The formation of asymmetries in Multiple Shell Planetary Nebulae due to interaction with the ISM

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Abstract.
Multiple shell planetary nebulae (MSPNe) are most likely a consequence of the modulation of the mass-loss rate during the thermal pulses on the AGB. By using numerical simulations of their formation, the models’ predictions and the history of the winds can be investigated. As their halos have low densities and expansion velocities, MSPNe are expected to be affected by interaction with the ISM. This would then give us evidence of the local ISM conditions.

In order to study the formation of MSPNe, we have performed numerical simulations following the evolution of the stellar winds for a 1M⊙ star from the AGB to the post-AGB stages. 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.

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.

1. Introduction

The existence of faint shells surrounding PNe was pointed out by Duncan (1937), and Chu, Jacoby & Arendt (1987) studied and classified a large sample of MSPNe. Since then, the use of more sensitive CCD detectors and the HST telescope have revealed that these structures are more common than was originally believed. MSPNe appeared in 24% of a complete sample of spherical and elliptical PNe in the northern hemisphere (Manchado 1996); 40% of these show asymmetries in the halo that could be related to the interaction with the ISM. Many studies have been carried out to try to establish a connection between the central star evolution and the observed shells (Stanghellini & Pascuali 1995, Trimble & Sackmann 1978, Frank, van der Venn & Balick 1994). We have approached the problem from a different angle: to find out whether the predictions of discrete enhanced mass-loss rates during the AGB for low mass stars given by Vassiliadis & Wood (1993) are able to reproduce the observed MSPNe.
1.1. The MSPNe

We worked out numerical simulations using ZEUS-3D as a hydro-code and the stellar evolutionary models as the inner boundary conditions. We set up the time-dependent wind parameters using the models of Vassiliadis & Wood (1993) during the AGB and Vassiliadis & Wood (1994) for the post-AGB stages. During the transition time we adopted a linear interpolation between the wind values at the end of the AGB and wind values at the beginning of the post-AGB. In fig.1. we show the observed Hα emission brightness profile of the PN NGC 6826 and the computed ones at different evolutionary times.

![Figure 1.](image)

Figure 1. On the left Hα observed brightness profiles across the central part of NGC 6826, the central part is also shown but scaled accordingly. On the right computed Hα brightness profiles at different evolutionary times. Time zero is defined as the time where 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 on 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 Mendez, 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

The time spent by the star as it evolves during the AGB has been neglected in previous works related to the study of the interaction process (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, where reflecting boundary conditions have been used. An outflow boundary condition has been set at the outer radial direction.
Figure 2. The figure shows the log of 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 $n_0=0.1$ cm$^{-3}$. 
Interaction with the ISM (Figure 2) has been studied assuming that the star is moving supersonically with 20 km s\(^{-1}\) across an homogeneous external medium with density 0.1 cm\(^{-3}\). Isothermal sound speed of the unperturbed ISM is \(c = 3\) km s\(^{-1}\), which gives us a Mach number of 7. The movement takes place 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. The interaction between the wind expelled by the star and the ISM takes place from the beginning of the evolution. A bow-shock configuration is quickly established (our Mach number, 7, is enough to form a strong shock). The compression across a strong isothermal shock depends on the upstream Mach number. To keep the gas isothermal, the internal energy has to be radiated away. This internal energy would otherwise have limited the compression. Mass-loss rate associated with the last thermal pulse interacts directly with the local unperturbed ISM, giving rise to a less dense shell than the one formed by a steady star.

2. Conclusions

As a consequence of the evolution of a 1M\(_\odot\) from the models of Vassiladis & Wood (1993,1994) a Multiple Shell Planetary Nebulae is formed. 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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