ON THE CHEMICAL ABUNDANCES, EVOLUTIONARY STAGE AND BOLOMETRIC MAGNITUDE OF WR STARS

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I will comment on 3 problems concerning WR stars :

a. are WR stars core hydrogen/core helium burning?
b. are WR stars H-poor or do they have normal abundances?
c. can we use B.C. for WR stars which are similar as for O stars?

In literature one can distinguish three trends concerning the evolutionary stage and chemical abundances of WR stars :

i. WR stars are core hydrogen burning with normal abundances (Underhill, 1980,1981)
ii. WR stars are at the end of core hydrogen burning showing up products of the original convective core; computations have been presented by Noels et al. (1980)
iii. WR stars are core He burning stars, remnants after Roche lobe overflow in binaries or post red supergiant single stars (Maeder, 1980; the group of Padova; the group of Brussels).

Stating that WR stars are core H/core He burning, are H poor/H rich has important consequences on the M-L relation, the expected mass ratios (q) in WR binaries, the expected difference in absolute magnitude (ΔM_V) between both components in a WR binary, the expected number ratio WN/WC. It should first be recalled that the evolution of a single star during core hydrogen burning is similar to the evolution of that star when it is a component of a massive close binary , i.e. if case i) or ii) is valid for WR stars, it applies for WR binaries as well. Let us consider the known WR+OB binaries.

Case i)

Saying that WR stars are core hydrogen burning stars with normal composition and taking into account that on the average the mass of the WR star in binaries is a factor 2 lower than the mass of the OB companion implies by taking into account time isochrones that most of the WR stars would be situated close to the ZAMS, i.e. in the region of the class V stars. If the spectral type of the OB type companion is known it is possible then to give an estimate of ΔM_V. For the WR stars I have assumed a B.C. holding for normal OB type stars. The results are shown in table 1 for 6 systems where a ΔM_V is known from observations. As can

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 117–120.

Table 1

System	ΔM_V (exp)	ΔM_V (obs)
HD 97152	1.4	0.5
HD 168206	2.5	0
HD 186943	2.1	1.3
HD 190918	3.8	-
HDE 311884	0.5	-1.4
CX Cep	2.5	0

be seen there is no correspondence at all. Moreover if WR stars are normal stars with normal composition it is obvious that one should expect a large amount of WR binaries where the OB type star is the less massive component and this is not observed. The latter argument can easily be understood by considering a 20 $M_\odot$ WR star; a 20 $M_\odot$ normal hydrogen burning star appear much more frequent in a 20 $M_\odot$ + 10 $M_\odot$ binary than in a 20 $M_\odot$ + 40 $M_\odot$ binary. For these reasons I omit case i) as possible WR stage.

Case ii)

In the scenario proposed by Noels et al. (1980) once a star with ZAMS mass larger than ~40 $M_\odot$ exposes layers which were originally in the CNO burning core, the star is classified as a WR star. That this scenario does not apply for a large number of WR stars can be understood by considering the example illustrated in figure 1; starting from a 60 $M_\odot$ + 40 $M_\odot$ close binary and using the scenario under consideration the evolution of q and of the atmospherical H abundance X_{atm} is shown. The points

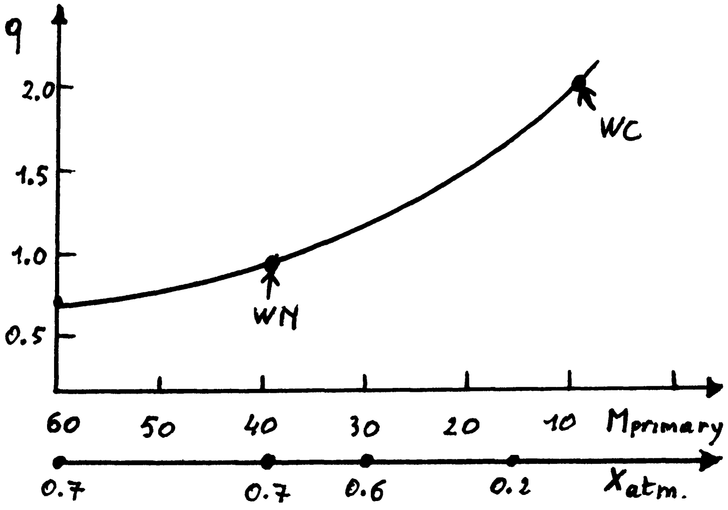

Figure 1.

