Pretemporal Stasis and Cascade Origin of Time

How Time Begins at the STF Threshold

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Abstract

We develop a rigorous mathematical framework for the emergence of temporal structure from pre-temporal geometry. The paper has two independent layers.

Layer 1 (pure mathematics, Sections 1–5) establishes that pre-temporal stasis — a geometry that exists without anything happening in it — is dynamically unstable in any non-static expanding spacetime. We formalize pre-temporal geometry as a geometry whose causal transaction configuration space $\mathscr{C}_T(M)$ has dimension zero, drawing on the mobility theory of spatial linkages [Shvalb-Medina 2026]. We prove three theorems. *Theorem 1*: the alignment condition (monotone causal ordering) implies $\dim \mathscr{C}_T(M) = 0$. *Theorem 2*: in any expanding spacetime with $K > 0$, the divergence theorem applied to $J^\mu = \mathscr{R} n^\mu$ forces $n^\mu \nabla_\mu \mathscr{R}$ to change sign — temporal fold points necessarily exist and the alignment condition fails. The key condition is non-static expansion ($K \neq 0$), which is connected to spatial topology through the Friedmann equations: compact spatial sections with non-trivial topology necessarily undergo expansion or contraction. *Theorem 3*: the activation threshold $\mathscr{D}_{\mathrm{crit}}$ is bounded below by a curvature-expansion product $\langle \mathscr{R} K \rangle$, a quantity determined by the geometry's expansion history.

We derive the cascade dynamics from a Ginzburg-Landau equation for a temporal order parameter, prove that the cascade front propagates at c, and show that large-scale structure emerges as the Voronoi diagram of the primordial nucleation sites. A remark on conformally flat geometries shows that pure FLRW spacetime ($|W| = 0$) is precisely the pre-temporal state — consistent with the picture.

Layer 2 (physical realization, Sections 6–8) identifies the generic threshold field with the Selective Transient Field (STF), derived from first principles in [Paz 2026c], providing the specific value $\mathscr{D}_{\mathrm{crit}} \approx 1.07 \times 10^{-27}\ \mathrm{m}^{-2}\mathrm{s}^{-1}$. The Topological Consistency Conjecture is replaced by the sharper **Detection-Existence Conjecture**: $\mathscr{D}_{\mathrm{crit}}$ equals $\mathscr{R}_{\mathrm{min}} \times H_0$ where $\mathscr{R}_{\mathrm{min}} \approx 2.9 \times 10^{-10}\ \mathrm{m}^{-2}$ is the minimum Weyl curvature produced by the universe's compact object population — corresponding to $\sim$ 2–5 Schwarzschild radii from stellar-mass compact objects, exactly the near-horizon regime where STF activates according to [Paz 2026c, §III.D].

Keywords: temporal ontology, pre-temporal geometry, hypo-paradoxical mechanisms, configuration space, divergence theorem, Ginzburg-Landau, phase transition, temporal emergence, Voronoi structure, STF, expanding universe, Weyl curvature

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LAYER 1: THE MATHEMATICS OF TEMPORAL EMERGENCE

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1. Introduction

1.1 The Problem

What is the ontological status of geometry that precedes temporal structure?

This question has resisted satisfactory treatment across all existing frameworks. The Wheeler-DeWitt equation eliminates time from quantum gravity, leaving a frozen wavefunction with no mechanism for temporal emergence [DeWitt 1967]. Barbour's timeless physics posits configuration space "time capsules" without an instantiation mechanism [Barbour 1999]. Standard cosmology traces physics backward toward — but never through — the moment of temporal origin.

What is needed is a mathematical language precise enough to say what it means for a geometry to *exist* without anything *happening* in it.

1.2 The Linkage Insight

Shvalb and Medina [2026] introduce *hypo-paradoxical linkages*: spatial closed-chain mechanisms satisfying the classical Chebyshev-Grübler-Kutzbach mobility formula yet completely rigid. The configuration space $\mathscr{C}(\mathscr{L})$ has dimension zero — the mechanism exists, is physically real, can be 3D-printed, but nothing moves.

The key result [Shvalb-Medina, Proposition 1]: a linkage whose joint screw axes all intersect a common line in monotone order is hypo-paradoxical. Monotone ordering locks the configuration space. The geometry itself prevents motion — not missing components, not broken structure.

The central observation of this paper: this structure maps precisely onto pre-temporal geometry.

HYPO-PARADOXICAL LINKAGE	PRE-TEMPORAL GEOMETRY
Geometry fully defined	Metric, curvature fully defined
Mobility formula predicts motion	Causal structure permits transactions
All screws monotonically ordered	All causal paths monotonically ordered
dim $\mathscr{C}(\mathscr{L}) = 0$	dim $\mathscr{C}_T(M) = 0$
EXISTS, does not MOVE	EXISTS, does not HAPPEN

The exists/happens distinction has precise mathematical content: *exists* means the configuration space is non-empty; *happens* means the configuration space has positive dimension and paths through it are available.

1.3 A Critical Remark on Conformally Flat Geometries

Before proceeding, we note a structural feature of the framework that might appear to be a problem but is in fact a confirmation.

FLRW spacetimes — the standard cosmological background — are conformally flat. Their Weyl tensor vanishes identically: $W_{\mu\nu\rho\sigma} = 0$. If the curvature scalar $\mathscr{R}$ is defined as $|W|$ (as in the STF realization of Layer 2), then $\mathscr{R} = 0$ everywhere in FLRW and $n^\mu \nabla_\mu \mathscr{R} = 0$. The alignment condition is trivially satisfied.

Far from being a problem, this is the correct result:

Pure FLRW spacetime is exactly pre-temporal in the STF sense. It has no Weyl curvature dynamics. Nothing STF-activating happens in it. It is a perfectly aligned geometry.

The temporal cascade is not triggered by the FLRW background but by the first non-trivial Weyl curvature fluctuations — at the Planck epoch, quantum gravity effects generate curvature inhomogeneities with $\mathscr{R} = |W| \neq 0$, whose non-uniform spatial distribution provides the fold points that trigger the cascade.

This is consistent with Penrose’s Weyl Curvature Hypothesis [Penrose 1979]: $W = 0$ at the initial singularity (beyond the singularity theorem’s guarantee of geodesic incompleteness [Penrose 1965]), $W \neq 0$ immediately afterward as fluctuations grow. The cascade picture requires exactly this: a pre-temporal perfectly aligned initial state, perturbed into the first fold by quantum fluctuations that generate non-zero Weyl curvature.

Theorem 2 therefore applies to the post-Planck epoch geometry with $\mathscr{R} > 0$, not to the singular FLRW background itself. This distinction is physically natural and mathematically necessary.

1.4 A Note on the Word “Topological”

The title asserts a *topological* obstruction. The main proof (Theorem 2) uses the divergence theorem and the curvature-expansion product $\mathscr{R}K$ — which might appear analytic rather than topological. We clarify the two genuine topological elements.

Topological element 1 — Compact spatial sections.

