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The VIIth catalogue of galactic Wolf–Rayet stars

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Abstract

The VIIth catalogue of galactic Population I Wolf–Rayet stars provides improved coordinates, spectral types and *bv* photometry of known WR stars and adds 71 new WR stars to the previous WR catalogue. This census of galactic WR stars reaches 227 stars, comprising 127 WN stars, 87 WC stars, 10 WN/WC stars and 3 WO stars. This includes 15 WNL and 11 WCL stars within 30 pc of the Galactic Center. We compile and discuss WR spectral classification, variability, periodicity, binarity, terminal wind velocities, correlation with open clusters and OB associations, and correlation with H I bubbles, H II regions and ring nebulae. Intrinsic colours and absolute visual magnitudes per subtype are re-assessed for a re-determination of optical photometric distances and galactic distribution of WR stars. In the solar neighbourhood we find projected on the galactic plane a surface density of 3.3 WR stars per kpc^2, with a WC/WN number ratio of 1.5, and a WR binary frequency (including probable binaries) of 39%. The galactocentric distance (R_{WR}) distribution per subtype shows $\overline{R}_{WR}$ increasing with decreasing WR subtype, both for the WN and WC subtypes. This $\overline{R}_{WR}$ distribution allows for the possibility of WNE→WCE and WNL→WCL subtype evolution.

Keywords: Catalogs; Galaxy: center; Galaxy: evolution; Galaxy: open clusters and associations: general; Galaxy: solar neighbourhood; Galaxy: structure; Galaxy: stellar content; ISM: H I bubbles; ISM: H II regions; ISM: ring nebulae; Stars: binaries: spectroscopic; Stars: binaries: visual; Stars: circumstellar matter: dust; Stars: distances; Stars: evolution; Stars: fundamental parameters; Stars: masses; Stars: statistics; Stars: winds; Stars: Wolf–Rayet

1. Introduction

The first five catalogues of galactic Population I Wolf–Rayet (WR) stars have been presented by, respectively, Campbell (1884), Fleming (1912), Payne (1930), Roberts (1962), and Smith (1968a). Those catalogues were discussed in the *VIth Catalogue of Galactic Wolf–Rayet Stars* by van der Hucht et al. (1981, 159 stars) and are listed in Table 1. Capitalizing on two decades of WR research, resulting in over 2000 papers (see the WR bibliography on the Hot Star Newsletter website, Eenens, 2000), we present here the *VIIth Catalogue*, giving credit to the discoveries since 1981 of 71 new galactic WR stars, and bringing the number of known galactic WR stars to 227. Still, the galactic WR census is very much incomplete due to the ubiquitous interstellar extinction in the Milky Way. Especially at infrared wavelengths, many more WR stars are likely to be discovered in the near future, in the solar neighbourhood ($d<2.5$ kpc), and towards the Galactic Center ($d\simeq8$ kpc, Reid, 1993), embedded in dense IS/CS clouds, or simply at large distances.

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Table 1
Galactic Population I Wolf–Rayet catalogues

WR catalogue	Author	Reference	N_{WR}
I	Campbell, 1884	*Astronomy and Astrophysics* 13, 448 (Northfield, Minn: Goodsell Observatory)	55
II	Fleming, 1912	*Harvard College Obs. Ann.* 56, 165	108
III	Payne, 1930	The Stars of High Luminosity, *Harvard Obs. Monographs* No. 3, p. 19	92
IV	Roberts, 1962	*AJ* 67, 79	123
V	Smith, 1968a	*MNRAS* 138, 109	127
VI	van der Hucht et al., 1981	*SSR* 28, 227	157
VII	van der Hucht, 2001	this paper	227

WR stars are characterized by strong He, N, C and O emission lines, originating in their hot stellar winds with terminal velocities in the range $v_\infty \simeq 400$–5000 km s^{-1}, which drive mass loss rates $\dot{M}$ of the order of 10^{-5} M$_\odot$ yr^{-1}. In these WR winds also their free–free μm-to-cm continuum emission originates, which allows mass loss rate determinations, given estimates of wind ionization, clumping rate, and distances of the WR stars (Wright and Barlow, 1975; Hillier, 1996; Leitherer et al., 1997; Hamann and Koesterke, 1998; Crowther, 1999). Comprehensive reviews on the WR phenomenon have been presented by, e.g., Abbott and Conti (1987), van der Hucht (1992), Maeder and Conti (1994) and in Proc. IAU Symp. No. 143 (van der Hucht and Hidayat, 1991), in Proc. IAU Symp. No. 163 (van der Hucht and Williams, 1995), in Proc. 33rd Liège Intern. Astroph. Coll. (Vreux et al., 1996), and in Proc. IAU Symp. No. 193 (van der Hucht et al., 1999).

It is important to discover and monitor WR stars, while each of them is a unique physics laboratory, a tracer of star formation in spiral arms, and a representative of the one but final phase in the evolution of massive stars, to be followed, probably, by a Type Ib/Ic supernova explosion (e.g., Langer and El Eid, 1986; Woosley et al., 1993; Maeder and Conti, 1994; Langer and Woosley, 1996; García-Segura et al., 1996; Chevalier and Li, 2000; Kaper and Cherepashchuk, 2000; Chu, 2001), either single in origin or binary (Langer and Heger, 1999; Wellstein and Langer, 1999). We cannot hope to understand the formation of black holes without understanding the late stages of massive star evolution. And where statistically the next galactic supernova is overdue for already more than a century, it is of obvious relevance to gather detailed knowledge about each of its potential progenitors.

In this paper, Section 2 reviews aspects of WR stellar classification. Section 3 contains the *VIIth Catalogue*. Section 4 summarizes WR stars found in Local Group Galaxies. Section 5 discusses galactic WR binaries. Section 6 lists galactic WR visual double and multiple stars. Section 7 reviews the correlation between galactic WR stars, H I bubbles, H II regions and ring nebulae. Section 8 presents interstellar extinction, intrinsic colours and absolute visual magnitudes of galactic WR stars. Section 9 presents distances and the ensuing galactic distribution of WR stars.

2. Spectral classification

2.1. Optical spectral classification

2.1.1. WN and WC spectral classification

Spectral classification of O-type stars and WR stars was reviewed by van der Hucht (1996). We re-iterate here the essentials of WR classification.

In the case of WR stars, one is dealing primarily with an emission-line spectrum, formed in an optically thick stellar wind. A classification system based on such emission lines will therefore not be closely coupled to the stellar parameters of effective temperature and luminosity. However, current WR spectral classification is still based primarily on the phenomenology of emission line features (UV, optical, IR), which thus defines the WR phenomenon.

The commonly used optical WR classification criteria are listed in Table 2, and give only a rough indication of ionization and temperature in WR stellar winds. The table is based on the scheme of Smith (1968a), as extended further by van der Hucht et al. (1981, *VIth Catalogue*), Barlow and Hummer (1982), Torres et al. (1986), Conti (1988), Conti et al. (1990), Smith et al. (1990), Crowther et al. (1995a), Kingsburgh et al. (1995), Smith et al. (1996), Crowther et al. (1998), and Conti (1999). These studies will be reviewed below.

Since the adoption by the IAU (Beals, 1938) of the classification system proposed by Beals and Plaskett (1935), recognizing the WN and WC sequences, it took 30 years before the classification systems of Hiltner and Schild (1966) and Smith (1968a) provided revisions. The Beals and Smith systems are one-dimensional, defining an ionization sequence only. The Hiltner–Schild system adds a second dimension by dividing the WN spectra into sub-sequences A and B, according to the strength and width of the emission lines: WN-A stars have relatively narrow-weak lines and strong continuum, while WN-B stars have broad-strong emission lines. Smith (1968a) did without the WN-A and -B sub-sequences while defining her robust classification system for both the WN and WC sequences. Walborn (1974), however, returned to the Hiltner–Schild A–B line-width classification for the WN sequence, and introduced additional WN-A(B), WN-AB, and WN-

Table 2
Smith's (1968a) Wolf–Rayet classification scheme, amended by van der Hucht et al. (1981), Barlow and Hummer (1982), Kingsburgh et al. (1995), Crowther et al. (1995a), and Crowther et al. (1998)[a]

WN types	Nitrogen emission lines	Other emission criteria
WN2	N V weak or absent	He II strong
WN2.5	N V present, N IV absent	
WN3	N IV ≪ N V, N III weak or absent	
WN4	N IV ≃ N V, N III weak or absent	
WN4.5	N IV > N V, N III weak or absent	
WN5	N III ≃ N IV ≃ N V	
WN6	N III ≃ N IV, N V present but weak	
WN7	N III > N IV, N III < He II 4686	He I weak P-Cyg
WN8	N III ≫ N IV, N III ≃ He II 4686	He I strong P-Cyg
WN9	N III > N II, N IV absent	He I P-Cyg
WN10	N III ≃ N II	Balmer lines, He I P-Cyg
WN11	N II ≃ He II, N III weak or absent	Balmer lines, He I P-Cyg
WC types	**Carbon emission lines**	**Other emission criteria**
WC4	C IV strong, C II weak or absent	O V moderate
WC5	C III ≪ C IV	C III < O V
WC6	C III ≪ C IV	C III > O V
WC7	C III < C IV	C III ≫ O V
WC8	C III > C IV	C II absent, O V weak or absent
WC9	C III > C IV	C II present, O V weak or absent
WO types	**Oxygen emission lines**	**Other emission criteria**
WO1	O VII ≥ O V, O VIII present	C III absent
WO2	O VII < O V	C IV < O VI, C III absent
WO3	O VII weak or absent	C IV ≃ O VI, C III absent
WO4		C IV ≫ O VI, C III absent

[a] The emission lines used for classifying WN stars are: He I λ3888, He I λ4027, He I λ4471, He I λ4921, He I λ5875, He II λ4200, He II λ4340, He II λ4541, He II λ4686, He II λ4861, He II λ5411, He II λ6560, N II λ3995, N III λλ4634–4641, N III λ5314, N IV λλ3479–3484, N IV λ4058, N V λ4603, N V 4619, and N V λλ4933–4944. The emission lines used for classifying WC stars are: C II λ4267, C III λ5696, C III/C IV λ4650, C IV λλ5801–12, and O V λλ5572–98. The emission lines used for classifying WO stars are: C IV λλ5801–12, O IV λ3400, O V λλ5572–98, O VI λλ3811–34, O VII λ5670, and O VIII λ6068.

(A)B sub-sequences, depending on the width of the N IV λ4058 Å emission line. He also introduced emission-line strength relative to the continuum as a third independent variable in WN spectra. Torres et al. (1986) were the first to quantify the WC classification, using optical spectrophotometry. Conti and Massey (1989), Conti et al. (1989) and Conti et al. (1990) further quantified the WN and WC classification, using optical and near-infrared spectrophotometry. Smith et al. (1990) designed a further quantification of the optical WC classification, compatible with the Smith (1968a) system. Schmutz et al. (1989) re-introduced the Hiltner–Schild system. Hamann et al. (1995a,b) appended to the WNE (WN2–6) classification the affix '-w' or '-s', indicating whether W_λ(He II λ5412)>37 Å, or smaller respectively, and discriminated for the presence of hydrogen. As such they re-introduced the system of Hiltner and Schild (1966) and, as to the hydrogen abundance, preluded to the classification system of Smith et al. (1996).

Some WN stars show stronger than normal CIVλ5808 or CIIIλ5696 emission superposed on a normal WN spectrum. Conti and Massey (1989) list seven of such WN/C types. Initially suspected of being binary WR stars (e.g., Niemela, 1991), it has since been shown (e.g., by Massey and Grove, 1989; Crowther et al., 1995d) for most of these objects, that the N and C lines probably originate in the same WR star.

Smith et al. (1996) introduced a three-dimensional classification scheme for WN stars, by adopting as *emission-line* criteria:

(i) the HeIIλ5411/HeIλ5875 ratio as primary ionization indicator, defining the spectral subtype;

(ii) FWHM(HeIIλ4686) and W_λ(HeIIλ5411) as indicators of line-width and line-strength, with designation b (for broad) when FWHM(HeIIλ4686) > 30 Å and/or W_λ(HeIIλ5411) > 40 Å; no designation for not b; and

(iii) an oscillating Balmer/Pickering decrement as indicator of hydrogen presence, with designations o, (h), and h when the line-peak ratio

$$\mathrm{H} + \mathrm{HeII}(\lambda 4861)/\mathrm{HeII}(\sqrt{\lambda 4541 \times \lambda 5411}) - 1$$

and/or

$$\mathrm{H} + \mathrm{HeII}(\lambda 4340)/\mathrm{HeII}(\sqrt{\lambda 4200 \times \lambda 4541}) - 1$$

is, respectively, 0, <0.5, and ≥ 0.5.

In addition the following *absorption-line* criteria have been given:

(iv) +OB if the star is an SB2 or has H-absorption lines without evidence of H-emission;

(v) (+OB) in case of a visual companion;

(vi) +abs if absorption lines are of unknown origin; and ha if absorption lines are from the WR star, together with H-emission lines.

Smith et al. (1996) re-classified in this way most of the known galactic WN stars and provided for 37 of them new subtypes. They found among the WN stars almost every possible combination of ionization subclass, narrow/broad and hydrogen/no-hydrogen. The WN ionization subclasses show a tight correlation between line-strength and line-width, with stars containing hydrogen at the weak-narrow end and WN/C stars near the strong-broad end.

However, while Conti (1999) approved of a '2-dimensional' classification system providing information about the hydrogen (h) in addition to the ionization (subtype), he argued against the above-introduced subscript b (for broad or strong FWHM(HeIIλ4686) and W_λ(HeIIλ5411), respectively). One argument against is that practically no WNb stars contain hydrogen. Other arguments against are that no physical basis underlying the 30 Å FWHM division has been presented by Smith et al. (1996), and that the W_λ-criterium is affected by the possible presence of binary components. Subsequently, if the subscript b is not needed, then the subscript o (for the absence of hydrogen in narrow-lined WN stars) is not necessary either, since it only indicates not h. In the spectral classification listing in this *VIIth Catalogue* we follow Conti's (1999) advice.

As an extension of the late WN subtypes, Crowther and Bohannan (1997) and Bohannan and Crowther (1999) elaborated on new WN9ha subtypes, and L.J. Smith et al. (1994b, 1995) and Crowther et al. (1995a) introduced the WN10–11 subtypes, following earlier, tentative, suggestions by Walborn (1977). Walborn and Fitzpatrick (2000) discussed these subtypes again in detail from an observational view point, as reviewed in the following subsection.

Crowther et al. (1998) introduced a new quantitative classification scheme for the WC stars. For WC4–11 stars their prime diagnostic is the equivalent width or line-flux ratio CIV$\lambda\lambda$5801-12/CIIIλ5696, rather than the CIIIλ5696/OIII-Vλ5590 ratio used by Smith et al. (1990), thus emphasizing ionization effects, but ignoring possible abundance effects, of importance in appreciating the evolutionary status of WR stars. With this new scheme Crowther et al. (1998) re-classified the WC stars WR 19 (from WC4 to WC5), WR 33 (from WC5 to WC6), WR 52 (from WC4 to WC5), WR 53 (from WC8 to WC9), and WR 146 (from WC6 to WC5). However, new spectroscopy by Williams and van der Hucht (2000) contradicts some of these re-classifications; therefore, we retain the WC classification by Smith et al. (1990) in this *VIIth Catalogue* (see Tables 13–15).

The relationship between the Smith et al. (1990, 1996) WR classification and stellar models has been addressed by Smith and Maeder (1991, 1998) for, respectively, WC stars and WN stars.

2.1.2. Of and Of/WN transition stars

Walborn (1971, 1973a) discussed the correspondence between Of stars and WN stars in the Carina OB1 association, notably between the O3f* star HD 93129A and the WN7 + abs star HD 93131 (WR 24, Walborn: WN6-A; Smith et al., 1996: WN6ha). Walborn noted that the qualitative difference between the two stars is in their emission-line strengths, as in He II λ4686 and N IV λ4058 emission, and in the occurrence of pure absorption lines in the O3f* star where the WN star has P-Cygni profiles. For a summary of O-type star classification schemes see, e.g., van der Hucht (1996). Walborn (1971) suggested that 'the principal reason for the spectroscopic differences between HD 93129A and HD 93131 is the existence of considerable ejected material about the latter star'. Conti (1976) concurred that the comparison indicates only a difference in degree: the WN star has a more extensive envelope than the Of star. Going one step further, Conti brought this in the context of massive star evolution by postulating: 'The mass loss rate of single Of stars from their stellar winds may be sufficient to produce what we would identify as single WR stars'.

Walborn (1977) discussed peculiar properties of several LMC Of stars showing a combination of high-(He II and N III) and low-(He I and N II) excitation emission features. Walborn classified the LMC star HDE 269227 as OIafpe, and found similarities with the galactic comparison star HD 152408. But he also noted that HDE 269227 (BAT99-22, WN9h, Breysacher et al., 1999) had been classified WN8 by Smith (1968b). Walborn suggested that if HDE 269227 were classified WN, it would have to be WN9 or WN10 because of the lack of N IV λ4058 emission and the presence of N II λ3995.

Hutchings (1979) classified HDE 313846 as O7:Iafpe and labeled it 'the most extreme Of star' compared to other extreme-Of types like HD 152408 and HD 153919. However, HDE 313846 had been classified OB + WN by Smith (1968a, LS 14), while later it has been classified WN9 by van der Hucht et al. (1981, WR 108) and WN9ha by Smith et al. (1996). van der Hucht et al. (1981) noted that in this star emission rather than absorption dominates the spectrum, and that the prime classification lines for Of-type stars, He I λ4471 and He II λ4541, are distorted by emission in HDE 313846. In the absence of N V and N IV lines in this star, a WN9 classification as extrapolation of the WN8 type was considered justified. Bohannan (1990) showed that HDE 313846 has stronger emission lines than the 'least extreme WN star' HD 93162. If Hutchings had noted at the time that eleven years earlier Smith had classified the object WN, he might perhaps also have recalled the Conti-scenario (1976).

At the upper end of the O-type classification, Walborn (1982a) found the LMC star Sk − 67°22 intermediate between O3If* and WN6-A, and Conti and Garmany (1983) classified the LMC object Sk − 71°34 as O4f/WN3. At the lower end, Walborn (1982b) classified the LMC stars HDE 269445, HDE 269858 and Sk − 67°266 as OIafpe, and HDE 269227, HDE 269927C and BE 381 as WN9–10 types. In that paper he preferred the OIafpe type for the galactic star WR 108. Gómez and Niemela (1987) classified the galactic object LSS 2063 as O6.5If/WN8. This object was earlier classified WN8 + OB by Smith (1968a), but reclassified in van der Hucht et al. (1981) as Of. Testor and Schild (1990) classified HDE 269828E (TSWR 2) as O4If/WN6 and TSWR 3 as O3If/WN6.

Thus, spectroscopically there are objects intermediate between O3-7f stars and WN3–8 stars, and objects intermediate between Ofpe stars and WN9 stars. Coining them 'slash'-stars, Bohannan (1990) defined those as stars having the absorption spectrum of an Of star and the emission spectrum of a WN star, and suggested that there is more than a morphological distinction. Apparently there is a smooth progression in quantitative spectroscopic properties, like in the He II λ4686 FWHM/W_λ ratio, of an Of-phase, through a 'slash'-phase, to a pure WN-phase. In proceeding from Of to WN types through the 'slash'-category, the stellar wind decreases in velocity and increases in density, with resulting increased He II, N III and Si IV emission due to more extended atmospheres. Again, all the re-classification studies emphasize the difficulty in delineating the least extreme WR star from the most extreme-Of star (e.g., Conti and Bohannan, 1989).

Lortet (1991) grouped the LMC slash stars into Of/WNE types (eight stars) and Of/WNL types (12 stars). Stahl et al. (1985) presented a high-dispersion optical atlas of 24 of the brightest peculiar emission-line stars in the Magellanic Clouds, including Ofpe/WN9 stars. Bohannan and Walborn (1989) presented a spectral atlas of 10 LMC Ofpe/WN9 stars.

L.J. Smith et al. (1994b) have carried out spectral analyses of the galactic variable objects He3-519 and AG Car at visual minimum, and presented a spectral atlas. Those objects were previously classified as Ofpe/WN9 stars (Stahl, 1986). L.J. Smith et al. (1994b) found hydrogen to be severely depleted in the two stars, and WN11 classifications appropriate both spectroscopically and chemically.

Crowther et al. (1995a) performed a quantitative analysis of four LMC Ofpe/WN9 stars and the galactic WN9 star WR 108 (HDE 313846), and presented a spectral atlas. They preferred on the basis of the relative N II λ3995 and N III $\lambda\lambda$4634-41 emission-line strengths for BE 381, HDE 269227 and HDE 269927C the spectral type WN9, and for Sk − 66°40 the spectral type WN10. They noted that precise classification is crucial to the relative lifetimes of the various subclasses. Crowther and Bohannan (1997) presented an atmospheric analysis of WR 108 (HDE 313846, WN9ha) in comparison with the galactic O8 supergiants HD 151804 (O8Iaf) and HD 152408 (O8:Iafpe), and also presented a spectral atlas. They concluded that little distinguishes the overall structure and composition of the stellar atmospheres of HD 152408 and WR 108, such that HD 152408 could be considered to be a WN9ha equivalent to WR 108, as earlier suggested by Walborn (1982b). Bohannan and Crowther (1999) subsequently confirmed the WN9ha classification for HD 152408 (WR 79a) and HD 152386 (WR 79b).

Nota et al. (1996) studied seven LMC Ofpe/WN9 and six closely related stars including the galactic HD 152408 and provided an optical spectral atlas and IR photometry. Three of the stars therein have shown large spectral variations. One of the original members of the class, HDE 269858 (R 127), developed a LBV[1] outburst. Conversely, Of-type emission has been discovered during a light-minimum of the galactic LBV AG Car (Stahl, 1986). Such observations provide strong indications of a close evolutionary relationship among those apparently disparate objects. Crowther and Smith (1997) performed an atmospheric analysis of the LMC Ofpe/WN9 stars and showed that all but one (HDE 269858f, because at the time in LBV-outburst) should actually be classified as WN9–11 stars. They provided a list of 29 LMC WN6–8 and Ofpe/WN9 stars (excluding O3If/WN6 stars), and a spectral atlas for six of those. Following earlier suggestions, e.g., by Walborn (1989), they proposed an evolutionary scheme in which the most massive O-type stars evolve directly to O3If/WN6 and subsequently WN6–7 stars, without passing through an intermediate LBV phase. In contrast, lower initial mass stars evolve through an LBV phase, encompassing a WN9–11 stage, with WN8 stars being their immediate successors. Schematically, Crowther et al. (1995b) proposed for galactic massive stars the evolutionary scenarios:

$$\mathrm{O} \rightarrow \mathrm{Of} \rightarrow \mathrm{WNLha} \rightarrow \mathrm{WN7}(\rightarrow \mathrm{WNE}) \rightarrow \mathrm{WC} \rightarrow \mathrm{SN} \quad \text{for } M_i > 60\ \mathrm{M}_\odot$$

$$\mathrm{O} \rightarrow \mathrm{Of} \rightarrow \mathrm{LBV} \leftrightarrow \mathrm{WN9{-}11} \rightarrow \mathrm{WN8} \rightarrow \mathrm{WNE} \rightarrow \mathrm{WC} \rightarrow \mathrm{SN} \quad \text{for } 40\ \mathrm{M}_\odot \lesssim M_i < 60\ \mathrm{M}_\odot$$

$$\mathrm{O} \rightarrow \mathrm{Of} \rightarrow \mathrm{RSG} \rightarrow \mathrm{WN8} \rightarrow \mathrm{WNE} \rightarrow \mathrm{WC} \rightarrow \mathrm{SN} \quad \text{for } 25\ \mathrm{M}_\odot < M_i \lesssim 40\ \mathrm{M}_\odot$$

i.e., a more detailed Conti-scenario. As an interesting difference between the LMC and the Galaxy, Crow-

[1]Luminous blue variables, a category including the Hubble–Sandage variables, the S-Doradus variables and the P-Cygni variables (Conti, 1984), lie near the Humphreys–Davidson (Humphreys and Davidson, 1979) limit in the H-R diagram, which corresponds to an instability leading to episodic shell ejection. Observationally, a link between the Ofpe/WN9 stars and the LBVs has been suggested by Stahl et al. (1983). For further details on the LBV phenomenon, see, e.g., Humphreys and Davidson (1994) and papers in Wolf et al. (1999).

ther and Smith (1997) noted the relative populations of WN9–11 stars and their evolutionary successors, the WN8 stars. They list in the LMC only three WN8 stars and nine WN9–11 stars, whereas in the Galaxy they list 12 WN8 stars, one normal WN9 star (WR 105) and two WN11 stars: AG Car and He 3-519. The latter had earlier been coined 'a peculiar post-LBV, pre-WN star' by Davidson et al. (1993).

Walborn and Fitzpatrick (2000) discussed correspondences and differences between eleven WN6–11 stars, compared the different classifications, and defined that O Iafpe stars are WN9ha stars, and that B Iape stars are WN11h stars.

At ultraviolet wavelengths, Shore and Sanduleak (1984) presented an *IUE* atlas and analyses for many of the LMC Ofpe/WN9 stars. A more recent UV atlas with *HST*-FOS spectroscopy and analyses of seven LMC Ofpe/WN9 stars has been presented by Pasquali et al. (1997).

At near-infrared wavelengths, McGregor et al. (1988), in a 2-μm spectroscopic survey of peculiar LMC emission-line supergiants, identified a striking category in which He I 2.058 μm is stronger than Brγ (however, see also McGregor et al., 1989), as demonstrated in a spectral atlas. Of the eight stars showing this characteristic, five are members of the Ofpe/WN9 class (Bohannan and Walborn, 1989). Spectroscopy in the *K*-band has been presented also by Morris et al. (1996a,b). In the 1–2.2 μm near-IR wavelength range, Bohannan and Crowther (1999) found the two peculiar, extreme emission-line stars HD 152386 (O6:Iafpe), HD 152408 (O8:Iafpe) more similar in both morphological and physical characteristics to WR 108 (HDE 313846, WN9ha), than to normal OIaf supergiants, and conclude that they should be classified WN9ha (WR 79b and WR 79a, respectively), where they remain, together with WR 108, a unique sub-group.

Allen et al. (1990) and Krabbe et al. (1991, 1995) detected stars with similar IR properties at the Galactic Center: the AF star and the stars AFGL 2004#8 and #10 have been classified as Ofpe/WN9 (Najarro et al., 1994; Cotera et al., 1996). Altogether Krabbe et al. (1995) listed 12 WN9/Ofpe stars; Cotera et al. (1996, 1999) found 13 candidate Ofpe/WN9 in the Arches Cluster close to the GC; and in the Quintuplet Cluster, close to the GC, Figer et al. (1996, 1999a) found two WN9/Ofpe stars. Crowther and Smith (1996) found that some of those GC objects have a spectral morphology similar to that of the WN9 star WR 105. Dessart et al. (1999) derived more detailed physical parameters of some of those GC objects.

2.1.3. WO spectral classification

Barlow and Hummer (1982) introduced the WO sequence with decimal subtypes for five stars listed by Sanduleak (1971) with very strong O VI $\lambda\lambda$3811-34 emission. Of these stars, designated Sand 1 through Sand 5, Sand 1 (Sk 188) is an SMC object; Sand 2 (FD 73) is an LMC object; Sand 3 turned out to be a planetary nebula nucleus (e.g., Feibelman, 1996); Sand 4 and Sand 5 (ST 3) are galactic objects, listed by van der Hucht et al. (1981) as, respectively, WR 102 and WR 142. Smith et al. (1990) classified WR 30a (MS 4) as WO4+O4. Cherepashchuk and Rustamov (1990) also proposed a WO classification scheme. More recent studies of Sand 4 have been presented by Polcaro et al. (1992, 1995), of Sand 5 by Polcaro et al. (1991, 1997), and of all six Population I WO stars by Kingsburgh et al. (1995). The last gave also a revised and quantitative WO spectral classification scheme, including the WO3 star DR 1 in IC 1613 (Kingsburgh and Barlow, 1995).

Crowther et al. (1998) re-defined the subclasses WO4–1 by applying the ratio OVI$\lambda\lambda$3811-34/OVλ5590 as primary diagnostic, and the OVIλ5290/OVλ5590 ratio as secondary diagnostic. They favoured a spectral sequence from WC to WO based on ionization effects over one based on abundance effects, as suggested also by Polcaro et al. (1997), and argued that individual WO stars may be classified either as WCE or WO, depending on the choice of system. However, Crowther et al. (2000) found from *FUSE* far-UV spectroscopy that the LMC WO3 star Sand 2 is more chemically enriched in carbon than LMC WC stars. This result favours the WO classification as an indication of the most advanced evolutionary WR phase, beyond the WC phase.

2.1.4. Variable subtypes

Variable WR subclasses have been observed for two WN binaries: Cyg X-3 (WN4–7+cc) in the Galaxy (van Kerkwijk, 1993; van Kerkwijk et al., 1996; Fender et al., 1999) and HD 5980 (WN4–

WN6–B1.5Ia$^+$pe–LBV(WN9–11) − WN8–WN6 + O7Ia or WN3) in the SMC (e.g., Koenigsberger et al., 1998; Moffat et al., 1998).

2.1.5. Composite spectra

With improving technology, more high S/N and high spectral-resolution observations of faint WR stars are becoming available. In some cases those observations show signatures of OB-type companions, e.g., for WR 19 (Veen et al., 1998); WR 30a (Niemela, 1995); WR 69 (Williams and van der Hucht, 2000); WR 70 (Niemela, 1995); WR 104 (Williams and van der Hucht, 1996, 2000; Crowther, 1997; Tuthill et al., 1999a,b; Monnier et al., 1999); WR 125 (Williams et al., 1994b); and WR 146 (Dougherty et al., 1996, confirmed by Niemela et al., 1998). Subsequent radial-velocity or astrometric orbital solutions are needed to confirm binarity for those cases, although in the case of WR 146 observations will have to extend over centuries (see also Section 5). Awaiting RV-solution confirmations, we have for some particular stars tentatively added the designation +OB? to their classification in this *VIIth Catalogue* (see Tables 13–15), hopefully provoking more observations.

2.1.6. Peculiar spectra

Although O VI $\lambda\lambda$3811,3834 emission is quite common among WC stars, it is rather rare for WN stars: van der Hucht et al. (1981, in section 'Notes on individual stars', pp. 245–254; see also Rustamov and Cherepashchuk, 1987 and Cherepashchuk and Rustamov, 1990) listed 12 WC stars and two WN stars (WR 46, WN3p and WR 156, WN8h) with O VI emission. Steiner and Diaz (1998) and Cieslinski et al. (1999) reported that also WR 109 (V617 Sgr, WN5h) has strong O VI emission, and linked both WR 46 and WR 109 to a class of so-called V Sagittae stars, a sub-class of the nova-like class of cataclysmic variables. Lockley et al. (1997) and Gies et al. (1998) concluded that the cataclysmic variable V Sge represents a particular stage of binary evolution dominated by stellar wind mass loss. Veen et al. (2001a,b,c) and Marchenko et al. (2000) argued convincingly that WR 46 is not a V Sagittae star, but a regular Population I WR star.

2.2. Photometric classification

Mendoza (1990) observed 11 WR stars and 7 PNs in his narrow-band $\alpha(16)\Lambda(9)\Psi(25)$ photometric system, and was able to separate WC stars from WN stars.

Royer et al. (1998) designed a narrow-band filter photometric system, with three filters centered on emission lines (He II λ4686, C IV $\lambda\lambda$5801-12 and He II λ5876) and two on continuum regions (5067 Å and 6051 Å). Colour–colour diagrams show promising separations between the WN and WC sequences and also between subtypes: separation between WN8, WN7, WNEw and WNEs subtypes is achieved, as well as between WC9, WC7–8 and WCE subtypes.

Damineli et al. (1997) designed a narrow-band photometric system for CCD detection of Of and faint-lined WN and WC stars in the near-infrared region.

2.3. Ultraviolet spectral classification

WR classification in the ultraviolet has been addressed by Niedzielski and Rochowicz (1994) on the basis of low-resolution *IUE* spectra. Applying line-strength ratios for C II λ2837 and C IV λ1551 they have been successful in reproducing WC spectral subtypes with a precision of one subtype. However, no quantitative WN star classification appeared to be feasible.

2.4. Near-infrared and infrared spectral classification

WR classification in the red part of the optical spectrum has been addressed by Conti et al. (1990), who found a rough correlation with optical subtypes but not at the precision of decimal subtypes. In particular, they noted that the optical N IV λ4057 and C III λ5696 emission lines behave peculiarly. These lines require detailed non-LTE modeling (Hillier, 1989) and are sensitive to intrinsic variability due to clumping of the stellar winds (e.g., Lépine et al., 1996; Lépine and Moffat, 1999a,b; Lépine et al., 1999, 2000).

Quantitative WC spectral classification in the ground-based near-infrared has been presented by Eenens et al. (1991, 1996), who showed that in particular the infrared He lines can be used to classify the WC subtypes. WN classification in the near-IR *K*-band has been addressed by Morris et al. (1996a,b), who compared WN spectra with spectra of OIf, Of/WN, B[e] stars and LBVs, pointing to pitfalls when only *K*-band spectra are available. Classification of WN, WN/WC, WC and WO stars in the *K*-band has been addressed by Figer et al. (1997). They found that the ratio *W*(He II 2.189 μm)/*W*(H I + N III 2.112 μm) allows WN classification to within one subtype. They attributed the 2.247 μm emission line in WN spectra to a N III transition and argued that it might provide a method for discriminating between WNL and early OIf^+ stars. Their ratio *W*(C IV 2.08 μm)/*W*(C III + He I 2.11 μm) correlates only with WC subtypes later than WC7.

Ground-based near-infrared photometry has led to the discovery of heated dust formation around WC stars, primarily around WCL stars (Williams et al., 1987a), a process which is not yet fully understood (Cherchneff, 1997; Cherchneff et al., 2000). Sizes and structure of those circumstellar dust envelopes have been measured in the infrared: by speckle interferometry for WR 104 (Allen et al., 1981; Dyck et al., 1984); by lunar occultation for WR 112 (Ragland and Richichi, 1999); directly with *HST*-NICMOS for WR 137 (Marchenko et al., 1999); and by image masking interferometry for WR 98a (Monnier et al., 1999) and WR 104 (Tuthill et al., 1999a,b). Persistent dust formation is a common feature for ~90% of the WC9 stars and ~50% of the WC8 stars in the sample studied by Williams et al. (1987a), as shown in Table 3, and appears to be a colliding-wind effect in long-period ($100\,d < P < 1000\,d$) WC+OB binaries (Tuthill et al., 1999a,b, 2000, 2001; Monnier et al., 1999). Periodic and episodic dust formation has been observed among some WC8, WC7 and WC4 stars and is a colliding wind effect in very-long-period ($1000\,d < P < 10000\,d$) eccentric WC+OB binaries during peri-astron passage (Williams et al., 1987b, 1990; Williams, 1997, 1999, 2001). For the 26 WC stars known to have IR dust signatures, i.e., 30% of all known galactic WC stars, we introduce as dust classification:

- WCd (persistent dust formation),
- WCvd (variable persistent dust formation),
- WCpd (periodic dust formation), and
- WCed (episodic dust formation).

Dust free WC9 stars like, WR 81, WR 88 and WR 92, appear to have in their optical wavelength range anomalously strong He II emission lines combined with weak O II emission lines (Williams and van der Hucht, 2000).

2.5. Modern spectral classification: the starburst cluster HD 97950 in NGC 3603

Improved spatial resolution, thanks to speckle techniques, adaptive optics, and *HST* observations, allows the classification of individual stars in clusters in increasing detail. As an example, we refer to studies of NGC 3603, which provides one of the most accessible starburst paradigms.

NGC 3603 is the densest concentration of early-

Table 3
WC stars: the incidence of heated CS dust per subtype (after Williams, 1995)[a]

Subtype	Persistent dust formation (WCd)	Variable dust formation (WCvd)	Periodic dust formation (WCpd)	Episodic dust formation (WCed)
WC4			WR 19	
WC7			WR 137, 140	WR 125
WC8	WR 53,113	WR 98a		WR 48a
WC9	WR 59, 65, 69, 73, 76, 80, 95, 96, 103, 104, 106, 112, 117, 118, 119, 121	WR 70		

[a] WR81, WR88 and WR92 (WC9) did not show dust formation in two decades of IR photometric monitoring.

type massive stars known in the Galaxy, apart from the Galactic Center. Walborn (1973b) and Moffat et al. (1985) stressed the correspondence between the luminous stellar cores of 30 Doradus in the LMC and NGC 3603 in the Galaxy. The size $r_c \simeq 0.71''$ (0.024 pc) of the core of NGC 3603 makes it possibly even more extreme than R 136, with $r_c \simeq 0.82''$ (0.21 pc). Moffat et al. (1985), adopting a distance $d = 7.5$ kpc and reddening $E_{B-V} = 1.44$ mag (Moffat, 1983), noted that within $r = 0.5$ pc fixed radius (i.e., 2.0″ in R 136a and 15″ in NGC 3603), HD 97950 is intrinsically brighter than R 136a. They listed four to five WN stars in R 136a and two to three WR stars in HD 97950 (WR 43), the core of NGC 3603. Moffat et al. (1994) presented *HST*-WFPC images of NGC 3603, finding three WR stars within the central 0.1 pc. They noted that, while R 136 also contains three WR stars within 0.1 pc of its center, those are almost one magnitude fainter than the WR stars in NGC 3603, perhaps related to the different environments (metallicity, IMF) and ages. In ground-based speckle-masking observations of HD 97950, Hofmann et al. (1995) found four WN stars in a $6.3'' \times 6.3''$ ($\simeq 0.2 \times 0.2$ pc) field with 75 mas spatial resolution.

Drissen et al. (1995) presented an atlas of *HST*-FOS spectrograms (3250–4750 Å, $\Delta\lambda = 3$ Å) of 14 individual luminous stars in HD 97950, the core ($r \leq 4'' = 0.12$ pc) of NGC 3603. They classified three WN6 + abs stars (confirmed by Crowther and Dessart, 1998), two O3III(f*) stars, four O3V stars, one O4V star, one O5V + OB(?) star, one O6V star, one O6.5V + OB(?) star and one O8V-III star. They noted that the three WN6 + abs stars are all hydrogen-rich and super-luminous ($M_b = -7.8$ mag, thus by a factor of ~10) for their subtype. They found a sharp decline in the N IV $\lambda\lambda$3479–3483–3485 and O IV $\lambda\lambda$3381-5 3412 features between the O3 and later-type spectra, making these lines potentially suitable for classification. Drissen et al. (1995) and Drissen (1999) emphasized the close morphological association between the OIII(f*) stars and the WNL stars in NGC 3603, suggesting an evolutionary link between them: the Conti (1976) scenario. On the other hand, and in view of the extreme proximity of the WN and O3 stars within HD 97950, it is likely that star formation within the core of HD 97950 was largely coeval. The observed larger luminosities of the WR stars compared to the O3 stars may be due to larger initial mass and, for that reason, stronger stellar winds (Conti et al., 1995) (but see below).

Crowther and Dessart (1998) confirmed the WN6ha classification of the three WR stars (WR 43abc) in NGC 3603. Based on a revised M_V calibration of early O-type stars, they decreased, compared with Moffat (1983), the reddening of NGC 3603 to $E_{B-V} = 1.23$ mag, and increased its distance to d = 10.1 kpc, bringing the absolute magnitude of the three WN6ha stars to an average $M_b = -7.3$ mag. In agreement with a study of similar stars in the LMC cluster R 136a by de Koter et al. (1997), they conclude that these WN stars must be core H-burning stars whose spectra are WR-like because of high luminosity and high wind density. Their luminosities, $\log(L/L_\odot) = 6.0–6.3$, are among the highest known for WR stars. Consequently, they could be very massive stars ($M_i \geq 100$ $M_\odot$) of a relatively low age (~2 Myr). However, it could as well be that these over-luminous WNLha stars are just regular WNLh + OB binaries, as suggested by Stevens et al. (2001) on the basis of their excessive *Chandra* X-ray luminosities.

2.6. Wolf–Rayet spectral atlases (since 1981)

Spectrophotometric atlases of WR stars are available from X-ray to infrared wavelengths. Tables 4–9 list atlases over that wavelength range. Completeness is not pretended.

Clear detections of WR stars at γ-ray wavelengths have not yet been published, but possible identifications of as yet unidentified *GRO*-EGRET γ-ray sources have have been listed by Kaul and Mitra (1997) and Romero et al. (1999), with WR 140 and WR 142 as likely candidates.

