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2D Ionization Structure of Haloes of Wind Driven Nebulae

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Abstract. The study of the nebular environments of stars provides clues to their recent evolution: the history of stellar winds and ejecta is written in the extended nebulae around massive (Wolf-Rayet Ring Nebulae (WRNe)) and intermediate mass stars (Planetary Nebulae (PNe)). Fast winds can produce shock excitation of the interstelar medium in the haloes of PNe and WR nebulae producing an extra source of heating to their thermal balance. We have explored the impact on the interstellar medium of this effect by searching for shock-heated gas in the 2D ionization structure of haloes, derived from deep multi-filter imaging of a sample of wind-driven nebulae. In this work, we present results for candidate regions where fotoionization does not appear to be the main ionization mechanism.

Key words. Nebulae: planetary nebulae – Nebulae: ring nebulae – Nebulae: photoionization – Nebulae: shock excitation

1. Introduction

The study of the environments of stars provides important clues to their evolution. The history of a changing stellar output of winds and ejecta is written in the close environments of massive and intermediate mass stars. Wolf-Rayet Ring Nebulae (WRNe), surrounding the evolved descendant of massive OB stars, and Multiple Shell Planetary Nebulae (MSPNe), constitute ideal laboratories to study the stellar mass loss history in these nebulae. These Planetary Nebulae (PNe) are surrounded by faint structures such as shells, haloes and other irregular outer structures. These outer haloes are of great interest, as they are presumably the remains of the original stages of mass loss from the progenitor stars. WRNe typically show a wind-blown bubble of interstellar material that, in some cases, presents ejecta of matter processed by the star. It has been claimed that the haloes of some MSPNe (e.g. NGC 6543 and NGC 7662) are hotter than their respective cores (Manchado & Pottasch 1989; Meaburn et al. 1991; Middlemass et al. 1989, 1991). Middlemass et al. (1989) have shown that photo-electric heating is not able to reproduce the high temperatures observed in the halo of NGC 6543, and an extra heating source is required. A candidate for the extra energy source is the fast wind passing the cold filamentary knots observed in the haloes of these Planetary Nebulae. A similar scenario is expected to operate in WRNe (e.g. NGC 6888 and M1-67; Chu et al. (2003); Garcia-Segura et

Send offprint requests to: D. Martín-Gordón al. (1996); Langer et al. (1998)), though in this case, physical processes such as the socalled mass-loaded flows (Hartquist et al. 1986) can play an important role. Both scenarios of nebulae formation open the door to the presence of shock excitation of their gaseous material.

The aim of this work is the detection and study of substructures of these nebulae that are good candidates to host shock-heated gas, in particular in their haloes. Our new approach to this problem makes use of the 2D information of the ionization structure of the haloes and outer shells, in order to select a group of candidate nebulae for a high (spatial and spectral) resolution spectroscopy follow-up. This is part of an observational program aimed to study the ionization structure and the fine-scale structures in the haloes of MSPNe and WRNe. As a first approach to this subject, we have obtained narrow band images of a selected group of MSPNe and WRNe, using narrow-band filters including the emission from low-ionization (e.g. [SII]) to high ionization species (e.g. [OIII]). The comparison of the emission from different states of ionization or different emissivity conditions provides direct evidence for fine-scale structure within the haloes of the nebulae. Narrow-band images were obtained at the 2.5 m INT (La Palma) with WFC, and at the 2.2 m Telescope at Calar Alto using BUSCA during three runs (2002 from July to December). In total, we have obtained images of 14 nebulae (including MSPNe and WRNe). We followed standard image reduction techniques for the bias-substracting, flat-fielding, and removing cosmic rays using IRAF packages. The study of the haloes of these nebulae requires the determination of the scattered light from the bright cores (Corradi et al. 2003). We determined the underlying scattered continuum at the location of the fine-scale structure of the haloes, which was substracted accordingly. Next, the flux calibration was accomplished using spectrophotometric standard stars.

Here we present preliminary results for two well known prototypes of MSPN and WRN.

