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POINT-SYMMETRY AND THE DOUBLE PLANETARY NEBULA KJPN 8

J. A. López,[1] L. F. Rodríguez,[1] G. García-Segura,[1] J. Meaburn,[2] J. Franco,[1] R. Vázquez,[1] W. Steffen,[3] L. F. Miranda,[4] and M. Bryce[2]

RESUMEN

Presentamos resultados recientes de dos problemas de actualidad sobre la evolución dinámica de nebulosas planetarias (NPs) donde la presencia de núcleos binarios, rotación estelar y campos magnéticos son relevantes. Primero, para el caso de morfologías con simetría de punto se muestra que los modelos MHD que consideran el eje de colimación magnética inclinado con respecto al eje de simetría del viento bipolar reproducen exitosamente por primera vez muchas de las morfologías observadas. Comparamos el caso de la NP bipolar Sa 2-237 con resultados de estos modelos. Segundo, discutimos el origen de la extraordinaria nebulosa KjPn 8. Se espera que una porción substancial de los objetos que atraviesan la etapa de NP contengan núcleos binarios, pudiendo influenciar así el proceso de evolución estelar de forma importante durante y después de la fase de NP. Dependiendo de la separación y cociente de masa de las componentes, fenómenos tales como variables cataclísmicas, nebulosas simbióticas y novas pueden eventualmente formarse. En estos casos los cocientes de masa de los nucleos binarios están lejos de la unidad por lo que las componentes evolucionan en escalas temporales muy distintas. En contraste, observaciones obtenidas en distintas frecuencias con telescopios terrestres y el *Telescopio Espacial Hubble* han mostrado que en KjPn 8 podríamos estar siendo testigos del caso donde dos eventos tipo nebulosa planetaria han ocurrido de forma consecutiva, siendo detectados simultáneamente, y muy probablemente originados por un núcleo binario con componentes de masa muy similar evolucionado casi en paralelo. En este caso, KjPn 8 puede ser un objeto raro en la Galaxia y el primero detectado de esta clase.

ABSTRACT

We present recent results of two topical problems on dynamical evolution of Planetary Nebulae (PNe) where binary nuclei, stellar rotation and magnetic fields play relevant roles. Namely, point-symmetry and multiple, collimated outflows. Firstly, for point-symmetric morphologies, MHD models considering a steady misalignment of the magnetic collimation axis with respect to the symmetry axis of the bipolar wind outflow are shown to successfully reproduce for the first time many of the morphologies that are observed. We compare the case of the bipolar PN Sa 2-237 with model results. Secondly, we discuss the origin of the extraordinary nebula KjPn 8. A substantial portion of the objects that go through the PN stage are expected to have binary nuclei, which may largely influence the stellar evolution process during and after the PN phase. Depending on the separation and mass ratio of the components, phenomena such as cataclysmic variables, symbiotic objects and novae may eventually be formed. In these cases, the mass ratios of the binary cores are far from unity and consequently the components evolve with widely different time scales. In contrast, ground-based multifrequency and *HST* observations indicate that in KjPn 8 we may be witnessing the case where two distinct and consecutive bipolar planetary nebulae-like events have been detected simultaneously, most probably originating from a binary core evolution with components of very similar mass having evolved nearly in parallel. In this case, KjPn 8 may be a rare object in our Galaxy and the first ever detected of this class.

Key Words: **ISM: JETS AND OUTFLOWS — PLANETARY NEBULAE: INDIVIDUAL (KJPN 8, SA 2-237)**

1. INTRODUCTION

The diversity of collimated outflows that are now known to exist in PNe (e.g., López 2000) have been interpreted as a combination of magneto hydrodynamic processes (e.g., García-Segura 1997; Franco et al. this volume; Blackman et al. 2001) and the effects of binary core evolution (cf. Soker & Rappaport 2000; Reyes-Ruiz & López 1999 and references therein). New, alternative mechanisms for the production of jets and ansae in the absence of magnetic fields have also been recently explored (see Steffen, López, & Lim, this volume). Among these phenomena, the origin of point-symmetric structures (cf. Gonçalves, Corradi, & Mampaso 2001; Guerrero,

[1]Instituto de Astronomía, UNAM.
[2]Jodrell Bank Observatory, U. of Manchester.
[3]Instituto de Astronomía y Meteorología, U. de G.
[4]Instituto de Astrofísica de Andalucía.

