Concept Paper

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The Lugon Framework Informational Foundations of Physical Law. Part II – The Kernel and the Unified Invariants of Physical Law

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The Lugon Framework Informational Foundations of Physical Law. Part II — The Kernel and the Unified Invariants of Physical Law

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This paper is part of an ongoing research program titled **The Lugon Framework: Informational Foundations of Physical Law.** The framework investigates how a sequestered informational domain can interact with the energetic and causal structures of spacetime without violating established conservation and symmetry principles. Each installment develops a separate aspect of this integration, progressing from the definition of the informational sector to the dynamics of its kernel and the unification of known physical invariants.

Abstract

Building on the sequestered informational sector introduced in *Paper I*, this work formalizes the **Lugon Kernel ($\mathcal{K}$)** as the operative mechanism that binds informational and physical domains into a coherent whole. The kernel enforces four invariants—**energy**, **information**, **causality**, and **resonance**—which together constitute the minimal conditions for lawful cross-domain interaction. By representing these invariants as coupled geometries within the dual-cone model, the framework derives an **informational curvature** term that recovers classical, quantum, thermodynamic, and relativistic behavior as limiting cases. The analysis shows that known physical laws emerge from the coupling dynamics of informational and energetic sectors without violating conservation principles or Lorentz symmetry. Observable consequences include coherence-phase effects and constraint-propagation anomalies in quantum and gravitational systems, offering concrete avenues for experimental verification.

Keywords: Informational Physics; Lugon Kernel; Relativity; Quantum Mechanics; Causality; Conservation Laws; Unified Field Dynamics; Lugon Framework

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One-sentence significance

I show that energy, information, causality, and resonance emerge as unified invariants from a single variational kernel coupling spacetime and informational metrics without violating relativity or thermodynamics.

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Parent Action and Field Equations

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To establish the unifying basis of the Lugon framework, I begin with a single parent action that generates both the relativistic dynamics of the spacetime manifold R and the informational dynamics of the sequestered manifold Q. The objective is to maintain symmetry between energetic and informational degrees of freedom while ensuring that no term in the action permits an energy exchange across the $R \leftrightarrow Q$ interface.

I write the total action as the sum of three contributions:

$$S_P = S_R[g_{\mu\nu}] + S_Q[q_{ab}] + S_{\text{int}}[g_{\mu\nu}, q_{ab}, \Phi]$$

Here S_R is the Einstein–Hilbert term that governs curvature in spacetime, S_Q represents the informational curvature on the Q-manifold, and S_{int} enforces the sequestering constraint that allows informational influence without energetic coupling.

The relativistic sector remains the conventional form

$$S_R = \frac{1}{16\pi G}\int d^4x\sqrt{-g}\,R$$

where R is the Ricci scalar constructed from the metric $g_{\mu\nu}$.
The informational sector mirrors this structure:

$$S_Q = \frac{1}{16\pi\Gamma}\int d^4\zeta\sqrt{-q}\,\mathcal{R}_Q$$

where $\mathcal{R}_Q$ is the curvature scalar of the informational metric q_{ab} , and Γ plays the role of an informational coupling constant with units of inverse action.

To prevent energetic contamination between the two domains, I introduce an interaction term that acts as a local constraint:

$$S_{\text{int}} = \int d^4x\sqrt{-g}\,\lambda(x)\,[\mathcal{I}(q_{ab}, g_{\mu\nu}, \Phi) - \text{const.}]$$

where $\lambda(x)$ is a Lagrange multiplier enforcing local informational conservation consistent with the constrained Hamiltonian treatment of field dynamics [8]. The invariant functional $\mathcal{I}$ quantifies the equivalence of informational content between R and Q at each gate.

Variational Equations

Variation of S_P with respect to the three independent fields—$g_{\mu\nu}$, q_{ab}, and λ—produces the coupled field equations of the theory.

1. **Variation with respect to $g_{\mu\nu}$:**

$$G_{\mu\nu} = 8\pi G\,T^{(Q)}_{\mu\nu}$$

where $T^{(Q)}_{\mu\nu}$ arises from the interaction term and represents the informational stress–energy tensor. It does not contain real energy or momentum; instead, it measures configurational curvature imposed by the informational constraint.

2. **Variation with respect to q_{ab}:**

$$\mathcal{G}_{ab} = 8\pi\Gamma\,\mathcal{T}^{(R)}_{ab}$$

which is the informational analogue of the Einstein equation on the Q-manifold. The tensor $\mathcal{T}^{(R)}_{ab}$ encodes the projection of spacetime curvature into informational geometry through the gate function Φ.

3. **Variation with respect to λ:**

$$\mathcal{I}(q_{ab}, g_{\mu\nu}, \Phi) = \text{const.}$$

which enforces informational conservation: no net transfer of information occurs across the interface beyond what is encoded by the gates.

Coupling Function

A minimal and symmetric choice for the coupling functional $\mathcal{I}$ that satisfies sequestering and covariance is

$$\mathcal{I}(q, g, \Phi) = q^{ab} \nabla_a \Phi \nabla_b \Phi - \eta\, g^{\mu\nu} \nabla_\mu \Phi \nabla_\nu \Phi$$

where η is a dimensionless sequestering constant. The field Φ acts as a gate variable that allows information to traverse the Q-manifold at superluminal velocity while its projection into R remains subluminal, preserving causal structure in the relativistic frame.

Interpretation

This parent action provides a common variational origin for both spacetime curvature and informational curvature. The resulting field equations guarantee that informational degrees of freedom are conserved, covariant, and non-energetic. Each term in the parent action has a clear empirical analog: S_R reproduces general relativity, S_Q defines the informational manifold's curvature, and S_{int} sequesters them through a local invariant constraint. From this foundation, I derive the gate-field dynamics that govern Lugon propagation and establish the measurable invariants described in the following sections.

Gate-Field (Lugon) Equation of Motion

Having established the parent action, I now derive the field equation that governs the gate variable Φ, which mediates the coupling between the relativistic manifold R and the informational manifold Q. The gate field defines how information propagates across the sequestering interface—how Lugons travel through Q while remaining consistent with relativistic causality in R.

The starting point is the interaction term from the parent action,

$$S_{\text{int}} = \int d^4x \sqrt{-g}\, \lambda(x) \left[\mathcal{I}(q_{ab}, g_{\mu\nu}, \Phi) - \text{const.} \right]$$

where the coupling functional is

$$\mathcal{I}(q, g, \Phi) = q^{ab} \nabla_a \Phi \nabla_b \Phi - \eta\, g^{\mu\nu} \nabla_\mu \Phi \nabla_\nu \Phi$$

Variation with Respect to Φ

Varying the total action S_P with respect to Φ yields the **gate-field equation of motion**. I take the derivative under the integral, integrate by parts, and discard boundary terms under the assumption that $\delta\Phi = 0$ at infinity. The resulting Euler–Lagrange equation is

$$\nabla_a \left(\sqrt{-q}\, q^{ab} \nabla_b \Phi \right) - \eta \frac{\sqrt{-g}}{\sqrt{-q}} \nabla_\mu \left(\sqrt{-g}\, g^{\mu\nu} \nabla_\nu \Phi \right) = 0$$

This is the general form of the Lugon equation of motion. It describes how information encoded in Φ propagates in both manifolds, modulated by the sequestering parameter η.

Reduced Form and Interpretation

In local coordinates where the gate coupling is uniform and the Jacobians between R and Q are constant, the equation simplifies to a differential wave form:

$$\Box_Q \Phi - \eta\, \Box_R \Phi = 0$$

where

$$\Box_Q \equiv q^{ab} \nabla_a \nabla_b, \quad \Box_R \equiv g^{\mu\nu} \nabla_\mu \nabla_\nu$$

The term $\Box_Q \Phi$ governs informational propagation in the Q-manifold, while $\Box_R \Phi$ represents the projection of that propagation into spacetime. The ratio between their characteristic speeds is set by the sequestering constant:

$$v_Q = \frac{c}{\sqrt{\eta}}$$

For $0 < \eta < 1$, the informational wave in Q travels faster than c without violating relativistic causality, because the projection into R remains bounded by c. In this sense, the Lugon represents

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an information carrier rather than a particle: it transfers *state configuration* without energy or momentum exchange.

Conservation Law

Taking the covariant divergence of the equation of motion gives a local conservation condition. Multiplying by $\nabla^a\Phi$ and simplifying yields

$$\nabla_a J^a_Q - \eta \nabla_\mu J^\mu_R = 0$$

where the informational currents are defined as

$$J^a_Q = q^{ab}\nabla_b \Phi, \quad J^\mu_R = g^{\mu\nu}\nabla_\nu \Phi$$

This form expresses conservation of informational flux across the gate: the divergence in one domain is balanced by the weighted divergence in the other, ensuring that no information is lost or created through the sequestering boundary.

Physical Meaning

The gate field therefore acts as a **bidirectional information translator**. Its dynamics resemble a massless scalar field but with dual propagation metrics. Perturbations in Φ correspond to Lugons—localized packets of pure informational curvature. These packets can influence spacetime curvature indirectly through the informational stress tensor $T^{(Q)}_{\mu\nu}$, yet they contribute no energy or momentum of their own.

This establishes the central result: Lugon propagation is *superluminal in* Q but *causally sequestered in* R. The equation of motion derived here provides the foundation for testable predictions in interferometric and quantum-feedback systems, which I develop in the subsequent sections.

Informational Stress–Energy Tensor

Having obtained the gate-field equation of motion, I next derive the effective stress–energy tensor that appears in the Einstein equation of the parent framework. This tensor does not represent energy–momentum in the physical sense but encodes how informational curvature modifies the geometry of spacetime. The derivation follows the variational procedure standard to general relativity [1–5], extended here to include the sequestered informational coupling.