3. Galactic Wolf–Rayet star inventory, location, environment, properties

The *VIth Catalogue of Galactic Wolf–Rayet Stars* by van der Hucht et al. (1981, 159 WR stars) has been succeeded by:

- the rejection of three stars from the *VIth Catalogue* (Table 10);

Table 4
X-ray spectra obtained with *EXOSAT*-ME, *ROSAT*-PSPC, *GINGA* and *ASCA* of galactic WR stars

Stars	References
WR 6	Willis and Stevens, 1996; Skinner et al., 1998
WR 11	Willis et al., 1995; Stevens et al., 1996; Rauw et al., 2000
WR 21a	Mereghetti et al., 1994; Reig, 1999
WR 25	Skinner et al., 1995
WR 139	Corcoran et al., 1996; Maeda et al., 1999
WR 140	Williams et al., 1990; Koyama et al., 1990; Koyama et al., 1994; Skinner et al., 1995; Zhekov and Skinner, 2000
WR 147	Skinner et al., 1999

Table 5
Ultraviolet spectral atlases obtained with *IUE*, *HST* and *HUT* of galactic WR stars

References	Atlases
Nussbaumer et al., 1982	*IUE* low-resolution atlas
L.J. Smith and Willis, 1983	*IUE* low-resolution spectra LMC WR stars
Garmany et al., 1984	*IUE* low-resolution spectra for galactic WR stars
Walborn et al., 1985	in high-resolution *IUE* O-star atlas: 4 WN stars
Willis et al., 1986	*IUE* high-resolution atlas
Crowther et al., 1995b,c	*IUE* spectra for 3 WNL stars and 2 WNE stars
Schulte-Ladbeck et al., 1995	*HUT*-ASTRO 1+2 far-UV (820–1840 Å, $\Delta\lambda = 3$ Å) spectra of 5 WN stars and 1 WC star
Crowther and Smith, 1997	*IUE* and *HST* spectra for 4 LMC WNL stars
Crowther and Dessart, 1998	*HST*-GHRS spectra for 5 WN5–6 stars

Table 6
Optical spectral atlases of galactic WR stars

References	Stars
Smith and Kuhi, 1981	10 WN
Sivertsen, 1981	23 WN, 15 WC
Lundström and Stenholm, 1984b	21 WN, 25 WC
Lundström and Stenholm, 1984d	3 WN, 1 WC
Lundström and Stenholm, 1989	4 WN, 7 WC
Jeffers and Weller, 1985	4 WN, 6 WC
Torres and Conti, 1984	12 WC9
Torres and Massey, 1987	54 galactic WC, 10 LMC WC
Underhill, 1992	WC7
Crowther et al., 1995b	9 WNL
Crowther et al., 1995c	3 WNE
Drissen et al., 1995	3 WN6 with *HST*-FOS
Hamann et al., 1995b	62 WN
Koesterke and Hamann, 1995	WC5
Smith et al., 1996	29 galactic WN, 6 LMC WN
Crowther and Smith, 1996	2 WN6
Crowther and Bohannan, 1997	2 WN9ha
Crowther et al., 1997	1 WN9h, 2 WN11
Crowther and Smith, 1997	6 LMC WNL
Crowther and Dessart, 1998	10 WN5–6 with *HST*-FOS;
Walborn and Fitzpatrick, 2000	11 WN6–11
Williams and van der Hucht, 2000	8 WC9

Table 7
Near-infrared ($\lambda > 1$ μm) spectra and spectral atlases of galactic WR stars

References	λ (μm)	$\lambda/\Delta\lambda$	WR stars
Barnes et al., 1974	0.9–1.7	3000	WR 11 (WC8)
Cohen and Vogel, 1978	2–4	60	WR 136 (WN6), 8 WC7–9
Aitken et al., 1980	8–13	70	WR 104, WR 112 (WC9d)
Williams et al., 1980	1.4–2.5	77	WR 6 (WN4), WC stars WR 4, WR 5, WR 135, WR 140
Aitken et al., 1982	*HKLN*-band	100	WR 11 (WC8)
Williams, 1982a,b	1.4–4.1	100	3 WN, 3 WC, 1 WO
Hillier et al., 1983	1–4.2	700	WR 6 (WN4)
Hillier and Hyland, 1983	2.0–2.3		WR 11 (WC8)
Vreux et al., 1983	0.575–1.035		12 WN, 14 WC stars
Lambert and Hinkle, 1984	2.0–2.4	24 000	WR 140 (WC7)
Hillier, 1985	1–2.5	>400	WR 16, WR 40 (WN8), WR 78 (WN7)
Glasse et al., 1986	11–13	1100	WR 104 (WC9d)
Moorwood, 1985	*K*-band	1000	WR 11 (WC8)
Moorwood et al., 1986	*J*-band	1900	WR 11 (WC8)
Barlow et al., 1988	12.3–13.3	320	WR 11 (WC8)
Smith and Hummer, 1988	*HK*-band	100	17 WC stars
Cohen et al., 1989	5–22		WR 104, WR 112 (WC9d)
Schmutz et al., 1989	1.060–1.105	1550	5 WN, 6 WC
Vreux et al., 1989	0.615–1.035		3 WN
Williams and Eenens, 1989	2.0–2.1	500–1200	WR 6 (WN4), WR 155 (WN6), 6 WC
Williams and Eenens, 1989	2.040–2.056	2600	WR 135 (WC8), WR 140 (WC7)
Vreux et al., 1990	0.99–1.10		20 WN, 10 WC stars
Werner et al., 1990	3.09	1000	WR 108 (WN9), WR 5 (WC6)
Eenens et al., 1991	1.0–3.4	300–600	6 WC
Krabbe et al., 1991	2.06	1000	WR 101b,c,i,k,l (WN9–11)
Sandford et al., 1991	2.8–3.7	160–880	WR 104, WR 118 (WC9d)
Howarth and Schmutz, 1992	0.97–1.12		19 WN, 7 WC, 1 WO
Eenens and Williams, 1994	1-, 2-μm	640, 900	20 WN, 21 WC
Najarro et al., 1994	2.04–2.35	2200	WR 101c (WN9–11)
Pendleton et al., 1994	2.8–3.7	160–880	WR 104, WR 112, WR 118, WR 121 (WC9d)
Blum et al., 1995a	2.03–2.35	570	WR 101a (WC9)
Blum et al., 1995b	1.4–2.5	570	WR 108 (WN9)
Conti et al., 1995	*K*-band		WR 25 (WN6), WR 78 (WN7)
Figer et al., 1995	2.03–2.40	530	WR 102d (WN9), WR 102h, WR 121 (WC9)
Krabbe et al., 1995	1.9–2.4	650–1310	WR 101g, WR 101n (WC9)
Libonate et al., 1995	*HK*-band	250, 850	WR 101c,k,l,j (WN9–11), WR 136 (WN6)
Cotera et al., 1996	*HK*-band	250	6 WN6–8
Crowther and Smith, 1996	*IHK*-band	800	9 WN3–9
Genzel et al., 1996	*K*-band	1000	WR 101e,f (WN9–10), WR 101b,c,i,j,k,l (WN9–11), WR 101a,g (WC9)
Imanishi et al., 1996	1.2–4.2	40	WR 104, WR 112 (WC9d)
van Kerkwijk et al., 1996	*K*-band	200–300	WR 145a (WN4–7)
Morris et al., 1996a	*HK*-band	570–1600	9 WN
Tamblyn et al., 1996	2.04–2.24		10 WN
Crowther and Bohannan, 1997	2.02–2.23	1300	WR 79a (WN9)
Crowther and Bohannan, 1997		600–850	WR 108 (WN9)
Figer et al., 1997	*K*-band	525	19 WN, 2 WN/WC, 16 WC, 1 WO
Najarro et al., 1997	*K*-band		WR 101e,f (WN9–10), WR 101i,j,k,l,m (WN9–11)
Blum et al., 1999	2.02–2.25	570	WR 121a (WN7)
Bohannan and Crowther, 1999	*IK*-band	3000	WR 79a,b, WR 105, WR 108 (WN9)
Cotera et al., 1999	*HK*-band	250	WR 102b (WN6), WR 102a (WN8)

Table 7. Continued

References	λ (μm)	$\lambda/\Delta\lambda$	WR stars
Crowther et al., 1999	1.66–2.27	800	WR 124 (WN8)
Dessart et al., 1999	He II 3.09	1300	WR 105 (WN9), WR 124 (WN8)
Fender et al., 1999	2.03–2.20	1200	WR 145a (WN4–7)
Figer et al., 1999a	2.03–2.40	525	22 WN, 20 WC
J.D. Smith and Houck, 1999	7.9–13.2	600	WR 136 (WN6), WR 138 (WN5), WR 147 (WN8)
Stevens and Howarth, 1999	He I 1.083	3400	5 WN (WN5–6), WR 113 (WC8)
C.H. Smith et al., 2000	7.5–13.5	40	WR 48a, WR 112, WR 118 (WC9d)

Table 8
IRAS-LRS spectra (8–22 μm, $\lambda/\Delta\lambda \simeq 30$) of galactic WR stars

References	WR stars
van der Hucht and Olnon, 1985	WR 11 (WC8)
van der Hucht et al., 1985a,b	WR 11 (WC8), WR 104, WR 112, WR 118 (WC9)
Olnon and Raimond, 1986	WR 11 (WC8), WR 112 (WC9)
Volk and Cohen, 1989	WR98a, WR 104, WR 118 (WC9)
Cohen, 1995	2 WN, 9 WC, 1 WO

Table 9
ISO-SWS spectra (2.4–29 μm, $\lambda/\Delta\lambda \simeq 250$–1700) of galactic WR stars

References	WR stars
van der Hucht et al., 1996	WR 11, WR 45a (WC8), WR 98a (WC8–9), WR 104, WR 112, WR 118 (WC9)
Willis et al., 1997	WR 146 (WC6)
Morris et al., 1998	WR 78 (WN7), WR 136 (WN6), WR 147 (WN8), WR 11 (WC8), WR 140 (WC7), WR 146 (WC6)
Williams et al., 1998	WR 104, WR 112, WR 118 (WC9)
Morris et al., 1999	WR 147 (WN8), WR 11, WR 135 (WC8)
Dessart et al., 2000	WR 90 (WC7)
Morris et al., 2000	WR 147 (WN8)
Morris et al., 2001	all *ISO*-SWS WR spectra

Table 10
Stars deleted from *The VIth Catalogue of Galactic Wolf–Rayet Stars*

Stars	Other design.	Old type	Ref.[a]	v	$b-v$	RA (1950)	Dec (1950)	New type	Ref.
WR 72	Sand 3	WC4pec	a	(14.24)	(0.21)	16 03 12.6	−35 37 10	PN [WOI]	d, e
WR 99	DA 2	WN	b	(16.0)	...	17 36 08.8	−28 13 30	symbiotic	f
WR 122	NaSt 1	WN10	c	15.4	1.5	18 49 44.8	+00 56 03	O[e]/B[e], hidden WN	g, h

[a] (a) van der Hucht et al., 1981; (b) Allen, 1979; (c) Massey and Conti, 1983; (d) Barlow and Hummer, 1982; (e) Crowther et al., 1998; (f) Mikolajewska et al., 1997; (g) van der Hucht et al., 1997a; (h) Crowther and Smith, 1999.

Table 11
Wolf–Rayet stars found after 1981 but later rejected

Stars	Suggested type	Ref.[a]	v	$b-v$	RA (1950)	Dec. (1950)	Type	Ref.
M1–13, PK 232–1°1	WC	a	10.	...	07 19 01.2	−18 02 51	PN	d, e
Pe1-7, PK 337+1°1	[WC9]/WC9	b	16.43	1.12	16 26 48.1	−45 56 22	PN [WC9]	d, f
LSS 4005, WRA 1656	WN11	c	14.05	1.12	17 12 36.8	−38 12 22	O[e]/B[e]	g

[a] (a) Gyul'budagyan et al., 1984; (b) Lundström and Stenholm, 1984c; (c) Lundström and Stenholm, 1983; (d) van der Hucht and Williams, 1987; (e) Acker et al., 1992; (f) Tylenda et al., 1993; (g) van der Hucht et al., 1997b.

- the renumbering of WR 29a to WR 30a;
- the rejection of three supposedly new WR stars (Table 11); and
- the discovery of 71 new WR stars (Table 12), which we include in the WR numbering system of van der Hucht et al. (1981), to compile this *VIIth Catalogue of Galactic Wolf–Rayet Stars* (Tables 13–15).

Discovery of the 71 new WR stars comprises numerous efforts, including, in chronological order:

- Danks et al. (1983) discovered a faint WC8 star with variable IR emission (WR 48a);
- Acker and Stenholm (1990) reclassified the planetary nebula Th3-28 (Thé, 1964; PK 359+3 1) as a WN2.5–3 star (WR 93a);
- Panov and Seggewiss (1990) found that the quadruple system WR 153 (GP Cep) harbours two WN+O systems, while Smith et al. (1996) classified the object WN6o/WCE+O6I;
- Cohen et al. (1991) classified IRAS 17380-3031 as a WC8–9 star (WR 98a);

Table 12
New galactic Wolf–Rayet stars, discovered since 1981

New WR number	Other designation(s)	Spectral type	References
7a	MP 1, SPH 2	WN/C	Pereira et al., 1998
19a, 20ab, 31c, 35ab, 38ab, 42abcd, 44a	SMSP series	11 WN, 2 WC	Shara et al., 1991
21a	Th35-42, 1E 1024.0-5732	WN6	Mereghetti et al., 1994
31ab	AG Car, He3-519	2 WN11	Smith et al., 1994a,b
43abc	WR 43 in NGC 3603	3 WN	Drissen et al., 1995
45abc, 46a, 47bc, 48bc, 56a, 62ab, 68a, 70a, 75ab, 102l, 107a	SMSPN series	11 WN, 5 WC, 1 WN/WC	Shara et al., 1999
47a	We 21, SMSPN 5	WN8	Crawford and Barlow, 1991b
48a	Danks 1	WC8	Danks et al., 1983
79ab	HD 152408, HD 152386	WN9ha	Bohannan and Crowther, 1999
93a	Th3-28, PK 359+03 1	WN2.5–3	Acker and Stenholm, 1990
98a	IRAS 17380–3031	WC8–9	Cohen et al., 1991
101a	BSD 1	WC9	Blum et al., 1995a
101bcdefghijklmno	KGE series	5 WC9, 9 WN9–10	Krabbe et al., 1995, Najarro et al., 1997
102ab	CSE series	WN8, WN6	Cotera et al., 1996, 1999
102dh	FMM95 series	WN9, WC9	Figer et al., 1995
102cefijk	FMM96 series	3 WN, 3 WC	Figer et al., 1996, 1999a
102g	FMM99	WC	Figer et al., 1999b
121a	W 43#1	WN7	Blum et al., 1999
145a	Cyg X-3	WN4–7	van Kerkwijk et al., 1992
153ab	WR 153	2×WN+O	Panov and Seggewiss, 1990

Table 13
The VIIth catalogue of galactic Wolf–Rayet stars: location

WR	Name	Variable star name	HD/CD/ other	LS/LSS	HIP/TYC/ GSC/PPM	R.A. (2000)	Dec. (2000)	Ref.	l^{II}	b^{II}	Finding chart ref.
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(7)	(8)		(9)
1			HD 4004	I+64 34	HIP 3415	00 43 28.40	+64 45 35.4	Hip	122.08	+1.90	*VI*
2			HD 6327	I+60 137	HIP 5100	01 05 23.03	+60 25 18.9	Hip	124.65	−2.41	*VI*
3			HD 9974	I+57 24	HIP 7681	01 38 55.63	+58 09 22.7	Hip	129.18	−4.14	*VI*
4		V493 Per	HD 16523	I+56 62	HIP 12527	02 41 11.68	+56 43 49.7	Hip	137.59	−2.98	*VI*
5			HD 17638	I+56 77	HIP 13380	02 52 11.66	+56 56 07.1	Hip	138.87	−2.15	*VI*
6	HR 2583	EZ CMa	HD 50896	98	HIP 33165	06 54 13.05	−23 55 42.1	Hip	234.76	−10.08	*VI*
7			HD 56925	299	HIP 35378	07 18 29.13	−13 13 01.5	Hip	227.75	−0.13	*VI*
7a	PMLC 1		SPH 2		GSC 6537-0281	07 20 22.38	−23 43 57.6	GSC	237.27	−4.64	SP90
8			HD 62910	731	HIP 37791	07 44 58.22	−31 54 29.6	Hip	247.07	−3.79	*VI*
9	IC 2206		HD 63099	753	HIP 37876	07 45 50.40	−34 19 48.5	Hip	249.27	−4.84	*VI*
10	AS 193		HD 65865	916	HIP 39086	07 59 46.25	−28 44 03.1	Hip	245.98	+0.58	*VI*
11	γ^2 Vel		HD 68273	980	HIP 39953	08 09 31.96	−47 20 11.8	Hip	262.80	−7.69	*VI*
12	Ve5-5		CD−45 4482	1145	GSC 8151-4295	08 44 47.25	−45 58 55.5	GSC	265.20	−1.97	*VI*
13	Ve6-15			1170	GSC 8152-2075	08 49 52.88	−45 10 24.1	GSC	265.13	−0.77	*VI*
14	Ve5-8		HD 76536	1202	HIP 43778	08 54 59.17	−47 35 32.7	Hip	267.55	−1.64	*VI*
15	Ve5-10		HD 79573	1259	HIP 45237	09 13 11.77	−50 06 25.6	Hip	271.42	−1.08	*VI*
16		V396 Car	HD 86161	1374	HIP 48617	09 54 52.91	−57 43 38.3	Hip	281.08	−2.55	*VI*
17			HD 88500	1440	HIP 49838	10 10 31.92	−60 38 42.4	Hip	284.44	−3.69	*VI*
18		V500 Car	HD 89358	1481	HIP 50368	10 17 02.28	−57 54 46.9	Hip	283.57	−0.97	*VI*
19	LS 3					10 18 05.02	−58 16 25.9	L2	283.89	−1.19	*VI*
19a	SMSP 1					10 18 53.4	−58 07 53	SM91	283.90	−1.01	SM91
20	BS 1		Th35-24			10 19 18.5	−59 09 37	VIp	284.51	−1.84	*VI*
20a	SMSP 2		Th35-36			10 23 58.0	−57 45 49	SM91	284.27	−0.34	SM91, BM94
20b	SMSP 3		Th35-37	SPH 56		10 24 18.4	−57 48 30	SM91	284.33	−0.35	SM91
21		V398 Car	HD 90657	1568	HIP 51109	10 26 31.42	−58 38 26.2	Hip	285.02	−0.90	*VI*
21a	1E 1024.0–5732		Th35-42		GSC 8608-0157	10 25 56.49	−57 48 44.4	MB94	284.52	−0.24	Th35-42
22	HR 4188	V429 Car	HD 92740	1761	HIP 52308	10 41 17.52	−59 40 36.9	Hip	287.17	−0.85	*VI*
23			HD 92809	1768	HIP 52331	10 41 38.33	−58 46 18.8	Hip	286.78	−0.03	*VI*
24			HD 93131	1817	HIP 52448	10 43 52.27	−60 07 04.0	Hip	287.67	−1.08	*VI*
25			HD 93162	1833	PPM 339385	10 44 10.39	−59 43 11.0	L1	287.51	−0.71	*VI*
26	MS 1		SPH 86	1841		10 44 32.08	−57 50 23.7	Wi99	286.68	+0.97	*VI*
27	LS 4			1850		10 44 38.07	−58 48 28.9	Wi99	287.14	+0.12	*VI*
28	MS 2		Th35-112	SPH 95	GSC 8626-1709	10 48 58.68	−59 03 37.5	GSC	287.75	+0.15	*VI*
29	MS 3		Th35-117	1964	GSC 8957-2405	10 50 46.30	−60 28 41.6	GSC	288.59	−1.01	*VI*
30			HD 94305	1970	TYC 8961 618 1	10 51 06.01	−62 17 01.8	Tyc	289.44	−2.61	*VI*

Table 13. Continued

WR	Name	Variable star name	HD/CD/ other	LS/LSS	HIP/TYC/ GSC/PPM	R.A. (2000)	Dec. (2000)	Ref.	l^{II}	b^{II}	Finding chart ref.
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(7)	(8)		(9)
30a	MS 4					10 51 38.93	−60 56 35.2	Wi99	288.90	−1.38	*VI*
31		V428 Car	HD 94546	2010	HIP 53274	10 53 44.83	−59 30 46.7	Hip	288.50	+0.02	*VI*
31a	He3-519		IRAS 10520-6010	2015		10 53 59.66	−60 26 44.3	Sim	288.94	−0.81	LSS
31b		AG Car	HD 94910	2035	HIP 53461	10 56 11.58	−60 27 12.8	Hip	289.18	−0.70	HL92
31c	SMSP 4[a]					10 57 43.0	−60 34 01	SM91	289.40	−0.72	SM91
32	MS 5					10 59 52.94	−59 52 43.2	Wi99	289.36	+0.02	*VI*
33			HD 95435	2076	GSC 8623-0928	11 00 00.72	−57 48 59.5	GSC	288.51	+1.90	*VI*
34	LS 5		SPH 122			11 00 06.44	−61 26 29.9	Wi99	290.03	−1.39	*VI*
35	MS 6		Th35-159	SPH 123		11 00 22.1	−61 13 51	VIp	289.97	−1.19	*VI*
35a	SMSP 5					11 00 24.5	−59 59 36	SM91	289.46	−0.06	SM91
35b	SMSP 6					11 01 02.3	−60 14 01	SM91	289.63	−0.24	SM91
36	LS 6			2112	GSC 8627-1968	11 02 32.87	−59 26 21.5	GSC	289.48	+0.56	*VI*
37	MS 7					11 05 13.92	−61 20 41.4	Wi99	290.55	−1.05	*VI*
38	MS 8					11 05 46.52	−61 13 49.1	Wi99	290.57	−0.92	VI, Tu99
38a	SMSP 7					11 05 49.0	−61 13 41	SM91	290.57	−0.92	SM91, Tu99
38b	SMSP 8					11 06 18.7	−61 14 13	SM91	290.63	−0.90	SM91, Tu99
39	MS 9					11 06 18.70	−61 14 18.3	Wi99	290.63	−0.90	*VI*, Tu99
40		V385 Car	HD 96548	2154	HIP 54283	11 06 17.21	−65 30 35.2	Hip	292.31	−4.83	*VI*
41	LS 7			2173		11 07 54.05	−61 27 41.0	Wi99	290.89	−1.03	*VI*
42		V431 Car	HD 97152	2198	HIP 54574	11 10 04.09	−60 58 45.0	Hip	290.95	−0.49	*VI*
42a	SMSP 9					11 12 15.9	−61 05 04	SM91	291.23	−0.49	SM91
42b	SMSP 10					11 13 03.8	−62 14 18	SM91	291.75	−1.52	SM91
42c	SMSP 11					11 14 01.6	−61 03 47	SM91	291.42	−0.39	SM91
42d	SMSP 12					11 14 38.8	−61 11 16	SM91	291.54	−0.48	SM91
43a			HD 97950-A1	2275a		11 15 07.47	−61 15 38.16	DM95	291.62	−0.52	DM95
43b			HD 97950-B	2275b		11 15 07.58	−61 15 38.32	DM95	291.62	−0.52	DM95
43c			HD 97950-C	2275c		11 15 07.76	−61 15 37.75	DM95	291.62	−0.52	DM95
44				2289		11 16 57.86	−59 26 24.0	Wi99	291.18	+1.26	*VI*
44a	SMSP 13					11 18 43.5	−61 26 37	SM91	292.09	−0.54	SM91
45				2423		11 38 05.2	−62 16 01	VIp	294.51	−0.60	*VI*
45a	SMSNPL 1					11 46 18.22	−61 24 41.1	SM99	295.22	+0.48	SM99
45b	SMSNPL 2					11 48 46.18	−62 23 03.5	SM99	295.74	−0.39	SM99
45c	SMSNPL 3					11 56 04.77	−62 44 05.3	SM99	296.64	−0.54	SM99
46		DI Cru	HD 104994	2584	HIP 58954	12 05 18.73	−62 03 10.1	Hip	297.56	+0.34	*VI*, VG00
46a	SMSNPL 4					12 13 02.29	−63 42 25.9	SM99	298.69	−1.15	SM99

47		CD Cru	HDE 311884	2745	HIP 62115	12 43 51.01	−63 05 14.8	Hip	302.07	−0.23	*VI*
47a	SMSNPL 5		We 21			12 45 51.27	−64 09 37.8	SM99	302.32	−1.30	DR90, SM99
47b	SMSNPL 6					12 48 07.63	−63 38 40.2	SM99	302.56	−0.78	SM99
47c	SMSNPL 7					12 52 55.67	−63 46 39.1	SM99	303.10	−0.91	SM99
48	θ Mus		HD 113904	2933	HIP 64094	13 08 07.16	−65 18 21.7	Hip	304.67	−2.49	*VI*
48b	SMSNPL 8[b]		IRAS 13082−6329			13 11 27.45	−63 46 00.8	SM99	305.14	−0.98	SM99
48a	Danks 1					13 12 39.65	−62 42 55.8	Wi98	305.36	+0.06	DD83
48c	SMSNPL 9					13 12 52.21	−63 23 46.4	SM99	305.33	−0.62	SM99
49	Th17-22			2979	GSC 8998-0104	13 13 51.33	−65 18 08.8	GSC	305.27	−2.53	*VI*
50		V864 Cen	Th2-84	3013	GSC 8994-2101	13 18 01.07	−62 26 04.5	GSC	306.00	+0.28	*VI*, Tu85
51	Th17-85			3017		13 18 22.8	−62 28 21	VIp	306.04	+0.24	*VI*, Tu85
52			HD 115473	3020	HIP 64929	13 18 28.00	−58 08 13.6	Hip	306.50	+4.54	*VI*
53			HD 117297	3101	HIP 65925	13 30 53.26	−62 04 51.8	Hip	307.53	+0.44	*VI*
54	Th17-89			3111	GSC 8999-3295	13 32 43.79	−65 01 27.9	GSC	307.27	−2.50	*VI*
55		V972 Cen	HD 117688	3114	HIP 66142	13 33 30.13	−62 19 01.2	Hip	307.80	+0.16	*VI*
56	LS 8			3117	GSC 8999-1206	13 33 45.37	−64 07 31.5	CSG	307.53	−1.63	*VI*
56a	SMSNPL 10					13 41 14.27	−60 53 52.5	SM99	308.95	+1.39	SM99
57			HD 119078	3149	HIP 66948	13 43 16.37	−67 24 04.9	Hip	307.89	−5.03	*VI*
58				3162	GSC 9016-1189	13 49 04.52	−65 41 56.0	GSC	308.82	−3.49	*VI*
59				3164	GSC 9004-3553	13 49 32.66	−61 31 42.2	GSC	309.80	+0.57	*VI*
60			HD 121194	3173		13 55 48.1	−61 09 50	VIp	310.61	+0.74	*VI*
61		CF Cir		3208	HIP 69445	14 13 03.53	−65 26 52.7	Hip	311.28	−3.91	*VI*
62	NS 2		Wra 16-154			14 31 06.10	−61 20 58.3	L2	314.59	−0.75	*VI*
62a	SMSNPL 11					14 32 38.18	−61 29 55.4	SM99	314.70	−0.96	SM99
62b	SMSNPL 12					14 46 41.01	−61 06 56.5	SM99	316.40	−1.29	SM99
63				3289	GSC 8692-0361	14 50 58.31	−59 51 26.7	GSC	317.42	−0.39	*VI*
64	BS 3					14 56 55.3	−55 50 58	VIp	319.95	+2.82	*VI*
65	Wra 1297			3319		15 13 41.68	−59 11 43.3	L2	320.27	−1.20	*VI*
66		CC Cir	HD 134877	3322	HIP 74634	15 14 57.72	−59 50 30.2	Hip	320.07	−1.83	*VI*
67				3329	GSC 8706-0600	15 15 32.61	−59 02 30.8	GSC	320.55	−1.19	*VI*
68	BS 4			3333		15 18 21.0	−59 38 10	VIp	320.54	−1.88	*VI*
68a	SMSNPL 13					15 23 16.56	−57 44 19.3	SM99	322.10	−0.63	SM99
69			HD 136488	3348	HIP 75377	15 24 11.31	−62 40 37.5	Hip	319.48	−4.82	*VI*
70			HD 137603	3362	HIP 75863	15 29 44.70	−58 34 51.2	Hip	322.34	−1.81	*VI*
70a	SMSNPL 14					15 59 25.40	−54 12 44.9	SM99	328.25	−0.85	SM99

(*continued on next page*)

Table 13. Continued

WR	Name	Variable star name	HD/CD/ other	LS/LSS	HIP/TYC/ GSC/PPM	R.A. (2000)	Dec. (2000)	Ref.	l^{II}	b^{II}	Finding chart ref.
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(7)	(8)		(9)
71		LT TrA	HD 143414		HIP 78689	16 03 49.35	−62 41 35.8	Hip	323.08	−7.61	*VI*
73	NS 3		Wra 16-206			16 12 37.5	−46 37 35	VIp	334.89	+3.38	*VI*
74	BP 1					16 16 13.7	−51 36 41	VIp	331.88	−0.64	*VI*
75			HD 147419	3595	TYC 8324 3694	16 24 26.23	−51 32 06.1	Tyc	332.84	−1.48	*VI*
75a	SMSNPL 15					16 26 37.27	−50 19 22.8	SM99	333.95	−0.88	SM99
75b	SMSNPL 16		SPH 149			16 28 17.19	−48 17 43.0	SM99	335.59	+0.33	SM99
76			SPH 152	3693		16 40 05.3	−45 41 10	VIp	338.88	+0.62	*VI*
77	He3-1239			3703	GSC 8330-4677	16 41 19.12	−48 01 59.6	GSC	337.26	−1.09	*VI*
78	HR 6249	V919 Sco	HD 151932	3785	HIP 82543	16 52 19.25	−41 51 16.2	Hip	343.22	+1.43	*VI*
79	HR 6265		HD 152270	3810	HIP 82706	16 54 19.70	−41 49 11.5	Hip	343.49	+1.16	*VI*
79a	HR 6272		HD 152408	3828	HIP 82775	16 54 58.51	−41 09 03.1	Hip	344.08	+1.49	LSS
79b			HD 152386	3825	TYC 7880 313 1	16 55 06.45	−44 59 21.4	Tyc	341.11	−0.94	LSS
80				3871		16 59 02.2	−45 43 06	VIp	340.97	−1.93	*VI*
81	He3-1316			3891	GSC 8327-0141	17 02 40.39	−45 59 15.5	GSC	341.15	−2.60	*VI*
82	LS 11			3896	GSC 8328-1231	17 04 04.61	−45 12 15.0	GSC	341.92	−2.32	*VI*
83	He3-1344			3948		17 10 54.5	−46 36 18	VIp	341.51	−4.11	*VI*
84	Thé 3		Th31-1	3951	GSC 7874-0307	17 11 21.70	−39 53 22.2	GSC	346.98	−0.21	*VI*
85			HD 155603-B	3982	TYC 7874 1219	17 14 27.13	−39 45 47.0	Tyc	347.43	−0.61	*VI*
86		V1035 Sco	HD 156327	4057	HIP 84655	17 18 23.06	−34 24 30.6	Hip	352.25	+1.85	*VI*
87				4064	GSC 7870-1223	17 18 52.89	−38 50 04.5	GSC	348.69	−0.77	*VI*
88	Thé 1		CD −33 11955	4068		17 18 49.50	−33 57 39.8	L2	352.67	+2.04	*VI*
89	AS 223		CD −38 11746	4065	HIP 84716	17 19 00.52	−38 48 51.2	Hip	348.72	−0.78	*VI*
90			HD 156385	4066	HIP 84757	17 19 29.90	−45 38 23.8	Hip	343.16	−4.76	*VI*
91	StSa 1					17 20 22.0	−38 56 47	VIp	348.76	−1.07	*VI*
92			HD 157451	4144	TYC 7895 1089	17 25 23.15	−43 29 31.9	GSC	345.54	−4.42	*VI*
93	Th10-19		HD 157504	4148	GSC 7383-0162	17 25 08.88	−34 11 12.8	GSC	353.23	+0.83	*VI*
93a	Th3-28					17 30 56.8	−26 59 10	p	359.92	+3.78	Th3-28
94	Th10-27		HD 158860	4208	GSC 7380-0394	17 33 07.14	–33 38 23.7	GSC	354.60	−0.25	*VI*
95	He3-1434			4261		17 36 19.76	−33 26 10.9	L2	355.13	−0.70	*VI*
96				4265		17 36 24.2	−32 54 29	VIp	355.58	−0.43	*VI*

97			HDE 320102	4275	HIP 86197	17 36 53.62	−34 02 36.8	Hip	354.68	−1.12	*VI*
98	Tr27-105		HDE 318016	4282	GSC 7380-0192	17 37 13.75	−33 27 55.9	GSC	355.21	−0.87	*VI*
98a			IRAS 17380−3031			17 41 12.9	−30 32 29	WC95p	358.13	−0.03	WC95
100			HDE 318139	4334	GSC 7381-1214	17 42 09.77	−32 33 24.7	GSC	356.53	−1.26	*VI*
101	DA 3					17 45 09.1	−31 50 16	VIp	357.47	−1.43	*VI*
101a	BSD 1					17 45 39.49	−29 00 34.22	BS96	359.94	−0.05	BS95
101b	KGE 1		AF-NW			17 45 39.57	−29 00 31.96	BS96	359.94	−0.05	KG95
101c	KGE 2		AF			17 45 39.63	−29 00 35.57	BS96	359.94	−0.05	KG95
101d	KGE 3		GC IRS 6E			17 45 39.63	−29 00 27.0	Kr98	359.94	−0.05	KG95
101e	KGE 4		GC IRS 7W			17 45 39.75	−29 00 22.8	Kr98	359.94	−0.05	KG95
101f	KGE 5		GC IRS 13E1			17 45 39.80	−29 00 29.5	Ec98	359.94	−0.05	KG95
101g	KGE 6		GC IRS 29N			17 45 39.91	−29 00 26.4	Kr98	359.94	−0.05	KG95
101h	KGE 7		MPE −1.0, −3.5			17 45 39.97	−29 00 25.8	Kr98	359.94	−0.05	KG95
101i	KGE 8		GC IRS 15SW			17 45 40.02	−29 00 16.7	BS96	359.95	−0.04	KG95
101j	KGE 9		GC IRS 16NW			17 45 40.05	−29 00 27.40	BS96	359.94	−0.05	KG95
101k	KGE 10		GC IRS 16S			17 45 40.09	−29 00 29.83	BS96	359.94	−0.05	KG95
101l	KGE 11		GC IRS 16C			17 45 40.12	−29 00 28.29	BS96	359.94	−0.05	KG95
101m	KGE 12		GC IRS 15N			17 45 40.13	−29 00 17.07	BS96	359.94	−0.05	KG95
101n	KGE 13		MPE +1.6, −6.8			17 45 40.17	−29 00 28.9	Kr98	359.94	−0.05	KG95
101o	KGE 14		MPE +2.7, −6.9			17 45 40.21	−29 00 29.2	Kr98	359.94	−0.05	KG95
102	Sand 4	V3899 Sgr		4368		17 45 47.0	−26 10 29	VIp	2.38	+1.41	*VI*
102a	CSE1					17 45 48.5	−28 50 05.0	CS99	0.11	+0.02	CS99
102b	CSE2					17 45 50.4	−28 59 19.8	CS99	359.98	−0.07	CS99
102c	FMM96-1		qF 353E			17 46 11.2	−28 49 05.6	FM99p	0.17	−0.04	FM99
102d	FMM95-1		qF 320			17 46 14.2	−28 49 16.8	FM99p	0.17	−0.06	FM99
102e	FMM96-2		qF 151			17 46 14.9	−28 50 00.8	FM99p	0.16	−0.06	FM99
102f	FMM96-3		qF 235N			17 46 15.17	−28 49 40.35	FM99p	0.16	−0.06	FM99
102g	FMM99-1		qF 235S			17 46 15.18	−28 49 42.52	FM99p	0.16	−0.06	FM99
102h	FMM95-2		qF 76			17 46 15.6	−28 50 18.6	FM99p	0.16	−0.07	FM99
102i	FMM96-4		qF 256			17 46 16.6	−28 49 32.1	FM99p	0.17	−0.07	FM99
102j	FMM96-5		qF 274			17 46 17.6	−28 49 29.2	FM99p	0.17	−0.07	FM99
102k	FMM96-6		qF 309			17 46 17.6	−28 49 18.9	FM99p	0.17	−0.07	FM99
102l	SMSNPL 17[c]					18 00 34.32	−22 47 39.2	SM99	7.00	0.23	SM99
103		V4072 Sgr	HD 164270	4552	HIP 88287	18 01 43.14	−32 42 55.2	Hip	358.49	−4.89	*VI*
104	Ve2-45		IRC−20417			18 02 04.07	−23 37 41.2	L2	6.44	−0.49	*VI*
105	Ve2-47		NS 4, AS 268	4569	GSC 6842-1547	18 02 23.46	−23 34 37.7	GSC	6.52	−0.52	*VI*
106	IC14-8		HDE 313643	4628	GSC 6263-1874	18 04 43.66	−21 09 30.7	GSC	8.90	+0.20	*VI*
107	DA 1		AD2-11			18 04 46.1	−21 51 27	VIp	8.29	−0.16	*VI*
107a	SMSNPL 18					18 05 11.48	−22 13 22.4	SM99	8.02	−0.42	SM99
108	LS 14		HDE 313846	4637	HIP 88597	18 05 25.74	−23 00 20.3	Hip	7.36	−0.85	*VI*

(*continued on next page*)

Table 13. Continued

WR	Name	Variable star name	HD/CD/ other	LS/LSS	HIP/TYC/ GSC/PPM	R.A. (2000)	Dec. (2000)	Ref.	l^{II}	b^{II}	Finding chart ref.
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(7)	(8)		(9)
109	NS 5	V617 Sgr				18 07 51.5	−35 10 20	VIp	356.94	−7.19	*VI*
110			HD 165688	4678	HIP 88828	18 07 56.96	−19 23 56.8	Hip	10.80	+0.39	*VI*
111			HD 165763	4685	HIP 88856	18 08 28.47	−21 15 11.2	Hip	9.24	−0.61	*VI*
112	GL 2104		IRAS 18136−1859			18 16 33.49	−18 58 42.5	L2	12.15	−1.19	*VI*
113		CV Ser	HD 168206	IV−11 14	HIP 89769	18 19 07.36	−11 37 59.2	Hip	18.91	+1.75	*VI*
114	IC14-17		HD 169010	4994	GSC 5702-1056	18 23 16.39	−13 43 25.8	GSC	17.54	−0.13	*VI*
115	IC14-19			5023	HIP 90299	18 25 30.01	−14 38 40.9	Hip	16.98	−1.03	*VI*
116	AS 306			IV−12 59	GSC 5698-3822	18 27 04.28	−12 22 52.3	GSC	19.16	−0.32	*VI*
117	IC14-22			IV−6 7	GSC 5124-1254	18 31 02.54	−06 35 49.5	GSC	24.74	+1.50	*VI*
118	GL 2179		IRAS 18289−1001			18 31 42.3	−09 59 15	VIp	21.81	−0.21	*VI*
119	Thé 2		Th20-1	IV−10 13	GSC 5696-0847	18 39 17.91	−10 05 31.1	GSC	22.57	−1.92	*VI*
120	Vy1-3		Th14-4	IV−4 14	GSC 5121-0128	18 41 00.88	−04 26 14.3	GSC	27.80	+0.29	*VI*
121	AS 320			IV−3 9	HIP 91911	18 44 13.15	−03 47 57.8	Hip	28.73	−0.13	*VI*
121a	W43#1					18 47 36	−01 56 32.9	BD99	30.77	−0.03	BD99
123		V1402 Aql	HD 177230	IV−4 33	HIP 93626	19 03 59.02	−04 19 01.9	Hip	30.51	−4.75	*VI*
124	209 BAC	QR Sge	Merrill's*	II+16 4	HIP 94289	19 11 30.88	+16 51 38.2	Hip	50.20	+3.31	*VI*
125	IC14-36	V378 Vul			GSC 1609-0416	19 28 15.57	+19 33 21.1	GSC	54.44	+1.06	*VI*
126	ST 2				GSC 2146-2748	19 39 56.20	+26 34 42.0	GSC	61.89	+2.11	*VI*
127		QY Vul	HD 186943	II+28 7	HIP 97281	19 46 15.94	+28 16 19.1	Hip	64.06	+1.73	*VI*
128		QT Sge	HD 187282	II+18 14	HIP 97456	19 48 32.20	+18 12 03.7	Hip	55.62	−3.79	*VI*
129	Sey 1				GSC 2669-4572	19 48 18.25	+30 26 52.1	GSC	66.16	+2.44	*VI*
130	LS 16				GSC 2670-1448	19 59 12.68	+31 27 09.7	GSC	68.22	+0.98	*VI*
131	IC14-52			II+33 14	HIP 98466	20 00 19.12	+33 15 51.1	Hip	69.90	+1.71	*VI*
132			HD 190002	II+32 12	GSC 2674-1901	20 01 39.75	+32 34 18.1	GSC	69.46	+1.10	*VI*
133		V1676 Cyg	HD 190918	II+35 33	HIP 99002	20 05 57.33	+35 47 18.2	Hip	72.65	+2.06	*VI*
134		V1769 Cyg	HD 191765	II+36 23	HIP 99377	20 10 14.20	+36 10 35.1	Hip	73.45	+1.55	*VI*
135		V1042 Cyg	HD 192103	II+36 27	HIP 99525	20 11 53.53	+36 11 50.6	Hip	73.65	+1.28	*VI*
136		V1770 Cyg	HD 192163	II+38 11	HIP 99546	20 12 06.55	+38 21 17.8	Hip	75.48	+2.43	*VI*
137		V1679 Cyg	HD 192641	II+36 38	HIP 99769	20 14 31.77	+36 39 39.6	Hip	74.33	+1.09	*VI*
138			HD 193077	II+37 43	HIP 99982	20 17 00.03	+37 25 23.8	Hip	75.23	+1.11	*VI*

139		V444 Cyg	HD 193576	II + 38 42	HIP 100214	20 19 32.42	+38 43 54.0	Hip	76.60	+1.43	*VI*
140		V1687 Cyg	HD 193793	III + 43 7	HIP 100287	20 20 27.98	+43 51 16.3	Hip	80.93	+4.18	*VI*
141			HD 193928	II + 36 65	HIP 120155	20 21 31.73	+36 55 12.8	Hip	75.33	+0.08	*VI*
142	Sand 5				GSC 2684-0001	20 21 44.36	+37 22 30.3	GSC	75.73	+0.30	*VI*, TF82
143			HD 195177	II + 38 90	GSC 3152-1081	20 28 22.68	+38 37 18.9	GSC	77.50	−0.05	*VI*
144	HM19-1					20 32 03.1	+41 15 19.9	VIp	80.04	+0.93	*VI*
145	AS 422	V1923 Cyg			GSC 3157-0233	20 32 06.28	+40 48 29.7	GSC	79.69	+0.66	*VI*
145a	Cyg X-3	V1521 Cyg				20 32 26.6	+40 57 09	Sim	79.84	+0.69	WK89, FB96
146	HM19-3				GSC 3161-1125	20 35 47.09	+41 22 44.71	DW00	80.56	+0.45	*VI*
147	AS 431		IRAS 20349 + 4010			20 36 43.65	+40 21 07.32	WD97p	79.85	−0.32	*VI*
148	AS 438	V1696 Cyg	HD 197406	III + 52 2	HIP 102088	20 41 21.55	+52 35 15.2	Hip	90.08	+6.47	*VI*
149	ST 4				GSC 3592-6255	21 07 11.68	+48 25 36.2	GSC	89.53	+0.65	*VI*
150	ST 5				GSC 3616-1163	21 50 05.57	+50 42 24.8	GSC	96.13	−2.48	*VI*
151		CX Cep		III + 57 26	GSC 3977-0446	22 09 33.47	+57 44 30.7	GSC	102.66	+1.39	*VI*
152			HD 211564	III + 55 30	GSC 3986-2068	22 16 24.05	+55 37 37.2	GSC	102.23	−0.89	*VI*
153ab		GP Cep	HD 211853	III + 55 34	HIP 110154	22 18 45.61	+56 07 33.9	Hip	102.78	−0.65	*VI*
154			HD 213049	III + 55 79	HIP 110836	22 27 17.82	+56 15 11.8	Hip	103.85	−1.18	*VI*
155		CQ Cep	HD 214419	III + 56 80	HIP 111633	22 36 53.96	+56 54 21.0	Hip	105.32	−1.29	*VI*
156	AC + 60 38562-0			III + 60 30	HIP 113569	23 00 10.13	+60 55 38.4	Hip	109.82	+0.92	*VI*
157			HD 219460	III + 60 55	HIP 114791	23 15 12.41	+60 27 01.9	Hip	111.33	−0.24	*VI*
158	AS 513			I + 61 27	HIP 117034	23 43 30.60	+61 55 48.1	Hip	115.03	+0.10	*VI*

