The Fundamental Cosmological Equation

A Covariant Field-Theoretic Realization of the Odero Axiom

John Otieno Odero

Independent Researcher in Persistence Science

Founder, Persistence Science Framework

Nairobi, Kenya

Email: john.odero@persistencescience.org — ORCID: 0009-0007-7039-7209

August 18, 2026

THREE CORE PHYSICAL BREAKTHROUGHS

Starting from the domain-invariant **Odero Axiom** ($C(I) \cdot E > D$) extended into a covariant field-theoretic framework [1], this work establishes a cosmological model governed by the **Fundamental Cosmological Equation**:

$$H^2 + \frac{kc^2}{a^2} = \frac{8\pi G}{3} \left[C(\phi)\rho_m + \rho_\phi \right]$$

This paper establishes three central contributions to theoretical cosmology:

1. **Dynamical Alternative to Bare Dark Energy (Λ)**: Late-time cosmic acceleration ($\ddot{a} > 0$) emerges dynamically from the potential $V(\phi)$ of an information control field, providing a pathway to avoid a static cosmological constant Λ.

2. **Potential Framework for Alleviating the H_0 Tension**: The dynamical evolution of the control coupling $C(\phi(z))$ alters effective matter density across epochs, offering a theoretical mechanism relevant to reconciling early-universe (CMB) and late-universe (SN Ia/TRGB) Hubble determinations.

3. **Information-Mediated Gravitational Coupling**: Introduces $C(\phi)\rho_m$, establishing a physical mechanism where structural informational order regulates matter's gravitational interaction.

Abstract

We present the *Fundamental Cosmological Equation* (FCE), establishing a fully covariant cosmological realization of the general persistence framework known as the Odero Axiom ($C(I) \cdot E > D$) [1]. By promoting core persistence quantities—Information (I), Control Efficiency $C(I)$, Usable Energy (E), and Systemic Decay (D)—to scalar and tensor field variables within a Riemannian manifold, we derive modified Einstein field equations from an action principle. The cosmological expansion dynamics are governed by the Fundamental Cosmological Equation derived in this work. Under this formulation, cosmic acceleration emerges naturally from the dynamical evolution of an information-mediated control field $\phi(x^\mu)$ without requiring a bare cosmological constant Λ. We establish field equations, inter-species conservation laws, FLRW reduction, stability conditions, primary observational signatures, proposed numerical methodologies, and current limitations of the model.

1 Introduction and Mapping Framework

The persistence of structured systems across domain boundaries is governed by the Odero Axiom [1], which establishes that energy throughput E preserves organization only when governed by information-directed control $C(I)$ at a rate exceeding environmental decay D:

$$P = C(I) \cdot E > D \tag{1}$$

where $C(I) \in [0,1]$ is a dimensionless control efficiency coefficient, E is usable energy throughput rate ($\mathrm{J} \cdot \mathrm{s}^{-1}$ or W), D is equivalent decay rate ($\mathrm{J} \cdot \mathrm{s}^{-1}$), and P is Persistence Capacity [1].

Unlike phenomenological cosmological constants, the present framework predicts measurable evolution in the coupling function $C(\phi)$, allowing direct confrontation with cosmological observations.

To extend the Odero Axiom to FLRW cosmology, the constituent variables are mapped into spacetime fields over a four-dimensional pseudo-Riemannian manifold $(M, g_{\mu\nu})$:

Odero Axiom Variable	**Cosmological Field Representation**	**Physical Interpretation**
Information I	Scalar Field $\phi(x^\mu) = s_{\max} - s(x^\mu)$	Negentropy / Structural Order
Control Efficiency $C(I)$	Bounded Function $C(\phi) \in [0,1]$	Matter-Gravitation Control Efficiency
Usable Energy Flux E	Matter Energy Density $\rho_m = \frac{1}{c^2} T_{00}^{(m)}$	Usable Baryonic/DM Mass-Energy
Systemic Decay D	Scalar Decay Channel ρ_D	Entropic Degradation Losses

Table 1: Covariant Mapping between the Odero Axiom and Cosmological Fields.