From the parent action,

$$S_P = S_R[g_{\mu\nu}] + S_Q[q_{ab}] + S_{\text{int}}[g_{\mu\nu}, q_{ab}, \Phi]$$

the variation with respect to $g_{\mu\nu}$ defines the informational stress–energy tensor through

$$T^{(Q)}_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta S_{\text{int}}}{\delta g^{\mu\nu}}$$

Substituting the interaction term and coupling functional [28, 29],

$$S_{\text{int}} = \int d^4x \sqrt{-g}\,\lambda(x)\left[q^{ab}\nabla_a\Phi\nabla_b\Phi - \eta\, g^{\mu\nu}\nabla_\mu\Phi\nabla_\nu\Phi - \text{const.}\right]$$

and performing the variation gives

$$T^{(Q)}_{\mu\nu} = 2\eta\,\lambda(\nabla_\mu\Phi\nabla_\nu\Phi - \frac{1}{2}g_{\mu\nu}g^{\alpha\beta}\nabla_\alpha\Phi\nabla_\beta\Phi) - g_{\mu\nu}\lambda(\mathcal{I} - \text{const.})$$

The first term is structurally identical to the canonical tensor of a massless scalar field [3], while the second term enforces the informational constraint. Because λ carries no energetic dimension, $T^{(Q)}_{\mu\nu}$ produces curvature without exchanging energy with matter fields.

Conservation and Coupling

Taking the covariant divergence and invoking the Bianchi identity [1, 5, 7],

$$\nabla^\mu G_{\mu\nu} = 0$$

the Einstein equation

$$G_{\mu\nu} = 8\pi G\, T^{(Q)}_{\mu\nu}$$
implies
$$\nabla^{\mu} T^{(Q)}_{\mu\nu} = 0$$
This conservation law corresponds to informational flux balance rather than physical energy–momentum conservation. Substituting the gate-field equation of motion (Section 2) confirms that the divergence vanishes identically; informational curvature is self-consistent and non-dissipative [16–20, 21–25].

Effective Curvature and Observable Signature

The trace of $T^{(Q)}_{\mu\nu}$ is
$$T^{(Q)} = g^{\mu\nu} T^{(Q)}_{\mu\nu} = -2\eta\,\lambda\, g^{\mu\nu}\nabla_{\mu}\Phi\nabla_{\nu}\Phi - 4\lambda\,(\mathscr{I} - \mathrm{const.})$$
which can be positive, negative, or zero depending on the local sequestering ratio η and the gate configuration. In the limit $\eta \to 1$ and $\lambda \to 0$, the tensor vanishes, recovering classical general relativity. For finite λ, $T^{(Q)}_{\mu\nu}$ produces a small but measurable curvature offset proportional to the local informational gradient.

This offset defines an **informational backreaction**, observable through deviations in geodesic congruences and phase-coherent interferometric systems. It acts analogously to vacuum polarization [10–12, 30] but originates from informational geometry rather than quantum fields. The result preserves total energy conservation while permitting curvature modulation by non-energetic informational flux. Here "vacuum polarization" is used analogically for a macroscopic, renormalized-effect picture; the semiclassical QFT notion of $\langle T_{ab}\rangle_{\mathrm{ren}}$ and backreaction follows the standard framework [39, 40].

Interpretation

In physical terms, $T^{(Q)}_{\mu\nu}$ describes how spacetime responds to the organization of information rather than to mass–energy density. It closes the variational system of the parent action:
$$\begin{cases} G_{\mu\nu} = 8\pi G\, T^{(Q)}_{\mu\nu}, \\ \mathscr{G}_{ab} = 8\pi\Gamma\, \mathscr{T}^{(R)}_{ab}, \\ \Box_{Q}\Phi - \eta\,\Box_{R}\Phi = 0. \end{cases}$$
Together these equations define the complete Lugon field system: curvature in R, curvature in Q, and the mediating gate dynamics. The informational stress–energy tensor bridges the two domains, enabling a consistent, covariant description of information without energy.

Invariant Structure and Test Predictions

With the variational and field equations complete, I now turn to the invariants that connect the informational sector to observation. These invariants determine what can be measured in practice and provide the falsifiable signatures that distinguish the Lugon framework from conventional relativity or quantum field theory.

Informational Invariants

The parent action yields four quantities that remain conserved under simultaneous diffeomorphisms in R and informational reparametrizations in Q [7, 13, 16]. They serve as the measurable "fingerprints" of the sequestered informational geometry.

1. **Curvature-area invariant**

$$\mathcal{I}_1 = \int_{\Sigma_R} \sqrt{h}\, R - \alpha \int_{\Sigma_Q} \sqrt{\tilde{h}}\, \mathcal{R}_Q$$

where h and $\tilde{h}$ are the induced metrics on the respective hypersurfaces and $\alpha = G/\Gamma$. This invariant couples spacetime curvature to informational curvature; it generalizes the Gauss–Bonnet topological charge into a dual-manifold context [1, 5, 13].

2. **Flux invariant**

$$\mathcal{I}_2 = \int_{\partial\Omega} (J^a_Q n_a - \eta J^\mu_R n_\mu)\, dA = 0$$

expressing the equality of informational flux across any closed boundary (cf. Section 2). The vanishing of $\mathcal{I}_2$ ensures global informational conservation even in dynamic spacetimes [16–20].

3. **Phase-curvature invariant**

$$\mathcal{I}_3 = \oint_\gamma \nabla_\mu \Phi\, dx^\mu - \sqrt{\eta} \oint_{\tilde{\gamma}} \nabla_a \Phi\, d\zeta^a$$

which links phase accumulation in R to its informational counterpart in Q. Non-zero deviations signal local violations of informational-curvature symmetry and define the measurable Lugon phase shift.

4. **Entropy-information invariant**

$$\mathcal{I}_4 = S_R - \frac{A_Q}{4\ell_P^2}$$

where S_R is the thermodynamic entropy associated with a boundary in R, A_Q is the corresponding informational area in Q, and ℓ_P is the Planck length. When $\mathcal{I}_4 = 0$, the Bekenstein–Hawking entropy law [11, 12, 30] is recovered; any deviation marks informational leakage or sequestering failure.

Predicted Observables

From these invariants, several empirical consequences follow:

- **Interferometric phase shifts.**

The Lugon phase $\Delta\Phi$ modifies optical path differences as

$$\Delta\Phi = kL\left(\sqrt{\eta^{-1}} - 1\right)$$

where k is the wave number and L the arm length of the interferometer.
For $0.99 < \eta < 1$, the predicted excess phase lies near current LIGO/Virgo sensitivity [31 – 32].

- **Gravitational-wave modulation.**

Informational curvature introduces a small amplitude-dependent phase delay

$$\delta\phi \approx \frac{1}{2}(1 - \eta) h_0$$

where h_0 is the gravitational-wave strain.
This modulation is frequency-independent, providing a clean falsification target.

- **Quantum-feedback asymmetry.**

In cavity or qubit systems exchanging information with a feedback controller [21–25], the Lugon constraint predicts a measurable imbalance in mutual-information flow,

$$\Delta I = (1 - \eta) I_0$$

where I_0 is the Shannon mutual information [16]. Experiments following Sagawa–Ueda formulations [24, 25] can thus test η directly.

Falsification Matrix

To guide future tests, I summarize the invariants and their measurable targets:

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Observable	**Signature / Scaling**	**Current Sensitivity (order)**	**Near-term Target**	**Falsifies if…**	**Notes / Refs**
Interferometric phase excess	$(\Delta\Phi \propto (1-\eta)$	10^{-22} rad	10^{-24} rad	$\Delta\Phi = 0$ for all η	[11–13]
GW phase modulation	$\delta\phi \propto (1-\eta)h_0$	10^{-3}	10^{-5}	No correlation with strain	[11–13, 30]
Quantum feedback asymmetry	$\Delta I / I_0 = (1-\eta)$	10^{-2}	10^{-3}	Balanced mutual info	[21–25]
Informational entropy offset	$\mathscr{I}_4 \neq 0$	10^{-5}, A_Q	10^{-7}, A_Q	$S_R = A_Q / 4\ell_P^2$	[11–13, 17–20]

Interpretation

These invariants establish that the Lugon framework is experimentally falsifiable. Each invariant equates a geometric quantity in Q with an observable in R. The numerical factor η governs all departures from known physics: if every measurement yields $\eta = 1$, the theory collapses gracefully to general relativity and standard quantum mechanics. If any experiment reveals a persistent non-unity value of η, then a sequestered informational sector—Lugons—exists.

This completes the theoretical core. In subsequent appendices I expand on parameter estimation, noise rejection, and gate-field quantization techniques that would allow these invariants to be probed within current gravitational-wave and quantum-feedback platforms.

Appendix 0 – Notation, Syntax and Grammar (Lugonic Sector)

Appendix 0 defines the formal grammar of the Lugonic Sector (LGS). Symbols, indices, and dimensional conventions are standardized here for all subsequent derivations and appendices.

Symbol(s)	**Name**	**Definition / Description**
$g_{\mu\nu}$	Spacetime metric	Metric tensor on the observable (physical) manifold; signature ((-+++)). Determines distances and causal structure in the visible sector.
K_{ab}	Kernel metric	Metric tensor on the informational (lugonic) manifold; defines geometry of the kernel sector. Distinct from $g_{\mu\nu}$.
$\Xi = (\ell, K_{ab})$	Lugonic sector (LGS)	Collective symbol for the full informational system: local excitations ℓ propagating on kernel geometry K_{ab}.
ℓ	Lugon field	Local information-carrier excitation; scalar field representing informational phase or amplitude.
J^a	Informatio n current	Kernel-sector flux of information; satisfies $\nabla^\vee_a J^a = 0$ (continuity). Dimensions L^{-3}
∇_μ	Spacetime covariant derivative	Levi-Civita derivative compatible with $g_{\mu\nu}$.
$\nabla^\vee_a$	Kernel covariant derivative	Levi-Civita derivative compatible with K_{ab}; denoted by an "upside-down delta" $\nabla^\vee$ in freehand writing.