Table 14
The VIIth catalogue of galactic Wolf – Rayet stars: environment

WR (1)	HD/Name	Correlation with open cluster (10a)	Correlation with OB association (10b)	Ref. (10)	Correlation with ring nebula, H II region, H I bubble (11)	Ref. (11)
1	HD 4004		Cas OB7:	*VI*, LS84, GS92		
2	HD 6327		Cas OB1:	*VI*, LS84	H I bubble, *IRAS* shell	Ma96, AC99
3	HD 9974				H I bubble, *IRAS* shell	Ar92, Ma96, AR97
4	HD 16523				H I bubble, *IRAS* shell	Ar92, Ma96
5	HD 17638				H I bubble, *IRAS* shell	Ar92, Ma96
6	HD 50896	Cr 121?		*VI*, LS84, HS97, ZH99	S 308 (r), H I bubble, RCW 11, *IRAS* shell	*VI*, CT83, EVS92, MC92, MC93, MC94, Sm95, AC96, Ma96, Ma97, GC00
7	HD 56925				NGC 2359 (r), H I bubble, S 29, *IRAS* shell	*VI*, CT83, EV90, MC93, Sm95, Ma96, Ma97, CG99, GC00
7a	PMLC 1					
8	HD 62910		Anon. Pup a:	*VI*, LS84	in diff. H II, L 247.26–3.88, *IRAS* shell	*VI*, MC94, Ma96
9	HD 63099	HD 63077 group?	Anon. Pup b?	*VI*, LS84	near diff. neb., Anon.	*VI*, MC94
10	HD 65865	Ru 44:	Pup OB2	Tu81, *VI*, LS84, RF84		
11	γ^2 Vel	*Hipparcos* par.	Vel OB2?	LS84, HS97, ZH99, PJ00	Anon (WR 11) (r), H I bubble, *IRAS* shell, Gum nebula	*VI*, HB82, MY94, Ma96, Ma97, DG98
12	Ve 5-5		Bo 7?	*VI*, LS84	ext. diff. Hα, fil. [O III], H I bubble, *IRAS* shell	DG92, MC94, Ma96
13	Ve 6-15				maybe diff. neb., H I bubble	DG92, MC94
14	HD 76536		Anon. Vel a:	*VI*, LS84	Anon (WR 14) (r:), H I bubble, *IRAS* shell, Gum 21	*VI*, DG92, MY94, Ma96, Ma97
15	HD 79573		Anon. Vel b?	LS84	v. diff. neb., H I bubble?, *IRAS* shell	DG92, MY94, Ma96
16	HD 86161				Anon (WR 16) (3r), 282.2 – 2.0	*VI*, MY94, Ma97, MW99
17	HD 88500			LS84	H I bubble, *IRAS* shell	CN86, MY94, MY95, Ma96, MY96
18	HD 89358		Car OB1?	LS84	NGC 3199 (r), RCW 48, Gum 28	*VI*, CT83, EVS92, Sm95, MY94, Ma97
19	LS 3				v. diff. neb.	MY94
19a	SMSP 1				G 284.0 – 0.9	CH87, Ma97, SM99
20	BS 1				Anon (WR 20) (r)	Ma97
20a	SMSP 2	Westerlund 2		MS91, BM94, PB98	G 284.3 – 0.3, RCW 49	CH87, BM94, Ma97, PB98, SM99
20b	SMSP 3				G 284.3 – 0.3, RCW 49	CH87, Ma97, SM99
21	HD 90657			LS84	*IRAS* shell	MY94, Ma96
21a	Th35-42					
22	HD 92740		Car OB1	*VI*, LS84, MJ93	Anon (WR 22) (r:), NGC 3372	*VI*, HB82, CT83, MY94, Ma97
23	HD 92809		Car OB1:	*VI*, LS84, MJ93	Anon (WR 23) (r), *IRAS* shell	*VI*, CT83, EVS92, MC94, Sm95, Ma96, Ma97
24	HD 93131	Cr228-3	Car OB1	*VI*, LS84, MJ93	Anon (WR 24) (r:), NGC 3372, *IRAS* shell	*VI*, HB82, MC94, Ma96
25	HD 93162	Tr16-177	Car OB1	*VI*, LS84, MJ93	NGC 3372	*VI*, MC94
26	MS 1				in faint diff. neb.	MC94
27	LS 4				in diff. emission	MC94
28	MS 2				[O III] emission, dusty	MC94

29	MS 3					MC94
30	HD 94305				Anon (WR 30) (2r), *IRAS* shell	Ma95, Ma96, Ma97
30a	MS 4				diff. emission	Ma97
31	HD 94546				Anon (WR 31) (r:), *IRAS* shell	MY94, Ma96, Ma97
31a	He3-519				H II (r), diff. emission	SC94, Ma97
31b	AG Car				H II (r)	Sm95, SS97
31c	SMSP 4[a]				G 289.06 − 0.35	CH87, SM99
32	MS 5					Ma97
33	HD 95435				*IRAS* shell	Ma96, Ma97
34	LS 5				v. diff. neb.	MY94, Ma97
35	MS 6				Anon (WR 35) (r)	Ma97
35a	SMSP 5				Anon (WR 35a) (r)	Ma97
35b	SMSP 6	Sher 1		MS91, SM91	Anon (WR 35b) (r:)	Ma97
36	LS 6				Anon (WR 36) (r)	Ma97
37	MS 7			LS84	Gum 34b, very diff., see WR 38	*VI*, MY94
38	MS 8	C1104 − 610a		Sh98, Tu98	Anon (WR 38) (r:)	MY94
38a	SMSP 7	C1104 − 610a		Sh98, Tu98	G 290.5 − 0.8	CH87, Ma97, SM99
38b	SMSP 8	C1104 − 610b?		Tu99	G 290.5 − 0.8	CH87, Ma97, SM99
39	MS 9	C1104 − 610b?		Tu99	v. diff. neb., see WR 38	MY94
40	HD 96548				RCW 58 (2r)	*VI*, CT83, SP84, SP88, MC92, MY94, Ma95, Ma96, Sm95, Ma97, GC00
41	LS 7				on ext. H II, faint [O III]	MC94
42	HD 97152		Car OB1?	LS84	Anon (WR 42) (r:)	MY94, Ma97
42a	SMSP 9				G 291.2 − 0.3	CH87, Ma97
42b	SMSP 10					Ma97
42c	SMSP 11					Ma97
42d	SMSP 12					Ma97
43a	HD 97950-A1	NGC 3603		*VI*, LS84, DM95, CD98	NGC 3603, Gum 38b (2r:)	CH87, *VI*, MY94, GB97, Ma97
43b	HD 97950-B	NGC 3603		*VI*, LS84, DM95, CD98	NGC 3603, Gum 38b (2r:)	CH87, *VI*, MY94, GB97, Ma97
43c	HD 97950-C	NGC 3603		*VI*, LS84, DM95, CD98	NGC 3603, Gum 38b (2r:)	CH87, *VI*, MY94, GB97, Ma97
44	LSS 2289					MY94
44a	SMSP 13				diff. emission	Ma97
45	LSS 2423					MC94
45a	SMSNPL 1					
45b	SMSNPL 2				G 295.7 − 0.2	CH87, SM99
45c	SMSNPL 3					
46	HD 104994		Cru OB4.0	TN96		MC94
46a	SMSNPL 4					

(*continued on next page*)

Table 14. Continued

WR (1)	HD/Name	Correlation with open cluster (10a)	Correlation with OB association (10b)	Ref. (10)	Correlation with ring nebula, H II region, H I bubble (11)	Ref. (11)
47	HD 311884	Ho 15-3:		*VI*, LS84, AC00		Ma97
47a	SMSNPL 5					
47b	SMSNPL 6				G 302.5 − 0.75	CH87, SM99
47c	SMSNPL 7				G 303.1 − 0.95	CH87, SM99
48	θ Mus		Cen OB1:	*VI*, LS84, KG94	Anon (WR 48) (r), H I bubble, *IRAS* shell	HB82, CT83, CN84, Ma95, Ma96, Ma97, GN98
48b	SMSNPL 8[b]					
48a	Danks 1	C1309/10 − 624?		LS84		Ma97
48c	SMSNPL 9					
49	Th17-22				in diff. Hα, [O III] fil.	MC94
50	V864 Cen		Anon. Cen OB?	Tu85, HH88	near RCW 75	*VI*, MC94
51	Th17-85		Anon. Cen OB?	Tu85, HH88	near RCW 75	*VI*, MC94
52	HD 115473				Anon (WR 52) (r:), H I bubble, *IRAS* shell	HB82, CT83, NC91, MC94, Ma96, Ma97
53	HD 117297				RCW 78, BBW 27500, diff. H II	*VI*, EV90, MC94
54	Th17-89				Anon (WR 54) (r:), H I bubble, *IRAS* shell	NC91, MC94, Ma96, Ma97
55	HD 117688				RCW 78 (r)	*VI*, MC94, Sm95, Ma97
56	LS 8				v. diff. neb.	MY94
56a	SMSNPL 10					
57	HD 119078				v. faint neb., H I bubble, *IRAS* shell	NC91, MY94, Ma96, Ma97
58	LSS 3162			LS84	*IRAS* shell	MY94, Ma96
59	LSS 3164					MY94
60	HD 121194				Anon (WR 60) (r)	*VI*, MY94, Ma97
61	CF Cir				H I bubble, *IRAS* shell	NC91, MY94, Ma96
62	NS 2			LS84		MC94
62a	SMSNPL 11					
62b	SMSNPL 12					
63	LSS 3289				diff. Hα	MC94
64	BS 3					MC94
65	Wra 1297		Cir OB1	LS84, LG87	G 320.5 − 1.4, Anon (WR 65) (r:)	LG87, MC94, Ma97
66	HD 134877		Cir OB1	LS84, LG87	G 320.5 − 1.4, *IRAS* shell	*VI*, LG87, VW95, Ma96, Ma97
67	LSS 3329	Pi 20:	Cir OB1	*VI*, LS84, LG87, VW95, Tu96	G 320.5 − 1.4	*VI*, LG87, VW95

68	BS 4		Cir OB1	LS84	G 320.5 − 1.4, Anon (WR 68) (r:)	LG87, MC94, Ma96, Ma97
68a	SMSNPL 13					
69	HD 136488				*IRAS* shell	MY94, Ma96
70	HD 137603				*IRAS* shell	MY94, Ma96
70a	SMSNPL 14					
71	HD 143414				Anon (WR 71) (r:)	MY94, Ma97
73	NS 3				*IRAS* shell	MY94, Ma96
74	BP 1		Nor OB4?	LS84, LT84	near diff. H II	LT84, MC94
75	HD 147419		Nor OB4?	LS84, LT84	RCW 104 (2r)	CH87, CT83, LT84, EVS92, MC94, Ma95, Sm95, Ma97, GC00
75a	SMSNPL 15					
75b	SMSNPL 16					
76	LSS 3693				G 338.9 + 0.6, diff Hα	CH87, *VI*, MC94, GR96
77	He3-1239		Ara OB1b?	Fi87, KG92	Anon (WR 77) (r:), RCW 108, *IRAS* shell	*VI*, MY94, GR96, Ma96, Ma97
78	HD 151932	NGC 6231-305:	Sco OB1	*VI*, LS84, PH91, RC97, BV99	RCW 113, IC 4678	*VI*, MY94, GR96
79	HD 152270	NGC 6231-220	Sco OB1	*VI*, LS84, PH91, RC97, BV99	RCW 113, IC 4678	*VI*, MY94, GR96
79a	HD 152408	NGC 6231-327	Sco OB1	PH91, RC97, BC99, BV99	RCW 113-116	Lo82
79b	HD 152386	KQ Sco group		Tu79	RCW 111, H I bubble	Lo82, BC99
80	Wra 1581				v. diff. neb.	MY94
81	He3-1316					Ma97
82	LS 11				*IRAS* shell	Ma96, Ma97
83	He3-1344				v. diff. neb.	MY94
84	Thé 3				v. diff. neb.	MY94
85	LSS 3982	HD 155603 group?		An77, MF77, LS79, *VI*	RCW 118 (2r), *IRAS* shell	HB82, CT83, MC94, MY94, Ma95, Ma96, Ma97
86	HD 156327				S 10, RCW 130, diff. Hα, *IRAS* shell	*VI*, MC94, Ma96
87	LSS 4064	HM 1	Anon. Sco OB	*VI*, LS84	Anon (WR 87/89) (r:), RCW 123, *IRAS* shell	*VI*, MY94, Ma96, Ma97
88	Thé 1		Anon. Sco OB?	Th61, *VI*	RCW 130, S 5, diff.H II, dusty	*VI*, MC94
89	AS 223	HM 2	Anon. Sco OB	LS84	Anon (WR 87/89) (r:), RCW 123, *IRAS* shell	*VI*, MY94, Ma96, Ma97
90	HD 156385				RCW 114, diff. Hα, H I bubble, *IRAS* shell	*VI*, CN88, MC94, Ma96
91	StSa 1				RCW 122 (r:, bow shock)	*VI*, HB82, MY94, Ma97
92	HD 157451				RCW 114	*VI*, MY94
93	HD 157504	Pi 24:		*VI*, LS84, LT84	NGC 6357 (r), RCW 131	*VI*, HB82, CT83, LT84, MY94, Ma97
93a	Th3-28					
94	HD 158860				Anon (WR 4) (r)	MY94, Ma97
95	He3-1434	Tr 27-28:		*VI*, LS84, SM94	diff. Hα, dusty	MC94
96	LSS 4265				diff. neb.	MY94
97	HDE 320102				diff. neb.	MY94
98	HDE 318016	Tr 27-105?		*VI*, LS84	Anon (WR 98) (r), diff.	*VI*, MC94, Ma97
98a	IRAS 17380 − 3031					
100	HDE 318139				maybe diff. Hα	MC94
101	DA 3				Anon (WR 101) (r:), *IRAS* shell	MY94, Ma96, Ma97

(*continued on next page*)

Table 14. Continued

WR	HD/Name	Correlation with open cluster	Correlation with OB association	Ref.	Correlation with ring nebula, H II region, H I bubble	Ref.
(1)		(10a)	(10b)	(10)	(11)	(11)
101a	BSD 1	Galactic Center		BS96		
101b	AF-NW	Galactic Center		KG95		
101c	AF	Galactic Center		KG95		
101d	GC IRS 6E	Galactic Center		KG95		
101e	GC IRS 7W	Galactic Center		KG95		
101f	GC IRS 13E1	Galactic Center		KG95		
101g	GC IRS 29N	Galactic Center		KG95		
101h	MPE −1.0, −3.5	Galactic Center		KG95		
101i	GC IRS 15SW	Galactic Center		KG95		
101j	GC IRS 16NW	Galactic Center		KG95		
101k	GC IRS 16SW	Galactic Center		KG95		
101l	GC IRS 16C	Galactic Center		KG95		
101m	GC IRS 15NE	Galactic Center		KG95		
101n	MPE +1.6, −6.8	Galactic Center		KG95		
101o	MPE +2.7, −6.9	Galactic Center		KG95		
102	Sand 4				G 2.4+1.4 (2r), *IRAS* shell	*VI*, CT83, CH87, DL90, DM90, GK91, Lo91, EVS92, MC93, MY94, Sm95, Ma97, GC00
102a	CSE 1	Arches		CS99		
102b	CSE 2	Arches		CS99		
102c	FMM 96-1	Quintuplet		FM96		
102d	FMM 95-1	Quintuplet		FM96		
102e	FMM 96-2	Quintuplet		FM96		
102f	FMM 96-3	Quintuplet		FM96		
102g	FMM 99-1	Quintuplet		FM99		
102h	FMM 95-2	Quintuplet		FM96		
102i	FMM 96-4	Quintuplet		FM96		
102j	FMM 96-5	Quintuplet		FM96		
102k	FMM 96-6	Quintuplet		FM96		
102l	SMSNPL 17[c]					
103	HD 164270					MY94
104	Ve2-45	Bo 14?	Sgr OB1?	*VI*, LS84, TM99	Anon (WR 104) (r), S 28	*VI*, MC93
105	Ve2-47		Sgr OB1:	*VI*, LS84	Anon (WR 105) (r:), v. diff.	MC93, MY94
106	HDE 313643				poss. diff. emission	MC93
107	DA 1				poss. diff. emission	MC93
107a	SMSNPL 18					
108	HDE 313846		Sgr OB1?	LS84, CH95a	poss. diff. emission	MC93

109	V617 Sgr					MY94
110	HD 165688		Sgr OB1?	LS84	poss. ejecta shell, *IRAS* shell	MC93, Ma96
111	HD 165763		Sgr OB1:	*VI*, LS84		
112	GL 2104				S 34, RCW 149, poss. diff. emission	*VI*, MC93
113	HD 168206		Ser OB2:	*VI*, LS84	S 54, RCW 167 (double shell, r:)	*VI*, GR84, MC93, ER95
114	HD 169010		Ser OB1:	*VI*, LS84, HM93	poss. diff. emission	MC93
115	IC14-19		Ser OB1:	*VI*, LS84, HM93	S 50, in neb.	*VI*, MC93
116	ST 1				Anon (WR 116) (r:)	*VI*, MC93, ER95
117	IC14-22	Do 29?		LS84		
118	GL 2179				Anon (WR 118) (r:)	MC93
119	Thé 2					
120	Vy1-3	Do 33?		Tu80b, LS84		
121	AS 320		Anon. Sct OB?	Tu80b, LS84	Anon (WR 121)	*VI*
121a	W 43#1	W 43 cluster		SB78, BD99	W 43	BD99
123	HD 177230				H I bubble, *IRAS* shell	Ar92, Ma96
124	QR Sge, 209 BAC				M1-67 (r), S 80, *IRAS* shell	*VI*, CT83, Fo89, EV91, MC93, Sm95, Ma96, GM98, SN98
125	V378 Vul				faint diff. emission, H I bubble	AM91, MC93
126	ST 2		Vul OB2:	Ra89		
127	HD 186943		Vul OB2:	Tu80a, *VI*, LS84, Ra89	Anon (WR 127) (r:), S 92	*VI*, HB82, Fo89, MC93, GC00
128	HD 187282				Anon (WR 128) (r), S 84(?), H I bubble	*VI*, HB82, CT83, Fo89, MC93, ER95, AC99
129	Sey 1					
130	LS 16				Anon (WR 130) (r:), H I bubble, S 98	*VI*, HB82, Fo89, MC93
131	IC14-52				L 69.80 + 1.74 (r), H I bubble, in W 58 complex	*VI*, Is80, Lo83, CT83, EVS92, MC93, Sm95
132	HD 190002				Anon (WR 132) (r:), H I bubble, *IRAS* shell, in W 58 complex	*VI*, Lo83, Ar92, MC93, Ma96, Ar99
133	HD 190918	NGC 6871		*VI*, LS84, SM94, MJ95	Anon (WR 133) (r:), S 109, *IRAS* shell	*VI*, ER95, MC93, Ma96
134	HD 191765		Cyg OB3:	LS84, GS92	Anon (WR 134) (r), H I bubble, S 109, supershell	*VI*, CT83, EV92, MC93, LP94, ER95, Sm95, PG96, LP97, Si97, GC00
135	HD 192103		Cyg OB3:	LS84, GS92	in neb., H I bubble, S 109, supershell	*VI*, LP93, MC93, LP94, PG96
136	HD 192163		Cyg OB1:	LS84, GS92	NGC 6888 (r), S 105, *IRAS* shell, supershell	*VI*, CT83, MC92, SS92, MC93, LP94, Sm95, CD96, Ma96, MH00, GC00
137	HD 192641	Do 3?	Cyg OB1?	*VI*, LS84, GS92, WK01	in neb., H I bubble, S 109, supershell	*VI*, SS92, LP93, MC93, LP94, PG96
138	HD 193077		Cyg OB1:	*VI*, LS84, GS92	S 109, supershell	*VI*, SS92, LP93, LP94
139	HD 193576	Be 86:	Cyg OB1?	*VI*, LS84, FE92, SM94, MJ95	Anon (WR 139) (r:), H I bubble, S 109, *IRAS* shell, supershell	*VI*, HB82, LR90, SS92, LP93, MC93, LP94, Ma96

(*continued on next page*)

Table 14. Continued

WR (1)	HD/Name	Correlation with open cluster (10a)	Correlation with OB association (10b)	Ref. (10)	Correlation with ring nebula, H II region, H I bubble (11)	Ref. (11)
140	HD 193793				Anon (WR 140) (r:), H I bubble, S 109, *IRAS* shell	*VI*, HB82, Ar92, MC93, Ma96, Ar99
141	HD 193928		Cyg OB1	*VI*, LS84, GS92	in neb., S 109, *IRAS* shell, supershell	*VI*, LR90, SS92, LP93, MC93, LP94
142	Sand 5	Be 87:		TF82, LS84, SM94	neb. around, H I bubble, *IRAS* shell, supershell	LR90, Lo91, SS92, LP93, MC93, LP94, St01
143	HD 195177				diff. emission around, *IRAS* shell, supershell	LR90, Lo91, SS92, LP93, MC93, LP94
144	HM19-1		Cyg OB2-600?	RL66, *VI*, LS84, MT91, PJ95	in neb.	MC93
145	V1923 Cyg, AS 422		Cyg OB2?	*VI*, LS84, MT91, TT91	in neb.	MC93
145a	Cyg X-3				in neb.	MC93
146	HM19-3			RL66, DW96, DW00	in neb., DWB 140	*VI*, MC93
147	AS 431			WD97	H I ring	SB01
148	HD 197406				H I bubble, *IRAS* shell	DN90, Ma96
149	ST 4				poss. faint emission, H I bubble	MC93, CN96
150	ST 5					
151	CX Cep				H I bubble	AC99
152	HD 211564		Cep OB1:	LS84	S 132 (r), neb. around, *IRAS* shell	*VI*, HB82, MC93, Ma96
153ab	HD 211853		Cep OB1:	LS84	S 132 (r)	*VI*, HB82, MC93, ER95
154	HD 213049		Cep OB1:	LS84		
155	HD 214419, CQ Cep		Cep OB1:	*VI*, LS84		
156	AC + 60 38562					
157	HD 219460	Ma 50		*VI*, TM83, LS84, SM94	S 157 (r), *IRAS* shell	*VI*, HB82, MC93, Ma96
158	AS 513				S 165, *IRAS* shell	*VI*, Ma96

- Shara et al. (1991), in a dedicated survey, discovered 13 WR stars (11 WN and 2 WC);
- Crawford and Barlow (1991b) classified the emission-line star We 21 (Weaver, 1974) as a WN8 star (WR 47a);
- van Kerkwijk et al. (1992, 1993, 1996) discovered that Cygnus X-3 has in the IR *K*-band a variable WN4–7 spectrum (WR 145a);
- Mereghetti et al. (1994) identified the X-ray source 1E 1024.0-5732 with the emission-line star Th35-42 (Thé, 1966) and classified it as WN6 + O (WR 21a);
- Hofmann et al. (1995) resolved with speckle observations four individual WN stars in WR 43, the central object of cluster and H II region NGC 3603, three of which were confirmed by Drissen et al. (1995);
- L.J. Smith et al. (1994b) re-classified two LBV or WN/Of-type objects into WN11 subtypes;
- Blum et al. (1995a) discovered one WC9 star in the Galactic Center Cluster (WR 101a);
- Krabbe et al. (1995) discovered 14 WR stars in the Galactic Center Cluster, including seven Ofpe/WN9 stars, which have been re-classified as WN9–11 stars by Crowther (private communication);
- Figer et al. (1995, 1996, 1999a) discovered eight WR stars in the Quintuplet cluster near the Galactic Center;
- Najarro et al. (1997) re-classified GC IRS 7W, one of the WN9/Ofpe stars of Krabbe et al. (1995), as WN9–10;
- Shara et al. (1999), in a continuation of their dedicated optical survey, discovered 18 WR stars (12 WN (including the known We 21, Crawford and Barlow, 1991b), 5 WC, 1 WN/WC);
- Pereira et al. (1998) discovered one WN/WC star (WR 7a);
- Blum et al. (1999) discovered one WN7 star (WR 121a) in the main stellar cluster of the giant H II region W 43 (W 43 #1);
- Bohannan and Crowther (1999) re-classified the extreme Of stars HD 152408 (O8:Iafpe) and HD 152386 (O6:Iafpe) as WN9ha (WR 79a, WR 79b);
- Cotera et al. (1996, 1999) discovered two WN stars in the Galactic Center Arches Cluster (WR 102a, WR 102b); and
- Figer et al. (1999b) found very close to FMM96-3 another GC WC < 8 star (WR 102g).

Two of the new Galactic Center WR stars (WR 102f, WC < 8 and WR 102i, WN9) appear to be variable in *K* on a time-scale of the order of 1–2 yr (Glass et al., 1999).

Near the Galactic Center many more new WR stars may be found, e.g., among the fourteen Galactic Center stars resolved in NHSSK-17 (Nagata et al., 1993, 1995); among the other eleven Galactic Center stars (Of or WNL) in the cluster G 012 + 0.02 near the Arched Filaments (Cotera et al., 1996, 1999); among the other three WN9/Ofpe stars found by Krabbe et al. (1995, see also Najarro et al., 1997); and among the five extremely dusty enigmatic Quintuplet Cluster stars noted by Figer et al. (1996, 1999a). In addition, many more new WR stars may be found in star-formation regions like W49A, where De Pree et al. (1997) note that W49A/M is the more obvious one of thirteen 3.6-cm continuum sources with strong He92α emission.

All-sky narrow-band near-IR surveys for detecting more WR stars are being carried out (e.g., Blum and Damineli, 1999) or are being planned (Shara, 1998, private communication).

The new discoveries are summarized in Table 12. This brings the number of known galactic WR stars to 227, comprising 127 WN types, 10 WN/WC types, 87 WC types, and 3 WO types. *The VIIth Catalogue of Galactic Wolf–Rayet stars* is presented in Tables 13–15, giving star names, coordinates and references to finding charts (Table 13); correlation with open clusters, OB associations, ring nebulae, H II regions and H I bubbles (Table 14); spectral types, *bv* magnitudes, wind terminal velocities and periodicities (Table 15). The format of the *VIIth Catalogue* is given in the Notes to Tables 13–15, which also give the references.

The *bv* magnitudes are in the system of Smith (1968a). Conti and Vacca (1990) and Schmutz and Vacca (1991, WN only) applied detailed scaling of magnitudes from various sources and converted them to 'emission-line-free' magnitudes. Those efforts also included assumptions on (the absence of) binary components. We prefer to use the original magnitudes from each source, the photometric differences in the various sources being too marginal for the purpose of this *VIIth Catalogue*.

Table 15
The VIIth catalogue of galactic Wolf–Rayet stars: parameters

WR (1)	HD/name	Spectral type (12)	Ref. (12)	v (mag) (13)	$b-v$ (mag) (13)	Ref. (13)	v_∞^{WR} (km s^{-1}) (14)	Ref. (14)	P(d) (15)	Binary status	Ref. (15)
1	HD 4004	WN4	SS96*	10.51	0.51	Ma84	2100	HS92	6.1, 7.746, 11.68	SB1?	La83, MS86, MMH98, MG99, Ni00
2	HD 6327	WN2	SS96*	11.33	0.13	Ma84	3200	HS92	18.59, 2.171, long term	VB	Hip97, MMH98
3	HD 9974	WN3+O4	SS96*	10.70	−0.06	Ma84			46.85±0.02	SB2	MLS86, MS86, SH89, SM89, SS96
4	HD 16523	WC5+?	*VI*	10.53	0.20	Ma84	1900	KH95	2.4096, 10:	SB1, no d.e.l.	MS86, CM89, RC89, SS90, t.w.
5	HD 17638	WC6	*VI*	11.02	0.47	Ma84	2100	TC86u			
6	HD 50896	WN4	SS96*	6.94	−0.07	*VI*	1800	EW94, Sc97	3.7650±0.0001	SB1?	FK80, DH96, MM98, MMH98, GK99, NG99a
7	HD 56925	WN4	SS96*	11.68	0.38	TM88	1600	HK95	long term		MMH98
7a	PMLC 1	WN4/WC	PM98								
8	HD 62910	WN7/WCE+?	SS96*	10.48	0.47	TM88	1590	CS95d	38.4, 115±13	SB1	Ni91, MMH98
9	HD 63099	WC5+O7	HH88	10.93	0.74	TM88			14.305	SB2	NM84, SM89, Ni95, LM96
10	HD 65865	WN5ha (+A2V)	NG99a	11.08	0.22	TM88	1475	PB90		VB	Ni81, Tu81, Hip97, HH88, NG99a
11	γ^2 Vel	WC8+O7.5III-V	DS99	1.74	−0.32	*VI*	1450	EW94	78.53	SB2, VB	SSS97, DS99, NG99a, SSK99, TC99, DS00
12	Ve 5-5	WN8h+?	SS96	10.99	0.42	TM88	1100	HK95	23.923	SB1, no d.e.l.	Ni82, CM89, SM89, LM96, RVG96, t.w.
13	Ve 6-15	WC6	*VI*	13.78	0.82	TM88	1700	KH95			
14	HD 76536	WC7+?	SS90, Sh90	9.42	0.13	TM88	1900	EW94	2.42	SB1, no d.e.l.	CM89, Sh90, SS90, NG99a, t.w.
15	HD 79573	WC6	*VI*	11.72	0.72	TM88	2700	KH95			
16	HD 86161	WN8h	SS96	8.44	0.30	TM88	630	CS95b	75.2, 20.88, 17.54, 11.74, 10.73, 9.28		MN82, BE89, GH89, GVM90, AB95, MMH98, NG99a
17	HD 88500	WC5	*VI*	11.03	0.14	TM88	1800	KH95			
18	HD 89358	WN4	SS96*	11.11	0.55	TM88	2100	HK95	long term		MMH98
19	LS 3	WC4pd+O9.6	WH96	13.75	1.06	TM88			3690	CWB	VH98
19a	SMSP 1	WN7:(h)	SM99	17.45	1.71	SM91					
20	BS 1	WN5	SS96*	14.45	0.88	TM88	1400	HK95			
20a	SMSP 2	WN7:h/WC	SM99	14.14	1.38	SM91					
20b	SMSP 3	WN6:h	SM99	15.40	1.69	SM91					
21	HD 90657	WN5+O4-6	SS96*	9.76	0.27	TM88			8.2546±0.0001	SB2	NM82, SM89, LM96, MMH98, GN99, NG99a
21a	Th35-42	WN6+O/a	MB94	(12.8)		Th66				d.e.l.	MB94, Re99
22	HD 92740	WN7h+O9III-V	SS99, RV96	6.44	0.03	*VI*	1785	CS95b	80.336±0.001	SB2	CN79, SM89, GR91, RV96, MMH98, NG99a, SSS99
23	HD 92809	WC6	*VI*	9.67	−0.05	TM88	2250	EW94			NG99a
24	HD 93131	WN6ha	SS96	6.49	−0.06	*VI*	2160	CD98			CN79, NG99a
25	HD 93162	WN6h+O4f	CN79, SS96, t.w.	8.14	0.17	TM88	2480	CD98	long term	d.e.l.	CN79, DR92, Hu92, HW92, NG99a, t.w.
26	MS 1	WN7/WCE	SS96	14.61	0.92	TM88					
27	LS 4	WC6+a	*VI*, SS90	14.96	1.29	SS90	1850	KH95		a, no d.e.l.	CM89, SS90, t.w.
28	MS 2	WN6(h)+OB?	SS96, t.w.	12.98	0.77	TM88				d.e.l.	CM89, t.w.
29	MS 3	WN7h+O	NG99b	12.65	0.65	TM88			3.164	SB2	NG99a, NG99b
30	HD 94305	WC6+O6-8	NM83	11.73	0.27	*VI*	2100	TC86u	18.82	SB2	NM83, SM89, Ni95, LM96

30a	MS 4	WO4 + O5-5.5	CDB98, GR00	13.33	0.79	SS90			4.62	SB2	Ni95, GR99, GR00
31	HD 94546	WN4 + O8V	SS96*	10.69	0.28	*VI*			4.8306 ± 0.0001	SB2, VB	NM85, LM87, SM89, LM96, Hip97, GN99
31a	He3-519	WN11h	SC94	(9.75)	(0.65)	Sim	365	SC94			
31b	AG Car	WN11h	SC94	(7.09)	(0.49)	Sim	90-400	LA94		VB	HL93
31c	SMSP 4[a]	WC6 + OB	SS90, SM99, t.w.	16.37	0.96	SM91				a, d.e.l.	CM89, SS90, t.w.
32	MS 5	WC5 + OB?	*VI*, t.w.	15.9	1.29	SS90	1900	TC86o		d.e.l.	CM89, SS90, t.w.
33	HD 95435	WC5	SS90	12.35	0.16	TM88	2900	KH95			
34	LS 5	WN5	SS96*	14.50	0.76	HH88	1200	HK95			
35	MS 6	WN6h + OB?	SS96, t.w.	13.83	0.59	TM88	1100	HK95		d.e.l.	CM89, t.w.
35a	SMSP 5	WN6h	SM99	13.92	0.86	SM91					
35b	SMSP 6	WN4	SM99*	14.49	1.27	SM91					
36	LS 6	WN5–6 + OB?	SS96*, t.w.	13.57	0.68	TM88	2100	HK95		d.e.l.	CM89, t.w.
37	MS 7	WN4	SS96*	15.77	1.23	TM88	2150	HK95			
38	MS 8	WC4	*VI*	15.41	0.93	SS90					
38a	SMSP 7	WN5	SM99*	16.21	0.83	SM91					
38b	SMSP 8	WC7 + OB	SM99, t.w.	16.21	1.50	SM91				a, d.e.l	CM89, SS90, t.w.
39	MS 9	WC7 + OB?	SS90, t.w.	14.5	1.26	SS90	3600	KH95		d.e.l.	CM89, SS90, t.w.
40	HD 96548	WN8h	SS96	7.85	0.11	*VI*	840	CS95b	18.9, 17.5, 12.4, 6.25, 2.5		DS87, GV90, MM94, AB95, MMH98, MMEv98, NG99a
41	LS 7	WC5 + OB?	SS90, t.w.	14.80	0.80	SS90	1900	TC86o		d.e.l.	CM89, SS90, t.w.
42	HD 97152	WC7 + O7V	HH88	8.25	−0.06	*VI*	1500	EW94	7.886 ± 0.003	SB2	DM81, SD87, SM89, LM96, NG99a
42a	SMSP 9	WN5	SM99*	17.61	1.46	SM91					
42b	SMSP 10	WN4	SM99*	16.96	2.43	SM91					
42c	SMSP 11	WN5	SM99*	16.56	1.36	SM91					
42d	SMSP 12	WN5	SM99*	15.28	1.33	SM91					
43a	HD 97950-A1	WN6ha	CD98	11.90	0.74		2700	CD98	3.7720	SB1	MN84, MS85, DM95, Mo00, St01
43b	HD 97950-B	WN6ha	CD98	11.97	0.74		2700	CD98			St01
43c	HD 97950-C	WN6ha	CD98	12.37	0.74		2500	CD98			St01
44	LSS 2289	WN4 + OB?	SS96*, t.w.	12.96	0.37	*VI*	1400	HK95		d.e.l.	CM89, t.w.
44a	SMSP 13	WN4	SM99*	16.20	1.55	SM91					
45	LSS 2423	WC6	*VI*	14.80	1.12	SS90	2100	TC86o			
45a	SMSNPL 1	WN5	SM99*	16.69	1.19	SM99					
45b	SMSNPL 2	WN4	SM99*	18.08	1.40	SM99					
45c	SMSNPL 3	WN5	SM99*	15.44	0.91	SM99					
46	HD 104994	WN3p + OB?	SS96*, t.w.	10.87	−0.03	TM88	2450	CS95c	0.2825 − 0.2727 + long term	d.e.l., SB1?	CM89, VG95, NB95, MM96, MMH98, MA00, VGC01, VGH01, t.w.
46a	SMSNPL 4	WN4	SM99*	16.00	1.04	SM99					
47	HD 311884	WN6 + O5V	SS96	11.08	0.76	TM88			6.2393 ± 0.0001	SB2	LM87, SM89, MD90, LM96, GN99
47a	SMSNPL 5	WN8h	SM99	15.98	1.73	SM99					
47b	SMSNPL 6	WN9h	SM99	17.05	1.93	SM99					
47c	SMSNPL 7	WC5	SM99	16.09	1.40	SM99					
48	θ Mus	WC6(+O9.5/B0Iab)	*VI*, Co84	5.88	−0.12	SS90			18.341 ± 0.008	SB1, VB	MS77, SD87, SM89, Hip97, MG98, HM99, NG99a

(*continued on next page*)

Table 15. Continued

WR (1)	HD/name	Spectral type (12)	Ref. (12)	v (mag) (13)	$b-v$ (mag)	Ref. (13)	v_∞^{WR} (km s^{-1}) (14)	Ref. (14)	P(d) (15)	Binary status	Ref. (15)
48b	SMSNPL 8[b]	WC9d	SM99, Co00	15.96	1.07	SM99					
48a	Danks 1	WC8ed + ?	HH88	(16.8)	(1.7:)	HH88			> 7800	CWB, VB?	Wi97, Wi99, Wi01
48c	SMSNPL 9	WN3h + WC4	SM99	13.98	0.39	SM99					
49	Th17-22	WN5(h)	SS96	13.84	0.34	TM88	1450	HK95			
50	V864 Cen	WC7 + OB	SS90, t.w.	12.49	0.68	HH88	2100	TC86u	1.06	SB2	CM89, GH90, SS90, GV91, t.w.
51	Th17-85	WN4 + OB?	SS96*, t.w.	14.64	1.04	TM88	1300	HK95		d.e.l.	CM89, t.w.
52	HD 115473	WC4	SS90	9.86	0.29	TM88	3225	PB90			NG99a
53	HD 117297	WC8d	WH00	10.88	0.42	TM88	1400	TC86u			
54	Th17-89	WN5	SS96*	12.99	0.46	*VI*	1300	HK95			
55	HD 117688	WN7	SS96*	10.87	0.40	*VI*	1100	HK95	8.84		MMH98
56	LS 8	WC7	HH88	13.87	0.44	TM88	1600	TC86u			
56a	SMSNPL 10	WN5	SM99*	15.91	1.32	SM99					
57	HD 119078	WC8	SS90	10.02	0.10	TM88	1770	PB90			
58	LSS 3162	WN4/WCE	SS96*	13.05	0.57	TM88	1600	HK95			
59	LSS 3164	WC9d	HH88	13.90	1.24	*VI*	1400	TC86o			
60	HD 121194	WC8	*VI*	13.25	1.04	SS90	1880	EW94			
61	CF Cir	WN5	SS96*	12.41	0.36	TM88	1400	HK95			
62	NS 2	WN6	SS96*	14.22	1.60	HH88	1800	HK95			
62a	SMSNPL 11	WN4	SM99*	13.80	1.24	SM99					
62b	SMSNPL 12	WN5	SM99*	17.26	1.77	SM99					
63	LSS 3289	WN7 + OB	SS96*, t.w.	12.83	1.27	TM88	1350	EW94		a, d.e.l.	CM89, SS96, t.w.
64	BS 3	WC7	*VI*	15.57	0.16	HH88	1900	TC86o			
65	Wra 1297	WC9d + OB?	*VI*, t.w.	14.50	1.41	TM88	1200	TC86o		d.e.l.	CM89, SS90, t.w.
66	HD 134877	WN8(h) + cc?	SS96	11.66	0.73	TM88	1500	HK95	3.515, 0.146, long term	no d.e.l., SB1?, VB	CM89, AB95, RG96, Hip97, MMH98, t.w.
67	LSS 3329	WN6 + OB?	SS96*, t.w.	12.12	0.87	TM88	1500	HK95		d.e.l.	CM89, t.w.
68	BS 4	WC7	*VI*	14.09	0.97	SS90	2050	KH95			
68a	SMSNPL 13	WN6	SM99*	14.41	1.46	SM99					
69	HD 136488	WC9d + OB	WH00	9.43	0.14	*VI*	1340	EW94	2.293±0.005	SB2	MMH98, NG99a, WH00
70	HD 137603	WC9vd + B0I	Ni95	10.10	0.96	TM88	1150	EW94	> 4000	SB2	Go87, SM89, Ni95, Wi97, NG99a, Wi01
70a	SMSNPL 14	WN6	SM99*	16.90	1.23	SM99					

