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Two-Scalar Bose-Einstein Condensates: From Stars to Galaxies

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We study the properties of Bose-Einstein Condensate (BEC) systems consisting of two scalars, focusing on both the case where the BEC is stellar scale as well as the case when it is galactic scale. After studying the stability of such systems and making contact with existing single scalar limits, we undertake a numerical study of the two interacting scalars using Einstein-Klein-Gordon (EKG) equations, including both non-gravitational self-interactions and interactions between the species. We show that the presence of extra scalars and possible interactions between them can leave unique imprints on the BEC system mass profile, especially when the system transitions from being dominated by one scalar to being dominated by the other. At stellar scales (nonlinear regime,) we observe that a repulsive interaction between the two scalars of the type $+\phi_1^2\phi_2^2$ can stabilize the BEC system and support it up to high compactness, a phenomenon only known to exist in the $+\phi^4$ system. We provide simple analytic understanding of this behavior and point out that it can lead to interesting gravitational wave signals at LIGO-Virgo. At galactic scales, on the other hand, we show that two-scalar BECs can address the scaling problem that arises when one uses ultralight dark matter mass profiles to fit observed galactic core mass profiles. In the end, we construct a particle model of two ultralight scalars with the repulsive $\phi_1^2\phi_2^2$ interaction using collective symmetry breaking. We develop a fast numerical code that utilizes the relaxation method to solve the EKG system, which can be easily generalized to multiple scalars.

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