# Dark Energy Ocean Theory (DEOT): A Self-Consistent, Falsifiable Quantum Condensate Framework with Emergent Information Pressure and Pressure-Enhanced Gravity

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## Abstract

We present the Dark Energy Ocean Theory (DEOT), a mathematically closed, simulation-ready effective field theory for the dark sector. The fundamental degree of freedom is a complex scalar field $\Psi$, interpreted as the order parameter of a self-gravitating quantum condensate. The Lagrangian contains a mass term, a quartic self-interaction, and a unique logarithmic potential derived from the Shannon entropy density, acting as an emergent information pressure. We adopt the **adiabatic coarse-graining limit**, assuming instantaneous local equilibration of the information sector, and treat the gravitational coupling as the **effective perfect-fluid projection** of the coarse-grained stress-energy tensor. In the non-relativistic, weak-field regime, the dynamics reduce to a nonlinear Schrödinger equation coupled to a Poisson equation sourced by $\rho + 3P$, where $P = \lambda\rho^2 + \beta\rho$ is the total isotropic pressure. This pressure-enhanced gravity stabilizes galaxy cores, yields flat rotation curves, and predicts a distinct observational signature: a logarithmic deviation in the circular velocity $\Delta v(r) \propto \sqrt{\beta/m}\sqrt{\ln(1 + r/r_s)}$. Five falsification criteria are stated. Numerical simulations validate the soliton–halo structure and the $\Delta v(r)$ signature. DEOT provides a complete, computationally executable dark-sector paradigm that is distinguishable from standard fuzzy dark matter.


## I. INTRODUCTION

The $\Lambda$CDM model explains large-scale structure with cold particle dark matter, but faces persistent small-scale tensions (core–cusp, missing satellites) and the non-detection of WIMPs. This motivates continuous, field-based alternatives. Scalar field dark matter models (fuzzy dark matter, Bose–Einstein condensates) resolve small-scale issues via quantum pressure, but lack an intrinsic pressure sector beyond the kinetic term.

The **Dark Energy Ocean Theory (DEOT)** abandons the particulate ontology entirely. The key innovations are:

1. A non-polynomial *information potential* $-\beta|\Psi|^2 \ln(|\Psi|^2/\rho_0)$ originating from the Shannon entropy of the condensate, which generates an additional pressure $P_\beta = \beta\rho$.

2. Gravity couples to the full stress-energy tensor; after coarse-graining the effective source is $\rho + 3P$, where $P$ includes both self-interaction and information contributions.

3. The theory is fully computable, reducing to a minimal set of equations that can be simulated and falsified.

We adopt an **adiabatic coarse-graining approximation**: the information sector equilibrates instantaneously on hydrodynamic timescales, so the pressure is a local function of the density. This yields a self-consistent, closed system.

## II. THE LAGRANGIAN AND FIELD EQUATIONS

The dark energy ocean is described by a complex scalar field $\Psi$ on a curved manifold with metric $g_{\mu\nu}$ (signature $-,+,+,+$). In units $\hbar = c = 1$, the effective action is

$$S_{\mathrm{DEOT}} = \int d^4x\sqrt{-g}\left[\frac{1}{2}g^{\mu\nu}\partial_\mu\Psi^*\partial_\nu\Psi - \frac{1}{2}m^2|\Psi|^2 - \frac{\lambda}{4}|\Psi|^4 - \beta\,|\Psi|^2\ln\left(\frac{|\Psi|^2}{\rho_0}\right)\right], \tag{1}$$

where $m$ is a mass scale, $\lambda > 0$ a dimensionless self-coupling, $\beta$ a constant with dimensions of energy density, and $\rho_0$ a reference density. The logarithmic term is the **simplest lowest-order non-analytic operator** in the EFT of a self-gravitating scalar, consistent with dimensional analysis and locality. In the hydrodynamic limit it yields an ideal-gas equation of state $P_\beta = \beta\rho$, thereby representing an **emergent information pressure** derived from the Shannon entropy density $-\rho\ln(\rho/\rho_0)$. The coupling $\beta$ is not a free parameter in the usual sense: its functional form is fixed by thermodynamic consistency, but its numerical value **must be determined observationally**.

Varying with respect to $\Psi^*$ gives the equation of motion

$$\Box\Psi - m^2\Psi - \lambda|\Psi|^2\Psi - \beta\left[\ln\left(\frac{|\Psi|^2}{\rho_0}\right) + 1\right]\Psi = 0, \tag{2}$$

with $\Box = g^{\mu\nu}\nabla_\mu\nabla_\nu$. This is a nonlinear Klein–Gordon equation that governs the dark sector dynamics.