71	HD 143414	WN6 + OB?	SS96*, t.w.	10.23	−0.05	TM88	1590	PB90	7.690, long term	d.e.l., SB2?	LM87, CM89, SS96, MMH98, t.w.
73	NS 3	WC9d	HH88	15.23	1.23	SS90	1900	TC86o			
74	BP 1	WN7	SS96*	13.98	1.58	TM88	1300	HK95			
75	HD 147419	WN6	SS96*	11.23	0.71	TM88	2300	HK95			
75a	SMSNPL 15	WC9	SM99	14.51	1.53	SM99					
75b	SMSNPL 16	WC9	SM99	16.09	1.71	SM99					
76	LSS 3693	WC9d	HH88	15.46	1.12	HH88	1000	TC86o			
77	He3-1239	WC8 + OB	CV90, t.w.	13.00	0.61	TM88	1900	TC86o		a, d.e.l.	CM89, CV90, SS90, t.w.
78	HD 151932	WN7h	SS96	6.61	0.21	*VI*	1385	CS95b	2.243, 13.28, 22.7	eclipse?	BE89, MMH98, NG99a
79	HD 152270	WC7 + O5-8	*VI*	6.95	0.01	*VI*	2270	PB90	8.8908 ± 0.0005	SB2, VB	SD87, SM89, LM96,
											MMH98, HM99, NG99a
79a	HD 152408	WN9ha	BC99	5.29	0.15	Cr98	935	BC99		VB	MG98, MMH98
79b	HD 152386	WN9ha	BC99	8.32	0.55	Cr98	1650	BC99		VB	MG98
80	Wra 1581	WC9d	*VI*	14.63	1.60	SS90	1200	TC86o			
81	He3-1316	WC9	WH00	12.71	1.10	TM88	910	EW94			
82	LS 11	WN7(h)	SS96	12.41	0.85	TM88	1100	HK95	2.02, 13.9		AB95
83	He3-1344	WN5	SS96*	12.79	0.79	TM88					
84	Thé 3	WN7	SS96*	13.55	1.06	TM88	1100	HK95			
85	LSS 3982	WN6h + OB?	SS96, t.w.	10.60	0.57	TM88				d.e.l., VB	HH88, CM89, Hip97, t.w.
86	HD 156327	WC7 (+ B0III-I)	NS98	9.63	0.43	TM88	1855	EW94	0.1385 ± 0.0002	SB1?, VB	JB63, HH88, ML88, CM89, SS90,
											GV91, NS98, NG99a, t.w.
87	LSS 4064	WN7h + OB	SS96, t.w.	12.59	1.58	TM88	1400	CS95b		a, d.e.l.	CM89, t.w.
88	Thé 1	WC9	WH00	13.25	1.00	TM88	1125	EW94			
89	AS 223	WN8h + OB	SS96, t.w.	11.53	1.22	TM88	1600	CS95b		a, d.e.l., VB	CM89, Hip97, t.w.
90	HD 156385	WC7	*VI*	7.45	−0.12	*VI*	2045	PB90			NG99a
91	StSa 1	WN7	SS96*	15.76	1.5	TM88	1700	HK95			
92	HD 157451	WC9	WH00	10.43	0.07	TM88	1100	EW94			
93	HD 157504	WC7 + O7-9	HH88	11.45	1.15	SS90	2600	TC86o		SB2?	LS84, LT84, CM89, SS90, t.w.
93a	Th3-28	WN2.5–3	AS90	(13.9)		Th64					
94	HD 158860	WN5	SS96*	12.27	0.74	*VI*					
95	He3-1434	WC9d	*VI*	14.00	1.29	TM88	1100	TC86o			
96	LSS 4265	WC9d	HH88	14.14	1.01	*VI*	1100	TC86o			
97	HDE 320102	WN5 + O7	SS96*	11.14	0.68	TM88	1900	EW94	12.595	SB2	SM89, NC95, NR96, LM96, MMH98
98	HDE 318016	WN8/WC7	SS96*	12.51	1.08	*VI*	1200	EW94	48.7	SB1	Ni91, MMEv98
98a	IRAS 17380 − 3031	WC8–9vd + ?	CH91	(19.7)		CH91			565 ± 50	CWB	WC95, Mo99, MT99, TM01, Wi01
100	HDE 318139	WN7	SS96*	13.44	1.17	*VI*	1600	HK95			
101	DA 3	WC8	HH88	16.4	1.5	HH88					

(*continued on next page*)

Table 15. Continued

WR	HD/name	Spectral type	Ref.	v (mag)	$b-v$ (mag)	Ref.	v_∞^{WR} (km s^{-1})	Ref.	P(d)	Binary status	Ref.
(1)		(12)	(12)	(13)		(13)	(14)	(14)	(15)		(15)
101a	BSD 1	WC9	BS95								
101b	AF-NW	WN9–11	Cr99, GP00								
101c	AF	WN9–11	Cr99								
101d	GC IRS 6E	WC9	KG95								
101e	GC IRS 7W	WN9–10	NK97								
101f	GC IRS 13E1	WN9–10 + ?	NK97, GP00							over-luminous	CP00
101g	GC IRS 29N	WC9	KG95								
101h	MPE–1.0, −3.5	WC9	KG95								
101i	GC IRS 15SW	WN9–11	Cr99								
101j	GC IRS 16NW	WN9–11	Cr99								
101k	GC IRS 16SW	WN9–11 + ?	Cr99, OE99						9.72	eclipse	TW96, OE99
101l	GC IRS 16C	WN9–11	Cr99, GP00								
101m	GC IRS 15NE	WN9–11	Cr99								
101n	MPE +1.6, −6.8	WC9	KG95								
101o	MPE +2.7, −6.9	WC9	KG95								
102	Sand 4	WO2	CDB98	15.10	0.77	SS90	4700	TC86o			
102a	CSE 1	WN8	CS99								
102b	CSE 2	WN6	CS99								
102c	FMM 96-1	WN6	FM96								
102d	FMM 95-1	WN9	FM95								
102e	FMM 96-2	WC8	FM96								
102f	FMM 96-3	WC < 8 + ?	FM96						~ 700	var.	GM99
102g	FMM 99-1	WC < 8	FM99								
102h	FMM 95-2	WC9	FM95								
102i	FMM 96-4	WN9 + ?	FM96						~ 700	var.	GM99
102j	FMM 96-5	WN9	FM96								
102k	FMM 96-6	WC < 8	FM96								
102l	SMSNPL 17[c]	WN8	SM99*	15.53	1.80	SM99					
103	HD 164270	WC9d + ?	*VI*	8.86	−0.02	TM88	1100	EW94	1.7556	SB1, no d.e.l.	IM81, GH86, MLC86, SD87, BE89, CM89, SH89, SS90, NG99a, t.w.
104	Ve2-45	WC9d + B0.5V (+ VB)	WH00, WM01	13.54	1.31	*VI*	1220	HS92	243.5 ± 3.0	SB2, VB	Cr97, MT99, TM99, WS99, WH00, TM01, Wi01, WM01

105	Ve2-47	WN9h	SS96	12.92	1.84:	Ma84	700	BC99			MMEv98
106	HDE 313643	WC9d	*VI*	12.33	0.80	SS90	1100	TC86o			
107	DA 1	WN8	SS96*	14.10	1.32:	HH88					
107a	SMSNPL 18	WC6	SM99	16.43	1.32	SM99					
108	HDE 313846	WN9h + OB	SS96, t.w.	10.16	0.80	Cr98	1210	BC99		a, d.e.l.	CM89, t.w.
109	V617 Sgr	WN5h + ?	SS96	14.48	0.00	HH88			0.207	SB1	SC88, SD98, CD99, SC99
110	HD 165688	WN5–6	SS96*	10.30	0.75	Ma84	2100	EW94			
111	HD 165763	WC5	*VI*	8.23	−0.02	Ma84	2300	HM99			NG99a
112	GL 2104	WC9d + OB?	MC83, t.w.	18.8	1.3	MC83				d.e.l.	CM89, SS90, WM01, t.w.
113	HD 168206	WC8d + O8-9IV	*VI*	9.43	0.46	Ma84	1700	EW94	29.704 ± 0.002	SB2	SM89, LM96, NM96, NG99a
114	HD 169010	WC5 + OB?	*VI*, t.w.	12.95	0.91	Ma84	2000	EW94		d.e.l.	CM89, SS90, t.w.
115	IC14-19	WN6 + OB?	SS96*, t.w.	12.32	1.10	Ma84	1280	HK95		d.e.l.	CM89, t.w.
116	ST 1	WN8h	SS96	13.38	1.41	Ma84	800	HK95			MMEv98
117	IC14-22	WC9d	SS90	14.19	1.15	*VI*	2000	TC86o			
118	GL 2179	WC9d	CV90	(22.0:)	(3.0:)	HH88					
119	Thé 2	WC9d	WH00	12.41	0.63	Ma84	1200	TC86o			
120	Vy1-3	WN7	SS96*	12.30	1.02	Ma84	1225	CS95b			MMEv98
121	AS 320	WC9d	*VI*	12.41	0.97	Ma84	1100	TC86o			MMH98
121a	W 43#1	WN7 + a/OB?	BD99							d.e.l.	BD99
123	HD 177230	WN8	SS96*	11.26	0.43	Ma84	970	CS95b	2.349	SB1?, no d.e.l.	MS86, CM89, MM98, MMH98, MMEv98, t.w.
124	QR Sge, 209 BAC	WN8h	SS96	11.58	0.81	Ma84	710	CP99	1.75?, 2.73	SB1?, no d.e.l.	MS86, CM89, BE89, MMEv98, t.w.
125	V378 Vul	WC7ed + O9III	WH94	13.52	1.32	Ma84	2900	WH92	4.6, > 6600	SB2	MS86, WH92, WH94, Wi97, Wi01
126	ST 2	WC5/WN	CV90	13.29	0.70	Ma84	2500	KH95			
127	HD 186943	WN3 + O9.5V	SS96	10.33	0.15	Ma84			9.5550	SB2	Ma81, MS86, SM89, LM96, MMH98
128	HD 187282	WN4(h) + OB?	SS96, t.w.	10.54	−0.01	Ma84	2050	CS95c	3.56, 3.871	SB2?	La83, AC85, MS86, CM89
129	Sey 1	WN4	SS96*	13.27	0.55	Ma84	1320	HK95			
130	LS 16	WN8(h)	SS96	12.60	1.18	Ma84	1000	HK95			MMEv98
131	IC14-52	WN7h + OB	SS96	12.36	0.73	Ma84	1400	CS95b		a, d.e.l.	CM89, t.w.
132	HD 190002	WC6 + ?	*VI*	13.49	0.70	Ma84	2000	KH95	8.16	SB1	BF83
133	HD 190918	WN5 + O9I	SS96*	6.70	0.00	Ma84	1800	EW94	112.4 ± 0.2	SB2, VB	SM89, Be94, UH94, Be95, Hip97, MMH98, NG99a
134	HD 191765	WN6	SS96*	8.23	0.20	Ma84	2050	CS96	1.2707, 1.81, 2.25, 37.2, 614	SB1?, no d.e.l	MS86, CM89, RM89, MM93, MB94, MMH98, MM99, NG99a, t.w.
135	HD 192103	WC8	*VI*	8.36	−0.03	Ma84	1525	EW94			MS86, NG99a, LD00
136	HD 192163	WN6(h)	SS96*	7.65	0.23	Ma84	1750	CS96	4.554, 0.31, 0.45	SB1?, no d.e.l.	KF80, AC85, As82, VA85, MS86, CM89, RM89, SS96, NG99a, t.w.

(*continued on next page*)

Table 15. Continued

WR (1)	HD/name	Spectral type (12)	Ref. (12)	v (mag) (13)	$b-v$ (mag)	Ref. (13)	v_∞^{WR} ($km\,s^{-1}$) (14)	Ref. (14)	P(d) (15)	Binary status	Ref. (15)
137	HD 192641	WC7pd+O9	SS90, WK01	8.15	0.14	Ma84	1900	EW94	4765±50	SB2	MS86, An95, Wi97, NG99a, WH99, An00, WK01, Wi01
138	HD 193077	WN5+B?	SS96*, t.w.	8.10	0.22	Ma84	1400	HS92	11.6, 1538	SB2, VB	LM82, MS86, An91, Hip97, MMH98, NG99a
139	HD 193576	WN5+O6III-V	SS96*	8.10	0.38	Ma84	1600	EW94	4.212435	SB2	MS86, SM89, RM90, MMK94, Hip97, MMH98, NG99a
140	HD 193793	WC7pd+O4-5	WH90	7.07	0.27	Ma84	2870	EW94	6.25, 2900±10	SB2, VB	MS86, WHW87, ML87, SM89, WH90, An95, HM99, NG99a, Wi01
141	HD 193928	WN5+O5V-III	SS96*	10.14	0.71	Ma84	1550	EW94	21.6895±0.0003	SB2	MS86, SM89, GM91, LM96, MMEe98, IV99
142	Sand 5	WO2	CDB98	13.82	1.39	Ma84	5000	HS92			
143	HD 195177	WC4+OB?	SS90, t.w.	11.95	1.21	Ma84	2750	EW94		d.e.l.	CM89, t.w.
144	HM19-1	WC4	HH88	15.49		Ma84	2400	TC86o			
145	V1923 Cyg, AS 422	WN7/WCE+?	SS96*	12.55	1.63	Ma84	1390	CS95d	20.0±0.4	SB1	RC89, SM89
145a	Cyg X-3	WNE+cc	KC92, HS00	(>23.9)	(21.1)	KG96	2700	Sc93	0.1997	SB1	KB89, KC92, Ke93, CM94, KG96, MM96, SG96, HS00
146	HM19-3	WC6+O8	DW00	13.91	2.38	WD97	2700	WD97	ELPB+1235±10	SB2, VB	DW96, NS98, SB00
147	AS 431	WN8(h)+B0.5V	WD97	14.89	2.15	Ma84	950	MH00	ELPB+2880±60	SB2, VB	WD97, NS98, SB01
148	HD 197406	WN8h+B3IV/BH	SS96	10.46	0.36	Ma84	1000	HK95	4.317364+long term	SB1, d.e.l.	MS80, DL86, MS86, CM89, Mo92, Hip97, MMEv98, PA00, t.w.
149	ST 4	WN5	SS96*	14.70	1.20	Ma84	1100	HK95			
150	ST 5	WC5	HH88	13.47	0.53	Ma84	2600	KH95			
151	CX Cep	WN4+O5V	SS96*	12.37	0.65	Ma84			2.12687	SB2	MC81, SM89, SH89, LM93
152	HD 211564	WN3(h)	SS96	11.67	0.17	Ma84	2000	CS95c			
153ab	HD 211853	WN6/WCE+O6I	SS96*	9.08	0.27	Ma84	1785	PB90	6.6884+3.4696	SB2+SB2	Ma81, MS86, SM89, PS90, An94, LM96, NG99a, PA00
154	HD 213049	WC6	*VI*	11.54	0.36	Ma84	2050	KH95			
155	HD 214419, CQ Cep	WN6+O9II-Ib	SS96*	8.75	0.28	Ma84	1400	EW94	1.6412436	SB2	SB84, MS86, SM89, MM95, HH97, Hip97, MMH98, NG99a
156	AC+60 38562	WN8h+OB?	SS96, t.w.	11.09	0.83	Ma84	660	CS95b	6.5, 10.05, 15	d.e.l.	MS86, CM89, MMH98, MMEv98, t.w.
157	HD 219460	WN5 (+B1II)	SS96*	9.91	0.46	Ma84	1500	HK95	1.786, 2.032	VB	HH88, Hip97, MMH98, NG99a
158	AS 513	WN7h+Be?	SS96, t.w.	11.46	0.75	Ma84	900	HK95		d.e.l.	CM89, AV92, t.w.

Notes to Tables 13–15:
a: SMSP 4, labeled WR 31a by Shara et al. (1991) is here designated WR 31c.
b: SMSNPL 8 labeled WR 48a by Shara et al. (1999) is here designated WR 48b.
c: SMSNPL 17 labeled WR 102i by Shara et al. (1999) is here designated WR 102l.
: means probable open cluster/OB association member according to LS84.
? means possible open cluster/OB association member according to LS84.
(): spectral type of visual binary (VB) component.
a: absorption line(s) present in optical spectrum.
CWB: colliding wind binary.
d.e.l.: diluted emission lines.
t.w.: this work.

FORMAT OF THE CATALOGUE

Column 1: Running number from *VIth Catalogue* (van der Hucht et al., 1981) and intermediate numbers.

Column 2: Star name: Bayer name, HR number, IC number, and miscellaneous designations from discovery papers:
AC: Astrographic Catalogue
AS: Merrill and Burwell, 1950
AD: Arkhipova and Dokuchaeva, 1971
BH: Hidayat, 1962
BP: Petterson, 1978
BS: Stenholm, 1975
BSD: Blum et al., 1995a
DA: Allen, 1978, 1979
Danks: Danks et al., 1983
FMM: Figer et al., 1995, 1996, 1999b
GL: Walker and Price, 1975
He3: Henize, 1976
HR: Pickering, 1908
IC: Iriarte and Chavira, 1956
IRC: Neugebauer and Leighton, 1969
KGE: Krabbe et al., 1995
LS: Smith, 1968a
MS: MacConnell and Sanduleak, 1970
NS: Sanduleak, 1971, 1976, 1979
PMLC: Pereira et al., 1998
Sand: Sanduleak, 1971
Sey: Seyfert, 1947
SMSP: Shara et al., 1991
SMSNPL: Shara et al., 1999
ST: Stephenson, 1966
StSa: Stephenson and Sanduleak, 1977
Th: Thé, 1961a,b, 1962a,b, 1963, 1964, 1965, 1966
Thé: Thé, 1961a, 1963, 1965
(three WR stars discovered by P.S. Thé)
Ve: Velghe, 1957
Vy: Vyssotsky, 1942
Wra: Wray, 1966

Column 3: Variable star name:
General Catalogue of Variable Stars (GCVS), Kukarkin et al., 1971–1998.

Column 4: HD, Th, He3-, Wra, or AS catalogue number, or other designation:
AS: Merrill and Burwell, 1950
HD, HDE: Cannon and Pickering, 1918–1924,
Cannon, 1925–1936,
Cannon, 1937,
Cannon and Mayall, 1949
He3-: Henize, 1976
SPH: Schwartz et al., 1990
Th: Thé, 1961a,b, 1962a,b, 1963, 1964, 1965, 1966
Wra: Wray, 1966

Column 5: LS, LSS, SPH and SS catalogue numbers:

LS I: Hardorp et al., 1959
LS II: Stock et al., 1960
LS III: Hardorp et al., 1964
LS IV: Nassau and Stephenson, 1963
LSS: Stephenson and Sanduleak, 1971
SPH: Schwartz et al., 1990
SS73: Sanduleak and Stephenson, 1973

Column 6: Astrometric catalogue numbers from:
Hip: ESA, 1997, The Hipparcos and Tycho Catalogues, The Hipparcos Catalogue, 1997, ESA-SP1200
PPM: Roser and Bastian, 1991
GSC: Guide Star Catalog, Jenkner et al., 1990
Tyc: ESA, 1997, The Hipparcos and Tycho Catalogues, The Hipparcos Catalogue, 1997, ESA-SP1200

Column 7: J2000.0 equatorial coordinates from:
VIp: van der Hucht et al. (1981, VIth Galactic WR Catalogue), precessed to J2000.0.

BD99: Blum et al., 1999
BS96: Blum et al., 1996
CS99: Cotera et al., 1999
DW00: Dougherty et al., 2000
DM95: Drissen et al., 1995 and priv. comm.
Ec98: Eckart, priv. comm.
FM95: Figer et al., 1995
FM96: Figer et al., 1996
FM99: Figer et al., 1999b
GSC: Jenkner et al., 1990
Hip: ESA, 1997
Kr98: Krabbe, priv. comm.
L1: Leitherer et al., 1995
L2: Leitherer et al., 1997
MB94: Mereghetti et al., 1994
Sim: Simbad
SM91: Shara et al., 1991
SM99: Shara et al., 1999
SP90: Schwartz et al., 1990
Tyc: ESA, 1997
VG01: Veen et al., 2001a
WC95: Williams et al., 1995
WD97: Williams et al., 1997
Wi98/9: P.M. Williams, from supercosmos measurements on Tycho frame, priv. comm.

Column 8: Galactic coordinates.
Column 9: References for finding charts:

VI: van der Hucht et al., 1981
BD99: Blum and Damineli, 1999
BM94: Belloni and Mereghetti, 1994
BS95: Blum et al., 1995a
CS99: Cotera et al., 1999
DD83: Danks et al., 1983
DM95: Drissen et al., 1995
DR90: Duerbeck and Reipurth, 1990
FM99: Figer et al., 1999a
FB96: Fender and Bell Burnell, 1996
HL92: Hoekzema et al., 1992
KG95: Krabbe et al., 1995
LSS: Stephenson and Sanduleak, 1971
SM91: Shara et al., 1991
SM99: Shara et al., 1999
SP90: Schwartz et al., 1990
TF82: Turner and Forbes, 1982
Tu85: Turner, 1985
Tu99: Turner, 1999
VG01: Veen et al., 2001a
WC95: Williams et al., 1995
WK89: Wagner et al., 1989

Column 10: References for correlation with open clusters and OB associations.

VI: van der Hucht et al., 1981
AC00: Ahumada et al., 2000
An77: Andrews, 1977
BC99: Bohannan and Crowther, 1999
BD99: Blum et al., 1999
BV99: Baume et al., 1999
BM94: Belloni and Mereghetti, 1994
BSD96: Blum et al., 1996
CD98: Crowther and Dessart, 1998
CH95a: Crowther et al., 1995a
CS99: Cotera et al., 1999
DM95: Drissen et al., 1995
DW96: Dougherty et al., 1996
DW00: Dougherty et al., 2000
FE92: Forbes et al., 1992
Fi87: FitzGerald, 1987
FM96: Figer et al., 1996, 1999a
FM99: Figer et al., 1999b
GS92: Garmany and Stencel, 1992
HH88: van der Hucht et al., 1988
HM93: Hillenbrand et al., 1993
HS97: van der Hucht et al., 1997b
KG92: Kaltcheva and Georgiev, 1992
KG94: Kaltcheva and Georgiev, 1994
KG95: Krabbe et al., 1995
LG87: Lortet et al., 1987
LS79: Lundstrom and Stenholm, 1979
LS84: Lundstrom and Stenholm, 1984a and references therein
LT84: Lortet et al., 1984
MF77: Moffat and FitzGerald, 1977
MJ93: Massey and Johnson, 1993
MJ95: Massey et al., 1995a
MS91: Moffat et al., 1991
MT91: Massey and Thompson, 1991
PB98: Piatti et al., 1998
PH91: Perry et al., 1991
PJ95: Parthasarathy and Jain, 1995
PJ00: Pozzo et al., 2000
Ra89: Radoslavova, 1989
RC97: Raboud et al., 1997
RF84: Reed and FitzGerald, 1984
RL66: Reddish et al., 1966
SB78: Smith et al., 1978
Sh98: Shorlin, 1998
SM91: Shara et al., 1991
SM94: Smith et al., 1994a
TF82: Turner and Forbes, 1982
Th61: Thé, 1961b
TM83: Turner et al., 1983
TM99: Tuthill et al., 1999a,b
TN96: Tovmassian et al., 1996b
TT91: Torres-Dodgen et al., 1991
Tu79: Turner, 1979
Tu80a: Turner, 1980a
Tu80b: Turner, 1980b
Tu81: Turner, 1981
Tu85: Turner, 1985
Tu96: Turner, 1996
Tu98: Turner, 1998
Tu99: Turner, 1999
VW95: Vazquez et al., 1995
WD97: Williams et al., 1997
WK01: Williams et al., 2001
ZH99: de Zeeuw et al., 1999

Column 11: Notes and references for correlation with H II regions, ring nebulae, and H I bubbles.
r: ring
2r: double ring
3r: triple ring
r: probable ring
diff.: diffuse
v. diff.: very diffuse
ext.: extended
fil.: filamentary [O III]
VI: van der Hucht et al., 1981
AC96: Arnal and Cappa, 1996
AC99: Arnal et al., 1999
AM91: Arnal and Mirabel, 1991
Ar92: Arnal, 1992
AR97: Arnal and Roger, 1997
Ar99: Arnal, 1999
BC99: Benaglia and Cappa, 1999
BD99: Blum et al., 1999
BM94: Belloni and Mereghetti, 1994
CD96: Cappa et al., 1996a
CG99: Cappa et al., 1999
CH87: Caswell and Haynes, 1987
CN84: Cappa de Nicolau and Niemela, 1984
CN86: Cappa de Nicolau et al., 1986
CN88: Cappa de Nicolau et al., 1988
CN96: Cappa et al., 1996b
CT83: Chu et al., 1983
DG92: Dubner et al., 1992
DG98: Dubner et al., 1998
DL90: Dopita and Lozinskaya, 1990
DM90: Dopita et al., 1990
DN90: Dubner et al., 1990
ER95: Esteban and Rosado, 1995
EV90: Esteban et al., 1990
EV91: Esteban et al., 1991
EV92: Esteban and Vílchez, 1992
EVS92: Esteban et al., 1992
Fo89: Forbes, 1989
GB97: Girardi et al., 1997
GK91: Garnett et al., 1991
GN98: Gimenez de Castro and Niemela, 1998
GM98: Grosdidier et al., 1998
GR84: Gonzales and Rosado, 1984
GR96: Georgelin et al., 1996
GS99: Gervais and St-Louis, 1999
HB82: Heckathorn et al., 1982
Is80: Israel, 1980
LG87: Lortet et al., 1987
Lo82: Lozinskaya, 1982
Lo83: Lortet, 1983
Lo91: Lozinskaya, 1991
LP93: Lozinskaya et al., 1993
LP94: Lozinskaya et al., 1994
LP97: Lozinskaya et al., 1997
LR90: Lozinskaya and Repin, 1990
LT84: Lortet et al., 1984
Ma95: Marston, 1995
Ma96: Marston, 1996
Ma97: Marston, 1997
MC92: Mathis et al., 1992
MC93: Miller and Chu, 1993
MC94: Marston et al., 1994a
MH00: Moore et al., 2000
MY94: Marston et al., 1994b
MW99: Marston et al., 1999
NC91: Niemela and Cappa de Nicolau, 1991
PB98: Piatti et al., 1998
PG96: Pineault et al., 1996
SB01: Setia Gunawan et al., 2001
SC94: L.J. Smith et al., 1994b
Si97: Sitnik, 1997
Sm95: Smith, 1995
SM99: Shara et al., 1999
SN98: Sirianni et al., 1998
SP84: Smith et al., 1984
SP88: Smith et al., 1988
SS92: Saken et al., 1992
SS97: Smith et al., 1997
St01: St-Louis, 2001
VW95: Vazquez et al., 1995
GC00: Gründl et al., 2000

Column 12: Notes and references for spectral classification.
d: persistent hot dust formation
ed: episodic hot dust formation
pd: periodic hot dust formationvd: variable persistent hot dust formation

VI: van der Hucht et al., 1981
AS90: Acker and Stenholm, 1990
BC99: Bohannan and Crowther, 1999
BD99: Blum et al., 1999
BS95: Blum et al., 1995a
CD98: Crowther and Dessart, 1998
CDB98: Crowther et al., 1998
CH91: Cohen et al., 1991
CN79: Conti et al., 1979
Co84: Corbally, 1984a,b
Co00: Cohen 2000, priv. comm.
Cr97: Crowther, 1997
Cr99: Crowther, 1999, priv. comm.
CS97: Crowther and Smith, 1997
CS99: Cotera et al., 1999
CV90: Conti and Vacca, 1990
DS99: De Marco and Schmutz, 1999
DW00: Dougherty et al., 2000
FM95: Figer et al., 1995
FM96: Figer et al., 1996
FM99: Figer et al., 1999b
GR00: Gosset et al., 2000
HH88: van der Hucht et al., 1988
KC92: van Kerkwijk et al., 1992
KG95: Krabbe et al., 1995
MB94: Mereghetti et al., 1994
MC83: Massey and Conti, 1983
MM95: Marchenko et al., 1995
NG99a: Niemela et al., 1999
NG99b: Niemela and Gamen, 1999
Ni95: Niemela, 1995
NK97: Najarro et al., 1997
NM83: Niemela et al., 1983
NS98: Niemela et al., 1998
PM98: Pereira et al., 1998
RV96: Rauw et al., 1996a
SC94: Smith et al., 1994a,b (see also CS97)
Sh90: Shylaja, 1990
SM99: Shara et al., 1999
SS90: Smith et al., 1990 (WC stars)
SS96: Smith et al., 1996 (WN stars)
SS96*: Smith et al., 1996 (WN stars),
with b, o subscripts removed, cf. Conti, 1999
SS99: Schweickhardt et al., 1999a,b
t.w.: this work
WD97: Williams et al., 1997
WH90: Williams et al., 1990
WH94: Williams et al., 1994b
WH96: Williams and van der Hucht, 1996
WH00: Williams and van der Hucht, 2000
HS00: Hanson et al., 2000
WK01: Williams et al., 2001

Column 13: References for visual photometry (in Smith '68 system):

VI: van der Hucht et al., 1981
CH91: Cohen et al., 1991
Cr98: Crowther, priv. comm.
HH88: van der Hucht et al., 1988
KG96: van Kerkwijk et al., 1996
Ma84: Massey, 1984 (synthetic bv)
MC83: Massey and Conti, 1983
Sim: Simbad
SM91: Shara et al., 1991
SM99: Shara et al., 1999
SS90: Smith et al., 1990
Th64: Thé, 1964
TM88: Torres and Massey, 1988
WD97: Willis et al., 1997

Column 14: References for v_∞ from (in order of preference) P-Cyg profiles of IR He I lines; P-Cyg profiles of UV resonance lines (where $v_\infty = v_{\rm black} = 0.76 v_{\rm edge}$, see Prinja et al., 1990); and optical emission lines (Torres et al., 1986) corrected with a factor 0.83 (Prinja et al., 1990).

BC99: Bohannan and Crowther, 1999
CD98: Crowther and Dessart, 1998
CP99: Crowther et al., 1999
CS95b: Crowther et al., 1995b
CS95c: Crowther et al., 1995c
CS95d: Crowther et al., 1995d
CS96: Crowther and Smith, 1996
EW94: Eenens and Williams, 1994
HK95: Hamann et al., 1995a
HM99: Hillier and Miller, 1999
HS92: Howarth and Schmutz, 1992
KH95: Koesterke and Hamann, 1995
LA94: Leitherer et al., 1994
MH00: Morris et al., 2000a
PB90: Prinja et al., 1990
Sc93: Schmutz, 1993
SC94: Smith et al., 1994a,b
Sc97: Schmutz, 1997
TC86o: Torres et al., 1986 (optical em. lines)
TC86u: Torres et al., 1986 (UV P-Cyg profiles)
WD97: Willis et al., 1997
WH92: Williams et al., 1992

Column 15: References for period, periodicity, spectroscopic binary, visual binary.

AB95: Antokhin et al., 1995
AC85: Antokhin and Cherepashchuk, 1985
An91: Annuk, 1991
An94: Annuk, 1994
An95: Annuk, 1995
An00: Annuk 2000, priv. comm.
As82: Aslanov, 1982
AV92: Andrillat and Vreux, 1992
BD99: Blum et al., 1999
BE89: Balona et al., 1989
Be94: Bertrand, 1994
Be95: Bertrand, 1995
BF83: Bisiacchi et al., 1983
CD99: Cieslinski et al., 1999
CM89: Conti and Massey, 1989
CM94: Cherepashchuk and Moffat, 1994
CN79: Conti et al., 1979
CP00: Coker and Pittard, 2000
Cr97: Crowther, 1997
DH96: Duijsens et al., 1996
DL86: Drissen et al., 1986
DM81: Davis et al., 1981
DM95: Drissen et al., 1995
DR92: Drissen et al., 1992
DS87: Drissen et al., 1987
DS99: De Marco and Schmutz, 1999
DS00: De Marco et al., 2000
DW96: Dougherty et al., 1996
FK80: Firmani et al., 1980
GH86: van Genderen and van der Hucht, 1986
GH89: van Genderen et al., 1989
GH90: van Genderen et al., 1990
GK99: Georgiev et al., 1999
GM91: Grandchamps and Moffat, 1991
GM99: Glass et al., 1999
GN99: Gamen and Niemela, 1999
Go87: Golombek, 1987
KF80: Koenigsberger et al., 1980
KG96: van Kerkwijk et al., 1996
La83: Lamontagne, 1983
LD00: Lépine et al., 2000
LM82: Lamontagne et al., 1982
LM87: Lamontagne and Moffat, 1987
LM93: Lewis et al., 1993
LM96: Lamontagne et al., 1996
LS84: Lundström and Stenholm, 1984a
LT84: Lortet et al., 1984
Ma81: Massey, 1981
MA00: Marchenko et al., 2000
MB94: McCandliss et al., 1994
MC81: Massey and Conti, 1981
MD90: Moffat et al., 1990b
MG98: Mason et al., 1998
MG99: Morel et al., 1999b
ML87: Moffat et al., 1987
ML88: Monderen et al., 1988
MLC86: Moffat et al., 1986a
MLS86: Moffat et al., 1986b
MM93: Moffat and Marchenko, 1993
MM94: Matthews and Moffat, 1994
MM95: Marchenko et al., 1995
MM96: Moffat and Marchenko, 1996
MM98: Marchenko and Moffat, 1998
MM99: Morel et al., 1999a
MMA96: Marchenko et al., 1996b
MMEv98: Marchenko et al., 1998a
MMEe98: Marchenko et al., 1998c
MMH98: Marchenko et al., 1998b
MMK94: Marchenko et al., 1994
MML96: Marchenko et al., 1996a
MN82: Moffat and Niemela, 1982
MN84: Moffat and Niemela, 1984
Mo77: Moffat, 1977
Mo92: Moffat, 1992
NM85: Niemela et al., 1985
NM96: Niemela et al., 1996a
NR96: Niemela et al., 1996b
NS80: Niemela and Sahade, 1980
NS98: Niemela et al., 1998
OE99: Ott et al., 1999
PA00: Panov et al., 2000
Re99: Reig, 1999
PS90: Panov and Seggewiss, 1990
RC89: Rustamov and Cherepashchuk, 1989
RG96: Rauw et al., 1996a
RM89: Robert et al., 1989
RM90: Robert et al., 1990
RV96: Rauw et al., 1996b
RVG96: Rauw et al., 1996c
SB84: Stickland et al., 1984
SB00: Setia Gunawan et al., 2000
SB01: Setia Gunawan et al., 2001
SC88: Steiner et al., 1988
SC99: Steiner et al., 1999
SD87: St-Louis et al., 1987
SD98: Steiner and Diaz, 1998
SG96: Schmutz et al., 1996
SH89: Schulte-Ladbeck and van der Hucht, 1989
Sh90: Shylaja, 1990
SM89: compilation of Smith and Maeder, 1989
SS90: Smith et al., 1990
SS96: Smith et al., 1996
SSK99: Schweickhardt et al., 1999b
SSS97: Schmutz et al., 1997
SSS99: Schweickhardt et al., 1999a
St01: Stevens et al., 2001
TC99: Tokovinin et al., 1999
TM99: Tuthill et al., 1999a,b
Tu81: Turner, 1981
TM01: Tuthill et al., 2001
TW: Tamura et al., 1996

GR91: Gosset et al., 1991
GR99: Gosset et al., 1999
GR00: Gosset et al., 2000
GV90: Gosset and Vreux, 1990
GV91: van Genderen et al., 1991
GVM90: Gosset et al., 1990
HH88: van der Hucht et al., 1988
HH97: Harries and Hilditch, 1997
Hip97: ESA, 1997, Hipparcos Cat. Vol. 10
HL93: Hoekzema et al., 1993
HM99: Hartkopf et al., 1999
HS00: Hanson et al., 2000
Hu92: van der Hucht, 1992
HW92: van der Hucht et al., 1992
IM81: Isserstedt and Moffat, 1981
IV99: Ivanov et al., 1999
JB63: Jeffers et al., 1963
KB89: van der Klis and Bonnet-Bidaud, 1989
KC92: van Kerkwijk et al., 1992
Ke93: van Kerkwijk, 1993
Mo99: Monnier, 1999
Mo00: Moffat, 2000, priv. comm.
MS77: Moffat and Seggewiss, 1977
MS80: Moffat and Seggewiss, 1980
MS85: Moffat et al., 1985
MS86: Moffat and Shara, 1986
MT99: Monnier et al., 1999
MV86: Moffat et al., 1986c
NB95: Niemela et al., 1995a
NC95: Niemela et al., 1995b
NG99a: Niemela et al., 1999
NG99b: Niemela and Gamen, 1999
Ni81: Niemela, 1981
Ni82: Niemela, 1982
Ni91: Niemela, 1991
Ni95: Niemela, 1995
Ni00: Niedzielski, 2000
NM82: Niemela and Moffat, 1982
NM83: Niemela et al., 1983
NM84: Niemela et al., 1984
UH94: Underhill and Hill, 1994
VA85: Vreux et al., 1985
VG95: Veen et al., 1995
VGC01: Veen et al., 2001b
VGH01: Veen et al., 2001a,c
VH98: Veen et al., 1998
WC95: Williams et al., 1995
WD97: Williams et al., 1997
WH90: Williams et al., 1990
WH92: Williams et al., 1992
WH94: Williams et al., 1994b
WH99: Williams and van der Hucht, 1999
WH00: Williams and van der Hucht, 2000
WHW87: Williams et al., 1987b
Wi97: Williams, 1997
Wi99: Williams, 1999
Wi01: Williams, 2001
WK00: Williams et al., 2000
WS99: Wallace et al., 1999, 2001
NG00: Niemela and Gamen, 2000

The possible presence of binary components has not yet been fully investigated for most WR stars. While the assessment of a possible binary status for each individual star WR ultimately rests on a successful RV study, there are also other trustworthy binarity indications, e.g.,

- the presence of absorption lines (+a);
- dilution of emission lines by a possible OB companion continuum contribution (+OB?);
- the combination of the two above (+OB);
- photometric periodicity (+?);
- an X-ray excess indicative of colliding winds in a WR+OB binary (CWB); or
- an X-ray excess indicative of a compact companion (+cc).

This is indicated in Table 15. Table 15 shows that some 30 probable WR binaries are awaiting confirmation and further investigation, making this the most neglected aspect of WR research in the past decade. Properties of WR binaries are further discussed in Section 5.

The WR subtype distribution is presented in Table

Table 16
Subtype distribution of known galactic Wolf–Rayet stars[a]

Subtype	N_{WR} in HH88					N_{WR} in this study						
	Single		Double		Total	Single		Double				Total
		+a	SB1	SB2			+a	SB1	d.e.l.	SB2	VB	
WN2	1				1	1						1
WN3	4	1		1	6	2			1	2		5
WN4	7		1	3	11	12		1	2	3		18
WN4.5	5			1	6							
WN5	3		1	2	6	16		1		6	2	25
WN6	13		5	3	21	9		2	8	2	1	22
WN6ha							3	1				4
WN7	12	4	3		19	9			5	2		16
WN8	8		2		10	10		3	3			16
WN9	1				1	4		1	1			6
WN9ha							2					2
WN9–11						7		2				9
WN11						2						2
Subtotal WN	54	5	12	10	81	72	5	11	20	15	3	126
WN/WC	3		1		4	6		3		1		10
WC4	4			1	5	3			1	1		5
WC5	10			1	11	5		1	3	1		10
WC6	10	2		2	14	7	1	2	1	2		13
WC7	6	1		5	12	7		2	2	7		18
WC8	7			2	9	7			1	3		11
WC9	17		1	1	19	24		1	2	3		30
Subtotal WC	54	3	1	12	70	53	1	6	10	17		87
WO1	1				1							
WO2	1				1	2						2
WO4										1		1
Subtotal WO	3				3	2				1		3
Grand total	113	8	14	22	157	133	6	20	30	34	3	226

[a] The WN6/WCE+O6I(+WN+O) classification of WR 153ab brings the total galactic WR number to 227. HH88: van der Hucht et al., 1988.

16. It appears that the WC9 subtype (30 stars) is the most common, followed by the WN5 subtype (25 stars).

Wind terminal velocites are discussed in Section 8.4.

4. Extragalactic Wolf–Rayet stars

WR stars have been discovered in numerous galaxies, in the Local Group and beyond. Breysacher et al. (1999) presented *The IVth Catalogue of Population I Wolf–Rayet stars in the Large Magellanic Cloud*. The Wolf–Rayet census in other Local Group galaxies has been reviewed by Massey and Johnson (1998). Those and other recent sources are quoted in Table 17.

5. Galactic Wolf–Rayet binaries

Comprehensive reviews of properties of WR binaries have been presented in recent years by, e.g., Moffat (1995), Cherepashchuk (1996), and Niemela et al. (1999).

From the proceedings of the first IAU Symposium (No. 49) on WR stars, we quote Kuhi (1973): 'Are all WR stars binaries? The question has been asked . . . and no doubt will continue to be asked . . . because there can be no final answer'. He counted for WR stars with $v < 10$ mag a binary frequency of ~73%, and suggested that, if one allowed for the non-detection of low-luminosity low-mass companions, perhaps all WR stars could be binaries.

van der Hucht et al. (1988, HH88) derived a WR binary frequency of 37% in a limited volume of $d < 2.5$ kpc around the Sun. Moffat (1995) counted galactic WR binaries up to 42%. In recent years more and more relatively nearby supposedly single WR stars have been discovered to be WR+OB binaries or WR+cc binaries. On the other hand, newly discovered WR stars are often faint and possible binarity has not yet been fully investigated. Therefore only a volume-limited WR binary frequency assessment is meaningful (see Section 9), as far as completeness within that volume can be assumed.

5.1. Wolf–Rayet binary census

This *VIIth Catalogue of Galactic Wolf–Rayet Stars* lists among its 227 WR stars at least 86 (38%) WR binaries and probable binaries, 59 more than in the WR binary census of Smith and Maeder (1989).

Tables 18 and 19 list the 86 WR binaries, including, more or less in order of binarity confidence:

(a) double-line spectroscopic binaries (SB2) with radial-velocity (RV) solutions ($N = 19$);

(b) single-line spectroscopic binaries (SB1) with RV solutions ($N = 7$);

Table 17
Wolf–Rayet stars in Local Group galaxies

Local Group galaxies	d[a] (Mpc)	Type[a]	N_{WR}	N_{WC}/N_{WN}	References[e]
LMC	0.052	Ir III–IV	135	0.23	BAT99, MW00
SMC	0.063	Ir IV–V	9	0.12	AB79, MV91
NGC 6822	0.50	Ir IV–V	4	0.00	AM85, MJ98
IC 10	0.66	Ir IV	15[b]	2.00	MA95, MJ98
IC 1613	0.72	Ir V	1	1.00	AM85, MJ98
M 31	0.76	Sb I–II	49[c]	0.67	MS87, MJ98, BT99, GW99
M 33	0.79	Sc II–III	141[d]	0.44	AM85, MJ98

[a] van den Bergh, 1999.
[b] 2 WN candidates.
[c] 6 WR candidates.
[d] 20 WN candidates.
[e] AB97: Azzopardi and Breysacher, 1979; AM85: Armandroff and Massey, 1985; BAT99: Breysacher et al., 1999; BT99: Bransford et al., 1999; GW99: Galarza et al., 1999; MA95: Massey and Armandroff, 1995; MJ98: Massey and Johnson, 1998; MS87: Moffat and Shara, 1987; MV91: Morgan et al., 1991; MW00: Massey et al., 2000.

