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Tracing Cosmic Ray Origins: From the First Fermi-LAT SNR Catalog to SuperTIGER

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Despite tantalizing evidence that supernova remnants (SNRs) are the source of Galactic cosmic rays (CRs), including the detection of a spectral signature of hadronic gamma-ray emission from two SNRs, their origin in aggregate remains elusive. Interactions between CRs and ambient gas emit photons via pion decay at GeV energies, providing an in situ tracer for CRs otherwise measured directly with balloon-borne and satellite experiments near the Earth. We address the long-standing question of Galactic CR nuclei origins using a statistically significant GeV SNR sample derived from Fermi-LAT data to estimate the contribution of SNRs to directly observed CRs. To do so, we have performed the first systematic survey of SNRs at energies from 1 to 100 GeV, including developing a method for estimating systematic errors arising from the diffuse, interstellar emission model, a key ingredient of all Galactic Fermi-LAT analyses. From the 279 known radio SNRs, we found more than 100 GeV candidates, 31 of which show significant overlap with the radio, making them likely counterparts, and 14 of which are marginally associated. These candidates span a wide range of multiwavelength properties, providing a critical context for complementary, in depth individual studies. Modeling this multiwavelength data demonstrates the need for improvements to previously sufficient, simple models describing the GeV and radio emission from hadronic and leptonic particle populations in these objects. Together with the >240 upper limits on GeV emission at the radio position and extension, our results enable us to indirectly constrain SNRs' aggregate ability to accelerate cosmic rays.

Additional evidence for revisions to current CR origin models comes from the balloon-borne TIGER and the recent, record-breaking SuperTIGER missions, which directly measure ultraheavy CRs, beyond iron. These results include a distinctive separation when including a mix of massive star material (˜20%) with nominal interstellar material, of refractory nuclei from volatile nuclei, suggesting a CR origin paradigm more closely tied to massive stars in OB associations. Further, the apparent preferential acceleration of refractory, dust-bound elements relative to volatiles has important implications for understanding the acceleration mechanism, including likely sputtering from dust grains formed in the winds of massive stars and SNRs, of highly energetic CR nuclei. Bringing together these direct and indirect results will lead us to a significantly deeper understanding of CRs' origins and acceleration mechanisms.

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