Covariant Structural Admissibility in Open Systems:

A Falsifiable Culmination Theory from Persistence to Weak-Field Gravity

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April 2026

Abstract

I present a culmination framework for open physical systems in which persistence, selection, structure, and gravity are unified within a covariant scalar–tensor theory. The construction proceeds in four steps. First, irreversible loss in open systems is encoded by a positive semi-definite Universal Selection Operator K, and persistence is defined by a repair inequality balancing maintenance against loss. Second, persistent organization is represented by a structural density $\sigma(x)$ obeying a continuity law in which sustained structure requires energy throughput. Third, admissibility is promoted to a dimensionless spacetime scalar $\Xi(x)$ whose field equations reduce to General Relativity in a stationary limit and yield Yukawa-screened weak-field corrections. Fourth, the structural density of driven non-equilibrium systems is promoted into the covariant matter sector, generating a nonzero effective trace in the stress–energy tensor even when the underlying electromagnetic sector is traceless. This structural trace sources the admissibility field and produces a modified Poisson equation in which continuously driven, highly constrained systems can, in principle, generate measurable local deviations in effective gravitational acceleration.

The paper states the full action, derives the field equations, identifies the equilibrium recovery limits, and formulates sharp experimental tests. The theory is falsifiable: if local gravimetric, interferometric, or resonant measurements near high-throughput, high-constraint systems fail to scale with the predicted structural source term after standard electromagnetic, thermal, acoustic, vibrational, and buoyancy backgrounds are removed, the framework is ruled out in its present form. I distinguish clearly between what is derived, what is inferred, and what remains conjectural.

1. Introduction

Most of physics is formulated around closed or effectively closed systems. Yet the systems that persist in practice—living cells, stars, plasmas, superconducting devices, turbulent media, reactors, ecosystems, and detectors—are open: they survive only by continuously offsetting irreversible loss. This motivates a foundational question: what dynamical quantity distinguishes mere transient order from persistent physical structure? Schrödinger framed this in thermodynamic language as the ability of life to maintain order by "feeding on negative entropy" [1]. The broader question is more general: what allows any structured open system to persist at all in the presence of irreversible failure modes?

In earlier work I introduced the Universal Selection Operator (USO), a positive semi-definite operator K encoding irreversible loss channels in open systems [11, 12]. Persistence then becomes a rate-balance condition rather than a static property. I next argued that selection induces a geometry on state space [13], that universality classes can be organized by the geometry of survival rather than by shared microphysics [14], and that persistent organization can be represented by a structural density obeying a continuity relation under energy throughput [15]. I then introduced a scalar admissibility field $\Xi(x)$ coupled to geometry and stress–energy, with General Relativity recovered in a stationary limit and Yukawa-screened corrections appearing in the weak-field regime [16]. Subsequent applications suggested non-factorizable conditioning in correlated systems [17], selection-load organization in chaotic N-body outcomes [18], and phenomenological admissibility structure in collider data [19].

The aim of the present paper is to state the full culmination theory in one place and in a form designed to be *rigorous, explicit, and falsifiable.* The central claim is not that anomalous gravity has been observed. The central claim is narrower and theoretical: *if* sustained non-equilibrium structure is a covariant physical load, then it contributes a traceful sector to the effective stress–energy tensor, and this sector sources the admissibility field in precisely those regimes where ordinary traceless fields would not. From this claim follows a modified weak-field equation and a family of laboratory predictions.

The paper is organized as follows. In section 2 I restate the open-system foundation. In section 3 I define structural density and its continuity law. In section 4 I summarize the admissibility field equations. In section 6 I promote structural density covariantly and derive the effective stress–energy trace. In **??** I derive the weak-field limit and modified Poisson equation. In section 8 I state falsifiable predictions and null tests. In section 10 I delimit what the theory does and does not yet establish.

2. Open-system foundation: persistence, loss, and repair

2.1. Universal Selection Operator

Let $\rho(t)$ denote the density operator, or more generally the state distribution, of an open physical system. In the USO framework, irreversible loss is represented by a positive semi-definite operator $K \geq 0$ entering the evolution law as

$$\frac{d\rho}{dt} = \mathcal{L}(\rho) - \frac{1}{2}\{K, \rho\} + M[\rho], \tag{1}$$

where $\mathcal{L}$ denotes reversible dynamics and $M[\rho]$ denotes maintenance, repair, replenishment, or externally supplied compensation [11, 12]. The trace evolves as

$$\frac{d}{dt}\operatorname{Tr}(\rho) = -\operatorname{Tr}(K\rho) + \operatorname{Tr}(M[\rho]). \tag{2}$$

Definition 1 (Persistence)**.** *A system is persistent on a timescale τ if $\operatorname{Tr}(\rho(t))$ remains nonzero on that timescale.*

Definition 2 (Repair inequality)**.** *Persistence requires*

$$\operatorname{Tr}(M[\rho]) \geq \operatorname{Tr}(K\rho). \tag{3}$$

Equation (3) states that persistence is a dynamical inequality, not a metaphysical category. Open systems survive only by offsetting irreversible loss with external free-energy-driven maintenance [2, 1]. This is the conceptual origin of the throughput term that later appears covariantly.