where we see a WN star and a WC star according to this scenario are indicated. It is easy to compute the expected average q for WN binaries with this scenario. For a large variety of initial mass ratio distributions for O type binaries one always finds an average q lower than 1.5 whereas the observed value for WN binaries lies around 2.5. Moreover the expected number ratio WN/WC should be at least a factor 5 larger than the observed value for the Galaxy (assuming a stellar wind mass loss rate during both phases which does not vary very much, see also section). I conclude that only a minor fraction of the whole WR population is formed according to the scenario proposed by Noels et al. One could remark by considering figure 1 that MR 42 and HD 214419 may be in a phase at the end of core H burning when CNO processed material has just started to appear at the surface. The period of HD 214419 makes the latter very improbable whereas the fact that the OB component in MR 42 is a class V star and the WN6 star is ~1.4 mag brighter indicates that the WR star originates from a very massive star (~100 $M_\odot$). Moreover the lack of observed hydrogen lines in the WN6 star is a strong indicator that the star is a He burning star. I conclude that most of the WR stars, members of WR+OB close binaries, are H deficient ($X \leq 0.2$) core He burning stars. Due to the similarity between WR single stars and binaries, I am inclined to conclude that also single WR stars are H deficient core He burning stars.

The bolometric magnitude of WR stars

Let us now adopt that WR stars in binaries are core He burning stars (i.e. $X_{atm} \leq 0.2$). Using a $T_{eff} \simeq 30\,000$ K and a corresponding B.C. ≃ 3 mag, given the mass of the WR star (thus also its luminosity from evolutionary computations), the expected ΔM_V values can be computed between the WR star and a companion with different spectral types. This is done in table 2 for a 20 $M_\odot$ WR star. As can be noticed in most of the cases the OB star should be the fainter component whereas in most of the observed WR+OB binaries the OB type star is the brightest. This discrepancy can be removed stating that the B.C. $\gtrsim$ 4.5 mag. The WR star in HD 186943 has an $M_V \simeq -3$ mag, whereas $M_{WR} \geq 8\ M_\odot$; this implies a B.C. $\geq$ 4.5 mag if the WR star is a He burning star. The WR star in HDE 311884 has an $M_V \simeq -5.6$ mag and $M_{WR} \geq 40\ M_\odot$; again this implies a B.C. $\geq$ 5 mag. Maybe in this context the term B.C. is badly chosen.

Table 2 : The expected ΔM_V between a 20 $M_\odot$ WR star and different OB type companions

Sp.type	M_V (V)	M_V (III)	M_V (Ib)	M_V (Ia)
O5	1.2	0.3		
O7	1.7	1.1		
O9	2.4	1.1	0.7	-0.4
B0	3.1	1.8	0.7	-0.4
B0.5	3.1	1.8	0.7	-0.4

The definition of B.C. does not allow to arbitrary increase it with 1 or 2 mag. However, one may wonder whether or not the expression M_V-B.C. for WR stars gives a parameter which can directly be compared to the nuclear luminosity L_N resulting from evolutionary computations. It may be that a large amount of energy (ΔE) is necessary to sustain the very extended and outflowing atmosphere of a WR star. If so then one can only compare the expression M_V-B.C.+ΔE with L_N. Not knowing the value of ΔE it is premature at present to compare M_{bol} and L_N for WR stars i.e. we only know an underlimit of the nuclear luminosity for the position of WR stars in the HR diagram.

REFERENCES

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Noels, A., Conti, P.S., Gabriel, M., Vreux, J.M. 1980, Astron.Astrophys. 92, 242.
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Underhill, A.B. 1981, Astrophys.J. 244, 963.

DISCUSSION

Maeder: I have two points. Firstly concerning the Noels and Gabriel evolutionary picture, it seems clear to me that this picture can account for only a small number of WR stars. Secondly, there are many uncertainties in the input parameters of binary O stars, e.g. the distribution of mass ratios, of semi-major axes; how do these uncertainties affect the output resutlts ? In other terms is it really necessary to change the bolometric corrections on the basis of arguments based on binary statistics ?

Vanbeveren: Due to the limited time I did not have time to outline the influence of different input parameters of binary O stars. The analysis presented in the talk depends only marginally on these input parameters. However, concerning the B.C., these results are not affected by any statistics at all, as I used individual cases.

Henize: Your analysis of magnitude differences between the WR star and its companion is very interesting. It reminds me of a dilema I feel in the UV data: if the companion is an O III star, then the CIV λ1550 intensity should be significantly affected by the companion, and, if the companion is an OB supergiant, then its effect should be seen in both CIV λ1550 and SiIV λ1400 (see Henize, Wray & Parsons, A.J.,86, 1658). Yet I do not see this clearly in my data and I do not find other investigators making such allowances when using the CIV λ1550 intensities.