CORE OSCILLATIONS IN FUZZY DARK MATTER

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*Relevant talks: **I-Kang (Gary) Liu***
Coherent to incoherent structures in fuzzy dark matter halos
*[**IDM2022**]*



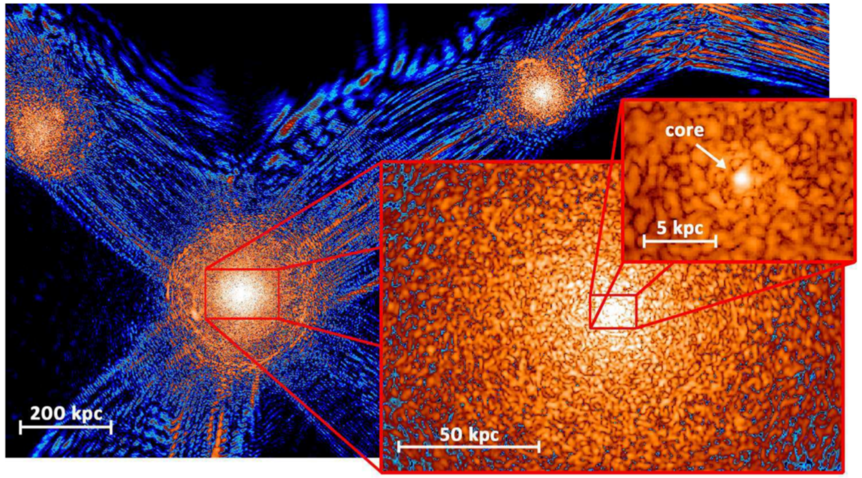

FUZZY DARK MATTER – A BACKGROUND

Ultralight boson

10^{-22} eV $\leq m \leq 10^{-20}$ eV $\longrightarrow$ $\lambda \sim$ kpc

Non-interacting case → Schrodinger—Poisson
With interactions → Gross-Pitaevskii—Poisson

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + V\psi + g|\psi|^2\psi \longrightarrow g = \frac{4\pi\hbar^2 a_s}{m}$$

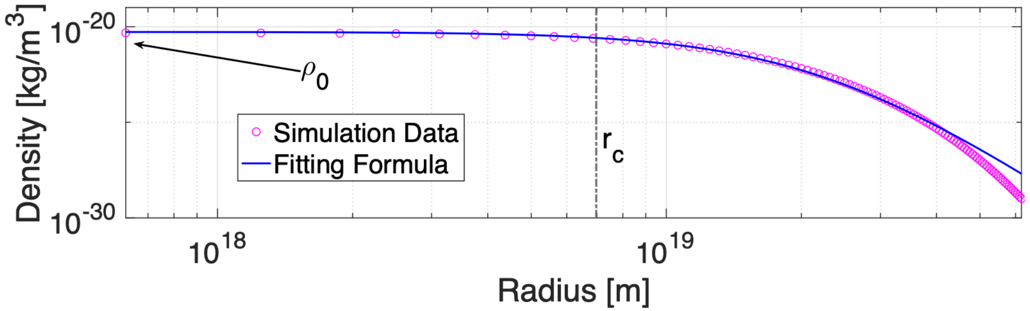


Schive H Y, Chiueh T and Broadhurst T
2014 Nature Physics **10** 496–9

Cores form at the centre of FDM halos, propped up by the quantum pressure (or self-interaction) - these are the ground state solution!

