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3D Hydrodynamical models of the planetary nebulae M 1-32 and M 3-15

Jackeline S. Rechy-García[1], Pablo F. Velázquez[2], Miriam Peña[1] and Alejandro C. Raga[2]

[1]Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 70264, 04510, Ciudad de México, México.
email: jrechy,miriam@astro.unam.mx

[2]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apdo. Postal 70543, 04510, Ciudad de México, México.
email: pablo,raga@nucleares.unam.mx

Abstract. High-resolution, long-slit spectroscopic observations of two planetary nebulae, M1-32 and M3-15 are presented. The observations were obtained with the 2.1-m telescope at the OAN-SPM, and MES spectrograph. M1-32 shows wide wings on the base of its emission lines and M3-15 has two very faint high-velocity knots. To model both PNe we built a 3D model consisting in a jet interacting with an equatorially concentrated slow wind, emulating the presence of a dense torus, by using the hydrodynamical code Yguazú. The synthetic position-velocity (PV) diagrams obtained from our models reproduce well the observed PV diagrams.

Keywords. hydrodynamics, planetary nebulae: individual (M 1-32, M 3-15).

1. Introduction

More than 80% of planetary nebulae (PNe) are asymmetrical (Douchin *et al.* 2013), showing structures such as jets, knots, tori, etc. It has been proposed that this morphological variety of PNe is due to a binary-system scenario (Soker *et al.* 1992), where the progenitor star of the PN interacts with a stellar companion.

In this work, we use high resolution spectra to analyze the kinematical behavior of the gas in two PNe, M 1-32 and M 3-15, and by using a hydrodynamical model we investigate if the morphological structure of these PNe can be produced by the interaction between a jet and a dense torus. We compare the position-velocity (PV) diagrams obtained from the observations with those predicted by the hydrodynamical models.

2. Observations

High-resolution spectra for both PNe were obtained with the Manchester Echelle Spectrometer (MES; Meaburn *et al.* 2003) attached to the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, B.C, México (OAN-SPM). Observations were obtained for three different regions of each object. In Fig. 1 we show the PV diagrams for the slit located in the centre for both PNe. For M1-32, two bright knots (at a heliocentric systemic velocity of -86.4 km s^{-1}) and wings at high velocities ($\pm$180 km s^{-1}, relative to the system) are visible. For M3-15, a bright condensation (at systemic velocity of 96 km s^{-1}) and jets, ending in knots at $\pm$90 km s^{-1} (relative to the system) are seen.

3. Simulations

We have calculated hydrodynamical models using the code Yguazú (Raga *et al.* 2000). Our model considers two components: a dense torus and a bipolar system of conical jets. In the Fig. 2 we show the synthetic PV diagrams for both PNe. The simulation for M 1-32 was carried out until an integration time of 4500 yr. In our model, the jet axis

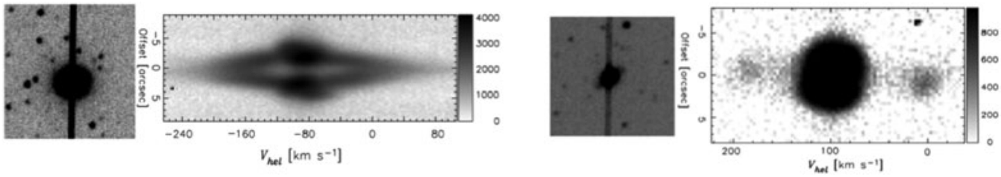

Figure 1. Slits located in the centre and PV diagrams for M 1-32 (left) and M 3-15 (right). The intense central emission corresponds to a toroidal component. The wide faint components correspond to a bipolar jet.

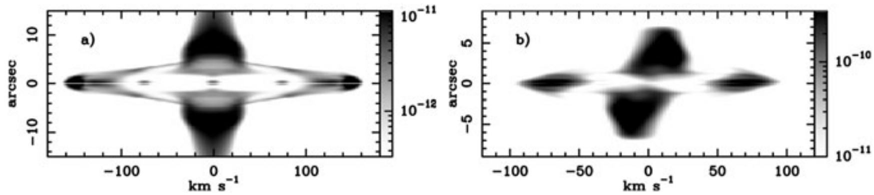

Figure 2. Synthetic position-velocity diagrams. The slit is located on the axis of the model. Left: M1-32. Right: M3-15. The logarithmic grey scale is in erg cm^{-3} sr^{-1}.

is nearly pole-on, at 0° with respect to the line of sight. We reproduce the central knots corresponding to the dense torus, and the wide wings associated with the jet material, at velocities of 160 km s^{-1}. The simulation for M 3-15 was obtained after an integration time of 3500 yr. We obtained a good agreement with observations if the jet axis was tilted by -55° with respect to the North direction, and at an inclination of 30° with respect to the line of sight.

4. Conclusions

The bipolar ejection leaves the central star, expanding through the poles of the torus at high velocities, of the order of 160 km s^{-1} and 100 km s^{-1} for M 1-32 and M 3-15, respectively. With the simulations we reproduce both the observed morphology and the PV diagrams of these nebulae, after an integration time of 4500 yr, for M1-32, and 3500 yr, for M 3-15, which are in agreement with the age of PNe of young population. In summary, we find that the spectral characteristics of M 1-32 and M 3-15 can be explained with the same physical model -a jet moving inside an AGB wind- using different parameters (physical conditions and position angles of the jet). Although the morphology of M 1-32 and M 3-15 are classified as spheroidal in the catalogs, due to their round appearance, spectroscopically both show a torus and high-velocity bipolar ejections. Therefore, we propose to call them "spectroscopic bipolars".
A full version of this work can be found in (Rechy-García *et al.* 2017).

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