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Study of protoplanetary nebulae

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Abstract. We have performed 3D hydrodynamic simulations of a symmetrical jet ejection following previous works (Raga *et al.* 2009, Riera *et al.* 2014, Velázquez *et al.* 2014). The jet is emitted from a binary system in elliptical orbit, and its direction changes describing a precession cone. We have considered that the jet has a time-dependence density ejection or a time-dependence velocity ejection, in order to propose an alternative model to explain the morphology of PPNe's. Also in our description we have included the effect of the photoionization of the central source. From numerical results, synthetic Hα maps were obtained, and a proper motion study were carried out. We found that the photoionization has an important effect on the case with variation density resulting in a increse in the Hα emission.

Keywords. ISM, jets and outflows, numerical methods, planetary nebulae, radiation mechanisms

1. Simulations

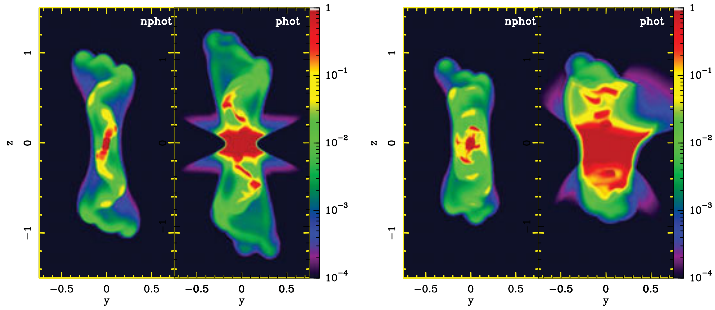
1.1. *Code and initial setup*

We have performed simulations with a 3D mesh parallel HD/MHD code (Esquivel *et al.* 2009; Esquivel & Raga 2013). This code solves the gas dynamical equations and incorporates various modules, including one for radiation transfer based on a Monte Carlo ray tracing method.

We used the values of 10^{-6}M$_\odot$ yr^{-1} for the AGB mass loss rate and a wind velocity of 15km s^{-1}. For the jet, we have a velocity of 400km s^{-1} and a density of 2.15×10^{-19}g cm^{-3}. Also we imposed a precession cone angle of 15°, a density variation of 0.95%, and a velocity variation 0.5% in each model. The precession period is 62.13 yr. For the binary system, we consider a white dwarf with a mass of 0.5 $M_\odot$ and a companion star of 2.14 $M_\odot$. The total integration time of the simulations is 130 yr.

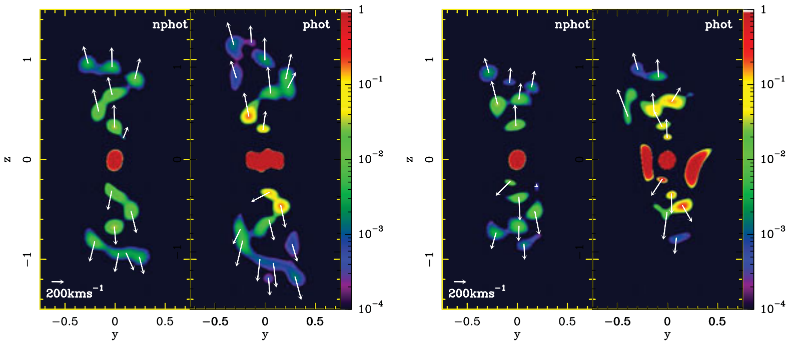
1.2. *Wavelets technique*

This method (Raga *et al.* 2016) degrades the resolution of the original images by means of a convolution with a smoothing function given by a "Mexican Hat" wavelet of half-width σ



(a) (b)

Figure 1. Synthetic Hα maps obtained for hidrodynamical simulations which consider a) a jet with a time density variation and b) a jet with time-dependent ejection velocity. Panels display the results for the simulations that include (do not include) photoionization effects. The logarithmic color scale gives de Hα emission in units of erg cm^{-2} s^{-1} sr^{-1}. Both axes are given in units of 10^{17} cm.



(a) (b)

Figure 2. Proper motions for the case with a) density variation and with b) velocity variation. For both cases, we have used the wavelets technique, which allows to highlight the most intense structures obtained in the synthetic maps.

$$g_\sigma(x,y) = \frac{1}{\pi\sigma^2}\left(1 - \frac{x^2+y^2}{\sigma^2}\right)e^{-(\frac{x^2+y^2}{\sigma^2})}, \qquad (1.1)$$

with x and y the coordinates in pixels on the plane of the images. Then the shifts in the identifiable intensity peaks are measured. For all the cases, we choose σ=10 because it shows more defined structures.

2. Results

2.1. *Density and velocity variation with and no photoionization*

We have obtained the synthetic Hα emission maps (Fig.1), where the y axis is the line of sight and the z and x axes correspond to the plane of the sky.

2.2. *Proper motions*

The proper motions are obtained using the Hα maps of two consecutive images with ten years of difference between them, for each case. In these images we apply the wavelets technique described above. Our results are shown below

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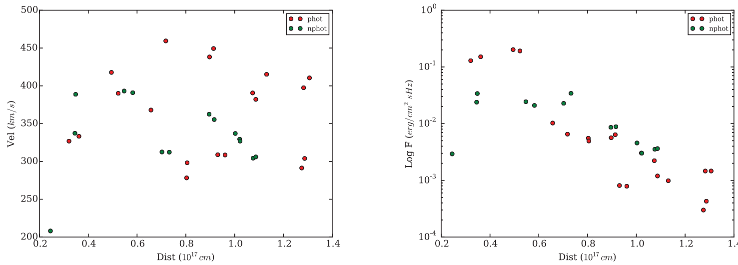
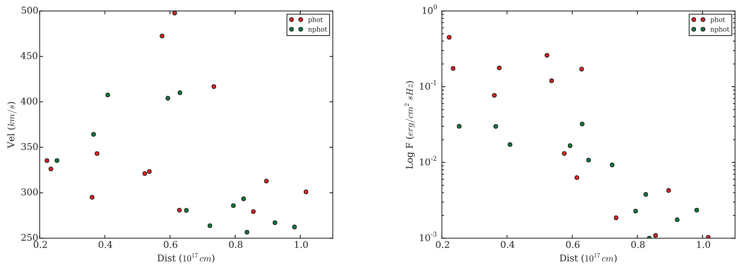


(a) (b)

Figure 3. a) Distance vs velocity plot and b) Distance vs flux plot obtained for the case of a jet with density variation, including or not the photoionization effects.



(a) (b)

Figure 4. Idem Figure 3, but for the case of a jet with a time-dependent ejection velocity.

3. Conclusions

We have made an attempt to reproduce the morphology of PPNe proposing a variation of density and velocity as a possible explanation to the observed structures in these objects. Furthermore, we have included the photoionization of the central source in the simulations. On the obtained synthetic maps, a proper motion study was performed. This study reveals that the photoionization has an important effect on both the emission and proper motion velocities.

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