2.2. Selection geometry and non-factorizability

The operator K induces a geometry of survivability on state space [13]. In this geometry, trajectories differ not only by kinematics but by differential exposure to loss. This provides the conceptual basis for treating survival landscapes, selection loads, and admissibility gradients as physically meaningful observables.

A separate structural result is relevant later: under flat marginals, nontrivial pair correlations cannot be generated by fully factorized conditioning [17]. This theorem matters because the present theory is not local bookkeeping over independent subsystems; it is a global conditioning theory in which persistent configurations can be organized by non-factorizable admissibility constraints.

3. Structure as a physical load

3.1. Structural density

In earlier work I defined structure as constraint-bearing organization relative to an unconstrained entropy baseline [15]. Let X be the state space and $\rho(x,t)$ a normalized density. A structural density can be written schematically as

$$\sigma(x,t) = -\rho(x,t)\ln\rho(x,t) - S_{\text{baseline}}(x), \tag{4}$$

with integrated structural load

$$\mathcal{S}(t) = \int_X \left[S_{\max}(E) - S(\rho(x,t))\right] dx. \tag{5}$$

The details of coarse-graining can vary across applications; what matters here is that σ measures deviation from an admissible maximal-entropy reference at fixed energy.

3.2. Structural continuity law

The key open-system relation is the structural continuity equation

$$\frac{d\mathcal{S}}{dt} + \Phi_{\text{diss}} = \Pi_{\text{input}}, \tag{6}$$

where $\Phi_{\text{diss}} \geq 0$ is structural dissipation and Π_{input} is structural input supplied by ongoing energy throughput [15]. For closed systems, $\Pi_{\text{input}} = 0$ and therefore $d\mathcal{S}/dt \leq 0$: structure decays monotonically.

Equation (6) is the bridge from open-system persistence to covariant field theory. It states that nonequilibrium structure is not free: it is maintained against dissipation by a sustained throughput. The claim of the present paper is that this maintained load must appear in the covariant matter sector.

4. Admissibility as a covariant scalar field

I summarize the previously proposed admissibility field theory [16]. Admissibility is represented by a dimensionless scalar field $\Xi(x) > 0$ on spacetime, interpreted as a local measure of dynamical viability or persistence under load. The action is

$$S_\Xi = \int d^4x\sqrt{-g}\left[\frac{M_{\text{Pl}}^2}{2}\Xi R - \frac{\omega}{2\Xi}(\nabla\Xi)^2 - V(\Xi) + \mathcal{L}_m\right]. \tag{7}$$

Variation yields the metric equations

$$\Xi G_{\mu\nu} = \frac{1}{M_{\text{Pl}}^2}\left(T_{\mu\nu} + T_{\mu\nu}^{(\Xi)}\right), \tag{8}$$

with

$$T_{\mu\nu}^{(\Xi)} = \frac{\omega}{\Xi}\left(\nabla_\mu\Xi\nabla_\nu\Xi - \frac{1}{2}g_{\mu\nu}(\nabla\Xi)^2\right) + \nabla_\mu\nabla_\nu\Xi - g_{\mu\nu}\Box\Xi - g_{\mu\nu}V(\Xi), \tag{9}$$

and the scalar equation

$$M_{\text{Pl}}^2 R + \frac{\omega}{\Xi^2}(\nabla\Xi)^2 - \frac{2\omega}{\Xi}\Box\Xi - V'(\Xi) = 0. \tag{10}$$

4.1. Stationary and weak-field limits

If $\nabla_\mu\Xi = 0$ and $\Xi = \Xi_0$ sits at a minimum of V, General Relativity is recovered as the stationary configuration [16]. In the weak-field expansion,

$$\Xi = 1 + \delta\Xi, \qquad |\delta\Xi| \ll 1, \tag{11}$$

with quadratic potential

$$V(\Xi) = \frac{1}{2}m_\Xi^2(\Xi - 1)^2, \tag{12}$$

the scalar dynamics reduce to a sourced Klein–Gordon equation of the schematic form

$$(\Box - m_\Xi^2)\delta\Xi = \frac{1}{2\omega M_{\text{Pl}}^2}T, \tag{13}$$

where $T = g^{\mu\nu}T_{\mu\nu}$ is the trace of the matter stress–energy tensor. In the static nonrelativistic limit this modifies Poisson's equation to

$$\nabla^2\Phi = 4\pi G\rho + \frac{1}{2}\nabla^2\delta\Xi, \tag{14}$$

yielding Yukawa-screened corrections [6, 7].

