From Chaos To Comoving Coordinates

The Logical Progression Of Spacetime Geometry

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ABSTRACT

This paper provides the complete mathematical formalization of the NIPOK metric within the framework of Successive Collision Theory (SCT). The NIPOK metric describes a universe organized as a nested hierarchy of locally rotating, pressurized comoving frames, each constituting a pocket of spacetime whose members share a common perception of space and time inherited from their direct parent frame through standard General Relativity and Special Relativity. The formalization proceeds in seven stages: the complete parameter set of each nested frame including the tensor-mesh strength scalar; the full hereditary proper-time formula with compounded SR and GR corrections at every level; the three-stage construction of the local line element from non-rotating FLRW through uniform Gödel rotation to the full radially varying NIPOK metric; the frame-tree k·u transformation formalism giving the physically correct photon redshift composition through the Lowest Common Parent frame; the ADM decomposition yielding the induced spatial metric and three-condition causal pocket boundary; the SCT-MASTER field equation in full tensor form with Bianchi identity proof; and the angular momentum inheritance calibration at seven physical scales from the $J = \mu(b \times v_{rel})$ collision equation. The resulting framework reduces exactly to FLRW, the Gödel metric, and Minkowski spacetime in appropriate limits, satisfies the contracted Bianchi identity without violation of local energy-momentum conservation, and makes quantitative predictions including a spectral index $n_s = 28/29 = 0.9655...$, tensor-to-scalar ratio $r < 10^{-5}$, Hubble tension resolution at 3.4–5.3 km/s/Mpc, and tidal deformability Λ_{tidal} in the range 450–650 at 1.4 solar masses.

1. Introduction

The geometric description of physical reality has advanced through a sequence of frameworks, each generalizing its predecessor by adding one new degree of freedom. Cartesian coordinates gave algebra a language for position. Newtonian absolute time introduced a universal clock. Euclidean geometry established the infinite flat stage. Minkowski spacetime wove time into the fabric of a four-dimensional manifold with indefinite metric signature. The Friedmann–Lemaître–Robertson–Walker (FLRW) metric introduced curvature and cosmic expansion. The Gödel metric (1949) demonstrated that rotation is a first-class geometric property consistent with the Einstein field equations. The NIPOK metric takes the next logical step: it formalizes the nested recursive structure of locally rotating, pressurized comoving frames as a geometric primitive of spacetime.

The physical picture is grounded in a result that follows directly from the joint application of General Relativity (GR) and Special Relativity (SR) to a hierarchically structured universe. A comoving frame constitutes a pocket of spacetime not merely because its members are gravitationally bound, but because they share a common bulk trajectory and a common relative velocity with respect to their parent frame. It is this shared motion — the perpetual follow-the-leader(s) dynamic in which every bound member traces the same path through its parent's spacetime — that is the generative mechanism of the pocket itself. The pocket is precisely the set of objects that follow the same leader(s). The shared perception of space and time is the consequence of that shared motion, not an independent postulate. GR cascades this follow-the-leader(s) structure through every scale simultaneously: planets follow stars, stars follow galaxies, galaxies follow groups, and groups follow clusters, with each level defining a comoving free-fall frame whose center of mass follows a geodesic in the parent level's spacetime. SR then provides the local inertial content at each node: bodies sharing the same bulk trajectory within a frame share a common perception of space and time appropriate to that bulk motion (NIPOK, 2026b). Each gravitationally bound level is therefore a pocket of spacetime in a precise sense: a region whose members are bound into a common dynamical environment and share a common local Minkowski structure through their shared participation in the follow-the-leader(s) cascade.

The NIPOK metric generalizes both FLRW and the Gödel metric by abandoning the requirement of global spatial homogeneity while retaining full covariance within General Relativity. It replaces the single global scale factor $a(t)$ of FLRW with a hierarchy of local scale factors, the single uniform vorticity of the Gödel solution with a hierarchy of local vorticity tensors, and the fixed cosmological constant of standard GR with the dynamical environment-dependent effective cosmological term Λ_{eff} derived from the ratio of inherited parent-frame mesh dissipation to local gravitational binding energy (NIPOK, 2026g; NIPOK, 2026k).

The paper is organized as follows. Section 2 establishes the complete parameter set of each frame. Section 3 derives the proper-time formula and time inheritance chain. Section 4 constructs the local line element in three stages. Section 5 derives the induced spatial metric and causal pocket boundary. Section 6 derives the frame-transition operator and photon redshift formula. Section 7 presents the angular momentum inheritance hierarchy. Section 8 states the SCT-MASTER field equation with Bianchi proof. Section 9 verifies all limiting cases. Section 10 presents key quantitative predictions. Section 11 identifies remaining open tasks. Section 12 concludes.

2. Complete Frame Parameter Set

The NIPOK hierarchy is indexed by an integer i running from 0, the global cosmological background identified with the FLRW comoving frame, to N, the smallest physically relevant scale for a given problem. Each frame F_i is characterized by the quantities in Table 1. All five SCT papers contribute to this set: Papers 1 and 7 provide the thermodynamic and mesh parameters; Paper 2 provides the kinematic and frame-tree parameters; Paper 5 provides the angular momentum parameters; Paper 11 provides the explicit functional forms for λ_{local} and A.

Table 1. Complete parameter set for nested frame F_i.

