PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
IAU Symposium, Vol. 209, 2003
S. Kwok, M. Dopita, and R. Sutherland, eds.

Revised Abundances & Ionizing Fluxes for [WC]-Type PN Central Stars Using Line Blanketed Models

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Abstract. UV (IUE), far-UV (FUSE) and optical (INT) spectroscopy of four Galactic [WC]-type PN central stars are analysed by means of sophisticated model atmosphere codes which allow for detailed line blanketing and clumping, and make comparisons with earlier non-LTE models. Crucially, we find no systematic difference between carbon abundances amongst late and early-type [WC] stars, removing the main obstacle against evolution from [WCL] to [WCE] subtypes.

Planetary Nebulae with Wolf-Rayet type central stars ([WC]-type CSPN), though small in number, represent important subset of H-deficient CSPN. Evolution is generally considered to proceed from late-type [WC] ([WCL]) through early-type [WC] ([WCE]) and subsequently PG 1159 CSPN, ultimately expiring as a H-deficient white dwarf. Although evolutionary models can now qualitatively reproduce the surface abundances of such stars (Herwig et al. 1999), there is a discrepancy between the [WCL] and [WCE] stars from spectral analyses (e.g. Koesterke & Hamann 1997) in that the derived surface carbon abundances of [WCE] stars (e.g. 31% by mass for NGC 6751) are significantly lower than those of [WCL] stars (50% by mass for NGC 40: Leuenhagen, Hamann & Jeffrey 1996), contrary to expectations if these form a genuine evolutionary sequence.

This paper summarises recent work based on ground- (2.5m Isaac Newton Telescope) and space-based (Far-Ultraviolet Spectroscopic Explorer, International Ultraviolet Explorer) absolutely flux calibrated datasets of two late-type (BD+30 3639, NGC 40) and two early-type (NGC 6751, NGC 6905), together with sophisticated model atmosphere codes of Hillier & Miller (1998). In contrast with earlier studies, models now account for line blanketing by heavy elements, such as iron, and the clumped nature of the stellar winds of [WC] stars.

We follow the same analysis technique as discussed in Dessart et al. (2000) for massive WC stars - stellar temperatures follow from simultaneous fits to lines of He I-II, C II-IV and O III-VI, whilst E_{B-V} is obtained from matching de-reddening observed energy distrubutions to synthetic spectra. It is only for BD+30 3639 that a reliable distance of 1.2 kpc is established (Harrington et al., these proc.) implying a luminosity of $4250L_\odot$ which is also adopted for the other program stars. For BD+30 3639 and NGC 40, IUE high-resolution data are of sufficiently good quality that we have been able to attempt determination of iron abundances from the Fe IV-VI spectrum in the far-UV, for which 0.2–0.5 $Z_\odot$ provide a reasonable match. In Table 1 we present derived properties for our program stars. Mass-loss rates assume volume filling factors of 10%, such that unclumped models would imply rates a factor of $\sqrt{10}$ times higher. Although exact filling factors remain uncertain, comparisons with observations definitely exclude non-clumped models.

Table 1. Properties of [WC] stars. Spectral types are taken from Crowther, De Marco & Barlow (1998). For all cases, distances are derived assuming a stellar luminosity of $\log L/L_\odot$=3.63 (see text), whilst a volume filling factor of 10% is adopted.

PN	HD	Sp. Type	E_{B-V} mag	d kpc	T_* kK	R_* $R_\odot$	v_∞ km s^{-1}	$\dot{M}$ $M_\odot$yr^{-1}	He:C:O %
NGC 6905	193949	[WO1]	0.11	2.3	150	0.1	2450	9×10^{-8}	50:40:10
NGC 6751	177656	[WC4]	0.32	3.2	140	0.1	2350	5×10^{-7}	45:45:10
NGC 40	826	[WC8]	0.43	1.4	90	0.3	1100	5×10^{-7}	50:40:10
BD+30 3639	184739	[WC9]	0.31	1.2	55	0.7	650	8×10^{-7}	55:35:10

Our principal result is that carbon abundances amongst [WCE] stars are not systematically lower than for [WCL] stars. The reason for this is due to a combination of improved observations, the inclusion of clumping and line blanketing in calculations. This resolves the previous inconsistency involving evolution between [WCL] and [WCE] subtypes.

Line blanketing also affects the ionizing flux output – the tendancy is to require both higher stellar temperatures than previously derived (leading to harder fluxes) but redistribution of high energy photons to lower energies due to blanketing (leading to softer fluxes). Consequently, we are in the process of testing these revised Lyman continuum fluxes in photo-ionization models. The importance of appropriate treatment of line blanketing has previously been illustrated by Crowther et al. (1999).

Acknowledgments. We would like to thank Alex Fullerton for processing FUSE data through the latest pipeline software. PAC greatly appreciates financial support from the Royal Society.

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