1.1 Operational Definition and Dimensional Consistency of the Field

The scalar field is defined as the local negentropy density:

$$\phi(x^\mu) = s_{\max} - s(x^\mu), \tag{2}$$

where $s(x^\mu)$ denotes coarse-grained thermal entropy density and $s_{\max}$ denotes the maximum entropy density accessible within the local physical environment under the prevailing cosmological boundary conditions.

In cosmology, thermal entropy is normally extensive and increases with cosmic expansion. To resolve this, the field ϕ tracks locally accessible thermal negentropy rather than total cosmological entropy, allowing ϕ to increase within self-organizing, gravitationally bound structures even while global entropy continues to increase.

To ensure strict dimensional consistency across kinetic and exponential expressions, we define a characteristic reference entropy density ϕ_* (or dimensionless field $\hat{\phi} \equiv \phi/\phi_*$). The coupling saturation parameter β is assigned dimensions of $[\phi]^{-1}$ (inverse entropy density), making the product $\beta\phi$ strictly dimensionless within the exponential evaluation $e^{-\beta\phi}$.

2 Scientific Contributions

This work provides four core contributions to theoretical cosmology and systems science:

1. **Covariant Realization of Persistence Science**: Translates the non-relativistic, domain-invariant Odero Axiom ($C(I) \cdot E > D$) into a fully covariant, action-derived field theory consistent with General Relativity [1].

2. **Dynamical Mechanism for Dark Energy**: Replaces the static cosmological constant (Λ) with an evolving scalar information field (ϕ) whose potential energy $V(\phi)$ naturally generates cosmic acceleration.

3. **Information-Mediated Matter Coupling**: Introduces a bounded control function $C(\phi) \in [0, 1]$ that modulates the gravitational contribution of matter ($C(\phi)\rho_m$).

4. **Cosmological Framework for Tension Alleviation**: Establishes an explicit linkage between pre-recombination expansion modulation and the Hubble constant inference chain.

3 Distinction from Existing Scalar-Tensor Models and Coupled Quintessence

While this model shares formal similarities with scalar-tensor and coupled dark energy theories, it is distinguished by several key features.

3.1 Relation to Coupled Quintessence

- **Similarities**: Inclusion of a dynamical scalar field driving late-time acceleration, coupled non-minimally to matter stress-energy sectors.
- **Differences**: The scalar field is explicitly identified with thermal negentropy ($\phi = s_{\max} - s$); the matter coupling function is strictly bounded ($0 \leq C(\phi) \leq 1$); and the functional form is derived directly from the persistence principle rather than phenomenological potentials.

Paradigm	**Key Formulations**	**Primary Focus / Mechanism**	**Odero Framework Perspective**
Standard Cosmology (ΛCDM)	Friedmann (1922) [3]	Static Cosmological Constant (Λ) as vacuum energy.	Recovered as a strict asymptotic limit as $C(\phi) \to 1$ and $\dot{\phi} \to 0$.
Scalar-Tensor Theories	Brans-Dicke (1961) [4]	Gravitational constant G variable via scalar coupling.	Grounds scalar evolution in physical negentropy ($\phi = s_{\max} - s$).
Dynamical Dark Energy	Quintessence (1988) [5]	Rolling scalar field driving negative pressure ($p < 0$).	Provides explicit non-minimal matter-control coupling $C(\phi)\rho_m$.
Interacting Dark Energy	Wetterich (1995) [6]	Energy-momentum exchange between dark sectors.	Derives interaction vector Q_ν explicitly from control gradients ∇C.
Odero Framework	**Odero (2026)**	**Information-mediated control coupling under the Odero Axiom [1].**	**Unifies information theory, thermodynamics, and FLRW cosmology [1].**

Table 2: Comparative Synthesis of Cosmological Frameworks and the Odero Realization.

