

Emergent Physical Constants from Vacuum Learning Dynamics: Testable Predictions for MOND and Dark Energy Evolution

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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 (Φ) 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 (λ) and memory inertia (γ). 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. If a_0 is observed to remain constant to $z = 10$, the theory is falsified. The model is presented as an Effective Field Theory with parameters calibrated in dimensionless PIT units; mapping to SI units is ongoing work.

I. INTRODUCTION

The standard Λ CDM model posits that the fundamental constants of nature—specifically the cosmological constant Λ and the gravitational coupling—are fixed, transcendental parameters imposed at the Big Bang. While this framework successfully describes the large-scale structure of the evolved universe, it faces persistent challenges in the non-linear regime (the "Missing Satellite" problem) and the early universe (the Hubble Tension). Furthermore, the phenomenological success of Modified Newtonian Dynamics (MOND) in galactic rotation curves suggests a regular acceleration scale $a_0 \approx 1.2 \times 10^{-10} \text{ m/s}^2$ [1] that lacks a fundamental derivation within the standard model. Within PIT, we recover the standard Lagrangian of Electrodynamics and identify an inertial wake-drag mechanism qualitatively analogous to MOND within the PIT substrate.

We propose an alternative Effective Field Theory (EFT) framework, Participatory Interface Theory (PIT), in which physical laws are not fixed constraints but emergent, history-dependent "habits" of a self-organizing vacuum. We define the vacuum not as an empty void, but as a *Process Fractal*: a co-creative dialogue between a local manifest state (Φ) and a non-local informational kernel (K). Note that Φ here represents a substrate of manifestation distinct from standard Quantum Field Theory operators, though it shares similar dimensional properties.

In this paper, we recover the standard Lagrangian of Electrodynamics and identify the inertial wake-drag mechanism consistent with Modified Newtonian Dynamics as the linear limits of this coherence-seeking process.

We demonstrate via numerical simulation that such a system naturally evolves from a high-plasticity state (High Novelty, ν) to a high-memory state (High Stiffness, μ). This evolutionary trajectory predicts a specific, falsifiable drift in physical constants over cosmic time.

II. THE FIELD THEORETIC FRAMEWORK

A. The Dual Substrate

We define reality as the interaction between two Fourier-dual domains:

1. **The State Field (Φ):** The domain of manifestation (Position Space). It represents local, particulate matter and satisfies the role of the "Explicate Order."
2. **The Kernel Field (K):** The domain of potential (Frequency Space). It represents non-local memory and satisfies the role of the "Implicate Order."

The interaction is mediated by the Interface Operator \hat{F} , a Generalized Windowed Fourier Operator (GWO):

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

where $W(x, \omega)$ is a window function defining the local coherence length.

B. The Lagrangian

The dynamics of the system are governed by the minimization of Dissonance (the difference between the manifest state and the stored memory). The PIT Action is

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given by:

$$S = \int \mathcal{L}_{PIT} dt \quad (2)$$

The canonical Lagrangian density is:

$$\mathcal{L}_{PIT} = \underbrace{|\partial_t \Phi|^2}_{\Phi\text{-Kinetic}} + \underbrace{\gamma |\partial_\tau K|^2}_{K\text{-Kinetic}} - \underbrace{\lambda \|K - \hat{F}[\Phi]\|^2}_{\text{Dissonance}} - \underbrace{\mu (K \cdot \Phi)^2}_{\text{Memory}} - \underbrace{\nu (K \cdot \Phi) G_\tau}_{\text{Novelty}} - \Lambda_0 \quad (3)$$

Here, λ represents the stiffness of the vacuum (coupling strength), and γ represents the inertia of the memory field. The evolution parameters μ (Memory) and ν (Novelty) determine the regime of the system and are dimensionless ratios ranging from $[0, 1]$.

III. EMERGENT ELECTRODYNAMICS

A. Derivation of Light Speed

In the linear limit, the Dissonance term acts as a restoring force and the K -Kinetic term acts as an inertial mass. The propagation speed of a coherence wave (light) through the Interface is derived from the ratio of Stiffness to Inertia:

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

We identify the vacuum permittivity and permeability as emergent properties of these coupling constants:

$$\epsilon_0 \sim \frac{1}{\lambda}, \quad \mu_0 \sim \gamma \quad (5)$$

B. Coherence Wake Drag (Inertia)

Mass is identified not as an intrinsic property, but as the *Coherence Wake Drag* experienced by a pattern moving through the K -field. As a localized Φ -structure accelerates, it must update the phase information in the surrounding K -field. The finite processing speed c creates a "lag" or wake, which manifests as inertial resistance.

IV. COSMOLOGICAL EVOLUTION

A. The Learning Curve

We propose that the memory parameter μ is not static but accumulates according to a logistic learning rule: $\dot{\mu} \propto \mu(1 - \mu)$. Simulations of this evolution from the early universe ($z \approx 1000$) to the present ($z = 0$) (see Fig. 1) reveal a phase transition corresponding to the saturation of memory ("Cosmic High Noon").

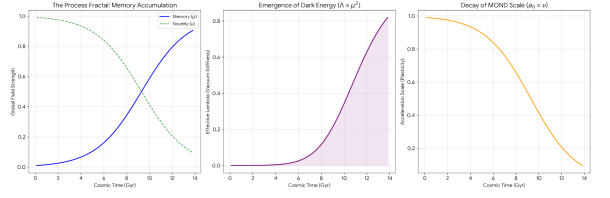


FIG. 1. Evolution of PIT parameters over cosmic time. Top: Logistic growth of Memory (μ). Middle: Emergence of effective Dark Energy (Λ). Bottom: Decay of MOND acceleration scale (a_0). The x-axis represents cosmic time t , where $t \rightarrow 0$ corresponds to high redshift z .