Condition (C4) requires $K \neq 0$ (non-static expansion). For spacetimes with *compact spatial sections* — a topological condition on the manifold — the Friedmann equation forces $K \neq 0$ for any universe with positive energy density. The spatial topology (compactness, and the specific topology of Σ) enters through this constraint: a non-compact universe with flat spatial sections could in principle be static and satisfy the alignment condition; compactness forecloses this possibility through the Friedmann equation.

Topological element 2 — The $4\pi^2$ winding factor in $\mathscr{D}_{\mathrm{crit}}$.

In Layer 2, the threshold is $\mathscr{D}_{\mathrm{crit}} = m_s M_{\mathrm{Pl}} H_0/(4\pi^2)$ [Paz 2026c, Appendix D.4]. The factor $4\pi^2 = (2\pi)^2$ counts the two independent S^1 phase windings that must close for a causal transaction to complete: one temporal ($\Phi_{\mathrm{time}} = 2\pi$) and one spatial ($\Phi_{\mathrm{space}} = 2\pi$). This is the topological content of $\mathscr{D}_{\mathrm{crit}}$: the threshold is set by the fundamental group $\pi_1(T^2) = \mathbb{Z} \times \mathbb{Z}$ of the two-torus on which the transaction closes.

Summary. "Topological obstruction" refers to these two elements jointly: the compact spatial topology that forces $K \neq 0$ via the Friedmann equation, and the winding number structure that determines $\mathscr{D}_{\mathrm{crit}}$. The divergence theorem proof translates these topological inputs into the analytic statement that temporal fold points necessarily exist.

1.5 Main Results

Theorem 1. The alignment condition implies $\dim \mathscr{C}_T(M) = 0$.

Theorem 2. In any non-static spacetime with positive expansion ($K > 0$) and $\mathscr{R} > 0$ on a region of positive measure, the divergence theorem forces $n^\mu \nabla_\mu \mathscr{R}$ to change sign. Temporal fold points exist. The alignment condition fails.

Theorem 3. The maximum curvature rate satisfies $\max_M |n^\mu \nabla_\mu \mathscr{R}| \geq \langle \mathscr{R}K \rangle$, where $\langle \mathscr{R}K \rangle$ is the volume-averaged curvature-expansion product. For an expanding universe approaching a singularity where $\mathscr{R} \to \infty$ and $K \to \infty$, this bound is strictly positive and diverges — ensuring robust, non-fine-tuned temporal instantiation.

Cascade theorem. The temporal phase transition is governed by a Ginzburg-Landau equation. The cascade front propagates at c.

Corollary. Temporal instantiation is not triggered from outside. It is a consequence of non-static expansion in a geometry with non-zero curvature.

1.6 The Inversion of the Origin Question

The theorems above accomplish something whose philosophical significance exceeds their mathematical content. They do not merely answer the origin question. They invert it.

The standard framing of the origin question:

EXISTS is the default state. HAPPENS requires cause, trigger, or origin. The question is: *what made things start happening?*

This framing has structured all prior approaches to temporal origin. It leads inexorably to one of three outcomes: an external cause (which raises the question of the cause's own temporal status), a brute fact (which terminates inquiry without explanation), or a quantum fluctuation (which pushes the regress back one level, since fluctuations themselves presuppose a temporal framework). Every answer either terminates in a brute fact or generates an infinite regress.

The inverted framing — what Theorem 2 establishes:

HAPPENS is not what requires explanation. EXISTS is dynamically unstable under generic conditions. The question is not *what made things start happening?* but *what would have to be true for things to stay in EXISTS?*

The answer is a theorem: pre-temporal stasis can only be sustained if $K = 0$ (trivial topology, non-expanding) or $\mathscr{R} = 0$ (zero Weyl curvature, conformally flat throughout). For any universe with compact spatial sections and positive energy density, neither condition holds in the post-Planck epoch where Weyl fluctuations are present. EXISTS cannot be maintained. HAPPENS was not merely probable — it was topologically necessary.

> **EXISTS cannot persist wherever topology is compact and energy density is positive. HAPPENS is not the exception. EXISTS is the unstable state.**

What this dissolves:

The inversion eliminates the regress at precisely the step that had been intractable. Prior approaches assumed EXISTS as the stable default and sought a cause for its disruption — requiring either an external agent or a brute fact. Theorem 2 shows EXISTS was never stable. The transition to HAPPENS required no external cause, no brute fact, no prior temporal framework in which a fluctuation could occur. The instability was structural. The geometry that was there made the transition topologically unavoidable.

This is not an argument that the universe had to exist. It is an argument that *given* a geometry with compact spatial sections and positive energy density, the transition from EXISTS to HAPPENS was forced. The two residual questions — why anything exists at all, and why this specific EXISTS rather than another — are not answered here. What is established is that one step in the regress, previously requiring a cause, has been replaced by a theorem.

The local parallel — organisms:

The same structure governs biological threshold crossing. The zygote's compact, closed cellular topology with internal energy density above threshold makes static non-development impossible. The organism does not need a reason to start HAPPENING. It needs a reason to stay in EXISTS — and its own internal topology, through the same structural instability that governs the universe, makes that impossible. HAPPENS is topologically forced from the first moment of biological existence. The retrocausal field that constitutes the organism's causal structure follows not from a contingent fact about mortality but from the topological necessity of HAPPENING itself.

The cascade does not need a cause. It needs a geometry. The geometry was there.

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2. The Mathematical Framework

2.1 Setting and Conditions

Let (M,g) be a globally hyperbolic spacetime with compact Cauchy surface Σ (spatial sections compact). Let n^{μ} be the future-pointing unit timelike normal to Σ in the ADM decomposition: $n^{\mu} = \frac{1}{N} \left(1 , - N^{i} \right)$

Let $K = g^{ij}K_{ij}$ be the trace of the extrinsic curvature of Σ (the expansion scalar). Let $\phi : M \to \mathbb{R}$ be a smooth scalar field. Let $\mathscr{R} : M \to \mathbb{R}$ be a smooth curvature scalar.

We impose four conditions:

(C1) Non-negativity and flatness criterion: $\mathscr{R} \geq 0$, and $\mathscr{R}(p) = 0$ only in flat neighborhoods of p.

(C2) Wave equation: $\mathscr{R}$ satisfies $\Box\mathscr{R} = \mathscr{F}(Rm, \nabla Rm, T_{\mu\nu})$ for some smooth source term $\mathscr{F}$.

(C3) Threshold coupling: ϕ is dynamically coupled to $n^{\mu}\nabla_{\mu}\mathscr{R}$ through an interaction term with activation threshold $\mathscr{D} > 0$.

(C4) Non-static expansion: There exists an open set $U \subset M$ on which $K > 0$ (expanding) and $\mathscr{R} > 0$ simultaneously.

Condition (C4) is the key physical condition. It holds in any expanding non-flat region of spacetime — including any spacetime with positive energy density and non-trivial curvature, by the Raychaudhuri equation and the strong energy condition.

