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On the making of a PN: the interaction of a multiple stellar wind with the ISM

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Abstract. NGC 7293, the Helix nebula, represents one of the rare instances in which theoretical predictions of stellar evolution can be accurately tested against observations since the precise parallax distance and the velocity and proper motion of the star are well known. We present numerical simulations of the formation of the Helix PN that are fully constrained by the progenitor stellar mass, stellar evolution history, and star-interstellar medium (ISM) interaction. In the simulations, multiple bow-shock structures are formed by fragmentation of the shock front where the direct interaction of the stellar wind with the ISM takes place.

Keywords. hydrodynamics–ISM: planetary nebula: general; planetary nebula: individual (NGC 7293) – stars: AGB and post-AGB.

1. Introduction

NGC 7293 (a.k.a The Helix, PN G036.1 − 57.1) is one of the planetary nebula (PN) with a very good determination of its distance; 202 pc from Gaia DR3 (González-Santamaría et al. 2021). The central star has a mass of 0.60±0.02 $M_\odot$ so (Benedict et al. 2009) and a high temperature T_{eff} = 104 000 K (Guerrero & De Marco 2013) implying that the star+nebula system is in a rather evolved stage. The *Galaxy Evolution Explorer* (*GALEX*; Martin et al. 2005) wide field-of-view (26 arcminutes) revealed for the first time striking morphological features in the form of extended bow-shocks beyond the nebular halo (Bianchi et al. 2012).

2. Numerical simulations

The numerical simulations have been performed with the fluid solver ZEUS-3D (Stone, Mihalas, & Norman 1992), developed by M. L. Norman and the Laboratory for Computational Astrophysics. The computations have been carried out on a 2D spherical polar grid with the angular coordinate ranging from 0° to 180° and a physical radial extension of 3 pc. They have been run at a resolution of 1600 × 1440 zones in the radial and angular coordinates of the grid respectively (or equivalently ∼ 388 au × 0.125°).

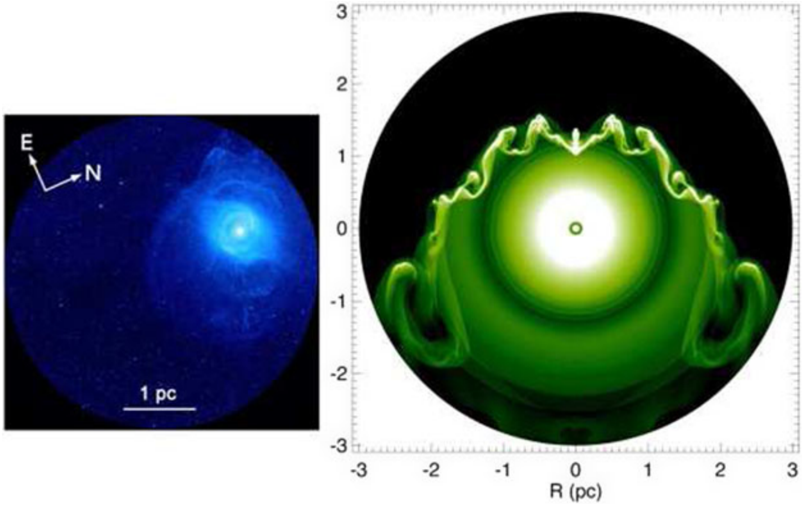

Figure 1. Left, *GALEX* FUV image of NGC 7293. At a distance of 202 pc, the FOV is 4.23 pc. Right, density map from our simulations, the snapshot corresponds to a ∼1 000 yr old PN. The morphology of the UV features is reproduced by the simulations; more important, the physical scale of the predicted structures matches the observations.

Our boundary conditions are the AGB stellar wind of a 1.5 $M_\odot$ star and a ISM density of $n_{\rm ISM}$= 0.06 cm^3, and a relative velocity respect to its ambient medium of 40 km s^{-1}. For the post-AGB stage and PN evolution we follow the stellar wind according to the prescription given in Villaver et al. (2002a) by using the post-AGB evolutionary sequence given by Vassiliadis & Wood (1994) for a hydrogen burner with solar metallicity for the assumed stellar mass.

3. RESULTS

In Fig.1, (right panel) we show the result of the numerical simulation after 819000 yr in the AGB, and 1000 yr, after the onset of the photoionization. In the left panel we show the *GALEX* FUV filter image, which at a distance of 202 pc has a FOV of 4.23 pc. It is remarkable that both figures show bow shock structures in the direction of the movement, and that the actual size in parsec is quite similar. We conclude that the morphology of the Helix can be explained by the evolution of a 1.5 $M_\odot$ star interacting with an ISM with a relative velocity of 40 km s^{-1}. apparent multiple bow-shocks.

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