THE C/N RATIO IN WN AND WC STARS

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We present new determinations of the C/He, N/He and C/N ratios in 6 WN and 4 WC stars, resulting from a Sobolev analysis of new IUE UV line measurements in these species. Through improved observations of more stars, the present work extends an earlier, UV-based, study carried out by Willis & Wilson (1978, WW), which gives details of the Escape Probability Modelling (EPM) utilised. Full details of the current IUE observations, measurements and modelling will appear in *Monthly Notices*: here we summarise the results. Table 1 lists the ten WR stars currently studied - all were observed at low resolution and the brightest eight at high resolution.

We consider the EPM used here and by WW as best suited to the treatment of transitions (which generally occur in the UV) between low-lying levels whose populations are dominated by bound-bound processes. Such C and N lines observed in our IUE spectra are as follows, where in () we note which sequences they are observed: CIII] λ1909, CIII λ2297 (WC); CIV λ1550 (WN,WC); NIII] λ1750 (WN); NIV] λ1486, NIV λ1718 (WN). Where these lines are not seen we place upper limits of $W_\lambda \leqslant 1\text{Å}$ as inferred from our high resolution IUE spectra. In addition the new UV data allow reliable measurements and modelling of the HeII λ1640 and HeII (n-3) series in both WN and WC spectra. In the WN stars these are complemented by measurements of the visible HeII (n-4) series taken from our own tracings or from Smith & Kuhi (1981). The visible HeII (n-4) series in WC spectra are hopelessly blended, but fortunately the (n-3) transitions in the UV are reasonably separated from neighbouring carbon lines and are thus amenable to analysis.

The model adopted uses a single point EPM approximation as used and described by Castor & Van Blerkom (1970) and WW. Fixed input parameters are adopted for each star as follows: the stellar blackbody core continuum temperature, T*; the core and representative emission region radii, R_c and R_p respectively and the wind expansion velocity at the latter, V_p. These are taken for each star from complementary IUE-based studies by Nussbaumer *et al.* (1981) and Willis (1981), and are listed in Table 1. For each star at the adopted representative radius values of T_e, N_e and species ionic densities $N(X^+)$ are derived in the following manner.

C. W. H. de Loore and A. J. Willis (eds.), Wolf-Rayet Stars: Observations, Physics, Evolution, 113–116.

Table 1

EPM Input Parameters and Model Results

STAR	SpT	T^*(K)	v_p(kms^{-1})	T_e(K)	N_e(cm^{-3})	CIV/N	(CIII+CIV)/N
HD 187282	WN4	40 000	2000	6×10^4	3×10^{11}	1.1(-2)	≤7.5(-2)
HD 50896	WN5	40 000	1800	5×10^4	4×10^{11}	1.8(-2)	≤4.6(-2)
HD 191765	WN6	36 000	1800	5×10^4	4×10^{11}	3.5(-2)	≤7.1(-2)
HD 192163	WN6	36 000	1500	5×10^4	4×10^{11}	2.3(-2)	≤6.0(-2)
HD 151932	WN7	24 000	1200	2.5×10^4	1.0×10^{11}	4.3(-3)	≤9.0(-2)
HD 96548	WN8	32 000	800	3×10^4	2.3×10^{11}	8.6(-3)	≤3.9(-2)
HD 165763	WC5	40 000	2100	3×10^4	2×10^{11}		≥94
HD 16523	WC6	40 000	1800	3×10^4	1.2×10^{11}		≥20
HD 156385	WC7	30 000	1900	3×10^4	1.6×10^{11}		≥63
HD 192103	WC8	26 000	1300	2.8×10^4	1.2×10^{11}		≥65

R_p = 30R_o (WN,WC); = 60R_o (WC8) R_c = 7.5R_o (WNE,WC); = 20R_o (WNL); = 15R_o (WC8)

For the WN stars, we use the semi-forbidden and allowed NIV lines and the HeII line measurements to fix N_e, T_e, N(NIV) and N(He) as illustrated by the model results for HD 50896 (WN5) shown in Fig. 1. The NIV diagram shows for several T_e, locii of N(NIV) and N_e which give in the model grids the observed NIV] λ1486 and NIV λ1718 equivalent widths. For each T_e,N_e intersection, reduced intensities of the HeII (n-3) and (n-4) lines are computed and compared to those observed to obtain the best fit, as shown in the HeII diagram in Fig 1. The densities of the other ionic species (NIII, CIV, CIII) are then deduced by fitting the observed (or upper limits) UV line strengths in model curves of growth at the deduced T_e and N_e.

