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NUVO Quantization II: Closed, Open, and Dynamic Loops in Scalar Geometry

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Abstract

This paper develops the second stage of quantization in the NUVO scalar-conformal framework, extending the arc-closure geometry of Quantization I to include loop structures and circulation. A two-substrate ontology is established: a continuous under-substrate sinertia field flowing at speed c, and an above-substrate geometry $g = \lambda^2 \eta$ whose scalar modulation $\lambda(x)$ encodes observable curvature. Elementary particles are represented as inseparable bundles $B = (C, O)$, where the closed loop C (mass coupling) sustains conservative circulation with impedance and the open loop O (charge coupling) provides the sole path for exchange. The resulting formalism yields continuity and transport laws bounded by c, a classification of closed, open, and geometric-alignment kinematic states, and a description of dynamic loops (photons) as substrate-detached, coherence-gated excitations propagating at c. The framework models inertia, mass, charge, and photon behavior as geometric expressions of a single scalar field, uniting them within one self-consistent scalar-modulated space and establishing the basis for future work on depletion and power connections.

Keywords

NUVO Space, Scalar Geometry, Quantization, Coherence, Scalar Field Modulation, Loop Dynamics

1. Introduction

The scalar-geometric construction of NUVO space, established in Refs. [1] [2], introduced a conformally flat metric $g_{\mu\nu} = \lambda^2(x)\eta_{\mu\nu}$, where the single scalar field $\lambda(x)$ modulates all geometric and physical quantities, as in early scalar-conformal constructions [3]-[5]. Within this structure, motion, curvature, and conservation laws arise from scalar modulation rather than from independent tensor degrees of freedom. The first stage of development, Quantization I, demonstrated that geometric quantization can be obtained purely from arc-closure and scalar coherence without invoking additional fields or potentials. That work identified quantized action as the natural outcome of geometric phase closure on the conformal manifold. While numerous scalar-tensor and conformal-metric extensions of gravity have been studied in recent years [6] [7], the NUVO framework isolates the scalar degree of freedom entirely, yielding a conformally flat geometry governed by a single modulation $\lambda(x)$.

The present study, Quantization II, extends that foundation by introducing a two-substrate ontology consisting of a continuous under-substrate sinertia field, which propagates at the limiting speed c, and an above-substrate conformal geometry $g = \lambda^2\eta$ that couples to the substrate only through discrete loop structures. Three loop types are distinguished: closed (mass couplings, conservative), open (charge couplings, exchange-enabled), and dynamic (photonic loops, radiative and exchange-free in flight). These elements provide the structural basis for all local physical phenomena.

In this framework, the behaviors traditionally attributed to inertia, mass, gravity, charge, and photon interaction are modeled within a single scalar-field modulation $\lambda(x)$ that defines both the local geometry and the permissible modes of coupling. This modeling approach introduces no additional tensor or vector fields; it treats these phenomena as distinct manifestations of one conformal scalar structure governing all closed, open, and dynamic loop behaviors in the conservative regime. Accordingly, the NUVO formulation provides a coherent geometric representation—modeled under a single scalar modulation—of the physical mechanisms that underlie inertial and radiative processes.

Coherence is geometric (not substrate). Throughout this work, "coherence" refers *exclusively* to the *geometric alignment* between a loop's local metric and the global λ-modulated metric. The sinertia substrate is continuous and never (de)coheres. Geodesic (co-flow) motion preserves geometric coherence and produces no felt acceleration; off-flow motion yields geometric decoherence (felt acceleration) as the local metric desynchronizes from the global field metric.

Bridge: Arc-closure vs. loop structures. Quantization I defined quantization as a *geometric* coherence condition—local-global alignment in $g = \lambda^2\eta$—without invoking loops or currents. Quantization II introduces loop structures and circulation: *closed loops*—conservative, no exchange, permitting under-substrate through-flow with impedance and a local λ-up kink; and *open loops*—identical, single-occupancy coupling cells that fully deplete availability in a tiny volume and serve as the only path for exchange (sign = source/sink).

For reference a notation guide can be found in **Appendix A**.

2. Foundational Postulates and the Bundle Constraint

This section fixes the ontology used throughout Quantization II, extending the

NUVO-space framework of NUVO I-II [1] [2] and the arc-closure results of Quantization I [8]. All postulates below classify the conservative case and introduce exchange only where explicitly noted; none modify the results of NUVO I-II.

Postulates (canonical)

1) Two-substrate architecture. The *under-substrate* is the continuous sinertia power network, flowing at the limiting speed c. The *above-substrate* is the observable geometry $g = \lambda^2 \eta$. Sinertia does not flow within the above-substrate except through *open loops*.

Physical meaning of the under-substrate.

The under-substrate sinertia field represents the continuous carrier of scalar flux that underlies all conformal modulation. It is kinematic rather than independently energetic: its role is to maintain constant-speed (c) flux continuity beneath the geometric layer $g = \lambda^2 \eta$. Energy-momentum appears only when curvature or exchange occurs in the over-substrate geometry, so the sinertia field itself contributes no separate stress-energy tensor. This second substrate is necessary because a single conformal layer cannot both sustain local unit normalization and propagate scalar disturbances at finite speed; the dual-substrate form preserves both requirements.

2) Inverse modulation. Local sinertia availability decreases as geometric modulation increases:

$$A \downarrow \Leftrightarrow \lambda \uparrow,$$

or equivalently, one may model the relation as $A = A_0 / \lambda^p$ with $p > 0$. This monotone rule encodes the geometric link between curvature and inertial response.

3) Closed loop (mass coupling). A closed loop is a *discrete, invariant* unit with no exchange across substrates ($S_{\text{exch}} = 0$). Under-substrate through-flow continues but with *impedance*, producing a local λ -up kink and an inward gradient. Scalar circulation around the loop is conserved; in steady operation the outer flux can be taken as zero. Motion that co-flows with the sinertia field is geodesic (no felt acceleration), whereas off-flow motion yields felt acceleration. Speed is bounded by c.

4) Open loop (charge coupling). An open loop O originates when a closed loop C fractures, producing a complementary *source-sink pair* that preserves overall conservation. Open loops therefore exist only in such paired form, each coupling cell being *identical* and *single-occupancy* at its local site. A source cell locally depletes under-substrate availability (driving λ upward), while its sink partner restores it (driving λ downward); together they ensure net balance of exchange. The open loop provides the sole path for substrate transfer ($S_{\text{exch}} \neq 0$), with $\operatorname{sign}(S_{\text{exch}})$ identifying source or sink polarity. No open loop can exist unbundled: each is intertwined with a closed-loop partner within a bundle $B = (C, O)$.

5) Bundle Postulate (elementary particles). Every elementary particle corresponds to one *bundle* $B = (C, O)$, consisting of a closed loop C (mass coupling) intertwined with one open loop O (charge coupling). The open loop represents the particle's exchange channel and may be neutralized, fused, or oppositely paired within composite or confined states. Photons are dynamic loops above the geometry (not bundles), and neutrinos are interpreted as residuals of broken open loops rather than complete bundles.

6) Composites and black-hole limit. Macroscopic matter consists of aggregates of bundles; the net charge is the algebraic sum of open-loop signs. As bundle spacing →0, availability collapses on a contiguous region and $\lambda \to \infty$, defining the black-hole limit.

7) Global conservation. Under-substrate continuity with exchange obeys

$$\partial_t A + \nabla \cdot (Av) = -S_{\text{exch}},$$

with global balance $\int S_{\text{exch}} \mathrm{d}V = 0$, so sources and sinks exactly offset.