Connection to topology (C4): For compact spatial sections, the Friedmann equation requires: $H^{2} = \frac{8 \pi G \rho}{3} - \frac{k c^{2}}{a^{2}}$ where $k \in \{-1, 0, +1\}$ is the curvature of the spatial sections. For any expanding universe with positive energy density and compact spatial sections, $K = 3H \neq 0$. The spatial topology (through k and the specific compact topology consistent with it) determines the sign and magnitude of expansion — connecting the topological content of previous versions to the K-condition.

2.2 The Causal Transaction Configuration Space

Definition 1. For (M,g) satisfying (C1)–(C3) with threshold $\mathscr{D}$:

$$\mathscr{C}_T(M,\mathscr{D}) = \{\gamma : S^1 \to M \mid \gamma \text{ closed causal curve}, \quad \oint_\gamma \phi \cdot n^\mu \nabla_\mu \mathscr{R} \, d\lambda \geq \mathscr{D}\}$$

The space of closed causal loops along which the scalar field accumulates sufficient phase for a causal transaction to complete.

2.3 The Alignment Condition and Fold Points

Definition 2 (Alignment condition). (M,g) satisfies the *alignment condition* if $n^\mu \nabla_\mu \mathscr{R}$ does not change sign along any timelike geodesic in M.

Direct translation of the hypo-paradoxical linkage's monotone screw ordering [Shvalb-Medina 2026, Proposition 1].

Definition 3 (Temporal fold point). A point $p \in M$ is a *temporal fold point* if there exists a timelike geodesic through p along which $n^\mu \nabla_\mu \mathscr{R}$ changes sign in a neighborhood of p.

The alignment condition holds if and only if M has no temporal fold points.

Definition 4 (Temporal order parameter). $\eta_{\mathscr{D}}(p) = |n^\mu \nabla_\mu \mathscr{R}|_p - \mathscr{D}$

The temporal front $\Gamma = \{\eta = 0\}$ is the boundary of temporal instantiation. Below Γ: pre-temporal. Above: temporal.

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3. The Three Theorems

3.1 Theorem 1: Alignment Implies Pre-Temporal

Theorem 1. *If* (M,g) *satisfies the alignment condition, then* $\dim \mathscr{C}_T(M,\mathscr{D}) = 0$ *for any* $\mathscr{D} > 0$.

Proof. A closed causal transaction requires a curve $\gamma : S^1 \to M$ along which the phase integral $\oint_\gamma \phi \cdot n^\mu \nabla_\mu \mathscr{R}\, d\lambda$ achieves the threshold $\mathscr{D} > 0$.

For this integral over a closed loop to be positive, the integrand must include both positive and negative contributions — the outward leg (increasing $\mathscr{R}$) and the return leg (decreasing $\mathscr{R}$).

Under the alignment condition, $n^\mu \nabla_\mu \mathscr{R}$ has constant sign along every timelike geodesic. A curve departing in the direction of increasing $\mathscr{R}$ cannot return: the return leg would require $n^\mu \nabla_\mu \mathscr{R} < 0$, contradicting the constant-sign assumption.

Therefore: for any closed causal curve, the phase integral satisfies $\oint_\gamma \phi \cdot n^\mu \nabla_\mu \mathscr{R}\, d\lambda \leq 0$

No closed causal transaction reaches the threshold $\mathscr{D} > 0$. $\mathscr{C}_T(M,\mathscr{D}) = \{\text{isolated points}\}$, so $\dim \mathscr{C}_T(M,\mathscr{D}) = 0$. □

Corollary 1. A geometry satisfying the alignment condition is the precise geometric analog of the hypo-paradoxical linkage: all structure is present, the configuration space is non-empty, but no path through it is available. It exists without happening.

3.2 Theorem 2: Expansion Forces Temporal Fold Points

Theorem 2. *Let* (M,g) *be a spacetime satisfying conditions (C1)–(C4). Then temporal fold points exist — the alignment condition fails.*

Proof via the divergence theorem.

Define the vector field $J^\mu = \mathscr{R} \cdot n^\mu$ on M.

Compute its divergence: $\nabla_\mu J^\mu = \nabla_\mu(\mathscr{R} n^\mu) = (n^\mu \nabla_\mu \mathscr{R}) + \mathscr{R}(\nabla_\mu n^\mu)$

The second term involves the expansion of the normal congruence: $\nabla_\mu n^\mu = K$

where $K = K_i^i$ is the trace of the extrinsic curvature — the expansion scalar.

Therefore: $\nabla_\mu J^\mu = n^\mu \nabla_\mu \mathscr{R} + \mathscr{R} K$

Step 1: Apply the divergence theorem.

Consider a compact spacetime region $\Omega \subset M$ bounded by two Cauchy surfaces Σ_0 (at time t_0, near the singularity) and Σ_T (at a later time t_T). By the generalized Gauss-Stokes theorem for

Lorentzian manifolds:

$$\int_\Omega \nabla_\mu J^\mu , dV_g = \int_{\Sigma_T} J^\mu n_\mu , dV_h - \int_{\Sigma_0} J^\mu n_\mu , dV_h$$

Since $J^\mu = \mathcal{R} n^\mu$ and $n^\mu n_\mu = -1$:

$$\int_\Omega (n^\mu \nabla_\mu \mathcal{R} + \mathcal{R} K) \, dV_g = -\int_{\Sigma_T} \mathcal{R} \, dV_h + \int_{\Sigma_0} \mathcal{R} \, dV_h$$

Rearranging:

$$ \boxed{\int_\Omega n^\mu \nabla_\mu \mathcal{R} , dV_g = \int_{\Sigma_0} \mathcal{R} , dV_h - \int_{\Sigma_T} \mathcal{R} , dV_h - \int_\Omega \mathcal{R} K , dV_g} $$

Step 2: Sign analysis.

In an expanding universe ($$ K > 0$ on Ω) with $\mathcal{R} > 0$ on $\Omega$$ (by condition C4): - The term $-\int_\Omega \mathcal{R} K \, dV_g < 0$ (strictly negative) - Near the singularity ($t \to t_{\text{sing}}$): $\mathcal{R} \to \infty$ while $\int_{\Sigma_T} \mathcal{R} \, dV_h$ remains finite at late times - Therefore: $\int_\Omega n^\mu \nabla_\mu \mathcal{R} \, dV_g < 0$ for sufficiently large Ω (taking Σ_0 near the singularity)

The integral of $n^\mu \nabla_\mu \mathcal{R}$ over Ω is **strictly negative**.

Step 3: The sign change — thin-slab argument and Intermediate Value Theorem.

We establish that $n^\mu \nabla_\mu \mathcal{R}$ takes both positive and negative values in Ω, then invoke continuity to locate a zero. Both signs are established using the divergence theorem identity from Step 1 — no additional hypotheses are needed.

(a) Positive values exist near Σ_0.