$$\boxed{\rho = \rho_0(1+\lambda(r/r_c)^2)^{-8}}$$

$$\boxed{\rho_0 \propto r_c^{-4} \text{ when } g = 0!}$$

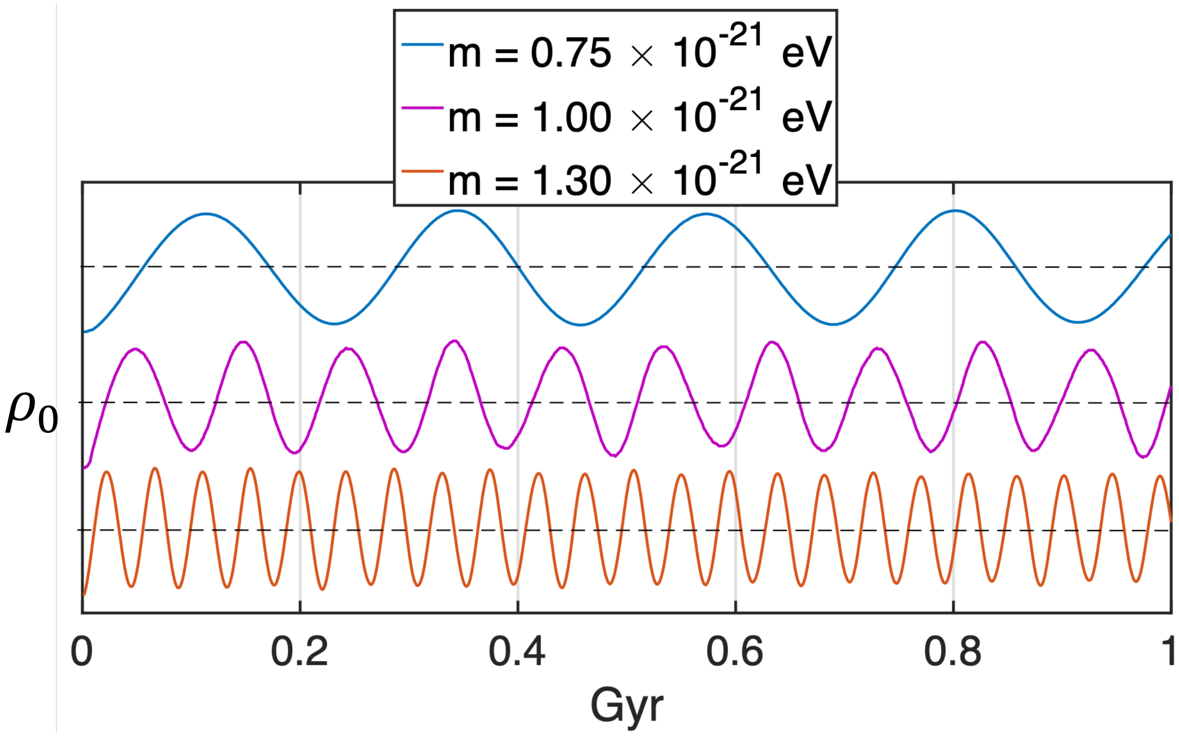


Cores oscillate & random walk!

THE SIMULATION

3D:
Split-Step Fourier (Kick-Drift-Kick) method

1D:
Imply spherical symmetry & solve the radial GPP equations.
(Huge computational speed-up!)



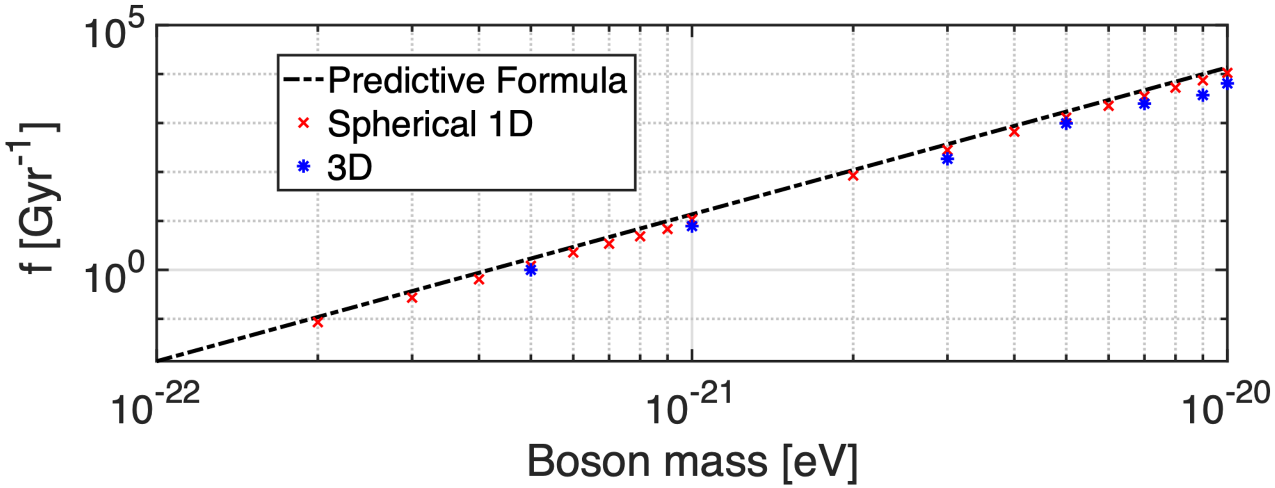
1. Obtain ground state through imaginary time propagation
2. Propagate in real time
3. Fourier analysis of the central/peak density oscillation