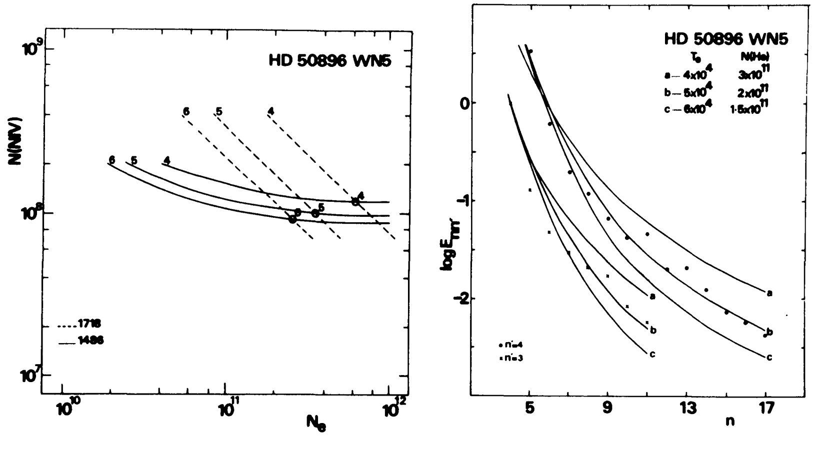

Fig 1. The NIV and HeII model fits for the WN5 star, HD 50896.

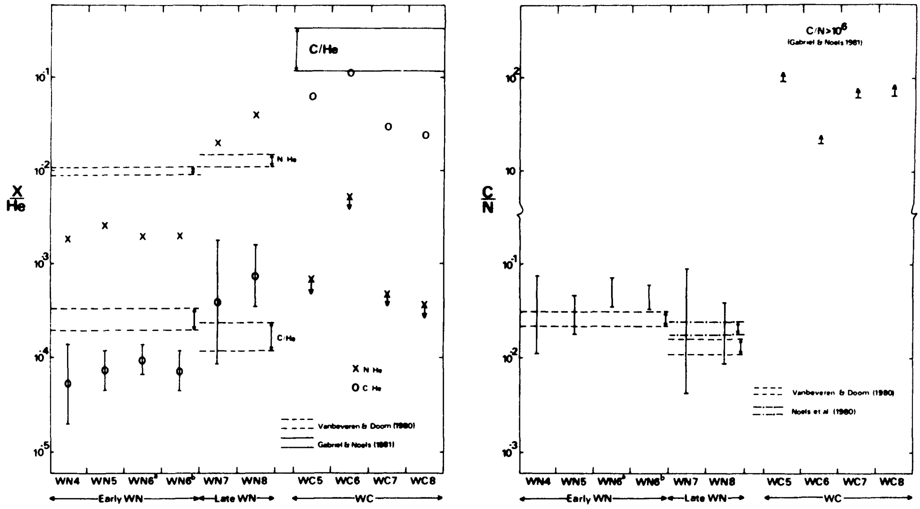

Fig. 2. The C/He, N/He and C/N ratios for 10 WR stars.

For the WC stars we proceed as above but use the CIII] λ1909, CIII λ2297 and HeII (n-3) lines to fix T_e, N_e, N(CIII) and N(He), and subsequently deduce ionic densitirs for CIV, and upper limits to NIII and NIV. In this analysis the H/He ratio is taken as 0.0 for WNE and WC stars; 1.0 for HD 151932 (WN7) and 1.9 for HD 96548 (WN8).