The crucial point is that *the source is the trace*. Pure radiation and the standard electromagnetic sector are traceless in the relevant limit, so they do not directly source Ξ through (13). This is exactly where structural loading becomes necessary.

5. Covariant promotion of structural density

5.1. Motivation

A driven, constrained, far-from-equilibrium system is not equivalent to an equilibrium lump of the same invariant mass. The reason is not mystical. The reason is that maintaining its constrained structural state requires continual throughput, and that throughput is organized by spatially and temporally varying structural gradients. If the theory of admissibility is to couple to physical organization rather than to rest mass alone, the covariant matter action must include the maintained structural load.

5.2. Effective action

I therefore promote the structural density $\sigma(x)$ to a covariant scalar sector and define the effective matter Lagrangian density

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_m + \mathcal{L}_{\text{EM}} + \lambda\left(\partial_\mu\sigma\partial^\mu\sigma - \Pi(x)\right). \tag{15}$$

Here:

- $\mathcal{L}_m$ is the ordinary matter Lagrangian;
- $\mathcal{L}_{\text{EM}}$ is the electromagnetic Lagrangian;
- $\sigma(x)$ is the structural density field;
- $\Pi(x)$ is the local structural input density required to offset dissipation;
- λ is a coupling constant with units chosen so that $\mathcal{L}_{\text{eff}}$ has units of energy density.

This is an effective theory. It is not claimed that (15) is the unique ultraviolet completion. It is the lowest-order covariant ansatz consistent with the earlier structural continuity law and with the requirement that spatially varying structural organization contribute to the action.

5.3. Effective stress–energy tensor

Varying the action with respect to $g^{\mu\nu}$ gives

$$T^{\text{eff}}_{\mu\nu} = T^{(m)}_{\mu\nu} + T^{(\text{EM})}_{\mu\nu} + T^{(\sigma)}_{\mu\nu}, \tag{16}$$

where

$$T^{(\sigma)}_{\mu\nu} = 2\lambda\,\partial_\mu\sigma\,\partial_\nu\sigma - g_{\mu\nu}\lambda\left(\partial_\alpha\sigma\,\partial^\alpha\sigma - \Pi\right). \tag{17}$$

Taking the trace in four dimensions yields

$$T_{\text{eff}} = T_m + T_{\text{EM}} + T_\sigma = T_m - 2\lambda\,\partial_\mu\sigma\,\partial^\mu\sigma + 4\lambda\,\Pi, \tag{18}$$

where $T_{\text{EM}} = 0$ for the standard electromagnetic sector in four dimensions.

Equation (18) is the central structural result. Even when the electromagnetic sector is intrinsically traceless, a *driven structural state* built and maintained by that sector can generate a nonzero *effective* trace through the covariant structural load.

5.4. Comments on interpretation

Three comments are important.

First, σ is not introduced as an arbitrary scalar field unrelated to the earlier framework. It is the covariant continuation of the structural density already defined in the conservation-of-structure program.

Second, the throughput term Π is not extra mass. It is the local rate at which externally supplied free energy is consumed to maintain structure against dissipation. Its appearance with positive sign in the trace is a direct reflection of the continuity law (6).

Third, the gradient term $-2\lambda\,\partial_\mu\sigma\,\partial^\mu\sigma$ means that steep structural localization can compete against ordinary positive mass-density sourcing. This competition is where the possibility of anomalous weak-field behavior enters.

