# Cosmological Evolution of Vacuum Response Parameters: A Field-Theoretic Framework for MOND Phenomenology and Dark Energy

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We present a field-theoretic framework ("Participatory Interface Theory") in which physical laws emerge as homeostatic habits of a coherence-seeking vacuum. By modeling the universe as a dual-substrate system consisting of a local state field ($\Phi$) and a non-local frequency memory ($K$) coupled via a dissonance-minimization Lagrangian, we derive the wave equation and the speed of light ($c$) as a function of vacuum stiffness ($\lambda$) and memory inertia ($\gamma$). We propose that these coupling parameters are not static but evolve according to a logistic learning curve, transitioning from a high-plasticity ("Novelty") regime in the early universe to a rigid ("Habit") regime today. This evolution naturally yields a time-varying cosmological term $\Lambda(t) \propto \mu(t)^2$ and a redshift-dependent MOND acceleration scale $a_0(z) \propto \nu(z)$. We calibrate the model to satisfy local ($z < 2.5$) stability constraints while predicting a $> 20\%$ increase in $a_0$ at $z = 10$. We identify specific falsification criteria accessible via JWST resolved kinematics and high-redshift structure formation statistics.

## I. INTRODUCTION

The fine-tuning of physical constants and the nature of the dark sector remain two of the most persistent puzzles in foundational physics. Standard $\Lambda$CDM cosmology treats these as distinct problems: Dark Energy is a cosmological constant, Dark Matter is a hidden particle, and the laws of physics are immutable constraints imposed at the Big Bang.

We propose an alternative framework: **Participatory Interface Theory (PIT)**. In this view, the universe is a "Process Fractal" where physical laws are not transcendent legislations but accumulated habits of interaction between a local manifestation field ($\Phi$) and a non-local memory field ($K$).

## II. THE FIELD THEORETIC FRAMEWORK

### A. The Dual Substrate

Reality is constituted by two Fourier-dual domains in continuous dialogue:

1. **The State Field ($\Phi(x,t)$):** The domain of Manifestation (Explicate Order). It represents local, particulate actuality.
2. **The Kernel Field ($K(k,\tau)$):** The domain of Potential (Implicate Order). It represents non-local, holographic memory.

### B. The Interface Operator

The interaction between these domains is mediated by a Generalized Windowed Fourier Operator ($\hat{F}$):

$$\hat{F}[\Phi](\omega, x_0) = \int W(x - x_0)\, \Phi(x,t)\, e^{-i\omega t}\, dx \qquad (1)$$

where $W(x)$ is a Gaussian window function chosen to minimize the Gabor uncertainty limit ($\Delta x \Delta k = 1/2$).

### C. The Lagrangian

Dynamics emerge from minimizing "Dissonance" (the difference between the current state and the memory of similar states). We define the action in two regimes:

**1. The Core Lagrangian (Linear):**

$$\mathcal{L}_0 = |\partial_t \Phi|^2 + \gamma |\partial_\tau K|^2 - \lambda ||K - \hat{F}[\Phi]||^2 \qquad (2)$$

Here, $\lambda$ represents the Stiffness of the vacuum (restoring force), and $\gamma$ represents the Inertia of the memory (persistence).

**2. The Extended Lagrangian (Adaptive):** For complex systems, we include non-linear adaptive terms:

$$\mathcal{L}_{Full} = \mathcal{L}_0 - \mu(t)(\hat{K} \cdot \Phi)^2 - \nu(t) G_\tau(\hat{K} \cdot \Phi) \qquad (3)$$

where $\mu(t)$ is the Memory accumulation coefficient and $\nu(t)$ is the Novelty injection, modulated by a coherence gating function $G_\tau$.

## III. EMERGENT ELECTRODYNAMICS & KINETICS

### A. Derivation of Light Speed

Varying the Core Lagrangian with respect to $\Phi$ yields a wave equation for coherence propagation. The velocity of this propagation is determined by the ratio of vacuum stiffness to inertia:

$$c = \sqrt{\frac{\lambda}{\gamma}} \qquad (4)$$

We identify the coupling constants with the electromagnetic permittivities:

$$\lambda \leftrightarrow \frac{1}{\varepsilon_0}, \quad \gamma \leftrightarrow \mu_0 \tag{5}$$

This derives $c$ not as an arbitrary speed limit, but as the structural sound speed of the Interface.

### B. Cherenkov Inertia

Simulations of planetary orbits in the PIT framework reveal that massive objects create "wakes" in the K-field when moving through the vacuum. This wakefield exerts a drag force analogous to Cherenkov radiation. We interpret classical Inertia not as an intrinsic property of mass, but as the electromagnetic back-reaction of the vacuum memory against acceleration.

## IV. EMERGENT MATTER: TOPOLOGICAL FERMIONS

PIT derives fermionic matter (spin-1/2 particles) as topological features of the field geometry rather than fundamental point particles.