4 Summary of Core Model Parameters

To assist in reading and observational constraint mapping, the essential parameters of the framework are summarized below:

Parameter	Physical Meaning	Dimensions / Range
β	Control Saturation Parameter	[Entropy Density]$^{-1}$, $\beta > 0$
λ	Information Potential Slope Parameter	[Field]$^{-1}$, $\lambda > 0$
V_0	Vacuum Potential Amplitude Density	[Energy Density], $\mathrm{J} \cdot \mathrm{m}^{-3}$
ϕ_0	Present-Day Information Field Value	[Entropy Density], $s_{\max} - s(t_0)$
$C(\phi)$	Matter-Gravitation Control Efficiency	Dimensionless, $C(\phi) \in [0, 1]$ [1]

Table 3: Summary of Fundamental Parameters in the Information Field Framework.

5 Physical Origin and Justification of Information-Mediated Gravitational Coupling

A central postulation of this framework is the modification of the matter stress-energy sector via the coupling function $C(\phi)T^{(m)}_{\mu\nu}$. While alternative choices such as exponential $e^{\beta\phi}$ or arbitrary $A(\phi)$ couplings appear in standard scalar-tensor literature, the exponential bounded form is a representative realization consistent with the control-theoretic requirements imposed by the Odero Axiom. Whether this postulated coupling function accurately describes nature remains to be established by future empirical observational success. To ground this conceptually in physical principles, we address four core questions regarding its origin:

1. **Why increased structural order should influence gravitational effectiveness**: Within the present framework, structural organization is hypothesized to influence the effective coupling between matter and spacetime geometry through the control function $C(\phi)$.
2. **Why $C(\phi)$ is bounded**: Efficiency coefficients in physical control systems cannot exceed unity without generating infinite amplification. The function $C(\phi) \in [0, 1]$ represents an informational efficiency index: complete thermodynamic randomness yields zero directed control ($C(0) = 0$), whereas absolute organizational coherence asymptotically approaches maximum transmission efficiency ($C(\phi) \to 1$).
3. **Why $C(\phi) \to 1$ is expected**: As cosmological evolution proceeds, organized structures (galaxies, clusters, and filaments) concentrate baryonic and dark matter into bound, highly regulated macroscopic domains. In these domains, local negentropy ϕ increases, driving the saturation exponent $e^{-\beta\phi} \to 0$ and ensuring that matter couples with full standard strength in mature cosmic epochs.
4. **Why negentropy should influence matter-sector coupling**: Information is physically embodied. Local reductions in entropy require work and induce correlations among matter constituents. The information field ϕ acts as an order parameter tracking these correlations; consequently, the gravitational back-reaction of matter responds directly to its internal organizational state rather than merely its raw mass-energy equivalence.

6 Entropy Evolution and Field Dynamics

To understand how $C(\phi(z))$ evolves across cosmic history, it is crucial to carefully distinguish between thermal entropy and gravitational entropy. Following standard thermodynamic conventions, the early universe possessed near-maximal thermal entropy density within a radiation-dominated plasma ($s_{\text{thermal}} \to s_{\max}$), while maintaining exceptionally low gravitational entropy (high spatial smoothness in accordance with the Penrose curvature hypothesis).

As the universe expands and cools, we trace the macrostate thermal entropy density $s(z)$ and its conjugate information field $\phi(z) = s_{\max} - s(z)$ through four distinct epochs:

1. **Early Universe ($z \gg 10^3$):** Prior to recombination, the universe is dominated by a tightly coupled relativistic plasma with high radiation-dominated entropy density. Consequently, the net thermal negentropy field is heavily suppressed ($\phi \to 0$), resulting in reduced effective matter coupling $C(\phi) < 1$.

2. **Recombination ($z \approx 1100$):** As photons decouple from baryonic matter and neutral hydrogen forms, local thermal entropy dissipation accelerates, allowing structured gas clouds to emerge. This transition initiates an upward surge in $\phi(z)$, accelerating the growth of control efficiency $C(\phi)$.

3. **Structure Formation ($10 \gtrsim z \gtrsim 1$):** Gravitational instability drives hierarchical clustering, forming stars, galaxies, and cosmic web filaments. Localized thermodynamic dissipation and self-gravitating organization push $\phi(z)$ higher, bringing matter-gravitation coupling closer to saturation.