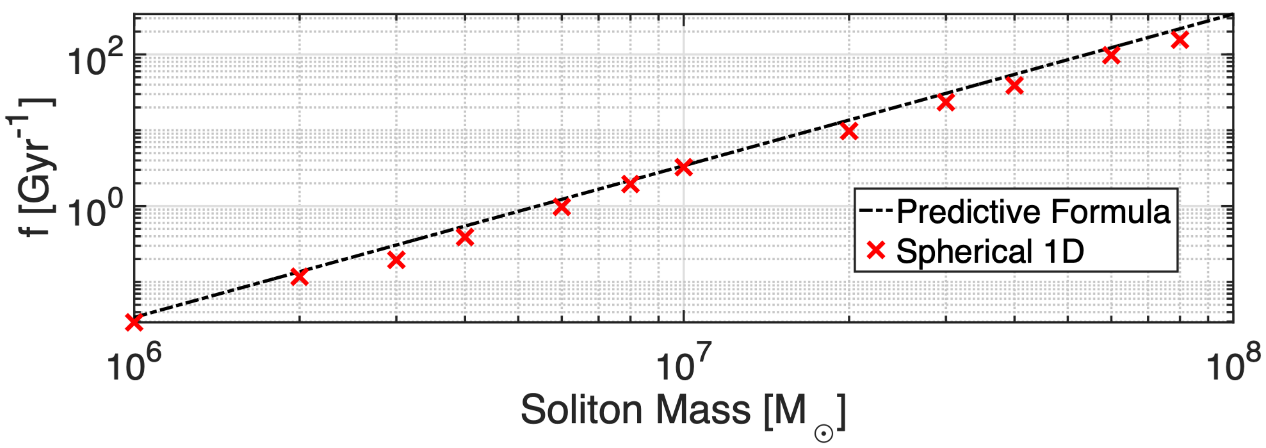
CORE OSCILLATIONS

Analytic expression for radial oscillations in non-interacting case[1]:

$$\omega^2 = \frac{\nu^4 G^4 M^4 m^6}{8\,\sigma^3 \alpha \hbar^6}$$

$$\boxed{\omega^2 = \frac{4\pi^2 \nu \gamma G \rho_0}{\alpha \lambda^{3/2}}}$$



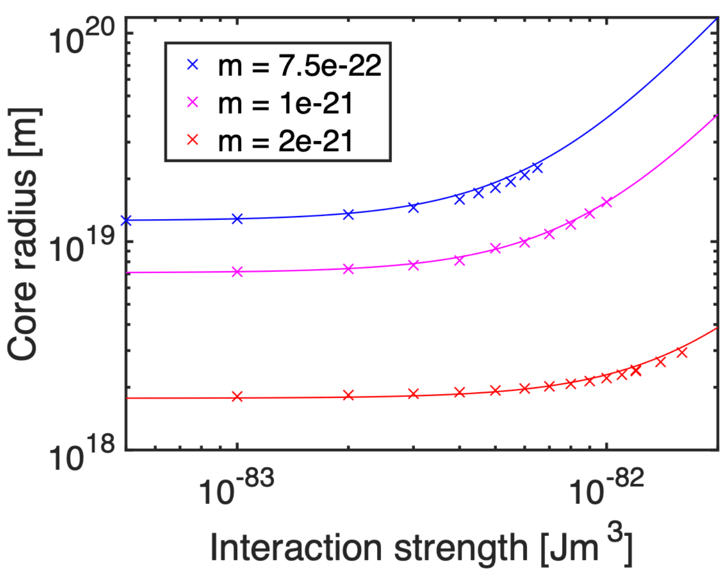


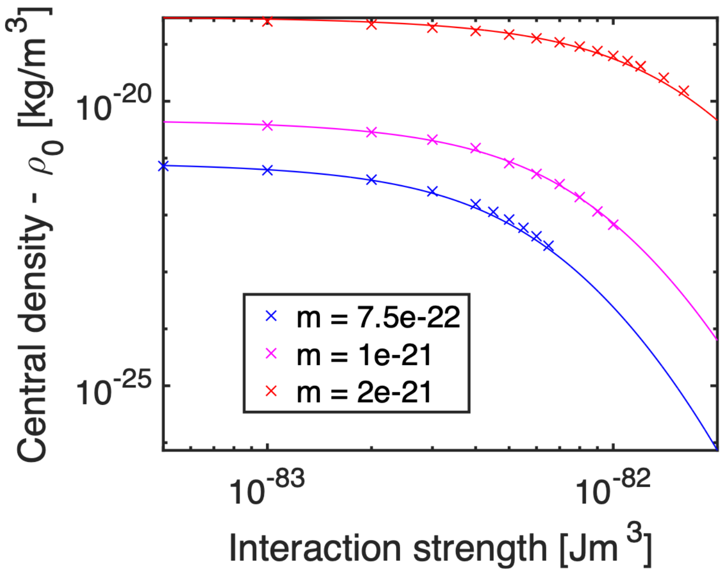
[1] Chavanis, P.-H. 2011 Physical Review D - Particles, Fields, Gravitation and Cosmology **84** 1–27

ADDITION OF SELF INTERACTION

→ Empirical fit for radius:

$$\boxed{r_c(g) = r_c(g=0) + \frac{C_1}{m^4 M} g^2}$$





→ Assess the mass relation for density using empirical density profile [2]:

$$\rho = \rho_0(1+\lambda(r/r_c)^2)^{-8} \longrightarrow M = \frac{4\pi^2\gamma(g=0)\rho_0(g=0)r_c^3(g=0)}{\lambda^{3/2}} \longrightarrow \boxed{\rho_0(g) = \frac{\lambda^{3/2}M}{4\pi^2\gamma(g)r_c^3(g)}}$$

$$\gamma(g) = 0.0081\exp\left(\frac{C_2}{m}g\right)$$

[2] Schive, H.-Y., Chiueh, T. and Broadhurst, T. 2014 Nature Physics **10** 496–9

