band spectra with that for WR20a, one of the most massive binaries known to date (O3 If*/WN6 + O3 If*/WN6) for which masses of 83 and 82 M_{\odot} were derived (Bonanos et al. 2004; Rauw et al. 2004), and by the match of the WR20c *H*- and *K*-band spectra with that of WR21a, another extremely massive binary system (O3 If*/WN6 + early O), for which Niemela et al. (2008) estimated minimum masses of 87 and 53 M_{\odot} , respectively.

Conti, Hanson & Morris (1995) showed that some O4 If stars (like HD 16691 and HD 190429) can be erroneously classified as WN stars if observed only in the *K* band. In fact, their *K*-band emission features are morphologically identical to those seen in the spectra presented in Fig. 1. However, as can be seen in Blum et al. (1997), at least in the case of HD 190429 this is not true for the *H* band. Indeed, the *H*-band spectrum of HD 190429 is completely different from those shown in Fig. 1, being virtually featureless in the mentioned spectral range. Also, Hanson et al. (2005) present

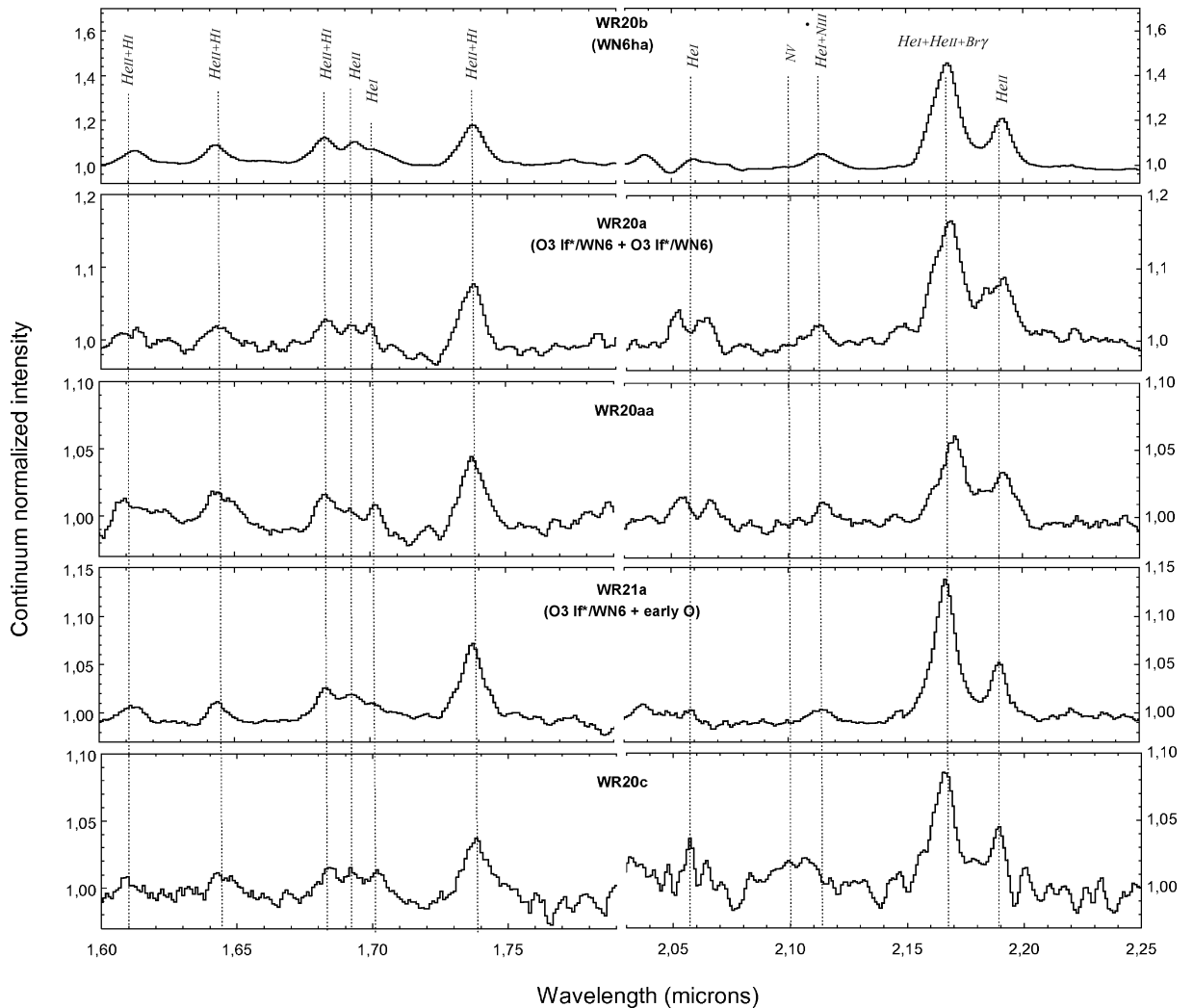


Figure 1. The *H*- and *K*-band continuum normalized ESO-NTT-SofI archival spectra of the stars WR20a (O3 If*/WN6 + O3 If*/WN6), WR20b (WN6ha), WR21a (O3 If*/WN6 + early O) together with that of the new stars WR20aa and WR20c. The main H, He and N emission lines are identified by labels.

Table 3. Equivalent widths (Å) of the main emission lines detected in the NTT-SOFI *H*- and *K*-band spectra of WR20aa, WR20c, WR20a, WR20b and WR21a.

Line	He II+Br12	He II+Br11	He II	He I	He II+Br10	He I+N III	He I+He II+Brγ	He II
λ (μm)	1.645	1.685	1.693	1.702	1.738	2.115	2.167	2.190