6. Field equations of covariant structural admissibility

Substituting the effective trace (18) into the weak-field admissibility equation (13) gives

$$(\Box - m_\Xi^2)\delta\Xi = \frac{1}{2\omega M_{\text{Pl}}^2}\left(T_m - 2\lambda\,\partial_\mu\sigma\,\partial^\mu\sigma + 4\lambda\,\Pi\right). \tag{19}$$

For a stationary driven system, $\partial_t = 0$, and in the nonrelativistic limit $T_m \simeq \rho_m c^2$. Then

$$\nabla^2\delta\Xi - m_\Xi^2\delta\Xi = -\frac{1}{2\omega M_{\text{Pl}}^2}\left(\rho_m c^2 - 2\lambda|\nabla\sigma|^2 + 4\lambda\Pi\right). \tag{20}$$

Combining (20) with (14), the gravitational potential obeys

$$\nabla^2\Phi = 4\pi G\rho_m + \frac{1}{2}\nabla^2\delta\Xi. \tag{21}$$

Inside the screening radius, where $r \ll m_\Xi^{-1}$ and the screening term can be neglected at leading order, we obtain

$$\nabla^2\Phi \approx 4\pi G\rho_m - \frac{1}{4\omega M_{\text{Pl}}^2}\left(\rho_m c^2 - 2\lambda|\nabla\sigma|^2 + 4\lambda\Pi\right). \tag{22}$$

Equation (22) is the weak-field culmination equation of the framework. It states that the local effective gravitational source is not determined solely by invariant mass density. It is altered by the maintained structural density gradients and by the ongoing throughput required to sustain them.

7. Recovery limits and consistency conditions

Any viable extension of gravity must recover standard physics in the appropriate limits. The present framework does so only under explicit conditions, which I list to make the falsifiability transparent.

7.1. Closed or equilibrium limit

If the system is closed or effectively equilibrated, then

$$\nabla\sigma \approx 0, \qquad \Pi \approx 0. \tag{23}$$

Equation (19) reduces to the ordinary admissibility sourcing by invariant matter trace, and (22) reduces to the previous weak-field admissibility correction. If, in addition, $\delta\Xi \to 0$, General Relativity is recovered.

7.2. Pure radiation limit

For a pure electromagnetic configuration in vacuum with no maintained structural sector,

$$T_{\rm EM} = 0, \qquad \sigma = \text{const}, \qquad \Pi = 0, \tag{24}$$

so the present theory predicts no direct structural sourcing from the electromagnetic field alone. The predicted effect is *not* "electricity gravitates differently." The predicted effect is that *externally maintained structural nonequilibrium* contributes an effective trace.

7.3. Weak-coupling limit

If $\lambda \to 0$ or if $\omega \to \infty$, the structural contribution decouples from the admissibility field, and standard weak-field behavior is recovered.

7.4. Stability and sign conditions

The effective theory should be regarded as viable only in parameter regimes satisfying:

1. positivity of the background kinetic sector for Ξ;
2. boundedness of the structural effective action in the regime of use;
3. absence of runaway growth in σ under realistic throughput;
4. compatibility with existing null results from weak-field gravitational experiments.

Failure of any of these conditions falsifies the model or forces a revision of the effective ansatz.

8. Observables and falsifiable predictions

A culmination theory is not scientific unless it risks failure. The present theory makes direct, testable predictions.

8.1. Structural source law

Define the *structural source density*

$$\mathcal{Q}_\sigma(x) \equiv -2\lambda|\nabla\sigma|^2 + 4\lambda\Pi. \tag{25}$$

Then in the near-field weak-screening regime the anomalous part of the gravitational source scales linearly with $\mathcal{Q}_\sigma$:

$$\Delta(\nabla^2\Phi) \propto \mathcal{Q}_\sigma. \tag{26}$$

This implies the following falsifiable scaling law: two apparatuses with equal rest mass but different sustained non-equilibrium structural loads should exhibit different local gravimetric signatures, with the difference correlated with a measurable proxy for $\mathcal{Q}_\sigma$.

8.2. Turn-on/turn-off prediction

Because Π is a throughput term, the effect should be *state-dependent and reversible.* A device driven into a high-constraint state should produce a different signal from the same device at thermal equilibrium, with the signal disappearing when the throughput is removed and the structural gradients relax.

8.3. Geometry dependence

The gradient term depends on $|\nabla\sigma|^2$. Therefore, holding total power fixed while changing the spatial concentration of structural constraint should change the signal. Highly localized structural gradients are predicted to be more effective than diffuse loads.

8.4. Screening prediction

Because the admissibility sector is Yukawa-screened, any effect should exhibit a finite characteristic range m_Ξ^{-1}. If a putative signal does not show any range dependence or shows the wrong range dependence, the theory is disfavored.

8.5. Frequency-domain prediction

If the structural sector is periodically modulated, the gravitational anomaly should contain synchronous components phase-locked to the modulation of $\mathcal{Q}_\sigma(t)$, not merely to the input electrical signal. This helps distinguish the theory from straightforward electromagnetic pickup.