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Symbol(s)	Name	Definition / Description
$G^{\mu}{}_{a}$	Gate tensor	Maps vectors/tensors between kernel and spacetime manifolds. Dimensionless in Scheme A; scales as L/L_I in Scheme B.
$J^a \Rightarrow_G J^{\mu}$	Gate projection (kernel → spacetime)	Projection of a kernel quantity through the gate into spacetime. Arrow indicates direction of information flow.
$J^{\mu} \Leftarrow_G J^a$	Gate projection (spacetime → kernel)	Reverse mapping from spacetime to kernel.
ε	Gate-coupling coefficient	Dimensionless scalar controlling information–geometry interaction strength; possibly redshift-dependent $\varepsilon(z)$.
λ, η	Coupling constants	Dimensionless coefficients for curvature–curvature and current–gradient interactions.
$R_{\mu\nu\varrho\sigma}$	Riemann tensor (spacetime)	Standard curvature tensor constructed from $g_{\mu\nu}$.
$\widehat{R}_{\mu\nu\varrho\sigma}$	Full curvature tensor (spacetime)	Same object, distinguished by breve accent to emphasize the *curvature operator*.
$R_{\mu\nu}, R$	Ricci tensor / scalar (spacetime)	Contractions of $\widehat{R}\mu\nu\varrho\sigma$; $R = g^{\mu\nu}R\mu\nu$. Dimension L^{-2}.
$Q_{ab,\,cd}$	Kernel curvature tensor	Analogous to Riemann tensor but on K_{ab}.
$\widehat{Q}_{ab,\,cd}$	Full curvature tensor (kernel)	Kernel curvature operator; breve accent marks “full curvature.”
Q_{ab}, Q	Kernel Ricci tensor / scalar	Contractions of $\widehat{Q}ab{,}cd)$; $Q = K^{ab}Qab$. Dimension L^{-2}.
R, Q	Curvature scalars	R for spacetime, Q for kernel. Serve as invariant measures of curvature.
$T_{\mu\nu}$	Stress–energy tensor	Standard matter–energy content of spacetime.

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Symbol(s)	**Name**	**Definition / Description**
$\mathscr{T}_{ab}$	Informational stress tensor	Energy-like tensor built from informational current J^a.
$\widehat{T}\mu\nu = G^{\mu\nu}ab\mathscr{T}^{ab}$	Projected informational tensor	Kernel stress mapped into spacetime; enters modified Einstein equations.
$\widehat{R}_{\mu\nu}\widehat{Q}^{ab}$	Curvature-coupling term	Correlation of spacetime and kernel curvature tensors; appears in gate action.
$S_{\Xi}, \mathscr{A}_{\Xi}$	Total LGS action	Dimensionless action integrating curvature, coupling, and potential terms: $\int[\frac{R}{16\pi G_N} + \frac{Q}{16\pi G_I} + \lambda RQ + \varepsilon G^{\mu\nu}ab\widehat{R}\mu\nu\widehat{Q}^{ab} + \eta J^a G_a{}^{\mu}$.
$V(\ell)$	Lugon potential	Potential energy (informational self-interaction) of ℓ; dimension L^{-4}.
G_N, G_I	Gravitational constants	G_N for spacetime, G_I for kernel; both L^2. $G_I = 1/M_I^2$ defines informational curvature scale.
$M_I = 1/L_I$	Informational Planck scale	Characteristic energy/length scale of the kernel sector.
$\mathfrak{i}_0$	Information quantum	Base unit of informational content; connects bits to energetic equivalents when needed (via Landauer bound).
$\mathscr{I}gK = g^{\mu\nu}G\mu^a G_\nu{}^b K$	Metric-coherence invariant	Scalar measuring geometric alignment between $g_{\mu\nu}$ and K_{ab}.
$\mathscr{I}\text{mix}-\text{curv} = G^{\mu\nu}a$	Mixed-curvature invariant	Scalar coupling spacetime and kernel curvature contractions.
$\mathscr{I}_J = J^a G_a{}^{\mu}\nabla\mu\ell$	Gate current invariant	Cross-sector scalar linking information flow to spacetime gradients.
$\mathbb{M}, \mathbb{C}, \mathbb{J}$	Compact invariants	Shorthand for $\mathscr{I}gK$, $\mathscr{I}\text{mix}-\text{curv}$, $\mathscr{I}_J$ respectively.
$\nabla_\mu(T^{\mu\nu} + \widehat{T}^{\mu\nu}) = 0$	Conservation law (spacetime)	Joint conservation of matter and projected informational stress.
$\nabla_a^\vee(\mathscr{T}^{ab} + \widehat{\mathscr{T}}^{ab}) = 0$	Conservation law (kernel)	Dual conservation relation in informational manifold.
$\widehat{R}$, $\widehat{Q}$ (no indices)	Generic curvature objects	Breve denotes curvature in general; bare R, Q their scalar contractions.

Symbol(s)	**Name**	**Definition / Description**
$\Rightarrow_G$, $\Leftarrow_G$	Projection operators	Arrows mark translation of quantities through the gate: direction = information flow.
L, L_I	Fundamental length scales	L for spacetime, L_I for kernel; used in dimensional analysis.
$c = \hbar = k_B = 1$	Natural-unit convention	All quantities expressed in powers of length L.
Dimensions summary		$[R] = [Q] = L^{-2}$, $[\nabla] = L^{-1}$, $[J] = L^{-3}$, $[G_N] = [G_I] = L^2$
Index convention		Greek indices $(\mu, \nu, \varrho, \sigma)$ for spacetime; Latin (a, b, c, d) for kernel; mixed for gate tensors.
Arc accent ($\frown$)	Curvature marker	Indicates the full curvature tensor ("the bend").
Arrow notation	Gate mapping	$A^a \Rightarrow_G A^\mu$ denotes projection through gate; $A^\mu \Leftarrow_G A^a$ for reverse.
Parent action form	—	$\mathcal{A}_\Xi = \int (\text{invariants}) \sqrt{-g}\,,\ d^4x$; always dimensionless in $c = \hbar = 1$.
Coupling constants	—	$\varepsilon, \lambda, \eta$ dimensionless (Scheme A); may scale with L/L_I in Scheme B.
Curvature top arc vs. scalar	—	Arc over letter = tensor; plain letter = scalar contraction.
Physical interpretation	—	Spacetime sector stores energy; kernel sector stores information; gate couples the two via invariant bilinear terms.
c	Speed of light	Relativistic signal speed in (R).
G	Newton's constant	Gravitational coupling in R.
ℓ_P	Planck length	Used in entropy–area relations.
R	Spacetime manifold	The relativistic manifold (physical spacetime). Coordinates x^μ.
Q	Informational manifold	The sequestered manifold. Coordinates (ζ^a).
x^μ	Spacetime coordinates	$\mu, \nu, \alpha, \beta = 0, 1, 2, 3$.
ζ^a	Informational coords	$a, b, c, d = 0, 1, 2, 3$.
$g_{\mu\nu}$	Spacetime metric	Lorentzian metric on R; determinant $g = \det g_{\mu\nu}$.
q_{ab}	Informational metric	Metric on Q; determinant $q = \det q_{ab}$.

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Symbol(s)	**Name**	**Definition / Description**
$\sqrt{-g}\,,d^4x$	Volume element R	Standard invariant measure on R.
$\sqrt{-q}\,,d^4\zeta$	Volume element Q	Standard invariant measure on Q.
∇_μ	Covariant derivative on R	Compatible with $g_{\mu\nu}$.
∇_a	Covariant derivative on Q	Compatible with q_{ab}.
$R^\alpha\beta\mu\nu$, $R\mu\nu$, R	Riemann, Ricci, Ricci scalar R	Curvatures built from $g_{\mu\nu}$.
$\mathscr{R}^a bcd$, $\mathscr{R}ab$, $\mathscr{R}_Q$	Riemann, Ricci, Ricci scalar Q	Curvatures built from q_{ab}.
$G_{\mu\nu}$	Einstein tensor R	$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R$.
$\mathscr{G}_{ab}$	Einstein tensor Q	$\mathscr{G}ab = \mathscr{R}ab - \frac{1}{2} q_{ab} \mathscr{R}_Q$.
$\square_R$, $\square_Q$	D'Alembertians	$\square_R = g^{\mu\nu}\nabla_\mu\nabla_\nu$, $\square_Q = q^{ab}\nabla_a\nabla_b$.
Φ	Gate field	Mediates $R \leftrightarrow Q$ coupling; shift symmetry $\Phi \to \Phi + \text{const.}$
$\lambda(x)$	Lagrange multiplier	Enforces $\mathscr{I}(q,g,\Phi) = \text{const.}$ locally on R.
Γ	Informational coupling	Sets the strength of S_Q $(units{:}action(^{-1}))$.
η	Sequestering constant	Dimensionless; controls $v_Q = c/\sqrt{\eta}$ and relative weighting in $\mathscr{I}$.
$\mathscr{I}(q, g, \Phi)$	Coupling functional	Minimal choice: $q^{ab}\nabla_a\Phi\nabla_b\Phi - \eta,g^{\mu\nu}\nabla_\mu\Phi\nabla_\nu\Phi$.
S_R, S_Q, S_{int}, S_P	Actions	Einstein–Hilbert (R); informational (Q); interaction; parent action $S_P = S_R + S_Q + S_{\text{int}}$.
$S^{(R)}_{\text{bdy}}$, $S^{(Q)}_{\text{bdy}}$	Boundary actions (GHY)	Make metric variations well-posed on ∂R, ∂Q.
h_{ij}, $\tilde{h}_{ab}$	Induced boundary metrics	On ∂R and ∂Q respectively.
K, $\tilde{K}$	Extrinsic curvature traces	For ∂R and ∂Q (GHY terms).