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Vázquez, & López 1999) are particularly puzzling. In the first part of this contribution we present recent results of a 3D-MHD model that considers a steady tilt of the magnetic collimation axis with respect to the symmetry axis of the wind outflow to reproduce point-symmetric morphologies and jets (García-Segura & López 2000). In particular, models of bipolar nebulae with point-symmetric nebular shapes along the inner borders of their opposing lobes are compared with the case of the bipolar nebula Sa 2-237. In the second part of this paper we describe results on the multipolar nebula KjPn 8, which represents a singularly unusual case among PNe for its formation history and shaping cannot be explained within a single PN-like mass loss event, nor from a single progenitor. The extraordinary nature of the poly-polar nebula KjPn 8 has been revealed through a series of ground-based and *Hubble Space Telescope* observations spanning optical, infrared and radio frequencies (see López et al. 2000; Rodríguez, Gómez, & López 2000 and references therein).

2. MHD MODELS FOR POINT-SYMMETRIC PNe

A detailed account of the models can be found in García-Segura & López (2000), here we just describe the basic idea and main results. A schematic view of the model is shown in Figure 1 where the magnetic collimation axis is seen tilted with respect to the symmetry axis of the bipolar wind outflow, which in turn is perpendicular to the equatorial density enhancement. Here a rotating star produces the outflowing magnetized wind, in which the toroidal component is dominant with respect to the poloidal contribution at large distances. The simulations have been performed using the MHD code ZEUS-3D, originally developed by M. L. Norman. The computations are done in Cartesian coordinates and have grids of $100 \times 100 \times 200$ equidistant zones, with an extent of $0.1 \times 0.1 \times 0.2$ pc in x, y, and z. The wind's origin is located at the center of the computational volume and is set based on the rotating wind solutions by Bjorkman & Cassinelli (1993) and the approach to those equations by García-Segura et al. (1999). A range of mass-loss rates, magnetic field strengths, stellar rotation to critical rotation ratios, magnetic field energy density to kinetic energy density ratios in the fast wind and a variety of inclinations of the magnetic collimation axis with respect to the bipolar wind outflow have been explored. The results of the computational survey have been presented by García-Segura & López (2000). The models have been run for the bipolar and elliptical

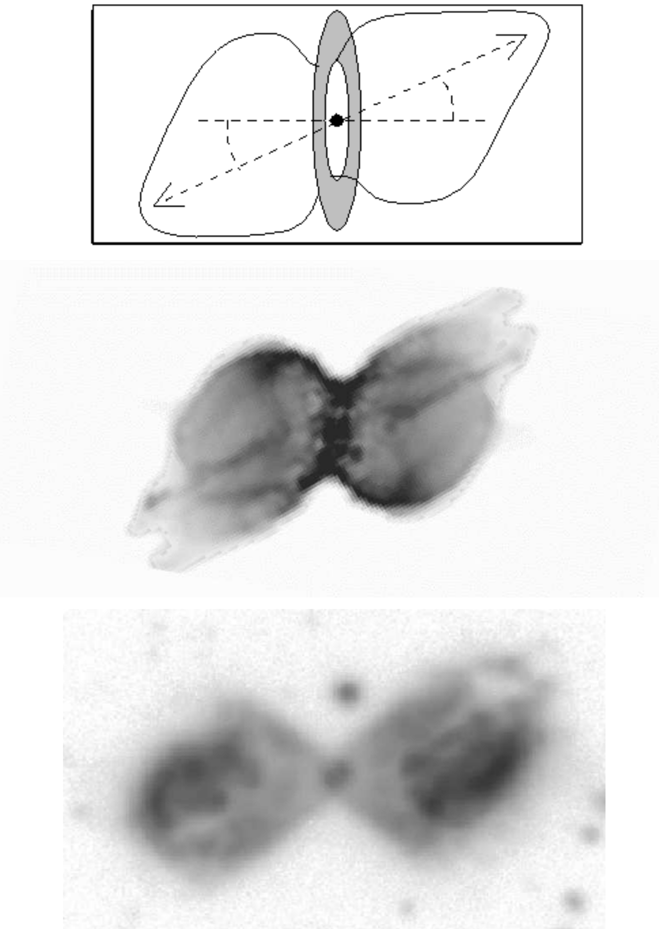

Fig. 1. Top panel: schematic view of the models. The magnetic collimation axis (arrowed line) is tilted with respect to the symmetry axis of the bipolar wind outflow. Middle panel: a model that closely matches the main morphological features of Sa 2-237. For details see text. Adapted from García-Segura & López (2000). Bottom panel: an [N II] image of Sa 2-237.

cases with good results. A particularly interesting outcome of these models is that jet formation is detected only for dense enough winds with mass-loss rates $\geq 10^{-7} M_{\odot}\,\mathrm{yr}^{-1}$. For lower mass-loss rates the jets tend to vanish leaving behind only ansae-like structures at the tips of the lobes, as is commonly observed.

