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Cosmic ray propagation in the ISM: the importance of mirroring diffusion to produce ultra high energy gamma rays in the Galaxy

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Cosmic rays (CRs) interact with turbulent magnetic fields in the interstellar medium (ISM), generating non-thermal emission. After many decades of studies, the theoretical understanding of their diffusion in the ISM continues to pose a challenge. This study numerically explores a recent prediction termed "mirror diffusion" and its synergy with traditional diffusion mechanism based on scattering. Our study combines 3D MHD simulations of star-forming regions with test particle simulations to analyze CR diffusion. We demonstrate the significance of mirror diffusion in CR diffusion parallel to the magnetic field, when the mirroring condition is satisfied. Our results support the theoretical expectation that the resulting particle propagation arising from mirror diffusion inhibits the much faster diffusion induced by scattering. Our study highlights the necessity to reevaluate the diffusion coefficients traditionally adopted in the ISM based on scattering alone. For instance, our simulations imply a diffusion coefficient $\sim 10^{27} cm^2/s$ for particles with a few hundred TeV within regions spanning a few parsecs around the source, which is 10 to 100 times smaller than standard predictions. This estimate is in agreement with recent ultra high gamma-ray observations, showing the relevance of our results for understanding of diffuse gamma-ray emission in star-forming regions and extended gamma-ray halos.
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