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THE INTERACTION OF MULTIPLE SHELL PLANETARY NEBULAE WITH THE ISM

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RESUMEN

Las nebulosas planetarias con capas múltiples (MSPNe), son aquellas que, además de la capa principal brillante, presentan una o dos capas externas añadidas. A menudo, estas capas externas débiles, llamadas halos, presentan geometrías no esféricas indicativas de que se podría estar produciendo una interacción con el medio interestelar (ISM) circundante. Nuestro objetivo es investigar, en primer lugar, si los actuales modelos teóricos de evolución estelar son capaces de reproducir las diferentes capas observadas y, segundo, cuáles han de ser las condiciones del ISM necesarias para que el efecto del movimiento de la estrella central sea visible en los halos. Para ello hemos realizado simulaciones hidrodinámicas de la evolución de los vientos estelares predichos por los modelos teóricos. El estudio se ha llevado a cabo en dos partes: primero abordamos el caso de la formación de capas múltiples cuando la estrella central está en reposo, y después investigamos la interacción de las diferentes capas con el ISM producida por el movimiento de la estrella central.

ABSTRACT

Multiple shell planetary nebulae (MSPNe) are those which, in addition to the main bright inner shell, show one or two additional external shells. These faint external shells often have aspherical geometries, indicating an interaction with the surrounding interstellar medium (ISM). Our aim is to investigate, first of all, if the current theoretical stellar evolutionary models are able to reproduce the different observed shells and secondly, which ISM conditions are necessary in order to see the effect of a moving central star in the PN halo. We have performed hydrodynamical simulations following the evolution of the stellar winds predicted by the theoretical stellar evolutionary models. The study has been done in two parts: first, we approach the problem of the formation of multiple shells in the case of a star at rest, then we investigate the interaction of the different shells with the ISM due to a moving central star.

Key Words: **HYDRODYNAMICS — ISM: STRUCTURE — PLANETARY NEBULAE: GENERAL**

1. INTRODUCTION

Kaler (1974), Fusi-Pecci, & Renzini (1976), and Kwok (1981) interpreted the different shells as the result of remnants of the red giant winds decelerated by the ISM. Since then, new stellar evolutionary models have appeared which predict discrete enhanced mass-loss rates during the AGB for low mass stars (Vassiliadis & Wood 1993). Many studies have been carried out to try to establish a connection between the central star evolution and the observed shells (Stanghellini & Pasquali 1995; Trimble & Sackmann 1978; Frank, van der

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Venn, & Balick 1994). We have approached the problem from a different angle: to find out whether the predictions given by Vassiliadis & Wood (1993) are able to reproduce the observed MSPNe.

1.1. *The MSPNe*

We performed numerical simulations using ZEUS-3D as a hydro-code with the stellar evolutionary models as the inner boundary conditions. We set up the time-dependent wind parameters during the whole evolution of the star, that is AGB and post-AGB stages. We also took into account the hardening of the radiation field as the star evolves towards higher temperatures during the post-AGB stage. To allow comparison with observations, we have computed the Hα emission brightness profile by integrating over the line of sight. In Figure 1 we show the observed Hα emission brightness profile of the PN NGC 6826 and the computed ones at different evolutionary times from the beginning of the photoionization.

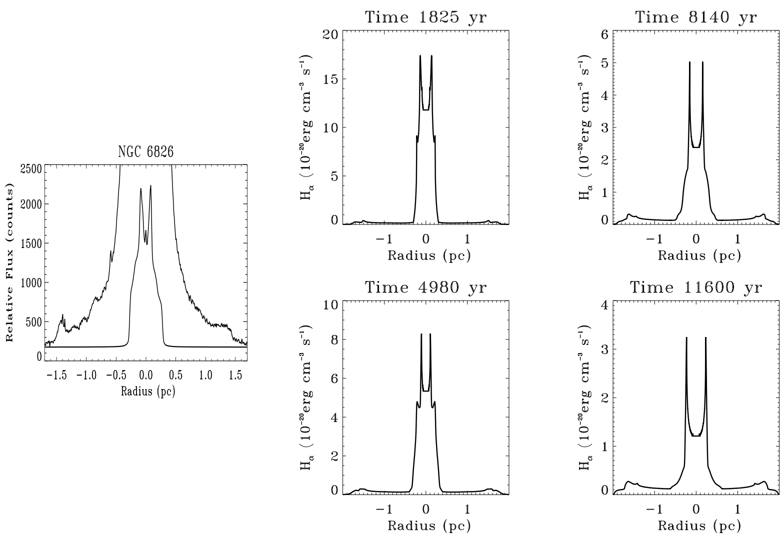

Fig. 1. *(Left)* Hα observed brightness profiles across the central part of NGC 6826, the central part is also shown but scaled accordingly. *(Right)* Computed Hα brightness profiles at different evolutionary times. Time zero is defined as the time when photoionization begins.

