5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1 Oct, 2021, Remote e-conference

The origin of galactic cosmic rays

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The origin of cosmic rays (CRs) is a key problem in particle astrophysics. Since the discovery of CRs in early 1900s, many particle acceleration mechanisms and astrophysical sources have been proposed for their origin. It is generally accepted that CRs with energies below the spectral knee of about 1 PeV are mostly accelerated by sources in the Milky Way galaxy while those with energies above the spectral ankle of about 1 EeV have an extragalactic origin. High-energy and very high-energy gamma-ray observations of the past two decades have advanced our understanding of galactic CR sources significantly. In general, these observations are consistent with the scenario that supernova remnants (SNRs) dominate the fluxes of galactic CRs (Figure 1). Moreover, there appears to be two populations of SNRs with distinct GeV spectra (Figure 2). GeV CRs are likely accelerated by shocks of SNRs evolving in a dense environment with soft GeV spectra while TeV CRs are mostly accelerated by fast shocks propagating in a low-density medium with hard GeV spectra. [1] However, there is evidence that shocks of SNRs are not efficient PeV CR accelerators (PeVtrons). [2]

The ultra-high-energy (>100TeV) gamma-ray astronomy is a new astronomy branch that is being opened by air shower detections. In particular, the kilometer square array (KM2A) of the Large High Altitude Air Shower Observatory (LHAASO) has detected several photons above 1 PeV. Early results suggest that most ultra-high-energy gamma-ray sources are associated with Pulsar Wind Nebulae (PWNs). [3] The center of the Milky Way galaxy and star clusters are also promising PeVatrons. In combination with high-energy neutrino and multiwavelength observations, the origin of PeV cosmic rays and their acceleration mechanisms will be addressed in the coming few years.

This work is supported by National Key R&D Program of China: 2018YFA0404203, a startup grant from the Southwest Jiaotong University for S.M. Liu, NSFC grants: U1738122, U1931204, 11761131007, 11573070, U2031111, the Natural Science Foundation for Young Scholars of Jiangsu Province, China (No. BK20191109), and by the International Partnership Program of Chinese Academy of Sciences, grant No. 114332KYSB20170008.

References

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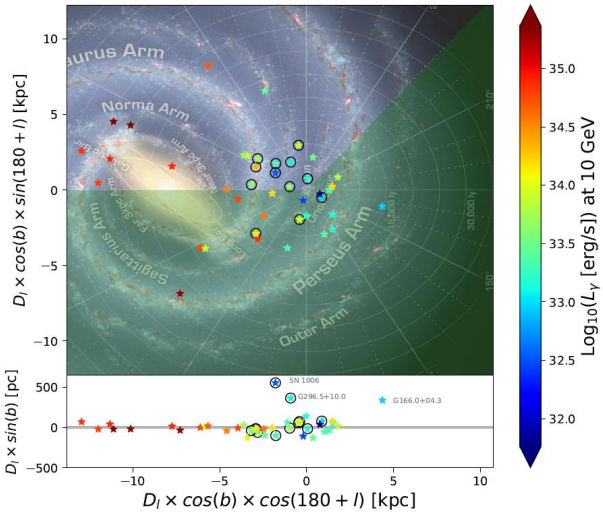

Figure 1: Location and 10 GeV luminosity of a sample of gamma-ray SNRs. Sources with hard GeV spectra are indicated with an extra black circle. The green color indicates the sky covered by the millimeter telescope in Delingha, Qinghai.

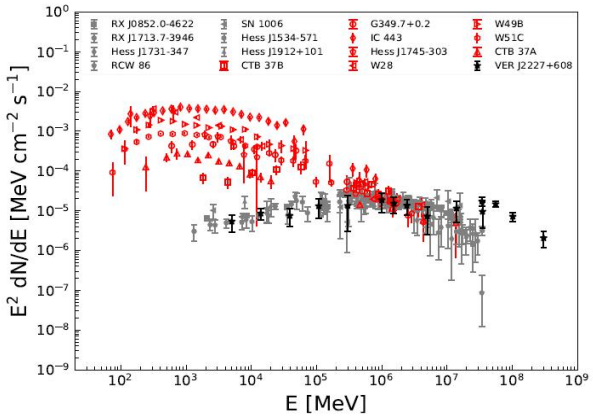

Figure 2: Gamma-ray spectra of a sample of SNRs evolving in a low (gray) or a high (red) density environment. The black data points are for VER J2227+608, which is likely powered by a PWN.