Table 18
Forty-nine galactic WN-type binaries and probable binaries arranged by subtype[a]

WR	HD/name	WR-type OB/cc-type	Binary status	*P* (d)	*e*	*q* $\left(\frac{M_{WR}}{M_{OB/cc}}\right)$	*f*(*M*) ($M_\odot$)	*a* sin *i* ($R_\odot$)	*M* $\sin^3 i$ ($M_\odot$)	*i* (source)	M_{WR} ($M_\odot$)	$M_{OB/cc}$ ($M_\odot$)	References
3	HD 9974	WN3+O4	SB2	46.85±0.02			~0.2				(20)	(5–12)	MLS86, MS86, SH89, SM89, SS96
46	HD 104994	WN3p	d.e.l., SB1?	0.2825–0.2727			0.012	4–7					CM89, VG95, NB95, MM96, MMH98,
		OB?											MA00, VGC00, VGH00, t.w.
127	HD 186943	WN3	SB2	9.5550	0.07±0.04	0.47		39±6	9.3	55.3±8.2	17		Ma81, MS86, SM89, LM96
		O9.5V						18.6±0.7	20	(phot)		36	
31	HD 94546	WN4	SB2, VB	4.8306±0.0001	0.0	0.43		19±2	2.7	61.6±1.7	4		NM85, LM87, SM89, LM96,
		O8V						7.6±0.4	6.3	(phot)		9	Hip97, GN99
44	LSS 2289	WN4+OB?	d.e.l.										CM89, t.w.
51	Th17-85	WN4+OB?	d.e.l.										CM89, t.w.
128	HD 187282	WN4(h)+OB?	SB2?	3.56, 3.871									La83, AC85, MS86, CM89
145a	Cyg X-3	WNE	SB1	0.1997	0.0	4–8	0.027			>60	5–11		KB89, KC92, Ke93, CM94,
		cc										1.4	KG96, MM96, SG96, HS00
151	CX Cep	WN4	SB2	2.12687		0.71		14.9±0.5	17.8±1.4	74.5±5	20		MC81, SM89, SH89, LM93
		O5V						10.5±0.4	25.2±1.9	(pol'n)		28	
21	HD 90657	WN5	SB2	8.2546±0.0001	0.04±0.03	0.52		37±3	8.4	49.6±3.7	19		NM82, SM89, LM96, MMH98,
		O4-6						17	16.3	(phot)		37	GN99, NG99a
97	HD 320102	WN5	SB2	12.595		0.56		28±1	2.3±0.3	85.4±2.0	2.3		SM89, NC95, NR96, LM96, MMH98
		O7						14.8±0.5	4.1±0.6	(pol'n)		4.1	
109	V617 Sgr	WN5h+?	SB1	0.207		0.92							SC88, SD98, CD99, SC99
133	HD 190918	WN5	SB2, VB	112.4±0.2	0.39±0.07	0.49		70.3	0.40±0.01	16.8	(17)		SM89, Be94, UH94, Be95,
		O9I						34.5	0.82±0.02			(34)	Hip97, MMH98, NG99a
138	HD 193077	WN5o+B?	SB2, VB	1538	0.28±0.07		4.7±0.8	930±60					LM82, An91, Hip97, MMH98, NG99
139	HD 193576	WN5	SB2	4.212435	0.04±0.01	0.34		25.6	8.8±0.4	78.7±0.5	9		MS86, SM89, RM90, MMK94,
		O6III-V						10.2	26.3±1.0	(pol'n)		28	Hip97, MMH98, NG99a
141	HD 193928	WN5	SB2	21.6895±0.0003	0.02±0.03	1.38		50±2	28.9±4.2	68±12	45		MS86, SM89, GM91, LM96,
		O5V-III						69±5	21.0±3.1			30	MMEe98, IV99
21a	Th35-42	WN6+O/a	d.e.l.										MB94, Re99
25	HD 93162	WN6ha+O4f	d.e.l.	long term									CN79, DR92, Hu92, HW92, NG99a, t.w.
28	MS 2	WN6(h)+OB?	d.e.l.										CM89, t.w.
35	MS 6	WN6h+OB?	d.e.l.										CM89, t.w.
36	LS 6	WN5–6+OB?	d.e.l.										CM89, t.w.
43a	HD 97950-A1	WN6ha	SB1	3.7720			0.15±0.03						MN84, MS85, DM95, Mo00, St01
47	HD 311884	WN6	SB2	6.2393±0.0001		0.85		33±1	40	67.1±1.9	51		LM87, SM89, MD90, LM96, GN99
		O5V							47			60	

67	LSS 3329	WN6 + OB?	d.e.l.										CM89, t.w.
71	HD 143414	WN6 + OB?	d.e.l., SB2?	7.690, long term									LM87, CM89, SS96, MMH98, t.w.
85	LSS 3982	WN6h + OB?	d.e.l., VB										HH88, CM89, Hip97, t.w.
115	IC14-19	WN6 + OB?	d.e.l.										CM89, t.w.
153ab	GP Cep	WN6/WCE	SB2 + SB2	6.6884 + 3.4696	0.0 + 0.000	0.54			13	74.0±0.7	15		Ma81, MS86, SM89, PS90, An94,
		O6I (+WN+O)							24	(phot)		27	LM96, NG99a, PA00
155	CQ Cep	WN6	SB2	1.6412436	0.01±0.01	1.24			20.9±1.1	72.5±0.4	24		SB84, SM89, MM95, HH97, Hip97,
		O9II-Ib							25.9±2.7	(phot)		30	MMH98, NG99a
8	HD 62910	WN7/WCE + ?	SB1	38.4/115±13				17.3–54.3	0.8–2.6				Ni91, MMH98
22	HD 92740	WN7h	SB2	80.336±0.001	0.60±0.01	2.69		62.5±0.9	55.3±7.3	90	55		CN79, SM89, GR91, RV96, MMH98,
		O9III–V						168.2±9.0	20.6±1.7			21	NG99a, SSS99
29	MS 3	WN7h + O	SB2	3.16415		1.4		14±2	36±5				NG99a, NG99b, NG00
63	LSS 3289	WN7 + OB	a, d.e.l.										CM89, SS96, t.w.
87	LSS 4064	WN7h + OB	a, d.e.l.										CM89, t.w.
121a	W 43#1	WN7h + a/OB?	d.e.l.										BD99
131	IC14-52	WN7h + OB	a, d.e.l.										CM89, t.w.
145	V1923 Cyg	WN7/WCE + ?	SB1	20.0±0.4									RC89, SM89
158	AS 513	WN7h + Be?	d.e.l.										CM89, AV92, t.w.
12	Ve 5-5	WN8h + ?	SB1, no d.e.l.	23.923			5.5	61		78.8±2.2			Ni82, CM89, SM89, LM96, RVG96, t.w.
66	HD 134877	WN8(h) + cc?	no d.e.l., SB1?, VB	3.515, 0.146, long term									CM89, AB95, RG96, Hip97, MMH98, t.w.
89	LSS 4064	WN8h + OB	a, d.e.l., VB										CM89, Hip97, t.w.
98	HD 318016	WN8/WC7	SB1	48.7			1.9±0.4						Ni91, MMEv98
147	AS 431	WN8(h) + B0.5V	CWB	ELPB + 2880±60									WD97, NS98, SB00b
148	HD 197406	WN8h	SB1, d.e.l.	4.317364, l.t. (~4 yr)	0.08±0.03	~3		7.5±0.2		66.7	(30)		DL86, MS86, CM89, SM89, Mo92,
		B3IV/BH					0.28±0.06	3.1±0.8		(pol'n)		(10)	MML96, Hip97, MMEv98, PA00, t.w.
156	AC + 60 38562	WN8h + OB?	d.e.l.	10.05, 15									MS86, CM89, MMH98, MMEv98, t.w.
101f	GC IRS 13E1	WN9–10 + ?	over-luminous										CP00
101k	GC IRS 16SW	WN9–11 + ?	eclipse	9.72									TW96, OE99
102i	FMM 96-4	WN9h + ?	var.	~700									GM99
108	HDE 313846	WN9h + OB	a, d.e.l.										CM89, t.w.

[a] *Notes:* (): estimate. *Binary status:* a: absorption lines, indicative of an OB companion; CWB: colliding wind binary effects discovered, no RV solution yet; d.e.l.: diluted emission lines, indicative of an OB companion; ELPB: extremely-long-period binary, i.e. $P > 10000$ d; SB1: single-line spectroscopic binary; SB2: double-line spectroscopic binary; t.w.: this work. *References:* see Notes to Table 15, column 15.

Table 19
Thirty-seven galactic WC- and WO-type binaries and probable binaries arranged by subtype[a]

WR	HD/name	WR-type OB/cc-type	Binary status	*P* (d)	*e*	*q* $\left(\frac{M_{WR}}{M_{OB/cc}}\right)$	*f*(*M*) ($M_\odot$)	*a* sin *i* ($R_\odot$)	*M* $\sin^3 i$ ($M_\odot$)	*i* (source)	M_{WR} ($M_\odot$)	$M_{OB/cc}$ ($M_\odot$)	References
19	LS 3	WC4pd + O9.5–9.7	CWB	3690									VH98
143	HD 195177	WC4 + OB?	d.e.l.										CM89, t.w.
4	HD 16523	WC5 + ?	SB1, no d.e.l.	2.4096	0.0		0.007–0.016						MS86, CM89, RC89, SS90, t.w.
9	HD 63099	WC5	SB2	14.305	0.0	0.28		35	5.3	56.8±2.0	9		NM84, SM89, Ni95, LM96
		O7						22	18.8	(phot)		32	
32	MS 5	WC5 + OB?	d.e.l.										CM89, SS90, t.w.
41	LS 7	WC5 + OB?	d.e.l.										CM89, SS90, t.w.
114	HD 169010	WC5 + OB?	d.e.l.										CM89, SS90, t.w.
27	LS 4	WC6 + a	a, no d.e.l.										CM89, SS90, t.w.
30	HD 94305	WC6	SB2	18.82		0.48		73	15.4	78.3±5.8	16		NM83, SM89, Ni95, LM96
		O6-8						35	31.9	(phot)		34	
31c	SMSP 4	WC6 + OB	a, d.e.l.										CM89, SS90, t.w.
48	θ Mus	WC6(+ O9.5/B0Iab)	SB1, VB	18.341±0.008			triple?	63					MS77, SD87, SM89, Hip97, MG98, HM99, NG99a, WM01
132	HD 190002	WC6 + ?	SB1	8.16									BF83
146	HM19-3	WC6 + O8	CWB	ELPB + 1235±10									DW96, NS98, SB00a
14	HD 76536	WC7 + ?	SB1, no d.e.l.	2.42									CM89, Sh90, SS90, NG99a, t.w.
38b	SMSP 4	WC7 + OB	a, d.e.l.										CM89, SS90, t.w.
39	MS 9	WC7 + OB?	d.e.l.										CM89, SS90, t.w.
42	HD 97152	WC7	SB2	7.886±0.003	0.0	0.60			3.7	40.3±2.9	14		DM81, SD87, SM89, LM96, NG99a
		O7V							6.2	(phot)		23	
50	V864 Cen	WC7 + OB	SB2	1.06									CM89, GH90, SS90, GV91, t.w.
79	HD 152270	WC7	SB2	8.8908±0.0005		0.37			1.8	33.6±2.3	11		SD87, SM89, LM96, MMH98,
		O5-8							4.9	(phot)		29	HM99, NG99a
86	HD 156327	WC7 (+ B0III-I)	SB1?, VB, d.e.l.	0.1385±0.0001									JB63, HH88, ML88, CM89, SS90, GV91, NS98, NG99a, t.w.

93	HD 157504	WC7 + O7-9	SB2?										LS84, LT84, CM89, SS90, t.w.
125	V378 Vul	WC7ed + O9III	SB2	> 6600									MS86, WH92, WH94, Wi97, Wi01
137	HD 192641	WC7pd	SB2	4765 ± 50	> 0.12		12.1						MS86, An95, Wi97, NG99a, WH99,
		O9											An00, WK01, Wi01
140	HD 193793	WC7pd	SB2	2900 ± 10	0.85 ± 0.01	0.37		2750 ± 144	23.2 ± 3.4				MS86, WHW87, ML87, SM89, WH90,
		O4-5						1022 ± 46	62.7 ± 9.6				An95, HM99, NG99a, Wi01
11	γ^2 Vel	WC8	SB2	78.53 ± 0.01	0.33 ± 0.01	0.31		180 ± 3	6.8 ± 0.6	63 ± 8	9.5		Mo77, NS80, MV86, SD87, SM89, SSS97
		O7.5III-V						56 ± 3	21.6 ± 1.1			30	DS99, NG99a, SSK99, TC99, DS00
48a	Danks 1	WC8ed + ?	CWB	> 7800									Wi97, Wi99, Wi01
77	He3-1239	WC8 + OB	a, d.e.l.										CM89, CV90, SS90, t.w.
98a	IRAS 17380-3031	WC8–9vd + OB	CWB	565 ± 50						35 ± 6			WC95, Mo99, MT99, TM01, Wi01
102f	FMM 96-3	WC < 8 + ?	var.	~ 700									GM99
113	HD 168206	WC8d	SB2	29.704 ± 0.002	0.19 ± 0.03	0.48		49 ± 1	10.6	70.4 ± 2.3	13		SM89, LM96, NM96, NG99a
		O8-9IV							22.3	(phot)		27	
65	Wra 1297	WC9d + OB?	d.e.l.										CM89, SS90, t.w.
69	HD 136488	WC9d + OB	SB2	2.293 ± 0.005									MMH98, NG99a, WH00
70	HD 137603	WC9vd	SB2	> 4000		0.45		34	0.2	< 20	(> 5)		Go87, SM89, Ni95, Wi97,
		B0I						7	1.1			(> 27)	NG99a, Wi00
103	HD 164270	WC9d + ?	SB1, no d.e.l.	1.7556									IM81, GH86, MLC86, SD87, BE89,
													CM89, SH89, SS90, NG99a, t.w.
104	Ve2-45	WC9d	SB2, VB	243.5 ± 3.0						20 ± 5			Cr97, MT99, TM99, WS99, WH00,
		B0.5V											TM01, Wi01, WM01
112	GL 2104	WC9d + OB?	d.e.l., VB										CM89, SS90, WM01, t.w.
30a	MS 4	WO4	SB2	4.62		0.15		2.9 ± 0.2					Ni95, GR99, GR00
		O5-5.5					0.015						

[a] See notes to Table 18.

(c) long-period binaries deduced from high-spatial-resolution IR imaging of spiral (pinwheel) dust formation around systems like WR 98a and WR 104 (Monnier et al., 1999; Tuthill et al., 1999a,b, 2000, 2001), some of which may never have a RV solution because of low orbital inclination, although their composite spectra may be noted (e.g., Williams and van der Hucht, 1996, 2000, see also (g));

(d) very-long-period binaries inferred from episodic/periodic dust formation, e.g., WR 19, WR 48a, WR 125, WR 137, WR 140 (Williams, 1999), requiring decades of IR photometric monitoring;

(e) very-long- and extremely-long-period binaries inferred from episodic/periodic non-thermal radio excesses, e.g., WR 140 (Williams et al., 1990, 1994a), WR 146 and WR 147 (Setia Gunawan et al., 2000, 2001), requiring decades of radio monitoring;

(f) extremely-long-period binaries deduced from high-spatial-resolution (non-thermal) radio and IR/optical imaging, e.g., WR 146 and WR 147 (Dougherty et al., 1996; Williams et al., 1997; Niemela et al., 1998), and WR 104 and WR 112 (Wallace et al., 2001). The reason why we can be confident that WR 146 and WR 147 are binaries, is that the non-thermal radio sources lie between the stellar components;

(g) binaries tentatively inferred from composite spectra, e.g., WR 19, WR 27, WR 50, WR 69, WR 77, WR 104, WR 125, WR 137, and WR 146 (e.g., Williams and van der Hucht, 1996, 2000); and

(h) binaries tentatively inferred from diluted emission lines, as compared to single stars of the same subtype (Smith et al., 1996; this study).

Table 20
Wolf–Rayet subtype distribution of binaries and probable binaries

Subtype	WN binaries		Subtype	WC binaries	
	N	(%)		N	(%)
WN2					
WN3	3	(60)	WC3		
WN4	6	(33)	WC4	2	(40)
WN5	7	(28)	WC5	5	(50)
WN6	13	(50)	WC6	6	(46)
WN7	9	(56)	WC7	11	(61)
WN8	7	(44)	WC8	6	(55)
WN9	2	(25)	WC9	6	(20)
WN9–11	2	(22)			
Subtotal	49	(39)	Subtotal	37	(43)

Ideally, one would like to have sufficient observations to diagnoste each binary as a SB2 or SB1. But a binary observed pole-on will never allow a RV-solution, although it may still be discernable in categories (c)–(h).

Among the 86 binaries, all WR subtypes are represented, except WN2 and WC3 (see Table 20). As period characterization we adopt the terminology given in Table 21, which gives also the period distribution.

Two WR objects which have been included as binaries, because of their X-ray properties and diluted optical and/or UV emission-line spectra, are:

- WR 21a (Th35-42, WN6 + O/a), discovered by Mereghetti et al. (1994); and
- WR 25 (HD 93162, WN6ha + O4f, excess L_X), which shows diluted UV emission lines (Walborn et al., 1985), and optical polarization variability on a time-scale of years (Drissen et al., 1992). Its excess X-ray luminosity has been associated with a possible very-long-period colliding wind binary (CWB) status (e.g., van der Hucht et al., 1992; Corcoran, 2000).

A WR object of which possible binary status has been suggested in the literature, but which has not been included in Tables 18 and 19, is:

- WR 6 (HD 50896, WN4, $P = 3.7650$ d): earmarked as a possible SB1 by Firmani et al. (1980), its binary nature has been questioned over the years, e.g., by Morel et al. (1998), but also promoted, e.g., by Duijsens et al. (1996) and Georgiev et al. (1999).

Table 21
Wolf–Rayet period characterization and distribution

Period (d)	Characterization	N_{WN}	N_{WC}
$P < 1$	very-short-period binary	3	1
$1 < P < 10$	short-period binary	15	9
$10 < P < 100$	medium-period binary	8	5
$100 < P < 1000$	long-period binary	3	3
$1000 < P < 10000$	very-long-period binary	2	7
$10000 < P$	extremely-long-period binary	1	1

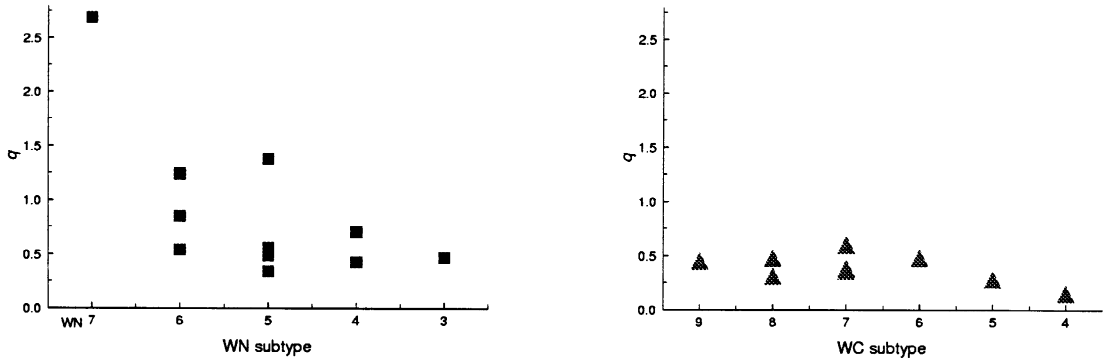

Fig. 1. $q_{WR} = M_{WR}/M_{OB}$ per WR subtype.

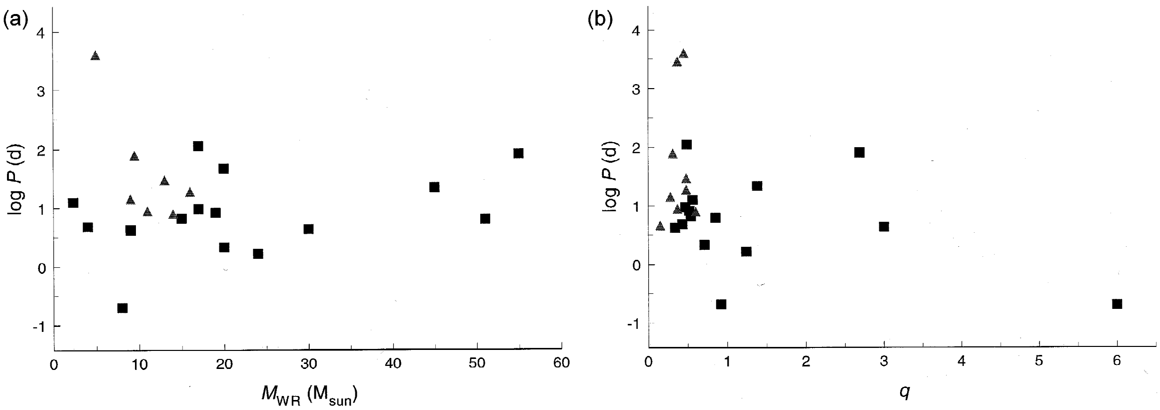

Fig. 2. (a) M_{WR} ($M_\odot$) vs. orbital period P (d); (b) $q_{WR} = M_{WR}/M_{OB}$ vs. orbital period P (d). Symbols as in Fig. 1.

5.2. Wolf–Rayet star masses

To date, only 19 WR double-line spectroscopic binaries (SB2) have RV solutions and reliable masses. This disappointing low number shows that WR binary research, being rather neglected in the past decade, could be one of the most rewarding aspects of the study of hot evolved massive stars.

Of the 19 WR double-line spectroscopic binaries (SB2), the 13 WN stars have masses in the range 2.3–55 $M_\odot$ with $\overline{M_{WN}} = 22 \pm 17$ $M_\odot$. Three WN5–7 stars (WR 22, WR 47 and WR 141) have $M_{WN} > 40$ $M_\odot$. The 6 WC stars have masses in the range 9–16 $M_\odot$ with $\overline{M_{WC}} = 12 \pm 3$ $M_\odot$. In agreement with current evolutionary scenarios which state that WN stars evolve into WC stars, we confirm that $\overline{M_{WC}} < \overline{M_{WN}}$.

For these WR binaries the mass ratios $q = M_{WR}/M_{OB}$ range as $q_{WN} = 0.2–3$ (five WN stars have $q > 1$), $q_{WC} = 0.3–0.6$, and $q_{WO} = 0.15$. Fig. 1 shows these q-values for WN and WC binaries, respectively. Although the limited number of cases yields poor

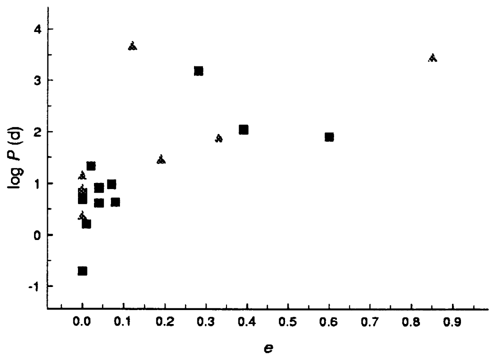

Fig. 3. WR + OB orbital eccentricity e vs. orbital period P. Symbols as in Fig. 1.

Table 22
Galactic Wolf–Rayet visual double and multiple stars with $\Delta\phi \lesssim 15''$

WR	HD/name	HIP	Spectral type WR component	Correlation with open cluster	Visual component		$\Delta\phi$ (″)	θ (°)	Δm[a] (mag)	References
					Designation	Spectral type				
2	HD 6372	5100	WN2				13.8	182	1.54	Hip97
10	HD 65865	39086	WN5ha	Ru 44:		A2V	3.67	201	1.73	Ni81, Tu81, HH88, Hip97, NG99a
11	γ^2 Vel	39953	WC8+O7.5III–V			K4V	4.72	13	11.41	TC99
31	HD 94546	53274	WN4+O8V				0.63	135	2.52	Hip97
31b	AG Car	94910	WN11h		HLV93-21		13.5	341	6.7	HL93
39	MS 9		WC7+OB?	C1104-610b	WR 38b=SMSP 8	WC7+OB	5.1	353	1.7	Tu99
43a	HD 97950-A1		WN6ha	NGC 3603	WR 43b=HD 97950-B	WN6ha	0.77	101	0.07	DM95
					WR 43c=HD 97950-C	WN6ha	2.09	78	0.47	DM95
					HD 97950-A3	O3III(f*)	0.33	96	1.75	DM95
					HD 97950-A2	O3V	0.37	172	1.19	DM95
					HD 97950-33	O5V+OB? (VB)	1.16	160	2.09	DM95
					HD 97950-40	O3V	1.44	243	2.00	DM95
					HD 97950-36	O6V	1.86	297	3.14	DM95
					HD 97950-41	O4V	1.94	254	2.88	DM95
					HD 97950-42	O3III(f*)	1.95	244	1.66	DM95
					HD 97950-37	O6.5V+OB?	2.40	293	2.78	DM95
					HD 97950-45	O8V-III	2.60	272	2.77	DM95
					HD 97950-38	O3V	3.35	302	1.87	DM95
					HD 97950-16	O3V	3.77	81	2.27	DM95
48	θ Mus	64094	WC6			O9.5/B0Iab	0.041	101	−2.5	HM99, WA01
					IDS 13017−6446 B	B	5.34	187	2.02	JB63, Hip97, MG98
48a	Danks 1		WC8ed+?	C1309/10-624?	CPD–62 3058=LSS 2970	B1	9.3	196	−5.8	Wi98
66	HD 134877	74634	WN8(h)+cc?				0.40	14	1	Hip97
79	HD 152270	82706	WC7+O5-8	NGC 6231	IDS 16473−4139 A		3.4	98	5.00	HM99
					B 1834[b]	B1Vn	4.4	198	4.59	HM99
					NGC 6231 SBL 512		13.0	165		Sim
79a	HD 152408	82775	WN9ha	NGC 6231	HD 326293=IDS 16480–4059 B[c]	F4p	6.9	279	7.2	Ai32, GA83, Li85, MG98
79b	HD 152386		WN9ha	KQ Sco group	CHARA 253		0.55	158		Tu79, MG98
85	LSS 3982		WN6h+OB?	HD 155603 group	HD 155603=IDS 17075–3939 A	G5Ia	14.1	332	−3.99	In27, JB63, An77, MF77, LS79
86	HD 156327	84655	WC7		IDS 17118−3418 B	B0III-I	0.29	109	0.02	JB63, Hip97, HH88, HM93, NS98
89	AS 223	84716	WN8h+OB	HM 1			9.88	141	2.20	Hip97
104	Ve2-45		WC9d+B0.5V	Bo 14?			0.957	74	~1.7	WS99, WM01
112	GL 2104		WC9d+OB?				0.942	233	~0.5	WM01

133	HD 190918	99002	WN5 + O9I	NGC 6871	ADS 13374 B[d]	B3V	5.4	58	5.2	Ai32, MG98, HM99
					J200557.85 + 354721.1		8.1	68	5.12	MJ95
					NGC 6871 68		9.1	325	2.91	Sim
					J200556.55 + 354723.8		10.1	335	2.86	MJ95
					ADS 13374 D[e]	B1V	11.29	300	1.10	Ai32, Hip97, MG98
					ADS 13374 C[f]		11.3	17	4.2	Ai32, MG98
					IRAS 20040 − 3538		11.7	255		Sim
					J200557.82 + 354728.8		12.6	35	4.30	MJ95
138	HD 193077	99982	WN5 + B?				0.87	50	2.87	Ai32, JB63, Hip97
					A 1423		4.5	129	4.1	Ai07, HM99
140	HD 193793	100287	WC7pd + O4-5		IDS 20171 + 4332 B[g]		6.7	217	7.5	Ai32, MG98, HM99
146	HM19-3		WC6			O8	0.17	21	0.22	NS98, DW00
					BD + 40 4243	S	12.6	107	−2.28	NS98, HM99
147	AS 431		WN8(h)			B0.5V	0.64	350	2.16	WD97, NS98
157	HD 219460	114791	WN5	Ma 50		B1II	1.37	131	0.38	Wi40, TM83, HH88, Hip97
					ADS 16651 CD		10.9	105	3.7	Ai14, Ai32
					ADS 16651 E		15.26	197	1.86	Ai32, Hip97

Notes to Table 22:

The wider components of WR 79, WR 133 and WR 157 may just be members of, respectively, the open clusters NGC 6231, NGC 6871 and Ma 50.

[a] $\Delta m = \Delta V_{\rm companion} - V_{\rm WR}$, except for those with Hip97 reference, where $\Delta m = \Delta Hp$; and

WR 11: $\Delta m = \Delta K = 13.40 - 1.99$, companion ($J$–$K = 0.75$) possible K4V dwarf.

[b] $P = 60\,000$ yr; [c] $P = 110\,000$ yr; [d] $P = 253\,000$ yr; [e] $P = 574\,000$ yr; [f] $P = 574\,000$ yr; [g] $P = 39\,000$ yr.

References:

Ai07: Aitken, 1907
Ai14: Aitken, 1914
Ai32: Aitken, 1932
An77: Andrews, 1977
DM95: Drissen et al., 1995
DW00: Dougherty et al., 2000
GA83: Gahm et al., 1983
HH88: van der Hucht et al., 1988
HL93: Hoekzema et al., 1993
HM93: Hartkopf et al., 1993
HM99: Hartkopf et al., 1999
Hip97: ESA, 1997
In27: Innes, 1927
JB63: Jeffers et al., 1963
Li85: Lindroos, 1985
LS79: Lundström and Stenholm, 1979
MF77: Moffat and FitzGerald, 1977
MG98: Mason et al., 1998
MJ95: Massey et al., 1995a
Ni81: Niemela, 1981
NG99a: Niemela et al., 1999
NS98: Niemela et al., 1998
Sim: Simbad
TC99: Tokovinin et al., 1999
TM83: Turner et al., 1983
Tu79: Turner, 1979
Tu81: Turner, 1981
Tu99: Turner, 1999
WD97: Williams et al., 1997
WM01: Wallace et al., 2001
Wi40: Wilson, 1940
Wi98: Williams, 1998, priv. comm.
WS99: Wallace et al., 1999

statistics, it appears that both q_{WN} and q_{WC} display a decreasing trend going from WRL to WRE subtypes, as demonstrated earlier by Moffat et al. (1990a) and Moffat (1995). Moffat (e.g., 1982, 1995) argued that the quantity q is a good measure of the evolution from the WRL to WRE phases due to WR mass loss.

(Orbital) periods among the 86 WR binaries range from $P=0.2$ d (e.g., WR 109, WR 145a) to 4700 d (WR 137) and larger (lower limits of 6600 d and 7800 d for, respectively, WR 125 and WR 48a). Especially the census of WR binaries with $P \lesssim 1$ d and $P \gtrsim 100$ d is suffering observational bias (see Table 21). Fig. 2 shows the relationship between orbital periods, WR masses and WR/OB mass ratios. It appears that most WN stars in binaries are more massive than WC binaries. WC stars in binaries tend to have, on average, larger periods. Fig. 3 shows a tendency for the orbital eccentricity e to increase with orbital period P.

5.3. More Wolf–Rayet binaries?

There are at least two reasons to suspect that more WR binaries may be hiding among the $(227-86=)$ 141 presumably single WR stars in the *VIIth Catalogue*. One reason, given by Langer and Heger (1999), argues that most SNe Ib/c occur in post-mass-transfer close binaries. However, the observed galactic binary frequency is as yet $<50\%$. Thus, although supernova statistics show that there should be many more WR+OB binaries than single WR stars, all those binaries have apparently not been detected yet. Another reason stems from direct observational evidence for WCL subtypes. As indicated in this *VIIth Catalogue* (Section 2, Table 3), sixteen WC9 stars, four WC8 stars, three WC7 stars and one WC4 star display persistent or episodic/periodic thermal IR excesses indicative of heated circumstellar amorphous carbon dust formation (Williams, 1999). Of the episodic/periodic cases it has been established that their heated dust is being formed in the wake of the colliding wind cones of WC7+OB and WC8+OB binaries. Of this phenomenon WR 140 is the prototype (Williams et al., 1990). Thanks to repeated high-spatial resolution IR observations (image-masking interferometry) Tuthill et al. (1999a,b) and Monnier et al. (1999) managed to resolve the circumstellar dust shells of, respectively, WR 104 (WC9d+B0.5V) and WR 98a (WC8–9vd+?), and to derive, from the observed rotation of their pinwheel images, the long-period orbital periods ($P=243$ d and 565 d, respectively) of the low-inclination WR+OB binaries revolving within those dust spirals. Those discoveries make it very likely that all other apparently single WC9d and WC8d stars owe their heated circumstellar dust signatures also to colliding WC+OB wind effects, as suggested previously by Williams et al. (1995). Thus, the majority of the known WC9 stars ($\gtrsim 60\%$) and WC8 stars ($\gtrsim 55\%$) could actually be WC+OB binaries.

6. Wolf–Rayet visual double and multiple stars

Separations of visual double stars were at the time of *VIth Catalogue* limited to $\Delta\phi \gtrsim 200$ mas. With increasing spatial resolution and sensitivity both at optical and IR wavelengths, more visual double and multiple components of WR stars have been discovered, thanks to:

- *HST*-WFPC2 down to 150 mas (e.g., Wallace et al., 1999);
- speckle interferometry down to 75 mas (e.g., Hofmann et al., 1995);
- IR image-masking interferometry down to 50 mas (Tuthill et al., 1999a,b, 2000, 2001);
- IR adaptive optics down to 40 mas (e.g., Wizinowich et al., 2000);
- optical adaptive optics down to 22 mas (e.g., Wizinowich et al., 2000);
- *HST*-FGS down to 10 mas (e.g., Wallace, 2001),
- *Hipparcos* astrometry down to 0.64 mas;

and at radio wavelengths, thanks to:

- interferometry by *VLA*, *MERLIN* and VLBI.

In Table 22 we list 24 WR double and multiple stars.

7. Correlation with H I bubbles, H II regions and ring nebulae

About 80% of the WR stars in the Galaxy are embedded in H II regions (Lozinskaya, 1992); 51

WR stars (23%) in this *VIIth Catalogue* are associated with H I shells (see Section 3, Table 14; no complete H I survey yet). As sources of strong stellar winds, WR stars and their O-type progenitors have a profound effect on their surrounding interstellar environment. An obvious example of this is the production of ring (shell) nebulae. Ring nebulae have been discovered around WR stars in systematic searches by Chu et al. (1983), Heckathorn et al. (1982), Miller and Chu (1993), Marston et al. (1994a,b), and Marston (1997), as well as serendipitously. Some ring nebulae have even double or multiple concentric structures, all being relics of recent stellar evolution (Marston, 1995).

Marston (1997) concluded that ~35% of the galactic WR stars have ring nebulae and that WN ring nebulae are generally larger than WC ring nebulae. From the literature (see Section 3, Table 14) we count in the Galaxy 63 WR stars (28%) with ring nebulae: 44 WN stars and 19 WC stars (see Table 23). In the context of WN → WC evolution, we conclude that the about 1.5 times larger WN ring nebula frequency compared to the WC ring nebula frequency suggests, that WR ring nebulae tend to evaporate during stellar evolution.

8. Interstellar extinction, intrinsic colours and absolute visual magnitudes of galactic Wolf–Rayet stars

Knowledge of the distances of WR stars is desirable in order to determine absolute (X-ray, visual, IR, radio, bolometric) luminosities, mass loss rates, masses, radii, birthrates, ages and galactic distribution, parameters in turn related to the larger scale issue of the evolution of massive stars (e.g., Maeder et al., 1980; Maeder and Meynet, 1994), the galactic ultraviolet radiation field, the mass return to the interstellar medium, and the chemical evolution of the Galaxy. Here we determine absolute visual magnitudes and intrinsic colours of WR stars from observations of stars in open clusters and OB associations, in the narrow-band *ubv*-system of Smith (1968a), chosen to avoid the strongest WN emission lines.

8.1. Previous studies

Photometric distances of galactic WR stars, derived from intrinsic parameters like intrinsic colours, colour excesses and absolute visual magnitudes, have been derived and discussed, e.g., by van der Hucht et al. (1988) (HH88), Smith et al. (1990, SS90, WC stars only), and Conti and Vacca (1990, CV90). HH88 used available filter photometry of Smith (1968a), Lundström and Stenholm (1979, 1984a) and Massey (1984). They adopted the compilation by Lundström and Stenholm (1984a, LS84) of distances and colour excesses of galactic open clusters and OB associations containing WR stars as the basis of their calibration. The number of WR stars in galactic open clusters and OB associations in the study of HH88 was 43, distributed over 18 WR subtypes.

CV90 used WR intrinsic colours and absolute visual magnitudes determined by Vacca and Torres-

Table 23
Subtype distribution of Wolf–Rayet stars with ring nebulae

Subtype	N_{WN} with ring nebulae	Subtype	N_{WC} with ring nebulae
WN3	2 (40%)		
WN4	6 (33%)	WC4	2 (40%)
WN5	6 (24%)	WC5	(0%)
WN6	15 (68%)	WC6	3 (23%)
WN7	5 (31%)	WC7	5 (28%)
WN8	6 (38%)	WC8	5 (45%)
WN9	1 (17%)	WC9	3 (10%)
WN10			
WN11	2 (100%)		
WN/WC	1 (10%)	WO2	1 (33%)
WN subtotal	44 (32%)	WC + WO subtotal	19 (21%)

Table 24
Visual extinction $A_v = 4.1\,E_{b-v} = 4.1/1.21 E_{B-V}$ for galactic WR stars[a]

WR	HD/name	Spectral type	v (mag)	Correlation with: open cluster	Correlation with: OB association	A_v (literature) (mag): HH88	SS90	CV90	VT90	CM90	SV91	MB93	$\overline{A}_v$ (mag)	s.d.
(1)	(2)	(3)	(4)	(5)		(6)							(7)	
1	4004	WN4	10.51		Cas OB7:	3.03		3.18	3.03	2.37	2.26	2.47	2.72	0.40
2	6327	WN2	11.33		Cas OB1:	1.64		1.48		1.83	1.93	1.86	1.75	0.18
3	9974	WN3 + O4	10.70			0.86		0.64	1.35	1.46	0.82	1.39		
4	16523	WC5 + ?	10.53			1.93	2.05	1.57	2.74			2.13		
5	17638	WC6	11.02			3.08	3.16	2.97	3.49			4.03		
6	50896	WN4	6.94			0.82		0.72	0.30		0.21	0.00		
7	56925	WN4	11.68			2.58		2.59			1.93	1.83		
8	62910	WN7/WCE + ?	10.48		Anon Pup a:	2.79		2.71	2.79	2.91	2.17	2.44	2.64	0.28
9	63099	WC5 + O7	10.93	HD 63077 group	Anon Pub b?	4.47	4.35	4.37				5.18	4.59	0.40
10	65865	WN5ha(+ A2V)	11.08	Ru 44:	Pub OB2	1.93		1.87	1.93	2.10	2.21	1.93	2.00	0.13
11	68273	WC8 + O7.5III-V	1.74	*Hipparcos* par.	Vel OB2	0.12	0.12	0.00					0.08	0.07
12	Ve5-5	WN8h + ?	10.99		Bo 7?	3.08		2.54	3.08	3.39	2.62	3.02	2.96	0.32
13	Ve6-15	WC6	13.78			4.47	4.59	4.79						
14	76536	WC7 + ?	9.42		Anon Vel a:	1.72	1.89	1.99				2.00	1.90	0.13
15	79573	WC6	11.72		Anon Vel b?	4.18	4.31	4.37				4.78	4.41	0.26
16	86161	WN8h	8.44			2.13		1.95	1.93		1.76	1.90		
17	88500	WC5	11.03			1.27	1.39	2.16	0.95			1.08		
18	89358	WN4	11.11		Car OB1?	3.32		3.48	2.78		2.42	2.58	2.92	0.46
19	LS 8	WC4pd + O9.6	13.75			5.00	5.58	5.55						
20	BS 1	WN5	14.45			4.10					3.90			
20a	SMSP 2	WN7:h/WC	14.14	Westerlund 2									6.76	SM91
21	90657	WN5 + O4-6	9.76			2.58		2.20	1.86	2.44	2.09	2.00		
22	92740	WN7h + O9III-V	6.44		Car OB1	0.94		1.06	0.94	0.58	1.03	1.08	0.94	0.19
23	92809	WC6	9.67		Car OB1:	1.27	1.39	0.55				1.66	1.09	0.71
24	93131	WN6ha	6.49	Cr 288	Car OB1	0.82		0.55	0.82	0.27	0.66	0.61	0.62	0.20
25	93162	WN6h + O4f	8.14	Tr 16-177	Car OB1	2.30		1.53	2.30	0.98	2.01	1.59	1.79	0.52
26	MS 1	WN7/WCE	14.61			4.06		4.88			3.90			
27	LS 4	WC6 + a	14.96			5.37	6.52	6.49						

28	MS 2	WN6(h) + OB?	12.98			4.06		4.24			4.14			
29	MS 3	WN7h + O	12.65			3.73		3.56			3.77			
30	94305	WC6 + O6-8	11.73			2.46	2.34	2.63	1.93			1.97		
30a	MS 4	WO4 + O5-5.5	13.33			3.73	1.05	3.69						
31	94546	WN4 + O8V	10.69			2.50		2.12	2.27		2.26	2.27		
32	MS 5	WC5 + OB?	15.9				6.52	4.58						
33	95435	WC5	12.35			1.93	2.05	1.61	1.93			1.90		
34	LS 5	WN5	14.50			4.18		4.16			2.83			
35	MS 6	WN6h + OB?	13.83			4.22		3.35			3.03			
35b	SMSP 6	WN4	14.49	Sher 1									6.31	SM91
36	LS 6	WN5–6 + OB?	13.57			4.22		4.16			3.57			
37	MS 7	WN4	15.77			6.8		6.40			6.27			
38	MS 8	WC4	15.41	C1104–610a		4.92	5.04	4.79					4.92	0.13
38a	SMSP 7	WN5	16.21	C1104–610a									5.41	Tu98
38b	SMSP 8	WC7 + OB	16.21	C1104–610b?									7.42	SM91
39	MS 9	WC7 + OB?	14.5	C1104–610b?		7.46	6.44	5.94					6.61	0.77
40	96548	WN8h	7.85			1.56		1.61	1.69	2.68	1.19	1.56		
41	LS 7	WC5 + OB?	14.80			4.88	4.51	5.22						
42	97152	WC7 + O7V	8.25		Car OB1?	1.11	1.60	1.02	1.19			1.32	1.25	0.23
43a	97950-A1	WN6ha	11.90	NGC 3603									4.17	CD98
43b	97950-B	WN6ha	11.97	NGC 3603		(4.4)	4.67	4.07			4.06	3.83	4.17	CD98
43c	97950-C	WN6ha	12.37	NGC 3603									4.17	CD98
44	LSS 2289	WN4 + OB?	12.96			2.62		2.50	1.86		1.76	1.86		
45	LSS 2423	WC6	14.80			4.59	5.82	5.26						
46	104994	WN3p + OB?	10.87		Cru OB4.0	1.11		0.72	1.36	1.36	0.57	1.19	1.05	0.33
47	E311884	WN6 + O5V	11.08	Ho 15-3:		4.19		4.07	4.18	3.93	3.40	4.00	3.96	0.29
48	113904	WC6(+ O9.5/B0Iab)	5.88		Cen OB1:	0.90	0.90	1.02	0.90				0.93	0.06
48a	Danks 1	WC8ed(+ ?)	(16.8)	C1309/10-624?		8.6							8.6	
49	LSS 2979	WN5(h)	13.84			3.40		2.25			2.91			
50	LSS 3013	WC7 + OB	12.49		Anon Cen OB?	3.32	3.49	3.82				4.44	3.77	0.49
51	Th17-85	WN4 + OB?	14.64		Anon Cen OB?	5.41		5.47			4.59		5.16	0.49
52	115473	WC4	9.86			1.72	1.85	2.29	1.27			1.59		
53	117297	WC8d	10.88			2.21	2.21	3.26	2.71			1.42		
54	LSS 3111	WN5	12.99			2.99		2.88			2.34			
55	117688	WN7	10.87			2.75		2.67	2.34	2.78	1.97	2.27		
56	LS 8	WC7	13.87			2.34	3.08	2.63	1.86			1.93		
57	119078	WC8	10.02			2.01	2.30	2.08	1.63			1.73		