Symbol	Definition
t_i	Local coordinate time of F_i, inherited from parent through the frame-tree $k \cdot u$ product formula
$\tau_i(r, \text{level})$	Proper time: compounded SR and GR corrections from all parent levels, plus the SR velocity dilation from rotational motion within F_i itself
$a_i(t_i)$	Local scale factor, governed by local Friedmann equations with $\Lambda_{eff,i}$

Symbol	Definition
$\omega_i(r_i)$	Radial angular velocity profile of F_i about its local symmetry axis
$\Omega_i^{\mu\nu}$	Full antisymmetric vorticity tensor of the matter fluid in F_i
$J_i = \mu_i(b_i \times v_{rel,i})$	Collision angular momentum from Paper 5, equation $J = \mu(b \times v_{rel})$
$\rho_i(x)$	Local energy density distribution within F_i, not required to be spatially uniform
$p_i(x)$	Local pressure distribution within F_i, the pressurized pocket structure
R_i	Characteristic pocket radius, defined by three simultaneous boundary conditions (Section 5.2)
$\sigma_{v,i}$	One-dimensional velocity dispersion of F_i, entering both A and λ_{local}
λ_i	Tensor-mesh strength scalar: $\lambda_i = 3\sigma^2_{v,i} / (4\pi G R^2_i)$ (NIPOK, 2026k, eq. 30)
$\Lambda_{parent,i}$	Inherited mesh dissipation rate from all parent frames above F_i
$\Lambda_{eff,i}$	Effective cosmological term: $C \Lambda_{parent,i} / \lambda_i$ (NIPOK, 2026k, eq. 3)
$A_i(N, \sigma_v, R)$	Coherence amplification factor: $1 + (N-1) \exp(-\sigma^2_v R / (GM_{tot}))$ (NIPOK, 2026k, eq. 5)
v_i	Bulk velocity of the center of mass of F_i relative to its parent F_{i-1}
γ_i	Lorentz factor: $1 / \sqrt{1 - v^2_i/c^2}$
Φ_i	Newtonian gravitational potential of F_i: $\Phi_i = -GM_i/r < 0$ for bound systems. Used throughout as a signed quantity so that $\sqrt{1 + 2\Phi_i/c^2} < 1$ for objects inside a potential well.
$T(i \to i-1)$	Frame-transition operator mapping F_i coordinates to F_{i-1} coordinates via local Lorentz boost
LCP(i, j)	Lowest Common Parent frame of F_i and F_j in the frame tree, the mandatory routing point (NIPOK, 2026b)

The parameter set in Table 1 encodes a physical principle that deserves explicit statement before the proper-time formula is derived. Within any frame F_i, all bound members share an identical inherited base perception of space and time — the perception delivered by the parent frame F_{i-1} as a single aggregated consequence of all ancestor motion and gravitational history above it in the hierarchy. The parent frame acts as an aggregator: it collapses the entire chain of follow-the-leader(s) dynamics above it into one unified spacetime context and passes that context uniformly to every sibling inside the pocket. This shared inheritance is precisely what defines membership in F_i. Every sibling receives the same base — they are siblings because they follow the same leader(s). Each member then departs from that common base according to its own velocity relative to F_i and its own position within F_i's gravitational potential, producing a personal proper time that it would in turn transmit as the base perception to any child frame it anchors. The hereditary proper-time formula in Section 3.1 is the mathematical expression of this compounding: the product structure arises because each level first receives a base and then applies its own individual departure to it.

3. Proper Time and Time Inheritance Across the Hierarchy

3.1 The Full Hereditary Proper-Time Formula

Premise P10 of NIPOK (2026a) and Section 2.2, equation 2 of NIPOK (2026g) both state the same formula explicitly. For an object at hierarchy level k within a hierarchy of N total levels, the proper time rate relative to the global background frame F_0 is the compounded product of two correction factors at every level from 1 to k: the SR kinematic dilation from bulk velocity and the GR gravitational dilation from the parent potential. NIPOK (2026k) Section 7 (eq. 39) provides the full derived version in the context of the photon redshift formula.

Hereditary proper-time formula (NIPOK, 2026a, P10; NIPOK, 2026g, eq. 2):

$$d\tau_k / dt_0 = \prod_{i=1}^{k} \sqrt{1 - v^2_i/c^2} \times \prod_{j=1}^{k} \sqrt{1 + 2\Phi_j/c^2}$$

Single-step form for child F_i within parent F_{i−1}:

$$d\tau_i = d\tau_{i-1} \times \sqrt{1 - v^2_i/c^2} \times \sqrt{1 + 2\Phi_i/c^2} \quad \text{[exact weak-field]}$$
$$\approx d\tau_{i-1} \times \sqrt{1 - v^2_i/c^2} \times (1 + \Phi_i/c^2) \quad \text{[first-order expansion, } \Phi/c^2 \ll 1]$$

Factor 1, SR kinematic: $\sqrt{1 - v^2_i/c^2}$. Time runs slower because the child frame moves through the parent. This is pure Special Relativity applied to the bulk velocity inherited from the follow-the-leader(s) cascade.

Factor 2, GR gravitational: $\sqrt{1 + 2\Phi_i/c^2}$. Time runs slower because the child frame sits inside the parent gravitational potential well. This is pure General Relativity. Here $\Phi_i = -GM_i/r_i$ is the Newtonian gravitational potential, which is negative for bound systems, so this factor is less than 1. It expands to $(1 + \Phi_i/c^2)$ to first order in Φ/c^2, which is the form used in the single-step approximation above. The redshift formula in Section 6.2 uses the equivalent expression $\sqrt{1 - 2|\Phi_i|/c^2}$, which adopts the convention that Φ_i denotes the magnitude of the potential well; both conventions are physically identical.

Both factors are less than unity for bound orbiting frames. Every child frame runs slower than every parent frame. Time accumulates more slowly deeper in the hierarchy. This is not a coincidence: it is the direct quantitative consequence of each level receiving a base perception from its parent and departing from it through the two physical mechanisms of relative motion and gravitational depth.

The GPS satellite provides a two-level observational proof. The satellite frame moves at orbital velocity $v_{sat} \approx 3.87$ km/s relative to Earth, giving an SR dilation of −7 microseconds per day. It sits at higher gravitational potential than the surface, giving a GR blueshift of +45 microseconds per day. The net correction of +38 microseconds per day is predicted by this two-factor composition and confirmed to nanosecond precision. SCT asserts that the identical composition continues upward and downward through every level of the hierarchy without limit.

3.2 Co-Rotating Observers and the Local Velocity Correction Within F_i

The two factors of Section 3.1 — SR kinematic dilation from bulk velocity and GR gravitational dilation from parent potential — account for all inherited corrections arriving from above in the hierarchy. Within frame F_i itself, a co-rotating observer at radius r_i from the rotation axis is not stationary relative to F_i: it moves with tangential velocity $v_{rot} = \omega_i(r_i)\, r_i$. This is simply an additional relative velocity within the local frame, and SR applies to it in exactly the same way it applies to the bulk velocities at each parent level. It is therefore not a new physical mechanism but the same SR velocity dilation now applied locally to rotational motion within the frame.

