

Reconciling Cosmological Tensions with Inelastic Dark Matter and Dark Radiation in a $U(1)_D$ Framework

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We propose a novel and comprehensive particle physics framework that addresses multiple cosmological tensions observed in recent measurements of the Hubble parameter, S_8 , and Lyman- α forest data. Our model, termed ‘{SIDR+z_t}’ (Self Interacting Dark Radiation with transition redshift), is based on an inelastic dark matter (IDM) scenario coupled with dark radiation, governed by a $U(1)_D$ gauge symmetry. This framework naturally incorporates cold dark matter (DM), strongly interacting dark radiation (SIDR), and the interactions between these components. The fluid-like behavior of the dark radiation component which originates from the self-quartic coupling of the $U(1)_D$ breaking scalar can suppress the free-streaming effects. Simultaneously, the interacting DM-DR system can attenuate the matter power spectrum at small scales. The inelastic nature of DM provides a distinct temperature dependence for the DM-DR interaction rate determined by the mass-splitting between the inelastic dark fermions which is crucial for resolving the Ly- α discrepancies. We present a cosmologically consistent analysis of the model by solving the relevant Boltzmann equations to obtain the energy density and number density evolution of different species of the model. The DR undergoes two steps of increased energy density when the heavier dark species freeze out and become non-relativistic, transferring their entropy to the dark radiation and enhancing ΔN_{eff} . The analysis showcases the model’s potential to uphold the Big Bang Nucleosynthesis (BBN) prediction of ΔN_{eff} but dominantly producing additional contributions prior to recombination, while simultaneously achieving correct relic density of DM through an hybrid of freeze-in and non-thermal production.

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