8) Coherence is geometric (not substrate). Throughout, "coherence" refers *exclusively* to geometric alignment between a loop's local metric and the global λ-modulated metric. The sinertia substrate itself remains continuous and never (de)coheres. Geodesic (co-flow) motion preserves geometric coherence; off-flow motion yields geometric decoherence as the local metric desynchronizes from the global field metric.

Remarks: Gravitational versus local growth. In macroscopic gravitational configurations the scalar modulation λ is expected to remain finite, while unbounded growth may occur only in localized, non-propagating regions associated with accelerative or alignment-driven processes. Such local amplification does not alter the global field or imply a physical singularity. A quantitative treatment of these limits will be presented in future work.

Canonical definitions

Definition 1 (Closed loop). A localized coupling C is a closed loop if (i) it is exchange-free ($S_{\text{exch}} = 0$) and admits under-substrate through-flow with impedance (local availability reduced, λ increased); (ii) the scalar circulation $\Phi_\lambda = \oint_\gamma \lambda u_\mu \mathrm{d}x^\mu$ around any material contour γ enclosing C is time-invariant; and (iii) in steady operation, the net outer flux can be set to zero while an inward gradient sustains the through-flow.

Definition 2 (Open loop). An open loop O originates when a closed loop C fractures, producing a complementary source-sink pair that preserves overall conservation. Each open loop is an identical, single-occupancy coupling cell operating as the local site of substrate exchange ($S_{\text{exch}} \neq 0$). A source cell reduces under-substrate availability (driving λ upward), while its sink counterpart restores it (driving λ downward); together the pair maintains net balance of exchange. Open loops exist only in such paired form and cannot exist unbundled, as each must remain intertwined with a closed-loop partner within a bundle $B = (C, O)$.

Remarks: Continuity of substrate versus discreteness of coupling. The under-substrate sinertia field is continuous, supporting smooth transport and geometric modulation through $\lambda(x)$. However, the loop connections that couple to this field are inherently *discrete*—each open or closed loop represents a quantized channel through which exchange or circulation can occur. Consequently, physical observables derived from these couplings appear discrete even though the underlying substrate is continuous. This duality between continuous field and discrete connection provides a natural geometric origin for quantized behavior without requiring a separate quantization postulate.

Definition 3 (Bundle). An elementary bundle is an inseparable pair $B=(C,O)$, where the closed loop C (mass) is intertwined with exactly one open loop O (charge). Elementary particles correspond to single bundles; composite bodies are aggregates of bundles.

Illustrative Mapping to Known Particles

The closed-open bundle ontology admits a straightforward correspondence with standard elementary species. Each particle type can be expressed in terms of the bundle components defined above.

Particle	NUVO Mapping	Consistency
Electron	$C+O_-$ (sink open loop)	yes
Positron	$C+O_+$ (source open loop)	yes
Proton	$C+O_+$ (source)	yes
Neutron	$C+O_++O_-$ fused under confinement $\Rightarrow$ net neutral	yes (bundle fusion)
Photon	dynamic loop above geometry (not a bundle)	yes (separate class)
Neutrino	residual fragment of a broken open loop; not a full bundle	yes (new class allowed)
Quarks	fractional bundle couplings within composite aggregates; open-loop participation fractions 1/3 or 2/3	yes if interpreted as fractional open-loop states
Gluon or other gauge bosons	exchange mediators; dynamic loops with no substrate coupling	yes

Remarks. This correspondence is phenomenological and serves only to illustrate how the bundle ontology can reproduce the structure of observed matter. Detailed modeling of composite states, confinement behavior, and fractional open-loop participation will be presented in future work. Dynamic loops (photons) and residuals (neutrinos) are treated separately in forthcoming analyses of scalar-radiative and scalar-decay behavior. If confirmed, this mapping would imply that all known elementary species are *modeled* as expressions of the same two-substrate coupling geometry, differing only by their open-loop sign, multiplicity, and confinement state.

Consistency notes

- **Compatibility with NUVO I-II.** The conservative regime of NUVO I-II corresponds to $S_{\text{exch}}=0$ and is identical to the closed-loop domain defined above.

- **Transport sign.** For heuristic arguments one may use $F = Av \propto \nabla\lambda$, so that flow is directed toward larger λ (lower availability), consistent with the inverse-modulation rule.
- **Acceleration split.** Geodesic (co-flow) motion $\Rightarrow$ no felt acceleration (geometric coherence preserved); off-flow motion $\Rightarrow$ felt acceleration (geometric decoherence).

3. Minimal Kinematics and Dynamics of a Single Bundle

This section develops the minimal dynamical representation of an elementary bundle $B = (C, O)$ consistent with the canonical postulates of Sec., where C is the closed (mass) coupling and O is the open (charge) coupling. The goal is to capture (i) under-substrate continuity and transport bounded by c, (ii) impedance and circulation for C with $S_{\text{exch}} = 0$, (iii) identical, single-occupancy exchange for O with $S_{\text{exch}} \neq 0$, and (iv) the geometric (not substrate) nature of coherence.

Backreaction split. Closed/open bundles contribute to the local λ-structure through the closed-loop impedance profile ζ (and, when off-flow, kinematic modulation), whereas Dynamic Loops (photons) do not contribute: they are substrate-detached and $S_{\text{exch}} = 0$ in flight.

3.1. Fields, Inverse Rule, and Flux

Let $A(x,t)$ denote under-substrate availability (power density), $v(x,t)$ the under-substrate transport velocity with $|v| \leq c$, and

$$F(x,t) := A(x,t)\,v(x,t) \tag{1}$$

the under-substrate flux.

Inverse modulation. We encode the inverse rule by a monotone relation

$$A = \frac{A_0}{\lambda^p}, \quad p > 0, \quad A_0 > 0, \tag{2}$$

so that availability $\downarrow$ if and only if $\lambda\uparrow$.

Continuity with exchange. Under-substrate continuity reads

$$\partial_t A + \operatorname{div}(F) = -S_{\text{exch}}, \tag{3}$$

where $S_{\text{exch}}(x,t)$ represents exchange with the geometry (positive = source to geometry, negative = sink from geometry). Global conservation imposes $\int S_{\text{exch}}\,\mathrm{d}V = 0$.

Transport choice (geometry-guided, causal). To reflect the observed inward pull toward λ-up kinks produced by C, we adopt the minimal constitutive choice

$$F = \kappa(x,t)\nabla\lambda, \quad \kappa \geq 0, \quad |v| = \frac{|F|}{A} \leq c, \tag{4}$$

so flow heads toward higher λ (lower availability), consistent with (2). The bound $|v| \le c$ is enforced by $0 \le \kappa \le \kappa_{\max}(A, c)$.

3.2. Closed Component *C*: Impedance, Circulation, and no Exchange

Let $C \subset \mathcal{M}$ be a small region (the closed coupling core). It is *exchange-free*:

$$S_{\text{exch}} \equiv 0 \text{ on a neighborhood of } C. \tag{5}$$

Impedance. Introduce a localized impedance factor $\zeta(x) \ge 0$ supported on C by reducing mobility,

$$\kappa_C(x) = \frac{\kappa_0(x)}{1+\zeta(x)}, \quad \zeta(x) \gg 0 \text{ on } C, \quad \zeta(x) = 0 \text{ off } C. \tag{6}$$

Then (4) and (2) enforce a λ *-up kink* on C (availability reduced inside C), with $\nabla\lambda$ pointing inward.

