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Large-Scale Condensation and Turbulent Vortex Tangles: Transferring Ideas from Quantum Gases to Cosmological Dark Matter

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Atomic Bose-Einstein condensates represent a controllable quantum many-body playground, in which the degree of coherence and non-equilibrium coupling between coherent (condensed) and incoherent (thermal) components can be tuned by various parameters – with typical experiments in inhomogeneous traps featuring a centrally-located condensate, surrounded by a thermal cloud, with the two sub-components dynamically coupled. In this work we demonstrate the rather-unexpected close qualitative analogy between such atomic condensates and the proposed underlying gravitationally-bound physical state of cosmological dark matter.

This is in the context of new models – gaining increasing recent attention in cosmological communities – which postulate the existence of an ultralight bosonic particle exhibiting galactic-size de Broglie wavelengths and thus facilitating a wave description, as an alternative to the established cold dark model (Λ-CDM) of incoherent particles 1: the underlying idea is that such "Fuzzy"Dark Matter model (based on cosmological condensation) not only accurately reproduces the successful Λ-CDM features of large-scale matter distribution in the Universe, but also resolves shorter (< galactic) scale features not correctly reproduced by Λ-CDM, by describing the galactic cores as "solitonic". Taking such a gravitationally-coupled Gross-Pitaevskii-type model onboard, we demonstrate the close qualitative analogy between such systems and those of harmonically-trapped atomic condensates 2.

Using standard tools in modelling finite-temperature non-equilibrium condensates 3, we firstly demonstrate the extremely high condensation fraction of such galactic-scale solitonic cores (supported by the balancing of gravitational attraction and quantum pressure) and demonstrate a spatial separation between such central inhomogeneous solitonic condensates and the surrounding incoherent particles, closely resembling the spatial separation seen in trapped atomic condensates. Moreover, we demonstrate that the environment surrounding such solitonic cores is in fact highly analogous to a quasi-condensate state, containing spatiotemporally-localised regions of enhanced coherence and a slowly-evolving quasi-equilibrium turbulent vortex tangle, with a characteristic k^{−3} tail in the incompressible kinetic energy spectrum. Building on such a successful spatial characterization, we further develop a kinetic model –along the lines of a spatially-separated self-consistently coupled condensate-thermal cloud description successfully used in modelling finite-temperature atomic condensates –which encompasses both conventional (Λ-CDM) and "fuzzy"dark matter models 4. Further studying small-amplitude fluctuations in the linearized limit of this model, large-scale periodic oscillations of the coherent solitonic part and the arising Bogoliubov-de Gennes modes, we demonstrate how one can place constraints on such cosmological models.

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1 H-Y Schive, T Chiueh, T Broadhurst, Nat. Phys., 10, 496 (2014).
2 I-K Liu, N P Proukakis, G Rigopoulos, Monthly Notices of the Royal Astronomical Society 521, 3625 (2023).
3 N.P. Proukakis, arXiv:2304.09541
4 N P Proukakis, G Rigopoulos and A Soto, arXiv:2303.02049

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