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Spatial dependence of the break in the energy spectrum of cosmic rays in the new anisotropic diffusion approach

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The observed spectrum of cosmic rays (CRs) measured on Earth exhibits a break around 4 PeV, known as the “knee” of cosmic rays. Recently, a significant number of studies, based on the joint analysis of experimental data obtained from experiments such as LHAASO and Fermi-LAT on ultra-high-energy gamma rays, have indicated a potential spatial dependence of this feature. It has been shown that the “universal knee,” which emerges within the framework of an isotropic diffusion approach, is inconsistent with gamma-ray observations.

We present a new diffusion model of cosmic ray propagation that accounts for the anisotropy of their transport. This model is based on the calculation of the diffusion tensor components within a realistically simulated large-scale magnetic field of the Milky Way. The model parameters are consistent with contemporary understanding of the structure of the large-scale Galactic magnetic field, the dynamics of small-scale turbulent CR propagation, as well as the distribution of sources and interstellar matter. We demonstrate that transitioning to an anisotropic description of CR propagation naturally explains the spatial dependence of the spectral break, and our calculated gamma-ray fluxes from the Galactic disk in the angular ranges $15° < l < 125°$, $|b| < 5°$ (inner Galaxy) and $125° < l < 235°$, $|b| < 5°$ (outer Galaxy) are in good agreement with Fermi-LAT and LHAASO data.

In this study, the authors achieved the following: the modulation of Galactic cosmic ray (GCR) spectra in the magnetic rigidity range of 1–30 PV (the CR knee) for protons, as well as for groups of light, intermediate, and heavy nuclei was demonstrated. The spatial variations of this phenomenon were investigated. The observed spectral modulation is explained by changes in the escape mechanism, while the possible spatial dependence of the CR knee is attributed to propagation effects.

Collaboration(s)

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