SNR G39.2–0.3, an hadronic cosmic rays accelerator
Summary

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Recent results obtained with gamma-ray satellites have established supernova remnants as accelerators of GeV hadronic cosmic rays. In such processes, CRs accelerated in SNR shocks interact with particles from gas clouds in their surrounding. In particular, the rich medium in which core-collapse SNRs explode provides a large target density to boost hadronic gamma-rays. SNR G39.2–0.3 is one of the brightest SNR in infrared wavelengths, and its broad multiwavelength coverage allows a detailed modelling of its radiation from radio to high energies. We reanalysed the *Fermi*-LAT data on this region and compare it with new radio observations from the MWISP survey. The modelling of the spectral energy distribution from radio to GeV energies strongly favours a hadronic origin. The combination of the radio and GeV data together with non-detection of non-thermal X-rays from the remnant clearly indicate that neither inverse Compton (due to a low amount of electrons) nor bremsstrahlung (due to the spectral shape) can be responsible for the observed GeV emission. On contrary, the hadronic scenario provides a relatively good fit to the data for a soft spectrum of protons with the spectral index of ~ 2.75. Such a soft spectrum above some break energy which reflects the current maximum energy of accelerated protons is expected for dynamically old SNRs due to the escape of CRs and decrease of the acceleration efficiency. The total energy stored in CRs reaches $\sim 10^{49}$ erg, which reflects a few percent efficiency of converting kinetic energy into CRs, similarly to what has been observed in other SNR interacting with dense gas in large molecular clouds.

The dense medium in which this SNR is evolving implies strong bremsstrahlung emission which in combination with observed GeV emission sets a lower limit on magnetic field of around $\sim 100\mu$G. Such a strong magnetic field is not typical for evolved SNRs but expected for remnants interacting with molecular clouds as the thick medium compresses the shock region, resulting in an amplification of the magnetic field. High magnetic field in principle favours the acceleration of protons to high energies. However, the dense matter also slows down the shock, preventing the acceleration to go beyond a few tens of GeV. Even considering this effect, the low break energy required in SNR G39.2–0.3 seems too low, when considering evolution models of SNRs and the featureless radio Synchrotron spectrum. We investigate further how to reproduce the observed spectral shape by considering several hypothesis. To explain the low-energy peak in the gamma-ray spectrum, the CR spectrum requires a very low break energy, i.e. current maximum energy of protons, of $E_{\rm b} \lesssim 3$ GeV and/or a softer than typical DSA spectrum of protons from the acceleration process, $s_1 \gtrsim 2.3$. Both requirements point to the old dynamical age of the remnant, which means that it is already at the late stages of its evolution. This is not surprising given the interaction with the molecular cloud which drastically increases the density of the ambient medium. However, both of these requirements are not trivial to fulfill even for a dynamically old SNR.

On the other hand, the core-collapse nature of the SNR implies that heavier composition of the surrounding medium may be reflected in the resulting cosmic-ray and gamma-ray spectra. Hadronic interactions involving heavy nuclei result in a peak of the gamma-ray emission at significantly lower energies then proton-proton interactions. We show that accounting for the heavy composition of the circumstellar medium which is translated into the heavy composition of accelerated particles may help to explain the observed gamma-ray spectrum without need for unusually soft spectrum or low break energy, but requiring that the progenitor was a Wolf-Rayet star rather than a red supergiant. This result implies that precise measurements of gamma-ray emission from evolved core-collapse SNRs might potentially probe the composition of the surrounding environment and even the nature of the progenitor star.

We also investigated a scenario in which pre-existing Galactic CRs are compressed within the radiative shell and emit gamma-rays through hadronic interactions. We found that an unrealistically large size of the shell is required to explain the observed gamma-ray emission, which imposes substantial difficulties of this model.