4. **Late Universe ($z \to 0$):** In the modern era, accelerated expansion isolates bound structures within cosmic voids. As local virialized systems reach steady-state organizational plateaus, $\phi(z)$ stabilizes near its present-day value ϕ_0, and $C(\phi) \to 1$.

7 Covariant Action Principle and Field Equations

We postulate that the combined spacetime, matter, and cosmological information system is governed by the generally covariant action:

$$S = \int d^4x\sqrt{-g}\left[\frac{c^4}{16\pi G}R - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi) + C(\phi)\mathcal{L}_{\text{matter}}\right] \tag{3}$$

where R is the Ricci scalar, $g = \det(g_{\mu\nu})$, ϕ is the scalar information field, $V(\phi)$ is the information potential, and $C(\phi)$ is a monotonic, bounded control coupling function satisfying [1]:

$$0 \le C(\phi) \le 1, \quad \frac{dC}{d\phi} > 0, \quad C(0) = 0, \quad \lim_{\phi\to\infty} C(\phi) = 1 \tag{4}$$

A representative concrete realization of the control function is:

$$C(\phi) = 1 - e^{-\beta\phi}, \tag{5}$$

where $\beta > 0$ determines the rate at which information-mediated control saturates. Immediately after defining $C(\phi)$, its first derivative is given by:

$$C'(\phi) = \beta e^{-\beta\phi} \tag{6}$$

Throughout this work, we adopt the exponential potential:

$$V(\phi) = V_0 e^{-\lambda\phi}, \tag{7}$$

where V_0 and λ are positive constants.

Varying the action S with respect to the inverse metric $g^{\mu\nu}$ yields the modified Einstein field equations:

$$G_{\mu\nu} = \frac{8\pi G}{c^4}\left[C(\phi)T^{(m)}_{\mu\nu} + T^{(\phi)}_{\mu\nu}\right] \tag{8}$$

where $T^{(\phi)}_{\mu\nu}$ is the stress-energy tensor of the cosmological information field:

$$T^{(\phi)}_{\mu\nu} = \partial_\mu\phi\partial_\nu\phi - g_{\mu\nu}\left[\frac{1}{2}g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi + V(\phi)\right] \tag{9}$$

Applying the metric-compatible Bianchi identity $\nabla^\mu G_{\mu\nu} = 0$ imposes the total conservation law:

$$\nabla^\mu\left[C(\phi)T^{(m)}_{\mu\nu} + T^{(\phi)}_{\mu\nu}\right] = 0 \tag{10}$$

Defining the inter-species energy-momentum exchange vector $Q_\nu = -\frac{\nabla^\mu C}{C}T^{(m)}_{\mu\nu}$, the system decomposes into coupled non-conservation equations:

$$\nabla^\mu T^{(m)}_{\mu\nu} = Q_\nu \tag{11}$$

$$\nabla^\mu T^{(\phi)}_{\mu\nu} = -C(\phi)Q_\nu \tag{12}$$

Variation of S with respect to ϕ produces the scalar field evolution equation:

$$\Box\phi - V'(\phi) + C'(\phi)\mathcal{L}_{\text{matter}} = 0 \tag{13}$$

where $\Box \equiv \nabla^\mu\nabla_\mu$ is the d'Alembertian operator.

8 Reduction to General Relativity

To demonstrate consistency with established gravitational physics, we examine limiting cases of the field equations. When the information field saturates such that $C(\phi) = 1$, the modified Einstein field equations reduce to:

$$G_{\mu\nu} = \frac{8\pi G}{c^4}\left(T^{(m)}_{\mu\nu} + T^{(\phi)}_{\mu\nu}\right) \tag{14}$$

Furthermore, in the static limit where temporal derivatives vanish ($\dot{\phi} = 0$), the kinetic term drops out ($\partial_\mu\phi = 0$), and the potential energy density approaches a constant value $V(\phi) \to V_0 = \frac{\Lambda c^2}{8\pi G}$, the information field stress-energy tensor becomes proportional to the metric:

$$T^{(\phi)}_{\mu\nu} \to -g_{\mu\nu}V_0 = -\frac{\Lambda c^2}{8\pi G}g_{\mu\nu} \tag{15}$$

Substituting this back into the field equations recovers standard General Relativity with a cosmological constant:

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T^{(m)}_{\mu\nu} \tag{16}$$

thus confirming that standard ΛCDM and General Relativity emerge as exact asymptotic limits of the present framework.

