

# Imaging and Long-Slit Spectroscopy of Compact Planetary Nebulae with Collimated Outflows

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**Abstract.** We present narrow-band images and high resolution long-slit spectra of the compact planetary nebulae M 1-66, He 2-115, K 3-1, K 3-13 and K 3-30, which present evidence of collimated outflows. Our data reveal the internal structure and kinematics of these objects for the first time.

**Keywords.** planetary nebulae, jets and outflows, interstellar medium

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## 1. Introduction

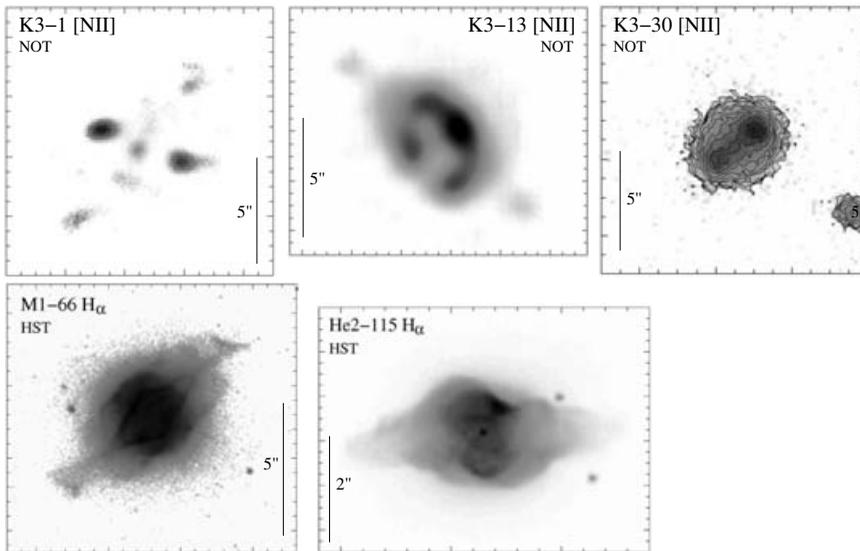
Planetary nebulae (PNe) are believed to be shaped by the dynamical action of collimated outflows (Sahai & Trauger 1998). To assess the dynamical effects of collimated outflows in PNe, we have started a study of the morphological and kinematical properties of compact, young PNe with evidence of collimated outflows. In this work we present preliminary results of five objects that had not been previously analyzed: M 1-66, He 2-115, K 3-1, K 3-13, and K 3-30.

## 2. Results

Direct H $\alpha$  images of M 1-66 and He 2-115 have been obtained from the *HST* archive (P.I.'s K. Borkowski and R. Sahai). As for K 3-1, K 3-13 and K 3-30, images in the H $\alpha$ , [N II] and [O III] filters have been obtained at the Nordic Optical Telescope (NOT, La Palma). Figure 1 presents images of these five PNe. Long-slit high resolution spectroscopy has been obtained with the echelle spectrograph of the 4 m telescope at the CTIO (He 1-115), the UES spectrograph at the WHT (M 1-66), and the IACUB spectrograph at the NOT (K 3-1, K 3-13 and K 3-30).

M 1-66 exhibits a diamond-shaped inner shell that is unique among PNe. The diamond sides extend outwards, delineating two outflows oriented along M 1-66's major axis (PA 310°). The rhomboidal inner shell is surrounded by an elliptical structure with brighter emission along its minor axis. The spectra show that the central regions expand at  $\pm 17$  km s<sup>-1</sup> with respect to the systemic velocity, whereas the outflows present radial velocities of  $\pm 8$  km s<sup>-1</sup>.

The *HST* image of He 2-115 shows a complex PN with various structures at different orientations, including an inner elliptical shell, two bright arcs near the equator, and a pair of outflows oriented at PA 275° that can be traced up to 2.8'' from the central star. A velocity splitting in the central regions of 15 km s<sup>-1</sup> is observed in the spectra, whereas at 3'' from the center along PA 275°, i.e., corresponding to the EW outflows, radial velocities of  $\pm 9$  km s<sup>-1</sup> are observed.



**Figure 1.** Images of M 1-66, He 2-115, K 3-1, K 3-13 and K 3-30. The telescope, filter and spatial scale are indicated in each panel. In order to emphasize the nebular morphology, the images of K 3-1 and K 3-13 presented here are the deconvolved version of the original ones. North is up, east to the left.

The  $H\alpha$  and  $[O\ III]$  images of K 3-1 (see Manchado *et al.* 1996) suggest a point-symmetric elliptical PN in which the emission is dominated by a bright equatorial ring. The deconvolved  $[N\ II]$  image (Fig. 1) shows the bright ring, as well as faint features that resemble a precessing bipolar outflow. The spectra show that the maxima at the ring present noticeable radial velocity differences that amount to  $\pm 35\text{ km s}^{-1}$  in the  $[N\ II]$  line. This implies that the maxima do not represent the edges of an equatorial ring but are part of a point-symmetric structure that is seen at an angle with respect to the observer.

In K 3-13, the basic structure is an elliptical shell with the major axis at PA  $25^\circ$ . Two compact knots separated  $10''$  are detected at PA  $50^\circ$ , although they can be traced to inner regions in the  $H\alpha$  and  $[O\ III]$  images. The long-slit spectrum at PA  $50^\circ$  shows a structure compatible with an elliptical PN. The knots are not clearly detected in this spectrum, but the NE knot is suggested by faint emission at  $3''$  from the center with a radial velocity of  $-16\text{ km s}^{-1}$  with respect to the systemic velocity.

K 3-30 presents an elliptical morphology in the  $[N\ II]$  image, with two bright emission knots along the major axis of the ellipse. These knots have a velocity difference of  $24\text{ km s}^{-1}$ . In the  $H\alpha$  and  $[O\ III]$  images of K 3-30, the elliptical structure is surrounded by a round halo-like structure of  $10''$  in size.

### Acknowledgements

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### References

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