WR20b (WN6ha)	-7.4 ± 1.5	-11.8 ± 2.1	-5.3 ± 1.0	-7.0 ± 0.8	-18.6 ± 2.1	-12.1 ± 1.9	-74.5 ± 10.6	-33.7 ± 4.5
WR20a (O3 If*/WN6 + O3 If*/WN6)	-3.0 ± 0.7	-3.3 ± 0.7	-1.7 ± 0.4	-1.3 ± 0.3	-8.0 ± 1.4	-2.0 ± 0.5	-29.9 ± 6.3	-14.5 ± 3.8
WR21a (O3 If*/WN6 + early O)	-1.5 ± 0.3	-2.3 ± 0.5	-2.9 ± 0.7	-1.9 ± 0.5	-10.2 ± 2.4	-1.2 ± 0.5	-20.1 ± 5.2	-5.3 ± 1.3
WR20aa (O2 If*/WN6)	-3.1 ± 1.0	-3.3 ± 1.0	-0.2 ± 0.1	-1.6 ± 0.4	-6.1 ± 1.3	-1.1 ± 0.4	-9.9 ± 2.1	-4.8 ± 1.2
WR20c (O2 If*/WN6)	-1.5 ± 0.5	-1.5 ± 0.6	-1.3 ± 0.5	-1.3 ± 0.4	-5.2 ± 1.2	-2.7 ± 0.7	-12.5 ± 2.7	-4.0 ± 1.2

the *H*-band spectrum of Cyg OB2 #7 (O3 If*), which shows several H and He lines in *absorption*. On the other hand, as can be noticed from Fig. 1 the *H*-band spectra of WR20aa and WR20c are *not* featureless, with all the H and He relevant lines clearly seen in *emission*. In this sense, *H*- and *K*-band spectra of heavily reddened massive star candidates may become useful tools to discriminate between the OIf* and OIf*/WN spectral types.

3.2 The optical spectrum confirms: WR20aa is an O2 If*/WN6 star

The spectral morphology derived from NIR spectrograms of one of the new sources (WR20aa) is confirmed from new optical spectroscopic observations. In Fig. 2, we present the optical spectrum of

WR20aa, together with the GOSSS spectra of HD 93129A (O2 If*) and WR25 (O2.5 If*/WN6) obtained with the same instrumentation and set-up, along with the archival ESO/EMMI spectrum of WR20a (O3 If*/WN6 + O3 If*/WN6). Table 4 lists the equivalent widths (EW) for the main diagnostic lines used for spectral classification of WR20aa, HD 93129A, WR20a and WR25.