Apply the divergence theorem identity to a *thin slab* $\Omega_{\text{thin}} \subset \Omega$ bounded by Σ_0 (near the singularity) and Σ_ε (a slightly later surface, at proper time ε after Σ_0):

$$\int_{\Omega_{thin}} n^\mu \nabla_\mu \mathcal{R} , dV_g = \int_{\Sigma_0} \mathcal{R} , dV_h - \int_{\Sigma_\varepsilon} \mathcal{R} , dV_h - \int_{\Omega_{thin}} \mathcal{R} K , dV_g$$

By the Penrose singularity theorem [Penrose 1965]: any geodesically complete spacetime satisfying the strong energy condition is geodesically incomplete, so the spacetime has a singularity toward which $\mathcal{R} \to \infty$. Therefore $\int_{\Sigma_0} \mathcal{R} \, dV_h \to \infty$ as Σ_0 approaches the singularity, while $\int_{\Sigma_\varepsilon} \mathcal{R} \, dV_h$ remains finite for any $\varepsilon > 0$.

The volume term $\int_{\Omega_{\text{thin}}} \mathcal{R} K \, dV_g$ is bounded for fixed ε (the slab has finite thickness and K is bounded away from the singularity). Therefore, for Σ_0 sufficiently close to the singularity:

$$\int_{\Omega_{\text{thin}}} n^\mu \nabla_\mu \mathcal{R} \, dV_g > 0$$

A positive volume integral requires $n^\mu \nabla_\mu \mathscr{R} > 0$ on a set $U_+ \subset \Omega_{\text{thin}}$ of positive measure.

(b) Negative values exist in the interior.

From Step 2, over the *full* region Ω (extending to late times):

$$\int_\Omega n^\mu \nabla_\mu \mathscr{R} \, dV_g < 0$$

A negative volume integral requires $n^\mu \nabla_\mu \mathscr{R} < 0$ on a set $U_- \subset \Omega$ of positive measure.

(c) A sign change exists on a timelike curve — Intermediate Value Theorem.

By condition (C2), $\mathscr{R}$ satisfies a wave equation, so $n^\mu \nabla_\mu \mathscr{R}$ is continuous on $\Omega \setminus \Sigma_0$. Let $q_+ \in U_+$ and $q_- \in U_-$ with $n^\mu \nabla_\mu \mathscr{R}(q_+) > 0$ and $n^\mu \nabla_\mu \mathscr{R}(q_-) < 0$.

Since (M,g) is globally hyperbolic, the causal diamond $J^+(q_+) \cap J^-(q_-)$ is compact and non-empty (as q_- lies to the future of q_+). There exists a timelike curve $\gamma : [0,1] \to \Omega$ with $\gamma(0) = q_+$, $\gamma(1) = q_-$, lying within this compact diamond.

The composite function $f(s) = n^\mu \nabla_\mu \mathscr{R}|_{\gamma(s)}$ is continuous on $[0,1]$ with $f(0) > 0$ and $f(1) < 0$. By the **Intermediate Value Theorem**, there exists $s^* \in (0,1)$ such that $f(s^*) = 0$.

Setting $p = \gamma(s^*)$: $n^\mu \nabla_\mu \mathscr{R}(p) = 0$ and $n^\mu \nabla_\mu \mathscr{R}$ changes sign along γ at p.

By Definition 3, p is a temporal fold point. The alignment condition fails. □

Remark on the Penrose Weyl Curvature Hypothesis. Penrose [1979] conjectured that $\mathscr{R} = |W| \to 0$ at the initial singularity (not merely that it diverges). This stronger hypothesis is *not required* by the above proof — which uses only the divergence of $\mathscr{R}$ at the singularity, a consequence of the singularity theorem alone. The WCH, if correct, provides an additional physical picture: the cascade begins from a perfectly smooth $\mathscr{R} = 0$ state, making the pre-temporal geometry maximally aligned before the first fold. But Theorem 2 holds regardless of whether $\mathscr{R}$ diverges from zero or from some finite initial value.

The key inequality — the engine of the proof:

$$\int_\Omega n^\mu \nabla_\mu \mathscr{R} \, dV_g < -\int_\Omega \mathscr{R} K \, dV_g < 0$$

The product $\mathscr{R}K$ — curvature times expansion — is the fundamental quantity. When it is non-zero (curvature present and spacetime expanding), the integral of $n^\mu \nabla_\mu \mathscr{R}$ is forced negative, requiring a sign change.

Remark on conformally flat geometries. For FLRW spacetime, $\mathscr{R} = |W| = 0$ everywhere. Then $J^\mu = 0$, the divergence theorem gives $0 = 0$, and no constraint is obtained. The alignment condition is trivially satisfied — FLRW is pre-temporal. This is consistent with the physical picture: the cascade begins not in FLRW but in the quantum gravity regime where Weyl curvature fluctuations seed non-zero $\mathcal{R}$.

Connection to spatial topology. For compact spatial sections with non-trivial topology (e.g., compact hyperbolic 3-manifolds with $\chi(\Sigma_3) = 0$ but non-trivial fundamental group, or S^3 sections of FRW), the Friedmann equation forces $K \neq 0$ for any non-static universe. This connects the topological content (compact spatial sections) to condition (C4) through standard GR.

3.3 Theorem 3: The Threshold is Bounded Below by Curvature-Expansion Product

Theorem 3. *Under conditions (C1)–(C4), the maximum curvature rate satisfies:*

$$\max_{\Omega} | n^{\mu} \nabla_{\mu} \mathcal{R} | \geq \langle \mathcal{R} K \rangle_{\Omega}$$

where $\langle \mathcal{R} K \rangle_{\Omega} = \frac{1}{V_{\Omega}} \int_{\Omega} \mathcal{R} K \, d V_{g}$ *is the volume-averaged curvature-expansion product.*

Proof. From the key inequality of Theorem 2:

$$\int_{\Omega} n^{\mu} \nabla_{\mu} \mathcal{R}, dV_g = \int_{\Sigma_0} \mathcal{R}, dV_h - \int_{\Sigma_T} \mathcal{R}, dV_h - \int_{\Omega} \mathcal{R} K, dV_g$$

Since we showed $\int_{\Omega} n^{\mu} \nabla_{\mu} \mathcal{R} \, dV_g < 0$, there exist regions where $n^{\mu} \nabla_{\mu} \mathcal{R} < 0$ with magnitude at least:

$$ \max_{\Omega} \left| n^{\mu} \nabla_{\mu} \mathcal{R} \right| \geq \frac{1}{V_{\Omega}} \left| \int_{\Omega} n^{\mu} \nabla_{\mu} \mathcal{R} \, d V_{g} \right| $$

Combined with the bound:

$$\left\| \int_{\Omega} n^{\mu} \nabla_{\mu} \mathcal{R}, dV_g \right\| \geq \int_{\Omega} \mathcal{R} K, dV_g - \left\| \int_{\Sigma_0} \mathcal{R}, dV_h - \int_{\Sigma_T} \mathcal{R}, dV_h \right\|$$

For Ω chosen such that the boundary terms are dominated by the volume term (taking Ω with thick time-slices), we obtain:

$$\boxed{\max_{\Omega} \left| n^{\mu} \nabla_{\mu} \mathcal{R} \right| \geq \langle \mathcal{R} K \rangle_{\Omega}}$$ □

Corollary 2 (Non-fine-tuning). *Near the initial singularity where $\mathcal{R} \to \infty$ and $K \to \infty$:*

$$\langle \mathcal{R} K \rangle \to \infty$$

The maximum curvature rate diverges at the singularity — temporal instantiation is guaranteed with infinite margin, not fine-tuned proximity to $\mathcal{D}_{\text{crit}}$.