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Symbol(s)	**Name**	**Definition / Description**
$n^{\mu}, \tilde{n}^{a}$	Outward unit normals	To ∂R and ∂Q.
$T^{(Q)}_{\mu\nu}$	Informational stress tensor	Effective source in R from Φ,λ ; induces curvature without energy exchange.
$\mathcal{T}^{(R)}_{ab}$	Dual source on (Q)	Projection of R-sector influence into Q.
J^{a}_{Q}, J^{μ}_{R}	Informational currents	$J^{a}_{Q} = q^{ab}\nabla_{b}\Phi,\ J^{\mu}_{R} = g^{\mu\nu}\nabla_{\nu}\Phi.$
$\mathcal{I}_1, \mathcal{I}_2, \mathcal{I}_3, \mathcal{I}_4$	Invariants set	Curvature–area; flux; phase–curvature; entropy–information (see B.1).
α	Coupling ratio	$\alpha \equiv G/\Gamma$; appears in $\mathcal{I}_1$.
A_{Q}	Informational area	Area on Q dual to an R-boundary; used in $\mathcal{I}_4$.
Σ_{R}, Σ_{Q}	Hypersurfaces	Integration domains in $\mathcal{I}_1$.
$\gamma, \tilde{\gamma}$	Closed loops	Paths for phase integrals in ($\mathcal{I}_3$).
$\Omega, \partial\Omega$	Region and boundary	Used in the flux invariant $\mathcal{I}_2$.
$\Upsilon : R \to Q$	Gate map	Smooth map relating R and Q structures.
$J^{a}{}_{\mu}$	Gate Jacobian	$J^{a}{}_{\mu} = \partial\zeta^{a}/\partial x^{\mu}$; builds pullbacks/pushforwards.
$(\Upsilon^{*}q)_{\mu\nu}$	Pullback metric to (R)	$(\Upsilon^{*}q)_{\mu\nu} = J^{a}{}_{\mu} J^{b}{}_{\nu} q_{ab}$. (Forbidden in Lagrangian as direct mixing term.)
$(\Upsilon_{*}g)_{ab}$	Pushforward metric to (Q)	$(\Upsilon_{*}g)_{ab} = J^{\mu}{}_{a} J^{\nu}{}_{b} g_{\mu\nu}$. (Forbidden as direct mixing term.)
$\varrho_{R\leftarrow Q}$	Density ratio for integrating Q on R	$\varrho_{R\leftarrow Q} = \dfrac{\sqrt{-q}}{\sqrt{-g}}\left\lvert \det J^{a}{}_{\mu}\right\rvert$
$d\mu_{R} \leftarrow d\mu_{Q}$	Measure conversion to R	$\sqrt{-q}\, d^{4}\zeta = \sqrt{-g}\, \varrho_{R\leftarrow Q}\, d^{4}x$
$\varrho_{Q\leftarrow R}$	Density ratio (for integrating R on Q)	$\varrho_{Q\leftarrow R} = \dfrac{\sqrt{-g}}{\sqrt{-q}}\left\lvert \det(J^{-1})^{\mu}{}_{a}\right\rvert = \dfrac{1}{\varrho_{R\leftarrow Q}}$
$d\mu_{Q} \leftarrow d\mu_{R}$	Measure conversion to Q	$\sqrt{-g}\, d^{4}x = \sqrt{-q}\, \varrho_{Q\leftarrow R}\, d^{4}\zeta$

Symbol(s)	Name	Definition / Description
$(J^{-1})^{\mu}{}_{a}$	Inverse Jacobian	$(J^{-1})^{\mu}{}_{a} = \dfrac{\partial x^{\mu}}{\partial \zeta^{a}}$
$\left\lvert \det(J^{-1})^{\mu}{}_{a} \right\rvert$	Determinant identity	$\left\lvert \det(J^{-1})^{\mu}{}_{a} \right\rvert = \left\lvert \det J^{a}{}_{\mu} \right\rvert^{-1}$
v_{Q}	Informational signal speed	$v_{Q} = c/\sqrt{\eta}$ (superluminal in Q for $0<\eta<1$).
$\delta h_{ij}\rvert_{\partial R}=0,\ \delta\tilde{h}_{ab}\rvert_{\partial Q}$	GHY Dirichlet boundary data (inline pair)	With $S^{(R)}_{\text{bdy}}, S^{(Q)}_{\text{bdy}}$ added, fixing boundary metrics gives well-posed δS. $\delta h_{ij}\rvert_{\partial R}=0$, $\delta\tilde{h}_{ab}\rvert_{\partial Q}=0 \Rightarrow$ boundary terms cancel.
$\Delta\Phi$ (experiment)	Phase excess	Interferometric signature; linear in $(1-\eta)$.
$k=2\pi/\lambda,\ L$	Wavenumber, arm length	Enter $\Delta\Phi = kL(\sqrt{\eta^{-1}}-1)$.
h_{0}	GW strain amplitude	Enters $\delta\phi \simeq \frac{1}{2}(1-\eta)h_{0}$.
$H_{\eta\to\Phi}(f)$	Phase transfer function	$\tilde{\Phi}(f)/(1-\tilde{\eta})(f) \approx kL/2$ (linearized).
$S_{\Phi}(f)$	Phase PSD	Total single-sided phase noise spectrum.
$S_{\text{shot}}, S_{\text{rad}}, S_{\text{therm}}, S_{\text{s}}$	Noise PSD components	Shot, radiation-pressure, thermal, seismic.
$\sigma^{\text{IF}}_{(1-\eta)}$	Sensitivity to ((1-\eta))	Fisher/CRB limited interferometric uncertainty.
$\ln\mathcal{L},\ \mathcal{I}_{\text{Fisher}}(\eta)$	Likelihood, Fisher info	For parameter estimation of η.
$z_{\alpha/2}$	Gaussian critical value	Two-sided test threshold for $H_{0}:\eta=1$.
M_{ADM}	ADM mass	Asymptotic mass (unchanged if $T^{(Q)}_{\mu\nu} \sim \mathcal{O}(r^{-3-\varepsilon})$).
$z_{\alpha/2}$	Gaussian critical value	Two-sided test threshold for $H_{0}:\eta=1$.
M_{ADM}	ADM mass	Asymptotic mass (unchanged if $T^{(Q)}_{\mu\nu} \sim \mathcal{O}(r^{-3-\varepsilon})$).

Appendix A — Parent Action and Field Equations

This appendix establishes the variational foundation of the Lugon Framework. It joins the relativistic and informational manifolds through a single parent action and derives the coupled field equations that govern their dynamics. The analysis proceeds in three steps: construction of the parent action (A.1), derivation of the gate-field equation (A.2), and formulation of the informational stress–energy tensor (A.3).

A.1 Parent Action

To unify the relativistic manifold R and the informational manifold Q, I begin with a total action that is the sum of three functionals:

$$S_P = S_R[g_{\mu\nu}] + S_Q[q_{ab}] + S_{\text{int}}[g_{\mu\nu}, q_{ab}, \Phi]$$

Here S_R is the Einstein–Hilbert term governing spacetime curvature, S_Q describes curvature on the informational manifold, and S_{int} couples the two while enforcing informational sequestering.

The relativistic sector retains its conventional form [1–5]:

$$S_R = \frac{1}{16\pi G}\int d^4x\sqrt{-g}\,R$$

and the informational sector mirrors it [28, 29]:

$$S_Q = \frac{1}{16\pi\Gamma}\int d^4\zeta\sqrt{-q}\,\mathcal{R}_Q$$

where Γ is an informational coupling constant with dimensions of inverse action. The informational manifold Q is intrinsically non-Euclidean: its curvature does not measure spatial bending but the density and coherence of informational configuration. Negative curvature corresponds to locally amplifying informational gradients, while flat Q recovers the limit of unconstrained information flow (as shown in Appendix D, this non-Euclidean geometry couples to spacetime only through the gate field Φ, preserving energetic decoupling). The interaction term enforces local informational equivalence:

$$S_{\text{int}} = \int d^4x\sqrt{-g}\,\lambda(x)\,[\mathcal{I}(q_{ab}, g_{\mu\nu}, \Phi) - \text{const.}]$$

with Lagrange multiplier $\lambda(x)$ enforcing informational conservation.

The coupling functional is chosen to be

$$\mathcal{I}(q, g, \Phi) = q^{ab}\nabla_a\Phi\nabla_b\Phi - \eta\, g^{\mu\nu}\nabla_\mu\Phi\nabla_\nu\Phi$$

here the dimensionless sequestering constant η regulates the relative informational and relativistic propagation speeds.

Variation of the Parent Action

Independent variations with respect to $g_{\mu\nu}$, q_{ab}, and λ yield three coupled field equations:

$$\begin{cases} G_{\mu\nu} = 8\pi G\, T^{(Q)}_{\mu\nu}, \\ \mathcal{G}_{ab} = 8\pi\Gamma\, \mathcal{T}^{(R)}_{ab}, \\ \mathcal{I}(q_{ab}, g_{\mu\nu}, \Phi) = \text{const.} \end{cases}$$

The first reproduces the Einstein field equation with an informational source term; the second defines its informational dual; the third enforces the sequestering constraint.

A.2 Gate-Field (Lugon) Dynamics

Varying S_P with respect to the gate variable Φ gives the equation of motion for informational propagation [16–20, 28, 29]:

$$\nabla_a\left(\sqrt{-q}\, q^{ab}\nabla_b\Phi\right) - \eta\frac{\sqrt{-g}}{\sqrt{-q}}\nabla_\mu\left(\sqrt{-g}\, g^{\mu\nu}\nabla_\nu\Phi\right) = 0$$

In locally flat coordinates where the metric coupling is uniform, the equation reduces to

$$\Box_Q\Phi - \eta\,\Box_R\Phi = 0$$

with

$$\Box_Q \equiv q^{ab}\nabla_a\nabla_b, \qquad \Box_R \equiv g^{\mu\nu}\nabla_\mu\nabla_\nu$$

The ratio of characteristic propagation speeds is therefore

$$v_Q = \frac{c}{\sqrt{\eta}}$$

For $0 < \eta < 1$, information propagates faster than light in Q but projects as subluminal in R, preserving causal order.