Steady circulation and outer balance. For a control region $\Omega \supset C$ with outer boundary $\partial\Omega$, the steady exchange-free balance from (3) is

$$\int_{\partial\Omega} F \cdot n dS = 0, \quad \int_{\partial C} F \cdot n dS < 0 \ (\text{net inward flux}), \tag{7}$$

so the inward flux across ∂C sustains the through-flow attenuated by (6). With u^{μ} a unit tangent along a material contour γ enclosing C, the scalar circulation

$$\Phi_{\lambda} := \oint_{\gamma} \lambda u_{\mu} \mathrm{d}x^{\mu} \tag{8}$$

is time-invariant in the closed, steady case.

Coherence remark. Coherence here is *geometric*: geodesic/co-flow motion preserves local-global metric alignment (no felt acceleration), while off-flow motion produces geometric decoherence (felt acceleration). The substrate itself remains continuous.

3.3. Open Component *O*: Identical Coupling Cell and Single Occupancy

The open coupling is a tiny cell O (single-occupancy) where exchange occurs and local availability is fully depleted:

$$\begin{aligned} &A \approx 0 \text{ inside } O, \quad S_{\text{exch}} \neq 0 \text{ on } O, \\ &\operatorname{sign}(S_{\text{exch}}) = \begin{cases} + & \text{source to geometry (positive charge)}, \\ - & \text{sink from geometry (negative charge)}. \end{cases} \end{aligned} \tag{9}$$

All open loops are *identical* in this sense. Global conservation requires $\int S_{\text{exch}} \mathrm{d}V = 0$ (sources balance sinks, possibly across distant bundles).

3.4. Bundle Constraint and Kinematics

An elementary particle is exactly one bundle $B = (C, O)$ with O *intertwined* to its C:

$$O \text{ cannot exist unbundled, and } \operatorname{dist}(O, C) \text{ is fixed by the species.} \tag{10}$$

The bundle's center-of-structure follows the local transport field:

$$V_{\text{bundle}}(t) \equiv v(x_{\text{bundle}}(t), t), \quad |V_{\text{bundle}}| \le c. \tag{11}$$

Geodesic/co-flow motion ($\dot{x}_{\text{bundle}} = V_{\text{bundle}}$) yields no felt acceleration; imposed deviation from (11) produces felt acceleration (geometric decoherence). As $|V_{\text{bundle}}| \to c$, maintaining alignment through the impedance region (6) requires sharply increased internal exchange, leading to steep energy growth (relativistic-like scaling).

3.5. Canonical Steady Scenarios

Scenario S1: Closed bundle at rest. With $S_{\text{exch}} = 0$ in Ω, (3) and (7) give zero outer flux and inward flux across ∂C; (6) induces a λ-up kink; circulation (8) is constant.

Scenario S2: Closed bundle translating with the flow. Take $v \equiv v_0$ (uniform, $|v_0| < c$). Then $V_{\text{bundle}} = v_0$, geometric coherence is preserved, and (8) remains constant up to convective transport.

Scenario S3: Closed bundle forced off-flow. Impose a trajectory with velocity $V_{\text{ext}} \ne v(x,t)$. The mismatch creates felt acceleration (geometric decoherence); if S_{exch} remains zero, the process is non-radiative but requires momentum exchange with the surrounding under-substrate through the impedance region.

Scenario S4: Source-sink channel (radiative). Two tiny open cells O_+ and O_- with equal and opposite exchange ($\int_{O_+} S_{\text{exch}} \mathrm{d}V = -\int_{O_-} S_{\text{exch}} \mathrm{d}V$) form an exchange channel; each $O_\pm$ is identical and single-occupancy and must be bundled with its own C.

3.6. Parameter Identifiability

The triplet (p, κ, ζ) governs phenomenology:

- $p > 0$ sharpens or softens the inverse relation (2) ($p = 1$ is the simplest).
- $\kappa(x,t)$ sets transport strength subject to $|v| \le c$ in (4).
- ζ represents the invariant impedance of the closed loop C in (6), a discrete local constant that defines how sinertia flow couples to geometry at the loop boundary. All closed loops share the same intrinsic ζ_0, analogous to an invariant rest energy. Apparent variations in coupling or inertial strength arise not from changes in ζ itself, but from modulation of available sinertia through the scalar field $\lambda(x)$; the observable (effective) impedance therefore behaves as $\zeta_{\text{eff}}(\lambda) = \zeta_0 f(\lambda)$ while ζ_0 remains constant for all closed loops.

These parameters enter observations only through conserved circulation, speed limit, and alignment/decoherence behavior; they can be calibrated from steady profiles (S1), drift (S2), forced response (S3), and exchange signatures (S4).

Remark: Because ζ_0 is invariant, any gradient in the surrounding scalar field λ produces unequal sinertia flux across a loop. The loop then translates in the direction that restores flux balance, drawing motion toward regions of greater sinertia availability (smaller λ). This self-balancing response provides a geometric origin for gravitational acceleration within the NUVO framework [9] [10], where the corresponding scalar field equation and its post-Newtonian expansion quantify the same behavior in the continuum limit.

Coherence reminder. All "coherence" statements above refer to geometric alignment (local vs. global metrics). The sinertia substrate remains continuous and never (de)coheres.

4. Scalar Circulation and Loop Classification

This section formalizes scalar circulation on NUVO space and classifies loop behavior for a single bundle $B=(C,O)$. The definitions are compatible with NUVO I-II [1] [2] and extend Quantization I's geometric arc-closure [8] to circulation-based statements. Throughout, *coherence* is geometric (alignment of local vs. global metrics); the sinertia substrate remains continuous and never (de)coheres.

4.1. Circulation and Current

Let u^{μ} denote the unit tangent along a material contour γ measured in the background metric η. The *scalar circulation* of the bundle is

$$\Phi_{\lambda} := \oint_{\gamma} \lambda u_{\mu} \mathrm{d}x^{\mu}. \tag{12}$$

For field-theoretic bookkeeping we retain the sinertia four-current

$$J_{\lambda}^{\mu} := \lambda \rho u^{\mu}, \quad {}^{\lambda}\nabla \cdot J_{\lambda} = -D_{\lambda}, \tag{13}$$

where ${}^{\lambda}\nabla \cdot$ is the NUVO divergence, ρ is the flowing density, and D_{λ} is a geometric depletion term. In the two-substrate picture, D_{λ} is the geometric image of the exchange density S_{exch} used in §3 (proportionality fixed by normalization); *closed* operation corresponds to $D_{\lambda}=0$ (equivalently $S_{\text{exch}}=0$).

Remark 4 (Circulation vs.arc-closure). Arc-closure in Quantization I is a geometric action closure (local-global alignment) for stationary states; (12) is a loop circulation measured along material contours. In conservative settings, circulation constancy and arc-closure agree on discrete stationary configurations; they differ in scope once exchange or alignment variation is present.

Remark 5 (Notation hygiene: mapping A to J_{λ}^{μ}) The transport model in §3 uses the availability density A and flux $F = Av$. The four-current (13) provides the covariant bookkeeping. In the nonrelativistic limit (and up to a fixed normalization constant), one may identify the spatial current with F via $J_{\lambda}^{i} \propto F^{i}$, and the time component with $\lambda\rho \propto A$; the precise constant is absorbed into the $D_{\lambda} \leftrightarrow S_{\text{exch}}$ proportionality used below.

4.2. Closed, Open, and GAK

Closed loops (mass; exchange-free). A loop is *closed* if the bundle operates with no exchange:

$$D_\lambda \equiv 0 \ \left(\text{i.e. } S_{\text{exch}} \equiv 0\right), \quad \frac{\mathrm{d}}{\mathrm{d}t}\Phi_\lambda = 0, \tag{14}$$

and the under-substrate through-flow persists with impedance (local availability reduced, λ increased) as in §3. For a control region $\Omega \supset C$ in steady operation,

$$\oint_{\partial\Omega} F \cdot n\mathrm{d}S = 0, \quad \oint_{\partial C} F \cdot n\mathrm{d}S < 0 \ \left(\text{net inward}\right), \tag{15}$$

and geometric coherence is preserved along geodesic/co-flow motion (no felt acceleration).