The blue spectrum of WR20aa is dominated by He II 4686 Å and N IV 4058 Å emission lines, together with less pronounced emission lines of N III 4634-41 Å and Si IV 4089 Å. Numerous absorption lines of H I and He II, and also some diffuse interstellar bands (DIBs) at $\lambda\lambda$ 4428, 4726, 4765 and 4865 Å are present. A special mention deserve the strong N V 4604-20 Å absorptions, which are characteristic of the earliest O-type (O2-3) and WNha stars. These absorption lines show weak P-Cyg profile structure.

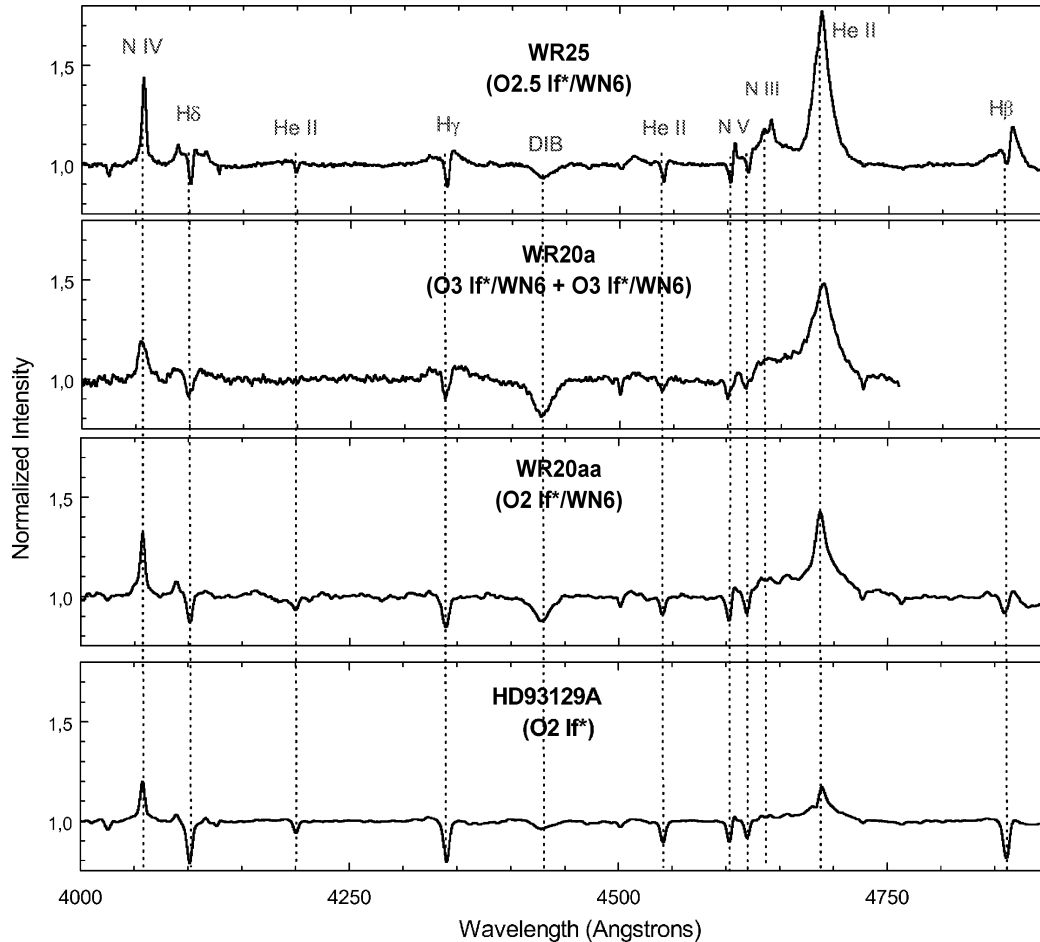


Figure 2. The optical spectrum of WR20aa, together with that for HD 93129A (O2 If*), WR 25 (O2.5 If*/WN6) and WR20a (O3 If*/WN6 + O3 If*/WN6). A comparison with the spectrum of HD93129A and that for WR20a shows that the optical spectrum of WR20aa approximates the latter better.

Table 4. Equivalent widths (Å) of the main diagnostic lines detected in the blue optical spectra of WR20aa, HD93129A, WR20a and WR25 stars.