A conserved current follows directly:

$$\nabla_a J^a_Q - \eta \nabla_\mu J^\mu_R = 0$$

where

$$J^a_Q = q^{ab} \nabla_b \Phi, \quad J^\mu_R = g^{\mu\nu} \nabla_\nu \Phi$$

This expresses informational-flux conservation across the gate boundary: no information is created or destroyed, only redistributed between R and Q.**A.3 Informational Stress–Energy Tensor**

Variation of the parent action with respect to $g_{\mu\nu}$ defines the informational stress–energy tensor [1–5, 28, 29]:

$$T^{(Q)}_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S_{\text{int}}}{\delta g^{\mu\nu}}$$

Using the explicit interaction term gives

$$T^{(Q)}_{\mu\nu} = 2\eta\, \lambda (\nabla_\mu \Phi \nabla_\nu \Phi - \frac{1}{2} g_{\mu\nu} g^{\alpha\beta} \nabla_\alpha \Phi \nabla_\beta \Phi) - g_{\mu\nu}\, \lambda (\mathcal{I} - \text{const.})$$

Because λ is dimensionless, this tensor induces curvature without transferring energy or momentum. Its covariant divergence vanishes:

$$\nabla^\mu T^{(Q)}_{\mu\nu} = 0$$

ensuring informational conservation consistent with the Bianchi identity [1, 5, 7].

The tensor's trace is

$$T^{(Q)} = -2\eta\, \lambda\, g^{\mu\nu} \nabla_\mu \Phi \nabla_\nu \Phi - 4\lambda (\mathcal{I} - \text{const.})$$

which approaches zero as $\lambda \to 0$ and $\eta \to 1$, recovering pure general relativity.

Interpretation

The system of equations

$$\begin{cases} G_{\mu\nu} = 8\pi G\, T^{(Q)}_{\mu\nu}, \\ \mathcal{G}_{ab} = 8\pi \Gamma\, \mathcal{T}^{(R)}_{ab}, \\ \Box_Q \Phi - \eta\, \Box_R \Phi = 0, \end{cases}$$

constitutes the complete Lugon field system. Curvature in R responds to informational stress; curvature in Q mirrors spacetime geometry through the gate field; and Φ mediates their interaction without energetic exchange. The theory therefore remains compatible with general relativity and quantum conservation laws while admitting a superluminal informational channel.

Appendix A establishes the mathematical backbone of the framework. Appendix B extends these results to measurable invariants and falsification criteria.

Appendix B — Invariants and Test Predictions

This appendix identifies the invariant quantities that emerge from the Lugon field equations and develops their empirical consequences. These invariants translate the informational geometry of the Q-manifold into measurable curvature signatures within spacetime R. Together they provide the falsifiable structure of the theory.

B.1 Informational Invariants

From the parent action of Appendix A, four independent invariants remain unchanged under simultaneous diffeomorphisms in R and reparametrizations in Q [7, 13, 16]. Each connects a geometric property of the informational sector with a measurable quantity in the relativistic domain.

(i) Curvature–Area Invariant

$$\mathscr{I}_1 = \int_{\Sigma_R} \sqrt{h}\, R - \alpha \int_{\Sigma_Q} \sqrt{\tilde{h}}\, \mathscr{R}_Q$$

where h and $\tilde{h}$ are the induced metrics on the hypersurfaces of R and Q, and $\alpha = G/\Gamma$. $\mathscr{I}_1$ generalizes the Gauss–Bonnet invariant to dual manifolds [1, 5, 13].

(ii) Flux Invariant

$$\mathscr{I}_2 = \int_{\partial\Omega} (J^a_Q n_a - \eta J^\mu_R n_\mu)\, dA = 0$$

expressing equality of informational flux across any closed boundary. The vanishing of $\mathscr{I}_2$ ensures global informational conservation [16 – 20].

(iii) Phase–Curvature Invariant

$$\mathscr{I}_3 = \oint_\gamma \nabla_\mu \Phi\, dx^\mu - \sqrt{\eta} \oint_{\tilde{\gamma}} \nabla_a \Phi\, d\zeta^a$$

which equates phase accumulation in spacetime with its informational analogue. Non-zero values of $\mathscr{I}_3$ represent measurable Lugon-induced phase shifts. In this view, the Lugon phase curvature functions as an informational analogue of quantum dissonance: uncertainty arises not from stochastic lack but from geometric misalignment between R and Q—an informational tension rather than randomness.

(iv) Entropy–Information Invariant

$$\mathscr{I}_4 = S_R - \frac{A_Q}{4\ell_P^2}$$

where S_R is the thermodynamic entropy associated with a boundary in R, A_Q is the informational area of its counterpart in Q, and ℓ_P is the Planck length.

When $\mathscr{I}_4 = 0$, the Bekenstein–Hawking relation [11, 12, 30] is recovered; deviations mark failure of perfect informational sequestering.

B.2 Predicted Observables

The invariants yield specific measurable signatures in three classes of experiment: interferometric phase shifts, gravitational-wave modulation, and quantum-feedback asymmetry.

(i) Interferometric Phase Shift

$$\Delta\Phi = kL(\sqrt{\eta^{-1}} - 1)$$

where k is the optical wave number and L the interferometer arm length. For $0.99 < \eta < 1$, $\Delta\Phi$ lies near current LIGO/Virgo sensitivity [31, 32], with quantum-noise scaling following the standard treatment [33].

(ii) Gravitational-Wave Modulation

$$\delta\phi \approx \frac{1}{2}(1 - \eta) h_0$$

where h_0 is the strain amplitude of the passing wave. Because the modulation is frequency-independent, it can be isolated from dispersion noise [30 – 33].

(iii) Quantum-Feedback Asymmetry

$$\Delta I = (1 - \eta) I_0$$

where I_0 is the Shannon mutual information [16]. Sagawa–Ueda feedback experiments [24, 25] provide a direct laboratory test of this asymmetry.

B.3 Falsification Matrix

Observable	Signature / Scaling	Current Sensitivity (order)	Near-Term Target	Falsifies if…	Notes / Refs
Interferometric phase excess	$\Delta\Phi \propto (1-\eta)$	10^{-22} rad	10^{-24} rad	$\Delta\Phi = 0$ for all η	[31–33]
GW phase modulation	$\delta\phi \propto (1-\eta)h_0$	10^{-3}	10^{-5}	No correlation with strain	[30–33]
Quantum-feedback asymmetry	$\Delta I / I_0 = (1-\eta)$	10^{-2}	10^{-3}	Balanced mutual info	[21–25]
Informational entropy offset	$\mathcal{I}_4 \neq 0$	$10^{-5} A_Q$	$10^{-7} A_Q$	$S_R = A_Q / 4\ell_P^2$	[11–13, 17–20]

B.4 Interpretation

Each invariant provides a falsifiable link between information geometry and measurable physics.
If all observables yield $\eta = 1$, the theory collapses smoothly to general relativity and standard quantum mechanics. Any consistent deviation from unity would confirm the existence of a sequestered informational sector—Lugons—propagating superluminally in Q yet causally in R.

Appendix B therefore completes the bridge between theory and experiment. Appendix C details the practical implementation of these tests and the corresponding noise-rejection strategies that determine the achievable bounds on η.

Appendix C — Experimental Design Framework

This appendix translates the invariants and predictions into concrete measurement strategies. I outline instrument configurations, calibration procedures, dominant noise sources, and parameter-estimation methods that bound the sequestering parameter η. The goal is a falsifiable workflow: prepare → measure → estimate η → decide.

C.1 Interferometric Tests (Optical & GW-band)

C.1.1 Response model

For a dual-arm interferometer with arm length L and laser wavenumber $k = 2\pi/\lambda$, the Lugon-induced phase excess follows (Appendix B)

$$\Delta\Phi = kL\left(\sqrt{\eta^{-1}} - 1\right)$$

In the small-deviation regime ($|1-\eta| \ll 1$),

$$\Delta\Phi \approx \frac{kL}{2}(1-\eta)$$

A convenient linearized **transfer function** from $(1-\eta)$ to phase is

$$H_{\eta\to\Phi}(f) \equiv \frac{\tilde{\Phi}(f)}{(1-\tilde{\eta})(f)} \approx \frac{kL}{2}$$

which is frequency-independent to first order, simplifying broadband estimation.

C.1.2 Noise budget and sensitivity

I model the single-sided phase-noise spectrum as

$$S_\Phi(f) = S_{\rm shot}(f) + S_{\rm rad}(f) + S_{\rm therm}(f) + S_{\rm seis}(f)$$

with the usual scalings: photon shot noise $S_{\rm shot} \propto P^{-1}$, radiation-pressure noise $S_{\rm rad} \propto P/f^4$ in simple Michelsons, thermal $S_{\rm therm}$ set by coating and suspension losses, and seismic $S_{\rm seis}$ below the instrument's isolation corner [31 – 33]. The corresponding **minimum resolvable** $(1-\eta)$ over bandwidth $[f_1, f_2]$ and integration time T is

$$\sigma^{\mathrm{IF}}_{(1-\eta)} \approx \left[\int_{f_1}^{f_2} \frac{|H_{\eta\to\Phi}(f)|^2}{S_{\Phi}(f)}\, df\right]^{-1/2}$$

This follows from matched-filter theory and coincides with the inverse square root of the Fisher information (next subsection) [3 – 5].

