Understanding Particle Acceleration in the Remnants of Supernovae

Supernova remnants (SNRs) are the result of some of the most powerful explosions in the Universe, and they have great impact on their host galaxies, especially on their chemical enrichment and evolution. SNR shocks interact with the surrounding medium, heating and compressing it, as well as accelerating particles to cosmic ray (CR) energies. Hence, the study of SNRs allows for understanding a variety of issues of great importance in astrophysics, like the mass loss history of their progenitor stars, the nature of stellar collapse, and the mechanism behind the production of Galactic CRs. Additionally, since the compact remnants of supernovae (such as neutron stars) have extreme densities and magnetic fields, the study of these objects, and their interaction with their surroundings, provides great insight into the physics of ultra-dense matter, as well as the nature of particle winds generated in rapidly-rotating, highly-magnetized systems.

2013: Where are we now? Supernova remnant science has advanced in great strides in the last couple of decades, especially due to the launch of space telescopes which have allowed for a much clearer view of these objects across several different energy bands. *Spitzer*, *Herschel* and several other telescopes have allowed for a much clearer understanding of dust in supernova remnants, its production in the progenitor explosion and the interaction between SNR shocks and pre-existing dust in the circumstellar and interstellar medium. *Chandra*, *XMM-Newton*, and *Suzaku* have allowed for spatially resolved spectral studies of SNRs in the X-ray band, yielding great insight into how shocks heat the material with which they interact, the atomic physics of how plasmas emit, and into high energy non-thermal emission. Our understanding of particle acceleration in the shocks of SNRs and pulsar wind nebulae (PWNe) has become much more sophisticated due to analytic and semi-analytic approaches to the theory of diffusive shock acceleration, and also thanks to the wealth of observational data gathered in the X-rays, as well as in γ-rays with ground based Cerenkov telescopes and the NASA *Fermi* satellite.

2023: First Station The next decade will bring many new opportunities for SNR science. The recent launch of *NuStar* will allow us to study SNRs and PWNe in great detail in the hard X-ray band, and will likely result in advances in our understanding of particle acceleration since it samples energies where non-thermal emission will be dominant in these objects, as well as providing insight into the explosive nucleosynthesis processes in supernovae through observations of line emission from titanium (Ti^{44}) and hence help constrain our understanding of the explosion mechanism. The launch of *Astro-H*, as well as the Micro-X rocket payload, will also allow us to perform spatial studies with formerly unavailable spectral resolution in X-rays through their use of micro-calorimeters. High spectral resolution studies of SNRs will yield a wealth of information about the state of both shocked circumstellar material and ejecta, and how the shocks heat and compress these plasmas. It will also allow us to determine the proper motions of different elements and hence test our simulations of supernova explosions happen.

The success of the *Fermi* mission, which has opened the MeV-GeV window and hence allowed us to understand γ-ray emission from remnants, pulsars and their wind nebulae, must be used as motivation to start designing the next generation γ-ray space telescope.

2033: Second Station The 2023-2033 decade must bring advances in our theoretical understanding of SNRs and PWNe which match the quality of the data that we will have gathered. That SNRs and PWNe accelerate particles to CR energies is no longer in question, but there are many crucial issuess yet to be addressed. We still lack detailed knowledge about the efficiency of the process of particle acceleration at the shocks of these objects, the effect of CR production on the evolution of SNRs, the properties and amplification of magnetic fields in these systems, and the nature of CR escape and diffusion away from these systems.

2043: Third Station By 2043 we must have developed and launched space telescopes in X-rays and γ-rays which revolutionize the field. A telescope with the spatial resolution of *Chandra* and the spectral resolution of micro-calorimeters will allow us to answer many questions about the nature of the circumstellar material with which the SNR shock interacts and hence understand the late-phase activity of the progenitors of supernovae, the velocities of the different ions contributing line emission and hence how the different elements are distributed and ejected in the explosion, and the detailed thermal and ionization structure of the post-shock material. While the Fermi Large Area Telescope has helped us gain great insight into particle acceleration at the shocks of SNRs and PWNe, by 2043 we must have developed a γ-ray telescope in the MeV-GeV energy range with a spatial resolution smaller than a few arc minutes. The morphological characteristics of the γ-ray emitting regions in SNRs and PWNe are crucial for understanding how particles are accelerated in these objects and how they diffuse away from the acceleration sites. Hence, the nature of pulsars and their winds, as well as the acceleration and propagation of cosmic rays, can only be fully understood if such high spatial resolution γ-ray detector is developed and launched.