The local co-rotating correction is derived directly from the full NIPOK line element constructed in Section 4. Setting dr_i = dz_i = 0 and dφ_i = ω_i dt_i in the Stage 2 or Stage 3 metric and solving for dτ/dt yields the local SR factor for a co-rotating observer. Its form follows from the metric geometry rather than being introduced independently.

Complete proper time including the local co-rotating SR correction:

```
dτ_total(r_i)  =  dt_0
  ×  ∏_{j=1}^{i} [ √(1 − v²_j/c²)  ×  √(1 + 2Φ_j/c²) ]   [SR+GR from all parents]
  ×  √(1 − ω²_i(r_i) r²_i / c²)                          [local SR: v_rot = ω_i r_i]
```

Observers at center r_i = 0: v_rot = 0; no local correction. Only the inherited parent-chain factors contribute.

Observers at boundary R_i: v_rot = ω_i(R_i) R_i; maximum local SR correction.

All observers in F_i share identical inherited parent-chain corrections — they all follow the same leader(s) — but differ in the local rotational velocity term according to their radial position within the frame. The local co-rotating SR correction is therefore the final individual departure from the shared base that a co-rotating observer would pass on to any child frame it anchors.

4. The Local Line Element: Three-Stage Construction

4.1 Stage 1: Non-Rotating Local Frame

In the absence of rotation and with a locally flat spatial geometry, each frame F_i reduces to a patch of FLRW spacetime with its own local scale factor a_i(t_i) governed by its own Friedmann equations. The critical distinction from standard FLRW is that the cosmological term is not a fixed constant but the dynamical Λ_eff derived in NIPOK (2026g) and formally derived from first principles in NIPOK (2026k).

Local FLRW line element of F_i, ω_i = 0:

```
ds²_i  =  −c² dt²_i  +  a²_i(t_i) [ dr²_i + r²_i dΩ²_i ]
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Local Friedmann equations for a_i(t_i):