ID	N iv 4058	He II 4686	H β	N v 4604	N III 4634-40-42
WR25	-2.5 ± 0.1	-15.6 ± 0.7	-2.7 ± 0.1	0.3 ± 0.1	-0.4 ± 0.1
WR20a	-2.3 ± 0.1	-14.0 ± 0.6	–	0.4 ± 0.1	-0.2 ± 0.1
WR20aa	-2.4 ± 0.1	-9.6 ± 0.5	0.3 ± 0.1	0.7 ± 0.1	-0.2 ± 0.1
HD93129A	-1.3 ± 0.1	-3.4 ± 0.4	1.3 ± 0.1	0.5 ± 0.1	-0.1 ± 0.1

The strength of the N iv 4058 Å emission line relative to the N III 4634-40-42 Å emission lines indicates that the spectral type of WR20aa is at least as early as O2, according to the criteria described in Walborn et al. (2002). In addition, the presence of a weak P-Cyg profile in the H β line of WR20aa, compared to the same line in HD93129A, which shows no emission, and the P-Cyg profile observed in WR25, is indicative of an intermediate spectral type between OIf* and WNha. In this way, Crowther & Dessart (1998) suggest that genuine WN6 stars are those with EW of He II 4686 Å lower than -12 Å. The measurement of He II 4686 Å line in WR20aa (-9.6 Å, see Table 4) also indicates an intermediate spectral type. On the other hand, no detection of He I absorptions is also indicative of a spectral type earlier than the O3. This picture is seen in a direct comparison with the spectra of HD93129A and WR20a, which shows that the blue spectrum of WR20aa resembles the latter better (as it was already noticed from the NIR regime). It is also noticeable from Table 4 that the emission lines of WR20aa are closer in strength to those from WR20a, with the lines from the latter being slightly broader (this difference is perhaps related to the binary nature of WR20a). Consequently, we classify the spectrum of WR20aa as O2If*/WN6 (Crowther & Walborn 2011).

A spectral classification for WR20c using optical MK criteria is not possible in this moment due to the lack of a good signal-to-noise ratio optical spectrum of this star. From an inspection of our NIR *H*- and *K*-band spectra, we find that WR20c is spectroscopically very similar to WR20aa, consequently we propose that WR20c should also be classified as O2If*/WN6. During the proof stage of the paper, Crowther & Walborn (2011) redefined the schema of spectral classification for those intermediate stars showing a smooth transition from early-O supergiants to WN6ha stars, with the corresponding standard stars for each sub-type.

3.3 The new O2 If*/WN6 stars and the Westerlund 2 cluster: are they related?

Fig. 3 shows a mosaic made from the 3.6 μ m *Spitzer* IRAC images (Churchwell et al. 2004) of the region towards the RCW49 complex. There we identify WR20a, WR20b and WR21a together with WR20aa and WR20c. It is interesting to notice that the three already known WR stars are well displaced from the core of the Wd2 cluster, which harbours at least a dozen of early O-type stars (Rauw et al. 2007). The closest of them (WR20a) is located about 0.6 arcmin from the cluster centre, with the others being placed at core distances of about 3.7 and 15.6 arcmin, respectively. The situation for WR20aa and WR20c is similar to that of WR21a, with the stars localized at angular distances (from the cluster centre) of 15.7 and 25 arcmin, well beyond the Wd2 cluster core. The presence of such massive stars well isolated on the outskirts of the RCW49 complex naturally leave us to ask: how did they arrive there?

3.3.1 Interstellar extinction and absolute visual magnitudes

The assumption of a possible physical connection between WR20aa and WR20c with the Wd2 cluster population in principle can be tested by comparing the $(B - V)$ colours of these new stars with those of the presently accepted cluster members (WR20a and the 12 known early O-type members), which we do in Table 5. For the sake of completeness, we also included here the colours of WR20b and WR21a, the other two known WR stars in the vicinity of Wd2. The $(B - V)$ colours of WR20aa and WR20c were computed from the *B*- and *V*-band photometry shown in Table 1, while the values for the other stars were taken from Rauw et al. (2007) (WR20a and the early-O stars), Nazé, Rauw & Manfroid (2008) (WR20b), and Niemela et al. (2008) (WR21a). In the case of the early O-stars, we indicate the interval of $(B - V)$ colours shown in table 1 of Rauw et al. (2007). The corresponding visual extinctions were computed considering intrinsic colours $(B - V)_0 = -0.3$ magnitudes, and the canonical value for the ratio of total to selective extinction $R_V = 3.1$. Finally, absolute visual magnitudes were estimated assuming a distance of about 8 kpc (Moffat, Shara & Potter 1991; Rauw et al. 2007).