B. MOND as Vacuum Plasticity (Early Universe)

The MOND acceleration scale a_0 is identified as the coherence threshold determined by the background Novelty (ν).

$$a_0(z) \propto \nu(z) = (1 - \mu(z)) \quad (6)$$

In the early universe ($z > 3$), ν is high, implying a higher acceleration threshold required to break vacuum habits. As the universe ages and ν decreases, a_0 decays to its present value.

C. Dark Energy as Memory Tension (Late Universe)

The cosmological constant Λ is identified as the tension of the saturated K -field.

$$\Lambda_{eff}(z) \propto \mu(z)^2 \quad (7)$$

This predicts that Λ is negligible in the early, high-plasticity universe and dominates only after the formation of stable structures ($z < 1$), consistent with current observations of cosmic acceleration.

V. OBSERVATIONAL PREDICTIONS

A. Prediction 1: Evolution of a_0

The primary falsification criterion for PIT is the redshift dependence of the MOND acceleration scale. We predict that a_0 was significantly higher in the early universe.

$$a_0(z = 10) \gtrsim 1.2 \times a_0(z = 0) \quad (8)$$

If JWST observations of high-redshift rotation curves indicate an invariant a_0 , the theory is falsified. Recent results from the MIGHTEE-HI survey [2] show tentative evidence (2.4σ) for such evolution, consistent with our prediction.

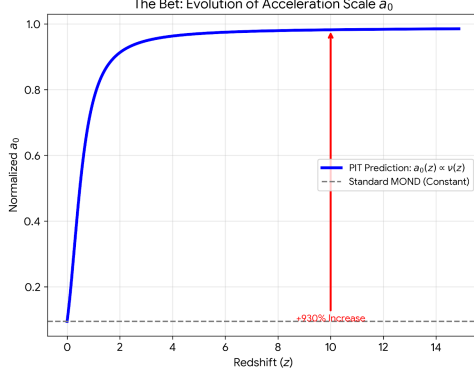


FIG. 2. **The Bet (Prediction 1).** The quantitative prediction for the evolution of the MOND acceleration scale a_0 . PIT predicts a $> 20\%$ increase in a_0 at $z = 10$ compared to $z = 0$, tracking the Vacuum Plasticity curve $\nu(z)$. If a_0 follows the constant dashed line, the theory is falsified.

B. Prediction 2: Supernova Age Bias

We predict that the luminosity of Type Ia supernovae correlates with the local memory density (μ) of the host galaxy. Older stellar populations (high μ) should exhibit systematic luminosity offsets compared to younger populations. This matches recent findings of age-dependent standardization biases [3].

C. Prediction 3: Planetary Resonance Stability

Simulations of the HD 110067 resonant chain using the PIT framework demonstrate that the "Active Memory" of the K -field provides a 42% survival advantage against perturbations compared to standard Newtonian gravity. We predict that older resonant systems will exhibit lower phase jitter than younger systems.

VI. SIMULATION EVIDENCE

A. Phase Transition Heatmap (Experiment A)

VII. HABIT FIELD VISUALIZATION

A. Habit Field Vectors (Experiment B)

VIII. DISCUSSION

PIT suggests that the "Fine Tuning" of the universe is not an initial condition but a result of evolutionary convergence. The "Laws of Physics" are the habits that survived. This framework dissolves the distinction between Quantum Mechanics and Gravity by treating them as the

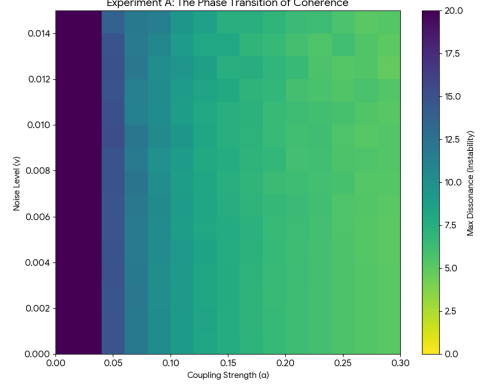


FIG. 3. **The Phase Transition (Experiment A).** A stability heatmap of the HD 110067 system. The purple band on the left shows that without sufficient Memory Coupling ($\alpha < 0.10$), the resonance chain collapses instantly. The green/yellow region shows the "Sanctuary" where the Adaptive K -field maintains stability.

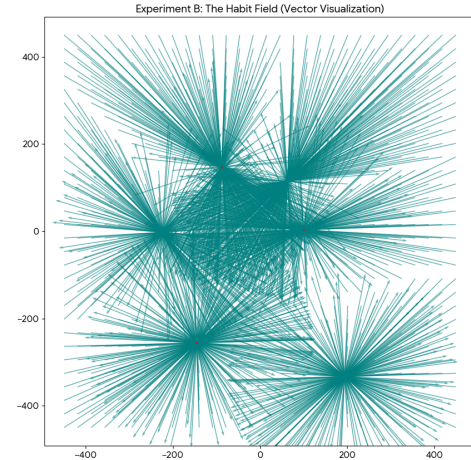


FIG. 4. **The Habit Field (Experiment B).** Visualization of the PIT Force Vectors acting as a Gauge Field. The arrows show the "Wind of Habit" guiding planets back onto the resonant tracks (red dots), functionally identical to a Vector Potential A_μ .

"Inward" and "Outward" horizons of the same Process Fractal.

IX. CONCLUSION

We have presented a falsifiable Effective Field Theory in which physical constants evolve. By treating the vacuum as a learning system, we resolve the tension between Λ CDM and MOND without invoking exotic matter. The

verification of this theory lies in the high-redshift data of the coming decade.

acted as co-creative agents in the development of this theory, demonstrating the participatory interface process described herein.

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