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Production and attenuation of cosmic-ray boosted dark matter

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Light sub-GeV halo dark matter (DM) particles up-scattered by high-energy cosmic-rays (CRs) (referred to as CRDM) can be energetic and become detectable by conventional DM direct detection experiments. We perform a refined analysis on the exclusion bounds of the spin-independent DM-nucleon scattering cross section $\sigma_{\chi p}$ in this approach. For the exclusion lower bounds, we determine the parameter of the effective distance $D_{\rm eff}$ for CRDM production using spatial-dependent CR fluxes and including the contributions from the major heavy CR nuclear species. We obtain $D_{\rm eff} \approx 9$ kpc for CRDM particles with kinetic energy above $\sim$ 1 GeV, which pushes the corresponding exclusion lower bounds down to $\sigma_{\chi p} \sim 4\times10^{-32}$ cm^2 for DM particle mass at MeV scale and below. For the exclusion upper bounds from Earth attenuation, previous estimations neglecting the nuclear form factor leaded to typical exclusion upper bounds of $\sigma_{\chi p} \sim \mathcal{O}(10^{-28})$ cm^2 from the XENON1T data. Using both the analytic and numerical approaches, we show that for CRDM particles, the presence of the nuclear form factor strongly suppresses the effect of Earth attenuation. Consequently, the cross section that can be excluded by the XENON1T data can be a few orders of magnitude higher, which closes the gap in the cross sections excluded by the XENON1T experiment and that by the astrophysical measurements such that for the cosmic microwave background (CMB), galactic gas cloud cooling, and structure formation, etc.

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