In the case of WR20aa we notice that its derived $(B - V)$ colour and visual extinction are compatible with those for the other massive stars in Wd2, while a very red colour index $(B - V) = 2.6$ was obtained for WR20c, which corresponds to about twice of the visual extinction inferred for the early-O stars of Wd2. The higher interstellar extinction derived for WR20c is probably due to the presence of a foreground molecular cloud as can be inferred from an inspection of the 2MASS *J*-band source density map⁵ of the region towards Wd2. Also, we remember that in the case of WR20c, the star is almost on the Galactic plane which increases the probability that a dusty screen is on the line of sight of this star. In fact, it is not unusual that star-forming regions present highly variable visual extinctions at scales of a few arcminutes. As examples, we can mention M17 (Hanson, Howarth & Conti 1997) and the Cygnus OB2 associations (Knödseder 2000) in which the massive stars present a wide range ($A_V = 5$ -12 and $A_V = 5$ -20 magnitudes, respectively) of individual visual absorptions.

On the other hand, the absolute visual magnitudes derived for WR20aa and WR20c are similar to that for WR20b, which is the only one, in the area of RCW49, not known to be a binary. Indeed, if we correct the absolute visual magnitudes of WR20a and WR21a in order to take into account the binary companion contribution (by 0.7 and 0.5 magnitudes, respectively), we can see that WR20aa is probably as luminous as the other O If*/WN or WN6ha stars in Wd2, with WR20c being a bit less luminous than them. This is not surprising if one considers that stars of the same specific spectral types may span a range in absolute magnitudes (see Table 3 of Crowther & Walborn 2011).

