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Minimal decaying dark matter: from cosmological tensions to neutrino signatures

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The invisible decay of cold dark matter into a slightly lighter dark sector particle on cosmological time-scales has been proposed as a solution to the S_8 tension. In this work we discuss the possible embedding of this scenario within a particle physics framework, and we investigate its phenomenology. We identify a minimal dark matter decay setup that addresses the S_8 tension, while avoiding the stringent constraints from indirect dark matter searches. In our scenario, the dark sector contains two singlet fermions $N_{1,2}$, quasi-degenerate in mass, and carrying lepton number so that the heaviest state (N_2) decays into the lightest (N_1) and two neutrinos via a higher-dimensional operator $N_2 \to \bar{N}_1 \nu\nu$. The conservation of lepton number, and the small phase-space available for the decay, forbids the decay channels into hadrons and strongly suppresses the decays into photons or charged leptons. We derive complementary constraints on the model parameters from neutrino detectors, freeze-in dark matter production via $\nu\nu \to N_1 N_2$, collider experiments and blazar observations, and we show that the upcoming JUNO neutrino observatory could detect signals of dark matter decay for model parameters addressing the S_8 tension if the dark matter mass is below $\simeq$ 1GeV.

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