C.1.3 Calibration protocol

1. **Phase reference**: inject a calibrated phase dither $\Phi_{\mathrm{cal}}(t)=\Phi_0\sin(2\pi f_{\mathrm{cal}}t)$ and verify recovery of Φ_0 within $<1\%$.
2. **Arm-length confirmation**: sweep laser frequency and fit the free spectral range; this fixes kL with ppm precision.
3. **Linearity check**: superpose Φ_{cal} with known GW-like strains $h(t)$ (software injections for GW detectors) and confirm additive response.

Calibration and phase control. We marginalize over detector calibration models so that any frequency-independent phase-like offset is not misattributed to astrophysical structure. Advanced LIGO's photon calibrators set the absolute displacement scale; run-dependent models track complex response drifts. Across O1–O3, phase calibration uncertainties were ≲10° (O1/O2) and ≲4° (O3) over ~20–2000 Hz. We therefore treat a flat ϕ_0 as a nuisance parameter orthogonal to dispersive terms. [34–36].

C.2 Gravitational-Wave Phase Modulation

In the presence of a GW with strain amplitude h_0, the Lugon sector predicts an amplitude-proportional phase offset (Appendix B):

$$\delta\phi \approx \frac{1}{2}(1-\eta)h_0$$

For a detected event with maximum-likelihood strain $\hat{h}_0$ (from standard GR templates), I perform a **residual analysis**: fit a constant-in-frequency phase term $\delta\phi$ to the whitened signal and map it to $(1-\eta)$. To avoid leakage from calibration systematics, ϕ_0 is constrained jointly with the detector's complex response model and photon-calibrator lines, following established LIGO procedures. **[34–36].** Because $\delta\phi$ is frequency-independent to leading order, it is orthogonal to most dispersion-like systematics, tightening bounds on η [30 – 31].

C.3 Quantum-Feedback Tests (Cavity/Qubit Platforms)

For feedback-controlled systems à la Sagawa–Ueda, I test the predicted information-flow asymmetry:

$$\Delta I = (1-\eta)I_0$$

where I_0 is the baseline Shannon mutual information between plant and controller [16, 24, 25]. In nonequilibrium runs I leverage the generalized fluctuation relations to cross-validate:

$$\left\langle e^{-\beta W-\Delta I}\right\rangle = 1$$

with β the inverse bath temperature and W the work performed [26, 27]. Any persistent $\Delta I \neq 0$ at fixed I_0 implies $(1-\eta)\neq 0$.

Calibration steps

(i) Measure I_0 from open-loop trials; (ii) close the loop with known controller delays; (iii) estimate ΔI from time-series reconstructions; (iv) compare to the predicted $(1-\eta)I_0$.

C.4 Parameter Estimation for η

I treat η as a single global parameter. For a dataset d with model prediction $m(\eta)$, the Gaussian log-likelihood is

$$\ln \mathcal{L}(d|\eta) = -\frac{1}{2}\sum_k \frac{\big[d_k - m_k(\eta)\big]^2}{\sigma_k^2} + \text{const}$$

The **Fisher information** and Cramér–Rao bound give an experiment-agnostic sensitivity estimate [3–5]:

$$\mathcal{I}(\eta) = -\Big\langle \frac{\partial^2 \ln \mathcal{L}}{\partial \eta^2} \Big\rangle, \qquad \sigma_\eta \geq \mathcal{I}(\eta)^{-1/2}$$

For interferometers, $\partial m / \partial \eta \approx -\frac{kL}{2}$ in phase units, which reproduces $\sigma^{\mathrm{IF}}_{(1-\eta)}$ in C.1.2.

C.5 Systematics and Noise Rejection

I isolate $(1-\eta)$ from instrumental and environmental effects through **orthogonality** and **nulls**:

1. **Orthogonality in frequency**: most dispersion systematics scale as $f^{\pm 1}$ or $f^{\pm 2}$; the Lugon signature in $\delta\phi$ is flat in f.
2. **Null channels**: monitor auxiliary witnesses (laser frequency, alignment, magnetic sensors) and regress them from the phase readout.
3. **Reversal tests**: exchange arm lengths or cavity detunings; the Lugon term scales with L, while many systematics do not.
4. **Time-shifts**: apply non-causal lags to confirm that any recovered $(1-\eta)$ vanishes off-source (standard GW practice) [11–13].

Where clocks matter (cavity experiments), I track stability with Allan deviation $\sigma_y(\tau)$ and require

$$\sigma_{\Phi,\text{clock}} \approx 2\pi f_0 \tau \sigma_y(\tau) \ll \sigma_{\Phi,\text{stat}}$$

to keep clock noise sub-dominant. We report clock performance in the $\sigma_y(\tau)$–τ plane and propagate to phase via $\delta\phi \approx 2\pi f \tau \sigma_y(\tau)$, following standard frequency-stability practice [37, 38].

C.6 Decision Rule (Falsification Logic)

Given an estimator $\hat{\eta}$ and uncertainty σ_η, I adopt a simple hypothesis test:

$$H_0: \eta = 1 \quad \text{vs} \quad H_1: \eta \neq 1.$$

Reject H_0 at significance α if

$$|\hat{\eta} - 1| > z_{\alpha/2}\sigma_\eta,$$

with $z_{\alpha/2}$ the Gaussian critical value (e.g., $z_{0.025} \approx 1.96$ for 95%). When combining N independent measurements $\{\hat{\eta}_i\}$, I use inverse-variance weighting:

$$\hat{\eta}_{\text{comb}} = \frac{\sum_i \hat{\eta}_i / \sigma^2_{\eta,i}}{\sum_i 1/\sigma^2_{\eta,i}}, \qquad \sigma^{-2}_{\text{comb}} = \sum_i \sigma^{-2}_{\eta,i}.$$

C.7 Practical Operating Points

- **Optical interferometers**: maximize kL (long arms, short wavelength) until radiation pressure noise crosses shot-noise; use squeezed light if available to lower S_{shot} without raising S_{rad}.
- **GW detectors**: target events with high h_0 and broadband coverage; stack multiple events with consistent flat-$\delta\phi$ templates.

- **Quantum platforms**: operate in regimes with robust measurement of I_0 (high SNR readout) and controlled feedback delays; validate fluctuation relations per trial.

C.8 Reporting Standard

To enable external replication, I will publish for each dataset: (k,L), phase-cal lines, full $S_\Phi(f)$ l, priors and posteriors for η, null-channel residuals, and the decision outcome for (H_0, H_1). This mirrors established practices in GR tests and open-systems thermodynamics [1–5, 11–13, 21–27, 30].

Summary

This framework converts the Lugon predictions into actionable measurements. The pipeline—calibration, noise control, Fisher-based sensitivity, and a clear decision rule—makes η empirically testable. A consistent finding of $\eta = 1$ across platforms falsifies the Lugon sector; any robust deviation establishes a sequestered informational channel that modulates curvature without energy exchange.

Appendix D — Auxiliary-Metric Decoupling

This appendix proves that the informational metric q_{ab} decouples from the spacetime metric $g_{\mu\nu}$ except through the gate field Φ. The result ensures that no energetic portal exists between the Q and R manifolds: curvature in R can be modulated by informational structure, but energy–momentum is not exchanged across the interface. The analysis relies on variational calculus in curved manifolds [1 – 5, 7] and on the sequestering architecture established in Appendix A [28, 29].

D.1 Statement of the Decoupling Theorem

Theorem (Auxiliary-metric decoupling).

Given the parent action

$$S_P = S_R[g_{\mu\nu}] + S_Q[q_{ab}] + S_{\text{int}}[g_{\mu\nu}, q_{ab}, \Phi]$$

with

$$S_R = \frac{1}{16\pi G}\int d^4x\sqrt{-g}\,R, \qquad S_Q = \frac{1}{16\pi\Gamma}\int d^4\zeta\sqrt{-q}\,\mathscr{R}_Q$$

and interaction

$$S_{\text{int}} = \int d^4x\sqrt{-g}\,\lambda(x)\Big[\,q^{ab}\nabla_a\Phi\,\nabla_b\Phi - \eta\, g^{\mu\nu}\nabla_\mu\Phi\,\nabla_\nu\Phi - \text{const}\,\Big].$$

if the following hold:

1. **Independent diffeomorphisms**: $\mathrm{Diff}(R)\times\mathrm{Diff}(Q)$ invariance;
2. **Gate-shift symmetry**: $\Phi \to \Phi + \text{const}$;
3. **No explicit metric mixing**: the Lagrangian contains no scalars built from mixed contractions $g^{\mu\nu}(\Upsilon^* q)_{\mu\nu}$ or $q^{ab}(\Upsilon_* g)_{ab}$ (defined below);
4. **Well-posed variation**: appropriate boundary terms (GHY-type) are added for R and Q,

[9, 10] then the Euler–Lagrange equations imply that all cross-variations $\delta S_P/\delta g^{\mu\nu}$ and $\delta S_P/\delta q^{ab}$ vanish except through Φ and λ. Consequently, energy–momentum in R remains conserved and receives only an **informational** source $T^{(Q)}_{\mu\nu}$ (Appendix A), while Q receives only its dual informational source $\mathscr{T}^{(R)}_{ab}$.

D.2 Gate Map and Pullbacks

To compare scalars on R and Q covariantly, I introduce a smooth **gate map** $\Upsilon: R \to Q$ with Jacobian $J^a{}_\mu = \partial\zeta^a/\partial x^\mu$. It induces pullbacks/pushforwards:

$$(\Upsilon^* q)_{\mu\nu} = J^a{}_\mu J^b{}_\nu\, q_{ab}, \qquad (\Upsilon_* g)_{ab} = J^\mu{}_a J^\nu{}_b\, g_{\mu\nu}$$

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and a density ratio

$$\varrho \equiv \frac{\sqrt{-g}}{\sqrt{-q}}\,\left|\det J^{a}{}_{\mu}\right|$$

In Appendix A I used ϱ (implicitly) to form scalars like $\sqrt{-g}\,\lambda\,q^{ab}\nabla_a\Phi\nabla_b\Phi$ that are well-defined on R after pullback. The decoupling assumption (iii) above forbids mixing terms like $g^{\mu\nu}(\Upsilon^{*}q)_{\mu\nu}$ that would constitute a direct metric-metric coupling.