⁵ <http://aladin.u-strasbg.fr/java/nph-aladin.pl>

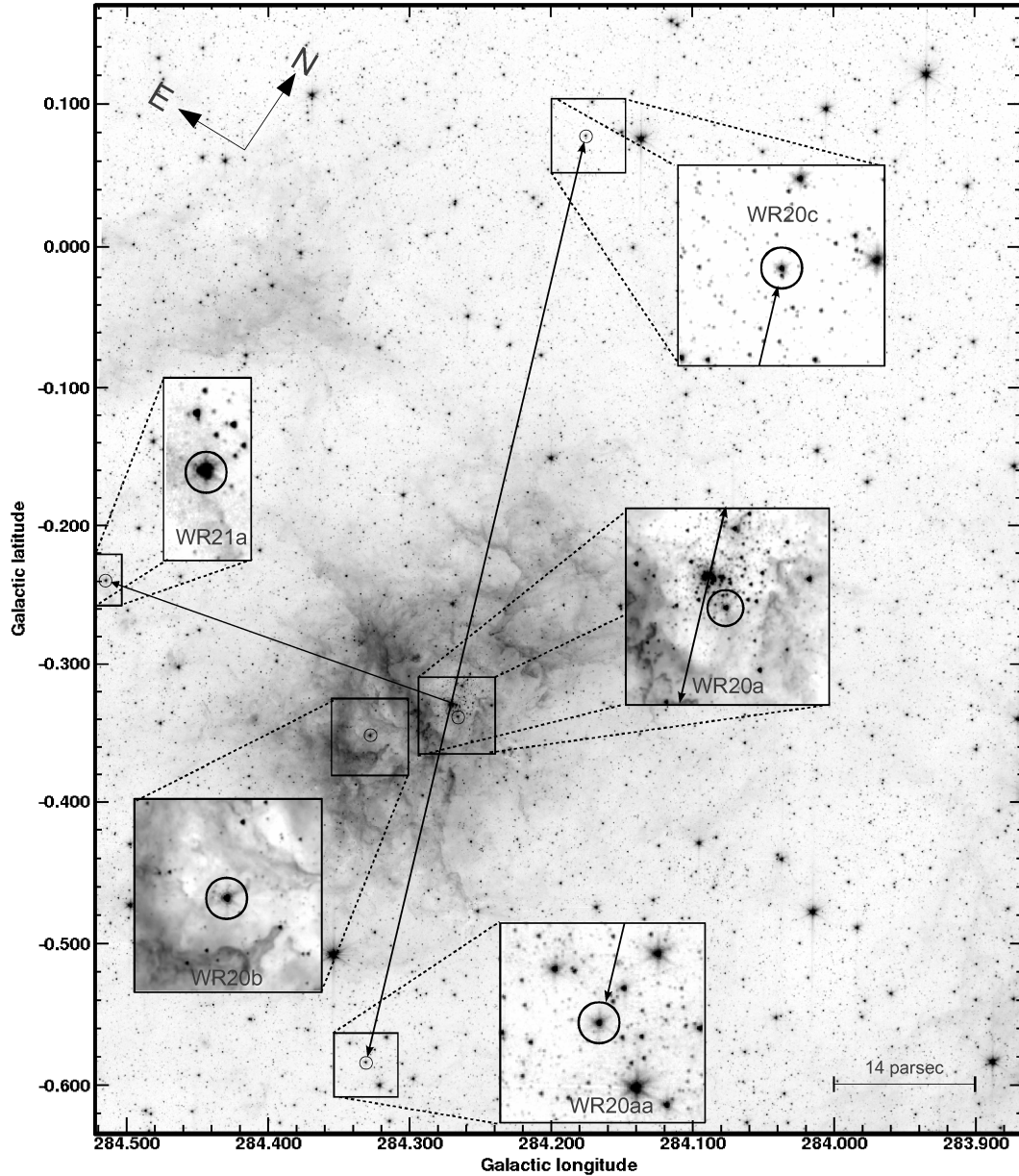


Figure 3. A mosaic made from the 3.6- μm *Spitzer* IRAC images (taken from the GLIMPSE survey archival data) of the region towards the RCW49 complex (6 arcmin \approx 14 pc at an heliocentric distance of 8 kpc). Here we identify the stars WR20a, WR20b and WR21a together with the two newly found O2 If*/WN6 objects, WR20aa and WR20c. We notice that a line connecting WR20aa and WR20c intersects the cluster centre just where the surface stellar density hits a maximum.

Table 5. ($B - V$) colour, colour excess, visual extinction and absolute visual magnitudes for WR20aa, WR20c, WR20a and WR20b. Data for WR21a are included as a complement. In the entry labelled *Early O members*, we present the interval of ($B - V$) colours, colour excess and visual extinction for the 12 known members of Wd2. The last column shows the equivalent single star magnitudes which follow from the consideration that WR21a and WR20a are binary systems (see text).

Star	($B - V$)	$E(B - V)$	A_V	M_V	$M_V(\text{corr})$
WR20aa (O2If*/WN6)	1.2	1.5	4.7	-6.5	-6.5
WR20c (O2If*/WN6)	2.6	2.9	9.0	-6.1	-6.1
WR20a (O3 If*/WN6 + O3 If*/WN6)	1.6	1.9	5.9	-7.0	-6.3
Early-O members	1.2–1.6	1.5–1.9	4.7–5.9	–	–
WR20b (WN6ha)	1.5	1.8	5.6	-6.6	-6.6
WR21a (O3 If*/WN6ha+O)	1.4	1.7	5.3	-7.2	-6.7

3.3.2 Two runaway stars?

It is an observational fact that very massive stars preferentially are found in the core of their parental clusters, normally forming binary or multiple systems. However, there are a certain number of very young and massive stars that are found well isolated in the field. Two canonical scenarios try to explain the origin of these stars. The first one, known as the *binary-supernova scenario*, considers the disruption of a short-period binary system from the asymmetric supernova explosion of one of the binary components, while the second one, named *dynamical ejection scenario*, involves dynamical three- or multiple-body encounters in dense stellar systems.

The time-scale for the binary-supernova scenario involves values larger than the expected age (1–2 Myr) for WN6ha stars (Crowther et al. 2010) although lower mass counterparts could reasonably be rather older (approximately 2.5 Myr). On the other hand, the multiple ejection of massive stars from dense massive clusters is not a new idea (see discussion in Zinnecker & Yorke 2007), and recent discoveries of very massive runaway stars (e.g. 30 Dor #16) highlighted the importance of this scenario in the evolution of massive clusters (Evans et al. 2010; Gvaramadze, Kroupa & Pflamm-Altenburg 2010). For more details on the two models, see for example the discussion in Gvaramadze & Gualandris (2010) and references therein.

