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Modeling the mixed-morphology supernova remnant VRO 42.05.01

S. Ustamujic[1], S. Orlando[1], M. Miceli[2,1], F. Bocchino[1], and R. Giuffrida[2,1]

1 INAF-Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy
2 Dipartimento di Fisica e Chimica, Università di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy

Email: sabina.ustamujic@inaf.it

CONTEXT

VRO 42.05.01 is an evolved Galactic supernova remnant (SNR) that has been classified as a mixed-morphology SNR, showing a shell-like morphology in the radio band and centrally dominated X-ray emission. The remnant reveals a very intriguing morphology consisting of two major components, a 30' semi-circular shell and a larger triangular component. This peculiar morphology indicates that the remnant probably encountered a non-homogeneous ambient medium during its evolution.

AIMS

In this study we aim at investigating the origin of the complex morphology and X-ray emission observed in VRO 42.05.01, and determine the geometry and density distribution of the ambient medium.

METHODS

We developed a 3D hydrodynamic (HD) model for VRO 42.05.01, which describes the interaction of the SNR with the non-uniform environment, characterized by a low density cavity and interstellar clouds (following the scenario first proposed by Pineault et al. 1985, A&A, 151, 52; 1987, ApJ, 315, 580). The calculations were carried out with the PLUTO code (Mignone et al. 2007, ApJS, 170, 228).

We performed an ample exploration of the parameter space describing the initial blast wave and the environment, including the mass of the ejecta, the energy and position of the explosion, as well as the density, structure, and geometry of the surrounding ambient medium.

From the simulations, we synthesized the X-ray emission maps, including the deviations of equilibrium of ionization and the deviations of ion-electron temperature equilibration, and compared them with actual X-ray data collected by XMM-Newton.

RESULTS

Our model reproduces the morphology of VRO 42.05.01 and the centrally-peaked X-ray emission characteristic of mixed-morphology SNRs, considering the explosion occurred at the inhomogeneous environment described above.

The maps presented here correspond to the best fit case at t~36000 years. The star exploded in a uniform ambient medium with density ~7 cm^{-3}, and during the expansion encountered a cavity with density ~$7x10^{-2}$ cm^{-3} where expanded rapidly forming the triangular larger component. After the expansion the remnant interacted with a molecular cloud with density ~100 cm^{-3} where the forward shock is reflected heating the central ejecta.

The ejecta mass and energy considered In the model for the explosion are ~10 $M_{\odot}$ and ~10^{51} erg, respectively.

From the comparison of the X-ray emission maps shown on the right, we conclude that the proposed scenario is compatible with a remnant situated at a distance d > 3 kpc.

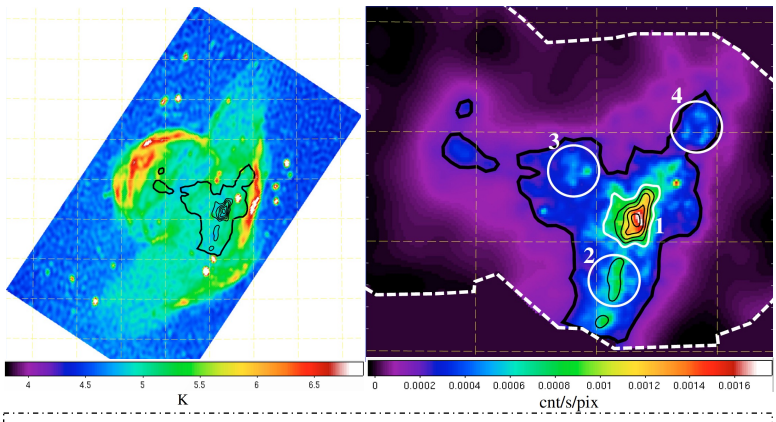

Figure 1: Adapted from Bocchino et al. 2009, A&A, 498, 139. **Left:** 1420 MHz CGPS DRAO radio image of VRO 42.05.01. X-ray contours from right panel are shown in black. **Right:** XMM-Newton EPIC images of VRO 42.05.01 in the 0.3–5 keV band background subtracted and vignetting corrected.

Proposed scenario. The environment is characterized by three differentiated zones: a uniform ambient medium were the star explodes, a low-density cavity where the supernova blast wave breaks out during the expansion, and a molecular cloud in the southwestern area interacting with the SNR after the expansion.

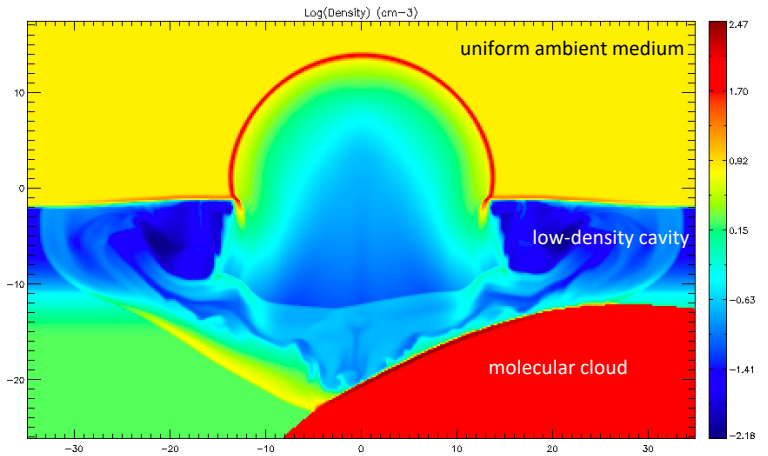

Figure 2: Density distribution in logarithmic scale in the (x; 0; z) plane at t ~ 36000 years. The three differentiated zones characterizing the environment are indicated.

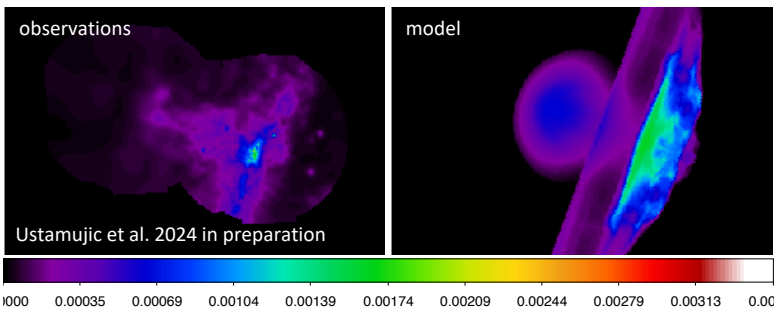

Figure 3: Comparison of X-ray count rate maps in the [0.3-5] keV band: observations (left); synthetic images derived from the model (right).