Evolution of Planetary Nebulae with WR-type Central Stars

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Abstract

This thesis presents a study of the kinematics, physical conditions and chemical abundances for a sample of Galactic planetary nebulae (PNe) with Wolf-Rayet (WR) and weak emission-line stars (*wels*), based on optical integral field unit (IFU) spectroscopy obtained with the Wide Field Spectrograph (WiFeS) on the Australian National University 2.3 telescope at Siding Spring Observatory, and complemented by spectra from the literature. PNe surrounding WR-type stars constitute a particular study class for this study. A considerable fraction of currently well-identified central stars of PNe exhibit 'hydrogen-deficient' fast expanding atmospheres characterized by a large mass-loss rate. Most of them were classified as the carbon-sequence and a few of them as the nitrogen-sequence of the WR-type stars. What are less clear are the physical mechanisms and evolutionary paths that remove the hydrogen-rich outer layer from these degenerate cores, and transform it into a fast stellar wind. The aim of this thesis is to determine kinematic structure, density distribution, thermal structure and elemental abundances for a sample of PNe with different hydrogen-deficient central stars, which might provide clues about the origin and formation of their hydrogen-deficient stellar atmospheres.

Hα and [N II] emission features have been used to determine kinematic structures. Based on spatially resolved observations of these emission lines, combined with archival *Hubble Space Telescope* imaging for compact PNe, morphological structures of these PNe have been determined. Comparing the velocity maps from the IFU spectrograph with those provided by morpho-kinematic models allowed disentangling of the different morphological components of most PNe, apart from the compact objects. The results indicate that these PNe have axisymmetric morphologies, either bipolar or elliptical. In many cases, the associated kinematic maps for PNe around hot WR-type stars also show the

presence of so-called fast low-ionization emission regions (FLIERs).

The WiFeS observations, complemented with archival spectra from the literature, have been used to carry out plasma diagnostics and abundance analysis using both collisionally excited lines (CELs) and optical recombination lines (ORLs). ORL abundances for carbon, nitrogen and oxygen have been derived where adequate recombination lines were available. The weak physical dependence of ORLs has also been used to determine the physical properties. It is found that the ORL abundances are several times higher than the CEL abundances, whereas the temperatures derived from the He I recombination lines are typically lower than those measured from the collisionally excited nebular-to-auroral forbidden line ratios. The abundance discrepancy factors (ADFs) for doubly-ionized nitrogen and oxygen are within a range from 2 to 49, which are closely correlated with the dichotomy between temperatures derived from forbidden lines and those from He I recombination lines. The results show that the ADF and temperature dichotomy are correlated with the intrinsic nebular Hβ surface brightness, suggesting that the abundance discrepancy problem must be related to the nebular evolution.

Three-dimensional photoionization models of a carefully selected sample of Galactic PNe have been constructed, constrained by the WiFeS observations (Abell 48 and SuWt 2) and the double echelle MIKE spectroscopy from the literature (Hb 4 and PB 8). The WiFeS observations have been used to perform the empirical analysis of Abell 48 and SuWt 2. The spatially resolved velocity distributions were used to determine the kinematic structures of Hb 4 and Abell 48. The previously identified non-LTE model atmospheres of Abell 48 and PB 8 have been used as ionizing fluxes in their photoionization models. It is found that the enhancement of the [N II] emission in the FLIERs of Hb 4 is more attributed to the geometry and density distribution, while the ionization correction factor method and electron temperature used for the empirical analysis are mostly responsible for apparent inhomogeneity of nitrogen abundance.

However, the results indicate that the chemically inhomogeneous models, containing a small fraction of metal-rich inclusions (around 5 percent), provide acceptable matches to the observed ORLs in Hb 4 and PB 8. The observed nebular spectrum of Abell 48 was best produced by using a nitrogen-sequence non-LTE model atmosphere of a low-mass progenitor star rather than a massive Pop I star. For Abell 48, the helium temperature predicted by the photoionization model is higher than those empirically derived, suggesting the presence of a fraction of cold metal-rich structures inside the nebula. It is found that a dual-dust chemistry with different grain species and discrete grain sizes likely produces the nebular *Spitzer* mid-infrared continuum of PB 8. The photoionization models of SuWt 2 suggest the presence of a hot hydrogen-deficient degenerate core, compatible with what is known as a PG 1159-type star, while the nebula's age is consistent with a born-again scenario.

Declaration of Originality

This thesis is submitted in fulfillment of the requirements of the degree of Doctor of Philosophy at Macquarie University, Australia. I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other universities or institutions, either in Australia or overseas.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis. Some of the text found within has been published in the list of refereed papers and conference proceedings found in the appendix, on which I have been the leading author.

Any views expressed in this dissertation are those of the author and do not represent those of Macquarie University.

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Contents

List of Figures

List of Tables