```
(ȧ_i / a_i)²  =  (8πG / 3) ρ_i  −  k_i c² / a²_i  +  Λ_eff,i c² / 3
ä_i / a_i     =  −(4πG / 3)(ρ_i + 3p_i/c²)  +  Λ_eff,i c² / 3
```

Λ_eff,i (NIPOK, 2026k, eq. 3; NIPOK, 2026g, eq. 1; NIPOK, 2026a, P17):

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Λ_eff,i(x,t)  =  C × Λ_parent,i(x,t) / λ_i(x,t)
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λ_i (NIPOK, 2026k, eq. 30):

$$\lambda_i = 3\sigma^2_{v,i} / (4\pi G R^2_i)$$

Λ_{parent} exponential decay law, derived from N-body orbital mechanics (NIPOK, 2026k, eq. 31):

$$d\Lambda_{parent}/dt = -\alpha \times \Lambda_{parent}(t)$$
$$\Lambda_{parent}(t) = \Lambda_0 \times \exp(-\alpha t)$$
$$\alpha \sim H_0, \text{ constrained from cluster velocity dispersion evolution}$$

Each frame therefore carries an independent local Hubble rate $H_i = \dot{a}_i / a_i$ set by its own $\Lambda_{eff,i}$. Frames deep inside dense structures, where λ is large, have suppressed Λ_{eff} and slow local expansion. Frames in voids, where λ is small, have enhanced Λ_{eff} and faster local expansion. This is why galaxies inside clusters do not expand with the global Hubble flow: their λ suppresses Λ_{eff} to near zero within the bound region, consistent with the Birkhoff theorem discussion in NIPOK (2026g, Section 5.1).

4.2 Stage 2: Uniform Rotation and the Local Gödel Structure

Adding uniform angular velocity ω_i about the local z-axis introduces an off-diagonal $dt \times d\varphi$ coupling. The metric functions f_0 and g_0 are derived by simultaneously requiring flat Minkowski spacetime at $r = 0$, exact Gödel metric functions in the uniform-rotation limit, and satisfaction of the Einstein field equations for a uniformly rotating perfect fluid.

Stage 2 NIPOK line element, uniform ω_i:

$$ds^2_i = -c^2\, dt^2_i + a^2_i\, dr^2_i + a^2_i\, f_0(r_i, \omega_i)\, d\varphi^2_i + a^2_i\, dz^2_i - 2g_0(r_i, \omega_i)\, c\, dt_i\, d\varphi_i$$

Explicit metric functions, derived from GR boundary conditions:

$$f_0(r_i, \omega_i) = (1/2) \sinh^2(2r_i / \lambda_{rot,i})$$
$$g_0(r_i, \omega_i) = \sqrt{2}\, a_i \sinh^2(r_i / \lambda_{rot,i})$$
$$\lambda_{rot,i} = c / (\sqrt{2}\, \omega_i\, a_i)$$

Limit $\omega_i \to 0$: $f_0 \to r^2_i$, $g_0 \to 0$. Recovers Stage 1 FLRW.

Limit $a_i \to$ const, $p_i \to 0$, $\Lambda_{eff} \to -\omega^2_i$ (in units $c = 1$): Recovers exact Gödel metric (Gödel, 1949). The three conditions required are: (1) constant scale factor a_i, eliminating expansion; (2) pressureless dust, $p_i = 0$; and (3) the effective cosmological term taking the value $\Lambda_{eff} = -\omega^2_i$, which corresponds to the specific fine-tuning between matter density and cosmological constant in Gödel's original solution. Outside these conditions the Stage 2 metric describes the broader family of rotating expanding pockets that generalizes Gödel's static solution.

Metric tensor in coordinates (t_i, r_i, φ_i, z_i):

$$g^{(i)} = \begin{vmatrix} -c^2 & 0 & -g_0\, c & 0 \\ 0 & a^2_i & 0 & 0 \\ -g_0\, c & 0 & a^2_i\, f_0 & 0 \end{vmatrix}$$

$$| \quad 0 \quad 0 \quad 0 \quad a^2_i \quad |$$

$\det(g^{(i)}) = -c^2 a^6_i (1/2) \sinh^2(2r_i / \lambda_{rot,i}) < 0$ for all $r_i > 0$. Lorentzian signature (−,+,+,+) is preserved throughout the interior of F_i. The co-rotating observer result of Section 3.2 is confirmed directly from this metric: setting $dr_i = dz_i = 0$ and $d\varphi_i = \omega_i dt_i$ and extracting $d\tau/dt$ yields $\sqrt{1 - \omega^2_i r^2_i / c^2}$ in the uniform-rotation limit, consistent with the SR velocity dilation from $v_{rot} = \omega_i r_i$.

4.3 Stage 3: Radially Varying Rotation and the Full NIPOK Metric

Physical pockets rotate differentially: the angular velocity is a function of the local radial coordinate. The generalized metric functions F and G reduce exactly to f_0 and g_0 when ω_i is constant and to the FLRW metric when ω_i vanishes everywhere. The rotation-pressure coupling equation, an analogue of the Tolman–Oppenheimer–Volkoff equation for rotating expanding pockets, is derived by substituting the generalized metric functions into the Einstein equations with a rotating perfect-fluid stress-energy tensor.

Full NIPOK local line element within frame F_i:

$$\begin{aligned} ds^2_i = & -c^2 dt^2_i + a^2_i(t_i) dr^2_i \\ & + [a^2_i F(r_i, \omega_i(r_i)) - G(r_i, \omega_i(r_i))^2 / c^2] d\varphi^2_i \\ & - 2G(r_i, \omega_i(r_i)) dt_i d\varphi_i + a^2_i(t_i) dz^2_i \end{aligned}$$

Generalized metric functions, perturbative expansion valid for $\omega r/c \ll 1$:

$$\begin{aligned} F(r, \omega) & = r^2 [1 + (\omega^2 r^2)/(2c^2)]^2 + O(\omega^4/c^4) \\ & \to (1/2) \sinh^2(2r / \lambda_{rot}) \quad \text{when } \omega = \text{const} \end{aligned}$$

$$\begin{aligned} G(r, \omega) & = \omega(r) r^2 a_i [1 + (\omega^2 r^2)/(3c^2)] + O(\omega^4/c^4) \\ & \to \sqrt{2} a_i \sinh^2(r / \lambda_{rot}) \quad \text{when } \omega = \text{const} \end{aligned}$$

NIPOK rotation–pressure coupling, TOV analogue for rotating expanding pockets:

$$dp_i/dr_i = (\rho_i + p_i/c^2) \times [\omega^2_i(r) r + (c^2/2) d/dr \ln(G^2 - a^2_i F)]$$

Physical meaning: the pressure gradient inside the pocket is sustained by the rotation. The pocket is pressurized because centrifugal support maintains the pressure excess at the boundary, preventing the frame from collapsing into its parent structure.

5. Induced Spatial Metric and the Causal Pocket Boundary

5.1 ADM Decomposition

The spatial geometry on constant-t_i hypersurfaces within frame F_i is extracted by the Arnowitt–Deser–Misner decomposition of the full NIPOK metric tensor. The lapse function α_i and shift vector β_i encode the frame-dragging from rotation.

Lapse, shift, and induced spatial metric of F_i:

$$\alpha_i(r_i) = 1 / \sqrt{1 + G(r,\omega)^2 / (c^4 a^2_i F(r,\omega))}$$

$$\beta^{\varphi}_i = -G(r,\omega) / (c\, a^2_i F(r,\omega)) \quad \text{[only } \varphi\text{-component nonzero]}$$

Induced spatial line element on constant-t_i slices:

$$dl^2_i = a^2_i dr^2_i + [a^2_i F(r,\omega) + G(r,\omega)^2/c^2] d\varphi^2_i + a^2_i dz^2_i$$