The derived values of T_e, N_e and the C/N ratios are given in Table 1. The deduced C/He, N/He and C/N ratios are shown as a function of subclass in Fig 2. For the WN stars the C/He and C/N ratios lie between the value derived from the measured CIV λ1550 line and an upper bound given by the CIII+CIV density. For the WC stars the N/He and N/C ratios are lower limits, since the appropriate NIII,NIV lines are not observed in our data. The results in Table 1 show a clear reversal between the C/N ratio in the WN and WC sequences: from $0.6\text{-}4\times10^{-2}$ for WNL stars, $2\text{-}6\times10^{-2}$ at WNE to 60 for the WC stars. This confirms the basic conclusion of WW that chemical differences are responsible for the dichotomy of the WN and WC sequences, and supports the hypothesis that the WR stars are evolved objects in which changing nuclear processed material generated in the stellar interiors is exposed by mass loss stripping of the outer atmospheres during H-burning and He-burning evolution.

Recently stellar evolution models have been undertaken to study the outer atmospheric chemistries in massive hot stars in which heavy mass removal has occured either through mass exchange in binary systems (Vanbeveren & Doom 1980) or heavy stellar wind mass loss in single stars (Noels *et al.* 1980). Gabriel & Noels (1981) have extended the single star studies to the He-burning phases. The theoretically predicted chemistries are compared with our deduced results in Fig 2. Both the binary and single star models agree that, given sufficient mass removal,

https://doi.org/10.1017/S007418090002876X Published online by Cambridge University Press

a very low H/He ratio is encountered near the end of core H-burning, with the He,C and N abundances reflecting the equilibrium products of CNO burning. Vanbeveren & Doom (1980) give results for the stages when the atmospheric H/He ratio is 0.2 - presumed to resemble a WNL star, and at 0.0 corresponding to WNE. Our deduced H/He and C/He ratios are ~ 4 times less than that predicted for the WNE stars, with a better agreement for WNL stars. Similar disrepancies appear between the deduced and predicted C/He ratios for the WC stars. However, we consider the agreement acceptable, with the differences probably resulting from oversimplification in our modelling, in which no ionisation or excitation stratification is accounted for. Better agreement will require more sophistication. The deduced C/N ratios show a much better agreement with the evolutionary predictions for the WN stars, particulary with the likelihood that CIII<CIV in WNE stars, and CIII$\geqslant$CIV in WNL stars. We place considerable reliance on our derived C/N ratios because of the use in the modelling of similar transitions in similar ions in these species. Changing input parameters, T_e or N_e does not significantly alter the derived C/N abundance ratios. A lower limit of C/N$\geqslant$60 is derived for the WC stars in the sample , which is much less than the value of $\geqslant 10^6$ predicted by Gabriel & Noels (1981), who, in effect, assert that for WC stars to be well advanced in He-burning, their N abundance should be zero. Our current anaysis does not rule this out, but we note that evidence for some atmospheric nitrogen in WC stars does exist (Willis, these proceedings). Clarification on this matter will require confirmation of the theoretical evolutionary predictions as well as further searches for N lines in WC spectra over the widest possible wavelength range.

In summary the He/C/N abundance ratios deduced from recent IUE data agree tolerably well with recent predictions from stellar evolutionary models, giving strong support to the scenario that the WR stars are evolved objects. The derived C/N ratios, in particular, show close agreement to the predicted exposition of nuclear burning products with, in general, WNL stars located near the end of core H-burning, WNE stars further evolved and WC stars well into core He-burning.

LJS acknowledges travel support to this symposium from the IAU and the Perren Chair of Astronomy at UCL.

REFERENCES

Castor,J.I.& Van Blerkom,D.,1970,*Astrophys.J.*,161,485
Gabriel,M.& Noels,A.,1981,*Astron.Astrophys.Lett.*,94,L1
Noels,A.,Conti,P.S.,Gabriel,M.& Vreux,J-M.,1980,*Astron.Astrophys.*,92,242
Nüssbaumer,H.,Schmutz,W.,Smith,L.J.& Willis,A.J.,1981, *Astron.Astrophys.Suppl.*,in press
Smith,L.F.& Kuhi,L.V.,1981,*JILA* Report No. 117
Vanbeveren,D.& Doom,C.,1980,*Astron.Astrophys.*,87,77
Willis,A.J.,1981,*Mon.Not.R.astr.Soc.*,198, in press
Willis,A.J.& Wilson,R.,1978,*Mon.Not.R.astr.Soc.*,182,559