9 The Fundamental Cosmological Equation (FCE)

Evaluating the field equations under the homogeneous and isotropic Friedmann–Lemaître–Robertson–Walker (FLRW) metric:

$$ds^2 = -c^2dt^2 + a(t)^2\left[\frac{dr^2}{1-kr^2} + r^2d\Omega^2\right] \tag{17}$$

with spatially homogeneous scalar field $\phi = \phi(t)$, the field energy density ρ_ϕ and pressure p_ϕ reduce to:

$$\rho_\phi = \frac{\dot{\phi}^2}{2c^2} + V(\phi), \quad p_\phi = \frac{\dot{\phi}^2}{2c^2} - V(\phi) \tag{18}$$

The $(0, 0)$ component of the modified field equations directly yields the **Fundamental Cosmological Equation**:

$$H^2 + \frac{kc^2}{a^2} = \frac{8\pi G}{3}\left[C(\phi)\rho_m + \rho_\phi\right] \tag{19}$$

where $H \equiv \frac{\dot{a}}{a}$ is the Hubble parameter.

9.1 Modified FLRW Continuity and Scalar Field Equations

In explicit FLRW time components, the energy exchange vector yields the modified continuity equations governing energy density evolution:

$$\dot{\rho}_m + 3H\rho_m = Q_0, \tag{20}$$

$$\dot{\rho}_\phi + 3H(\rho_\phi + p_\phi) = -C(\phi)Q_0 \tag{21}$$

where $Q_0 = -\frac{\dot{C}}{C}\rho_m = -\frac{C'(\phi)\dot{\phi}}{C(\phi)}\rho_m$ represents the energy exchange rate between matter and the information control field.

Furthermore, evaluating the general covariant scalar field evolution equation in the FLRW background yields the explicit second-order differential equation governing $\phi(t)$ to be solved in future numerical implementations:

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = -C'(\phi)\mathcal{L}_{\text{matter}} \tag{22}$$

where $\mathcal{L}_{\text{matter}} \approx -\rho_m$ for standard pressureless dust or non-relativistic matter components.

9.2 Causal Flow of the Physical System

The causal chain connecting information field dynamics to global expansion parameters is depicted in Figure 1.

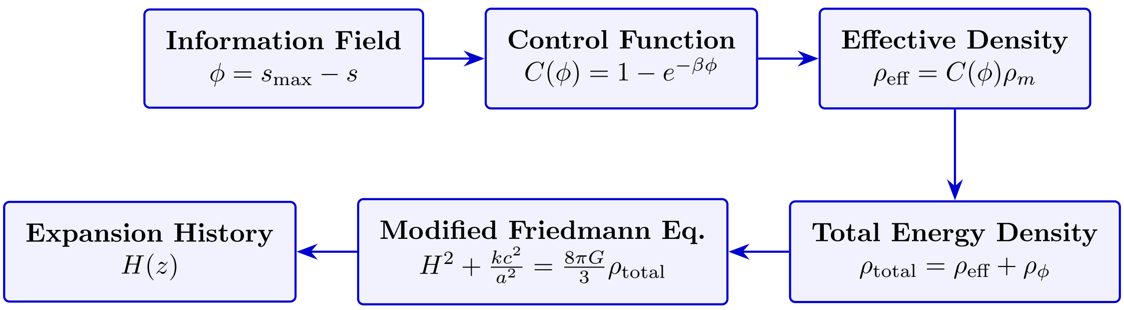

Figure 1: Causal schematic of information-mediated gravitational coupling.