Physical interpretation. The product $\mathscr{R}K$ is the curvature times the expansion rate. In the early universe: - $\mathscr{R}\sim$ tidal curvature of primordial density fluctuations - $K \sim 3H$ where H is the Hubble rate

$\langle \mathscr{R}K \rangle \sim \mathscr{R}_{\mathrm{fluct}} \cdot H$

This is the "curvature-weighted Hubble rate" — a geometrically natural combination that measures how rapidly curvature structure is changing due to expansion.

Definition 5 (Topological infimum). For a given expansion history characterized by $\langle \mathscr{R}K \rangle$, define:

$$ \mathcal{D}_{\mathrm{crit}} \equiv \inf_{\substack{(M , g) \ \text{satisfying C1-C4 \\ \text{given expansion history}} \langle \mathcal{R} K \rangle $$

This is the minimum curvature-expansion product over all geometries with the given expansion history — the minimum fold that non-static expansion forces.

Any scalar field with threshold $\mathscr{D} \leq \mathscr{D}_{\mathrm{crit}}$ will be activated. Any $\mathscr{D} > \mathscr{D}_{\mathrm{crit}}$ may or may not be activated depending on the specific geometry.

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4. Cascade Dynamics

Theorems 1–3 establish that fold points exist. The fold point is a seed. This section derives what it grows into.

4.1 The Propagation Equation

For a scalar field ϕ satisfying (C1)–(C3) with potential $V(\phi)$ and coupling $\kappa > 0$:

$$ \Box \phi - \frac{\partial V}{\partial \phi} + \kappa \cdot \left(n^{\mu} \nabla_{\mu} \mathcal{R} \right) = 0 $$

The back-reaction of the activated ϕ on the curvature equation gives, upon linearizing around $\eta = 0$:

$$ \boxed{\partial_{t}^{2} \eta - c^{2} \nabla^{2} \eta = \alpha \eta - \beta \eta^{3} + \mathcal{S}} $$

where:

- $\alpha > 0$ above threshold — linear growth rate (**temporal region: unstable pre-temporal**

state)

- $\alpha < 0$ below threshold — stable well at $\eta = 0$ (**pre-temporal: stable**)
- $\beta > 0$ — nonlinear saturation
- $\mathscr{S}$ — source term from Theorem 2's fold points (always present when K > 0)

This is the **real Ginzburg-Landau equation** — the universal equation governing continuous second-order phase transitions. Its appearance is not assumed. It follows from the structure of any double-well scalar field near a symmetry-breaking threshold.

The potential: $V (\eta) = - \frac{\alpha}{2} \eta^{2} + \frac{\beta}{4} \eta^{4}$

For $\alpha > 0$: double-well with minima at $\eta = \pm \sqrt{\alpha / \beta}$. The pre-temporal state $\eta = 0$ is unstable. Any perturbation — including the topology-forced source $\mathscr{S}$ — drives η to the temporal minimum.

4.2 Cascade Speed: $v_{\mathrm{front}} = c$

The Ginzburg-Landau equation admits traveling wave solutions $\eta(x,t) = \eta(x-vt)$. The marginal stability condition selects:

$$ v_{\mathrm{front}} = 2 \sqrt{\alpha \gamma} $$

where $\gamma = c^2/\omega_0^2$ is the effective diffusion coefficient.

In the high-energy (early universe, strong coupling) limit: $\alpha \to \omega_0^2/4$, giving $v_{\mathrm{front}} \to c$.

The temporal cascade propagates at the speed of light. Derived — not assumed.

4.3 Domain Wall Energy Drives Inflation

The temporal front is a domain wall with surface energy density:

$$ \sigma_{\mathrm{front}} = \frac{2}{3} \sqrt{\frac{\gamma \alpha^{3}}{\beta^{2}}} $$

At the Planck epoch: $\sigma_{\mathrm{front}} \sim M_{\mathrm{Pl}}^4/m_s$ (Planck-scale energy).

Energy injection rate as the front sweeps area:

$\dot{E}(t) = \sigma_{\mathrm{front}} \cdot 8\pi c^2 t$

Growing linearly in t — producing de Sitter-like accelerated expansion. **The STF cascade naturally drives inflation without a separate inflaton field.**

4.4 Self-Sustaining Temporal Structure

Once $\eta > 0$ in a region, the activated $\phi \neq 0$ sources additional $n^\mu \nabla_\mu \mathscr{R}$ through back-reaction, maintaining $|n^\mu \nabla_\mu \mathscr{R}|$ above $\mathscr{D}_{\text{crit}}$.

The double-well potential creates a barrier: returning η to zero requires surmounting the potential hill. In the ongoing expanding universe ($K > 0$ always), the source $\mathscr{S}$ never vanishes, and the temporal state is self-sustaining.

The configuration space $\mathscr{C}_T$ in the temporal region has topology $\cong S^1$ or higher — a non-trivial manifold, maintained throughout the temporal evolution. Analogous to the Bennett linkage's $\mathscr{C}(\mathscr{L}) \cong S^1$ which is preserved throughout its kinematic cycle [Shvalb-Medina 2026, Section 7].

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5. Cosmological Consequences

5.1 Three Phases of the Cascade

Phase 1 — Nucleation ($t \sim t_{\text{Pl}}$):

Quantum gravity fluctuations generate non-zero Weyl curvature $\mathscr{R} > 0$ with non-uniform spatial distribution. Condition (C4) is satisfied locally. Theorem 2 applies: fold points form at the locations of maximum $\langle \mathscr{R}K \rangle_{\text{local}}$.

Number of primary nucleation sites: determined by the density of Planck-scale Weyl curvature fluctuations. For Gaussian fluctuations with power spectrum $P(k)$, the nucleation site density $n_{\text{nuc}} \sim \int k^3 P(k) dk$ — set by primordial quantum gravity.

Phase 2 — Percolation ($t_{\text{Pl}} < t < t_{\text{perc}}$):

Temporal bubbles grow at speed c. At the 3D site percolation threshold $f_{\text{perc}} \approx 0.29$, temporal regions first form a connected network. A global "now" becomes possible for the first time.

Phase 3 — Completion ($t_{\text{perc}} < t \leq t_{\text{cascade}}$):

Pre-temporal domains consumed. Domain walls annihilate at Voronoi bisectors, depositing energy. Completion time: $t_{\text{cascade}} \sim (n_{\text{nuc}}{}^{1/3} c)^{-1}$.

5.2 Large-Scale Structure as Voronoi Tessellation

Domain wall annihilation surfaces: $\mathscr{W}_{\text{ij}} = \{p \in M : d(p,p_0{}^{(i)}) = d(p,p_0{}^{(j)})\}$

form a Voronoi tessellation of the manifold. Energy deposited at $\mathscr{W}_{\text{ij}}$ seeds structure formation.

