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Observational constraints on the maximum energies of accelerated particles in supernova remnants

Supernova remnants (SNRs) are thought to be the most plausible sources of Galactic cosmic rays. One of the principal questions is whether they are accelerating particles up to the maximum energy of Galactic cosmic rays (~PeV). In this work, a systematic study of gamma-ray-emitting SNRs is conducted. Our purpose is to measure the evolution of maximum particle energies with the current best statistics and age estimates. We model their gamma-ray spectra to constrain the particle-acceleration parameters. Two candidates of the maximum energy of freshly accelerated particles, the gamma-ray cutoff and break energies, are found to be well below PeV. We also test a spectral model that includes both the freshly accelerated and escaping particles to estimate the maximum energies more reliably, but no tighter constraints are obtained with current statistics. The average time dependences of the cutoff energy ($\propto t^{-0.81\pm0.24}$) and break energy ($\propto t^{-0.77\pm0.23}$) cannot be explained with the simplest acceleration condition (Bohm limit) and require shock–ISM (interstellar medium) interaction. The average maximum energy during lifetime is found to be < 20 TeV $(t_M/1\ \mathrm{kyr})^{-0.8}$ with t_M being the age at the maximum, which reaches ~PeV if $t_M < 10$ yr. The maximum energies during lifetime are suggested to have a variety of 1.1–1.8 dex from object to object. Although we cannot isolate the cause of this variety, this work provides an important clue to understanding the microphysics of particle acceleration in SNRs.

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