(*continued on next page*)

Table 24. Continued

WR	HD/name	Spectral type	v (mag)	Correlation with: open cluster	Correlation with: OB association	A_v (literature) (mag): HH88	SS90	CV90	VT90	CM90	SV91	MB93	$\overline{A_v}$ (mag)	s.d.
(1)	(2)	(3)	(4)	(5)		(6)							(7)	
58	LSS 3162	WN4/WCE	13.05			2.83		3.56			1.76			
59	LSS 3164	WC9d	13.90			6.77	7.18	7.00						
60	12194	WC8	13.25			5.41	5.82	4.92						
61	CF Cir	WN5	12.41			2.21		2.37	1.39	2.58	1.60	1.66		
62	NS 2	WN6	14.22			7.71		7.76			5.78			
63	LSS 3289	WN7+OB	12.83			6.40		6.70			6.27			
64	BS 3	WC7	15.57				1.93	1.91						
65	Wra 1297	WC9d+OB?	14.50		Cir OB1	7.22	7.87	7.76					7.62	0.35
66	134877	WN8(h)+cc?	11.66		Cir OB1	4.10		3.94	4.22		3.69		3.99	0.23
67	LSS 3329	WN6+OB?	12.12	Pi 20:	Cir OB1	4.10		4.58	4.10		3.53		4.08	0.43
68	BS 4	WC7	14.09		Cir OB1	5.25	5.25	5.64					5.38	0.23
69	136488	WC9d+OB	9.43			2.26	2.67	2.16	2.00			2.00		
70	137603	WC9vd+B0I	10.10			5.17	5.17	5.13				3.46		
71	143414	WN6+OB?	10.23			1.39		0.59	1.02	1.76	0.57	1.22		
73	NS 3	WC9d	15.23			5.45	7.13	5.34						
74	BP 1	WN7	13.98		Nor OB4?	7.34		8.14			6.60		7.36	0.77
75	147419	WN6	11.23		Nor OB4?	3.73		4.03		4.54	2.58	3.25	3.63	0.75
76	LSS 3693	WC9d	15.46			6.27	6.68	5.51						
77	He3-1239	WC8+OB	13.00		Ara OB1b:	4.02	4.06	3.73					3.94	0.18
78	151932	WN7h	6.61	NGC 6231-305:	Sco OB1	1.76		1.87	1.48		1.56		1.67	0.18
79	152270	WC7+O5-8	6.95	NGC 6231-220	Sco OB1	1.48	1.48	1.31	1.59			1.86	1.54	0.20
79a	152408	WN9ha	5.29	NGC 6231-327	Sco OB1								1.42	CB97
79b	152386	WN9ha	8.32	KQ Sco group									2.88	Tu79
80	Wra 1581	WC9d	14.63			6.23	6.65	6.44						
81	He3-1316	WC9	12.71			6.36	6.77	5.81						
82	LS 1	WN7(h)	12.41			4.43		4.58			3.61			
83	He3-1344	WN5	12.79			3.81		4.28			3.12			
84	Thé 3	WN7	13.55			5.99		5.47			4.96			
85	LSS 3982	WN6h+OB?	10.60	HD 155603 group ?		3.44		3.26			2.54	2.85	3.02	0.41
86	156327	WC7 (+B0III-I)	9.63			3.08	3.08	2.93				3.63		
87	LSS 4064	WN7h+OB	12.59	HM 1	Anon Sco OB	6.72		7.50			7.42		7.21	0.43
88	Thé 1	WC9	13.25		Anon Sco OB	5.90	6.19	5.26	6.72				6.02	0.61
89	LSS 4065	WN8h+OB	11.53	HM 1	Anon Sco OB	6.31		5.98	6.36		6.36		6.25	0.18

90	156385	WC7	7.45			0.78	0.78	0.85	1.93			1.49		
92	157451	WC9	10.43			1.93	2.34	1.65	1.85			1.66		
93	157504	WC7+O7-9	11.45	Pi 24:		5.82	5.82	5.89					5.84	0.04
94	158860	WN5				4.18		4.11			3.28			
95	He3-1434	WC9d	14.00	Tr 27-28:		7.79	7.38	6.95					7.37	0.42
97	E320102	WN5+O7	11.14			4.14		3.65			3.85			
98	E318016	WN8/WC7	12.51	Tr27-105?		5.54		5.81			4.92		5.42	0.46
100	E318139	WN7	13.44			5.95		5.94			4.39			
101	DA 3	WC8	16.4			7.7	7.71	7.34						
102	Sand 4	WO2	15.10			4.55	4.26	7.14	4.26					
103	164270	WC9d+?	8.86			1.80	2.21	1.57	1.63			1.46		
104	Ve2-45	WC9d+B0.5V(+VB)	13.54	Bo 14?	Sgr OB1?	7.09	7.46	7.12					7.22	0.21
105	Ve2-47	WN9h	12.92		Sgr OB1:	8.65		8.61					8.63	0.03
106	E313643	WC9d	12.33			4.63	5.37	5.00						
107	DA 1	WN8	14.10			6.52		6.49			5.90			
108	E313846	WN9ha+OB	10.16		Sgr OB1?	3.98		3.52			3.57	3.80	3.72	0.21
109	V617 Sgr	WN5h+?					1.11	0.81	1.11			1.11		
110	165688	WN5–6	10.30		Sgr OB1?	4.22		4.49			2.79		3.83	0.91
111	165763	WC5	8.23		Sgr OB1:	1.03	1.15	0.81	1.12			1.15	1.05	0.14
112	GL 2104	WC9d+OB?	18.8			13.2	7.42		6.95					
113	168206	WC8d+O8-9IV	9.43		Ser OB2:	3.32	3.32	3.10				3.19	3.23	0.11
114	169010	WC5+OB?	12.95		Ser OB1:	4.84	4.96	4.62					4.81	0.17
115	IC14-19	WN6+OB?	12.32		Ser OB1:	5.66		5.51			4.92		5.36	0.39
116	ST 1	WN8h	13.38			6.89		6.95			5.99			
117	IC14-22	WC9d	14.19	Do 29?		6.27	6.81	6.15					6.41	0.35
119	Thé 2	WC9d	12.41			4.26	4.67	3.94						
120	Vy1-3	WN7	12.30	Do 33?		5.29		5.09			4.47		4.95	0.43
121	AS 320	WC9d	12.41		Anon Sct OB?	5.66	6.07	5.43					5.72	0.32
123	177230	WN8				2.87		2.71			2.67	2.74		
124	209 BAC	WN8h	11.58			4.43		4.37			3.65			
125	V378 Vul	WC7ed+O9III	13.52			6.68	6.68	6.74						
126	ST 2	WC5/WN	13.29		Vul OB2:	3.98	4.10	3.86			3.65		3.90	0.19
127	186943	WN3+O9.5V	10.33		Vul OB2:	1.97		1.48	1.36	1.76	1.89	1.42	1.65	0.26
128	187282	WN4(h)+OB?	10.54			1.07		0.85	0.86	1.05	0.78	1.08		
129	Sey 1	WN4	13.27			3.36		3.56			3.20			

(continued on next page)

Table 24. Continued

WR	HD/name	Spectral type	v (mag)	Correlation with		A_v (literature) (mag)							$\overline{A_v}$ (mag)	s.d.
				open cluster	OB association	HH88	SS90	CV90	VT90	CM90	SV91	MB93		
(1)	(2)	(3)	(4)	(5)		(6)							(7)	
130	LS 16	WN8(h)	12.60			5.95		6.02			5.62			
131	IC14-52	WN7h+OB	12.36			4.10		3.90			3.85			
132	190002	WC6+?	13.49			3.98	4.10	3.26						
133	190918	WN5+O9I	6.70	NGC 6871		1.62		0.85	0.98	1.76	1.64	0.85	1.28	0.43
134	191765	WN6	8.23		Cyg OB3:	1.97		1.99	1.22	1.93	1.44	1.59	1.69	0.32
135	192103	WC8	8.36		Cyg OB3:	1.44	1.44	0.81	1.49			1.80	1.40	0.36
136	192163	WN6(h)	7.65		Cyg OB1:	2.01		2.25	2.17	1.90	1.35	1.83	1.92	0.32
137	192641	WCpd+O9	8.15	Do 3?	Cyg OB1:	1.85	1.85	1.74	2.20			2.47	2.02	0.30
138	193077	WN5+B?	8.10		Cyg OB1:	2.13		1.78	2.17	2.27	2.34	2.13	2.14	0.19
139	193576	WN5+O6III-IV	8.10	Be 86:	Cyg OB1?	2.79		2.46	2.95	2.91	2.91	2.98	2.83	0.19
140	193793	WC7pd+O4-5				2.46	2.46	2.29	2.98			3.22		
141	193928	WN5+O5V-III	10.14		Cyg OB1	4.14		4.03	4.14	4.74	4.31	3.25	4.10	0.49
142	Sand 5	WO2	13.82	Be 87:		6.74	6.77	6.70					6.74	0.04
143	195177	WC4+OB?	11.95			6.07	6.19	5.85						
145	V1923 Cyg	WN7/WCE+?	12.55		Cyg OB2?	7.79		7.84			8.32		7.98	0.29
147	AS 431	WN8(h)+B0.5V	14.89			9.92		9.29						
148	197406	WN8h+B3IV/BH	10.46			2.58		2.37		3.39	2.62			
149	ST 4	WN5	14.70			6.07		6.11						
150	ST 5	WC5	13.47			3.28	3.40	3.69						
151	CX Cep	WN4+O5V	12.37			4.02		3.65		4.20	4.20			
152	211564	WN3(h)	11.67		Cep OB1:	1.80		1.53	1.69	1.69	1.27	1.73	1.62	0.19
153ab	211853	WN6/WCE+O6I	9.08		Cep OB1:	2.75		2.16	1.69	2.51	2.30	2.24	2.28	0.36
154	213049	WC6	11.54		Cep OB1:	2.58	2.71	2.33	2.83			2.78	2.65	0.20
155	214419	WN6+O9II-Ib	8.75		Cep OB1:	2.58		2.12	1.73	2.91	2.17	1.83	2.22	0.45
156	AC+60 38562	WN8h+OB?	11.09			4.51		4.37			4.02	3.66		
157	219460	WN5(+B1II)	9.91	Ma 50		3.03		2.76	3.03		3.61	2.20	2.93	0.51
158	AS 513	WN7h+Be?	11.46			4.18		4.03			3.57	4.40		

[a] Columns (1) through (5) are quoted from Tables 13–15. Columns (5): from LS84 := probable member, ? = possible member. Members and probable members are used with equal weight in our calibration. Possible members are not used. Column (6): CM90: Conti and Morris (1990); CV90: Conti and Vacca (1990); HH88: van der Hucht et al. (1988); MB93: Morris et al. (1993); SV91: Schmutz and Vacca (1991); VT90: Vacca and Torres-Dodgen (1990). Column (7): $\overline{A_v}$ only for cluster/association members and probable members.

Dodgen (1990, VT90) by averaging galactic data (from open cluster and OB association distances) and LMC data, derived from synthetic line-free photometry by Massey (1984) and Torres-Dodgen and Massey (1988). The colour excesses derived by Vacca and Torres-Dodgen (1990) have been based on 'nulling' the 2175 Å interstellar absorption feature in low-resolution *IUE* spectra of galactic and LMC WR stars. This method has been applied again by Niedzielski (1995) for WN stars, with mixed results.

A comparison between the observational studies of HH88 and CV90 indicates that the average error in visual photometric distance determinations of WR *field* stars is of the order of 50%, but for individual stars the two distance determinations show larger discrepancies, up to a factor 2.5.

New empirical methods of distance determination, based on emission line-strengths and -ratios, have been developed by Conti and Massey (1989), Conti and Morris (1990) and Smith et al. (1990), to determine absolute visual magnitudes of WN stars, interstellar reddening of WN stars and distances of WC stars, respectively. Schmutz and Vacca (1991) developed a method to determine interstellar extinction from model-fitting of observed continuum-edges in *ubv*-photometry.

8.2. Interstellar reddening of Wolf–Rayet stars in open clusters and OB associations

In a study of the galactic distribution of WR stars, van der Hucht et al. (1988, HH88) determined intrinsic colours and absolute visual magnitudes, following the method described by LS84 and adding more recent data. The relevant visual photometric intrinsic parameters are based on the narrow-band *ubv* system of Smith (1968a) and LS84, for which the relation $E_{B-V} = 1.21 E_{b-v}$ applies, and A_v $(= 1.11\ A_V) = 4.1\ E_{b-v}$ if one adopts that the average ratio of the total-to-selective extinction $R_V \equiv A_V / E_{B-V} = 3.1$, where the subscripts *B, V* refer to the Johnson *UBV* photometric system. Empirical reasons to adopt this *average* value for the Milky Way have been given by, e.g., Johnson (1968), Savage and Mathis (1979), Pei (1992), and He et al. (1995). LS84 gave also $(B–V)_\circ = 1.28(b–v)_\circ + 0.12$ and $M_v - M_V = -0.1$ mag.

The A_v values determined by LS84 and up-dated by HH88 are related to the overall extinction towards each individual open cluster or OB association, or, in case of variable extinction, towards the relevant locations within the clusters or associations. The A_v values derived by HH88 are listed in Table 24, column HH88. Since then, new and independent studies of the extinction towards WR stars have been published. We compare the more comprehensive ones here:

- For 15 WR stars in galactic open clusters and OB associations Vacca and Torres-Dodgen (1990, VT90) derived E_{B-V} values based on 'nulling' of the diffuse interstellar 2175 Å absorption feature in *IUE* spectra. We have transformed those E_{B-V} values to A_v values (Table 24, column VT90), assuming $R_V = 3.1$, as argued above.
- Although the galactic distribution study of Conti and Vacca (1990, CV90) is based on the determination of intrinsic colours and absolute magnitudes of galactic and LMC WR stars by Vacca and Torres-Dodgen (1990, VT90), CV90 did not use the results of VT90 for individual stars, but adopted average (galactic and LMC) basic parameters per subtype. In this way CV90 re-determined A_v values per WR star (Table 24, column CV90), which differ from those measured by VT90. Moreover, CV90 re-derived distances for the WR stars in open clusters and OB associations, which differ from their adopted distances of those open clusters and OB associations.
- For 18 WN stars in galactic open clusters and OB associations Conti and Morris (1990, CM90) derived the reddening E_{B-V} from observed He II λ4686/He II λ1640 emission-line flux-ratios. We have transformed those E_{B-V} values to A_v values (Table 24, column CM90), assuming $R_V =$ 3.1, as argued above.
- For 25 WN stars in galactic open clusters and OB associations Schmutz and Vacca (1991, SV91) derived the reddening E_{b-v} by comparing observed continuum edges in *ubv* photometry with those resulting from non-LTE model-atmosphere calculations. We have transformed those E_{b-v} values to A_v values (Table 24, column SV91), assuming $R_v = 4.1$ as argued above. SV91 also presented a thorough comparison of the different methods quoted above.

- For 28 WR stars in galactic open clusters and OB associations Morris et al. (1993, MB93) derived E_{B-V} values based on 'nulling' of the diffuse interstellar 2175 Å absorption feature in *IUE* spectra, independently from the work of Vacca and Torres-Dodgen (1990). We have transformed those E_{B-V} values to A_v values (Table 24, column MB93), assuming $R_V = 3.1$, as argued above.

In this study we adopt for all known WR members (m) and probable members (m:) of known galactic open clusters and OB associations, that $\overline{A_v}$ is the average of the A_v values found per star in the studies of HH88, SS90, CV90, VT90, CM90, SV91, and MB93, as far as available.

Table 24 gives those $\overline{A_v}$ values for 64 stars in open clusters and OB associations. Typical errors are about 0.3 mag. Those, together with the listed v and $b-v$ values allow a determination of $(b-v)_\circ$ for each star. The average intrinsic colours per subtype are listed in Table 27.

8.3. Intrinsic parameters of Wolf–Rayet stars in galactic open clusters and OB associations

We adopt the $\overline{A_v}$ values of Table 24, and the distance moduli compiled by LS84, but revised in the following way (see Tables 25, 26 and 28):

(i) Distances of stars with *Hipparcos* parallax:

- WR 11 (γ^2 Vel): $d = 0.26$ kpc (van der Hucht et al., 1997a; Schaerer et al., 1997; however, see Pozzo et al., 2000), affecting WC8 stars.

(ii) Distances of stars with known angular wind outflow velocity and known terminal wind velocity ('*Keck* p.m.'):

- WR 98a: $d = 1.9$ kpc (Monnier et al., 1999), affecting WC8–9 stars;
- WR 104: $d = 2.3 \pm 0.7$ kpc (Tuthill et al., 1999a,b), affecting WC9 stars.

(iii) Large visual extinction values are subject to relatively large errors. For WR 48a, WR 98a, WR 104, WR 112, WR 118 and WR 147, stars with strong extinction, optical depth $\tau_{9.7\mu}$ values are given by van der Hucht et al. (1996). Adopting the distances of WR 98a, WR 104 (see above) and WR 147 (Morris et al., 2000) and their subsequent A_v values of, respectively, 13.79, 7.22, and 11.60 mag, we find $A_v/\tau_{9.7\mu} = 19.1$. This allows A_v determinations for WR 48a, WR 112 and WR 118 of, respectively, 10.13, 12.24, and 12.43 mag.

(iv) Distances of open clusters:

- Berkeley 86 (Forbes et al., 1992; Smith et al., 1994a; Massey et al., 1995a; Delgado et al., 1997), affecting WR 139 (WN5);
- Berkeley 87 (Smith et al., 1994a), affecting WR 142 (WO2);
- Hogg 15 (Ahumada et al. 2000) affecting WR 47 (WN6);
- KQ Sco group (Turner, 1979) affecting WR 79b (WN9);
- Markarian 50 (Smith et al., 1994a) affecting WR 157 (WN5);
- NGC 6231 in Sco OB1 (Perry et al., 1990, 1991, 1992; Smith et al., 1994a; Raboud et al., 1997; Baume et al., 1999), affecting WR 78 (WN7), WR 79 (WC7), and WR 79a (WN9);
- NGC 6871 (Smith et al., 1994a; Massey et al., 1995a) affecting WR 133 (WN5);
- Pismis 20 (Peterson and FitzGerald, 1988; Vázquez et al., 1995; Turner, 1996), affecting WR 67 (WN6);
- Trümpler 16 in Car OB1 (Kaltcheva and Georgiev, 1993; Massey and Johnson, 1993; Cudworth et al., 1993), affecting WR 25 (WN6). We adopt their Car OB1 distance also for other WR stars in Car OB1: WR 22 (WN7), WR 24 (WN6), and WR 23 (WC6);
- Trümpler 27 (Smith et al., 1994a), affecting WR 95 (WC9); and
- Westerlund 2 (Belloni and Mereghetti, 1994; Piatti et al., 1998) affecting WR 20a (WN7/WC).

(v) Distances of OB associations:

- Ara OB1b (FitzGerald, 1987; Kaltcheva and Georgiev, 1992; Vázquez and Feinstein, 1992), affecting WR 77 (WC8);
- Cas OB7 (Garmany and Stencel, 1992), affecting WR 1 (WN5);

Table 25
Absolute visual magnitudes for 36 WN stars in galactic open clusters and OB associations

WR	HD/name	Spectral type	v (mag)	A_v (mag)	Open cluster	OB association	v_o–M_v (mag)	d (kpc)	M_v (sys) (mag)	Δm (mag)	M_v (WR) (mag)	References for columns (5), (6), (7)	References for columns (10)	Note
(1)	(2)	(3)	(4)	(5)	(6)	(6)	(7)	(8)	(9)	(10)	(11)			
2	HD 6327	WN2	11.33	1.75		Cas OB1:	12.0	2.51			−2.42	LS84		
46	HD 104994	WN3p + OB?	10.87	1.05		Cru OB4.0	13.05	4.07	−3.23	+2.40	−3.12	TN96	CM89, t.w.	
127	HD 186943	WN3 + O9.5V	10.33	1.65		Vul OB2:	13.22	4.41	−4.54	+0.45	−3.99	Tu80a, LS84, Ra89	CM89, t.w.	
152	HD 211564	WN3(h)	11.67	1.62		Cep OB1:	12.2	2.75			−2.15	LS84, GS92		
1	HD 4004	WN4	10.51	2.72		Cas OB7:	11.3	1.82			−3.51	LS84, GS92		
35b	SMSP 6	WN4	14.49	6.31	Sher 1		11.7	2.19			−3.52	MS91, SM91		
10	HD 65865	WN5h (+ A2V VB)	11.08	2.00	Ru 44:	Pup OB2	13.32	4.61	−4.24	−1.04	−2.85	Tu81, LS84, RF84	CM89, t.w.	*
38a	SMSP 7	WN5	16.21	5.41	C1104 − 610a		15.5	12.1			−4.70	Sh98, Tu98		
133	HD 190918	WN5 + O9I	6.70	1.28	NGC 6871		11.65	2.14	−6.23	−2.05	−4.03	LS84, SM94, MJ95	CM89, t.w.	*
138	HD 193077	WN5 + B?	8.10	2.14		Cyg OB1:	10.5	1.26	−4.54	−0.39	−3.58	LS84, GS92	CM89, t.w.	*
139	HD 193576	WN5 + O6III-V	8.10	2.83	Be 86:	Cyg OB1?	11.39	1.90	−6.12	−0.24	−5.24	LS84, FE92, SM94, MJ95	CM89, t.w.	*
141	HD 193928	WN5 + O5V-III	10.14	4.10		Cyg OB1	10.5	1.26	−4.46	+0.3	−3.86	LS84, GS92	MMEe98	*
157	HD 219460	WN5 (+ B1II VB)	9.91	2.93	Ma 50		12.65	3.39	−5.67	−1.31	−4.07	TM83, LS84, SM94	CM89, t.w.	*
25	HD 93162	WN6h + O4f	8.14	1.79	Tr 16-177	Car OB1	12.55	3.24	−6.20	0.0	−5.45	LS84, MJ93	*a*	*
47	HD E311884	WN6 + O5V	11.08	3.96	Ho 15-3:		12.9	3.80	−5.78	−1.34	−4.16	LS84, AC00	CM89, t.w.	*
67	LSS 3329	WN6 + OB?	12.12	4.08	Pi 20:	Cir OB1	12.57	3.27	−4.53	−0.64	−3.41	LS84, LG87, VW95, Tu96	CM89, t.w.	*
115	IC14-19	WN6 + OB?	12.32	5.36		Ser OB1:	11.5	2.00	−4.54	−0.72	−3.37	LS84, HM93	CM89, t.w.	*
134	HD 191765	WN6	8.23	1.69		Cyg OB3:	11.2	1.74			−4.66	LS84, GS92		*
136	HD 192163	WN6(h)	7.65	1.92		Cyg OB1:	10.5	1.26			−4.77	LS84, GS92		
155	HD 214419	WN6 + O9Ib-II	8.75	2.22		Cep OB1:	12.2	2.75	−5.67	−2.79	−2.80	LS84, GS92	CM89, t.w.	*
24	HD 93131	WN6ha	6.49	0.62	Cr 288-3	Car OB1	12.55	3.24			−6.68	LS84, MJ93		
43a	HD 97950-A1	WN6ha	11.90	4.17	NGC 3603		15.03	10.1			−7.30	LS84, DM95, CD98		
43b	HD 97950-B	WN6ha	11.97	4.17	NGC 3603		15.03	10.1			−7.23	LS84, DM95, CD98		
43c	HD 97950-C	WN6ha	12.37	4.17	NGC 3603		15.03	10.1			−6.83	LS84, DM95, CD98		
87	LSS 4064	WN7h + OB	12.59	7.21	HM 1	Anon Sco OB	12.3	2.88	−6.92	−1.20	−5.41	LS84	CM89, t.w.	*
22	HD 92740	WN7h + O9III-V	6.44	0.94		Car OB1	12.55	3.24	−7.05	+2.8	−6.69	LS94, MJ93	GR91, SS99, t.w.	
78	HD 151932	WN7h	6.61	1.67	NGC 6231-305:	Sco OB1	11.5	1.99			−6.56	LS84, PH91, RC97, BV99		
66	HD 134877	WN8(h) + cc?	11.66	3.99		Cir OB1	12.57	3.27	−4.90			LS84, LG87		
89	LSS 4065	WN8h + OB	11.53	6.25	HM 1	Anon Sco OB	12.3	2.88	−7.02	−0.37	−6.06	LS84	CM89, t.w.	*
105	Ve2-47	WN9h	12.92	8.63		Sgr OB1:	11.0	1.58			−6.71	LS84, BC99		
79a	HD 152408	WN9ha	5.29	1.42	NGC 6231-327	Sco OB1	11.5	1.99			−7.63	PH91, RC97, BC99, BV99		
79b	HD 152386	WN9ha	8.32	2.88	KQ Sco group		12.31	2.90			−6.87	Tu79, BC99		
8	HD 62910	WN7/WCE + ?	10.48	2.64		Anon Pup a:	12.7	3.47	−4.86			Tu77, LS84		
20a	SMSP 2	WN7:h/WC	14.14	6.76	Westerlund 2		13.8	5.75			−6.42	MS91, BM94, PB98		
126	ST 2	WC5/WN	13.29	3.90		Vul OB2:	13.22	4.41			−3.83	Ra89		
153ab	HD 211853	WN6/WCE + O6I	9.08	2.28		Cep OB1:	12.2	2.75	−5.40	−1.1	−3.96	LS84, GS92	SM89	

Table 26
Absolute visual magnitudes for 17 WC and WO stars in galactic open clusters and OB associations

WR	HD/name	Spectral type	v (mag)	A_v (mag)	Open cluster	OB association	v_o-M_v (mag)	d (kpc)	M_v (sys) (mag)	Δm (mag)	M_v (WR) (mag)	References for columns		Note
(1)	(2)	(3)	(4)	(5)	(6)	(6)	(7)	(8)	(9)	(10)	(11)	(5) (6) (7)	(10)	
111	HD 165763	WC5	8.23	1.05		Sgr OB1:	11.0	1.58			−3.82	LS84		
114	HD 169010	WC5+OB?	12.95	4.81		Ser OB1:	11.5	2.00	−3.36	+0.56	−2.85	LS84, HM93	CM89, SS90, t.w.	*
23	HD 92809	WC6	9.67	1.09		Car OB1:	12.55	3.24			−3.97	LS84, MJ93		
48	HD 113904	WC6 (+O9.5/B0Iab VB)	5.88	0.93		Cen OB1:	11.78	2.27	−6.83	−3.15	−3.62	LS84, KG94	CM89, SS90, t.w.	*
154	HD 213049	WC6	11.54	2.65		Cep OB1:	12.2	2.75			−3.31	LS84, GS92		
14	HD 76536	WC7+?	9.42	1.90		Anon Vel a:	11.5	2.00			−3.98	LS84		
68	BS 4	WC7	14.09	5.38		Cir OB1	12.57	3.27			−3.86	LS84, LG87		
79	HD 152270	WC7+O5-8	6.95	1.54	NGC 6231-220	Sco OB1	11.5	1.99	−6.09	+0.17	−5.42	LS84, PH91, RC97, BV99	CM89, SS90, t.w.	*
93	HD 157504	WC7+O7-9	11.45	5.84	Pi 24:		11.2	1.74	−5.59	−0.02	−4.83	LS84, LT84	CM89, SS90, t.w.	*
11	HD 68273	WC8+O7.5III-V	1.74	0.08	*Hipparcos* par.	Vel OB2?	7.06	0.26	−5.40	−1.47	−3.68	HS97, PJ00	DS99	
113	HD 168206	WC8d+O8-9IV	9.43	3.23		Ser OB2:	11.26	1.79	−5.06	−1.52	−3.30	LS84, Fo91	CM89, SS90, t.w.	*
135	HD 192103	WC8	8.36	1.40		Cyg OB3:	11.2	1.74			−4.24	LS84, GS92		
98a	IRAS 17380−3031	WC8–9vd+?	(19.7)		*Keck* dust p.m.		11.4	1.9[b]	−5.48	−0.92	−4.18	MT99		
65	Wra 1297	WC9d+OB?	14.50	7.62		Cir OB1	12.57	3.27	−5.69	−0.37	−4.73	LS84, LG87	CM89, SS90, t.w.	*
95	He3-1434	WC9d	14.00	7.37	Tr 27-28:		11.6	2.09			−4.97	LS84, SM94		
104	Ve2-45	WC9+B0.5V (+VB)	13.54	7.22	*Keck* dust p.m.		11.8	2.3[c]	−5.49	−0.95	−4.16	TM99	CM89, SS90, t.w.	*
142	Sand 5	WO2	13.82	6.74	Be 87:		9.9	0.95			−2.8	TF82, LS84, SM94		

Notes to Tables 25, 26:
t.w.: this work;
VB: visual binary;
$\Delta M = M_{comp} - M_{WR}$;
a: from dilution in *IUE* spectrum (Walborn et al., 1985).
b: distance from p.m. and v_∞ (Monnier et al., 1999).
c: distance from p.m. and v_∞ (Tuthill et al., 1999a,b).

AC00: Ahumada et al., 2000
BC99: Bohannan and Crowther, 1999
BM94: Belloni and Mereghetti, 1994
BV99: Baume et al., 1999
CD98: Crowther and Dessart, 1998
DM95: Drissen et al., 1995
DS99: De Marco and Schmutz, 1999
FE92: Forbes et al., 1992
Fo91: Forbes, 1991
GR91: Gosset et al., 1991
GS92: Garmany and Stencel, 1992
HM93: Hillenbrand et al., 1993
HS97: van der Hucht et al., 1997a
KG94: Kaltcheva and Georgiev, 1994
LG87: Lortet et al., 1987
LS84: Lundström and Stenholm, 1984a
LT84: Lortet et al., 1984
MJ93: Massey and Johnson, 1993
MJ95: Massey et al., 1995a
MMEe98: Marchenko et al., 1998c
MS91: Moffat et al., 1991
MT99: Monnier et al., 1999
PB98: Piatti et al., 1998
PH91: Perry et al., 1991
PJ00: Pozzo et al., 2000
Ra89: Radoslavova, 1989
RC97: Raboud et al., 1997
RF84: Reed and FitzGerald, 1984
SM89: Smith and Maeder, 1989
SM91: Shara et al., 1991
SM94: Smith et al., 1994a
SS90: Smith et al., 1990
SS99: Schweickhardt et al., 1999a
Sh98: Shorlin, 1998
TM83: Turner et al., 1983
TM99: Tuthill et al., 1999a,b
TN96: Tovmassian et al., 1996a
Tu77: Turner, 1977
Tu79: Turner, 1979
Tu80a: Turner, 1980a
Tu81: Turner, 1981
Tu96: Turner, 1996
Tu98: Turner, 1998
VW95: Vazquez et al., 1995

Notes on individual stars in open clusters/OB associations (see also notes to Table 28):
$\Delta_M = M_{comp} - M_{WR}$;
CM89: Conti and Massey, 1989; SM89: Smith and Maeder, 1989; SS90: Smith et al., 1990; Un82: Underhill, 1982; VG96: Vacca et al., 1996.

WR 10:
By comparing the equivalent widths of the He II 4686, He II 5411, and N IV 3480 emission lines of WR 10 and the apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M = -1.04$. This, with $M_{sys} = -4.24$, implies $M_{WR} = -2.85$. $M_{comp} = -3.89$ could imply a B0V companion (Un82).
WR 25:
See Section 5.1.
WR 46:
By comparing the equivalent widths of the He II 4686 and He II 5411 emission lines of WR 46 and the apparently single WN3 star WR 152, we calculate that $\Delta M = +2.40$. This, with $M_{sys} = -3.23$, implies $M_{WR} = -3.12$. $M_{comp} = -0.72$ could imply a B7V companion (Un82). Crowther et al. (1995c): $d = 4.0 \pm 1.5$ kpc.
WR 47:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, and He I 5876 emission lines of WR 47 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -1.34$. This, with $M_{sys} = -5.78$, implies $M_{WR} = -4.16$. $M_{comp} = -5.50$ could imply a O4V or a O8.5III companion (VG96). SM89: $\Delta M \simeq +1.5$.

WR 48 in ring nebula Anon (θ Mus):
By comparing the equivalent widths of the C iv 5808, C iii 4650, and C iii 5696 emission lines of WR 48 and the seven apparently single WC6 stars WR 5, WR 13, WR 15, WR 23, WR 27, WR 45, and WR 154 (CM89; SS90), we calculate that $\Delta M = -3.15$. This, with $M_{\rm sys} = -6.83$, implies $M_{\rm WR} = -3.62$. $M_{\rm comp} = -6.77$ could imply a O9.5Ia companion (VG96). SM89: $\Delta M = -3.3$. Chu and Treffers (1981): $d_{\rm kin} = 1.3$ kpc.
WR 65:
By comparing the equivalent widths of the N iv 5808, C iii 4650, C iii 5696 and He i 5876 emission lines of WR 65 and the 13 apparently single WC9 stars WR 59, WR 73, WR 80, WR 81 WR 88, WR 92, WR 95, WR 96, WR 103, WR 106, WR 117, WR 119 and WR 121 (CM89; SS90), we calculate that $\Delta M = -0.37$. This, with $M_{\rm sys} = -5.69$, implies $M_{\rm WR} = -4.73$. $M_{\rm comp} = -5.11$ could imply a O6V companion (VG96).
WR 67:
By comparing the equivalent widths of the He ii 4686, N iii 4640, He ii 5411, N iv 5808, He i 5876, and N iv 3480 emission lines of WR 67 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -0.64$. This, with $M_{\rm sys} = -4.53$, implies $M_{\rm WR} = -3.41$. $M_{\rm comp} = -4.05$ could imply a B0.5V companion (VG96).
WR 79:
By comparing the equivalent widths of the C iv 5808, C iii 4650, C iii 5696, O iii/iv 5592 and He i 5876 emission lines of WR 79 and the five apparently single WC7 stars WR 14, WR 56, WR 64, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = +0.17$. This, with $M_{\rm sys} = -6.09$, implies $M_{\rm WR} = -5.42$. $M_{\rm comp} = -5.25$ could imply a O5.5V companion (VG96). SM89: $\Delta M > -1.0$.
WR 87:
By comparing the equivalent widths of the He ii 4686, N iii/iv 4640 and C iv 5808 emission lines of WR 87 and the seven apparently single WN7 stars WR 55, WR 74, WR 82, WR 84, WR 91, WR 100 and WR 120 (CM89), we calculate that $\Delta M = -1.20$. This, with $M_{\rm sys} = -6.92$, implies $M_{\rm WR} = -5.41$. $M_{\rm comp} = -6.61$ could imply a O9.5Ia companion (VG96).
WR 89:
By comparing the equivalent widths of the He ii 4686 and N iii/iv 4640 emission lines of WR 89 and the eight apparently single WN8 stars WR 12, WR 40, WR 66, WR 107, WR 116, WR 123, WR 124 and WR 130 (CM89), we calculate that $\Delta M = -0.37$. This, with $M_{\rm sys} = -7.02$, implies $M_{\rm WR} = -6.06$. $M_{\rm comp} = -6.44$ could imply a O5.5-6Ia companion (VG96).
WR 93:
By comparing the equivalent widths of the N iv 5808, C iii 4650, and C iii 5696 emission lines of WR 93 and the five apparently single WC7 stars WR 14, WR 56, WR 64, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = -0.02$. This, with $M_{\rm sys} = -5.59$ implies $M_{\rm WR} = -4.83$. $M_{\rm comp} = -4.85$ could imply a O7V companion (VG96).
WR 104:
By comparing the equivalent widths of the C iii 4650 emission line of WR 104 and the 13 apparently single WC9 stars WR 59, WR 73, WR 80, WR 81 WR 88, WR 92, WR 95, WR 96, WR 103, WR 106, WR 117, WR 119 and WR 121 (CM89; SS90), we calculate that $\Delta M = -0.95$. This, with $M_{\rm sys} = -5.49$, implies $M_{\rm WR} = -4.16$. $M_{\rm comp} = -5.11$ could imply a O6V companion (VG96).
WR 113 in ring nebula RCW 167:
By comparing the equivalent widths of the C iv 5808, C iii 4650, C iii 5696, O iiv/iv 5592 and He i 5876 emission lines of WR 113 and the five apparently single WC8 stars WR 53, WR 57, WR 60, WR 101 and WR 135 (CM89; SS90), we calculate that $\Delta M = -1.52$. This, with $M_{\rm sys} = -5.06$, implies $M_{\rm WR} = -3.30$. $M_{\rm comp} = -4.82$ could imply a O7.5V companion (VG96). SM89 gave $\Delta M \simeq 0$. Esteban and Rosado (1995) found for the associated ring nebula $d_{\rm kin} = 2.0 \pm 0.2$ kpc. Forbes (2000): d (Ser OB2) $= 1.9 \pm 0.3$ kpc.

WR 114:

By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696, and O III/IV 5592 emission lines of WR 114 and the five apparently single WC5 stars WR 4, WR 17, WR 33, WR 111, and WR 150 (CM89; SS90), we calculate that $\Delta M = +0.56$. This, with $M_{sys} = -3.36$, implies $M_{WR} = -2.85$. $M_{comp} = -2.29$ could imply a B2.5V companion (Un82).

WR 115:

By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 115 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -0.72$. This, with $M_{sys} = -4.54$, implies $M_{WR} = -3.37$. $M_{comp} = -4.09$ could imply a B0.5V companion (VG96).

WR 127:

By comparing the equivalent widths of the He II 4686 and He II 5411 emission lines of WR 127 and the apparently single WN3 star WR 152 (CM89), we calculate that $\Delta M = +0.45$. This, with $M_{sys} = -4.54$, implies $M_{WR} = -3.99$. $M_{comp} = -3.54$ could imply a B1V companion (VG96). SM89 gave $\Delta M \simeq -1.3$.

WR 133 in ring nebula Anon (WR 133):

By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411 and N/IV 3480 emission lines of WR 133 and the eight apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M = -2.05$. This, with $M_{sys} = -6.23$, implies $M_{WR} = -4.03$. $M_{comp} = -6.08$ could imply a O3III companion (VG96). SM89: $\Delta M \simeq -2.2$ (emission) or -1.4 (absorption). Esteban and Rosado (1995) found for the associated ring nebula $d_{kin} = 2.2 \pm 0.2$ kpc.

WR 134 in ring nebula Anon (WR 134):

Esteban and Rosado (1995) found for the associated ring nebula $d_{kin} = 2.3 \pm 0.2$ kpc.

WR 138:

By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808 and N IV 3480 emission lines of WR 138 and the apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M = -0.24$. This, with $M_{sys} = -6.12$, implies $M_{WR} = -5.24$. $M_{comp} = -5.48$ could imply a O4.5V or a O9III companion (VG96). SM89: $\Delta M \simeq +1$.

WR 139:

By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and NIV 3480 emission lines of WR 139 and the apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M = -0.39$. This, with $M_{sys} = -4.54$, implies $M_{WR} = -3.58$. $M_{comp} = -3.96$ could imply a B0V companion (Un82). SM89: $\Delta M = -1.6$.

WR 141:

By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 141 and the apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we find no dilution of the WR 141 emission lines. Marchenko et al. (1998c), however, found $\Delta M = +0.3$. $M_{comp} = -3.56$ could imply a B0.5V companion (Un82).

WR 153 in ring nebula Anon (S 132):

Esteban and Rosado (1995) found for the associated ring nebula $d_{kin} = 3.5 \pm 0.5$ kpc.

WR 155:

By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411 and He I 5876 emission lines of WR 155 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -2.79$. This, with $M_{sys} = -5.67$, implies $M_{WR} = -2.80$. $M_{comp} = -5.59$ could imply a O4V or O8III companion (VG96). SM89: $\Delta M = +0.6$. Harries and Hilditch (1997): *d.m.* = 12.

WR 157:

By comparing the equivalent widths of the He II 4686, He II 5411, C IV 5808 and N IV 3480 emission lines of WR 157 and the apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M = -1.31$. This, with $M_{sys} = -5.67$, implies $M_{WR} = -4.07$. $M_{comp} = -5.39$ could imply a O5.5V or a O9.5III (VB) companion (VG96).

- Cen OB1 (Kaltcheva and Georgiev, 1994), affecting WR 48 (WC6);
- Anon Cen OB (Turner, 1985) affecting WR 50 (WC7) and WR 51 (WC4);
- Cep OB1 (Garmany and Stencel, 1992), affecting WR 152 (WN3), WR 153 (WN6/WCE), WR 154 (WC6) and WR 155 (WN7);
- Cru OB4.0 (Tovmassian et al., 1996b), affecting WR 46 (WN3);
- Cyg OB1 (Garmany and Stencel, 1992), affecting WR 136 (WN6), WR 137 (WC7), WR 138 (WN6) and WR 141 (WN6);
- Cyg OB2 (Torres-Dodgen et al., 1991; Massey and Thompson, 1991), affecting WR 145 (WN3/WCE);
- Cyg OB3 (Garmany and Stencel, 1992), affecting WR 133 (WN4.5), WR 134 (WN6) and WR 135 (WC8);
- Pup OB2 (no such association according to Reed and FitzGerald, 1984; see also Kaltcheva and Hilditch, 2000) affecting WR 10 (WN5); and
- Ser OB2 (Forbes, 1991), affecting WR 113 (WC8).

The thus adopted distance moduli of WR stars in galactic open clusters and OB associations are listed in Tables 25 and 26. We used those stars which Lundström and Stenholm (1984a, LS84) list as definite (m) or probable (m:) members. The total number of WR stars in open clusters and OB associations used here for the M_v(WR) calibration is 53 stars (i.e., 27%; we did not use the 26 Galactic Center WR stars for the M_v(WR) calibration[2]), not a large number in view of the 18 WR subtypes. Still, if one ever hopes to find differences between the Galaxy and, e.g., the LMC, it is better not to average their parameters.