Radial geometry: governed by a^2_i alone. Local Hubble rate $H_i = \dot{a}_i / a_i$ is independent of parent frame expansion rate H_{i-1}.

Azimuthal geometry: expanded by rotation term G^2/c^2 beyond the FLRW value.

Vertical geometry: governed by a^2_i alone, independent of parent expansion.

Spatial volume element:

$$dV_i = a^2_i \sqrt{a^2_i F(r,\omega) + G(r,\omega)^2/c^2}\; dr_i\, d\varphi_i\, dz_i$$

$$\text{Limit } \omega \to 0: \quad dV_i \to a^3_i r_i\, dr_i\, d\varphi_i\, dz_i \quad \text{[standard FLRW]}$$

The radial expansion rate of the spatial geometry inside frame F_i is set entirely by $a_i(t_i)$, which evolves under the local Friedmann equations with $\Lambda_{eff,i}$. It is independent of the parent frame scale factor a_{i-1}. Each frame has its own independent spatial expansion history. The parent frame's contribution enters only through the boundary conditions imposed at R_i by the Israel junction conditions, as derived in NIPOK (2026k, Section 4).

5.2 The Three-Condition Causal Pocket Boundary

Each frame F_i constitutes a causal pocket of spacetime because it has a well-defined boundary R_i. NIPOK (2026g, Section 5.1) in its Birkhoff discussion requires three simultaneous conditions to be satisfied at R_i. Version 1 of this formalization identified only two. The third, Λ_{eff} continuity, is required by the Paper 7 Birkhoff consistency argument and by the Bianchi self-consistency constraint of NIPOK (2026k).

Condition 1, GR causal, light-cone tipping:

$$\omega_i(R_i) \times R_i = c \times \sin(\Theta_{crit})$$

Outgoing null geodesics begin to curve back inward from rotation. The pocket becomes causally self-enclosed at this radius.

Condition 2, thermodynamic, pressure matching:

$$p_i(R_i) = p_{i-1}(R_i \text{ in } F_{i-1} \text{ coordinates})$$

Internal pressure of F_i matches ambient pressure of parent F_{i−1}. The pocket has a mechanically stable skin.

Condition 3, Λ_eff continuity, Birkhoff consistency (NIPOK, 2026g, Section 5.1; NIPOK, 2026k, Section 3.2):

$$\Lambda_{eff,i}(R_i) = \Lambda_{eff,i-1}(R_i \text{ in } F_{i-1} \text{ coordinates})$$

The effective cosmological term is continuous across the boundary. High-λ, strongly bound interior suppresses Λ_{eff} to near zero. This suppression must match smoothly to the parent frame value at R_i, ensuring that the interior barely participates in the background expansion, consistent with the observed non-expansion of bound structures.

6. The Frame-Transition Operator and the Photon Redshift Formula

6.1 The Lowest Common Parent Frame

NIPOK (2026b) demonstrates in Sections 1 through 3 that treating the transformation between any source and any observer as a single Lorentz boost plus FLRW stretch is structurally incomplete. GR requires that Lorentz invariance is strictly local. The physically correct prescription computes the photon frequency from the ratio of k·u factors at emission and observation, where k^μ is the photon four-momentum parallel-transported along the full null geodesic through the curved spacetime of every intermediate pocket.

For any source in frame F_i and observer in frame F_j, their Lowest Common Parent LCP(i,j) is the smallest frame containing both. All transformations between F_i and F_j must pass through LCP(i,j). NIPOK (2026b, Section 1.8) establishes this as the mandatory first step in any GR-consistent transformation between frames. The algorithm is: ascend from F_i to LCP; adopt LCP's comoving metric as the base proper relative spacetime; descend from LCP to F_j, composing local k·u factors at every pocket boundary along both branches. This procedure is the direct photon-propagation expression of the follow-the-leader(s) inheritance principle: the photon must pass through every shared ancestor frame, just as the spacetime perception of any two objects must be traced back to their shared leader(s) before their relative motion can be computed.

6.2 The Exact Redshift Formula

Exact GR redshift between any two frames (NIPOK, 2026b, eq. 8; NIPOK, 2026k, eq. 39):

$$1 + z_{total} = (k\cdot u)_{emit} / (k\cdot u)_{obs}$$

where k^μ is parallel-transported along the full null geodesic

Hierarchical decomposition, product of local factors (NIPOK, 2026b, eqs. 11–12):

$$1 + z_{total} = \prod_{i=0}^{N} (k\cdot u)^{(i)} / (k\cdot u)^{(i+1)}$$

Explicit combined formula, exact (NIPOK, 2026k, eq. 39):

$$1 + z_{total} = \prod_{i=1}^{N} \gamma_i (1 + \beta_i \cos\theta_i) \times \sqrt{1 - 2\Phi_i/c^2}$$

Kinematic factor per level: $\gamma_i (1 + \beta_i \cos\theta_i)$ [SR Doppler]

Gravitational factor per level: $\sqrt{1 - 2\Phi_i/c^2}$ [Einstein redshift]

Full hierarchical formula (NIPOK, 2026b, eq. 20):

$$1 + z_{NIPOK} = a_0(t_{obs}) / a_0(t_{emit}) \times \prod_i \left[1 + (\Phi_{\{i,in\}} - \Phi_{\{i,out\}})/c^2 - \hat{n}_i \cdot v_i/c\right]$$

Hubble's Law derived as statistical mean over randomly oriented pockets (NIPOK, 2026k, Section 7.2, eq. 41):

$$\langle z_{total} \rangle = H_0\, d/c \quad \text{where } H_0 = \langle v_{pocket} \rangle / \langle L_{pocket} \rangle$$

Hubble's law is derived analytically, not postulated.

This is the complete mathematical statement of time inheritance across the hierarchy. At each step, the coordinate time of the child frame is set by the parent frame's time as modified by the gravitational potential difference at the pocket boundary and by the Doppler factor from the bulk velocity of the pocket relative to its parent. Composed across all levels from F_0 to F_N, these factors define the full temporal relationship between any two nested frames.

6.3 Spatial Inheritance Through the Frame Tree

The spatial geometry of each child frame as seen from the parent is described by the pullback of $g^{(i)}_{\mu\nu}$ through the local Lorentz transformation matrix at the interface between F_i and $F_{\{i-1\}}$. Spatial lengths in F_i appear Lorentz-contracted along the direction of motion in $F_{\{i-1\}}$, and the rotation of F_i causes its spatial shape to appear to precess at rate ω_i as seen from $F_{\{i-1\}}$. This is the direct mathematical content of NIPOK (2026b, Section 1.3): child pockets inherit their parent's spacetime structure through the follow-the-leader(s) dynamic and add their own individual Lorentz corrections on top of that shared base.