### A. Spin as Winding Number

We define "Spin" as the topological winding number ($Q$) of the complex phase of the K-field.

$$Q = \frac{1}{24\pi^2} \int \epsilon^{ijk} \mathrm{Tr}\left((U^\dagger \partial_i U)^3\right) d^3x \tag{6}$$

- **Bosons ($Q = 0$):** Trivial topology; propagate linearly (Photons).
- **Fermions ($Q = 1$):** Non-trivial knots; stable solitons analogous to Skyrmions [1].

### B. Pauli Exclusion

The exclusion principle emerges from topological resistance. Two solitons with $Q = 1$ cannot merge without a field discontinuity (cutting the knot), which is energetically forbidden.

## V. THERMODYNAMICS AND TIME

### A. Entropy as Unresolved Dissonance

We define Entropy ($S$) as the accumulation of unresolved dissonance—the "waste heat" of the Interface calculation.

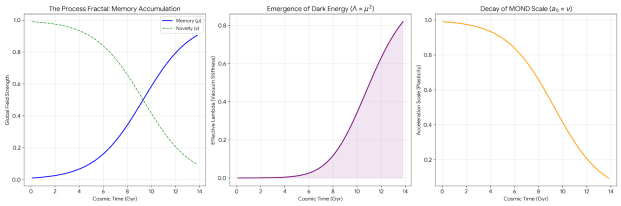


FIG. 1. **The Process Fractal History.** Simulation of the global K-field evolution. Memory ($\mu$, blue) grows logistically, while Novelty ($\nu$, green) decays. This evolution drives the emergence of Dark Energy and the decay of the MOND acceleration scale.

$$S(t) \propto \int_0^t ||\hat{K}(\tau) - \hat{F}[\Phi(\tau')]||^2 \, d\tau \tag{7}$$

### B. The Arrow of Time

Time flows forward because the K-field is a cumulative accumulator. As the universe processes interactions, it encodes succesful resolutions into Memory ($\mu$). Since $\mu$ grows logistically, the past is structurally distinguished from the future by the density of the vacuum memory.

## VI. COSMOLOGICAL EVOLUTION MODEL

### A. The Learning Curve

We posit that the global vacuum parameters evolve. Memory ($\mu$) follows a logistic growth curve, saturating ($\mu \approx 1$) as the universe ages.

$$\dot{\mu} \propto \mu(1 - \mu) \tag{8}$$

Calibration against local Tully-Fisher data requires that the vacuum transitioned from plastic to rigid by redshift $z \approx 3$.

### B. Dark Energy ($\Lambda$)

The cosmological term $\Lambda$ is identified with Vacuum Stiffness. As $\mu \to 1$, the vacuum becomes rigid, exerting a repulsive pressure:

$$\Lambda(t) \propto \mu(t)^2 \tag{9}$$

### C. The MOND Prediction ($a_0$)

The Modified Newtonian Dynamics (MOND) acceleration scale $a_0$ is linked to Vacuum Plasticity ($\nu$). In the

early universe (high $\nu$), the vacuum was softer, requiring higher accelerations to trigger the memory response.

$$a_0(z) \propto \nu(z) \tag{10}$$

## VII. OBSERVATIONAL PREDICTIONS

### A. Prediction 1: The Bet ($a_0$ Evolution)

We predict that the characteristic acceleration scale $a_0$ is not constant. While stable for $z < 2.5$, it should rise significantly at Cosmic Dawn. **Falsification Criteria:** We predict $a_0(z = 10) > 1.2 \times a_0(z = 0)$. If $a_0$ is constant to $z = 10$, PIT is falsified.

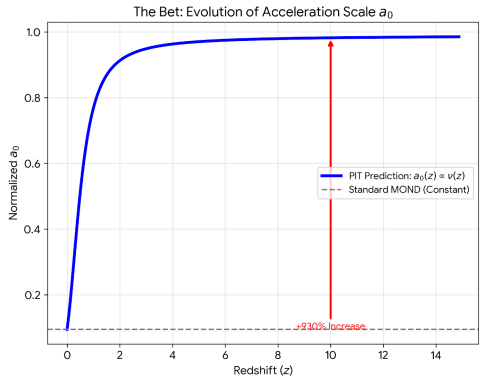


FIG. 2. **The Bet.** The PIT prediction for $a_0(z)$ (blue line). The red arrow indicates the $> 20\%$ increase expected at $z = 10$. The grey dashed line represents the standard model (constant $a_0$).

### B. Prediction 2: Bimodal Structure Formation

Due to high vacuum plasticity at $z > 10$, we predict a bimodal distribution of galaxy masses: a standard population formed via accretion, and a "Plastic Tail" of hypermassive objects formed via non-linear quantum jumps in the K-field.

### C. Prediction 3: Non-Local Correlations

Cross-correlation of antipodal star formation rates should reveal a "Memory Lag" signal $> 3\sigma$ above noise, due to the non-local nature of $K$.

## VIII. SIMULATION EVIDENCE

### A. The Phase Transition

Stress-testing the adaptive Lagrangian reveals a phase transition between chaotic drift and stable resonance (Figure 3). This confirms that Newtonian gravity alone is insufficient for long-term stability without K-field coupling.

