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MAPPING AND MODELING THE PROPERTIES OF BIPOLAR PLANETARY NEBULAE

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RESUMEN

Presentamos los primeros resultados de un proyecto destinado a derivar parámetros físicos, abundancias químicas y variaciones angulares de nebulosas planetarias resueltas espacialmente en la Galaxia y que tienen estructura bipolar. Se pueden usar estos resultados como datos iniciales y restricciones en simulaciones numéricas para reproducir sus propiedades en la banda visual del espectro. De esta manera se pueden examinar las inhomogeneidades presentes en este tipo de objetos, y también servir de herramienta para determinar sus propiedades intrínsecas, como la geometría tridimensional y la distribución de materia, así como las propiedades de la estrella central, su distancia y otras propiedades en forma autoconsistente. Aquí mostramos nuestros resultados para dos de estos objetos: IC 4406 y NGC 6572.

ABSTRACT

We present the first results of a project aimed to derive physical parameters, chemical abundances and angular variations of spatially resolved planetary nebulae in the Galaxy that have 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 findings for two of these objects: IC 4406 and NGC 6572.

Key Words: methods: numerical — planetary nebulae: individual (IC 4406, NGC 6572)

1. INTRODUCTION

Planetary Nebulae (PN) consist in a low mass star remnant surrounded by chemically processed material from the progenitor star. This is one of the known mechanisms by which the interstellar medium is chemically enriched. The surrounding gas results from the stellar evolution, and it is known for being non-homogeneous. The project goal is to describe the properties of a set of planetary nebulae and then build models for them.

2. OBSERVATIONAL DATA AND ANALYSIS

The observational data were obtained using the 1.6 m telescope at OPD/MCT-Brazil. The objects were selected by their bipolar morphology (see § 3 for more details). 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. In the second case IFU line ratio maps were derived from regions of $15 \times 30''$. 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. The data were reduced and analyzed using IRAF tasks: for reduction, the NOAO package was employed; for physical parameters and ionic abundances, the NEBULAR/STSDAS tasks. The ICFs adopted are those of Escudero et al. (2004).

3. MODELING

Modeling was executed with the well-known photoionization code Cloudy (Ferland et al. 1998), using its pseudo-3D version Cloudy_3D (Morisset 2006). One basic assumption for the models is that the radiation field is essentially radial.

The geometry and the matter distribution adopted in each case are consistent with the interacting winds scenario, proposed by Balick (1987). The bipolar morphology was a requirement to the object selection, and their symmetry was assumed in the models. Therefore, it was only required to simulate 1/8 of the volume of the object – then completed

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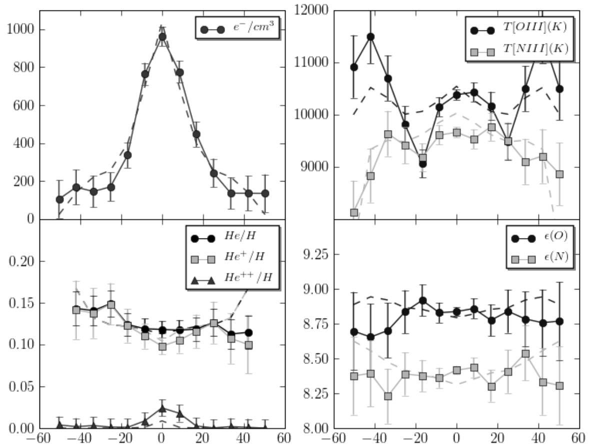

Fig. 1. Observational results (filled points) compared with model predictions (dashed lines). The error bars indicate the standard deviation of the local measurements.

with volume emission by mirroring the results according to the symmetry.

4. RESULTS

4.1. *IC4406*

This object is an example of the results derived using long slit (Figure 1). A previous angular study of this object was made by Corradi et al. (1997). Our results are in agreement with this work, though with a higher angular resolution. The object belongs to the butterfly class, and manly due to its high axes ratio, its main axis is assumed to be almost perpendicular to the line of sight. The adopted geometry is that of a tube, but with the distance-centered density function based on Dayal et al. (2000). The main properties of the final model are at Table 1.

4.2. *NGC 6572*

A comprehensive study of the NGC 6572 spectrum was made by Hyung et al. (1994), where a bipolar model was proposed. With this geometry, we were not able reproduce the angular properties saw in the IFU maps built for the object, mainly due the high and wide [SII] density distribution (Figure 2), however we propose a simple elliptical model that is in good agreement with the angular distribution of [SII] density and the [NII]/Hα flux ratio.

5. CONCLUSIONS

Both observational techniques used have shown to be suitable for the characterization of spatially resolved PNe, providing observational constraints appropriate to be used in the construction of models for these objects, and therefore allowing the self-consistent determination of the physical properties for them.

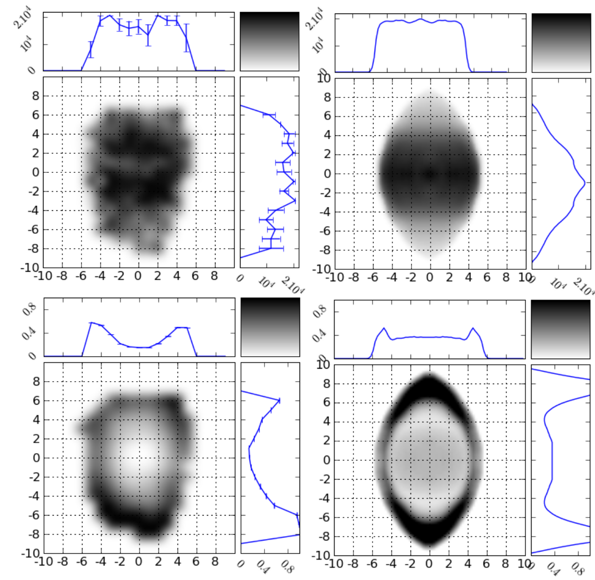

Fig. 2. Observational results (left) compared with model predictions (right). The error bars indicate the standard deviation of the local measurements. At top, the [SII]671.6/673.1nm density map (units of e^{-1} cm^{-3}). At bottom, the fluxes ratio of [NII]658.4nm/Hα lines.

TABLE 1

MODELS VALUES

PN	log T_*	log L_*	Hβ[a]	Dist.
IC4406	5.02 K	2.2 $L_\odot$	1.05	1.14 kpc
NGC 6572	4.73 K	3.4 $L_\odot$	1.03	1.27 kpc

[a]Ratio of predicted flux with those observed by Acker et al. (1992).

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