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The search for Galactic pevatrons

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The search and identification of pevatrons - astrophysical sites capable of accelerating particles up to 10^{15} eV - is a key science project of all gamma-ray and neutrino observatories optimized in the multi–TeV range. It could help identify the sources of Galactic cosmic rays (GCRs) and lead us to better understand mechanisms capable of accelerating particles to the highest energies. The recent years have shown us that the supernova remnant (SNR) paradigm, in which SNRs accelerate the bulk of GCRs, is facing difficulties and that the interpretation of the observations of the new–generation instruments remain tricky.

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1. The origin of Galactic cosmic rays

The search for Galactic sources capable of accelerating particles up to the PeV (10^{15}) range is crucial in the context of the origin of Galactic cosmic rays (GCRs). Indeed, the *knee* of the proton spectrum (90 % of GCRs are protons), where the slope of local spectrum steepens from $\sim E^{-2.7}$ to $\sim E^{-3}$ has been measured to be somewhere around 1 PeV: from $\sim$ 700 TeV [2] to $\sim 3-4$ PeV [1]. Up to the knee, the GCR protons arriving at the Earth are clearly expected to be of Galactic origin, and therefore, the sources of GCR are expected to be pevatrons for at least a period of their evolution. For long, supernova remnants (SNRs) have been seen as the most probable sources of GCRs [3]. Indeed, they can, in theory, for instance, easily sustain the measured power of GCRs, somewhat account for the measured slope $\sim E^{2.7}$ as a combined result of diffusive shock acceleration and the propagation in the Galaxy. However, the SNR hypothesis is facing several difficulties [7], one of them is that all studied SNRs seem not to be pevatrons. It could be that only a very small fraction of SNRs are, in fact, pevatrons for a short time of their evolution [6], that our understanding of particle acceleration at SNRs is very incomplete [15, 16], or that other astrophysical sites, such as massive stars [4, 5, 10], superbubbles [11, 12], or else, are playing a dominant role in the origin of GCRs.

2. Gamma rays

PeV protons interacting with protons of the ISM are typically producing gamma rays in the $\sim$ 100 TeV range through the production and decay of π^0. This is why the search, identification, and characterization of pevatrons is a natural goal for gamma-ray observatories optimized in the 100 TeV range, where it has often been claimed in the past that the detection of $\sim$ 100 TeV gamma rays would almost be a direct indication of the presence of PeV protons.

The current generation of Imaging Atmospheric Cherenkov Telescopes (IACTs) such as H.E.S.S., VERITAS, or MAGIC, are typically optimized in the $\sim$ TeV range. This means that in the past decade(s), the study of pevatrons through gamma rays was somewhat limited. Moreover, in the $1-10$ TeV range, the gamma rays can often be interpreted as the results of another mechanism: the inverse Compton scattering of accelerated electrons on soft photons. Thus, it is often arduous to ascribe gamma rays to high-energy protons or high-energy electrons. Let us mention that the detection of hard spectra up to several tens of TeV from the Galactic center region around Sgr A* [17], or other non-clearly identified sources, such as J1702-420 [13] was still sufficient for the IACTs to claim the detection of pevatrons.

In 2021, the new generation observatory LHAASO reported on detecting 12 Galactic pevatrons. The current angular resolution is not sufficient to identify the origin of PeV particles, and the spectral resolution also leaves room for interpretation. It especially demonstrated that several of these pevatrons could be electron-pevatrons or proton-pevatrons, thus indicating that even in the 100 TeV range or above, the detection of gamma-rays would, in fact, not directly testify of the presence of accelerated protons, and is a delicate issue [8, 9]. Detecting neutrinos from Galactic sources would help the hunt for pevatrons, as they directly indicate the presence of very high-energy hadrons.

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