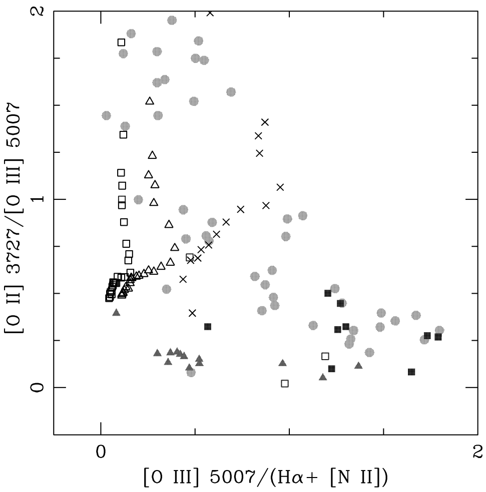

Fig. 1. Diagnostic diagram for NGC 6888. Models predictions for HII regions (circles, Stasinska (1982)); plane-parallel shock models: Hartigan et al. (1987) (crosses) and Riera (empty triangles and empty squares, private communication). Filled squares correspond to observations of type II PNe. Filled triangles correspond to our observations for NGC 6888, obtained in the blown cavity zones.

2. NGC 6888

NGC 6888 shows in our images a sharp ionization front in high excitation optical lines delineating a nearly spherical cavity, whereas the low excitation emission does not seem to follow this geometry. Diagnostic diagrams indicate that the line emission observed from the cavity gas cannot be reproduced by standard HII region models (Fig. 1). Recently, diffuse X-ray emission has been detected showing a limb-brightened morphology, with spatial extent similar to the nebular shell, through X-ray emission peaking interior to the optical emission (Gruendl et al. 2003). Follow-up spectroscopic observations of the areas highlighted by the 2D ionization structure have been performed at both high spatial and spectral resolution, aiming at the detection of shock-heated gas that should be associated with the highest excitation area.

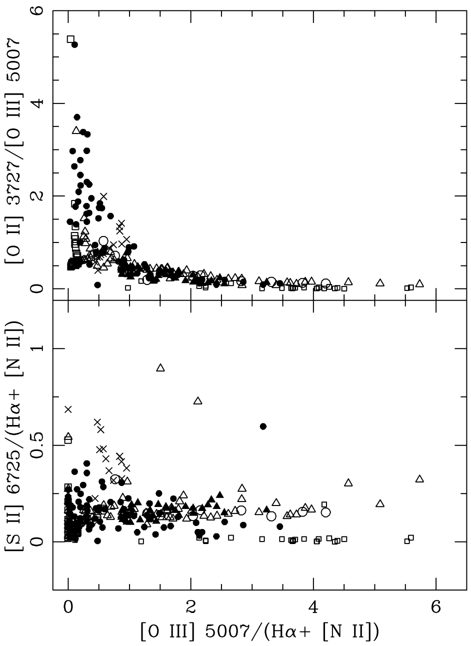

Fig. 2. Diagnostic diagrams for the halo of NGC 6543. Model predictions for HII regions (filled circles, Stasinska (1982)); plane-parallel shock models: Hartigan et al. (1987) (crosses) and Riera (big empty squares, private communication). Small empty squares correspond to observations of type II PNe. Triangles correspond to selected areas of the halo and empty circles correspond to dense structures detected in the halo.

3. NGC 6543

NGC 6543 is a typical example of a well known planetary nebula with an extended halo (Luridiana et al. 2003; Manchado & Pottasch 1989). For this nebula, it has been reported that its halo is hotter than its core (see introduction). It has been claimed that an extra heating source is required to explain the ionization observed (Manchado & Pottasch 1989; Meaburn et al. 1991; Middlemass et al. 1989, 1991). Here we do not present a study of the central parts of this nebula, but we are interested in the ionization structure of selected filamentary features detected in its halo.

In the diagnostic diagrams (Fig. 2) for NGC 6543, we show how the ionization structure of [OII]/[OIII] in the halo follows the general locus expected for HII regions and type II PN, far from the predictions of the shock models used. On the other hand, a major part of the observed [SII] emission, a tracer of the low ionization species, occupies an area of the diagnostic diagram out of the locus of the predictions for HII regions and type II PN. It is striking how the points representative of the filaments and condensations in the halo show the same excitation than the major part of the points of the halo emission. Only a handful of points of the halo show values with mesurable difference respect to the rest of the points.

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