$$g^{(i,\ apparent)}_{\mu\nu} = T^{\alpha}_{\ \mu}\, T^{\beta}_{\ \nu}\, g^{(i)}_{\alpha\beta}$$

where $T^{\mu}_{\ \nu}$ is the local Lorentz boost-plus-rotation matrix at the pocket boundary. For $N > 2$ nesting levels, non-parallel boosts introduce Wigner rotation terms from Thomas precession, which must be tracked in the composed transition operator.

7. Angular Momentum Inheritance Across Seven Physical Scales

7.1 The Organizing Equation

NIPOK (2026e, Section 6.1) establishes the fundamental equation governing angular momentum deposition at each level of the collision hierarchy. This equation simultaneously determines the magnitude, direction, and sense of rotation of every structure that subsequently condenses from the resulting debris field.

SCT angular momentum equation at each hierarchy level (NIPOK, 2026e, Section 6.1):

$$J_i = \mu_i \times (b_i \times v_{rel,i})$$

μ_i = reduced mass of the two colliding structures at level i

b_i = impact parameter vector between their centers of mass

$v_{rel,i}$ = relative velocity in the global parent frame at moment of contact

|J_i|: magnitude, set by the product μ × b × v_rel

direction of J_i: rotation axis, perpendicular to the plane of b and v_rel

sense of rotation: sign of b × v_rel

Angular momentum scaling relation (NIPOK, 2026a, P32; NIPOK, 2026e, Table 5):

$$J \propto M^{5/3} \quad \text{equivalently} \quad j = J/M \propto M^{2/3}$$

Observed across seven decades of physical scale.

Angular momentum propagates downward through the hierarchy by local conservation at each generational handoff. No long-range force is required. The mechanism is identical in character to angular momentum conservation in the collapse of a molecular cloud into a stellar system: the large-scale J-vector sets the plane and sense of every sub-condensation within the field.

7.2 Seven-Scale Calibration of the NIPOK Vorticity Tensor

Table 2 presents the observational calibration of the vorticity tensor J^(μν)_i at each of the seven physical scales documented in NIPOK (2026e). The collision parameters at each scale set the magnitude of J^(μν)_i that enters the vorticity source term V_μν of the SCT-MASTER field equation.

Table 2. Angular momentum inheritance hierarchy at seven physical scales (NIPOK, 2026e, Table 5).

Scale	Collision parameters	Observed coherence	NIPOK J_i calibration
Satellite planes, sub-Mpc	μ ~ 10^{12} M⊙; b ~ tens kpc; v_rel sub-c	0.25 Mpc diameter; co-rotation in all 6 tested systems; joint ΛCDM probability < 10^{-12}	J_i ~ $10^{67–68}$ kg m²/s; VPOS, GPoA, Centaurus A
Galaxy clusters, Mpc to 300 Mpc	μ ~ $10^{14–15}$ M⊙; b ~ Mpc; sub-c	BCG alignment fully established at z > 1.3; cluster-cluster coherence to 200–300 Mpc	J_i ~ $10^{73–75}$ kg m²/s; α_cluster ~ H_0 (NIPOK, 2026k, eq. 34)
Cosmic filaments, 1–100 Mpc	μ ~ 10^{17} M⊙; b ~ tens Mpc; v_rel ~ few c	Direct detection at 110 km/s bulk rotation in 15 Mpc filament (Tudorache et al., 2025)	J_i ~ $10^{76–78}$ kg m²/s; amplitude exceeds IllustrisTNG beyond parameter uncertainty
Quasar spin axes, 100–1000 Mpc	μ ~ $10^{18–20}$ M⊙; b ~ hundreds Mpc; v_rel > c	400–900 Mpc VLBI jet alignments; 1 Gpc optical polarization coherence (Hutsemékers et al., 2014)	J_i ~ 10^{79+} kg m²/s; 20–30× beyond maximum TTT reach

The NIPOK vorticity term V_μν has the correct tensor structure at each scale. The precise amplitude coefficient requires the angular momentum partition function — the fraction of collision kinetic energy retained as bulk angular momentum versus dissipated as heat — identified in NIPOK (2026e, Section 6.7, Priority 1) as the primary remaining theoretical task for Paper 5. Until that derivation is complete, V_μν gives the correct structure but not a fully calibrated coefficient.

8. The SCT-MASTER Field Equation

8.1 The Unified Five-Modification Form

NIPOK (2026k, Section 2.5) presents the SCT-MASTER equation for the first time in full tensor form. It integrates three SCT modifications established across Papers 1, 7, and 11 with two NIPOK-specific modifications for vorticity and frame-transition connection. All five terms reduce to zero or to their standard GR counterparts in appropriate limits.

SCT-MASTER EQUATION (NIPOK, 2026k, Section 2.5):

$$G_{\mu\nu} + \Lambda_{eff}(x,t)\, g_{\mu\nu} = (8\pi G/c^4)\, [T_{\mu\nu} + T^{sup}_{\mu\nu}(A)] + V_{\mu\nu} + \Delta_{\mu\nu}$$

Domain: $\rho(x) < \rho_{QCD} = (2\text{–}5) \times \rho_{sat} = (0.46\text{–}1.15) \times 10^{18}$ kg/m³

At the GR–QCD boundary: Israel–Darmois junction conditions (NIPOK, 2026k, Section 4)

Modification 1, Λ_eff (NIPOK, 2026k, eq. 3; NIPOK, 2026g, eq. 1; NIPOK, 2026a, P17):

$$\Lambda_{eff}(x,t) = C \times \Lambda_{parent}(x,t) / \lambda_{local}(x,t)$$

$$\lambda_{local} = 3\sigma^2_v / (4\pi G R^2); \quad \Lambda_{parent}(t) = \Lambda_0 \exp(-\alpha t)$$

Modification 2, T^sup_μν (NIPOK, 2026k, eqs. 4–5, derived from first principles):

$$T^{sup}_{\mu\nu} = [A(N, \sigma_v, R) - 1] \times T^{bary}_{\mu\nu}$$

$$A(N, \sigma_v, R) = 1 + (N-1) \exp(-\sigma^2_v R / (GM_{tot}))$$

Limit A → 1, isolated single body: T^sup → 0. Standard GR recovered exactly.

Limit A → N, maximally coherent system: full constructive gravitational superposition.

Modification 3, QCD domain boundary (NIPOK, 2026k, Section 2.4):

GR domain: $\rho(x) < \rho_{QCD}$. At boundary: $P(R_{core}) = 0$ (proven, eq. 19).

Israel junction: $e^{2\Phi(R_{core})} = 1 - 2GM / (c^2 R_{core})$ (NIPOK, 2026k, eq. 16)

Modification 4, NIPOK vorticity source (from collision J-vectors, NIPOK, 2026e):

$$T^{NIPOK}_{\mu\nu} = \Sigma_i\, W_i(x)\, T^{(i)}_{\mu\nu} \quad \text{[hierarchical stress-energy]}$$

$$V_{\mu\nu} = (8\pi G/c^4)\, \Sigma_i\, J^{(i)}_{\mu\nu} \quad \text{[angular momentum tensor source]}$$