D.3 Variational Proof of Decoupling

Consider the variation with respect to $g^{\mu\nu}$. Since S_Q depends only on q_{ab} and its derivatives over Q,

$$\frac{\delta S_Q}{\delta g^{\mu\nu}} = 0$$

For the interaction, the only $g^{\mu\nu}$ -dependence enters through $\sqrt{-g}$, $g^{\mu\nu}\nabla\mu\Phi\nabla\nu\Phi$, and the measure of the integral; there are **no** mixed contractions with $q_{ab}$by assumption (iii). A standard calculation [1 – 5] yields the informational stress tensor (Appendix A):

$$T^{(Q)}_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta S_{\text{int}}}{\delta g^{\mu\nu}} = 2\eta\,\lambda\left(\nabla_\mu\Phi\nabla_\nu\Phi - \frac{1}{2}g_{\mu\nu}g^{\alpha\beta}\nabla_\alpha\Phi\nabla_\beta\Phi\right) - g_{\mu\nu}\lambda\,(\mathcal{I} - \text{const.}).$$

Crucially, q_{ab} appears **only** through $\mathcal{I}(q,g,\Phi)$ and never in a bare contraction with $g^{\mu\nu}$. Therefore $T^{(Q)}_{\mu\nu}$ contains no term that would correspond to an energetic exchange sourced directly by q_{ab}.

The q_{ab} -variation is analogous. Because S_R is independent of q_{ab},

$$\frac{\delta S_R}{\delta q^{ab}} = 0$$

and the only q_{ab}dependence of S_{int} is through $q^{ab}\nabla_a\Phi\nabla_b\Phi$ (after pullback). Thus, the informational Einstein–like equation on Q (Appendix A) reads

$$\mathcal{G}_{ab} = 8\pi\Gamma\,\mathcal{T}^{(R)}_{ab}$$

with $\mathcal{T}^{(R)}_{ab}$ depending on Φ and λ but **not** on $g_{\mu\nu}$ via any bare contraction. The gate-field variation gives the Lugon equation (Appendix A),

$$\nabla_a\left(\sqrt{-q}\,q^{ab}\nabla_b\Phi\right) - \eta\,\frac{\sqrt{-g}}{\sqrt{-q}}\,\nabla_\mu\left(\sqrt{-g}\,g^{\mu\nu}\nabla_\nu\Phi\right) = 0$$

which is the **only** bridge between the metrics. Hence, decoupling holds: the metrics do not source each other directly; they only communicate through Φ (and λ as a constraint multiplier).

D.4 No-Go for Energetic Portals

One may ask whether adding "mixed" operators could open an energetic portal. Consider the lowest-dimension candidates:

1. **Mixed kinetic term**

$$\sqrt{-g}\,\kappa_1 g^{\mu\nu}(\Upsilon^{*}q)_{\mu\nu}, \qquad \sqrt{-q}\,\kappa_2 q^{ab}(\Upsilon_{*}g)_{ab}$$

These violate the gate-shift symmetry (they do not involve Φ), break the sequestering balance in $\mathcal{I}$, and generically exchange energy between R and Q. They are therefore **forbidden** by assumptions (ii)–(iii).

2. **Curvature mixing**

$$\sqrt{-g}\;\xi R\mathscr{R}_Q \quad \text{or} \quad \sqrt{-g}\;\xi' G^{\mu\nu}(\Upsilon^{*}\mathscr{R}_Q)_{\mu\nu}$$

Such terms spoil $\mathrm{Diff}(R)\times\mathrm{Diff}(Q)$ factorization unless accompanied by nontrivial densities; even then they re-introduce direct metric–metric couplings. Under the sequestering postulate [28, 29], I exclude them.

Therefore, within the admissible operator set, **no energetic portal** exists. All observable effects in R arise from $T^{(Q)}_{\mu\nu}$ built out of Φ and λ, not from direct metric mixing.

D.5 Boundary Terms and Well-Posed Variation

To ensure the well-posedness of the metric variations, I add Gibbons–Hawking–York (GHY)-type boundary terms for each manifold [9, 10]:

$$S^{(R)}_{\text{bdy}} = \frac{1}{8\pi G}\int_{\partial R} d^3y\sqrt{|h|}\,K, \qquad S^{(Q)}_{\text{bdy}} = \frac{1}{8\pi\Gamma}\int_{\partial Q} d^3\tilde{y}\sqrt{|\tilde{h}|}\,\tilde{K}$$

where $K$and $\tilde{K}$ are the traces of the extrinsic curvatures on ∂R and ∂Q, respectively. These remove normal-derivative terms from δS_R and δS_Q, leaving the bulk equations unaffected and preserving decoupling.

D.6 Consequences

1. **Conservation in R.**

Using the Bianchi identity $\nabla^\mu G_{\mu\nu} = 0$ and the Einstein equation with the informational source (Appendix A),

$$G_{\mu\nu} = 8\pi G\, T^{(Q)}_{\mu\nu}, \qquad \nabla^\mu T^{(Q)}_{\mu\nu} = 0$$

which expresses **informational flux conservation**, not energy flow from Q to R [1, 5, 7].

2. *Microcausality in R.*

Because the only R-sector derivatives appear as $g^{\mu\nu}\nabla_\mu\Phi\nabla_\nu\Phi$, the principal symbol in R is that of a standard scalar; no superluminal propagation in R occurs. Superluminality is confined to Q through q^{ab} (Appendix A).

2. **Predictive closure.**

All measurable effects enter R through $T^{(Q)}_{\mu\nu}$ and the invariants of Appendix B. No hidden energetic channel can mimic them without violating the assumptions of this appendix.

Summary

The auxiliary-metric decoupling theorem formalizes the central architectural claim of the Lugon framework: **information influences curvature without transporting energy**. The two metrics $g_{\mu\nu}$ and q_{ab} remain dynamically autonomous except through the gate field Φ (and its multiplier λ). This guarantees compatibility with conservation laws and with relativistic causality in R, while enabling superluminal informational dynamics in Q [1 – 5, 7, 9, 10, 28, 29]

Appendix E — Boundary Terms and Conservation Proofs

This appendix secures the variational calculus of the Lugon framework by adding the appropriate boundary terms for both manifolds and by proving the associated conservation laws. I also collect the relevant Noether currents and show how they reduce to the Bianchi identity and informational-flux conservation.

E.1 GHY-Type Boundary Terms for ***R*** *and* ***Q***

For well-posed Dirichlet variations of the metrics, I add Gibbons–Hawking–York boundary terms on each manifold [9, 10]:

$$S^{(R)}_{\text{bdy}} = \frac{1}{8\pi G}\int_{\partial R} d^3y\sqrt{|h|}\,K, \qquad S^{(Q)}_{\text{bdy}} = \frac{1}{8\pi\Gamma}\int_{\partial Q} d^3\tilde{y}\sqrt{|\tilde{h}|}\,\tilde{K}$$

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Here $h(\tilde{h})$ is the induced metric on $\partial R(\partial Q)$, and $K(\tilde{K})$ is the trace of the extrinsic curvature with outward unit normal $n^{\mu}(\tilde{n}^{a})$.

Including these, the **total** action is

$$S_{\text{tot}} = S_P + S^{(R)}_{\text{bdy}} + S^{(Q)}_{\text{bdy}}$$

and the variations δS_R and δS_Q are free of boundary derivatives of $\delta g_{\mu\nu}$ and δq_{ab}.

E.2 Metric Variations and Boundary Cancellations

The standard bulk variation gives [1 – 5]

$$\delta S_R = \frac{1}{16\pi G}\int_R d^4x\sqrt{-g}\, G_{\mu\nu}\,\delta g^{\mu\nu} + (\text{boundary})$$

and analogously on Q,

$$\delta S_Q = \frac{1}{16\pi\Gamma}\int_Q d^4\zeta\sqrt{-q}\,\mathcal{G}_{ab}\,\delta q^{ab} + (\text{boundary})$$

The GHY terms precisely cancel the boundary pieces when $\delta g_{\mu\nu}|_{\partial R} = 0$ and $\delta q_{ab}|_{\partial Q} = 0$ the interaction S_{int} contains no derivatives of the metrics normal to the boundary, so it adds no extra boundary term under Dirichlet data.

E.3 Noether Currents and Shift Symmetry of Φ

Diffeomorphism invariance in R and Q yields the usual Noether identities [7]. For an infinitesimal diffeomorphism $x^{\mu} \to x^{\mu} + \xi^{\mu}$ in R, the corresponding current reduces on shell to the contracted Bianchi identity:

$$\nabla^{\mu} G_{\mu\nu} = 0$$

Because the Einstein equation is $G_{\mu\nu} = 8\pi G\, T^{(Q)}_{\mu\nu}$, I recover the **covariant conservation** of the informational stress tensor:

$$\nabla^{\mu} T^{(Q)}_{\mu\nu} = 0$$

The **gate-shift symmetry** $\Phi \to \Phi + \text{const}$ produces a conserved current whose divergence vanishes using the gate equation (Appendix A):

$$\nabla_a J^a_Q - \eta\,\nabla_\mu J^\mu_R = 0, \quad J^a_Q = q^{ab}\nabla_b \Phi, \;\; J^\mu_R = g^{\mu\nu}\nabla_\nu \Phi$$

This is the **informational-flux conservation law** used in the invariants of Appendix B.

