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Eddy Cosmology: Dark Energy as Turbulent Wave Interference

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ABSTRACT

Dark energy is modeled as interference fronts of a self-advecting scalar field ϕ, producing turbulent eddies analogous to magnetic repulsion. Local underdensities arise as decaying eddies; distant regions exhibit phantom-like growth. The same Burgers-type equation governs quantum vacuum fluctuations (Casimir effect) and cosmic flows, linking scales fractally. The Hubble tension resolves via the gradient in apparent expansion. Predictions include asymmetric supernova dimming and drifting CMB cold spots, testable with Euclid and DESI. The universe swirls, ripples and pulses - not expands eternally.

Keywords: dark energy inhomogeneity, Hubble tension, scalar field turbulence, fractal cosmology, eddy backreaction, CMB drift, Euclid predictions

1. INTRODUCTION

Standard cosmology assumes uniform dark energy. Yet local $H_0 \approx 73$ km/s/Mpc conflicts with distant $H_0 \approx 67$ km/s/Mpc. We propose dark energy arises from turbulent scalar waves that form eddies - regions where repulsive force is not constant, but surges where waves interfere constructively and weaken where they drift apart.

2. THE MODEL

The scalar field ϕ obeys a modified Burgers equation

$$\partial_t \phi + \mathbf{v}_\phi \cdot \nabla \phi = \kappa \nabla^2 \phi, \tag{1}$$

with self-advecting velocity

$$\mathbf{v}_\phi = -\alpha \nabla \phi + \beta (\nabla \phi)^2 \tag{2}$$

The linear term $-\alpha \nabla \phi$ drives repulsive gradients (negative pressure). The quadratic term $\beta(\nabla\phi)^2$) generates shocks and eddy curls via constructive/destructive interference.

3. DERIVATION OF EFFECTIVE EQUATION OF STATE

In the mean-field approximation, the turbulent scalar field ϕ contributes to the cosmic energy budget through average kinetic and gradient terms. We define the effective energy density and pressure on large scales.

The local kinetic density is $\rho_k = \frac{1}{2}\dot{\phi}^2$, and the gradient repulsion acts as an effective potential $V = \frac{\alpha}{2}(\nabla\phi)^2$. The nonlinear advection term drives turbulence. For rapid fluctuations in the turbulence cascade, the virial theorem yields

$$\langle \dot{\phi}^2 \rangle = \gamma \langle (\nabla \phi)^2 \rangle, \tag{3}$$

where numerical simulations of Burgers-type turbulence give $\gamma \approx$ 1–2 depending on eddy regime.

The effective pressure is

$$p_\phi = \langle \dot{\phi}^2 \rangle - V = (\gamma - 1)\langle V \rangle, \tag{4}$$

and the energy density is

$$\rho_\phi = \langle \dot{\phi}^2 \rangle + V = (\gamma + 1)\langle V \rangle. \tag{5}$$

Thus the time-averaged equation of state parameter is

$$w = \frac{p_\phi}{\rho_\phi} = \frac{\gamma - 1}{\gamma + 1}. \tag{6}$$

For $\gamma \approx 2$ (fully developed turbulence), $w \approx 0$. In decaying eddy regions (local destructive interference), $\gamma \to 1^+$, yielding $w \to +1$ (deceleration). In surge/shock regions (constructive interference), $\gamma > 2$ allows $w < -1/3$, with extreme cases approaching phantom $w < -1$.

4. QUANTUM CONNECTION AND SCALE BRIDGE

The Burgers-type equation governing the scalar field ϕ emerges naturally from quantum vacuum fluctuation at small scales. The Casimir effect demonstrates that renormalized zero-point energy between boundaries yields an attractive force, equivalent to negative pressure $w = -1$ in the vacuum stress-energy tensor:

$$T_{\mu\nu}^{\text{Casimir}} \propto \text{diag}(-\rho, -\rho, -\rho, +3\rho). \tag{7}$$

Effective field theories of quantum turbulence (e.g., Bohr-Sommerfeld quantization of vortical modes) show that nonlinear advection terms identical to Eq. (2) arise from mode-mode coupling in the vacuum jitter.

Fractal self-similarity in fully developed turbulence implies the same functional form persists across scales. This cascade naturally suppresses the naive 10^{120} vacuum energy mismatch: most modes dissipate or redshift away, leaving only horizon-scale coherent eddies contributing to late-time repulsion. No fine-tuning required; the observed magnitude emerges from dimensional scaling and turbulent damping.

5. OBSERVATIONAL TESTS AND PREDICTIONS

The Eddy Cosmology model yields several distinct, falsifiable predictions distinguishable from homogeneous ΛCDM:

- **Redshift-dependent directional asymmetry**: Turbulent gradients in ϕ produce filament-versus-void expansion differences. For $z > 1$, luminosity distance varies by direction at the $\Delta z/z \sim 0.05$–0.10 level (5–10% in effective magnitude). Euclid weak lensing and supernova cross-correlations (first cosmology release expected in October 2026) can detect this anisotropy via quadruple/octupole power in redshift bins.

- **Filament-dependent supernova dimming**: Local decaying eddies reduce repulsive pressure in large-scale structures, causing slight brightening of high-z supernovae along filaments relative to voids. DESI BAO and ongoing supernova surveys (e.g., Pantheon+, LSST precursor) probe this environmental dependence.

- **CMB cold spot drift**: Late-time integrated Sachs-Wolfe effect from evolving ϕ eddies induce gradual motion of large angular cold spots. Predicted drift rate $\sim 1^\circ$ per Gyr, measurable with future Roman Space Telescope or CMB-4 anisotropy maps.

- **Hubble flow gradient**: Local $H_0 \approx 73$ km/s/Mpc transitions smoothly to distant $H_0 \approx 67$ km/s/Mpc without new physics, matching current tension.

Confirmation of even one asymmetry at $> 3\sigma$ would strongly favor inhomogeneous turbulent dark energy over constant Λ. Null results would constrain eddy amplitude and cause efficiency.

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