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STAGNATION KNOTS IN PLANETARY NEBULAE

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RESUMEN

Presentamos un modelo alternativo para la formación de regiones rápidas de baja ionización (FLIERs, ingl. fast low-ionization emission regions) en nebulosas planetarias. En este modelo, un choque de proa cóncavo se forma como resultado de un flujo de momento lineal reducido a la largo del eje de simetría del viento estelar. Los FLIERs se forman del medio *circundante* atravesado por la onda de choque. Ya que en la zona cóncava del choque de proa el material ambiental no puede fluir alejándose del eje de simetría, éste es comprimido a un objeto denso parecido a un chorro colimado o jet. En presencia de un viento estelar variable, estos nudos rebasarán la envoltura nebular y aparecen como FLIERs desacoplados. Presentamos simulaciones hidrodinámicas en dos dimensiones de la formación y evolución inicial de los nudos de estancamiento y jets.

ABSTRACT

We present an alternative model for the formation of fast low-ionization emission regions (FLIERs) in planetary nebulae. In this model, a concave bow-shock structure is formed as a result of a reduced momentum flow along the symmetry axis of a stellar wind. FLIERS are formed from the shocked *ambient* medium. Since in the concave region of the bow-shock the ambient material can not flow away from the symmetry axis, it is compressed into a dense knot or jet-like feature. In the presence of a variable stellar wind these knots eventually overrun the expanding nebular shell and may appear as detached FLIERS. We present two-dimensional hydrodynamic simulations of the formation and early evolution of stagnation knots and jets.

Key Words: **HYDRODYNAMICS — ISM: JETS AND OUTFLOWS — PLANETARY NEBULAE: GENERAL — STARS: AGB AND POST-AGB**

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FLIERs in planetary nebulae were originally identified with the structures previously known as ansae in elliptical planetary nebulae. Their nature has resisted a consistent explanation to date. Initially, FLIERs were considered as pairs of knots located symmetrically with respect to the PN nucleus and characterized by outflow radial velocities of the order of 30–50 km s^{-1}. However, and as pointed out by López (2000), the concept of FLIERs has been used in recent times to encompass nearly any [N II]-bright knot in the periphery of PN shells found to be traveling either with nearly null or very high radial velocity. A single model can hardly account for all the properties observed (see Steffen, López, & Lim 2002, for a discussion of other models). In the model presented here FLIERs are formed from external gas swept-up by a fast, low-density wind plowing into the ambient medium of the PN formed from the slow dense wind of the central star during its AGB-phase. The idea of what we call "stagnation knot" was used for the first time to reproduce the large-scale structure of the giant envelope of the PN KjPn8 (Steffen & López 1998).

Instead of an isotropic fast wind from the central region of the PN, we postulate a wind with the special property of a deficiency of momentum flux along the axis as compared to higher latitudes. This causes the bow-shock to become concave instead of convex near the axis (as seen from the outside). Passing through the oblique region of the concave outer shock, the *ambient* medium is then refracted towards the axis, instead of away from it. This material may then remain confined by the high pressure of the surrounding hot gas from the shocked fast wind. The former has sufficient time to cool and be compressed to a dense knot or long jet-like feature.

Using axially symmetric hydrodynamical simulations which include non-equilibrium cooling (see Steffen et al. 2002, for a description of code and parameters of the simulations), we show that at least three different types of FLIER structures can be produced: First, slow ansae which remain inside or near the rim of the main nebula; second, fast ansae which move a large distance out of the rim; third, very long, jet-like strings with a linear velocity increase as a function of distance from the source.

In the simulations we have varied the following parameters: The pole-equator ratios of the velocity of the fast flow, the densities, the opening-angle

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of the zone of momentum depletion, and the pole-equator density ratio in the ambient medium. Figure 1 shows representative results. As long as the central outflow is on, driving the expanding shock, the stagnation knot moves roughly at the same speed as the rest of the bow-shock and remains at the bright rim formed by shocked ambient gas (Fig. 1a). As soon as the outflow stops or reduces its power, the cooling envelope slows down rather quickly, whereas the dense knot continues to move at its original speed (Fig. 1b). It subsequently slows down as it expands and continues to sweep up mass from the ambient medium. Figure 1c shows a very long stagnation knot or jet. The most important parameters for the production of such a long jet are a small opening angle of the region of reduced momentum flow and a large pole-equator density ratio in the environment. We find that, in agreement with observations (e.g., MyCn 18, O'Connor et al. 2000), in the stagnation "jets" and groups of knots, the velocity increases linearly with distance (inset of Fig. 1c).

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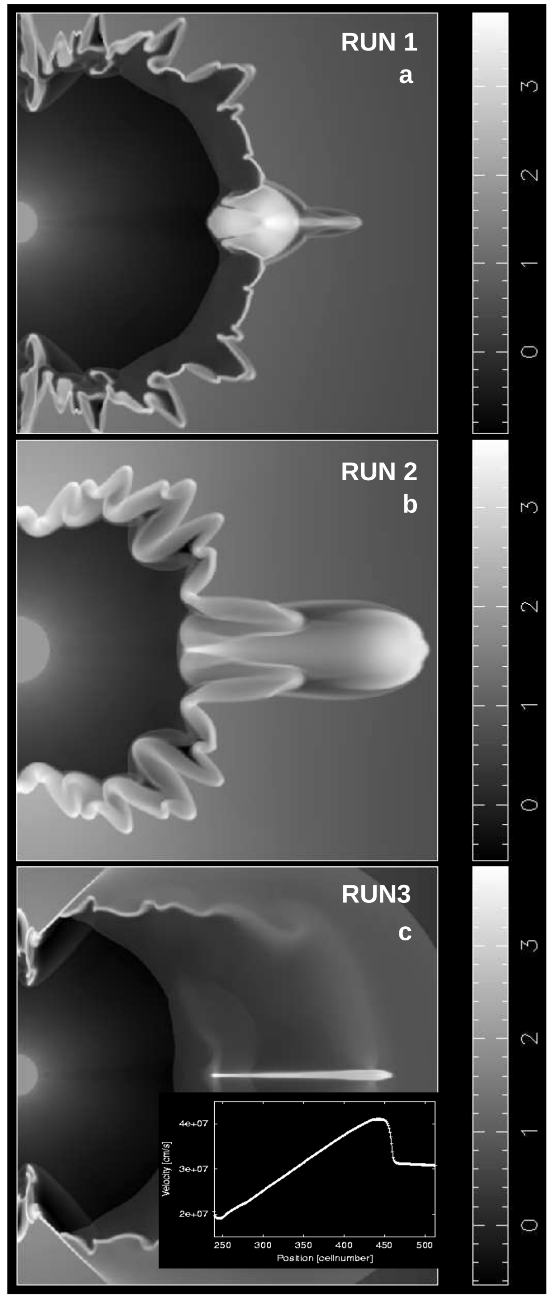

Fig. 1. Logarithmically scaled density cuts through axisymmetrical simulations of stagnation knots are shown.

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