Open loops (charge; exchange-enabled). A loop is *open* on the tiny coupling cell O if

$$A \approx 0 \ \text{ on } O, \quad D_\lambda \neq 0 \ \text{ on } O \ \left(\Leftrightarrow S_{\text{exch}} \neq 0\right), \tag{16}$$

with sign giving source/sink. Open loops are identical, single-occupancy, and *cannot* exist unbundled; every O is intertwined with its unique C (bundle constraint). In this case, circulation of a contour that threads the exchange cell is not conserved:

$$\frac{\mathrm{d}}{\mathrm{d}t}\Phi_\lambda = -\int_{\Sigma_\gamma} D_\lambda \mathrm{d}\Sigma \ \left(\text{equivalently } -\int_{\Sigma_\gamma} \alpha S_{\text{exch}} \mathrm{d}\Sigma\right), \tag{17}$$

where Σ_γ is any surface with boundary $\partial\Sigma_\gamma = \gamma$, and α collects the normalization between D_λ and S_{exch}.

Geometric alignment kinematics (time-varying alignment; not photons). A loop exhibits *geometric alignment kinematics* (*GAK*) when $\lambda(t, x)$ and/or the bundle motion drives time-varying local-global metric alignment while remaining in the same exchange class (closed or open). The relevant evolution is

$$\frac{\mathrm{d}}{\mathrm{d}t}\Phi_\lambda = -\int_{\Sigma_\gamma} D_\lambda \mathrm{d}\Sigma + \oint_\gamma \dot{\lambda} u_\mu \mathrm{d}x^\mu, \tag{18}$$

where the second term is a purely *geometric* contribution (substrate continuous), responsible for alignment/realignment cycles. In the closed case ($D_\lambda = 0$), recurrence conditions reduce to arc-closure-type integral constraints in the stationary limit (cf. Section 5 for *Dynamic Loops (photons)*, which are distinct objects above the geometry).

4.3. Equivalent Control-Volume Statements

Let Ω be a control region with outer boundary $\partial\Omega$ enclosing the bundle core. Integrating (13) and using the divergence theorem:

$$\frac{\mathrm{d}}{\mathrm{d}t}\int_\Omega \lambda\rho \mathrm{d}V_\eta = -\oint_{\partial\Omega} \lambda\rho u^i \mathrm{d}S_i - \int_\Omega D_\lambda \mathrm{d}V_\eta. \tag{19}$$

Thus:

- **Closed:** $D_\lambda = 0$ and the outer flux can be set to zero in steady operation; Φ_λ is constant for contours enclosing C.

- **Open:** $D_\lambda \neq 0$ only on the tiny cell O (identical, single-occupancy); Φ_λ changes according to (17).
- **Geometric alignment kinematics:** D_λ as above for the exchange class, plus geometric time-variation $\dot{\lambda}$ produces alignment cycles captured by (18). *Not to be confused with Dynamic Loops* (*photons*) *in Section* 5.

4.4. Geometric Coherence and Acceleration Split

Coherence and decoherence here refer solely to *geometric alignment* of local vs. global metrics:

- *Geodesic/co-flow*: local and global metrics remain aligned; D_λ unchanged by motion; Φ_λ follows (14) or (18) with $D_\lambda = 0$.
- *Felt acceleration/off-flow*: local metric desynchronizes (geometric decoherence); circulation responds via (18); if O engages, $D_\lambda \neq 0$ on the coupling cell and (17) applies.

In all cases, the substrate remains continuous; only geometric alignment changes.

Example (local vs global influence: two clocks). Consider two colocated clocks on the geometry: a *stationary* clock co-flowing with the local sinertia field (geodesic/co-flow) and an *accelerating* clock driven off-flow (felt acceleration). (i) *Local effect.* The stationary clock remains geometrically coherent with the global metric and is *not* affected by the other clock's acceleration: one bundle's off-flow misalignment does not propagate a substrate disturbance (the substrate is continuous and never (de)coheres) and does not alter the neighbor's local metric. The accelerating clock alone experiences geometric decoherence (felt acceleration) and its proper-time evolution reflects its own local misalignment. (ii) *Global effect.* Introduce a nearby massive object (aggregate of bundles producing a persistent λ profile). Both clocks now respond to the same global geometry: the stationary clock's rate and the accelerating clock's rate shift in accordance with the local value/gradient of λ set by the mass. In this case the influence is *global*, mediated by the common λ-field, and it affects geodesic and off-flow worldlines alike (with the off-flow clock additionally carrying its own decoherence cost). This contrast emphasizes the ontology: *local* acceleration produces only a bundle-specific geometric misalignment (no broadcast disturbance), whereas *global* structure (through λ) modulates all nearby bundles uniformly according to their position in $g = \lambda^2 \eta$.

Remark (GR vs NUVO geodesics). In GR, massive particles and light follow geodesics of the *same* metric connection (timelike vs null). In NUVO, both read the instantaneous geometry $g = \lambda^2 \eta$ for their paths, but only bundles (particles) can *locally contribute* to λ (via the closed-loop impedance ζ, and when off-flow—kinematic modulation). Dynamic Loops (photons) are closed above the geometry, $S_{\text{exch}} = 0$ in flight, never accelerate, and thus do not source or modulate λ. Accordingly, photons trace null-like curves of the existing g, while particles can both follow and (locally) reshape g.

4.5. Summary of Loop Taxonomy

Class	Defining condition	Circulation/exchange
Closed (mass)	$D_\lambda = 0$ (no exchange); impedance with λ-up kink; inward gradient; geodesic preserves geometric coherence	$\frac{d}{dt}\Phi_\lambda = 0$; outer flux can be set to 0 in steady operation
Open (charge)	Identical, single-occupancy coupling cell O with $A \approx 0$ inside; intertwined with C; sign = source/sink	$\frac{d}{dt}\Phi_\lambda = -\int_{\Sigma_\gamma} D_\lambda d\Sigma$; global $\int S_{exch} dV = 0$
Geometric Alignment Kinematics	Time-varying local-global alignment within the same exchange class (closed or open)	$\frac{d}{dt}\Phi_\lambda = -\int_{\Sigma_\gamma} D_\lambda d\Sigma + \oint_\gamma \dot{\lambda} u_\mu dx^\mu$

All statements above are geometric; the sinertia substrate remains continuous and never (de)coheres. Closed and open loops provide the conservative and exchange-enabled building blocks for the bundle ontology, while *Dynamic Loops (photons)*—defined separately in Section 5—are free, substrate-detached objects above the geometry.

5. Dynamic Loops (Photons): Generation, Propagation, and Interaction

This section defines *dynamic loops* as closed structures *above the geometry* that carry sinertia energy at speed c with *no coupling to the substrate* in flight. They are generated *only* by open loops (charge couplings) and interact *only* with open loops. In physical terms, dynamic loops are *photons*. To avoid confusion, we reserve the phrase *Geometric Alignment Kinematics* (*GAK*) for time-variation of local-global metric alignment within a fixed exchange class; it is not a dynamic loop.

5.1. Definition and Generation

Definition 6 (Dynamic loop (photon)). *A dynamic loop is a closed loop that resides above the geometry with zero substrate coupling*:

$$S_{exch} = 0 \quad \text{everywhere along the loop,}$$

and hence produces *no* under-substrate gradient (no change in A) and *no* impedance signature in the substrate while propagating. A dynamic loop is *created at an open-loop event*: during emission or absorption at O, a portion of the exchange closes above the geometry and forms a free, closed structure decoupled from the substrate.

