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Limitations of the Diffusion Approximation for GCR Transport

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Modern experiments provide a wealth of new data and reveal many new, still unexplained phenomena. To explain them, one needs a deep understanding of Galactic cosmic ray (GCR) transport, which is usually assumed to be diffusive. Many studies construct predictive models within different variants of this approach and achieve valuable results in explaining observed GCR spectra. However, the validity of this approximation has not been rigorously proven.

In this work, we study the microscopic transport of ultra-relativistic particles. Test-particle simulations are performed for different configurations of a model magnetic field. From the obtained trajectories, we extract the statistical properties of charged-particle reflections from magnetic field inhomogeneities. A data collapse of the joint distribution of reflection parameters is obtained using a self-similarity ansatz. The marginal path-length distribution exhibits intermediate power-law asymptotic behavior with an exponential cutoff. A strong correlation between particle displacements and path length also emerges. These results indicate that the diffusion approximation is applicable only at scales larger than the exponential cutoff, whereas at smaller scales the transport exhibits strong signatures of anomalous behavior.

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