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Space Velocity and Time Span of Jets in Planetary Nebulae

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Abstract

Fast highly collimated outflows, including bipolar knots, jetlike features, and point-symmetric filaments or strings of knots, are common in planetary nebulae (PNe). These features, generally known as jets, are thought to play an active role in the nebular shaping immediately before or while fast stellar winds and D-type ionization fronts shock and sweep up the nebular envelope. The space velocity, radial distance from the central star, and kinematic age of the jets in PNe cannot be determined because the inclination angle with the line of sight is usually unknown. Here we have used the large number of jets already detected in PNe to derive orientation-independent properties from a statistical point of view. We find that jets in PNe can be assigned to two different populations: most (about 70%) have space velocities below 100 km s^{-1}, and only 30% have larger velocities. Since a significant fraction of jets move at velocities similar to that of their parent PNe and are found close to the nebular edge, we propose that these jets have been slowed down in their interaction with the nebular envelope, contributing to the expansion of their PNe. The time spans before the jets dissolve are found to be generally shorter than 2500 yr. Since most jets are found in young PNe of similar (1000–3000 yr) age, it can be concluded that jets are mostly coeval with their PNe.

Unified Astronomy Thesaurus concepts: Planetary nebulae (1249); Jets (870); Circumstellar envelopes (237); Late stellar evolution (911)

1. Introduction

A fraction of planetary nebulae (PNe) present morphological and kinematic features indicative of fast and highly collimated outflows. These are mostly detected in narrowband images (e.g., Corradi et al. 1996) as low-ionization features with a variety of morphologies, including jetlike features, bipolar compact knots, and point-symmetric filamentary structures or strings of knots. Such morphological variety has made researchers coin a number of names to designate them, including bipolar rotating episodic jets (BRETs; López et al. 1995), fast low-ionization emission regions (FLIERs; Balick et al. 1993), or simply jets. Hereafter, we adopt the latter term to refer to them, despite their morphological diversity. Kinematically, they are characterized by anomalous radial velocities with respect to the velocity field of the PN and narrow, unresolved velocity structures.

Jets are found in PNe spanning almost all morphological classes (Guerrero et al. 1999; Gonçalves et al. 2001) and evolutionary stages (Bond & Livio 1990; Alcolea et al. 2000; Cox et al. 2000; Goldman et al. 2004). It is nowadays commonly accepted that jets play a critical role in the shaping of axisymmetric PNe (Sahai & Trauger 1998), although the first detection of such a fast collimated outflow in a PN, namely NGC 2392 (Gieseking et al. 1985), was completely unexpected because it was unforeseen that progenitor stars of PNe could host accretion disks and/or have strong magnetic fields to provide the required conditions for the collimation and acceleration of a jet (Livio 1999). Different models have been proposed to explain the formation of jets in PNe, including hydrodynamical focusing (Frank et al. 1996), magnetic collimation (García-Segura 1997), and accretion disks (Morris 1987; Soker & Livio 1994), but none of them offer a comprehensive explanation of all their properties (Balick et al. 1998; Gonçalves et al. 2001).

Most observational studies of jets report the spatial and kinematic properties in one single object or a small sample of sources (e.g., Balick et al. 1987; Miranda & Solf 1992; Lopez et al. 1993; Guerrero et al. 1999; Corradi et al. 2000; Akras & López 2012, among many others). Only a few studies have dealt with averaged properties for a sample of PNe, considering the morphological and kinematic properties (Gonçalves et al. 2001; Akras & Gonçalves 2016) or the linear momenta of the jets (Tocknell et al. 2014). The real space velocity of a jet could provide basic insights on its formation mechanisms and interactions with the nebular envelope, but it is unknown due to projection effects because the angle between the velocity vector and the line of sight cannot be determined. Only in a few cases is there some additional information that can be used to constrain the real space velocity. The width of the line at zero intensity, FWZI, is a direct measurement of the real space velocity (Hartigan et al. 1987). Unfortunately, this procedure requires a high signal-to-noise ratio in order to determine the zero-intensity level accurately. More frequently, the real space velocity of the collimated outflow is worked out after a spatiokinematic model has been built for the main nebula (e.g., Clark et al. 2010) or for multiple ejecta located at different orientations (e.g., Miranda et al. 1999), or the shock velocity is derived from suitable spectral diagnostics (e.g., Guerrero et al. 2004). This requires adopting simple assumptions on the geometry and kinematics of the jets and their relation to different nebular structures.

In this paper, we present an analysis of the spatial and kinematic properties of a sample of jets in PNe using a statistical approach. The observed distributions of radial velocity and distance to the central star (CSPN) projected on the plane of the sky have been modeled to derive the intrinsic distributions of space velocity and distance to the CSPN. This has allowed us to infer sound conclusions about their velocity