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Advancing cosmological simulations of fuzzy dark matter with physics-informed neural networks (PINNs)

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Physics-Informed Neural Networks (PINNs) have emerged as a powerful tool for solving differential equations by integrating physical laws into the learning process. This work leverages PINNs to simulate gravitational collapse, a critical phenomenon in astrophysics and cosmology. We introduce the Schrödinger-Poisson informed neural network (SPINN) which solve nonlinear Schrödinger-Poisson (SP) equations to simulate the gravitational collapse of Fuzzy Dark Matter (FDM) in both 1D and 3D settings. Results demonstrate accurate predictions of key metrics such as mass conservation, density profiles, and structure suppression, validating against known analytical or numerical benchmarks.

We also explore the use of generative models for learning the mapping from cold dark matter (CDM) to FDM simulations. This work highlights the potential of PINNs for efficient, possibly scalable modeling of FDM and other astrophysical systems, overcoming the challenges faced by traditional numerical solvers due to the non-linearity of the involved equations and the necessity to resolve multi-scale phenomena especially resolving the fine wave features of FDM on cosmological scales.

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