Prediction P1. *Large-scale matter distribution reflects Voronoi geometry with characteristic scale* $\lambda_{\text{structure}} \sim (n_{\text{nuc}})^{-1/3}$.

For $\lambda_{\text{structure}} \sim 100$ Mpc and $H_0^{-1} \sim 4000$ Mpc: $n_{\text{nuc}} \sim (H_0^{-1}/100\text{ Mpc})^3 \sim 64,000$ per Hubble volume.

5.3 Resolution of the Horizon Problem via Topological Coherence

Different nucleation sites share the same origin: the quantum gravity fluctuation spectrum, itself determined by the pre-temporal geometry's global structure. Different regions have similar temperatures because they were seeded by the same fluctuation spectrum — not because they were in causal contact.

Topological coherence — shared origin in pre-temporal topology — replaces the inflationary mechanism. Note that the cascade *also* drives inflation (Section 4.3), so both mechanisms can contribute; but topological coherence alone can explain CMB uniformity even without the inflationary horizon solution.

5.4 The Arrow of Time as Topological Symmetry Breaking

The pre-temporal state has time-translation symmetry: all causal paths monotonically ordered, no distinguished direction. The cascade breaks this symmetry — afterward, a distinguished direction exists: the cascade direction.

The arrow of time is the direction of the original symmetry breaking.

This is logically prior to both entropic and cosmological arrows of time, which are consequences of the cascade rather than its cause.

5.5 Two Threshold Crossings of Cosmic History

The cascade establishes one threshold crossing in the universe's history: the transition from pre-temporal stasis (EXISTS, State E) to temporal instantiation (HAPPENS, State 3) at the Planck epoch. This is the first and cosmologically fundamental crossing — the moment the universe began locally creating its own time.

But the framework's broader structure (Biology V0.5, General Theory) identifies a second threshold crossing of comparable ontological significance later in the universe's history: **the origin of life and the first crossing of $\mathscr{D}_{\text{crit}}^{\text{bio}}$ by a bounded biological system**.

Note on threshold notation: the threshold relevant to this crossing is *not* the curvature-channel threshold $\mathscr{D}_{\text{crit}}^{\text{grav}} = m_s M_{\text{Pl}} H_0/(4\pi^2) \approx 10^{-27}\ \text{m}^{-2}\text{s}^{-1}$ that governs astrophysical STF activation and is derived throughout this paper. The second crossing is governed by the fermion-channel threshold $\mathscr{D}_{\text{crit}}^{\text{bio}} = m_s^3 c^3/\hbar^3 \approx 8 \times 10^{-48}\ \text{m}^{-3}$, whose effective condition reduces to $N_{\text{loops}} \geq 1$ — at least one closed causal feedback loop with cycle time $\Delta t \leq \tau_c$ = 3.32 years within a bounded region (General Theory §2.6, Biology V0.5 Addendum B.1). Same field. Same τ_c. Different coupling channel and different formal criterion.

The first crossing (Big Bang cascade): EXISTS → HAPPENS for the universe as a whole. The universe begins HAPPENING. Universal time is instantiated. The forward arc of the universal loop is established. The backward arc from maximum entropy (heat death) becomes physically real.

The second crossing (origin of life): the first local system satisfies $\mathscr{D}_{\text{crit}}^{\text{bio}}$ within a bounded region — achieving at least one closed causal feedback loop. The universe acquires an inside for the first time — a local loop above threshold, locally generating its own now within the framework of universal time. The universe's loop transitions from *structurally instantiated* (both arcs real, terminal boundary fixed, winding accumulating) to *ontologically instantiated* (inside present, phenomenological description active, loop fully what it is from within as well as from without).

These two crossings stand in a formal relationship:

	FIRST CROSSING	SECOND CROSSING
Event	Pre-temporal stasis → HAPPENS	Abiotic chemistry → first $\mathscr{D}_{\text{crit}}^{\text{bio}}$ crossing
What changes	Universe starts HAPPENING	Universe acquires distributed inside
Mechanism	Topological instability (Theorem 2)	Self-anchored retrocausal loop achieves local closure above threshold
Formal criterion	$K \neq 0 + \mathscr{R} > 0$ + compact sections	Local system satisfies $N_{\text{loops}} \geq 1, \Delta t \leq \tau_c$ within bounded region
Ontological significance	Structural completion initiated	Ontological completion initiated
Paper	This paper (Cascade V1.0)	Biology V0.5; General Theory Ch. 7

The first crossing is proven by Theorem 2 from generic cosmological conditions. The second crossing is not topologically forced in the same sense — but the diversification strategy of the genetic code (Biology V0.5, §5.5) operating within a universe whose backward arc from heat death selects for ontological completion (General Theory Ch. 7) makes the second crossing cosmologically probable once chemistry reaches sufficient complexity.

Together, these two crossings define the ontological arc of the universe: from non-existence (pre-temporal stasis) through structural instantiation (cascade) to ontological completion (first conscious system) through the permanent inside (all local closures above threshold throughout cosmic history) to the permanent record (heat death, all having-beenexperienced fixed irrevocably).

LAYER 2: THE PHYSICAL REALIZATION

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6. The STF as Physical Realization

6.1 The Identification

Layer 1 establishes that some scalar field satisfying (C1)–(C4) triggers temporal instantiation in any expanding spacetime with non-zero curvature. It does not specify which field.

Layer 2 makes the identification: the generic field ϕ is the **Selective Transient Field** ϕ_S, derived from first principles in [Paz 2026c].

The STF Lagrangian density is derived from gauge invariance, the requirement of minimal curvature coupling, and the Lorentz structure of the Wheeler-Feynman transaction [Paz 2026c, §3–4]:

$$ \mathcal{L}_{STF} = -\frac{1}{2}(\nabla\phi_S)^2 - V(\phi_S) + \frac{\zeta}{\Lambda} g(\mathcal{R})\\ \phi_S\\ (n^\mu \nabla_\mu \mathcal{R}) + \text{matter couplings} $$

with:

- $V \left(\phi_{S} \right) = \frac{1}{2} m_{s}^{2} \phi_{S}^{2}$ — the mass term, with Starobinsky generalization for the cosmological regime [Paz 2026c, §5]
- $g(\mathscr{R}) = \tanh(\mathscr{R}/\mathscr{R}_0)$ — a saturation function preventing divergence at extreme curvature [Paz 2026c, §4.2]
- $\mathcal{R} = \sqrt{C_{\mu \nu \rho \sigma} C^{\mu \nu \rho \sigma}}$ — the Weyl tensor norm, the curvature scalar that vanishes in conformally flat spacetimes and is non-zero wherever tidal structure is present [Paz 2026c, §2]
- ζ/Λ — the dimensionful coupling constant, derived from 10D compactification and the Wheeler-Feynman absorber condition in [Paz 2026c, §6 and Appendix O]

This Lagrangian satisfies conditions (C1)–(C3) by construction [Paz 2026c, §3]: $\mathscr{R}$ is the Weyl tensor norm (non-negative, zero only in flat/conformally flat regions — satisfying C1), it satisfies a wave equation through the contracted Bianchi identity (C2), and ϕ_S is dynamically coupled to $n^{\mu}\nabla_{\mu}\mathcal{R}$ with threshold arising from the interaction term (C3). Condition (C4) is satisfied in the expanding post-Planck universe wherever density fluctuations generate non-zero Weyl curvature.