8.6. Null tests

The theory is falsified in its present effective form if careful experiments show one or more of the following:

1. no signal scaling with throughput after ordinary systematics are removed;
2. no dependence on structural localization at fixed power;
3. no reversible state-dependence between driven and equilibrium configurations;

4. no range behavior consistent with screened propagation;
5. observed anomalies fully explained by electrostatics, magnetostriction, buoyancy, acoustic coupling, thermal gradients, corona discharge, ion wind, dielectric charging, seismic pickup, or readout artifacts.

9. Experimental program

The theory motivates, but does not by itself establish, a laboratory program. Candidate platforms are those in which large throughput and high structural constraint coexist:

- cryogenic rapidly rotating lattices;
- driven superconducting or superfluid systems;
- high-field stressed dielectrics;
- resonantly pumped metamaterials;
- pulsed plasma or discharge systems with controlled geometry.

A minimal experiment would compare a driven state and a matched undriven control using:

1. a torsion balance or superconducting gravimeter for local acceleration;
2. environmental monitors for electromagnetic, thermal, acoustic, and vibrational contamination;
3. blind randomized drive cycles;
4. geometric variants that separate power from constraint localization.

A more decisive experiment would jointly measure the candidate structural proxy

$$\widehat{\mathcal{Q}}_\sigma = a_1 P_{\text{in}} + a_2 \int |\nabla\chi|^2 d^3x + \cdots , \tag{27}$$

for some experimentally calibrated order parameter χ, and test whether the gravimetric anomaly collapses onto a single curve versus $\widehat{\mathcal{Q}}_\sigma$. If no such collapse exists, the theory fails in operational form.

10. Relation to existing physics

This framework is not intended to replace the Standard Model, nonequilibrium statistical mechanics, or General Relativity in their validated regimes. It is an effective extension motivated by open-system persistence.

Relative to scalar–tensor gravity, the novelty is not the existence of a scalar field per se [5, 6, 7]. The novelty is the *source*: a covariant structural trace generated by maintained non-equilibrium organization. Relative to nonequilibrium thermodynamics [2, 3, 4], the novelty is promoting sustained structure itself into a covariant load-bearing sector. Relative to conventional emergent-gravity narratives, the present proposal remains explicitly field-theoretic and experimentally falsifiable.

The framework also does *not* claim that every anomaly report in the literature is explained by structural admissibility. It only claims that if a genuine effect exists in driven, highly constrained systems, then (22) provides a concrete mechanism to test against null hypotheses.

11. Discussion

The progression of the program can now be stated compactly. Open systems persist only by satisfying a repair inequality against irreversible loss. Persistent organization is a structural load maintained by throughput. Admissibility is a covariant scalar field responding to stress–energy trace. Therefore, if maintained structure contributes a traceful covariant sector, extreme non-equilibrium organization can source admissibility gradients and modify effective weak-field gravity.

The theory is attractive for one reason and vulnerable for the same reason: it is economical. The same logic that explains persistence under selection, structural continuity under throughput, and admissibility screening across scales is extended here into the gravitational weak-field sector. If the lab tests fail, the theory does not merely lose an application; it loses its strongest physical culmination. That is scientifically desirable.

There are clear limitations. The present paper is an effective theory. I have not derived σ from a unique microscopic coarse-graining procedure valid across all media. I have not proven renormalizability, established a unique UV completion, or shown compatibility with every existing precision test of gravity. I have not experimentally measured $\mathcal{Q}_\sigma$ directly. Those are not small omissions. They define the frontier between a structured research program and an established theory.

12. Conclusion

I have presented a single culmination paper unifying four ingredients: irreversible loss in open systems, structural continuity under energy throughput, admissibility as a scalar–tensor field, and the covariant promotion of maintained structural density into the matter action. The resulting effective stress–energy trace,

$$T_{\text{eff}} = T_m - 2\lambda\, \partial_\mu\sigma\, \partial^\mu\sigma + 4\lambda\, \Pi,$$

sources the admissibility field and yields a modified weak-field equation in which highly constrained, continuously driven systems can in principle alter their local effective gravitational potential.

The theory is falsifiable. It predicts reversible, state-dependent, geometry-dependent, screened anomalies tied not merely to electrical input but to sustained structural load. If those signatures are absent under clean controls, the framework fails in its present form. If they are present and scale with the predicted source term, then the long program from persistence to covariant structure will have crossed from speculative mathematical architecture into physics.

Acknowledgments

The author thanks the open scientific literature and public data efforts that make independent theoretical development possible.

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