Runaway stars and high-latitude supernova remnants

The population of non-thermal supernova remnants

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Figure 1: *Bow shock of the runaway supernova progenitor ζ Ophiuchi.*

In Short

- Many stars move and finally die as supernova.
- What are the morphologies and emission properties of high-latitude supernova remnants generated by those runaway stars ?
- How do they affect/contribute to the total Galactic non-thermal energy budget ?
- How does stellar binarity and/or (extra)galactic environments influence such mechanism ?
- Can the pre-supernova motion of stars help to better understand current high-energy galactic surveys ?

Supernova remnants stand as pivotal sources of cosmic rays within our Galaxy, with these energetic particles propelled by the expanding shock of the advancing blast wave. A significant portion of the several hundred remnants of supernovae observed in the Milky Way 1 exhibit pronounced asymmetries. These irregularities stem from interactions between the supernova blast wave and either the intrinsic anisotropies of their ambient interstellar medium or the intricate structures of stellar winds blown by the progenitor star over its lifespan.

Most remnants are influenced by the latter scenario, either due to originating from massive stars ($\geq 8\,\mathrm{M}_\odot$) or being progeny of binary systems. Prior to their cataclysmic explosions, these stars emit powerful winds that sculpt their surroundings into dense circumstellar nebulae (Fig. 1), rendering the local medium of the supernova progenitor anisotropic. Consequently, supernova remnants serve as archives of their progenitor(s)' stellar evolutionary history. Understanding and deciphering their morphologies is thus of prime importance in unraveling the nature of their non-thermal emissions.

Notably, runaway stars naturally engender substantial bow shock structures, introducing significant deviations from sphericity in the expanding supernova blast waves. These locales serve as ideal environments for the formation of anisotropic remnants, exemplified by Kepler's supernova remnant, and for the generation of atypical quantities of non-thermal emissions, diverging markedly from the canonical values typically associated with such objects. The functioning of supernova remnants must therefore be understood in detail, first at the level of individual objects, whose morphologies and emission properties are modeled with fluid dynamics models to be compared to observations. Additionally, it must be understood at the level of simulated populations of emitting supernova remnants, to be confronted with real data acquired by Galactic ground-based surveys operating at high energies 7.

First, we will perform 2.5-dimensional magneto-hydrodynamical simulations with the PLUTO code 2 of supernova remnants in the spirit of the studies of 4 and 5 but tailored to runaway progenitors which traveled from the galactic plane to the high latitude of the Milky Way (left-hand panel of Fig. 2). We will understand the structure of these defunct stellar environments and address questions regarding the low-density medium, their morphology, and non-thermal emission properties. This opens a new research avenue to be extended to extragalactic environments such as those of the Small and Large Magellanic Clouds and to serve as substrates for understanding peculiar objects like G181.1+9.5 3 from the point of view of their shape and radiation.

Secondly, this project will simulate the population of supernova remnants in the high-energy domain to compare it with the currently observed population of

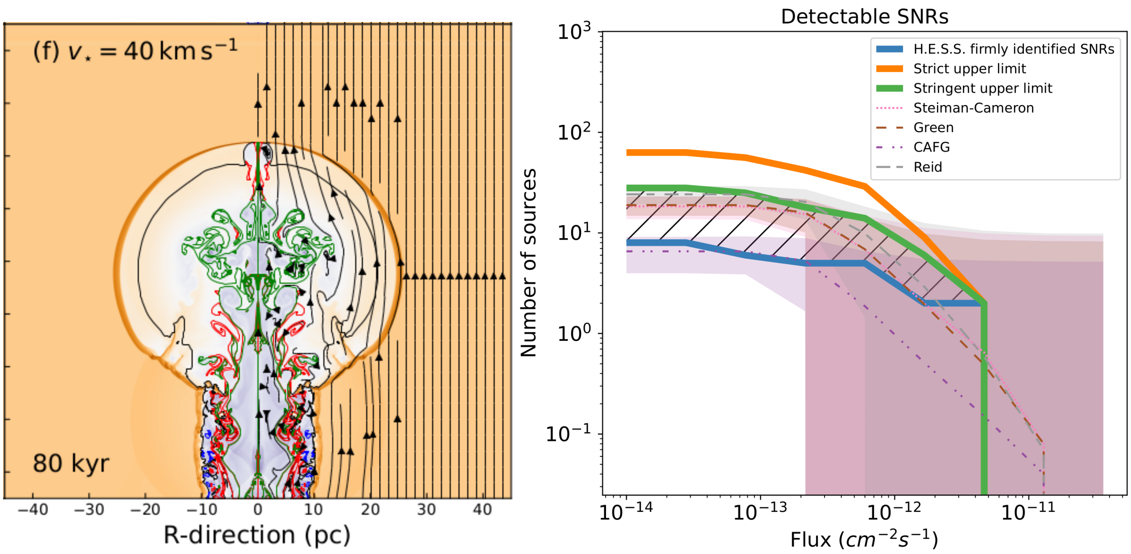

Figure 2: *Left: fluid dynamics model of the supernova remnant of a runaway star (Meyer et al. 2024). Right: predicted non-thermal energy spectrum of a synthetic population of galactic supernova remnants (Batzofin et al. 2024).*

TeV supernova remnants (right-hand panel of Fig. 2). In order to better constrain models with real data, we will consider the pre-supernova motion of the progenitor stars as a new degree of freedom in a Monte-Carlo model. Several properties intrinsic to the past stellar evolution of the sources will be explored, such as binarity. Eventually, we will perform population synthesis using the parameters from our fluid dynamics simulations to produce a consistent, detailed picture of high-energy supernova remnants' emission in the Milky Way.

This project is at the forefront of both fluid dynamics and population synthesis calculations and will provide a novel, original perspective on understanding the production of high-energy emissions in our galaxy and beyond.

WWW

https://www.uni-potsdam.de/en/astroparticle/experimental-astroparticle-physics

More Information

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Project Partners

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