3. COMPARISON OF THE MODELS WITH REAL NEBULAE, THE CASE OF SA 2-237

We have compared the results of one of the models with the bipolar planetary nebulae Sa 2-237 (López et al. 2002). Sa 2-237 is a narrow-waist bipolar nebula with prominent point-symmetric filaments along the inner borders of its opposite lobes. A

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secondary, collimated, bipolar outflow has its axis tilted with respect to the bipolar major axis, interacting with the inner walls of the bipolar cavities and creating a point-symmetric structure. In addition, compact jet-like structures protrude beyond the lobes along an axis coincident with the point-symmetric filaments—see Figure 1, bottom panel. A model from the García-Segura & López (2000) computational survey that closely matches the overall characteristics of Sa 2-237, is shown in the middle panel of Figure 1. The model in Figure 1 has a tilt of 45° between the symmetry axis of the bipolar wind outflow and the magnetic collimation axis. A mass loss rate $\dot{M} = 10^{-7} M_{\odot}\ \mathrm{yr}^{-1}$ and a ratio of magnetic field energy density to kinetic energy density of the fast wind, $\sigma = 0.01$ have been used in this case. The resemblance of the main morphological features of Sa 2-237 to the model is apparent, even though this particular model has not been fine-tuned for this particular nebula, though see López et al. 2002. It is worth noting that Sa 2-237 has a symbiotic nucleus composed of a white dwarf providing ionization and a red giant companion which is likely providing at least part of the outflowing wind material at this stage. The inclusion of binary nuclei in this analysis would only strengthen the conditions for the development of point-symmetry.

4. KJPN 8: A DOUBLE PLANETARY NEBULA

KjPn 8 is an extreme poly-polar planetary nebula with a large-scale, $14' \times 4'$, structure characterized by a giant, biconical envelope. Spasmodic bipolar ejections, in changing directions have occurred over thousands of years to create this extraordinary nebula. Furthermore, recent *HST*, NIR and molecular observations (see López et al. 2000 and references therein) have revealed that the ionized compact core is actually a very young planetary nebula embedded within the larger and older, giant bipolar envelope.

5. DYNAMICAL CHARACTERISTICS

Figure 2 shows the large scale structure of KjPn 8, characterized by nearly bi-conical lobes (C_1–C_2) oriented at PA 72°. The dynamical age of this structure has been estimated in $1\text{–}2 \times 10^4$ years and has been produced by the action of a bipolar episodic jet that is no longer energy driven and currently expanding at ≈ 100 km s^{-1}. A second set of younger bipolar lobes (A_1–A_2) are seen emerging from the core oriented at PA 126°; these outflows expand at 320 km s^{-1} and are $\leq 3.4 \times 10^3$ years old. The compact, $5''\!.2 \times 2''\!.7$ nebular core has been resolved by the *HST* into a remarkably young elliptical ring, expanding at 16 km s^{-1} and only $\approx 1.25 \times 10^3$ years old.

