Non-thermal supernova remnants of massive runaway stars

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In Short

- Supernova remnants from dead massive stars are a major source of cosmic rays in our Galaxy.
- A significant fraction of Galactic supernova remnants reveal strong asymmetries, mostly generated when the blastwave interacts with the asymmetric circumstellar medium of the defunct stars. The latter can be produced if the progenitor was a runaway stellar object, supersonically moving through the interstellar medium.
- The shape and (non-) thermal emission properties of supernova remnants therefore reflect the past stellar evolution history of their progenitors and/or their possible bulk motion through the interstellar medium.
- Using magneto-hydrodynamical (MHD) simulations, we will predict the properties and non-thermal emission signatures of asymmetric supernova remnants and compare them with observational data.

Massive stars are rare but crucial to understand the cycle of matter in the interstellar medium of the Milky Way, as they are the most important cosmic engines which drive the evolution of galaxies through the history of the Universe. Significantly influenced by their rotation, bulk motion or by the presence of a companion, their strong winds and ionising ultra-violet photons that heat gas, shape their surroundings while chemically augmenting their ambient medium. Throughout their live, the winds of massive stars undergo rapid changes provoking strong variations in the their close surroundings and this leads to a highly structured circumstellar medium. The final explosion of massive stars as supernova releases chemically-enriched ejecta and drives shocks inside their own organised circumstellar nebulae. Eventually, a pulsar wind can develop inside of the ejecta region of the remnants. Such events give birth to $\sim 100\,\mathrm{pc}$-large and efficient cosmic-ray-producer supernova remnants.

Although most massive stars form in group, a fraction of them (30%), classified as *runaway*, are ejected out of their parent cluster and they transform their circumstellar medium of from spherical stellar wind bubbles to arc-like bow shocks. As massive stars evolve through several distinct phases, the geometry of their circumstellar medium is therefore a direct function of their stellar winds and mass-loss history. The supernova blastwave produced at the stars' death initially expands inside the wind nebula and the shape of young supernova remnants consequently carry the imprints of the (an)isotropy of their ambient medium, as the distribution of circumstellar matter, largely influenced by the progenitor properties, affects the propagation of the supernova ejecta (Fig. 1). Particularly, the MHD bow shocks produced by runaway massive stars are an ideal site for the generation of local anisotropic interstellar density fields (Fig. 2).

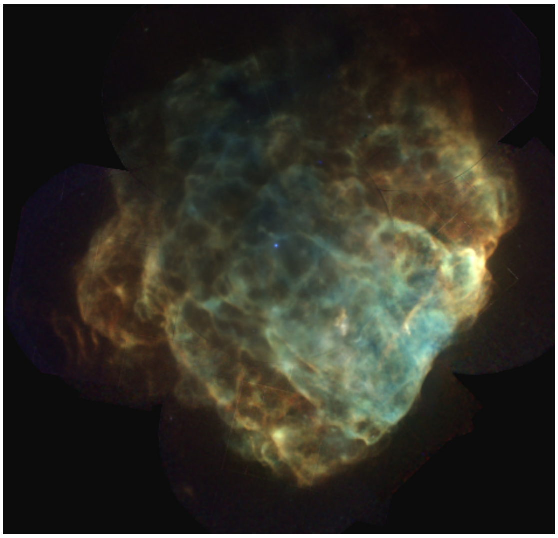

Figure 1: *The supernova remnant Puppis A (Dubner et al. 2013).*

After the supernova explosion of massive runaway star, the forward shock of the blast wave immediately interacts with the free-streaming stellar wind. About $10-100\,\mathrm{yr}$ after the explosion, the shock wave collides with the upstream stellar wind bow shock whereas it expands in the downstream cavity of wind material. After having hit the asymmetric wind bubble, the shock wave is partly reflected towards the centre of the explosion after the collision with a dense bow shock, inducing supernova remnants hosting strong mixing of supernova ejecta, stellar wind and ISM gas, respectively.

It is the long-term goal of this project to produce the first generatic non-thermal emission simulations of asymmetric supernova remnants generated by runwaway massive stars [5]. Making use of the MHD PLUTO code [1], it has been demonstrated than the magnetic fields of the interstellar medium greatly affects the formation of stellar wind nebulae around

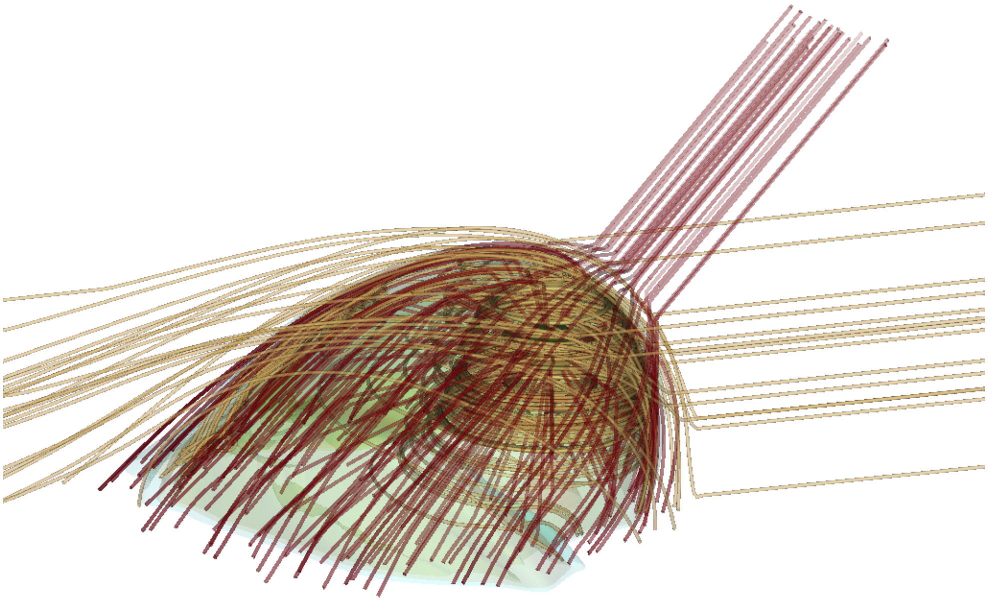

Figure 2: PLUTO *MHD simulation of the circumstellar bow shock around a dying runaway massive star [5].*

massive stars [3,6]. This project has shown that the bulk motion of the stellar progenitor can induce a lot of mixing of materials in the tail of the supernova remnant [2] and that the magnetic fields of the background medium can smooth the overall morphology of the supernova remnant [4]. Moreover, we have shown that the absence of stellar motion permit to generate rectangular supernova remnants such as Puppis A [6] and that the circumstellar medium of runaway massive stars can modify the appearance of pulsar wind nebulae eventually forming inside of asymmetric supernova remnants [7].

This project is currently devoted to the following questions:

- How the wind nebulae of evolved runaway massive stars can shape their subsequent supernova remnant and pulsar wind nebulae [2,3,5] ?
- What are the effects of the interstellar ambient medium on the morphology of supernova remnants and pulsar wind nebulae, for both static and runaway massive stars [5,6,7] ?
- What is the non-thermal feedback by cosmic-ray acceleration of those aspherical remnants [4,5] ?

Using magneto-hydrodynamical simulations [1] to self-consistently simulate the cosmic ray feedback of MHD supernova remnants from massive stars and synthetically generate their non-thermal emission properties (inverse Compton and radio synchrotron emission), this project will produce models to be compared with available high-energy observations.

WWW

https://www.app.physik.uni-potsdam.de/dmeyer/index.html

More Information

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Project Partners

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DFG Subject Area

311-01 Astrophysics and Astronomy