RevMexAA (Serie de Conferencias), **49**, 66–66 (2017)

XV Latin American Regional IAU Meeting (Cartagena de Indias, Colombia, 3-7 October 2016)
Editors: Mario Armando Higuera Garzón & Santiago Vargas Domínguez

OBSERVATIONS OF SUPERNOVA REMNANTS AND MOLECULAR CLOUDS: BRIDGING LOW AND HIGH ENERGY COSMIC RAYS

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New evidence that galactic cosmic rays (GCR: here protons and nuclei) are accelerated by supernova remnant (SNR) shocks has come from recent works combining γ-ray observations in the sub-GeV to TeV domain, and in the submm-mm domain. The results show an enhanced CR flux in regions of massive star formation in which SNRs interact with molecular cloud complexes. Such regions are thus ideal laboratories to study *in situ* CR acceleration by SNR shocks, and diffusion processes in their vicinity.

The origin of cosmic rays remains a challenge to modern-day astrophysics. We know their spectrum and composition over a very wide range of energies and fluxes: resp. $E \lesssim 10^7$ eV to $\approx 10^{21}$ eV; $F \sim 10^4$ to $\approx 10^{-28}$ particles/(m^2 sr s GeV) (e.g., Swordy 2001). Two regimes are seen, above and below a cut-off between the relativistic regime ($E \gtrsim 1$ GeV/nucleon), where the spectrum is very close to a power-law with a negative slope: $N(E) \propto E^{-2.4}$, and the subrelativistic regime ($E < 1$ GeV/nucleon), which is also a power-law, but $N(E) \propto E^{+1}$. This cut-off corresponds to the passage of GCR travelling from the ISM into the heliosphere, in which the nucleons are "repelled" by the (magnetized) solar wind: this is the "solar modulation" (e.g., Potgieter 2013).

We are thus faced with two main problems. (i) The solar modulation completely dominates the transport of GCR across the interplanetary medium, but it is a very complex process. As a result, the GCR spectrum at low energies (below ≈ 1 GeV) is poorly known. (ii) At higher energies, how can nuclei be accelerated up to $\sim 10^{21}$ eV ? We have good reasons to think that SNRs are the best "GCR accelerators" up to $\sim 10^{16}$ eV, via the so-called "diffusive shock acceleration" (e.g., Kirk & Dendy 2001), but above this energy, CR are likely extragalactic.

Here we focus on two observational regimes, when CR interact with dense matter, more precisely when a SNR collides with molecular clouds in star-forming regions (e.g., review by Gabici & Montmerle 2015): (i) the relativistic regime, where the interaction generates γ-rays (via the $p + p \rightarrow \pi^0 \rightarrow \gamma$ reaction), observable with satellites (now *Fermi*, in the range ≈ 20 MeV – 100 GeV) and ground-based Čerenkov telescopes (like *HESS*: ≈ 50 GeV – 50 TeV; *CTA* in the future). A number of γ-ray sources are known to be associated with SNR of this class, indicating *in situ* enhancements of the high-energy CR by $\sim \times$ 10-100, as already noticed by Montmerle (1979);
(ii) the nonrelativistic regime, where low-energy nuclei *ionize* the dense gas, creating radicals from the ambient molecules (e.g., HCO^+ and DCO^+), which can be observed with ground-based submm-mm telescopes like the *IRAM* 30-m telescope.

Case studies have been the W51 and W28 SNRs, known to be interacting with molecular clouds while being γ-ray sources (resp. Abdo et al. 2009, Aharonian et al. 2008). Ceccarelli et al. (2011), and Vaupré et al. (2014) have found a large ionization enhancement (≈ 100) in the vicinity of the SNR shock. For W28, there is a steep gradient towards the average galactic value over a few pc, so that a *diffusion coefficient* can be measured for the low-energy CR, roughly consistent with theoretical expectations.

A similar study is underway for the W44 SNR. Preliminary results also indicate an enhanced ionization near the SNR shock (Vaupré, S., et al. 2016).

While more γ-ray sources of the same class remain to be investigated, these results indicate for the first time that in an "acceleration region" like the vicinity of an SNR shock, the fluxes of low-energy and high-energy cosmic rays remain proportional, at least to first order. This provides new clues to understand the acceleration and diffusion of cosmic rays.

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