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Investigating Dissipative Dark Matter Interactions in a Two-State Model

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Dark matter (DM) is an invisible form of matter, accounting for most of the Universe's mass, and has a critical role in cosmic structure formation. Despite its abundance, dark matter remains poorly understood within current fundamental physics. Its specific particle nature and interaction mechanisms remain unknown. We are researching a promising theory, dissipative dark matter (DDM), where energy is lost through inelastic collisions. In this model, dark matter particles scatter into excited states and release energy as a light force-carrier particle, carrying energy out of dark matter structures. This research investigates a two-state dark matter model, encompassing both elastic and inelastic interactions between ground-state and excited-state dark matter particles. We are focused on calculating the rate at which DDM interactions occur using a different method to solve the Schrödinger equation than previously employed, one that remains stable even in kinematically forbidden regions. These interactions may explain the gap between collisionless dark matter simulations and astronomical observations, particularly at small halo scales.

Our goal was to implement a reduced form of the Schrödinger equation different from a preexisting code, which was unstable in the kinematically forbidden regime. We wrote a Python function for the newer derivation of the Schrödinger equation and solved it as an initial value problem using Python's built-in solvers. From this solution, we calculated the inelastic and elastic cross sections. We adapted the previously derived cross-section formula to work with this new method, deriving the required modifications by hand and incorporating them directly into my code. Finally, to make the cross-section velocity-dependent, we implemented published formulae between particle velocity and the Schrödinger equation's input parameters, complete with all necessary unit conversions, and ran the solver across a range of velocities and masses.

The code ran successfully and produced results that agreed with the previous implementation and the Born approximation, where the Born approximation is an analytical approximation to the Schrödinger equation. Importantly, the code remained stable and produced valid outputs in the kinematically forbidden region, where the previous implementation broke down.

In this talk, we will discuss the background motivation behind this research and the code we developed using a Python-based solver for the coupled Schrödinger equations that reliably computes elastic and inelastic cross sections across a broad range of velocities and masses of DM particles. These DDM interaction rates will allow us to run simulations to explore DDM's impact on halo structure and early compact-object formation.

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