

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

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**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).

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## 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.

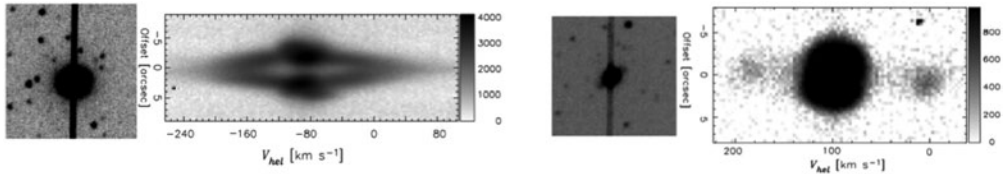
In this work, we use high resolution spectra to analyze the kinematical behavior of the gas in two PNe, M 1-32 and M 3-15, and by using a hydrodynamical model we investigate if the morphological structure of these PNe can be produced by the interaction between a jet and a dense torus. We compare the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

## 2. Observations

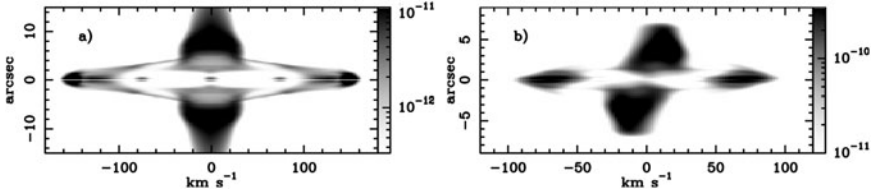
High-resolution spectra for both PNe were obtained with the Manchester Echelle Spectrometer (MES; Meaburn *et al.* 2003) attached to the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, B.C, México (OAN-SPM). Observations were obtained for three different regions of each 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  $-86.4 \text{ km s}^{-1}$ ) and wings at high velocities ( $\pm 180 \text{ km s}^{-1}$ , relative to the system) are visible. For M3-15, a bright condensation (at systemic velocity of  $96 \text{ km s}^{-1}$ ) and jets, ending in knots at  $\pm 90 \text{ km s}^{-1}$  (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 M1-32 (left) and M3-15 (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  $\text{erg cm}^{-3} \text{sr}^{-1}$ .

is nearly pole-on, at  $0^\circ$  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  $160 \text{ km s}^{-1}$ . The simulation for M3-15 was obtained after an integration time of 3500 yr. We obtained a good agreement with observations if the jet axis was tilted by  $-55^\circ$  with respect to the North direction, and at an inclination of  $30^\circ$  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  $160 \text{ km s}^{-1}$  and  $100 \text{ km s}^{-1}$  for M1-32 and M3-15, 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 M3-15, which are in agreement with the age of PNe of young population. In summary, we find that the spectral characteristics of M1-32 and M3-15 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 M1-32 and M3-15 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).

#### 5. Acknowledgements

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