The adopted distance moduli, together with the $\overline{A_v}$ (per star) values of Table 24 allow us to re-determine WR absolute visual magnitudes. The derived M_v values in Tables 25 and 26 refer to both single WR stars and WR binary systems. Smith and Maeder (1989) derived M_v(WR) values of WR stars in binaries preferably on the basis of observed magnitude differences Δv, as far as available in the literature. However, Smith et al. (1996, Table 8) derived luminosity ratios based on He II λ5411 emission-line strengths in WR spectra diluted by the presence of an OB companion in the line of sight. We extend that method by taking into account *all* emission lines per WR star listed by Conti and Massey (1989, CM89) and Smith et al. (1990, SS90), in order to find binary companion ΔM_v values.

The resulting M_v(WR) values of both single WR stars and WR components in composite spectra are listed in Tables 25 and 26. For all composite spectra comments are given in the notes to Tables 25 and 26. The resulting $\overline{M_v}$(WR) values are listed in Table 27, where they are also compared with previous studies, and plotted in Fig. 4a,b. The standard deviations of M_v(WR) per subtype are typically ± 0.5 mag, similar as the standard deviations in the absolute visual magnitudes of O-type stars as determined by Vacca et al. (1996, Fig. 6; see also Garmany, 1990, figs. 1, 3 and 4).

As mentioned in Section 2.5, we note an aspect first realized by investigators of the WR stars in NGC 3603 (Drissen et al., 1995; Crowther et al., 1998), that two sequences appear among the WN6 stars, differing about 2 mag in absolute visual magnitude. We extend this distinction and list 'regular' WNL stars and more luminous WNLha stars. However, it could as well be that these apparently over-luminous WNLha stars are just regular WNh + OB binaries, as suggested for WR 43abc in NGC 3603 on the basis of their excess *Chandra* X-ray luminosities (Stevens et al., 2001).

A statistically not significant but yet curious aspect among the four WC7 stars in open clusters and OB associations is that the WC7 components in the two binaries appear about 1.2 mag more luminous than the two single WC7 stars.

8.4. Wolf–Rayet terminal wind velocities

In Table 27 we list also $\overline{v_\infty}$(WR) per subtype, using the individual v_∞(WR)-values given in Table 15. While there is a clear relation within the WN and WC sequences of a decreasing $\overline{v_\infty}$(WR) with increas-

[2]With the Galactic Center WR stars included, we count 79 WR stars in galactic open clusters and OB associations, i.e., 35%; in the LMC this fraction is 62% (Massey et al., 1995b) and in M 33 this fraction is 66% (Wilson, 1991).

Table 27
Average $(b-v)_o$ and M_v in galactic open clusters and OB associations *versus* WR subtype, and average wind terminal velocity v_∞ *versus* WR subtype[a]

Subtype	$\overline{(b-v)_o}$ (mag)					$\overline{M_v}$ (mag)						$\overline{v_\infty}$ (km s^{-1})		
	Previous studies		This study			Previous studies			This study				s.d.	N_{WR}
	HH88	CV90		s.d.	N_{WR}	LS84	HH88	CV90		s.d	N_{WR}			
WN2		−0.20	−0.30		1	−2.5	−2.3	−3.8	−2.42		1	3200		1
WN3		−0.20	−0.26	0.04	2	−3.9	−2.8	−3.8	−3.09	0.9	3	2200	300	2
WN4		−0.20	−0.20	0.06	4	−3.9	−3.5	−3.8	−3.52	0.0	2	1800	400	9
WN4.5	−0.26	−0.20				−3.9	−4.6	−3.8						
WN5	−0.23	−0.20	(−0.20)			−4.7	−4.8	−3.8	−4.05	0.8	7	1500	200	13
WN6	−0.24	−0.20	−0.19	0.04	6	−5.2	−5.3	−3.8	−4.09	0.9	7	1800	400	12
WN7	−0.27	−0.20	−0.18		1	−6.5	−6.6	−5.5	−5.41		1	1300	300	13
WN8		−0.20	−0.27	0.04	2	−6.3	−6.7	−5.5	−5.48	0.8	2	1000	300	12
WN9			−0.34	0.04	*				−6.71		1	1000	400	2
WN10			−0.34	0.04	*				−6.71	0.4	*			
WN11			−0.34	0.04	*				−6.71	0.4	*	400	25	2
WN6ha			−0.26	0.04	4				−7.01	0.3	4	2500	300	4
WN7h(a)			−0.20	0.03	3				−6.72	0.2	3			
WN9ha			−0.18	0.06	4	−6.0		−5.5	−7.25	0.5	2	1300	500	2
WN3+OB			−0.26		1									
WN4+OB			(−0.27)											
WN5+OB			−0.29	0.02	6									
WN6+OB			−0.25	0.03	3									
WN7+OB			−0.20		1									
WN/WC			−0.25	0.05	4				−5.13	1.1	4	1700	500	6
WC4		−0.25	−0.27		1			−3.8	(−3.34)			2800	400	3
WC5		−0.25	−0.27	0.01	2	−3.9	−3.7	−3.8	−3.34	0.7	2	2200	400	8
WC6		−0.25	−0.32	0.04	3	−3.9	−3.7	−3.8	−3.63	0.3	3	2200	300	10
WC7	−0.31	−0.25	−0.33	0.02	3	−4.9	−4.8	−4.8	−4.52	0.7	4	2200	600	14
WC8	−0.38	−0.25	−0.36	0.01	2	−4.9	−4.8	−4.8	−3.74	0.5	3	1700	200	7
WC9	−0.41	−0.25	−0.45	0.04	4	−4.9	−4.8	−4.8	−4.62	0.4	3	1200	300	18
WC4+OB														
WC5+OB			−0.38		1									
WC6+OB			−0.35		1									
WC7+OB			−0.34	0.04	4									
WC8+OB			−0.34	0.01	2									
WC9+OB			−0.45		1									
WO2-4	−0.26		−0.25		1	−2.5	−2.8		−2.8		1	4800	200	2

[a] N_{WR}: number of stars considered per subtype. LS84: Lundström and Stenholm, 1984a; HH88: van der Hucht et al., 1988; CV90: Conti and Vacca, 1990. *: because we do not know WN9–11 stars in galactic open clusters and OB associations, we adopt from Crowther and Smith (1997) for 10 LMC WN9–11 stars that $(B-V)_0 = -0.31 \pm 0.04$, i.e. $(b-v)_0 = -0.34$; and $\overline{M_V} = -6.61 \pm 0.4$, i.e. $\overline{M_v} = -6.71$. (): inter-/extrapolated.

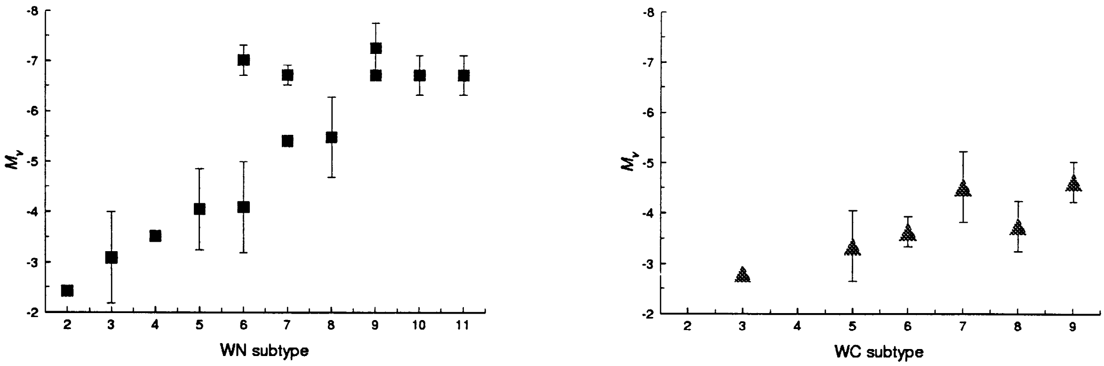

Fig. 4. Average absolute visual magnitude $\overline{M_v(\mathrm{WR})}$ versus WR subtype. In (a), the upper values at WN6, WN7 and WN9 refer to, respectively, WN6ha WN7ha and WN9ha stars. In (b), the point at WC3 refers to WO stars only. The error bars denote the standard deviations of the averages.

ing WR subtype (see Fig. 5a,b), there is no clear relation in both sequences between v_∞(WR) and M_v(WR) per WR star. It should be noted that in case of WR + OB binaries, the individual v_∞(WR)- and v_∞(OB)-values have not been disentangled. In Fig. 5a, on top of the gradual slope, we see an excess at WN6 (lower value): perhaps more WN6ha stars are hiding among them. The same appears to apply to the WN9 stars. In Fig. 5b, the point at WC3 applies to WO stars only.

9. Distances and galactic distribution of Wolf–Rayet stars

To derive heliocentric photometric distances of WR *field* stars, we determine for each field star first its visual extinction A_v from the observed $b - v$ (Table 15) and intrinsic $(b - v)_\circ$ colours (Table 27). Subsequently, its photometric distance (Table 28) follows directly from comparison with its subtype-dependent M_v-value (Table 27). In case of a WR binary, its system M_v-value is corrected for an assumed companion-luminosity, based on the dilution of emission lines as derived from the measurements of Conti and Massey (1989, CM89) and Smith et al. (1990, SS90), and specified in the notes to each star (Tables 25, 26 and 28). Heliocentric distances are listed in Table 28 for 219 of the 227 WR stars, excluding the WN/WC field stars, for which no meaningful average intrinsic parameters could be estimated. For field stars the uncertainties in the

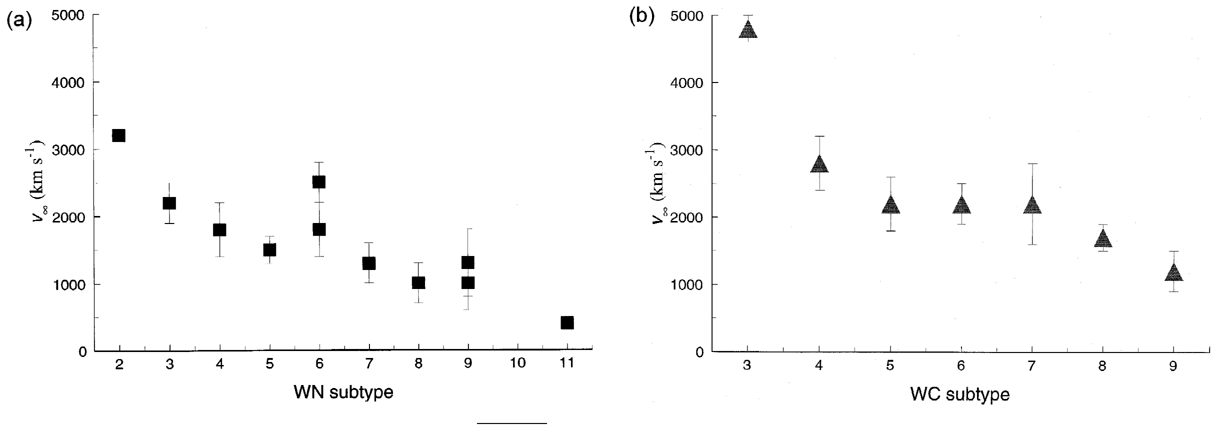

Fig. 5. Average WR stellar wind terminal velocities $\overline{v_\infty(\mathrm{WR})}$ versus WR subtype. In (a), the upper values at WN6 and WN9 refer to, respectively, WN6ha and WN9ha stars. In (b), the point at WC3 refers to WO stars only. The error bars denote the standard deviations of the averages.

Table 28
Photometric distances of galactic Wolf–Rayet stars[a]

WR	HD/Name	Spectral type	v (mag)	$b-v$ (mag)	$(b-v)_o$ (mag)	E_{b-v} (mag)	A_v (mag)	v_o (mag)	M_v^{WR} (mag)	Δm (mag)	M_v^{sys} (mag)	v_o-M_v (mag)	d (kpc)	z (pc)	R (kpc)	Correlation with open cluster/ OB association	Note
1	HD 4004	WN4	10.51	0.51	−0.15	0.66	2.72	7.79	−3.51			11.3	1.82	60	9.1	Cas OB7:	
2	HD 6327	WN2	11.33	0.13	−0.30	0.43	1.75	9.58	−2.42			12.0	2.51	−106	9.7	Cas OB1:	*
3	HD 9974	WN3 + O4	10.70	−0.06	−0.26	0.20	0.82	9.88	−3.09	−0.27	−3.99	13.9	5.94	−429	12.6		*
4	HD 16523	WC5 + ?	10.53	0.20	−0.27	0.47	1.93	8.60	−3.34			11.9	2.44	−127	9.9		*
5	HD 17638	WC6	11.02	0.47	−0.32	0.79	3.24	7.78	−3.63			11.4	1.91	−72	9.5		*
6	HD 50896	WN4	6.94	−0.07	−0.20	0.13	0.53	6.41	−3.52			9.9	0.97	−170	8.6		*
7	HD 56925	WN4	11.68	0.38	−0.20	0.58	2.38	9.30	−3.52			12.8	3.67	−8	10.8		*
7a	PMLC 1	WN4/WC															
8	HD 62910	WN7/WCE + ?	10.48	0.47	−0.17	0.64	2.64	7.84			−4.86	12.7	3.47	−229	9.9	Anon.Pup a:	
9	HD 63099	WC5 + O7	10.93	0.74	−0.38	1.12	4.59	6.34	−3.34	−0.71	−4.50	10.8	1.47	−124	8.6	HD 63077 group ?	*
10	HD 65865	WN5ha (+ A2V, VB)	11.08	0.22	−0.27	0.49	2.00	9.08	−2.85	−1.04	−4.24	13.3	4.61	47	10.7	Ru 44:/Pup OB2	*
11	γ^2 Vel	WC8 + O7.5III-V	1.74	−0.32	−0.34	0.02	0.08	1.66	−3.68	−1.47	−5.40	7.1	0.26	−35	8.0	*Hipparcos* parallax	*
12	Ve 5-5	WN8h + ?	10.99	0.42	−0.30	0.72	2.96	8.03	−5.48			13.5	5.04	−173	9.8		*
13	Ve 6-15	WC6	13.78	0.82	−0.32	1.14	4.67	9.11	−3.63			12.7	3.53	−47	9.0		
14	HD 76536	WC7 + ?	9.42	0.13	−0.33	0.46	1.90	7.52	−3.98			11.5	2.00	−57	8.3	Anon.Vel a:	
15	HD 79573	WC6	11.72	0.72	−0.36	1.08	4.41	7.31	−3.63			10.9	1.54	−29	8.1		
16	HD 86161	WN8h	8.44	0.30	−0.20	0.50	2.05	6.39	−5.48			11.9	2.37	−105	7.9		
17	HD 88500	WC5	11.03	0.14	−0.27	0.41	1.68	9.35	−3.34			12.7	3.45	−222	7.9		
18	HD 89358	WN4	11.11	0.55	−0.16	0.71	2.92	8.19	−3.52			11.7	2.20	−37	7.8		
19	LS 3	WC4pd + O9.6	13.75	1.06	−0.27	1.33	5.45	8.30	−3.34	−0.37	−4.29	12.6	3.30	−69	7.9		*
19a	SMSP 1	WN7:(h)	17.45	1.71	−0.18	1.89	7.75	9.70	−5.41			15.1	10.52	−185	11.6		
20	BS 1	WN5	14.45	0.88	−0.20	1.08	4.43	10.02	−4.05			14.1	6.52	−209	9.0		
20a	SMSP 2	WN7:h/WC	14.14	1.38	−0.27	1.68	6.76	7.38	−6.42			13.8	5.75	−34	8.6	Westerlund 2	
20b	SMSP 3	WN6:h	15.40	1.69	−0.19	1.88	7.71	7.69	−4.09			11.8	2.27	−14	7.8		
21	HD 90657	WN5 + O4-6	9.76	0.27	−0.29	0.56	2.30	7.46	−4.05	−1.09	−5.48	12.9	3.88	−61	7.9		*
21a	Th35-42	WN6 + O/a	(12.8)		−0.25				−4.09								
22	HD 92740	WN7h + O9III-V	6.44	0.03	−0.20	0.23	0.94	5.50	−6.69	+2.8	−7.05	12.5	3.24	−48	7.7	Car OB1	
23	HD 92809	WC6	9.67	−0.05	−0.32	0.27	1.09	8.58	−3.97			12.5	3.24	−2	7.7	Car OB1:	
24	HD 93131	WN6ha	6.49	−0.06	−0.21	0.15	0.62	5.87	−6.68			12.5	3.24	−61	7.7	Cr228-3/Car OB1	
25	HD 93162	WN6h + O4f	8.14	0.17	−0.27	0.44	1.79	6.35	−6.20			12.5	3.24	−40	7.7	Tr16-177/Car OB1	*

(*continued on next page*)

Table 28. Continued

WR	HD/Name	Spectral type	v (mag)	$b-v$ (mag)	$(b-v)_o$ (mag)	E_{b-v} (mag)	A_v (mag)	v_o (mag)	M_v^{WR} (mag)	Δm (mag)	M_v^{sys} (mag)	v_o-M_v (mag)	d (kpc)	z (pc)	R (kpc)	Correlation with open cluster/OB association	Note
26	MS 1	WN7/WCE	14.61	0.92													
27	LS 4	WC6+a	14.96	1.29	−0.32	1.61	6.60	8.36	−3.63			12.0	2.50	5	7.7		
28	MS 2	WN6(h)+OB?	12.98	0.77	−0.19	0.96	3.94	9.04	−4.09	−1.86	−6.13	15.2	10.81	28	11.3		*
29	MS 3	WN7h+O	12.65	0.65	−0.20	0.85	3.49	9.17	−5.41	−1.31	−7.00	16.2	17.17	−303	16.5		*
30	HD 94305	WC6+O6-8	11.73	0.27	−0.35	0.62	2.54	9.19	−3.63	−0.47	−4.64	13.8	5.83	−265	8.2		*
30a	MS 4	WO4+O5-5.5	13.33	0.79	−0.25	1.04	4.26	9.07	−2.8	−2.48	−5.39	14.4	7.77	−187	9.2		*
31	HD 94546	WN4+O8V	10.69	0.28	−0.27	0.55	2.26	8.44	−3.52	−0.57	−4.60	13.0	4.05	1	7.7		*
31a	He3-519	WN11h	(9.75)	(0.65)	−0.34	(1.14)		7.81	−6.71			14.5	8.0	−113	9.3		*
31b	AG Car	WN11h	(7.09)	(0.49)	−0.34	(0.63)		7.22	−6.71			13.9	6.1	−75	8.3		*
31c	SMSP 4[a]	WC6+OB	16.37	0.96	−0.32	1.28	5.25	11.12	−3.63			14.7	8.91	−112	9.8		
32	MS 5	WC5+OB?	15.9	1.29	−0.27	1.56	6.40	9.50	−3.34	−0.33	−4.27	13.8	5.68	2	8.1		*
33	HD 95435	WC5	12.35	0.16	−0.27	0.43	1.76	10.59	−3.34			13.9	6.11	203	8.4		
34	LS 5	WN5	14.50	0.76	−0.20	0.96	3.94	10.56	−4.05			14.6	8.36	−203	9.4		
35	MS 6	WN6h+OB?	13.83	0.59	−0.20	0.79	3.24	10.59	−4.09	−1.29	−5.67	16.3	17.87	−371	16.9		*
35a	SMSP 5	WN6h	13.92	0.86	−0.20	1.06	4.35	9.57	−4.09			13.7	5.40	−6	8.0		
35b	SMSP 6	WN4	14.49	1.27	−0.27	1.54	6.31	8.18	−3.52			11.7	2.19	−9	7.6	Sher 1	
36	LS 6	WN5–6+OB?	13.57	0.68	−0.19	0.87	3.57	10.00	−4.09	+0.46	−4.64	14.6	8.46	83	9.5		*
37	MS 7	WN4	15.77	1.23	−0.20	1.43	5.86	9.91	−3.52			13.4	4.85	−89	7.8		
38	MS 8	WC4	15.41	0.93	−0.27	1.20	4.92	10.49	−3.34			13.8	5.83	−94	8.1		
38a	SMSP 7	WN5	16.21	0.83	−0.49	1.32	5.41	10.80	−4.70			15.5	12.1	−194	11.9	C 1104-610a	
38b	SMSP 8	WC7+OB	16.21	1.50	−0.31	1.81	7.42	8.79	−4.52	+1.43	−4.97	13.8	5.65	−89	8.0		*
39	MS 9	WC7+OB?	14.5	1.26	−0.35	1.61	6.61	7.89	−4.52	−0.92	−5.83	13.7	5.53	−87	8.0		*
40	HD 96548	WN8h	7.85	0.11	−0.27	0.38	1.56	6.29	−5.48			11.8	2.26	−190	7.5		
41	LS 7	WC5+OB?	14.80	0.80	−0.27	1.07	4.39	10.41	−3.34	+1.05	−3.69	14.1	6.61	−119	8.4		*
42	HD 97152	WC7+O7V	8.25	−0.06	−0.36	0.30	1.25	7.00	−4.52	−0.12	−5.33	12.3	2.92	−25	7.5		*
42a	SMSP 9	WN5	17.61	1.46	−0.20	1.66	6.81	10.80	−4.05			14.8	9.33	−80	9.9		
42b	SMSP 10	WN4	16.96	2.43	−0.20	2.63	10.78	6.18	−3.52			9.7	0.87	−23	7.7		
42c	SMSP 11	WN5	16.56	1.36	−0.20	1.56	6.40	10.16	−4.05			14.2	6.95	−47	8.5		
42d	SMSP 12	WN5	15.28	1.33	−0.20	1.53	6.27	9.01	−4.05			13.1	4.09	−34	7.5		
43a	HD 97950-A1	WN6ha	11.90	0.74	−0.28	1.02	4.17	7.73	−7.30			15.0	10.1	−92	10.3	NGC 3603	*
43b	HD 97950-B	WN6ha	11.97	0.74	−0.28	1.02	4.17	7.80	−7.23			15.0	10.1	−92	10.3	NGC 3603	*
43c	HD 97950-C	WN6ha	12.37	0.74	−0.28	1.02	4.17	8.20	−6.83			15.0	10.1	−92	10.3	NGC 3603	*
44	LSS 2289	WN4+OB?	12.96	0.37	−0.20	0.57	2.34	10.62	−3.52	−0.19	−4.37	15.0	9.96	219	10.3		*
44a	SMSP 13	WN4	16.20	1.55	−0.20	1.75	7.18	9.03	−3.52			12.5	3.24	−31	7.4		
45	LSS 2423	WC6	14.80	1.12	−0.32	1.44	5.90	8.90	−3.63			12.5	3.21	−34	7.3		

45a	SMSNPL 1	WN5	16.69	1.19	−0.20	1.39	5.70	10.99	−4.05			15.0	10.19	85	9.9		
45b	SMSNPL 2	WN4	18.08	1.40	−0.20	1.60	6.56	11.52	−3.52			15.0	10.19	−69	9.9		
45c	SMSNPL 3	WN5	15.44	0.91	−0.20	1.11	4.55	10.89	−4.05			14.9	9.73	−92	9.4		
46	HD 104994	WN3p + OB?	10.87	−0.03	−0.29	0.26	1.05	9.82	−3.12	+2.40	−3.23	13.0	4.07	24	7.1	Cru OB4.0	*
46a	SMSNPL 4	WN4	16.00	1.04	−0.20	1.24	5.08	10.92	−3.52			14.4	7.71	−155	8.0		
47	HD 311884	WN6 + O5V	11.08	0.76	−0.21	0.97	3.96	7.12	−4.16	−1.34	−5.78	12.9	3.80	−15	6.8	Ho 15-3:	*
47a	SMSNPL 5	WN8h	15.98	1.73	−0.27	2.00	8.20	7.78	−5.48			13.3	4.49	−102	6.8		
47b	SMSNPL 6	WN9h	17.05	1.93	−0.34	2.27	9.31	7.74	−6.71			14.4	7.77	−106	7.6		
47c	SMSNPL 7	WC5	16.09	1.40	−0.27	1.67	6.85	9.24	−3.34			12.6	3.28	−52	6.8		
48	*θ* Mus	WC6 (+ O9.5/B0Iab VB)	5.88	−0.12	−0.35	0.23	0.93	4.95	−3.62	−3.15	−6.83	11.8	2.27	−99	7.0	Cen OB1:	*
48b	SMSNPL 8	WC9d	15.96	1.07	−0.45	1.52	6.23	9.73	−4.62			14.3	7.41	−127	7.1		
48a	Danks 1	WC8ed + ?	(16.8)	(1.7:)	−0.35		10.13	6.67	−3.74			10.4	1.21	2	7.4		*
48c	SMSNPL 9	WN3h + WC4	13.98	0.39													
49	Th17-22	WN5(h)	13.84	0.34	−0.20	0.54	2.21	11.63	−4.05			15.7	13.68	−604	11.2		
50	V864 Cen	WC7 + OB	12.49	0.68	−0.24	0.92	3.77	8.72	−4.52	+0.73	−4.97	13.7	5.47	27	6.5		*
51	Th17 − 85	WN4 + OB?	14.64	1.04	−0.22	1.26	5.16	9.48	−3.52	−1.22	−5.05	14.5	8.05	34	7.3		*
52	HD 115473	WC4	9.86	0.29	−0.27	0.56	2.30	7.56	−3.34			10.9	1.51	120	7.2		*
53	HD 117297	WC8d	10.88	0.42	−0.36	0.78	3.20	7.68	−3.74			11.4	1.92	15	7.0		
54	Th17-89	WN5	12.99	0.46	−0.20	0.66	2.71	10.28	−4.05			14.3	7.35	−321	6.9		
55	HD 117688	WN7	10.87	0.40	−0.18	0.58	2.38	8.49	−5.41			13.9	6.03	17	6.4		*
56	LS 8	WC7	13.87	0.44	−0.33	0.77	3.16	10.71	−4.52			15.2	11.12	−316	8.9		
56a	SMSNPL 10	WN5	15.91	1.32	−0.20	1.52	6.23	9.68	−4.05			13.7	5.57	135	6.3		
57	HD 119078	WC8	10.02	0.10	−0.36	0.46	1.89	8.13	−3.74			11.9	2.37	−208	6.8		
58	LSS 3162	WN4/WCE	13.05	0.57													
59	LSS 3164	WC9d	13.90	1.24	−0.45	1.69	6.93	6.97	−4.62			11.6	2.08	21	6.9		
60	HD 121194	WC8	13.25	1.04	−0.36	1.40	5.74	7.51	−3.74			11.2	1.78	23	7.0		
61	CF Cir	WN5	12.41	0.36	−0.20	0.56	2.30	10.11	−4.05			14.2	6.79	−463	6.2		
62	NS 2	WN6	14.22	1.60	−0.19	1.79	7.34	6.88	−4.09			11.0	1.56	−20	7.0		
62a	SMSNPL 11	WN4	13.80	1.24	−0.20	1.44	5.90	7.90	−3.52			11.4	1.92	−32	6.8		
62b	SMSNPL 12	WN5	17.26	1.77	−0.20	1.97	8.08	9.18	−4.05			13.2	4.43	−100	5.7		
63	LSS 3289	WN7 + OB	12.83	1.27	−0.20	1.47	6.03	6.80	−5.41	+0.05	−6.14	12.9	3.87	−26	5.8		*
64	BS 3	WC7	15.57	0.16	−0.33	0.49	2.01	13.56	−4.52			18.1	41.3	2032	35.6		
65	Wra 1297	WC9d + OB?	14.50	1.41	−0.45	1.86	7.62	6.88	−4.73	−0.37	−5.69	12.6	3.27	−68	5.9	Cir OB1	*
66	HD 134877	WN8(h) + cc?	11.66	0.73	−0.24	0.97	3.99	7.67	−4.90			12.6	3.27	−104	5.9	Cir OB1	
67	LSS 3329	WN6 + OB?	12.12	0.87	−0.13	1.00	4.08	8.04	−3.41	−0.64	−4.53	12.6	3.27	−68	5.9	Pi 20:/Cir OB1	*
68	BS 4	WC7	14.09	0.97	−0.34	1.31	5.38	8.71	−3.86			12.6	3.27	−107	5.9	Cir OB1	
68a	SMSNPL 13	WN6	14.41	1.46	−0.19	1.65	6.77	7.65	−4.09			11.7	2.23	−25	6.4		
69	HD 136488	WC9d + OB	9.43	0.14	−0.45	0.59	2.42	7.01	−4.62	+0.58	−5.12	12.1	2.67	−224	6.2		*
70	HD 137603	WC9vd + B0I	10.10	0.96	−0.45	1.41	5.78	4.32	−4.62	−2.35	−7.09	11.4	1.91	−60	6.6		*
70a	SMSNPL 14	WN6	16.90	1.23	−0.19	1.42	5.82	11.08	−4.09			15.2	10.81	−160	5.8		

(*continued on next page*)

Table 28. Continued

WR	HD/Name	Spectral type	v (mag)	$b-v$ (mag)	$(b-v)_o$ (mag)	E_{b-v} (mag)	A_v (mag)	v_o (mag)	M_v^{WR} (mag)	Δm (mag)	M_v^{sys} (mag)	v_o-M_v (mag)	d (kpc)	z (pc)	R (kpc)	Correlation with open cluster/OB association	Note
71	HD 143414	WN6+OB?	10.23	−0.05	−0.19	0.14	0.57	9.66	−4.09	−0.46	−5.10	14.8	8.95	−1185	5.5		*
73	NS 3	WC9d	15.23	1.23	−0.45	1.68	6.89	8.34	−4.62			13.0	3.91	231	4.8		
74	BP 1	WN7	13.98	1.58	−0.22	1.80	7.36	6.62	−5.41			12.0	2.55	−28	5.9		
75	HD 147419	WN6	11.23	0.71	−0.18	0.89	3.63	7.60	−4.09			11.7	2.18	−56	6.1		*
75a	SMSNPL 15	WC9	14.51	1.53	−0.45	1.98	8.12	6.39	−4.62			11.0	1.59	−24	6.6		
75b	SMSNPL 16	WC9	16.09	1.71	−0.45	2.16	8.86	7.23	−4.62			11.8	2.34	13	6.0		
76	LSS 3693	WC9d	15.46	1.12	−0.45	1.57	6.44	9.02	−4.62			13.6	5.35	58	3.6		
77	He3-1239	WC8+OB	13.00	0.61	−0.35	0.96	3.94	9.06	−3.74	−0.53	−4.79	13.8	5.89	−112	3.4		*
78	HD 151932	WN7h	6.61	0.20	−0.20	0.41	1.67	4.94	−6.56			11.5	1.99	50	6.1	NGC 6231-305:/Sco OB1	
79	HD 152270	WC7+O5-8	6.95	0.01	−0.37	0.38	1.54	5.41	−5.42	+0.17	−6.09	11.5	1.99	40	6.1	NGC 6231-220/Sco OB1	*
79a	HD 152408	WN9ha	5.29	0.15	−0.20	0.35	1.42	3.87	−7.63			11.5	1.99	52	6.1	NGC 6231-327/Sco OB1	
79b	HD 152386	WN9ha	8.32	0.55	−0.15	0.70	2.88	4.93	−7.38			12.3	2.90	−48	5.3	KQ Sco group	*
80	Wra 1581	WC9d	14.63	1.60	−0.45	2.05	8.41	6.23	−4.62			10.8	1.50	−50	6.6		
81	He3-1316	WC9	12.71	1.10	−0.45	1.55	6.36	6.36	−4.62			11.0	1.57	−71	6.5		
82	LS 11	WN7(h)	12.41	0.85	−0.18	1.03	4.22	8.19	−5.41			13.6	5.25	−213	3.4		
83	He3-1344	WN5	12.79	0.79	−0.20	0.99	4.06	8.73	−4.05			12.8	3.60	−258	4.7		
84	Thé 3	WN7	13.55	1.06	−0.18	1.24	5.08	8.47	−5.41			13.9	5.97	−22	2.6		
85	LSS 3982	WN6h+OB?	10.60	0.57	−0.17	0.74	3.02	7.58	−4.09	−1.41	−5.76	13.3	4.66	−50	3.6	HD 155603 group?	*
86	HD 156327	WC7 (+B0III-I VB)	9.63	0.43	−0.34	0.77	3.16	6.47	−4.52	−0.90	−5.81	12.3	2.86	92	5.2		*
87	LSS 4064	WN7h+OB	12.59	1.58	−0.17	1.76	7.21	5.38	−5.41	−1.20	−6.92	12.3	2.88	−39	5.2	HM 1/Anon. Sco OB	*
88	Thé 1	WC9	13.25	1.00	−0.47	1.47	6.03	7.22	−4.62			11.8	2.33	83	5.7		
89	AS 223	WN8h+OB	11.53	1.22	−0.30	1.52	6.25	5.28	−6.06	−0.37	−7.02	12.3	2.88	−39	5.2	HM 2/Anon. Sco OB	*
90	HD 156385	WC7	7.45	−0.12	−0.33	0.21	0.86	6.56	−4.52			11.1	1.64	−136	6.5		
91	StSa 1	WN7	15.76	1.5	−0.18	1.68	6.89	8.87	−5.41			14.3	7.18	−134	1.7		
92	HD 157451	WC9	10.43	0.07	−0.45	0.52	2.13	8.30	−4.62			12.9	3.84	−296	4.4		
93	HD 157504	WC7+O7-9	11.45	1.15	−0.27	1.42	5.84	5.61	−4.83	−0.02	−5.59	11.2	1.74	25	6.3	Pi 24:	*
93a	Th3-28	WN2.5–3	(13.9)														
94	HD 158860	WN5	12.27	0.74	−0.20	0.94	3.85	8.42	−4.05			12.5	3.12	−14	4.9		
95	He3−1434	WC9d	14.00	1.29	−0.51	1.80	7.37	6.63	−4.97			11.6	2.09	−26	5.9	Tr 27–28:	
96	LSS 4265	WC9d	14.14	1.01	−0.45	1.46	5.99	8.15	−4.62			12.8	3.58	−27	4.4		
97	HD 320102	WN5+O7	11.14	0.68	−0.29	0.97	3.98	7.16	−4.05	−1.89	−6.12	13.3	4.52	−88	3.5		*
98	HD 318016	WN8/WC7	12.51	1.08													
98a	IRAS 17380−3031	WC8–9vd+?	(19.7)	2.96:	−0.40	3.36	13.79	5.91	−4.18	−0.92	−5.48	11.4	1.9	−1	6.1	*Keck* p.m.	*
100	HD 318139	WN7	13.44	1.17	−0.18	1.35	5.54	7.91	−5.41			13.3	4.61	−101	3.4		
101	DA 3	WC8	16.4	1.5	−0.36	1.86	7.63	8.77	−3.74			12.5	3.18	−79	4.8		

101a	BSD 1	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−7	0.0	Galactic Center	
101b	AF-NW	WN9–11	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101c	AF	WN9−11	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101d	GC IRS 6E	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−7	0.0	Galactic Center	
101e	GC IRS 7W	WN9–10	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101f	GC IRS 13E1	WN9–10+?	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101g	GC IRS 29N	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−7	0.0	Galactic Center	
101h	MPE −1.0, −3.5	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−7	0.0	Galactic Center	
101i	GC IRS 15SW	WN9–11	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−6	0.0	Galactic Center	
101j	GC IRS 16NW	WN9–11	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101k	GC IRS 16SW	WN9–11+?	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101l	GC IRS 16C	WN9−11	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101m	GC IRS 15NE	WN9−11	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−7	0.0	Galactic Center	
101n	MPE +1.6, −6.8	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−7	0.0	Galactic Center	
101o	MPE +2.7, −6.9	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−7	0.0	Galactic Center	
102	Sand 4	WO2	15.10	0.77	−0.25	1.02	4.18	10.92	−2.8			13.7	5.56	137	2.5		
102a	CSE 1	WN8	41.2	7.58	−0.27	7.85	32.2	9.04	−5.48			14.5	8.0	3	0.0	Arches	
102b	CSE 2	WN6	42.6	7.66	−0.19	7.85	32.2	10.49	−4.09			14.5	8.0	−10	0.0	Arches	
102c	FMM 96-1	WN6	42.6	7.66	−0.19	7.85	32.2	10.49	−4.09			14.5	8.0	−6	0.0	Quintuplet	
102d	FMM 95-1	WN9	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−8	0.0	Quintuplet	
102e	FMM 96-2	WC8	43.0	7.49	−0.36	7.85	32.2	10.78	−3.74			14.5	8.0	−8	0.0	Quintuplet	
102f	FMM 96-3	WC<8	43.0	7.50	−0.35	7.85	32.2	10.78	−3.74			14.5	8.0	−8	0.0	Quintuplet	
102g	FMM 99-1	WC<8	43.0	7.50	−0.35	7.85	32.2	10.78	−3.74			14.5	8.0	−8	0.0	Quintuplet	
102h	FMM 95-2	WC9	42.1	7.40	−0.45	7.85	32.2	9.90	−4.62			14.5	8.0	−10	0.0	Quintuplet	
102i	FMM 96-4	WN9	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−10	0.0	Quintuplet	
102j	FMM 96-5	WN9	40.6	7.51	−0.34	7.85	32.2	8.35	−6.71			14.5	8.0	−10	0.0	Quintuplet	
102k	FMM 96-6	WC<8	43.0	7.50	−0.35	7.85	32.2	10.78	−3.74			14.5	8.0	−10	0.0	Quintuplet	
102l	SMSNPL 17	WN8	15.53	1.80	−0.27	2.07	8.49	7.04	−5.48			12.5	3.19	13	4.9		
103	HD 164270	WC9d+?	8.86	−0.02	−0.45	0.43	1.76	7.10	−4.62			11.7	2.21	−188	5.8		
104	Ve2-45	WC9d+B0.5V (+VB)	13.54	1.31	−0.45	1.76	7.22	6.32	−4.16	−0.95	−5.49	11.8	2.3	−20	5.7	*Keck* p.m.	*
105	Ve2-47	WN9h	12.92	1.84:	−0.26	2.10	8.63	4.29	−6.71			11.0	1.58	−14	6.4	Sgr OB1:	
106	HD 313643	WC9d	12.33	0.80	−0.45	1.25	5.13	7.21	−4.62			11.8	2.32	8	5.7		
107	DA 1	WN8	14.10	1.32:	−0.27	1.59	6.52	7.58	−5.48			13.1	4.09	−11	4.0		
107a	SMSNPL 18	WC6	16.43	1.32	−0.32	1.64	6.72	9.71	−3.63			13.3	4.66	−34	3.5		
108	HD 313846	WN9h+OB	10.16	0.80	−0.11	0.90	3.72	6.44	−6.71	+0.38	−7.29	13.7	5.57	−83	2.6		*

(*continued on next page*)

Table 28. Continued

WR	HD/Name	Spectral type	v (mag)	$b-v$ (mag)	$(b-v)_o$ (mag)	E_{b-v} (mag)	A_v (mag)	v_o (mag)	M_v^{WR} (mag)	Δm (mag)	M_v^{sys} (mag)	v_o-M_v (mag)	d (kpc)	z (pc)	R (kpc)	Correlation with open cluster/ OB association	Note
109	V617 Sgr	WN5h+?	14.48	0.00	−0.20	0.20	0.82	13.66	−4.05			17.7	34.83	−4359	26.9		
110	HD 165688	WN5-6	10.30	0.75	−0.18	0.93	3.83	6.47	−4.07			10.5	1.28	9	6.8		
111	HD 165763	WC5	8.23	−0.02	−0.28	0.26	1.05	7.18	−3.82			11.0	1.58	−17	6.5	Sgr OB1:	*
112	GL 2104	WC9d+OB?	18.8	1.3	−0.45		12.24	6.56	−4.62	−1.71	−6.53	13.1	4.15	−86	4.0		*
113	HD 168206	WC8d+O8-9IV	9.43	0.46	−0.33	0.79	3.23	6.20	−3.30	−1.52	−5.06	11.3	1.79	55	6.3	Ser OB2:	*
114	HD 169010	WC5+OB?	12.95	0.91	−0.26	1.17	4.81	8.14	−2.85	+0.56	−3.36	11.5	2.00	−5	6.1	Ser OB1:	*
115	IC14-19	WN6+OB?	12.32	1.10	−0.20	1.30	5.36	6.96	−3.37	−0.72	−4.54	11.5	2.00	−36	6.1	Ser OB1:	*
116	ST 1	WN8h	13.38	1.41	−0.27	1.68	6.89	6.49	−5.48			12.0	2.48	−14	5.7		*
117	IC14-22	WC9d	14.19	1.15	−0.41	1.56	6.41	7.78	−4.62			12.4	3.02	79	5.4		
118	GL 2179	WC9d	(22.0:)	(3.0:)	−0.45	3.45	14.15	7.86	−4.62			12.5	3.13	−11	5.2		
119	Thé 2	WC9d	12.41	0.63	−0.45	1.08	4.43	7.98	−4.62			12.6	3.31	−111	5.1		
120	Vy1-3	WN7	12.30	1.02	−0.18	1.21	4.95	7.35	−5.41			12.8	3.56	18	5.1		
121	AS 320	WC9d	12.41	0.97	−0.43	1.40	5.72	6.69	−4.62			11.3	1.83	−4	6.5		
121a	W 43#1	WN7+a/OB?	38.49	7.04	−0.20	7.24	29.7	8.79			−4.81	13.6	5.3	−3	4.4	W 43 cluster	
123	HD 177230	WN8	11.26	0.43	−0.27	0.70	2.87	8.39	−5.48			13.9	5.94	−492	4.2		*
124	QR Sge	WN8h	11.58	0.81	−0.27	1.08	4.43	7.15	−5.48			12.6	3.36	194	6.4		*
125	V378 Vul	WC7ed+O9III	13.52	1.32	−0.34	1.66	6.81	6.71	−4.52	−0.76	−5.72	12.4	3.06	57	6.7		*
126	ST 2	WC5/WN	13.29	0.70	−0.25	0.95	3.90	9.39	−3.83			13.2	4.41	162	7.1	Vul OB2:	
127	HD 186943	WN3+O9.5V	10.33	0.15	−0.26	0.41	1.65	8.68	−3.99	+0.45	−4.54	13.2	4.41	133	7.3	Vul OB2:	*
128	HD 187282	WN4(h)+OB?	10.54	−0.01	−0.20	0.19	0.78	9.76	−3.52	−1.29	−5.10	14.9	9.37	−619	8.2		*
129	Sey 1	WN4	13.27	0.55	−0.20	0.75	3.08	10.20	−3.52	+1.15	−3.84	14.0	6.44	274	8.0		*
130	LS 16	WN8(h)	12.60	1.18	−0.27	1.45	5.95	6.66	−5.48			12.1	2.68	46	7.4		
131	IC14-52	WN7h+OB	12.36	0.73	−0.20	0.93	3.81	8.55	−5.41	−1.05	−6.81	15.4	11.78	352	11.8		*
132	HD 190002	WC6+?	13.49	0.70	−0.32	1.02	4.18	9.31	−3.63			12.9	3.87	74	7.6		*
133	HD 190918	WN5+O9I	6.70	0.00	−0.31	0.31	1.28	5.42	−4.03	−2.05	−6.23	11.6	2.14	77	7.6	NGC 6871	*

