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What is shaping the planetary nebula K3-35?

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Abstract. K 3-35 is a very young planetary nebula (PN) with a characteristic S-shaped radio emission morphology. It is the first PN where water vapor maser was detected: the emission is located in a torus-like structure with a radius of 100 AU and also at the surprisingly large distance of 5000 AU from the star, in the tips of the bipolar lobes. Several mechanism have been proposed to explain the bipolar morphology of PNe, and in the case of K 3-35 we believe we may be observing several of them at the same time: i) a disk-like structure traced by the H_2O masers, ii) a precessing bipolar jet probably due to the presence of a binary companion and iii) circular polarization in the OH 1665 MHz masers, which suggests the presence of a magnetic field. Additional observations and modeling are needed to establish what mechanisms are shaping K 3-35.

Keywords. magnetic fields: masers - stars: planetary nebulae: individual (K 3-35), ISM: jets and outflows

1. Summary

It is known that intermediate mass stars ($0.8 < M_\star < 10\ M_\odot$), spend most of their life converting hydrogen into helium. However, when the hydrogen in the core is exhausted, they start a short phase of much more rapid evolution to the planetary nebula (PN) phase. A planetary nebula consists of a hot ($T_{eff} > 20{,}000$ K) central star, surrounded by an expanding ionized nebula that in most cases is not spherically symmetric. Recently, a considerable effort has been put to understand the precise shaping mechanisms responsible for the different morphologies observed in PNe that go from spherical round to bipolar with collimated jets (Balick & Frank 2002).

K 3-35 was the first, of three confirmed PNe, that exhibit water maser emission (Miranda *et al.* 2001; de Gregorio-Monsalvo *et al.* 2004; Gómez *et al.* 2008). The bipolar morphology, and the presence of large amounts of neutral molecular gas in these three PNe not only suggest that these objects are young, but also that they have followed a similar evolutionary track corresponding to massive progenitors (Gómez 2007; Tafoya *et al.* 2007; Tafoya *et al.* 2009).

Several mechanisms have been proposed to explain bipolar collimated jets in PNe, and in the particular case of K 3-35 we note that three of them are present at the same time. *i) A disk-like structure traced by the H_2O masers at the center of K3-35.* From a kinematic study of the H_2O masers, we suggest the presence of an expanding

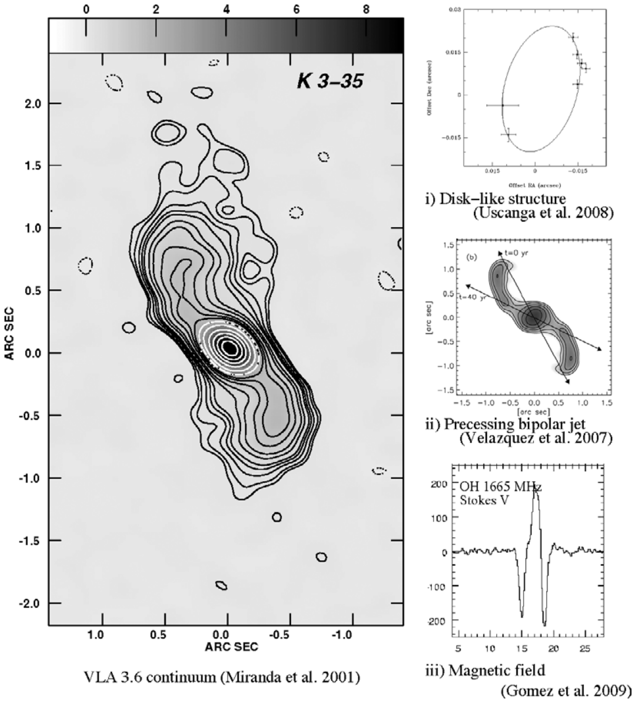

Figure 1. Left: VLA 3.6 cm continuum of K 3-35. Right: the three different mechanism that can be contributing in the jet collimation.

(V$\simeq$1.4 km s^{-1}) and rotating (V$\simeq$3.1 km s^{-1}) disk (Fig. 1), with a $\simeq$100 AU radius (Uscanga *et al.* 2008). *ii) A precessing bipolar jet.* The 'S' morphology shown by K 3-35 in the 8.3 GHz continuum image (see left side of Fig. 1) can be reproduced by hydrodynamical simulations, if the jet precesses with a period of 100 yrs on a cone with a half-opening angle of 20° (Velázquez *et al.* 2007). *iii) A magnetic field.* Circular polarization in the OH 1665 MHz masers traces a Zeeman pair, supporting the presence of a magnetic field of ~0.9 mG, at a radius of 150 AU (Gómez *et al.* 2009).

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