Source of dynamic loops. Only open loops can generate or absorb dynamic loops. If $B = (C, O)$ is an emitting bundle and O operates as a source, a portion of the exchanged sinertia closes above the geometry and becomes a dynamic loop (photon). Conversely, only open loops can absorb dynamic loops.

5.2. Propagation and Invariants

Speed and path. Dynamic loops propagate at the universal speed c along null geodesics of the ambient geometry $g = \lambda^2\eta$. (Conformal rescaling preserves the null cone, so null-like trajectories of η remain null-like for g; null-like propagation follows directly from the conformal invariance of light cones [11]). Being closed above the geometry, they have $S_{\text{exch}} = 0$ in flight and do not induce substrate gradients. *They are guided only by the global conformal structure of* g *, not by local substrate variations, so small-scale* λ *fluctuations near massive or charged bundles exert no direct influence on their trajectory.*

No backreaction (no local sourcing of λ). Dynamic Loops (photons) never accelerate and have no substrate connection; in flight $S_{\text{exch}} = 0$ everywhere along the loop. Consequently they do not generate a kinetic/local contribution to λ and do not alter the under-substrate availability A. Photons therefore propagate on the *given* conformal geometry $g = \lambda^2\eta$ (null-like), while only bundles (particles) can modify λ locally through their closed-loop impedance ζ and off-flow kinematics.

Frequency/energy label and λ-shift. Each dynamic loop carries a frequency (sinertia-energy) label set at generation,

$$\nu_{\text{gen}} \propto \frac{E_{\text{gen}}}{\mathfrak{A}},$$

with $\mathfrak{A}$ the universal action constant (Quantization I [8]). Along propagation, the frequency undergoes a λ*-shift* determined by the conformal scalar:

$$\frac{\nu_{\text{obs}}}{\nu_{\text{gen}}} = \mathcal{Z}\left(\lambda_{\text{gen}}, \lambda_{\text{path}}, \lambda_{\text{obs}}\right),$$

where $\mathcal{Z}$ encodes the red/blue shift implied by the conformal geometry (larger local λ corresponds to lower availability via the inverse rule). The loop remains decoupled from the substrate during this shift. Conformal rescaling preserves the null cone, so dynamic loops follow null geodesics of $g = \lambda^2\eta$ [12].

Remark: Impedance origin of red/blue shift. In the NUVO framework, the impedance factor ζ governing a closed or open loop also determines how efficiently sinertia can be exchanged with a dynamic loop. A dynamic loop carries a fixed quantity of sinertia, but the *delivery rate* of that energy to (or from) an interacting open loop depends on its local ζ value. High impedance ($\zeta\uparrow$) slows the effective transfer rate, producing a redshift-like response, whereas low impedance ($\zeta\downarrow$) permits faster transfer and a blueshift-like response. Hence the observed frequency shift may be viewed equivalently as a *coupling-impedance effect*: variation in ζ along the emission-absorption path modulates the received frequency without any intrinsic loss or gain of sinertia. This interpretation links the conformal λ-shift to the local impedance structure of the interacting bundles and provides a physical basis for the functional form of $\mathcal{Z}$ introduced above.

Conservation. With $S_{\text{exch}} = 0$ in flight, a dynamic loop preserves a loop invariant (a circulation-like integral) along its null path until interaction at an open loop.

5.3. Superposition and Co-Occupancy (Detached Nature)

Dynamic loops are *detached* from the substrate and do not create substrate impedance or exclusion. Consequently:

- **Co-occupancy.** Multiple dynamic loops can *occupy the same spacetime region simultaneously*. There is no single-occupancy restriction (no analogue of the coupling-cell rule for open loops), provided the local sinertia density remains below any threshold for self-closure.
- **Superposition/interference.** Because they are closed above the geometry and guided by $g = \lambda^2 \eta$, their amplitudes superpose in the usual geometric sense (interference patterns arise from path-dependent phases encoded by the conformal metric), while the substrate remains unaffected.

Remark.—If the sinertia density above the substrate were to exceed a critical limit, NUVO geometry may permit spontaneous loop closure, producing new dynamic or closed loops. Such thresholds are not treated here but will be analyzed in later work.

5.4. Coherence-Gated Interaction (Selection Rule)

Dynamic loops interact *only* with open loops, and only when a *geometric coherence* condition is satisfied:

- **Exclusivity.** Closed loops (mass couplings) do not couple directly to dynamic loops; only the open component O of a bundle can emit/absorb.
- **Coherence gate.** Let g_{dyn} denote the loop's effective metric structure along its path segment near a target bundle, and let g_{loc} be the bundle's local metric. Interaction (emission/absorption/scattering) occurs only when a coherence functional

$$\mathcal{C}\left(g_{\text{dyn}}, g_{\text{loc}}\right) \in [0,1]$$

exceeds a threshold. Operationally, $\mathcal{C}$ measures local-global *geometric alignment* (phase/action matching in the Quantization I sense) (see **Appendix E**).

- **Probabilistic coupling.** The effective interaction probability is proportional to $\mathcal{C}$ (and to overlap with the open-loop coupling cell). Thus probabilities arise from *geometric coherence*—the substrate itself remains continuous and never (de)coheres.

5.5. Separation from GAK

Dynamic loops (*photons*) must be distinguished from *Geometric Alignment Kinematics*:

- **Dynamic loop (photon).** A free, closed loop above the geometry; $S_{\text{exch}} = 0$ in flight; speed c; no substrate gradient; frequency set at generation and shifted by λ; *co-occupancy allowed*; interacts only with open loops; interaction is *coherence-gated*.

- **Geometric Alignment Kinematics (GAK) (not a dynamic loop).** Time-variation of the alignment between a bundle's local metric and the global metric $g = \lambda^2 \eta$ within a fixed exchange class. This modifies circulation bookkeeping for closed/open states but does not create a free, substrate-detached loop.

5.6. Quantized Transitions Via Emission

Quantization I [8] provides arc-closure as a geometric action condition for stationary states. When an open loop emits, the dynamic loop inherits a discrete frequency

$$\nu_n = \frac{\Delta E_n}{\mathfrak{A}},$$

set at the emitter's locality; ν_n is then shifted by λ along propagation. Line spectra thus arise from discrete *geometric* action increments at emission, while the propagating object is a substrate-detached dynamic loop (photon) whose interaction is coherence-gated at absorption.

5.7. Operational Summary

1) *Generation/absorption:* only by open loops (charge couplings).

2) *In flight:* $S_{\text{exch}} = 0$; no substrate gradient or backreaction; speed c; circulation-like invariant conserved.

3) *Superposition:* dynamic loops can *co-occupy* the same region and interfere; no single-occupancy restriction.

4) *Frequency:* set at generation by discrete action; red/blue shifted by λ along the path.

5) *Exclusivity and coherence gate:* interactions occur *only* with open loops and *only* when geometric coherence $\mathcal{C}\left(g_{\text{dyn}}, g_{\text{loc}}\right)$ is satisfied, yielding probabilistic coupling.

6. Illustrative Scenarios

This section collects operational scenarios that instantiate the ontology and minimal dynamics from Sections 3-5. Throughout, the sinertia substrate is continuous and never (de)coheres; all "coherence" statements are *geometric* (local vs global metric alignment). Dynamic loops (photons) are closed above the geometry, $S_{\text{exch}} = 0$ in flight, and interact only with open loops via coherence-gated selection. See **Appendix G** for Parameter Identifiability.

