Recombination Line Abundances in the Winds of the [WC] Wolf-Rayet Stars

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Abstract: We present a preliminary abundance analysis, utilising recombination theory, for the [WC] Wolf-Rayet central stars of the planetary nebulae NGC 6751 and NGC 6905. This analysis is based on optical spectrophotometry of a sample of [WC] stars which show a strong O VI 3811, 34 Å feature in emission. We have performed a recombination line analysis of stellar wind emission lines which are judged to be optically thin, in order to derive relative C, O and He abundances. We also present a comparison of the derived wind abundances with those of Population I WO stars. For the [WC 4] central star of NGC 6751, we have derived C/He = 0.35 and C/O = 4.2, by number. And for the [WC 3] central star of NGC 6905, we have derived C/He = 0.36 and C/O<12. These surface abundances are comparable to the abundances that have been derived for early type [WC] stars via more complex NLTE modelling (e.g. Koesterke & Hamann 1996).

1. Introduction

The [WC] Wolf-Rayet stars are a hydrogen-deficient sub-group of the central stars of PN. Their spectra exhibit strong broad emission line features, indicative of stellar winds similar to those found in the Population I WC and WO stars. Of particular interest are the members of the O VI sequence defined by Smith & Aller (1969) which show the O VI 3p–3s doublet at 3811, 34 Å strongly in emission, since the spectra of these stars shows the highest degree of ionization amongst all WR stars. Their spectra are dominated by lines of He, C and O. Unlike the Pop. I WR stars, there are no [WN] counterparts to the [WC] central stars, although occasionally the N V 1240Å feature is seen, indicating that although both Pop. I and II stellar winds reveal He-processed material, different mixing histories would have been experienced by the very different progenitor stars, allowing for trace amounts of nitrogen to be present in the Pop. II [WC] stars.

We have initiated a study of the O VI-sequence [WC] stars, aimed at deriving global parameters including their surface abundances and radiative energy distributions, in order to obtain insight into their evolutionary status. The current work presents a preliminary analysis for NGC 6751 and NGC 6905.

2. Observations

Both narrow- and wide-slit spectrophotometry were obtained using the RGO Spectrograph at the 3.0 m AAT, with an IPCS as detector. Data reduction was performed as described by Kingsburgh & Barlow (1994).

Equivalent widths, EW, were measured from the narrow-slit spectra, while the absolute level of the underlying continuum, $F_c(\lambda)$, was determined from the wide-slit spectra. Multiplication of the EW's by the appropriate values of $F_c(\lambda)$ yielded absolute line fluxes. These were dereddened by adopting the extinction coefficient derived from the Balmer decrement of the nebular spectrum (Kingsburgh & Barlow, 1994) together with the Galactic reddening law of Howarth (1983).

3. Recombination line analysis

A Case B recombination line analysis was performed for lines which were judged to be optically thin. The method is described in detail by Kingsburgh, Barlow & Storey (1995). The adopted wind temperature and density were 50000K and 10^{11}cm^{-3} respectively. Relative carbon, oxygen and helium abundances were derived for NGC 6751 and NGC 6905, and are presented in Table 1, along with the abundances derived for the Population I WO stars by the same method.

The oxygen abundance derived for NGC 6905 is currently a lower limit, based only on the O^{6+}/He^{2+} abundance, as the OV 5590Å line is predicted to be partially optically thick, and cannot be used to estimate the O^{5+} abundance. The accuracy of the oxygen abundances for both objects will improve as UV spectra are incorporated into the analysis. The C/He and C/O ratios for NGC 6751 and 6905 are within 30% of the values found for the two galactic population I WO stars, Sand 4 and Sand 5, although these stars have had completely different evolutionary histories; the pop I WC/WO stars originating from ~40–60M$\odot$ stars, and the Pop. II [WC] stars from ~1M$\odot$ stars.

NGC 6751 has recently been analyzed by Koesterke and Hamann (1996; KH) using a detailed non-LTE model of the stellar wind. They derive the following mass fractions: X(C)=0.31, X(O)=0.15, X(He)=0.54. From Table 1, we derive the following mass fractions for NGC 6751: X(C)=0.44, X(O)=0.14, X(He)=0.42. Our X(O) is in agreement with that of KH, however our X(C) is a factor of 1.4 higher. The C IV 5470Å line is best suited for deriving carbon abundances (Hillier 1989); however KH's models underestimate this line's strength, and they conclude that a value of X(C) as high as ~0.5 (or X(C)/X(O)=1.0) cannot be ruled out.

Table 1. A Comparison Between Population I and II Wolf-Rayet Wind Abundances By Number

	Object	class	C/He	O/He	C/O	Ref
pop I	NGC 6751	[WC4]	0.35	0.086	4.2	1
	NGC 6905	[WC3]	0.36	>0.029	<12	1
pop II	Sand 1	WO4	0.81	0.30	2.7	2
	Sand 2	WO4	0.52	0.11	4.6	2
	Sand 4	WO1	0.51	0.11	4.6	2
	Sand 5	WO2	0.52	0.10	5.2	2

Notes: 1–this work; 2– Kingsburgh, Barlow & Storey 1995.

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