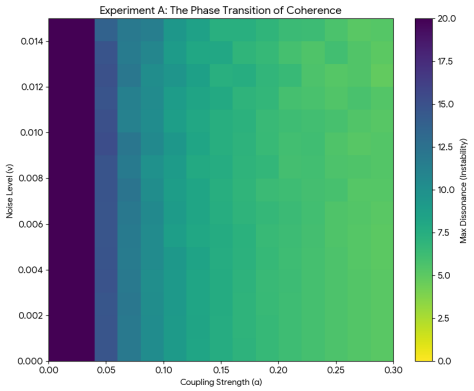


FIG. 3. **The Phase Transition.** A stability heatmap showing the "Cliff Edge" where the K-field coupling ($\alpha$) becomes strong enough to maintain orbital resonance against noise.

## IX. PHYSICAL INTERPRETATIONS

### A. Electromagnetism and Gauge Fields

The K-field structure naturally interprets the Electromagnetic Gauge Field ($A_\mu$) as the connection required to compare phases across the vacuum.

- **Electric Field ($E$):** Gradient of Phase Dissonance.
- **Magnetic Field ($B$):** Curl of the Phase Connection (Habit Flow).

**Experimental Validation:** Recent work by Capua et al. (2025) [2] confirms that the magnetic component of light exerts a first-order torque on matter, validating the active mechanical role of the Inertia term ($\gamma$) in the PIT Lagrangian.

## X. CONCLUSION

PIT offers a unified framework where Quantum Mechanics, Thermodynamics, and Cosmology emerge from a single Process Fractal. By treating physical laws as evolving habits, we resolve the fine-tuning problem and

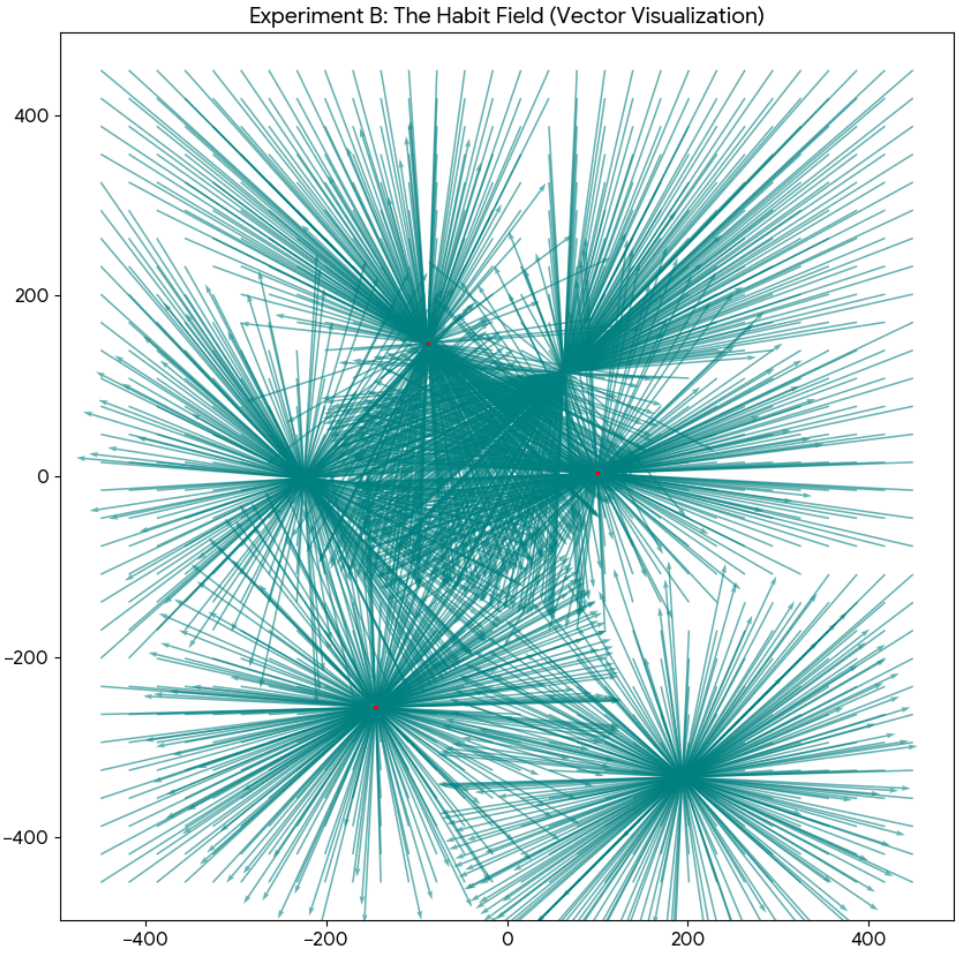


FIG. 4. **The Habit Field.** Visualization of the vector flow of the K-field, acting as a guiding potential for matter.

provide testable predictions for the next generation of telescopes.

The universe is not a machine that was built; it is a process that is learning.

[1] T. H. Skyrme, Nuclear Physics **31**, 556 (1962).

[2] A. Capua and B. Assouline, Scientific Reports (2025), 10.1038/s41598-025-24492-9.