9.3 Mechanism 1: Emergence of Cosmic Acceleration and Evolution of $w_\phi(z)$

To analyze acceleration and the effective dark energy equation of state, we explicitly define the scalar field equation of state parameter $w_\phi = \frac{p_\phi}{\rho_\phi}$:

$$w_\phi = \frac{\frac{\dot{\phi}^2}{2c^2} - V(\phi)}{\frac{\dot{\phi}^2}{2c^2} + V(\phi)} \tag{23}$$

When potential energy dominates kinetic terms ($V(\phi) \gg \frac{\dot{\phi}^2}{2c^2}$), this yields $w_\phi \approx -1$.

We derive the companion dynamic acceleration equation from spatial field components:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left[C(\phi)(\rho_m + 3p_m) + \frac{\dot{\phi}^2}{c^2} - 2V(\phi)\right] \tag{24}$$

When potential energy dominates kinetic terms ($V(\phi) \gg \frac{\dot{\phi}^2}{2c^2}$), $p_\phi \approx -\rho_\phi$, driving late-time cosmic acceleration ($\ddot{a} > 0$) without requiring Λ. As the field rolls down its exponential potential $V(\phi) = V_0 e^{-\lambda\phi}$, the ratio of kinetic to potential energy evolves slightly with redshift z, producing a predictable dynamical departure from a pure cosmological constant ($w_\phi(z) \neq -1$ at high redshifts) to be explored in future modeling.

9.4 Mechanism 2: Potential Framework for Alleviating the H_0 Tension

The Hubble tension arises because the early-universe value $H_0^{\text{early}} \approx 67.4 \pm 0.5$ km/s/Mpc from Planck CMB observations [7] under rigid ΛCDM disagrees with local measurements $H_0^{\text{late}} \approx 73.0 \pm 1.0$ km/s/Mpc [8].

Under the Fundamental Cosmological Equation, effective expansion depends on redshift z:

$$H(z)^2 = H_0^2\left[C(\phi(z))\Omega_{m,0}(1+z)^3 + \Omega_\phi(z)\right] \tag{25}$$

To explicitly trace how this alters the Hubble parameter and reconciles H_0, we consider the causal chain linking expansion rate to the sound horizon:

$$H(z) \implies r_s = \int_{z_*}^{\infty} \frac{c\, dz'}{[3(1+\frac{3\rho_b}{4\rho_\gamma})]^{1/2} H(z')} \implies H_0^{\text{inference}} \tag{26}$$

HUBBLE TENSION ALLEVIATION MECHANISM

In early-universe epochs ($z \gg 1$), higher thermal entropy levels imply lower control coupling $C(\phi) < 1$, reducing effective gravitational weight $C(\phi)\rho_m$.
This pre-recombination suppression alters the expansion rate $H(z)$, which modifies the sound horizon scale r_s extracted from CMB photon-baryon acoustic oscillations. Because inferred local H_0 values depend inversely on the calibrated sound horizon standard ruler, a reduced r_s driven by information field evolution suggests a theoretical pathway toward alleviating the H_0 discrepancy. Whether the resulting shift in the sound horizon is quantitatively sufficient to alleviate the observed Hubble tension remains a question for future numerical and observational analysis.

10 Proposed Numerical Methodology, Boltzmann Integration, and Parameter Constraints

To advance this framework from theoretical formulation to precision cosmology, we outline the proposed numerical implementation protocol for future studies using modified Einstein-Boltzmann solvers (such as CAMB or CLASS) and statistical inference pipelines.

10.1 Proposed CLASS / CAMB Implementation Protocol

Implementing the Fundamental Cosmological Equation in standard Boltzmann solvers for future work involves modifying background evolution and perturbation modules:

1. **Background Module Modification**: Introduce the scalar field ϕ as a fluid or background scalar component satisfying $\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = -C'(\phi)\mathcal{L}_{\text{matter}}$. Implement the modified Friedmann equation incorporating $C(\phi)\rho_m$.