We searched for some observational constraints that could support the scenario in which WR20aa and WR20c were ejected from the Wd2 cluster centre following the dynamical ejection model. We found the surprising result that a vector connecting WR20aa and WR20c (see Fig. 3) intercepts the cluster core *exactly* where the star surface density hits a maximum. Also interesting is the observation that a vector connecting WR21a and the Wd2 core (see Fig. 3) forms almost a right angle with the line connecting WR20aa and WR20c. This apparent configuration strongly resembles the dynamical scenario proposed by Gualandris et al. (2004) for the origin of AE Aur, μ Col and the very eccentric binary ι Ori, as runaway stars. From N -body simulations the authors conclude that these stars were ejected from their parental cluster as a result of binary–binary interactions occurred in the Trapezium cluster. In this sense, it is remarkable to point out that the massive binary system WR21a is known to present a high eccentricity ($e \sim 0.64$, Niemela et al. 2008).

The fine geometrical alignment between WR20aa, WR20c and the Wd2 core suggests that these stars possibly had a common origin somewhere in the central part of the cluster, being ejected from their birthplace (on a time-scale not greater than their own age of no more than 2 Myr (Crowther et al. 2010), with minimum recession velocities (projected into the sky plane) of 18 and 28 km s^{−1}, respectively. It is also interesting that Gvaramadze & Gualandris (2010) performed numerical simulations of a dynamical encounter between single massive stars and the very massive binary WR20a, finding that in a fly-by encounter the average recession velocity attained by a 70–80 M_⊙ star could be quite moderate (less than 30 km s^{−1}), being not formally classified as runaway.

Taking into account the fact that the O2 If*/WN6-type stars are very rare and the perfect alignment of the WR20aa–cluster-core–WR20c system, we postulate that both the stars probably were formed somewhere in the core of the Wd2 cluster, being ejected from their birthplace by a dynamical interaction with some other very massive star, in some previous stage of the cluster evolution. Of course, further observational (radial velocities, proper motions), and theoretical dynamical studies are still necessary to properly confirm our assumption. However, it is our opinion that the impressive alignment seen between such rare stars and the Wd2 cluster core, is in fact a strong clue favouring our hypothesis. In this sense,

we speculate that WR20aa and WR20c *may be* two of the most interesting Galactic runways known to date.

4 SUMMARY

In this work we report the detection of two new Galactic O2 If*/WN6 stars (WR20aa and WR20c) on the outskirts of the massive young cluster Wd2.

The similarity of the NIR spectra of WR20aa and WR20c to those of WR20a and WR21a (two of the most massive binaries known to date), is remarkable, suggesting that they could be members of the O2-3If*/WN6 group. Indeed, the optical spectral morphology indicates that WR20aa presents an intermediate O2If*/WN6 spectral type, based on the intensities of the emission lines of He II 4686 Å, N IV 4058 Å and N III 4634–40–42 Å, the N V absorptions at 4604–20 Å and the P-Cyg profile observed in H β . As an optical spectrum of WR20c is not yet available, we propose for it a spectral type similar to that of WR20a, based on the similarity of their NIR spectra.

From the analysis of the spatial distribution of the new O2 If*/WN6 stars through the mosaic made from the 3.6 μ m *Spitzer* IRAC images of the region towards the RCW49 complex, we found the very interesting result that WR20aa and WR20c are placed at angular distances of 15.7 arcmin (≈ 36 pc) and 25 arcmin (≈ 58 pc) from the Wd2 core, respectively. The stars are well isolated on the outskirts of the RCW49 complex with the radius vector connecting them by intercepting the cluster core *exactly* where the star density is maximum.

Considering the dynamical ejection model, we propose a scenario in which WR20aa and WR20c had a common origin somewhere in the central part of Wd2, being ejected from their birthplace on a time-scale not greater than their own age, which is probably no more than 1–2 Myr. Taking into account the *rarity* of such massive stars, and considering the perfect geometrical alignment observed between WR20aa, the cluster core and WR20c, we believe that WR20aa and WR20c may represent one of the most interesting cases supporting the ejection of massive stars, produced by a dynamical interaction with other massive companions.

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