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Early kinetic decoupling effect on the forbidden dark matter annihilations into standard model particles

The early kinetic decoupling (eKD) effect is an inevitable ingredient in calculating the relic density of dark matter (DM) for various well-motivated scenarios. It appears naturally in forbidden dark matter annihilation, the main focus of this work, which contains fermionic DM and a light singlet scalar that connects the DM and standard model (SM) leptons. The strong suppression of the scattering between DM and SM particles happens quite early in the DM depletion history, where the DM temperature drops away from the thermal equilibrium, $T_\chi < T_{\rm SM}$, leading to the decreased kinetic energy of DM. The forbidden annihilation thus becomes inefficient since small kinetic energy cannot help exceed the annihilation threshold, naturally leading to a larger abundance. To show the eKD discrepancy, we numerically solve the coupled Boltzmann equations that govern the evolution of DM number density and temperature. It is found that eKD significantly affects the DM abundance, resulting in almost an order of magnitude higher than that by the traditional calculation. We also discuss the constraints from experimental searches on the model parameters, where the viable parameter space shrinks when considering the eKD effect.

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