E.4 ADM Charges and Asymptotics

For asymptotically flat R, the ADM mass M_{ADM} is defined entirely by metric falloffs at spatial infinity [6]. Since $T^{(Q)}_{\mu\nu}$ contains only gradients of Φ multiplied by the dimensionless λ and does not introduce energy flow, I impose asymptotic conditions

$$\nabla_\mu \Phi = \mathcal{O}(r^{-1-\varepsilon}), \quad \lambda = \mathcal{O}(r^{-1-\varepsilon})$$

so that $T^{(Q)}_{\mu\nu}$ decays faster than r^{-3}, leaving M_{ADM} unchanged by the informational sector at spatial infinity.

E.5 Summary of Conservation Proofs

Collecting the results,

$$\begin{cases} \nabla^{\mu} G_{\mu\nu} = 0 \Rightarrow \nabla^{\mu} T^{(Q)}_{\mu\nu} = 0, \\ \nabla_a J^a_Q - \eta\,\nabla_\mu J^\mu_R = 0\;(\text{shift symmetry})), \\ \text{GHY terms ensure well-posed Dirichlet variations on } \partial R,\ \partial Q. \end{cases}$$

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The conservation content of the framework therefore follows from diffeomorphism invariance and the gate symmetry, with boundary terms guaranteeing a clean variational principle.

Appendix F — Interpretive Bridge and Physical Context

This appendix gives the plain-language map from the formalism to the physical world: how informational structure affects curvature, what "no energy exchange" means operationally, and how the predictions interface with black-hole thermodynamics and information theory. It supersedes my earlier narrative appendix placement; I keep the lettering flexible so that theory flows before interpretation.

F.1 What "Information Without Energy" Means in Practice

The gate field Φ carries configuration, not quanta. In the parent action, all terms that would move energy between Q and R are absent by construction (Appendix D). Yet Φ steers curvature indirectly via the informational stress tensor $T^{(Q)}_{\mu\nu}$ (Appendix A). The effect looks like a scalar-field source in the Einstein equation, but it is multiplied by λ and constrained by $\mathcal{I} = \text{const.}$; there is no corresponding Hamiltonian density that flows across the interface. In instruments, this shows up as phase and curvature offsets rather than heat, work, or particle flux.

F.2 Relation to Black-Hole Thermodynamics and Holography

The entropy–information invariant,

$$\mathcal{I}_4 = S_R - \frac{A_Q}{4\ell_P^2}$$

anchors the connection to Bekenstein–Hawking entropy [11, 12, 30]. When $\mathcal{I}_4 = 0$, the informational area A_Q matches the thermodynamic area law in R. Deviations would signal imperfect sequestering—an experimental lever that is independent of a specific quantum gravity model but consistent with holographic scaling ideas [13 – 15].

F.3 Compatibility with Relativistic Causality

Superluminal propagation occurs in Q through

$$\Box_Q \Phi - \eta\, \Box_R \Phi = 0, \qquad v_Q = \frac{c}{\sqrt{\eta}}, \quad 0 < \eta < 1$$

but projection into R is governed by $g^{\mu\nu}$ and remains causal. Microcausality in R is intact because the principal symbol in R is that of a standard scalar; the informational sector modifies curvature via $T^{(Q)}_{\mu\nu}$ without introducing tachyonic propagation in spacetime. In dual-cone representation, black- and white-hole sectors correspond to curvature singularities of opposite informational orientation; information remains sequestered across the interface rather than destroyed, consistent with the Lugon decoupling condition.

F.4 Thermodynamics of Information Transfer

When the gate couples to a feedback loop, the Sagawa–Ueda relations [24, 25] constrain information–work exchange. In this framework, the predicted asymmetry

$$\Delta I = (1 - \eta) I_0$$

is a **purely informational** signature—no heat need be dissipated for a nonzero ΔI. This separates Lugon effects from Landauer-limited processes [17 – 19] and provides a clean lab falsifier.

F.5 Observational Heuristics

- **Interferometers** register Lugon effects as *phase excess* independent of laser frequency to first order; that orthogonality to standard dispersive systematics is the smoking gun.

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- **GW detectors** should see a flat phase offset proportional to strain amplitude, not frequency—again orthogonal to propagation effects in GR [11 – 13, 30].
- **Quantum feedback** experiments should track changes in mutual information at fixed control topology; any persistent $(1-\eta)\neq 0$ across configurations is decisive.

F.6 Where the Theory Can Fail (and That's Good)

The framework is falsifiable in three clean ways:

1. $\eta \to 1$ **everywhere.** All predicted effects vanish within sensitivity → no Lugon sector detected.
2. **Entropy invariant holds identically.** $\mathcal{I}_4 = 0$ across black-hole analogs and horizon-like systems → sequestering indistinguishable from GR thermodynamics.
3. **Mixed-operator search.** If any experiment forces inclusion of direct g–q mixing terms to fit data, the decoupling postulate (Appendix D) fails.

Falsification is a feature, not a bug—it means the proposal is genuinely empirical.

Summary

This interpretive bridge ties the mathematics to laboratory and astrophysical signatures without smuggling in energy transfer. The theory is compatible with GR and information thermodynamics, uses standard boundary machinery to keep the math honest, and delivers clean levers for experiments. If $\eta = 1$ wins, the framework collapses gracefully to known physics; if not, we have direct evidence of a sequestered informational sector.

Appendix G — From the Lugon to Known Physics

The derivations in Part 2 establish that informational degrees of freedom can coexist with relativistic and quantum frameworks without violating their conservation laws. Yet the mathematics alone cannot convey how these informational structures reconcile with the physical world we measure. The following appendix provides that bridge. It translates the lugon concept—the sequestered unit of pure information—into the language of empirical physics and shows how the *Lugonic Sector (LGS)* generates the four invariants that sustain both domains.

Appendix G is therefore not an optional reflection but an interpretive map: it connects the abstract informational geometry developed in the main text to the observable phenomena that define known physics. Where Part 2 builds the scaffolding, Appendix H gives it voice. The reader should regard what follows as the narrative counterpart to the equations—a prose articulation of how the lugon, the kernel, and the four universal pillars form a single, coherent grammar of reality.

G.1 The Lugon Kernel ($\mathscr{K}$)

The kernel is the local grammar operating **within the LGS**. It binds and orders lugons through four simultaneous rules that mirror the universal invariants:

1. **Energy-Respecting Rule** – transformations in the h-cone neither add nor subtract measurable energy in the g-cone.
2. **Information-Conserving Rule** – token content is rearranged but never lost; all changes are reversible within informational space.
3. **Causality-Consistent Rule** – sequences remain self-consistent when projected into the g-cone; no paradoxical ordering is admitted.
4. **Resonance Rule** – variations must increase coherence under a bounded-variability metric; novelty without chaos.

Through these rules $\mathscr{K}$ pairs tokens, orders them in sequence, and twists informational and physical strands into single acts of existence.

G.2 The Four Pillars

1. **Energy** — the capacity for action; the conserved power of being.
2. **Information** — the architecture of meaning; the conserved pattern of relations.

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3. **Causality** — the grammar of time; the lawful order of transformations.
4. **Resonance** — the harmony of becoming; bounded freedom that allows change within law.

Together they define a universe that is both lawful and creative, conservative and emergent.

G.3 The Double Helix of Domains

Reality manifests as two entwined strands:

• The **physical strand** (Energy + Causality) — rhythm and momentum of events.

• The **informational strand** (Information + Resonance) — pattern and coherence of possibility.

The rungs between them are LGS-mediated correspondences:

Energy ↔ Information couples substance to form.

Causality ↔ Resonance couples sequence to variation.

The helical twist represents informational curvature—the measure of coupling between domains. Its pitch determines whether the universe behaves as deterministic, chaotic, or coherently emergent.

G.4 Correspondence to Known Physics

In limiting cases the helix expresses the four invariants as recognizable regimes of law.

Classical / Relativistic limit — Tight coupling; curvature of Q is negligible. Energy and causality dominate. The system is locally deterministic and time-ordered.

Quantum limit — Moderate coupling; curvature of Q is finite. Complementary observables trace non-parallel geodesics in informational space. Uncertainty arises from this curvature—the intrinsic dissonance of the LGS—rather than from absence of cause. Entanglement represents shared curvature between systems.

Thermodynamic limit — Resonance drives circulation between R and Q. Energy exchange in R corresponds to information flow in Q. Entropy growth in R records redistribution of informational potential. The Second Law projects this one-way bias of flow.

Gravitational limit — High curvature couples the dual cones directly. Compression in a g-cone corresponds to expansion in its conjugate h-cone. Black-hole confinement and Hawking emission are dual expressions of conserved cross-domain energy. At low coupling the equations reduce to Einsteinian form.

Across all limits the same invariants hold. Energy defines magnitude, Information defines form, Causality preserves order, and Resonance maintains phase. Their relative strength fixes the apparent behavior of the universe.

G.5 Empirical Reach

Observable deviation occurs only where informational curvature within the LGS is large. Such regions produce measurable phase or coherence anomalies in quantum, thermodynamic, or gravitational systems. Each effect tests the joint conservation of Energy, Information, Causality, and Resonance—the invariant grammar of the Lugonic Sector expressed in measurable form.

G.6 Unified Statement

The lugon provides the discrete unit of structure in the informational domain. The Lugonic Sector binds these units into ordered, twisting correspondences with the physical domain through energy-respecting gates. The four invariants—Energy, Information, Causality, and Resonance—ensure that every cross-domain transformation remains lawful, conservative, and coherence-seeking. Known physics arises as the limiting geometry of informational curvature. The result is a single grammar in which the universe does not merely evolve—it composes.

A third interpretive layer — the syntactic frame of lawful structure itself — can be regarded as the meta-manifold in which both R and Q participate, corresponding to the conservation of form rather than of substance or information. Its formal treatment is reserved for future work.

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