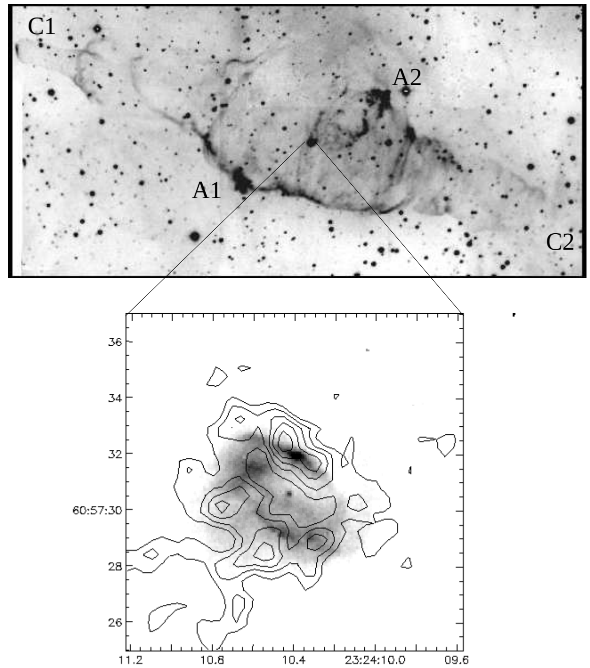

Fig. 2. A deep Hα mosaic of KjPn 8. The whole nebula is $14' \times 4'$ in extent. Inset: a contour map of excited 2.122 μm H_2 is shown overlaid on the [S II] *HST* image of the core of KjPn 8. The H_2, ionized and a larger CO disk, not shown here, all share morphology and orientation and their plane is perpendicular to the A_1–A_2 high-velocity bipolar outflows.

Furthermore, a ring or disk of excited H_2 surrounds it (inset in Fig. 2), itself located within a larger, massive CO disk (Forveille et al. 1998). Atomic hydrogen has also been detected towards the core of KjPn 8 (Rodríguez et al. 2000).

6. DISCUSSION

The small dimensions of the central ionized ring, associated massive atomic and molecular material and low excitation nebular spectrum indicate that the physical characteristics of the core of KjPn 8 are just those expected from a very young PN still undergoing photo-dissociation of its envelope. The formation of the A_1–A_2 high-speed lobes must have occurred during the pre-planetary nebula stage. For the current core conditions, the associated CO and H_2 molecular material must be related to a heavy mass-loss episode prior to the formation of the ionized nebular core. The disk-like structure and common orientations of the molecular and ionized rings confirm their connection. These characteristics are incompatible with the expected conditions that the core must have had at the time when the C_1–C_2

bipolar outflows were triggered. These elements lead to the conclusion that the formation of the giant bipolar envelope had its origin in a previous mass-loss event, unrelated to the creation of the present nebular core and associated bipolar outflows.

The most likely explanation for the formation of KjPn 8 seems to be the near simultaneous evolution of two relatively massive stars in a binary system, both reaching the end of the TPAGB phase $1\text{–}2\times10^4$ years one after the other. Deep close-ups of the *HST* images show hints of a companion to the central star that is apparent in the inset of Figure 2 (see López et al. 2000) located $\sim$ 500 pc south of the central star. This putative binary could have evolved as a detached or semidetached system in the AGB. Bipolarity may have developed in each case via magnetized winds, as described in the previous sections, where the bipolar axes are defined by the rotation axis of each star. In any case, for the components of this pair to end their lives within $1\text{–}2\times10^4$ years, the time separation between the creation of the extended and compact nebulae, the mass of the components need to be extremely coincident, within $\sim 10^{-4}$ if no mass-transfer or other effects are considered, a rare but not impossible event to happen (cf. Abt & Levy 1976). Mass transfer by a wind accretion process would help to speed-up the evolution of the less massive secondary. In summary, two distinct PN-type events are identified to have occurred $1\text{–}2\times10^4$ years apart, each producing bipolar outflows on each occasion and for each event having defined its own symmetry axis. Bipolarity in each outflow can develop via magnetized winds, possibly aided also by the effects of the companion.

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J. A. López, R. Vázquez, and G. García-Segura: Instituto de Astronomía, UNAM, Apartado Postal 877, 22800 Ensenada, B.C. (jal,vazquez,ggs@astrosen.unam.mx).
L. F. Rodríguez: Instituto de Astronomía, UNAM, Apartado Postal 72–3 (Xangari), 58089 Morelia Mich., México (l.rodriguez@astrosmo.unam.mx).
J. Meaburn and M. Bryce: Jodrell Bank Observatory, U. of Manchester, Lower Withington, Macclesfield, Cheshire SK11 9DL, UK (jm,mbryce@ast.man.ac.uk).
W. Steffen: Instituto de Astronomía y Meteorología, Universidad de Guadalajara, Apdo. Postal 1–1515, Guadalajara Jal. 44140, México (wsteffen@cencar.udg.mx).
J. Franco: Instituto de Astronomía, UNAM, Ciudad Universitaria, Apdo. Postal 70–264, México D.F. 04510, México (pepe@astroscu.unam.mx).
L. F. Miranda: Instituto de Astrofísica de Andalucía, Apdo. Correos 3004, Granada, E-18080, Spain (lfm@iaa.es).