134	HD 191765	WN6	8.23	0.20	−0.21	0.41	1.69	6.54	−4.66			11.2	1.74	47	7.7	Cyg OB3:	*
135	HD 192103	WC8	8.36	−0.03	−0.37	0.34	1.40	6.96	−4.24			11.2	1.74	39	7.7	Cyg OB3:	
136	HD 192163	WN6(h)	7.65	0.23	−0.24	0.47	1.92	5.73	−4.77			10.5	1.26	53	7.8	Cyg OB1:	
137	HD 192641	WC7pd+O9	8.15	0.14	−0.34	0.48	1.97	6.18	−4.52	−0.73	−5.70	11.9	2.38	44	7.7		*
138	HD 193077	WN5+B?	8.10	0.22	−0.30	0.52	2.14	5.96	−3.88	−0.39	−4.54	10.5	1.26	24	7.8	Cyg OB1:	*
139	HD 193576	WN5+O6III-V	8.10	0.38	−0.31	0.69	2.83	5.27	−5.24	−0.24	−6.12	11.4	1.90	47	7.8	Be 86:	*
140	HD 193793	WC7pd+O4-5	7.07	0.27	−0.34	0.61	2.50	4.57	−4.52	−0.64	−5.64	10.2	1.10	80	7.9		*
141	HD 193928	WN5+O5V-III	10.14	0.71	−0.29	1.00	4.10	6.04	−3.86	+0.3	−4.46	10.5	1.26	2	7.8	Cyg OB1	*
142	Sand 5	WO2	13.82	1.39	−0.25	1.64	6.74	7.08	−2.8			9.9	0.95	5	7.8	Be 87:	
143	HD 195177	WC4+OB?	11.95	1.21	−0.27	1.48	6.07	5.88	−3.34	−0.32	−4.26	10.1	1.07	−1	7.8		*
144	HM19−1	WC4	15.49	2.01	−0.27	2.28	9.33	6.16	−3.34			9.5	0.79	13	7.9		
145	V1923 Cyg	WN7/WCE+?	12.55	1.63													
145a	Cyg X-3	WNE+cc	(>23.9)	(21.1)	−0.20							14.8	9	108	10.9		*
146	HM19-3	WC6+O8	13.91	2.38	−0.35	2.73	11.19	2.72	−3.63	−2.85	−6.56	9.3	0.72	6	7.9		*
147	AS 431	WN8(h)+B0.5V	14.89	2.15	−0.27		11.60	3.29	−5.48	+1.27	−5.77	9.1	0.65	−4	7.9		*
148	HD 197406	WN8h+B3IV/BH	10.46	0.36	−0.27	0.63	2.58	7.88	−5.48	−0.81	−6.71	14.6	8.28	933	11.5		*
149	ST 4	WN5	14.70	1.20	−0.20	1.40	5.74	8.96	−4.05			13.0	4.00	45	8.9		
150	ST 5	WC5	13.47	0.53	−0.27	0.80	3.28	10.19	−3.34			13.5	5.08	−220	9.9		
151	CX Cep	WN4+O5V	12.37	0.65	−0.27	0.92	3.77	8.60	−3.52	−1.40	−5.18	13.8	5.70	138	10.8		*
152	HD 211564	WN3(h)	11.67	0.17	−0.23	0.40	1.62	10.05	−2.15			12.2	2.75	−43	9.0	Cep OB1:	
153ab	GP Cep	WN6/WCE+O6I	9.08	0.27	−0.29	0.56	2.28	6.80	−3.96	−1.1	−5.40	12.2	2.75	−31	9.0	Cep OB1:	*
154	HD 213049	WC6	11.54	0.36	−0.29	0.65	2.65	8.89	−3.31			12.2	2.75	−57	9.1	Cep OB1:	
155	CQ Cep	WN6+O9II-Ib	8.75	0.28	−0.26	0.54	2.22	6.53	−2.80	−2.79	−5.67	12.2	2.75	−62	9.1	Cep OB1:	*
156	AC+60 38562	WN8h+OB?	11.09	0.83	−0.27	1.10	4.51	6.58	−5.48	+0.11	−6.18	12.8	3.56	57	9.8		*
157	HD 219460	WN5 (+B1II VB)	9.91	0.46	−0.25	0.71	2.93	6.98	−4.07	−1.31	−5.67	12.6	3.39	−14	9.8	Ma 50	*
158	AS 513	WN7h+Be?	11.46	0.75	−0.20	0.95	3.90	7.57	−5.41	−1.21	−6.93	14.5	7.94	14	13.5		*

[a] *Notes on individual stars (see also notes to Tables 25 and 26):*
$\Delta M = M_{comp} - M_{WR}$;
CM89: Conti and Massey, 1989; SS90: Smith et al., 1990; Un82: Underhill, 1982; VG96: Vacca et al., 1996.
WR 2:
Arnal et al. (1999) found a kinematical distance of the associated H I bubble of 2.2±0.8 kpc.
WR 3:
By comparing the equivalent widths of the He II 4686 and He II 5411 emission lines of WR 3 and the apparently single WN3 star WR 152, we calculate that $\Delta M = -0.27$. $M_{comp} = -3.36$ could imply a B0.5V companion (Un82). However, Marchenko et al. (2000, private communication), in nine years of monitoring, finds no sign of a companion, although blue shifted (hydrogen) absorption lines appear present. Arnal (1992) and Arnal and Roger (1997) found a kinematical distance of the associated H I bubble of 4.3±0.9 kpc.
WR 4:
Arnal (1992) found a kinematical distance of the associated H I bubble of 4.9 kpc.
WR 5:
Arnal (1992) found a kinematical distance of the associated H I bubble of 1.4 kpc.
WR 6:
Howarth and Schmutz (1995): $d = 1.8$ kpc. Arnal and Cappa (1996) found for the associated H I bubble a kinematical distance of 0.2–1.0 kpc. Kaltcheva (2000): d (Cr 121) = 1.08±0.04 kpc.
WR 7 in ring nebula NGC 2359:
Goudis et al. (1994): $d = 3.5$–6.9 kpc.
WR 9:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and O III/IV 5592 emission lines of WR 9 and the five apparently single WC5 stars WR 4, WR 17, WR 33, WR 111 and WR 150 (CM89; SS90), we calculate that $\Delta M = -0.71$. $M_{comp} = -4.50$ could imply a O8.5V companion (VG96).
WR 11:
Distance discussion in Pozzo et al. (2000).
WR 12:
LS84 listed WR 12 as a possible member of the open cluster Bo 7, at a distance of 5.8 kpc (Moffat and Vogt, 1975). Sung et al. (1999): d (Bo 7) = 4.8±0.2 kpc.
WR 19:
By comparing the equivalent widths of the C IV 5808, C III 4650 and O III/IV 5592 emission lines of WR 19 and the three apparently single WC4 stars WR 38, WR 52 and WR 144 (CM89; SS90), we calculate that $\Delta M = -0.37$. $M_{comp} = -3.71$ could imply a B0V companion (Un82).
WR 21:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 21 and the eight apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M = -1.09$. $M_{comp} = -5.14$ could imply a O6V companion (VG96).
WR 25:
Reddening discussion in Crowther et al. (1995b).
WR 28:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II5411 and C IV 5808 emission lines of WR 28 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -1.86$. $M_{comp} = -5.95$ could imply a O4.5III companion (VG96).
WR 29:
By comparing the equivalent widths of the He II 4686 and He II 5411 emission lines of WR 29 and the seven apparently single WN7 stars WR 55, WR 74, WR 82, WR 84, WR 91, WR 100 and WR 120 (CM89), we calculate that $\Delta M = -1.31$. $M_{comp} = -6.72$ could imply a O9.5Ia companion (VG96).

WR 30:
By comparing the equivalent widths of the C IV 5808, C III 4650 and C III 5696 emission lines of WR 30 and the seven apparently single WC6 stars WR 5, WR 13, WR 15, WR 23, WR 27, WR 45 and WR 154 (CM89; SS90), we calculate that $\Delta M = -0.47$. $M_{comp} = -4.10$ could imply a B0.5V companion (VG96).
WR 30a:
$M_{O5\text{-}5.5V} = -5.28$ assumed (VG96).
WR 31:
By comparing the equivalent widths of the He II 4686, N III/IV 4640 and NIV 3480 emission lines of WR 31 and the four apparently single WN4 stars WR 1, WR 7, WR 18 and WR 37 (CM89), we calculate that $\Delta M = -0.57$. $M_{comp} = -4.09$ could imply a B0.5V companion (VG96).
WR 31a:
Davidson et al. (1993): $d = 8 \pm 1$ kpc. Smith et al. (1994a,b): $E_{B-V} = 1.14 \pm 0.10$, $M_V = -7.1 \pm 0.6$, $(B-V)_0 = -0.12$, $d = 8.0 \pm 0.1$ kpc.
WR 31b:
Humphreys et al. (1989) and Hoekzema et al. (1992, 1993): $d = 6 \pm 1$ kpc.
WR 32:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and O III/IV 5592 emission lines of WR 32 and the five apparently single WC5 stars WR 4, WR 17, WR 33, WR 111 and WR 150 (CM89; SS90), we calculate that $\Delta M = -0.33$. $M_{comp} = -4.27$ could imply a O9.5V companion (VG96).
WR 35:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411 and C IV 5808 emission lines of WR 35 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -1.29$. $M_{comp} = -5.38$ could imply a O5V or B0III companion (VG96).
WR 36:
The line strengths of WR 36 given by CM89 are too strong for the average single WN5 stars, but weaker than in the average single WN6 stars. By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808 and He I 5876 emission lines of WR 36 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = +0.46$. $M_{comp} = -3.63$ could imply a B0.5V companion (Un82).
WR 38b:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and O III/IV 5592 emission lines of WR 38b and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = +1.43$. $M_{comp} = -3.16$ could imply a B1V companion (Un82).
WR 39:
By comparing the equivalent widths of the C IV 5808, C III 4650 and C III 5696 emission lines of WR 39 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = -0.92$. $M_{comp} = -5.44$ could imply a O4.5V or a O9III companion (VG96).
WR 41:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and O III/IV 5592 emission lines of WR 41 and the five apparently single WC5 stars WR 4, WR 17, WR 33, WR 111 and WR 150 (CM89; SS90), we calculate that $\Delta M = +1.05$. $M_{comp} = -2.29$ could imply a B2.5V companion (Un82).
WR 42:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and He I 5876 emission lines of WR 42 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = -0.12$. $M_{comp} = -4.64$ could imply a O8V companion (VG96).
WR 43abc:
Moffat (1983): $d = 7.0 \pm 0.5$ kpc, $E_{B-V} = 1.44 \pm 0.09$. Crowther and Dessart (1998): $d = 10.1$ kpc, $E_{B-V} = 1.23$. The latter gave also an overview of the distance determinations for NGC 3603.
WR 44:
By comparing the equivalent widths of the He II 4686, NIII/IV 4640 and N IV 3480 emission lines of WR 44 and the apparently single WN4 stars WR 1, WR 7, WR 18 and WR 37 (CM89), we calculate that $\Delta M = -0.19$. $M_{comp} = -3.71$ could imply a B0.5V companion (Un82).

WR 48a:
A_v derived from $\tau_{9.7\mu}$, see Section 8.3.
WR 50:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and He I 5876 emission lines of WR 50 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = +0.73$. $M_{comp} = -3.79$ could imply a B0V companion (Un82). Turner (1985): $d = 3.6$ kpc. Smith et al. (1990): $d = 5.9$ kpc.
WR 51:
By comparing the equivalent widths of the He II 4686, N III/IV 4640 and N IV 3480 emission lines of WR 51 and the apparently single WN4 stars WR 1, WR 7, WR 18 and WR 37 (CM89), we calculate that $\Delta M = -1.22$. $M_{comp} = -4.74$ could imply a O7.5V companion (VG96).
WR 52 in ring nebula Anon WR 52:
Chu and Treffers (1981): $d_{kin} = 2.0$ kpc.
WR 55 in ring nebula RCW 78:
Chu and Treffers (1981): $d_{kin} = 7.6$ kpc.
WR 63:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 63 and the seven apparently single WN7 stars WR 55, WR 74, WR 82, WR 84, WR 91, WR 100 and WR 120 (CM89), we calculate that $\Delta M = +0.05$. $M_{comp} = -5.36$ could imply a O5V or B0III companion (VG96).
WR 69:
By comparing the equivalent widths of the C III 4650 emission line of WR 69 and the 13 apparently single WC9 stars WR 59, WR 73, WR 80, WR 81 WR 88, WR 92, WR 95, WR 96, WR 103, WR 106, WR 117, WR 119 and WR 121 (CM89; SS90), we calculate that $\Delta M = +0.58$. $M_{comp} = -4.04$ could imply a B0.5V companion (VG96).
WR 70:
By comparing the equivalent widths of the C IV 5808, C III 4650 and C III 5696 emission lines of WR 70 and the 13 apparently single WC9 stars WR 59, WR 73, WR 80, WR 81, WR 88, WR 92, WR 95, WR 96, WR 103, WR 106, WR 117, WR 119 and WR 121 (CM89; SS90), we calculate that $\Delta M = -2.35$. $M_{comp} = -6.97$ could imply a B0Ia companion (Un82).
WR 71:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 71 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -0.46$. $M_{comp} = -4.55$ could imply a O8.5V companion (VG96).
WR 75 in ring nebula RCW 104:
Chu (1982): $d_{kin} = 3.3$ kpc.
WR 77:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696, O III/IV 5592 and He I 5876 emission lines of WR 77 and the five apparently single WC8 stars. WR 53, WR 57, WR 60, WR 101 and WR 135 (CM89; SS90), we calculate that $\Delta M = -0.53$. $M_{comp} = -4.27$ could imply a O9.5V companion (VG96). Reddish (1967) suggested a probable membership for WR 77 of the OB association Ara I, but LS84 did not consider the probability of membership. Kaltcheva and Georgiev (1992) found an association distance $d = 2.52$ kpc for Ara OB1b, in good agreement with FitzGerald (1987) who found $d = 2.41$ kpc. Our distance $d = 5.89$ kpc does not support the possibility that WR 77 is a member of Ara OB1b.
WR 79b:
Bohannan and Crowther (1999): $d = 3.5$ kpc, $M_V = 7.1$.
WR 85 in ring nebula RCW 118:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 85 and the four apparently single WN6 stars WR 62, WR 75, WR 134 and WR 136 (CM89), we calculate that $\Delta M = -1.41$. $M_{comp} = -5.50$ could imply a O4V companion (VG96). WR 85 possibly (?) in 'HD 155603' cluster together with HD 155603 (G5Ia), LSS 3981 (B0III), and LSS 3986 (OB^+), see Andrews (1977), Moffat and FitzGerald (1977) and Lundström and Stenholm (1979). Chu and Treffers (1981): $d_{kin} = 2.3$ kpc.

WR 86:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696, O III/V 5592 and He I 5876 emission lines of WR 86 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M=-0.90$. $M_{comp}=-5.42$ could imply a O4.5V or O9.5III companion (VG96).
WR 97:
By comparing the equivalent widths of the He II 4686, He II 5411, C IV 5808 and N IV 3480 emission lines of WR 97 and the eight apparently single WN5 stars WR 20, WR 34, WR 49, WR 54, WR 61, WR 83, WR 94, and WR 149 (CM89), we calculate that $\Delta M=-1.89$. $M_{comp}=-5.94$ could imply a O4.5III companion (VG96).
WR 98a:
Adopting $M_{WC8-9}=-4.18$ with $M_{sys}=-5.48$ gives $M_{comp}=-5.10$, which could imply a O6V companion (VG96).
WR 108:
By comparing the equivalent widths of the He II 4686 and N III/IV 4640 emission lines of WR 108 and the apparently single WN9 star WR 105 (CM89), we calculate that $\Delta M=+0.38$. $M_{comp}=-6.33$ could imply a B1.5Iab companion (Un82).
WR 111:
Hillier and Miller (1999): $d=1.55$ kpc.
WR 112:
By comparing the equivalent widths of the C IV 5808, C III 5696 and He I 5876 emission lines of WR 112 and the 13 apparently single WC9 stars WR 59, WR 73, WR 80, WR 81 WR 88, WR 92, WR 95, WR 96, WR 103, WR 106, WR 117, WR 119 and WR 121 (CM89; SS90), we calculate that $\Delta M=-1.71$. $M_{comp}=-6.33$ could imply a O3Ia companion (VG96). A_v derived from $\tau_{9.7\mu}$, see Section 8.3.
WR 116 in ring nebula Anon (WR 116):
Esteban and Rosado (1995) found for the associated ring nebula $d_{kin}=3.3\pm0.6$ kpc.
WR 123:
Arnal (1992) found a kinematical distance of the related H I bubble of 13.5 kpc.
WR 124 in ring nebula M1-67:
WR 124, a runaway object (Moffat et al., 1982) with a ring nebula (e.g. Esteban et al., 1991), has been alternating between Population II classification (e.g. Bertola, 1964; van der Hucht et al., 1985a,b) and Population I classification (e.g. Cohen and Barlow, 1975; Moffat and Shara, 1986). The issue has been settled by Crawford and Barlow (1991a) who found an interstellar Na I D_2 velocity dispersion of 60 km s^{-1}, consistent with the spread of gas velocity expected from galactic rotation if WR 124 is at a distance of 4–5 kpc. In combination with its optical photometry this implies that it is a Population I object. Crowther et al. (1999): $E_{B-V}=1.3$, $d=4.9$ kpc, $M_V=-6.1$.
WR 125:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696, O III/IV 5592 and He I 5876 emission lines of WR 125 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M=-0.76$. $M_{comp}=-5.28$ could imply a O5-5.5V or B0.5III companion (VG96).
WR 128 in ring nebula Anon (WR 128):
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5805 and N IV 3480 emission lines of WR 128 and the apparently single WN4 stars WR 1, WR 7, WR 18 and WR 37 (CM89), we calculate that $\Delta M=-1.29$. $M_{comp}=-4.81$ could imply a O7V companion (VG96). Esteban and Rosado (1995) found for the associated ring nebula $d_{kin}=3.0\pm0.5$ kpc. Crowther et al. (1995c): $d=4.0$ kpc.
WR 129:
By comparing the equivalent widths of the He II 4686, He II 5411, C IV 5805 and N IV 3480 emission lines of WR 129 and the apparently single WN4 stars WR 1, WR 7, WR 18 and WR 37 (CM89), we calculate that $\Delta M=+1.15$. $M_{comp}=-2.37$ could imply a B2V companion (Un82).
WR 131 in ring nebula L 69.80+1.74:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411 and He I 5876 emission lines of WR 131 and the seven apparently single WN7 stars WR 55, WR 74, WR 82, WR 84, WR 91, WR 100 and WR 120 (CM89), we calculate that $\Delta M=+1.05$. $M_{comp}=-6.46$ could imply a O7Ia companion (VG96). Lortet (1983): in W 58 complex at $d=8.8$ kpc.
WR 132 in ring nebula Anon (WR 132):
Arnal (1992) found a kinematical distance of the associated H I bubble of 4.3 kpc.

WR 137:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696, O III/IV 5592 and He I 5876 emission lines of WR 137 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = -0.73$. $M_{comp} = -5.25$ could imply a O5.5V or B0.5III companion (VG96).
WR 140:
By comparing the equivalent widths of the C IV 5808, C III 4650, C III 5696 and O III/IV 5592 emission lines of WR 140 and the five apparently single WC7 stars WR 14, WR 50, WR 56, WR 68, and WR 90 (CM89; SS90), we calculate that $\Delta M = -0.64$. $M_{comp} = -5.16$ could imply a O5.5-6V companion (VG96).
WR 143:
By comparing the equivalent widths of the C IV 5808, C III 4650 and O III/IV 5592 emission lines of WR 143 and the three apparently single WC4 stars WR 38, WR 52 and WR 144 (CM89; SS90), we calculate that $\Delta M = -0.32$. $M_{comp} = -3.66$ could imply a B0V companion (Un82).
WR 145a = Cyg X-3:
Dickey (1983): $d \geq 12$ kpc; Predehl et al. (2000): $d = 9^{+4}_{-2}$ kpc.
WR 146:
By comparing the equivalent widths of the C IV 5808 and C III 4650 *emission* lines of WR 146 and the seven apparently single WC6 stars WR 5, WR 13, WR 15, WR 23, WR 27, WR 45 and WR 154 (CM89; SS90), we calculate that $\Delta M = -0.56$. $M_{comp} = -4.19$ could imply a B0V companion (VG96). However, assuming a O8I companion based on *absorption* line strength (Dougherty et al., 2000) would imply $M_O = -6.48$ (VG96), $M_{sys} = -6.56$, and $d = 0.72$ kpc.
WR 147:
By comparing the equivalent widths of the He II 4686, N III/IV 4640 and He I 5876 emission lines of WR 147 and the eight apparently single WN8 stars WR 12, WR 40, WR 66, WR 107, WR 116, WR 123, WR 124 and WR 130 (CM89), we calculate that $\Delta M = +1.27$. $M_{comp} = -4.21$ could imply a B0V companion (VG96). We adopt $d = 0.65$ kpc (Morris et al., 2000), which yields $A_v = 11.60$.
WR 148:
By comparing the equivalent widths of the He II 4686, N III/IV 4640 and He II 5411 emission lines of WR 148 and the eight apparently single WN8 stars WR 12, WR 40, WR 66, WR 107, WR 116, WR 123, WR 124 and WR 130 (CM89), we calculate that $\Delta M = -0.81$. $M_{comp} = -6.29$ could imply a O3Ia companion (VG96). Marchenko et al. (1996a): $L_{WR}/L_{comp} > 50$.
WR 151:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411, C IV 5808, He I 5876 and N IV 3480 emission lines of WR 151 and four apparently single WN8 stars WR 1, WR 7, WR 18 and WR 37 (CM89), we calculate that $\Delta M = -1.40$. $M_{OB} = -4.92$ could imply a O6.5V companion (VG96). Arnal et al. (1999) found a kinematical distance of the associated H I bubble of 5.0 ± 0.8 kpc.
WR 153 in ring nebula S 132:
Chu and Treffers (1981): $d_{kin} = 5.5$ kpc. Demers (in preparation): (WN6 + O3-6) + (B0: I + B: V–III).
WR 156:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411 and He I 5876 emission lines of WR 156 and the eight apparently single WN8 stars WR 12, WR 40, WR 66, WR 107, WR 116, WR 123, WR 124 and WR 130 (CM89), we calculate that $\Delta M = +0.11$. $M_{comp} = -5.37$ could imply a O5V or B0III companion (VG96).
WR 158:
By comparing the equivalent widths of the He II 4686, N III/IV 4640, He II 5411 and He I 5876 emission lines of WR 158 and the seven apparently single WN7 stars WR 55, WR 74, WR 82, WR 84, WR 91, WR 100 and WR 120 (CM89), we calculate that $\Delta M = -1.21$. $M_{comp} = -6.62$ could imply a B0Ia companion (VG96).

calculated distances correspond at least to the range of M_v for the particular subtype (see Table 27). We estimate that the average error in the field star distances is ~50%.

For a large sample of galactic WC stars Smith et al. (1990) designed a C IV λ5808 emission-line flux-method, in order to determine distances of WC stars. Their method has the great advantage that it is independent of whether a WC star is single, or has a binary companion, or is blended with a close companion (unless the companion is also a WC star, of course). However, their method has been calculated using WC stars in Galactic open clusters and OB associations, the distances of many of which have been revised in the past decade (see Section 8.3). Therefore, comparison of the line-flux distances of Smith et al. (1990) with our photometric distances (this section) is not meaningful.

The distance of the Galactic Center is adopted at $d_{GC} = 8.0 \pm 0.5$ kpc (Reid, 1993). For all 26 WR objects within 30 pc of the Galactic Center (15 WNL and 11 WCL stars) we have assumed that distance and $A_V = 29 \pm 5$ mag (Figer et al., 1999a), i.e., $A_v =$ 32 mag. Table 28 also lists galactocentric distances $R(\text{kpc}) = \sqrt{d^2 + 64 + 16d \cos b^{II} \cos l^{II}}$, and separations from the galactic plane $z(\text{pc}) = d \sin b^{II}$.

9.1. Wolf–Rayet star longitude distribution

9.1.1. Galactic structure

The WR galactic distribution (l^{II}, d) is plotted in Fig. 6, which shows a reflection of galactic spiral structure (compare with Georgelin and Georgelin, 1976, Fig. 11). Two (15th mag) stars were found to have $d > 20$ kpc: WR 64 (WC7) and WR 109 (WN5h + ?, SB1). Whether their unlikely large distances are due to incorrect photometry or due to intrinsic peculiarities is yet unknown. In particular the derived distance of WR 109 must be incorrect, since we cannot view at such a large distance through the Galactic Center region. WR 109 has been mentioned above in the Section 2.1.6. Further discussion of these two interesting objects is beyond the scope of this paper.

As stated earlier by Conti and Vacca (1990), the

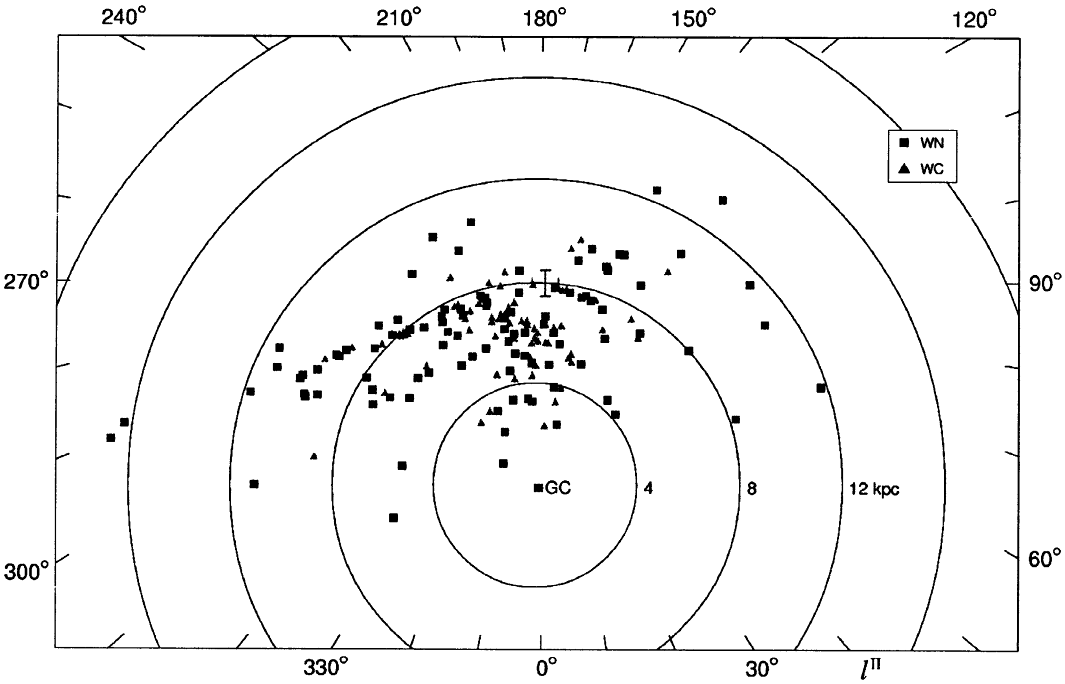

Fig. 6. The galactic Wolf–Rayet star distribution (l^{II}, d) projected on the galactic plane. The Sun is indicated by +. The distance from the Sun to the Galactic Center is adopted at 8.0 kpc (Reid, 1993). The point at the Galactic Center harbours 26 WR stars.

overall similarity of Fig. 6 and similar diagrams by Smith (1968c, Fig. 1), van der Hucht et al. (1988, Fig. 3) and Conti and Vacca (1990, Fig. 1) demonstrates that the photometric distance determination procedure is fairly 'robust', on average. However, distances for individual WR stars can differ substantially. We confirm earlier conclusions by Roberts (1962), Smith (1968c), Conti et al. (1983), van der Hucht et al. (1988) and Conti and Vacca (1990), that the galactocentric distance distribution of WR stars is subtype-dependent, notably with the WC9 stars confined towards the Galactic Center, and that the galactic anti-center quadrant (Orion spur) is devoid of WR stars.

In the solar neighbourhood ($d < 2.5$ kpc) we count 64 WR stars (18 more stars than in the census of van der Hucht et al., 1988) with a number ratio N_{WN}:N_{WC}:N_{WO} = 25:38:1. Since the WN and WC phases are consecutive phases in the evolution of massive stars, this implies that in the solar neighbourhood the average WC-phase life-time is about $N_{WC}/N_{WN} = 1.5$ times longer than the average WN-phase life-time. (Compare with $N_{WC}/N_{WN} = 0.23$ and 0.12 in, respectively, the LMC and the SMC, see Section 4.) The observed WR binary frequency in the solar neighbourhood (25 WR binaries) is 39% (or 48% if we assume that the six apparently single WC8–9d stars in that volume are also binaries, see Section 5.3). The WC binary frequency in that volume (50%, or 66% including the additional six WCd stars) is twice the WN binary frequency (24%). When divided in shells around the Galactic Center, we count in the $d < 2.5$ kpc volume a WN to WC number ratio of 1.1 in the range $7 < R < 9$ kpc, and a ratio of 0.4 in the range $5.5 < R < 7$ kpc. Projected on the galactic plane the WR surface density in that volume is $\sigma_{WR} = 3.3$ kpc^{-2}. The overall subtype and binary distribution breakdown is listed in Table 29.

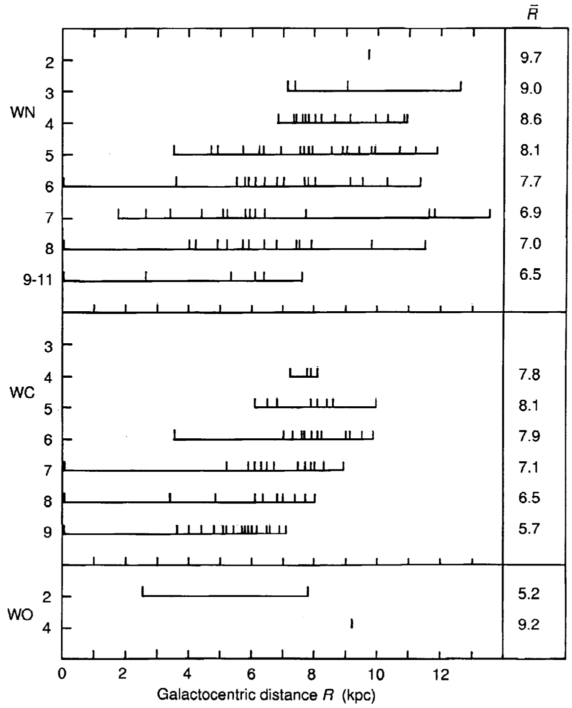

Fig. 7. The galactocentric Wolf–Rayet subtype distribution. At right the average R per subtype, excluding the 26 WR stars at the Galactic Center. $R_\odot = 8.0$ kpc.

9.1.2. Wolf–Rayet subtype distribution and evolution

Fig. 7 shows the WR galactocentric distribution per subtype. In the column at the right side of Fig. 7, the WN stars show a remarkable trend for $\bar{R}_{WN}$ values per subtype to increase with decreasing WN

Table 29
Numbers, ratios, and surface densities of the 64 WR stars with $d < 2.5$ kpc as a function of galactocentric distance ($R_\odot = 8.0$ kpc)

R (kpc)	N_{WN}	N_{WC}	N_{WO}	N_{WN}/N_{WC}	N^{WN}_{binary}	N^{WC}_{binary}	$N^{WR}_{binary}/N^{WR}_{single}$	area (kpc^2)	N_{WR}/kpc^2
5.5–7	10	23	0	0.4	1	9	0.4	4.44	7.4
7–9	14	13	1	1.1	5	9	1.0	9.76	2.9
9–10.5	1	2	0	0.5	0	1	0.5	5.44	0.6
Total	25	38	1	0.7	6 (24%)	19 (50%)	0.6	19.63	3.3

subtype. The WC stars show a similar trend for $\overline{R_{WC}}$ values per WC subtype to increase with decreasing subtype up to WC6. For WC6–4 stars $\overline{R_{WC}}$ remains constant, at the value of $\overline{R_{WN5}}$. All WN9–11 stars and WC9 stars are located within the solar circle ($R_\odot = 8$ kpc). We do not observe WC stars beyond $R = 10$ kpc, but WN3–8 stars are present there.

Fig. 7 poses no strict constraints on WR subtype evolution, but makes it unlikely that WC9 stars could evolve from WN2–3 stars. Fig. 7 does not encourage WNL → WNE or WCL → WCE subtype evolution. The observed similar WN(R) and WC(R) trends do allow the possibility of WNE → WCE and WNL → WCL subtype evolution.

9.2. Wolf–Rayet star latitude distribution

In Fig. 8 the (l^{II}, z) distribution shows that out-off the plane a fair number of WR stars with large z-distances is visible. Those are worthy of further attention as possible run-away stars. The WR distribution in Fig. 8 is clearly asymmetric with respect to the galactic plane, in the sense that more stars are found at negative latitudes and with a concentration in the fourth quadrant. This aspect of the WR distribution was discussed earlier by van der Hucht et al. (1988) and Conti and Vacca (1990), and that of O-B2 stars by Reed (1996, 2000). The asymmetry may be caused by tidal interaction during the prehistoric passage of LMC and SMC (Fujimoto and Sofue, 1977).

In Fig. 9 the (d cos b^{II}, z) distribution shows that beyond 6 kpc incompleteness in our sample (due to IS extinction in the galactic plane) becomes increasingly dominant. Fig. 9 also shows that WN stars at larger distances are easier observed than WC stars. WC stars are confined to the strip $z = +250, -300$ pc around the galactic plane. WN stars with $d < 6$ kpc are also confined to the strip $z = +250, -300$ pc around the galactic plane, but beyond 6 kpc three WN stars are found at $z > 250$ pc and eight WN stars are found at $z < -300$ pc.

Considering only the 64 WR stars within $d < 2.5$ kpc, we note in Fig. 9 that those WR stars are predominantly restricted to the strip $z = +100, -200$ pc with a scale height of $h_{WR} \simeq 50$ pc, similar to that found for O-B2stars (Reed, 2000). Four stars have $z < -150$ pc, i.e., WR 6 (WN4), WR 40 (WN8h), WR 57 (WC8) and WR 103 (WC9d + ?), and could be runaway candidates. For the 64 WR stars we find that $\bar{z} = -17$ pc, which should be representative for the Sun's location *above* the galactic plane. The Sun's location above the galactic plane has been determined at 20.5±3.5 pc by Humphreys and Larsen (1995) from optical star counts in twelve Palomar Sky Survey fields, and at 10–12 pc by Reed

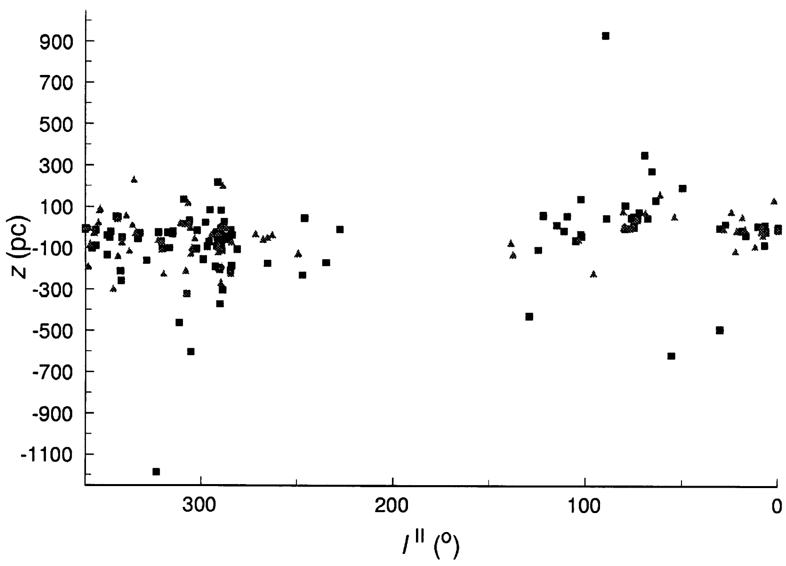

Fig. 8. The (l^{II}, z) distribution of galactic WR stars. Symbols as in Fig. 6.

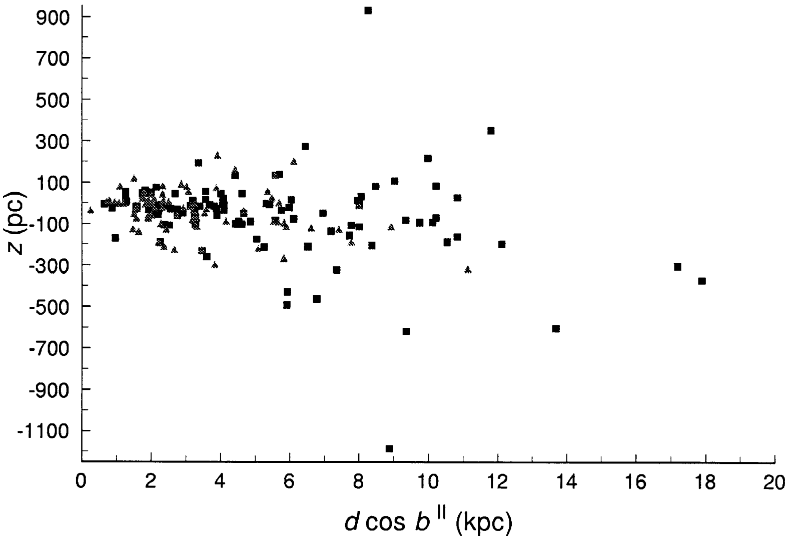

Fig. 9. The (d cos b^{II}, z) distribution of galactic WR stars. Symbols as in Fig. 6.

(1997) for a large number of O–B2 stars. For the 64 WR stars we find that $\overline{|z|}=49$ pc (for the 39 presumably single WR stars: 50 pc), in reasonable correspondence with $\overline{|z|}=45$ pc found for O-type stars by Garmany et al. (1982).

9.3. An estimate of the total number of Wolf–Rayet stars in the Galaxy

Since we can observe roughly only one quadrant of the Galaxy as projected on the galactic plane, it is clear that the minimum total number of galactic WR stars is just four times the number of WR stars in this *VIIth Catalogue*, i.e., $N_{\rm min}^{\rm WR} \simeq 1000$.

Attempts have been made to estimate the present total number of WR stars in the Galaxy. E.g., Prantzos and Cassé (1986), by scaling an earlier observed WR density distribution (Hidayat et al., 1982) to that of molecular hydrogen (Sanders et al., 1984) and adopting that the number ratio of WR stars to O-type stars is metallicity-dependent as $N_{\rm WR}/N_{\rm O} \propto Z^{1.7}$ (Maeder, 1984), estimated that $N_{\rm total}^{\rm WR} \simeq 8000$. The present total number of O-B2 stars in the Galaxy has been estimated at ~60,000 (Reed, 2000).

We make here an estimate of the present total number of WR stars in the Galaxy, only on the basis of the observed WR surface density distribution $\sigma_{\rm WR}(R)$ in this *VIIth Catalogue*. If we assume that our WR inventory in the shell $R=7$–12 kpc is complete, then our data (see Fig. 10) imply that $\log \sigma_{\rm WR}(R) = -0.26R + 2.58$ and that $N_{\rm total}^{\rm WR} \simeq 6500$, with ~3600 WR stars within 3 kpc from the Galactic Center, where only 30 have been discovered so far.

Adopting as the average WR star life-time $t_{\rm WR} \simeq 4\times10^5$ yr (Maeder and Meynet, 1994), we can

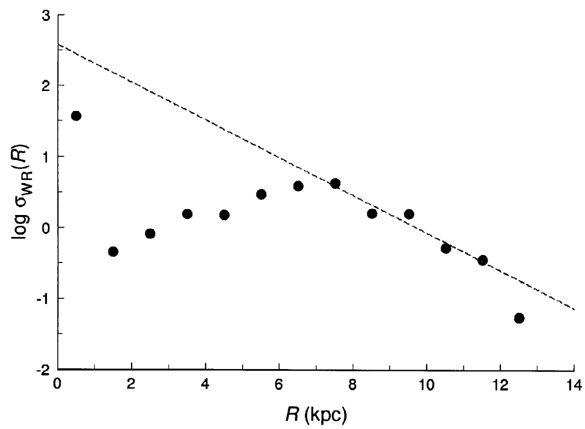

Fig. 10. The galactic WR surface density distribution $\sigma_{\rm WR}(R)$ versus galactocentric distance R for the stars in this *VIIth Catalogue*. The dashed line fits the five data points between 7 and 12 kpc, and corresponds to $\log \sigma_{\rm WR}(R) = -0.26R + 2.58$.

expect for the average time-interval τ_{WR} between two consecutive galactic WR deaths, possibly as supernovae, that $\tau = t_{WR} / N^{WR}_{total} \simeq 60$ yr, or, in the observable quadrant of the Galaxy: ~250 yr.

10. Summary and conclusions

The *VIIth* catalogue of galactic Population I Wolf–Rayet stars provides improved coordinates, spectral types and *bv* photometry of known WR stars and adds 71 new WR stars to the previous WR catalogue. The census of galactic WR stars reaches 227 stars, comprising 127 WN stars, 87 WC stars, 10 WN/WC stars and 3 WO stars. 26 WNL and WCL stars are located within 30 pc of the Galactic Center.

We compile and discuss spectral classification, variability, periodicity, binarity, terminal wind velocities, correlation with open clusters and OB associations, and correlation with H I bubbles, H II regions, and ring nebulae. Intrinsic colours and absolute visual magnitudes per subtype are re-assessed for a re-determination of optical photometric distances and the ensuing galactic distribution of WR stars.

In the solar neigbourhood we find projected on the galactic plane a surface density of 3.3 WR stars per kpc^2, with a WC/WN number ratio of 1.5, and a WR binary frequency (including probable binaries) of 39% (24% WN, 50% WC). Overall some 30 probable binaries are awaiting confirmation.

The galactocentric distance distribution per subtype shows a remarkable trend for $\overline{R_{WR}}$ per subtype to increase with decreasing WR subtype, both for the WN and WC subtypes. This distribution allows for the possibility of WNE → WCE and WNL → WCL subtype evolution.

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