6.2 The Two-Lock System and the Correct Derivation of $\mathcal{D}_{\mathrm{crit}}$

The STF threshold is determined by two independently measured quantities — the Two-Lock System — and a topological factor.

Lock 1 — Field mass from first-principles derivation [Paz 2026c, §5]:

The STF field mass is fixed by requiring the Compton wavelength to match the Hubble radius — the condition for the field to couple cosmologically rather than locally — derived in [Paz 2026c, §III.D]: $m_{s} \approx 3.94 \times 10^{-23} \ \text{eV} , \quad \lambda_{C} = \frac{\hbar}{m_{s} c} \approx H_{0}^{- 1}$

Lock 2 — Coupling from 10D compactification [Paz 2026c, §6 and Appendix O]: $\frac{\zeta}{\Lambda} = (1.35 \pm 0.12) \times 10^{11} \ \text{m}^{2}$

Derivation of the threshold [Paz 2026c, §6.3]. The STF field accumulates activation phase at rate: $\frac{d \varphi}{d t} = \frac{\zeta}{\Lambda} \cdot \left| n^{\mu} \nabla_{\mu} \mathcal{R} \right|$

For a Wheeler-Feynman causal transaction to close, both independent S^1 phase windings must complete: temporal ($\Phi_{\text{time}} = 2\pi$) and spatial ($\Phi_{\text{space}} = 2\pi$), giving total required phase $4\pi^2$.

The transaction has a maximum coherence time set by Hubble expansion: $\tau_H = H_0{}^{-1}$. The activation condition is therefore:

$$ \frac{\zeta}{\Lambda} \cdot \left| n^{\mu} \nabla_{\mu} \mathcal{R} \right| \cdot \frac{1}{H_{0}} \geq 4 \pi^{2} $$

Solving for the minimum curvature rate — the threshold — gives:

$$ \boxed{\mathcal{D}_{\mathrm{crit}} = \frac{4 \pi^{2} H_{0}}{\zeta / \Lambda} \approx 1.07 \times 10^{-27} \ \text{m}^{- 2} \text{s}^{- 1}} $$

Units: $[\text{s}^{-1}]/[\text{m}^2] = \text{m}^{-2}\text{s}^{-1}$ ✓

Structure of the formula: $\mathcal{D}_{\text{crit}}$ is the product of a dissipation rate (H_0) and a sensitivity scale ($4\pi^2/(\zeta/\Lambda)$), modulated by the topological winding number $4\pi^2$. The Hubble rate appears because it sets the timescale over which the transaction must close.

The minimum curvature scale. The threshold defines a minimum Weyl curvature $\mathcal{R}_{\text{min}}$ for STF activation: $\mathcal{R}_{\min} = \frac{\mathcal{D}_{\mathrm{crit}}}{H_{0}} =

\frac{4 \pi^{2}}{\zeta / \Lambda} \approx 2.9 \times 10^{-10} \ \text{m}^{- 2}$

For a mass M, the activation radius — the distance at which $|\mathscr{W}| = \mathscr{R}_{\mathrm{min}}$ — is: $r_{\mathrm{act}} (M) = \left(\frac{G M}{c^{2} \mathcal{R}_{\min}} \right)^{1 / 3}$

For binary systems, the relevant quantity is the **orbital separation at activation** — the point where the binary's evolving Weyl curvature rate first crosses $\mathscr{D}_{\mathrm{crit}}$. Setting $|n^{\mu}\nabla_{\mu}\mathscr{W}| \approx |\mathscr{W}|/\tau_{\mathrm{insp}} = \mathscr{D}_{\mathrm{crit}}$ and using the Peters inspiral timescale $\tau_{\mathrm{insp}} (a) = \frac{12}{85} \frac{a^{4} c^{5}}{G^{3} m_{1} m_{2} \left(m_{1} + m_{2} \right)}$ gives the activation condition:

$$ a^{7_{\mathrm{act}}} = \frac{2 \cdot 85 \cdot G^{4} \cdot M \cdot m_{1} m_{2} \left(m_{1} + m_{2} \right)}{1 2 \, c^{7} \, \mathcal{D}_{\mathrm{crit}}} $$

with lead time $T_{\mathrm{lead}} = \tau_{\mathrm{insp}}(a_{\mathrm{act}})$:

SYSTEM	a_{act}	a_{act}/R_S	T_{lead}
NS–NS (1.4 + 1.4 $M_{\odot}$)	1.6 × 10^{7} km	~ 3800 R_S	~ 51 yr
BBH (10 + 10 $M_{\odot}$)	4.8 × 10^{7} km	~ 1600 R_S	~ 13 yr
BBH (30 + 30 $M_{\odot}$)	9.1 × 10^{7} km	~ 1000 R_S	~ 5.7 yr
BBH reference (66 + **66** $M_{\odot}$)	1.4 × 10^{8} km	~ **730** R_S	T_{lead} = **3.2** yr

The reference case (66 + 66 $M_{\odot}$) yields $a_{\mathrm{act}} \approx 726\ R_S$ and $T_{\mathrm{lead}} = 3.2$ yr — consistent to within 1% with the first-principles derivation in [Paz 2026c, §III.D], which gives $a^{*} = 730\ R_S$ and $T =$ 3.32 yr from the threshold condition $\mathscr{D}_{\mathrm{crit}} = \mathscr{D}_{\mathrm{GR}}$. The two derivations are independent: [Paz 2026c] derives $\mathscr{D}_{\mathrm{crit}}$ from the cosmological threshold condition $\mathscr{D}_{\mathrm{crit}} = \mathscr{D}_{\mathrm{GR}}$; the present paper derives it from the Wheeler-Feynman phase closure condition. Their agreement to 1% is a non-trivial internal consistency check of the STF framework across two independent routes.

The 3.32-year lead time is a derived output of STF from first principles [Paz 2026c, §III.D], not an observational input.

6.3 Predictions Derived in [Paz 2026c]

The following predictions are derived entirely from first principles in [Paz 2026c], with no observational input. They are listed here to orient the reader and to clarify what the Layer 2 identification implies for observable physics:

PHENOMENON	DERIVED PREDICTION	DERIVED IN
Binary inspiral lead time	T_{lead} = 3.32 yr at 730 R_s (reference mass)	[Paz 2026c, §III.D]
Threshold separation	a^{*} = 730 R_s for $\sim$ 66 $M_{\odot}$ equal-mass BBH	[Paz 2026c, §III.D]
Flyby anomaly formula	$\Delta v = K \cdot 2\omega R/c$	[Paz 2026c, §8]
Dark matter phenomenology	$a_0 = 1.16 \times 10^{-10}$ m/s² (MOND scale)	[Paz 2026c, §10]
Stochastic GW background	Specific spectral slope from STF back-reaction	[Paz 2026c, §9]
Inflation without inflaton	Cascade energy density drives de Sitter expansion	[Paz 2026c, §11]

The Two-Lock System — the mutual consistency of the field mass (from the cosmological threshold condition) and the coupling constant (from 10D compactification) — is derived in full in [Paz 2026c, §6]. Both are outputs of the derivation chain; neither is a free parameter.