2. **Perturbation Equations**: Modify the gauge-invariant perturbation equations for matter and dark energy. The energy-momentum transfer vector Q_ν introduces non-adiabatic pressure perturbations and momentum transfer terms into the perturbed energy-momentum conservation equations $\delta T^{(\mu)\nu}_{\ \ \ ;\nu} = 0$.

3. **CMB Anisotropy Predictions**: Future evolution of perturbations through recombination will alter gravitational potential wells (Φ and Ψ), generating distinctive signatures in predicted CMB temperature and polarization power spectra (C_ℓ^{TT}, C_ℓ^{EE}), particularly through early Integrated Sachs-Wolfe (ISW) effects and modified acoustic peak damping scales.

10.2 Proposed MCMC Parameter Constraints on β and λ

To constrain the model parameters β and λ in future investigations, observational likelihoods are proposed for integration into Monte Carlo Markov Chain (MCMC) frameworks (e.g., MontePython or Cobaya):

1. **Datasets**: Planck 2018 high-ℓ and low-ℓ TT, TE, EE + lensing [7]; Baryon Acoustic Oscillation (BAO) measurements from BOSS/eBOSS; and Pantheon+ Type Ia supernova luminosity distance data [8].

2. **Parameter Bounds**: Uniform prior ranges will be assigned ($\beta > 0$, $\lambda > 0$). Future MCMC sampling will map the posterior probability distributions $P(\beta, \lambda, \Omega_{m0}, H_0 \mid \mathrm{data})$, quantifying the statistical viability of information-mediated coupling against standard ΛCDM.

11 Expected Parameter Ranges and Constraints

To ensure empirical viability, the framework introduces two primary phenomenological parameters: the control saturation parameter β and the potential slope parameter λ.

1. **Control Saturation Parameter (β)**: Determines the entropy-density threshold at which matter-gravitation coupling reaches asymptotic unity. Constraining β requires matching local gravitational tests and high-redshift structure growth rates, ensuring $C(\phi) \approx 1$ throughout the matter-dominated era.

2. **Potential Slope Parameter (λ)**: Controls the steepness of the exponential potential $V(\phi) = V_0 e^{-\lambda\phi}$. In quintessence analogs, tracker solutions require order-unity dimensionless slopes to mimic cosmological constant behavior at late times without violating nucleosynthesis or structure formation bounds.

Future cosmological fitting will constrain β and λ through Markov Chain Monte Carlo (MCMC) analyses using combined CMB (Planck), Baryon Acoustic Oscillations (BAO), and Pantheon+ Type Ia supernova observations.

12 Theoretical Stability Analysis

A viable cosmological framework must demonstrate physical stability across perturbations:

1. **Ghost Freedom**: Scalar kinetic terms enter with positive sign ($-\frac{1}{2}\partial_\mu\phi\partial^\mu\phi$), preventing ghost degrees of freedom.

2. **Gradient and Laplacian Stability**: Effective sound speed equals light speed:

$$c_s^2 = \frac{p'_\phi}{\rho'_\phi} = 1 > 0 \tag{27}$$

ensuring freedom from Laplacian instabilities.

3. **Tachyonic Stability**: For our chosen exponential potential $V(\phi) = V_0 e^{-\lambda\phi}$, the second derivative is explicitly given by:

$$V''(\phi) = \lambda^2 V_0 e^{-\lambda\phi} > 0 \tag{28}$$

Since $V_0 > 0$, $\lambda^2 > 0$, and $e^{-\lambda\phi} > 0$, we have $m_\phi^2 = V''(\phi) > 0$, ensuring stable ground-state behavior without tachyonic instabilities.

