Contribution ID: **475** Type: **Contributed talk**

Particle escape from supernova remnant shocks: gamma-ray and cosmic-ray signatures

Thursday, 7 July 2022 16:00 (15 minutes)

In the context of the supernova remnant (SNR) paradigm for the origin of Galactic cosmic rays (CRs), the escape process of accelerated particles represents a fundamental piece of information to interpret both the observed CR spectrum and the gamma-ray spectral signatures emerging from these sources. Under the assumption that in the spatial region immediately outside of the remnant the diffusion coefficient is suppressed with respect to the average Galactic one, we found that a significant fraction of particles can still be located inside the SNR long time after their nominal release from the acceleration region. This fact results into a gamma-ray spectrum arising from hadronic collisions that resembles a broken power law, similar to those observed in several middle-aged SNRs. Above the break, the spectral steepening is determined by the diffusion coefficient outside of the SNR and by the time dependence of maximum energy. Consequently, the comparison between SNR data and model predictions will possibly allow to determine these two quantities. Additionally, by further assuming that protons and electrons are accelerated at SNR shocks with the same slope, CR spectral measurements on Earth can then be reproduced if electrons are injected with a spectrum steeper than protons for energies above ~ 10 GeV. A possible scenario that can in principle justify the observed steeper electron spectrum relies on the combination of energy losses, due to synchrotron radiation in an amplified magnetic field, and time dependent acceleration efficiency.

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Session Classification: Contributed Talks