Planetary Nebulae: An Eye to the Future
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Physical parameters and chemical abundances in bipolar PNe

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Abstract. Bipolar nebulae constitute a large subset of the planetary nebulae population. We present the first results of a project aimed to map physical parameters and chemical abundances across extended planetary nebulae with bipolar structure. These results can be used as input and constraints into numerical simulations in order to reproduce their properties in the visual band of the spectrum. This provides a way to examine the non-homogeneity present in this kind of object, as well as a tool to derive their intrinsic properties, like tridimensional geometry and matter distribution, central star properties, distance, and other properties in a self-consistent way. Here we show our results for two of these objects: IC 4406 and NGC 6572.

Keywords. Techniques: spectroscopic, methods: numerical, planetary nebulae: individual (IC 4406, NGC 6572)

1. Introduction

Planetary Nebulae are low mass star remnants surrounded by chemically processed material from their progenitor stars. This is one of the known mechanisms by which the interstellar medium is chemically enriched and the resulting nebulae frequently have complex structures. The shape of the resulting nebulae are related to the mass ejection mechanism in the late stages of stellar evolution of the progenitors. Different shapes are related to the interaction between the fast wind of central star and the slow-moving material ejected during the AGB phase. In this project we are interested in bipolar objects and our goal is to describe the properties of a set of bipolar planetary nebulae and then model them using a photoionization code.

2. Observations

The observational data were obtained using the 1.6m telescope at OPD/MCT-Brazil. The objects were selected by their bipolar morphology, surface brightness and suitable angular size from the Acker *et al.* (1992) catalogue. One of two techniques was adopted to observe the targets: (1) long slit or (2) integral field spectroscopy. In the first case the methodology consisted in performing long slit spectroscopy along the largest axis of the object and in positions parallel to this axis. The spectra were then extracted in 8.4" steps, covering the whole object. In the second case the line ratio maps were derived for regions of 15"x30", the size of the integral field unit, in 0.93″ steps, the spacing between optical fibers. The longer axis of the IFU was kept aligned to the object axis.

With these methods, it was possible to collect the required data, from which physical parameters and chemical abundances were derived for distinct points of each nebula.

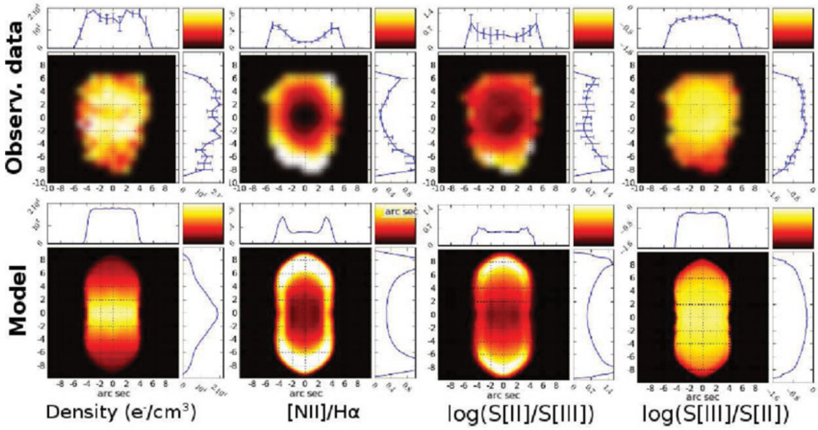

Figure 1. Line ratio maps for NGC 6572 from IFU observations (*top*) compared to the model outputs (*bottom*). Intensity profiles represent cuts at the center of each image, in both axes.

Data reduction and analysis were performed using the IRAF packages. Electron densities were derived from the [SII] lines 6716/6731Å line ratio and electron temperatures were based on the line ratios T[OIII] = (4959Å + 5007Å)/4363Å and T[NII] = (6548Å + 6583Å)/5755Å.

Helium abundance was derived from recombination, with corrections for collisional excitation. Nitrogen, oxygen, sulfur, argon and neon elemental abundances were calculated adopting ionization correction factors, adopting those of Escudero *et al.* (2004).

3. Model and results

Modeling was performed with the photoionization code Cloudy (Ferland *et al.* 1998), and the Cloudy-3D pseudo 3-D tool (Morisset 2006). The best models for the objects were selected from a Chi-square test over a grid of models.

The best model for NGC 6572 is an ellipsoid, with $R_0 = 5 \times 10^{16}$ cm, $n_0 = 4000$ cm^{-3}, with a specific density profile. Figure 1 displays the line ratio maps from observations (top) compared to the best model outputs (bottom) for this object. The figure also shows intensity profiles across the nebula for the same line ratios. For IC 4406, the chosen geometry is a tube, parametrized with the point angle to the axis of symmetry and extension. Its inner radius is $R_0 = 2 \times 10^{16}$ cm and the extension is 1.1×10^{17} cm, perpendicular to the equatorial plane, with a density profile depending on the extension.

These simulations are able to reproduce the major features of observations, even adopting simplifying assumptions, establishing limits for the intrinsic parameters of the objects. Another result from our sample is that density-bounded PNe may not be as frequent as expected. These and other issues will be examined later with a larger sample of objects.

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