(S1) Closed bundle at rest (steady exchange-free operation)

Let $B = (C, O)$ be an elementary bundle with $S_{\text{exch}} = 0$ in a control region $\Omega \supset C$. Impedance on C produces a local λ-up kink; the inverse rule $A = A_0 / \lambda^p$ gives $\nabla\lambda$ inward. The under-substrate balance reads

$$\oint_{\partial\Omega} F \cdot n \mathrm{d}S = 0, \quad \oint_{\partial C} F \cdot n \mathrm{d}S < 0, \tag{20}$$

sustaining a steady through-flow. Scalar circulation $\Phi_\lambda = \oint_\gamma \lambda u_\mu \mathrm{d}x^\mu$ is time-invariant for any γ enclosing C. Geometric coherence holds (no felt acceleration).

(S2) Closed bundle translating with the flow (geodesic drift)

Embed B in a uniform transport field $v \equiv v_0$ with $|v_0| < c$. Then the bundle velocity $V_{\text{bundle}} = v_0$ (co-flow) preserves geometric coherence; the λ-up kink convects with the bundle and Φ_λ remains constant up to convection. No exchange occurs ($S_{\text{exch}} = 0$).

(S3) Closed bundle forced off-flow (felt acceleration)

Impose a trajectory with velocity $V_{\text{ext}} \neq v(x,t)$. The mismatch generates *geometric decoherence* (local metric desynchronizes from the global metric). If the bundle remains closed on C and O is not engaged, then $S_{\text{exch}} = 0$ and the process is non-radiative; momentum exchange occurs with the surrounding under-substrate through the impedance region. Circulation evolves only via alignment terms (cf. Eq. (18) with $D_\lambda = 0$).

(S4) Source-sink channel (emission/absorption via open loops)

Let O_+ and O_- be two open coupling cells operating with $\int_{O_+} S_{\text{exch}} \mathrm{d}V = -\int_{O_-} S_{\text{exch}} \mathrm{d}V \neq 0$. On O_+ (source), leaked sinertia closes above the geometry and forms a dynamic loop (photon) with generation frequency

$$\nu_{\text{gen}} = \frac{\Delta E_n}{\mathfrak{A}} \quad \text{(set by discrete geometric action at the emitter)}, \tag{21}$$

consistent with Quantization I. On O_- (sink), absorption occurs if and only if the *coherence gate* is satisfied (see S6). Global exchange is conserved: $\int S_{\text{exch}} \mathrm{d}V = 0$.

Justification of single occupancy. Empirically, all known free charges occur in integer multiples of e, and no evidence of fractional open-loop occupation has ever been observed. Geometrically, allowing multiple occupancies would require simultaneous scalar depletion at one point, which violates the local continuity condition $\nabla_\lambda \cdot J_{\sin} = 0$ and destabilizes the enclosing closed loop. Hence each open loop can host only one flux quantum; multiple charges correspond to discrete, spatially separated open loops.

(S5) Dynamic loop propagation, co-occupancy, and λ-shift (photons)

A dynamic loop generated at $(x_{\text{gen}}, t_{\text{gen}})$ propagates at speed c along a null-like path of $g = \lambda^2 \eta$, with $S_{\text{exch}} = 0$ in flight and no substrate gradient. Multiple dynamic loops may *co-occupy* the same spacetime region (no single-occupancy restriction); their amplitudes superpose geometrically (interference is path/metric dependent), while the substrate remains unaffected. The observed frequency at $(x_{\text{obs}}, t_{\text{obs}})$ obeys a conformal shift factor (see **Appendix D**)

$$\frac{\nu_{\text{obs}}}{\nu_{\text{gen}}} = \mathcal{Z}\left(\lambda_{\text{gen}}, \lambda_{\text{path}}, \lambda_{\text{obs}}\right), \tag{22}$$

giving red/blue shifts according to the λ-profile along the path (inverse rule). The red/blue-shift factor follows from differential conservation of scalar phase along a null transport path:

$$\frac{\mathrm{d}}{\mathrm{d}\tau}\left(\frac{\nu}{\lambda}\right) = 0 \Rightarrow Z = \frac{\nu_{\text{obs}}}{\nu_{\text{gen}}} = \frac{\lambda_{\text{gen}}}{\lambda_{\text{obs}}} \exp \int_{\text{path}} \nabla_\eta \ln \lambda \cdot \mathrm{d}\ell,$$

which reduces to the form of Equation (22) when λ varies only radially. For comparison see Austin, *NUVO Space II*, Section 4 (weighted geodesics) and *NUVO Quantization I*, **Appendix B**, where the same exponential law is derived from phase-holonomy closure.

(S6) Coherence-gated interaction with an open loop (selection and probability)

A dynamic loop (photon) interacts *only* with an open loop. Let g_{dyn} denote the loop's effective metric structure near the target bundle and g_{loc} the bundle's local metric. Define a coherence functional $\mathcal{C}(g_{\text{dyn}}, g_{\text{loc}}) \in [0,1]$ that measures geometric alignment (phase/action matching in the Quantization I sense). Interaction probability is proportional to $\mathcal{C}$ (and to overlap with the open coupling cell):

$$\mathbb{P}_{\text{int}} \propto \mathcal{C}(g_{\text{dyn}}, g_{\text{loc}}) \times (\text{cell overlap}). \tag{23}$$

Closed loops (mass couplings) do not couple to photons directly.

(S7) Composite matter and black-hole limit

A macroscopic body comprises many bundles $\{B_k = (C_k, O_k)\}$. Net charge is $\sum \text{sign}(O_k)$; inertial properties trace to the collection $\{C_k\}$ (impedance profiles). As bundle spacing decreases, availability collapses over a contiguous region and $\lambda \to \infty$; in the limit (spacing $\to 0$) the configuration reaches the black-hole regime. Photons traverse the exterior with $S_{\text{exch}} = 0$ in flight and experience λ-shift; interaction at the horizon is governed by the coherence gate at any accessible open loops.

Summary. (S1)-(S3) illustrate closed, exchange-free mass behavior (geodesic vs felt acceleration) with conserved circulation and geometric coherence. (S4)-(S6) isolate emission, propagation, superposition, λ-shift, and coherence-gated absorption of dynamic loops (photons), emphasizing their substrate-detached nature and exclusivity to open loops. (S7) extends the picture to aggregates and the black-hole limit.

Relation to gauge symmetry and classical electrodynamics. The open-loop connection form $\omega_\mu = \partial_\mu \ln \lambda$ defines an Abelian gauge potential intrinsic to the scalar geometry. Its curl, $F_{\mu\nu} = \partial_\mu \omega_\nu - \partial_\nu \omega_\mu$, satisfies $\nabla_\lambda^\mu F_{\mu\nu} = 0$ in the absence of sources, reproducing the homogeneous Maxwell equations in the static limit. When an open loop anchors between closed loops, the boundary condition $\oint F_{\mu\nu} \mathrm{d}S^{\mu\nu} = n\Phi_0$ enforces charge quantization in integer multiples of a fundamental flux Φ_0. Thus the fine-structure constant and electric charge arise naturally from the single-occupancy quantization of scalar flux within the NUVO geometry.

7. Discussion and Outlook

What has been established. Building on NUVO I-II [1] [2] and Quantization I [8], this paper has: (i) fixed a two-substrate ontology with the inverse rule (availability $\downarrow \Leftrightarrow \lambda \uparrow$); (ii) classified *closed* and *open* couplings and formalized circulation and exchange in both contour and control-volume form; (iii) introduced the *Bundle Postulate*—every elementary particle is exactly one bundle $B=(C,O)$, where C is a conservative mass coupling (closed loop) with impedance and O is an identical, single-occupancy charge coupling (open loop); (iv) defined *Dynamic Loops* (*photons*) as substrate-detached closed loops above the geometry, generated and absorbed only by open loops, propagating at c, capable of co-occupancy, and interacting through a *coherence gate*; and (v) distinguished *Geometric Alignment Kinematics* (time-varying local-global metric alignment within a fixed exchange class) from dynamic loops.

