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Limits to gauge coupling in the dark sector set by the non-observation of instanton-induced decay of Super-Heavy Dark Matter in the Pierre Auger Observatory data

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We present a thorough search for signatures that would be suggestive of super-heavy X particles decaying in the Galactic halo in the data of the Pierre Auger Observatory. From the lack of signal, we derive upper limits for different energy thresholds above $\sim 10^8$ GeV on the expected secondary by-product fluxes from X-particle decay. Assuming that the energy density of these super-heavy particles matches that of dark matter observed today, we translate the upper bounds on the particle fluxes into tight constraints on the couplings governing the decay process as a function of the particle mass. We show that instanton-induced decay processes allow us to derive a bound on the reduced coupling constant of gauge interactions in the dark sector: $\alpha_X \approx 0.09$, for $10^{10} < M_X/\mathrm{GeV} < 10^{16}$. We show that this upper limit on α_X is complementary to the non-observation of tensor modes in the cosmic microwave background in the context of Planckian-interacting massive particles for dark matter produced during the reheating epoch. Viable regions for this scenario to explain dark matter are delineated in several planes of the multidimensional phase space that involves, in addition to M_X and α_X, the Hubble rate at the end of inflation, the reheating efficiency, and the non-minimal coupling of the Higgs with curvature.

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