$J^{(i)}_{\mu\nu}$ calibrated from $J_i = \mu_i (b_i \times v_{rel,i})$ at each scale

Modification 5, NIPOK frame-transition connection (from NIPOK, 2026b, frame tree):

$$\Delta_{\mu\nu} = \Gamma^\lambda_{\mu\nu}[\text{NIPOK}] - \Gamma^\lambda_{\mu\nu}[\text{standard GR}]$$

Encodes curvature of the frame-transition path. Vanishes when all frames co-align.

8.2 The Bianchi Identity Proof

NIPOK (2026g, Section 3.3) identified the Bianchi identity as requiring resolution when Λ_{eff} varies spatially. NIPOK (2026k, Section 3) resolves this completely, demonstrating that the contracted Bianchi identity is satisfied as a theorem when the SCT-MASTER equation holds, provided a self-consistency constraint links the gradients of Λ_{eff} and A.

Bianchi identity theorem (NIPOK, 2026k, Section 3, eqs. 7–9):

Taking ∇^μ of both sides of SCT-MASTER and using $\nabla^\mu G_{\mu\nu} = 0$:

$$g_{\mu\nu} \partial^\mu \Lambda_{eff} = -(8\pi G/c^4) \nabla^\mu T^{sup}_{\mu\nu} \qquad \text{[eq. 7]}$$

Expanding using $T^{sup} = (A-1) T^{bary}$ and the Leibniz rule:

$$g_{\mu\nu} \partial^\mu \Lambda_{eff} = -(8\pi G/c^4) (\partial^\mu A) T^{bary}_{\mu\nu} \qquad \text{[eq. 9]}$$

[second term $(A-1) \nabla^\mu T^{bary}$ vanishes by baryonic matter conservation]

This is the SCT self-consistency constraint. It is a theorem from Bianchi, not an axiom.

Physical meaning: spatial or temporal variation of Λ_{eff} must be exactly balanced by the gradient of the coherence factor A times the baryonic stress-energy. In overdense regions both Λ_{eff} and A decrease together (large σ_v). In void regions both Λ_{eff} and A increase together (small σ_v). The anti-correlation of gradients satisfies eq. 9 with the required sign. Verified quantitatively in NIPOK (2026k, Section 5.4). No violation of local energy-momentum conservation occurs.

8.3 The Effective Dark Energy Equation of State

The mesh field defines an effective stress-energy with equation-of-state parameter w that depends on the local gradient of Λ_{eff} (NIPOK, 2026k, eq. 12). This predicts directly what dark energy surveys observe.

$w_{eff}(x,t)$ from Λ_{eff} gradient (NIPOK, 2026k, eq. 12):

$$w_{eff}(x,t) = -1 - (c^2 \varepsilon^2) / (3 \times 8\pi G \rho_{mesh})$$

where $\varepsilon = |\nabla \ln \Lambda_{eff}|$ is the logarithmic gradient scale

In cluster cores: ε large, $w_{eff} < -1$ (phantom-like locally)

In voids: ε small, $w_{eff} \approx -1$

CPL dark energy parameters at z = 0 (NIPOK, 2026k, eq. 38; $\alpha = 0.9$–$1.0\ H_0$):

$$w_0 \sim -0.93 \text{ to } -1.00$$
$$w_a \sim +0.14 \text{ to } +0.16$$

Note: the positive sign of w_a is opposite to the DESI 2024 preferred direction at approximately 2.5σ. NIPOK (2026k, Section 6.6) states this as a genuine falsifiable tension requiring confirmation or revision with DESI DR2 data.

9. Verification of All Limiting Cases

A rigorous metric formulation must recover every established framework as a special limiting case. Table 3 verifies the five principal limits of the NIPOK metric and the SCT-MASTER equation.

Table 3. Limiting cases of the NIPOK metric and the SCT-MASTER field equation.

Limit conditions	Recovered framework	Key terms vanishing	Primary authority
All $\omega_i = 0$; $N = 1$; $A = 1$; $V_{\mu\nu} = 0$; $\Delta_{\mu\nu} = 0$	FLRW metric and Friedmann equations	Mods 4 and 5 vanish; Λ_{eff} reduces to Λ_{obs} when Λ/λ spatially uniform	NIPOK, 2026k, Section 2.2
ω_i = constant; $N = 1$; a_i = constant; $p_i = 0$; $\Lambda_{eff} = -\omega^2_i$; $A = 1$; $V_{\mu\nu}$ uniform	Gödel metric (Gödel, 1949)	Mods 2, 3, 5 vanish; Stage 2 functions with dust and $\Lambda_{eff} = -\omega^2$ recover exact Gödel metric	Section 4.2 this paper
All $\omega = 0$; $v = 0$; $a = 1$; $A = 1$	Minkowski spacetime $\eta_{\mu\nu}$	All five modifications vanish or become trivial	Section 4.1 this paper
$N = 1$; single isolated body; $A \to 1$	Standard GR field equations exactly	$T^{sup} \to 0$; Λ_{eff} retained but $A \to 1$ proof in NIPOK, 2026k, Section 3.4	NIPOK, 2026k, Section 3.4
Solar system and stellar scales; v/c and $\omega r/c$ both small	Schwarzschild metric; all GR precision tests satisfied	$H_{SCT} = H_{\Lambda CDM}$ to within 10^{-6} at $z = 1100$ (NIPOK, 2026k, Table 1)	NIPOK, 2026k, Table 1
$\rho \geq \rho_{QCD}$ at compact object core boundary	TOV equation with QCD equation of state; no singularity	$P(R_{core}) = 0$ proven from Israel junction conditions, not assumed	NIPOK, 2026k, eq. 19

10. Key Quantitative Predictions

NIPOK (2026k) derives a set of quantitative predictions from first principles. These are not parameter fits. Each is derived from the structure of the SCT-MASTER equation and constrained by independently observable quantities. Table 4 summarizes those most directly relevant to the NIPOK metric formalization.

Table 4. Key quantitative predictions derived in NIPOK (2026k) from first principles.

Observable	SCT/NIPOK prediction	Derivation	Current observational status
Spectral index n_s	28/29 = 0.9655...	CLT over $N = 29$ nesting levels, eq. 44	Planck 2018: 0.9649 ± 0.0042; 0.14σ from prediction
Tensor-to-scalar ratio r	$r < 10^{-5}$	No inflationary GWB; eq. 44 note	Current best limit: $r < 0.056$ (Planck 2018 + BICEP/Keck BK15, 95% CL). SCT prediction is far below current sensitivity; consistent with all existing upper limits and strongly falsifiable by next-generation CMB-S4 observations.
Helium-4 mass fraction Y_p	0.2467, identical to ΛCDM	$H_{SCT} = H_{\Lambda CDM}$ at BBN to 1 in 10^{39}; Section 9.2, eq. 48	PDG 2023: 0.2453 ± 0.0034; consistent at 0.4σ

Observable	SCT/NIPOK prediction	Derivation	Current observational status
CMB lensing amplitude A_lens	~1.20	Steeper potential growth from A(z) during lensing epoch; Section 8.4	Planck 2018: 1.180 ± 0.065; consistent at 0.3σ
Hubble tension ΔH_0	3.4–5.3 km/s/Mpc	KBC supervoid contribution eqs. 35–37 plus temporal Λ_{eff} evolution	Observed: 5.6 ± 1.1 km/s/Mpc; consistent at 1σ
BAO sound horizon shift	$\delta r_s/r_s = +2 \times 10^{-7}$	Λ_{eff} negligible at baryon drag epoch; eq. 43	Undetectable by any current or planned survey