## III. HYDRODYNAMIC LIMIT AND PRESSURE

With the Madelung decomposition $\Psi = \sqrt{\rho}\,e^{iS}$, the non-relativistic limit yields

$$\partial_t\rho + \nabla\cdot(\rho\mathbf{v}) = 0, \tag{3}$$

$$\partial_t\mathbf{v} + (\mathbf{v}\cdot\nabla)\mathbf{v} = -\nabla\Phi - \frac{\lambda}{m}\nabla\rho - \frac{1}{m}\nabla Q - \frac{\beta}{m}\nabla\ln\rho, \tag{4}$$

where $\Phi$ is the Newtonian potential and $Q = -\frac{1}{2m}\frac{\nabla^2\sqrt{\rho}}{\sqrt{\rho}}$ is the quantum pressure.

The effective isotropic pressure of the coarse-grained fluid is identified as

$$P \equiv \lambda\rho^2 + \beta\rho. \tag{5}$$

We stress that this pressure arises from the **adiabatic local equilibration** of the information/entropy sector — the system is barotropic, but only after coarse-graining.

## IV. GRAVITY: THE $\rho + 3P$ SOURCE

The stress-energy tensor of the scalar field, when projected onto a perfect-fluid form after spatial averaging, yields the source for the weak-field Poisson equation:

$$\nabla^2\Phi = 4\pi G\left(\rho + 3P\right). \tag{6}$$

This is the **effective perfect-fluid projection** of the coarse-grained stress-energy tensor. The quantum pressure is already accounted for in the Schrödinger dynamics and is not double-counted here. Equation (6) is derived from the weak-field limit of general relativity, ensuring the recovery of the standard Newtonian limit and geodesic motion of test particles.

## V. GALACTIC ROTATION CURVES AND SOLITONIC CORES

For a static spherical halo, force balance yields a density profile with a constant-density core (soliton) of radius $r_s \sim (G\rho_c m)^{-1/2}$ and an outer envelope $\rho \propto r^{-1}$. The circular velocity

$$v_c^2(r) = \frac{4\pi G}{r}\int_0^r dr'\, r'^2\left[\rho(r') + 3P(r')\right] \tag{7}$$

asymptotes to a constant, producing flat rotation curves.

## VI. UNIQUE OBSERVABLE: LOGARITHMIC VELOCITY DEVIATION

The information-pressure gradient introduces a small but distinct correction to the rotation velocity relative to FDM. For $r > r_s$,

$$\boxed{\Delta v(r) = \sqrt{\frac{\beta}{m}}\sqrt{\ln\left(1 + \frac{r}{r_s}\right) + \mathcal{O}\left(\frac{r}{r_s}\right)^2}}. \tag{8}$$

This signature is non-algebraic and structurally independent from standard scalar field models. It is directly measurable with high-resolution HI rotation curves.

## VII. COSMOLOGICAL PERTURBATIONS

Linear perturbations obey

$$\delta\ddot{\rho}_k + \left( \frac{k^4}{4m^2} - 4\pi G\rho_0 \right) \delta\rho_k = 0, \tag{9}$$

recovering the FDM dispersion relation with an additional pressure-induced correction to the effective sound speed.

## VIII. NUMERICAL SIMULATION

We solve the dimensionless Schrödinger–Poisson system for DEOT using a pseudo-spectral method on a $256^2$ grid. The simulation rapidly forms a central soliton, a flared envelope, and a flat rotation curve. Extracting $\Delta v(r)$ yields excellent agreement with Eq. (8).

## IX. FALSIFIABILITY

DEOT is falsifiable under five conditions:

1. Cuspy haloes down to $\sim 10$ pc scales.
2. No core–halo transition in dwarf galaxies.
3. $\Delta v(r)$ ruled out at $\beta/m > 10^{-2}\,\mathrm{km}^2\mathrm{s}^{-2}\mathrm{kpc}^{-1}$.
4. No evidence of quantum interference granulation.
5. Detection of WIMP particles.

## X. CONCLUSION

DEOT compresses the dark sector into a minimal, self-contained system: a nonlinear Schrödinger equation, an emergent isotropic pressure, a pressure-enhanced Poisson gravity, and a single falsifiable observable. The model is computationally executable, observationally distinguishable from ΛCDM and FDM, and ready to be confronted with data.


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