The halo brightness profiles are characterized by a continuous decline in the emission and a relative maximum at the edge caused by an abrupt enhancement of the density at the leading surface of the shell. The linear size of NGC 6826 has been computed by adopting the spectroscopic distance of 2.2 Kpc given by Méndez, Herrero, & Manchado (1990). A direct comparison of the observed and computed profiles shows that our simulations are able to reproduce the overall shape and size of the nebula.

1.2. *The Interaction Process*

MSPNe are a very common phenomenon, they appear in 24% of a complete sample of spherical and elliptical PNe in the northern hemisphere (Manchado 1996). If we search for asymmetries in the halo we find that 40% of these MSPNe show asymmetries that could be related to the interaction with the ISM. In previous studies of the interaction process, the evolution of the star has been neglected (Borkowski, Sarazin, & Soker 1990; Soker, Borkowski, & Sarazin 1991). To address this question we set up the time dependent wind parameters within a small spherical input region centered on the symmetry axis and we assume a homogeneous ISM with density 0.1 cm^{-3} moving supersonically at 20 km s^{-1} with respect to the star. An outflow boundary condition has been set at the outer radial direction and reflecting boundary conditions at the symmetry axis. In Figure 2 we show some density diagrams of the evolution.

The star moves perpendicular to the line of sight. The computation was performed in a 2D spherical grid with the angular coordinate ranging from 0 to 180 degrees and the radial coordinate covering two parsecs in radius. The isothermal sound speed in the unperturbed ISM is $c = 3$ km s^{-1}, which gives us a Mach number of 7. We found that the asymmetries caused by the interaction take place from the beginning of the evolution and have an enormous influence on the formation of the halo. The mass-loss rate associated with the last thermal

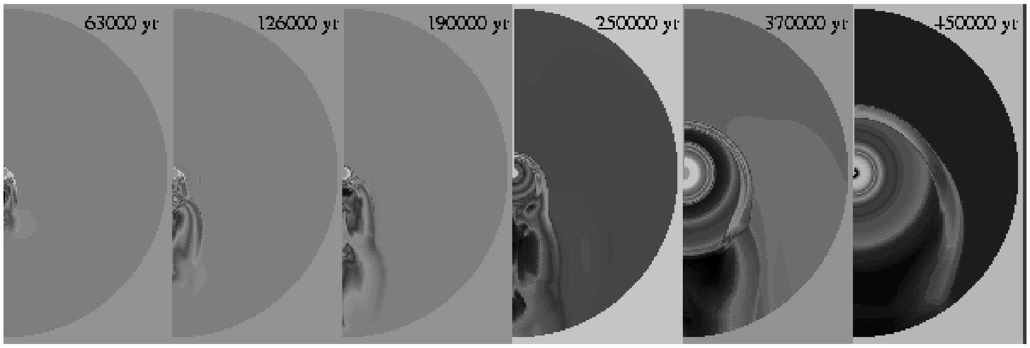

Fig. 2. Gray scale of the logarithm of the density at different evolutionary times of the shell generated by a star moving with a velocity of 20 km s^{-1} through an interstellar medium of density $n_o = 0.1$ cm^{-3}.

pulse interacts directly with the local unperturbed ISM, giving rise to a less dense shell than the one formed by a stationary star.

2. CONCLUSIONS

As a consequence of the evolution of a 1 $M_\odot$ star from the models of Vassiladis & Wood (1993; 1994) a Multiple Shell Planetary Nebula is formed. Without invoking any asymmetry for the stellar wind and taking into account the effects of a moving central star, an asymmetric halo is formed as a consequence of the interaction with the ISM. Since our assumptions of the velocities and the ISM conditions are very conservative, we can conclude that we will see a spherical halo only if the star is at rest in relation to the ISM or if it is moving at low angles in relation to the line of sight.

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