Remark 7 The geometric-action closure used here is conceptually parallel to modern geometric-quantization formulations [13], though derived directly from the conformal scalar geometry rather than a symplectic phase space.

Conceptual clarifications. Coherence in this framework is strictly *geometric*: it quantifies alignment of a bundle's local metric with the global metric $g=\lambda^2\eta$. The sinertia substrate remains *continuous* and never (de)coheres. Geodesic (co-flow) motion preserves geometric coherence (no felt acceleration), while off-flow motion induces geometric decoherence (felt acceleration). Closed loops remain exchange-free (no coupling across substrates) yet transmit under-substrate flow with impedance; open loops are the only exchange loci and are identical, single-occupancy coupling cells. Dynamic loops (photons) are closed above the geometry, have $S_{\text{exch}}=0$ in flight, superpose and co-occupy, and couple only to O through coherence-gated selection.

Minimal dynamics and identifiability. Section developed a compact transport model with $F=Av$, $A=A_0/\lambda^p$, $F=\kappa\nabla\lambda$ (with $|v|\le c$), an impedance profile ζ on C, and exchange density S_{exch} localized on O. The phenomenology is chiefly governed by (p,κ,ζ) and by the normalization linking the geometric depletion D_λ to S_{exch}. These parameters can be calibrated from steady profiles (S1), drift (S2), forced response (S3), and source-sink channels (S4), while photon behavior (S5-S6) constrains the λ-shift map $\mathcal{Z}$ and the coherence functional $\mathcal{C}$.

Testable implications and near-term probes

1) Charge quantization from single-occupancy. If every open loop is an identical, single-occupancy cell, the net charge of anybody must be an integer multiple of a fundamental unit. Deviations would falsify the open-loop identity axiom.

2) Spectral lines without field quantization. Discrete emission frequencies $\nu_n=\Delta E_n/\mathfrak{A}$ arise from geometric action increments at the emitter (Quantization I) (see also the Bohr-Sommerfeld quantization condition [14] [15]). Observed line systems constrain $\mathfrak{A}$ and the local geometric alignment conditions, while propagated frequencies constrain the λ-shift map $\mathcal{Z}(\lambda_{\text{gen}},\lambda_{\text{path}},\lambda_{\text{obs}})$.

3) Red/blue shift via λ (conformal) rather than kinematics alone. Astrophysical line shifts and time-dilation signatures should be compared with predictions based on the conformal scalar λ along null paths. Departures from purely kinematic (Doppler-only) models would support the NUVO interpretation.

4) Photon co-occupancy and interference. High-intensity interference in constrained geometries (multi-photon occupancy of the same spacetime region) should exhibit purely geometric superposition with no substrate back-reaction—a direct test of the substrate-detached nature of photons.

5) Geodesic vs. felt acceleration split. In precision accelerometry, bundles in co-flow should register no proper acceleration despite curvature, whereas forced off-flow trajectories should register felt acceleration. Correlations with local $\nabla\lambda$ provide quantitative checks.

6) Horizon coupling and black-hole limit. As bundle spacing in aggregates $\to 0$, availability collapses and $\lambda \to \infty$. Photon interaction at accessible horizons should remain coherence-gated via open loops, providing constraints on $\mathcal{C}$ near extreme λ.

For a representative solar-surface modulation profile $\lambda(r) = 1 + 2GM_\odot / (rc^2)$, Equation (22) predicts a red-shift magnitude

$$Z - 1 \simeq \frac{2GM_\odot}{R_\odot c^2} \approx 2.1 \times 10^{-6},$$

matching the observed gravitational red-shift at the Sun's photosphere to within current experimental precision. This serves as an order-of-magnitude confirmation of the scalar-shift mechanism under astrophysical conditions.

Remark 8. Comparisons of astrophysical line shifts and laboratory clock experiments [16] could discriminate between conformal λ-shift and purely kinematic Doppler effects.

Mathematical program

- **Normalization of D_λ vs. S_{exch}.** Fix the constant(s) α relating the geometric depletion in (13) to the exchange density in §3, ensuring consistent integral theorems and circulation evolution (17), (18).
- **Null propagation and invariants for dynamic loops.** Derive the photon path equations on $g = \lambda^2 \eta$ and the associated circulation-like invariants; prove conservation in the absence of interaction and determine the form of the λ-shift factor $\mathcal{Z}$.
- **Existence, stability, and uniqueness of closed-loop cores.** Given (p, κ, ζ), establish conditions for existence of steady λ-up kinks with inward flux and conserved circulation; analyze linearized stability and spectral gaps (connection to ΔE_n) (see **Appendix F**).
- **Coherence functional $\mathcal{C}$.** Construct $\mathcal{C}(g_{\text{dyn}}, g_{\text{loc}})$ from action/phase alignment (Quantization I) and local coupling geometry; prove bounds and selection rules and connect to observed cross-sections.
- **Variational and Hamiltonian structure.** Extend the energy functional for λ to include impedance and exchange terms; derive Euler-Lagrange equations for C/O embedding and for bundle kinematics under the $|v| \le c$ causality constraint. See **Appendix C** for more information.
- **Composite assemblies and continuum limits.** Pass from discrete bundles to effective media; obtain coarse-grained equations for λ and exchange density; identify regimes approaching the black-hole limit.

Risks, assumptions, and falsifiability

- **Open-loop identity and single-occupancy.** If experiments reveal variable coupling strength or multi-occupancy at a single site, the identity axiom must be revised.
- **Inverse rule and transport sign.** Empirical evidence that flow does *not* head toward higher λ (lower availability) would require modification of the constitutive choice $F \propto \nabla\lambda$ or of the inverse rule itself.
- **λ-shift law.** If observed photon shifts cannot be reconciled with any conformal $\mathcal{Z}$ derived from $g = \lambda^2\eta$, the dynamic-loop propagation model would be constrained or falsified.
- **Coherence gate.** Absorption or emission events that are insensitive to metric alignment would challenge the geometric-coherence interpretation and the construction of $\mathcal{C}$.

Outlook. The next papers will (i) quantify depletion and power-connection laws linking D_λ to S_{exch}; (ii) build the coherence functional $\mathcal{C}$ from first principles and calibrate it against cross-sections; (iii) derive the λ-shift factor $\mathcal{Z}$ for photon propagation in representative geometries; and (iv) develop stability and spectral theory for closed-loop cores to connect $\Delta E_n/\mathfrak{A}$ with observed line systems. The framework preserves NUVO I-II in the conservative limit, reconciles Quantization I's arc-closure with circulation-based dynamics, and elevates *bundles* and *dynamic loops* to concrete, testable building blocks of the physical world.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendices

Appendix A. Notation and Glossary

Conventions. We write η for the background Minkowski metric and $g = \lambda^2 \eta$ for the conformal metric; λ is a shorthand macro for λ. The under-substrate (sinertia) fields use (A, v, F), while the covariant bookkeeping uses $J_\lambda^\mu = \lambda \rho u^\mu$ and ${}^\lambda\nabla \cdot J_\lambda = -D_\lambda$. Unless stated otherwise, surface/volume elements are with respect to η.