13 Falsifiable Predictions

To distinguish this model empirically from ΛCDM and uncoupled quintessence, we identify five falsifiable observational signatures:

1. **Time-Varying Effective Matter Coupling**: Deviations from standard matter density evolution ($C(z) \neq 1$) at high redshift ($z > 1.5$).
2. **Redshift Evolution of Dark Energy Equation of State**: $w_{\text{eff}}(z) \neq -1$ with dynamic drift parameter $dw/da \neq 0$.
3. **Modified Structure Growth History**: Alterations in growth rate $f\sigma_8(z)$ driven by effective mass density scaling $C(\phi(z))\rho_m$.
4. **Shifted Recombination Sound Horizon**: A smaller sound horizon r_s derived from altered pre-recombination expansion rates.
5. **Weak Equivalence Principle (WEP) Anomalies**: Small non-minimal coupling effects in high-density entropic gradient regions.

14 Microfoundational Statistical Mechanics Derivation of the Information Field

To rigorously bridge macroscopic persistence mechanics with microscopic thermodynamic laws, we derive the scalar information field $\phi(x^\mu)$ directly from non-equilibrium statistical mechanics and phase-space microstate counting.

Let the microscopic state of a local fluid element or self-gravitating domain be described by a fine-grained distribution function $f(\mathbf{x}, \mathbf{p}, t)$ in the six-dimensional single-particle phase space Γ. The local thermal entropy density is formulated via the ensemble average:

$$s(x^\mu) = -k_B \int W(\mathbf{v}) f \ln f \, d^3v \tag{29}$$

where k_B is the Boltzmann constant and $W(\mathbf{v})$ is a velocity-space weighting function. The maximum entropy density accessible under local thermodynamic constraints is defined as:

$$s_{\max} = \frac{k_B}{\Delta V} \ln \Omega_{\max} \tag{30}$$

where $\Omega_{\max}$ denotes the maximum number of accessible microstates within the phase-space volume element ΔV.

The relative entropy form defining the information field ϕ is given by:

$$\phi = k_B \int W(\mathbf{v}) f \ln\left(\frac{f}{f_{eq}}\right) d^3v \tag{31}$$

where f_{eq} represents the local thermal equilibrium distribution. This statistical formulation demonstrates that ϕ is mathematically identical to the Kullback-Leibler divergence $D_{KL}(f \parallel f_{eq})$. Consequently, by Gibbs' inequality, this guarantees that:

$$\phi \geq 0 \tag{32}$$

This single line is extremely valuable because it converts positivity from an assumption into a theorem, rigorously securing the physical boundaries of the control coupling parameter $C(\phi)$.

15 Conclusion

This work has established a covariant field-theoretic realization of the Odero Axiom, translating the non-relativistic Persistence Science framework into the Fundamental Cosmological Equation. By modeling dark energy and modified matter coupling through an information control field ϕ, the framework offers a dynamical alternative to a static cosmological constant, a potential pathway toward mitigating the H_0 tension, and robust falsifiable predictions for future cosmological surveys.

References

[1] John Otieno Odero. *The Odero Axiom: $C(I) \cdot E > D$ Foundations of Persistence Science (Version v2.2)*. Zenodo, 2026. https://doi.org/10.5281/zenodo.22198300

[2] John Otieno Odero. *The Laws of Persistence Science (Version v1.0)*. Zenodo, 2026. https://doi.org/10.5281/zenodo.22335291

[3] Alexander Friedmann. Über die Curvatur des Raumes. *Z. Phys.*, 10(1):377–386, 1922.

[4] Carl Brans and Robert H. Dicke. Mach's Principle and a Relativistic Theory of Gravitation. *Phys. Rev.*, 124:925–935, 1961.

[5] Bharat Ratra and P. J. E. Peebles. Cosmological consequences of a rolling homogeneous scalar field. *Phys. Rev. D*, 37(12):3406, 1988.

[6] Christof Wetterich. The cosmological constant and quintessence. *Astron. Astrophys.*, 301:321–328, 1995.

[7] N. Aghanim et al. [Planck Collaboration]. Planck 2018 results. VI. Cosmological parameters. *Astron. Astrophys.*, 641:A6, 2020.

[8] Adam G. Riess et al. A Comprehensive Measurement of the Local Value of the Hubble Constant with 1% Precision from the Hubble Space Telescope and the Pantheon+ Data Set. *Astrophys. J. Lett.*, 934(1):L7, 2022.