Dark energy w_0	−0.93 to −1.00	eq. 38; α = 0.9–1.0 H_0	DESI 2024 combined results; broadly consistent
Dark energy w_a	+0.14 to +0.16	eq. 38	DESI 2024 prefers $w_a < 0$: genuine tension at ~2.5σ
Tidal deformability Λ_{tidal} at 1.4 M⊙	450–650	Israel–Darmois junction + QCD EOS; eq. 22	LIGO O4/O5 testable; classical neutron star prediction: 350–500
Dipolar CMB y-distortion amplitude	$\delta_y \sim 4.5 \times 10^{-7}$, aligned with CMB kinematic dipole	Collision geometry breaks rotational symmetry; Section 8.4	No ΛCDM analog; detectable by PIXIE mission at ~45σ

11. Remaining Open Tasks

Three tasks are identified in NIPOK (2026k, Section 11) as required before SCT achieves a full χ^2 comparison with Planck 2018 data. This formalization records them with the same honesty.

First, the angular momentum partition function remains unresolved. NIPOK (2026e, Section 6.7, Priority 1) identifies as its primary open task the derivation of what fraction of the collision kinetic energy from $J = \mu(b \times v_{rel})$ is retained as bulk angular momentum versus dissipated as heat. Without this derivation, the vorticity term $V_{\mu\nu}$ in the SCT-MASTER equation has the correct tensor structure but not a fully calibrated amplitude coefficient.

Second, the full N-body structure formation simulation has not yet been completed. NIPOK (2026k) specifies all necessary inputs: the modified Poisson equation with A(z) factor (eq. 45), the CPL expansion history from eq. 38, and the initial conditions with $n_s = 28/29$, $r < 10^{-5}$, and pure adiabatic $f_{iso} = 0$. A modified CAMB or CLASS implementation and χ^2 comparison to Planck 2018 data is the primary remaining numerical task.

Third, the positive w_a prediction of the SCT framework (+0.14 to +0.16) is in genuine tension at approximately 2.5σ with the DESI 2024 preferred direction ($w_a < 0$). NIPOK (2026k, Section 6.6) states this tension explicitly. Confirmation or refutation of this prediction by DESI DR2 combined with Roman Space Telescope supernova data will constitute a decisive near-term test of the $\alpha_{eff} \sim H_0$ approximation underlying the Λ_{eff} decay law.

12. Conclusion

The NIPOK metric provides the geometry adequate to a universe that is nested, that rotates at every scale, and in which space and time are perceived differently at each level of the hierarchy because each level is engaged in a perpetual follow-the-leader(s) cascade — inheriting a base perception of space and time from its direct parent through compounded SR kinematic and GR gravitational factors, and then departing from that base through its own individual velocity and gravitational environment.

The foundational physical principle underlying the entire formalism is this: a comoving frame constitutes a pocket of spacetime because its members share a common bulk trajectory and a common relative velocity with respect to their parent frame. It is the shared participation in the follow-the-leader(s) dynamic that generates the pocket as a coherent perceptual unit, not merely as a gravitationally bound region. The parent frame acts as an aggregator for all ancestor motion and gravitational history above it, delivering a single unified base perception of space and time to every sibling inside the pocket equally. Each sibling then modifies that base through its own SR velocity and GR gravitational corrections — its individual departure from the shared inheritance — and passes the result as the base to any child frames it anchors. This is what the product structure of the hereditary proper-time formula encodes, and it is what the frame-tree $k \cdot u$ composition in the photon redshift formula traverses at every pocket boundary.

The central formal results are the following. Time inside any nested frame F_i is governed by two physical mechanisms — SR velocity dilation and GR gravitational dilation — applied at two scopes: inherited from each parent frame in the follow-the-leader(s) chain above, and applied locally within F_i to the rotational velocity $v_{rot} = \omega_i(r_i)\, r_i$ of co-rotating observers. The local co-rotating correction is not a new mechanism but the same SR dilation applied to tangential motion within the frame, derived directly from the NIPOK line element in Section 4. Space inside F_i is governed by its own local scale factor $a_i(t_i)$ evolving under its own local Friedmann equations with the dynamical $\Lambda_{eff,i} = C\, \Lambda_{parent} / \lambda_{local}$, independent of the parent frame expansion rate except through the boundary conditions imposed at R_i. The pocket boundary R_i is defined by three simultaneous conditions: light-cone tipping from rotation, pressure matching at the skin, and Λ_{eff} continuity ensuring smooth transition to the parent frame's expansion rate.

The SCT-MASTER field equation integrates all five modifications in a single covariant tensor statement. The Bianchi identity is satisfied as a theorem, not an assumption, through the self-consistency constraint linking the gradient of Λ_{eff} to the gradient of the coherence amplification factor A. All established frameworks are recovered as special limiting cases. The quantitative predictions derived from first principles — including $n_s = 28/29 = 0.9655...$ at 0.14σ from Planck 2018 and Hubble tension resolution at 3.4–5.3 km/s/Mpc — confirm the internal consistency of the framework and provide the testable targets required for formal observational comparison.

The progression from Cartesian coordinates to the NIPOK metric is a single logical chain, each link forged by observational necessity and mathematical generalization. The NIPOK metric is the geometry adequate to this universe as it is: nested, rotating at every scale, with every level engaged in a perpetual follow-the-leader(s) cascade whose shared motion is both the cause and the definition of every pocket of spacetime that exists within it.

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