Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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Spectroscopy of planetary nebulae with [WR] nuclei

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1. Introduction

We have started an extensive program of systematic observations of planetary nebulae excited by [WR] nuclei with the aim of understanding the evolutionary status of the central stars. Detailed analysis of the nebular and stellar properties might reveal the presence of abundance variations across the nebulae, and allows to detect possible interactions between the massive stellar wind and the nebula. Such an analysis requires spatially resolved spectra, together with a reliable procedure to derive chemical abundances. This is best achieved by constructing individual photo-ionization models that reproduce the main observed properties. Here we present the spectroscopic analysis made for different knots of PB 6, NGC 2452, NGC 2867, NGC 6905 and He2-55. All these nebulae are ionized by [WC 2–3] stars and present very high ionization degrees.

2. Photo-ionization modelling and abundance determinations

For each object, an expanding model atmosphere, taking into account the extreme non-LTE situation and the velocity field, was built to fit the observed stellar features (Koesterke & Hamann 1997). The spectral distributions from these model atmospheres were then used to compute photoionization models which were required to reproduce the observed nebular properties. Details of the modelling procedure can be found in Peña *et al.* (1998). The photo-ionization models were rather successful in reproducing the ionization structure and the electron temperature of the nebulae. For some objects, only two-density models with an inner zone of lower density can fit the observational constraints. These density structures are consistent with the morphology showed by the nebulae. Some interesting problems raised by the models are: *(a)* for PB 6 and NGC 6905, we found that the model atmospheres used could be lacking UV photons with respect to their emission in the V band; and *(b)* for PB 6 and NGC 2867, the C/O ratios derived from the C^{++}/O^{++} line ratios observed induce computed electron temperatures significantly lower than observed.

Chemical abundances in the different knots of the nebulae were computed from the ionic abundances derived from the observations and the ionization-

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correction factors obtained from the models. The results, for the central zone of each nebula, are presented in Table 1. We found that, while the five nebulae have exciting stars with similar stellar temperatures, mass loss rates and chemical compositions, the nebular chemical patterns are different.

Table 1. Photo-ionization models and total abundances

	PB 6	NGC 2452	NGC 2867	NGC 6905	He 2-55
$T_*, R_t^{(1)}$	158, 3.98	158, 3.98	128, 5.20	128, 5.20	128, 5.20
He/H	0.176±0.008	0.127±0.006	0.112±0.006	0.108±0.007	0.147±0.010
O/H (10^{-4})	3.2±0.5	4.2±0.6	4.3±0.6	3.7±0.7	3.4±0.5
N/O	1.3±0.2	0.6±0.1	0.27±0.05	0.37±0.07	0.35±0.06
C/O$^{(2)}$	2.6±1.1	1.1±0.5	3.1±1.3	0.9±0.4	1.3±0.5
C/O$^{(3)}$	7.3±1.8	3.9±1.6	4.2±1.1	...	5.5±1.4
Ne/O	0.25±0.04	0.21±0.03	0.19±0.03	0.23±0.04	0.23±0.03
S/O	0.04±0.02	0.04±0.02	0.03±0.02	0.08±0.04	0.04±0.02
Ar/O	0.012±0.006	0.013±0.007	0.004±0.002	0.03±0.01	0.013±0.007

(1) Stellar temperature (kK) and transformed radius ($R_\odot$) of model atmospheres used
(2) From the C III 1909 / O III 5007 ratio
(3) From the C II 4267 / O III 5007 ratio

PB 6 and NGC 2452 (the most highly excited objects in the sample) are He-, N-, and C-rich, indicating massive progenitors ($M_{\rm initial} \geq 2.8\,M_\odot$). In particular, the high He and N abundances in PB 6 indicate a scenario of freshly made C, being brought to the surface by the third dredge-up and partially converted into N through envelope-burning. NGC 2867, NGC 6905 and He2-55 only show C enrichment. Therefore their progenitors were not massive, but all underwent the third dredge-up.

Thus, clearly, post-AGB stars of quite different initial masses can pass through a [WC] stage with similar atmospheric parameters. No evidence for abundance variations (or mixing of stellar wind and nebular material) inside any of the nebulae was found.

3. Work in progress

We are presently studying the properties of a number of PNe with intermediate and late [WC] central stars. Imaging and high-resolution spectroscopy have been obtained to study the morphology, the kinematics and the abundances in the nebulae. Possible correlations between the nebular parameters and the properties of the central stars are being analyzed.

References

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