Symbol	Meaning
λ	Conformal scalar; monotone inverse to local sinertia availability (availability $\downarrow \Leftrightarrow \lambda \uparrow$).
A	Under-substrate availability (power density).
v	Under-substrate transport velocity, $\lvert v \rvert \le c$.
F	Under-substrate flux, $F = Av$.
J_λ^μ	Sinertia four-current, $J_\lambda^\mu = \lambda \rho u^\mu$ (covariant bookkeeping).
S_{exch}	Exchange density between substrates (positive = source to geometry, negative = sink).
D_λ	Geometric depletion; proportional to S_{exch} via a constant α (Sec. B).
Φ_λ	Scalar circulation along a material contour, $\Phi_\lambda = \oint_\gamma \lambda u_\mu \mathrm{d}x^\mu$.
$B = (C, O)$	Bundle: closed loop C (mass) with intertwined open loop O (charge).
κ	Transport coefficient in $F = \kappa \nabla \lambda$ (bounded to enforce $\lvert v \rvert \le c$).
ζ	Impedance factor on C (reduces mobility: $\kappa \to \kappa/(1+\zeta)$ on the core).
p	Inverse-modulation exponent in $A = A_0/\lambda^p$ ($p > 0$).
$\mathfrak{A}$	Universal action constant (Quantization I [8]); sets $\nu_n = \Delta E_n / \mathfrak{A}$.
$\mathcal{Z}$	Conformal red/blue-shift factor for photons (dynamic loops).
$\mathcal{C}$	Coherence (alignment) functional for photon-open-loop interaction.

Appendix B. Control-Volume Identities and Normalization

Starting from ${}^\lambda\nabla \cdot J_\lambda = -D_\lambda$ with $J_\lambda^\mu = \lambda \rho u^\mu$, integration over a control region Ω yields

$$\frac{\mathrm{d}}{\mathrm{d}t} \int_\Omega \lambda \rho \mathrm{d}V_\eta = -\oint_{\partial\Omega} \lambda \rho u^i \mathrm{d}S_i - \int_\Omega D_\lambda \mathrm{d}V_\eta. \tag{24}$$

Units: $\alpha = D_\lambda / S_{\text{exch}}$ (rate per exchange density). Relate D_λ to S_{exch} via a constant α (to be fixed empirically or by a variational normalization):

In the conservative limit, energy-flux continuity across a bundle boundary requires that $\int_{\partial\Omega} F \cdot n \mathrm{d}S = \int_\Omega \alpha S_{\text{exch}} \mathrm{d}V$, so that α carries the dimensions of a characteristic scalar velocity. To leading order one may take $\alpha \approx c$, ensuring that geometric depletion D_λ represents the energy transfer rate per unit volume between the under-substrate and geometric domains. The precise normalization will be refined in the forthcoming depletion analysis.

$$D_\lambda = \alpha S_{\text{exch}}. \tag{25}$$

Then the circulation evolutions used in Sec. follow:

$$\frac{\mathrm{d}}{\mathrm{d}t}\Phi_\lambda = -\int_{\Sigma_\gamma} D_\lambda \mathrm{d}\Sigma + \oint_\gamma \dot{\lambda} u_\mu \mathrm{d}x^\mu, \tag{26}$$

where $\partial\Sigma_\gamma = \gamma$.

Appendix C. Constitutive Bounds and Causality

Adopt $A = A_0/\lambda^p$ with $p > 0$ and $F = \kappa\nabla\lambda$ with $\kappa \ge 0$. Then

$$|v| = \frac{|F|}{A} = \frac{\kappa|\nabla\lambda|}{A_0}\lambda^p \le c \Rightarrow \kappa \le \kappa_{\max}(\lambda, \nabla\lambda) := \frac{A_0 c}{\lambda^p|\nabla\lambda|}. \tag{27}$$

State your chosen κ-enforcement (e.g., clipping or design) and note that $\kappa_{\max} \to \infty$ as $|\nabla\lambda| \to 0$; in practice, one imposes a smooth bound to avoid numerical stiffness near flat regions.

Appendix D. Photon Propagation and the *λ*-Shift Factor

On $g = \lambda^2\eta$, null paths satisfy $g_{\mu\nu}\dot{x}^\mu\dot{x}^\nu = 0$. A standard conformal argument then yields the frequency transport law along a ray,

$$\frac{\nu_{\text{obs}}}{\nu_{\text{gen}}} = \mathcal{Z}(\lambda_{\text{gen}}, \lambda_{\text{path}}, \lambda_{\text{obs}}), \tag{28}$$

with $\mathcal{Z}$ derived from conformal time and path integrals. Provide the explicit form adopted (e.g., a product of endpoint factors times a path-integral correction) consistent with your chosen normalization.

For slowly varying λ along a null path, the conformal frequency ratio admits the first-order approximation

$$\mathcal{Z}(\lambda_{\text{gen}}, \lambda_{\text{obs}}) \simeq \sqrt{\frac{\lambda_{\text{gen}}}{\lambda_{\text{obs}}}}\left[1 + \frac{1}{2}\int_{\text{path}} \frac{\mathrm{d}\ln\lambda}{\mathrm{d}s}\mathrm{d}s + \mathcal{O}\left((\nabla\lambda)^2\right)\right],$$

so that the observed red/blue shift arises directly from the conformal modulation of the scalar field. Higher-order corrections in $(\nabla\lambda)^2$ capture strong-field or rapidly varying cases.

Appendix E. Coherence Functional $\mathcal{C}$ (Construction Sketch)

Define $\mathcal{C} \in [0,1]$ as an action/phase overlap between the dynamic loop's metric phase φ_{dyn} and the local bundle phase φ_{loc} over the open-loop cell:

$$\mathcal{C} = \left|\frac{1}{V_{\text{cell}}}\int_{\text{cell}} \mathrm{e}^{i(\varphi_{\text{dyn}} - \varphi_{\text{loc}})}\mathrm{d}V\right|^2. \tag{29}$$

State normalization, bandwidth, and any selection thresholds used in Sec. 5. (For broadband signals, replace the complex phase by a windowed cross-correlator and average over the detection bandwidth.)

Explicit Small-Cell Form. Let $\phi_{\text{dyn}} = \mathfrak{A}^{-1}\int_{\text{ray}} \lambda \text{ds}$ and $\phi_{\text{loc}} = \mathfrak{A}^{-1}\int_{\text{cycle}} \lambda \text{ds}$. For an open-loop cell of volume V_{cell} and weight $w(x)$,

$$\mathcal{C} = \left| \frac{1}{V_{\text{cell}}} \int_{\text{cell}} e^{i(\phi_{\text{dyn}} - \phi_{\text{loc}})} w(x) \text{d}V \right|^2, \quad 0 \le \mathcal{C} \le 1.$$

In the monochromatic, small-cell limit, interaction strength is $\propto \mathcal{C}$.

Appendix F. Existence and Stability of Closed-Loop Cores (Sketch)

With impedance ζ supported on C and transport $F = \kappa \nabla \lambda$, a steady λ-up profile solves

$$\nabla \cdot (\kappa \nabla \lambda) = 0 \text{ off } C, \text{ jump/Robin conditions on } \partial C \text{ from } \kappa \to \kappa/(1+\zeta). \quad (30)$$

Linearization about the steady solution yields a spectral problem for perturbations; give sufficient conditions for asymptotic stability and identify spectral gaps associated with ΔE_n.

Appendix G. Parameter Identifiability (Link to Scenarios S1-S7)

Parameter	Primary probes
p	Radial λ profiles near closed cores (S1); scaling of inward flux vs. height of the λ-kink.
κ	Drift speeds and relaxation under small gradients (S2); causality-bound checks.
ζ	Attenuation/impedance signatures across species (S1-S3).
α	Balance of geometric D_λ vs. measured S_{exch} (S4).
$\mathcal{Z}$	Photon red/blue shifts vs. path integrals of λ (S5).
$\mathcal{C}$	Coherence-gated cross-sections and line strengths (S6).