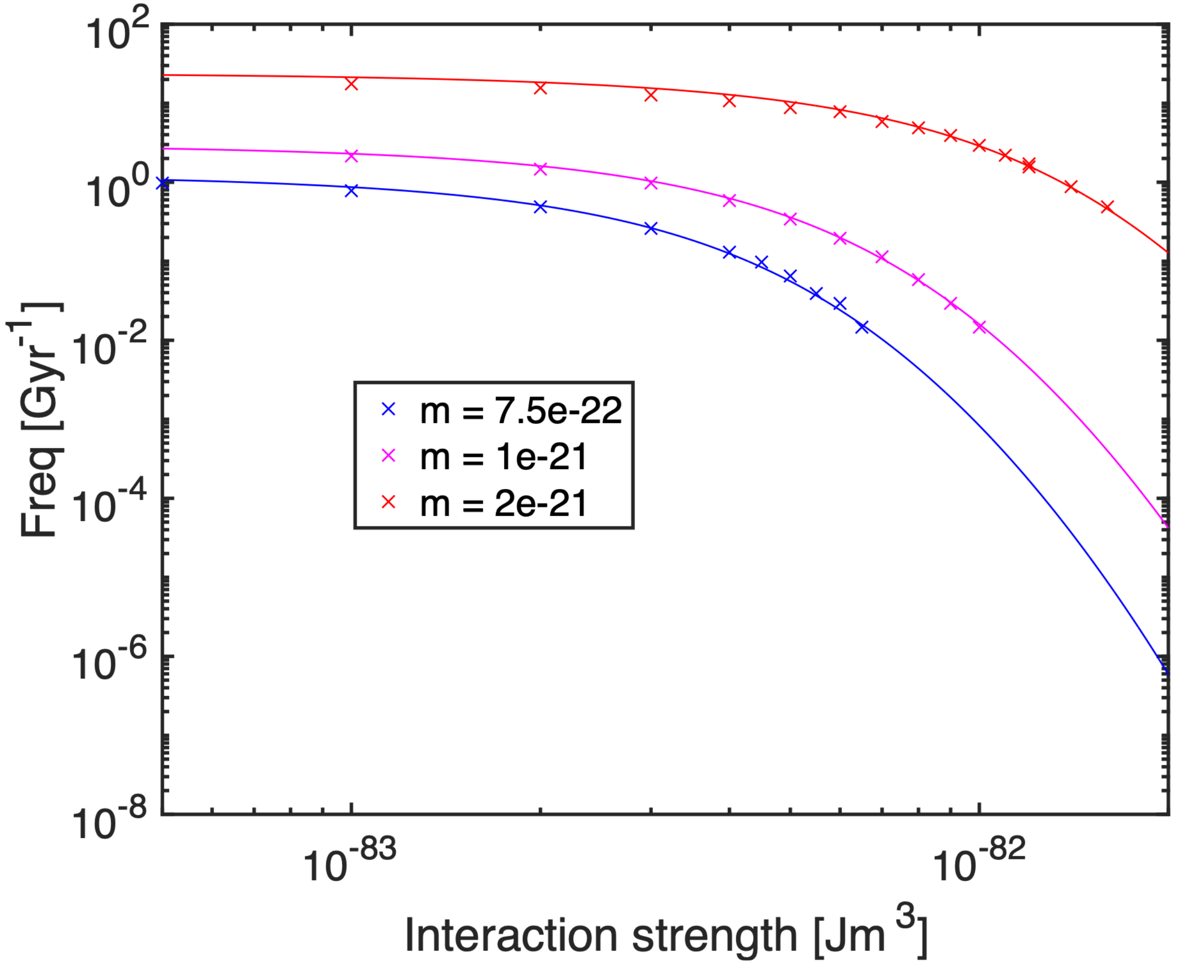
THE NEW FORMULA

$$\omega(g) = \frac{C_3}{m^{9/2}} \frac{\rho_0^{5/4}(g)}{M^3}$$

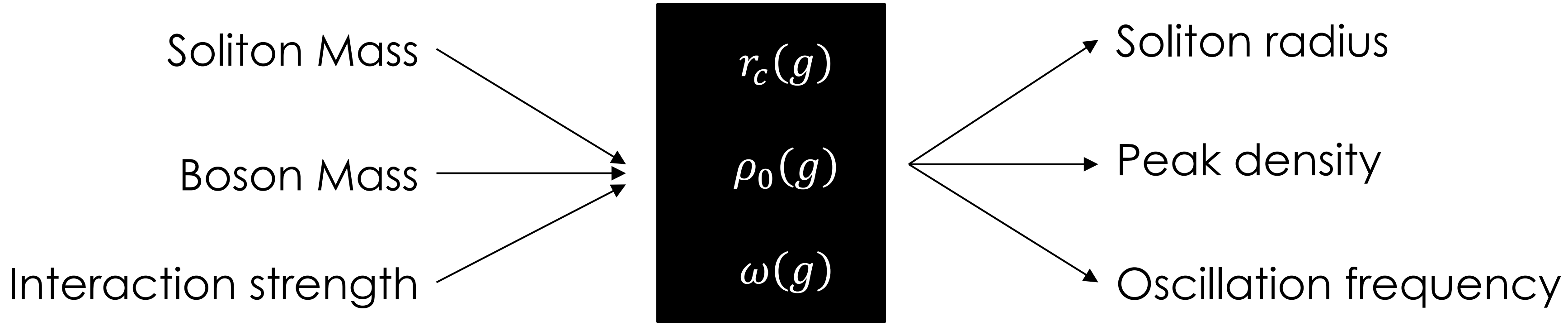
$\rho_0 \propto r_c^{-4}$ when $g = 0$!

$$\lim_{g\to 0} \frac{C_3}{m^{9/2}} \frac{\rho_0^{5/4}(g)}{M^3} = \left(\frac{4\pi^2 \nu\gamma G \rho_0(g=0)}{\alpha\lambda^{3/2}}\right)^{1/2}$$

$$\boxed{\omega(g) = \left(\frac{\nu G}{\alpha}\right)^{1/2} \left(\frac{4\pi^2\gamma}{\lambda^{3/2}}\right)^{5/4} \left(\frac{2\sigma\hbar^2}{G\nu m^2}\right)^{9/4} \frac{\rho_0^{5/4}(g)}{M^3}}$$



CONCLUSION



Expanding the parameter space for the allowed boson mass based on constraints linked to oscillation freqency? [3]
Study of observable effects with self interactions, such as density wavelets in dark matter halos [4]

THANK YOU FOR LISTENING

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[3] Marsh, D.J.E., & Niemeyer, J.C., Phys. Rev. Lett. **123**, 051103
[4] Church B.V., Mocz P. and Ostriker J.P. 2019 MNRAS **485** 2861–76