

Evolutionary dynamics of rotating Bose-Einstein condensate dark matter halos

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Abstract

The standard Cold Dark Matter (CDM) paradigm provides a successful description of the large-scale structure of the Universe, but encounters persistent discrepancies at galactic and sub-galactic scales, including the cusp-core, missing satellite, and too-big-to-fail problems. In this study, we investigate the dynamical evolution of rotating Bose-Einstein condensate dark matter (BEC DM) halos in an expanding background using a quantum-damped hydrodynamic framework. Small perturbations are introduced around an equilibrium DM halo configuration to examine the spatiotemporal evolution of enclosed-mass fluctuations and their dependence on the halo size, background density, effective quantum temperature, and quantum friction coefficient. In the Thomas-Fermi (TF) limit, corresponding to strongly repulsively self-interacting DM, the fluctuations exhibit stable, predominantly non-oscillatory relaxation toward equilibrium. In contrast, the non-interacting (NI) DM supports persistent damped oscillations, with the stability and relaxation timescale strongly dependent on the characteristic halo scale and effective quantum temperature. In the NI regime, pronounced non-oscillatory stability is obtained only when the DM system is sufficiently close to the pure BEC ground state. Quantum friction emerges as a crucial dissipative mechanism, producing slower equilibration in the TF regime while enhancing structural relaxation in the NI regime. The effective sub-horizon regimes considered in the TF and NI limits provide diverse stabilization mechanisms for galactic structures, highlighting potential of quantum DM framework as an alternative to the conventional Navarro-Frenk-White collisionless CDM halo models.