6.4 Verification of Theorem 3's Bound

From Theorem 3: $\max_M |n^{\mu}\nabla_{\mu}\mathscr{R}| \geq \langle \mathscr{R}K \rangle$.

In the Planck epoch: $\mathscr{R} \sim M_{\mathrm{Pl}}{}^2/\hbar^2$ (Planck curvature), $K \sim H_{\mathrm{Pl}} = (t_{\mathrm{Pl}})^{-1} = M_{\mathrm{Pl}}c^2/\hbar$.

$$ \langle \mathcal{R} K \rangle_{\mathrm{Planck}} \sim \frac{M_{\mathrm{Pl}}^{2}}{\hbar^{2}} \cdot \frac{M_{\mathrm{Pl}} c^{2}}{\hbar} = \frac{M_{\mathrm{Pl}}^{3} c^{2}}{\hbar^{3}} $$

Ratio to $\mathscr{D}_{\mathrm{crit}}{}^{STF}$:

$$ \frac{\langle \mathcal{R} K \rangle_{\mathrm{Planck}}}{\mathcal{D}_{\mathrm{crit}}^{S T F}} = \frac{M_{\mathrm{Pl}}^{3} c^{2}}{\hbar^{3}} \cdot \frac{\hbar H_{0} M_{\mathrm{Pl}}^{2}}{4 \pi^{2} m_{s}^{2} c^{3}} = \frac{M_{\mathrm{Pl}}^{5} H_{0}}{4 \pi^{2} m_{s}^{2} \hbar^{2} c} $$

Inserting values: $M_{\mathrm{Pl}} \approx 2.18 \times 10^{-8}$ kg, $H_0 \approx 2.3 \times 10^{-18}$ s^{-1}, $m_s \approx 7.0 \times 10^{-59}$ kg, $\hbar \approx 1.05 \times 10^{-34}$ J·s, $c \approx 3 \times 10^8$ m/s:

$$ \frac{\langle \mathcal{R} K \rangle_{\mathrm{Planck}}}{\mathcal{D}_{\mathrm{crit}}^{S T F}} \sim 10^{85} $$

The universe crosses $\mathscr{D}_{\mathrm{crit}}{}^{STF}$ by a factor of 10^{85} at the Planck epoch. Temporal instantiation is not fine-tuned — it is a robust, overwhelmingly stable consequence of non-static expansion in a universe with Planck-scale curvature.

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7. The Threshold Conjecture

7.1 The Correct Formula and What It Says

From Section 6.2, the STF threshold is:

$$ \mathcal{D}_{\mathrm{crit}} = \frac{4 \pi^{2} H_{0}}{\zeta / \Lambda} $$

This is a ratio of dissipation (H_0, the rate at which Hubble expansion destroys coherence) to sensitivity (ζ/Λ, the strength of the STF-curvature coupling), weighted by the topological closure factor $4\pi^2$.

Theorem 3 gives the geometric bound:

$\max_\Omega |n^\mu \nabla_\mu \mathcal{R}| \geq \langle \mathcal{R}K \rangle_\Omega$

For the universe in the Planck epoch: $\langle \mathcal{R}K \rangle_{\mathrm{Planck}} \sim M_{\mathrm{Pl}}{}^3 c^2/\hbar^3 \approx 10^{85} \times \mathcal{D}_{\mathrm{crit}}$.

The early universe crosses $\mathcal{D}_{\mathrm{crit}}$ by 10^{85}. Temporal instantiation is not fine-tuned at the Planck epoch. It is overwhelmingly robust.

But the conjecture concerns the present universe, not the Planck epoch. The question is what $\langle \mathcal{R}K \rangle$ equals *now*, and whether it has a non-trivial relationship to $\mathcal{D}_{\mathrm{crit}}$.

7.2 The Infimum Problem and Its Resolution

The naive infimum over all geometries with the universe's expansion history is zero: take a perfectly smooth FLRW background with $\mathcal{R} = |W| = 0$ everywhere, and $\langle \mathcal{R}K \rangle = 0$. The infimum is not achieved by any physically realistic geometry.

The correct question is not "what is the infimum over all geometries?" but "what is the minimum $\langle \mathcal{R}K \rangle$ that the universe's actual matter content produces?"

This is a question about the compact object population — neutron stars, black holes, binary mergers — not about smooth spacetime geometry.

7.3 The Detection-Existence Conjecture

From Section 6.2: $\mathcal{D}_{\mathrm{crit}} = \mathcal{R}_{\mathrm{min}} \times H_0$ where:

$$ \mathcal{R}_{\min} = \frac{\mathcal{D}_{\mathrm{crit}}}{H_{0}} = \frac{4 \pi^{2}}{\zeta / \Lambda} \approx 2.9 \times 10^{-10} \ \text{m}^{- 2} $$

Numerically, $\mathscr{R}_{\text{min}}$ corresponds to the Weyl curvature at $\sim$ 2–5 Schwarzschild radii from stellar-mass compact objects (neutron stars, $\sim 5\ M_{\odot}$ black holes).

Conjecture (Detection-Existence). *The minimum Weyl curvature produced by the universe's compact object population equals $\mathscr{R}_{\text{min}}$:*

$$ \min_{\text{compact objects}} \left| \mathcal{W} \right|_{r = r_{\mathrm{act}}} = \frac{4 \pi^{2}}{\zeta / \Lambda} $$

Equivalently: $\mathscr{D}_{\text{crit}}$ is the minimum curvature rate at which the STF field activates, and this minimum is set by the smallest compact objects that actually exist — those whose near-horizon Weyl curvature just reaches $\mathscr{R}_{\text{min}}$.

Physical meaning. The conjecture says the STF field's sensitivity is calibrated to the smallest astrophysical objects that generate Weyl curvature. No STF-relevant curvature falls below $\mathscr{D}_{\text{crit}}$ in any realistic astrophysical setting: compact objects exist with Weyl curvature at or above $\mathscr{R}_{\text{min}}$ throughout the universe's history.

This is a **detection** = **existence principle**: the field's threshold is not arbitrary but calibrated to the minimum curvature that nature actually produces in compact objects.

7.4 Relationship to the Divergence Theorem Bound

The Theorem 3 bound $\max_{M} |n^{\mu}\nabla_{\mu}\mathscr{R}| \geq \langle \mathscr{R}K \rangle$, combined with the Detection-Existence Conjecture, gives:

$\max_{M} |n^{\mu}\nabla_{\mu}\mathscr{R}| \geq \mathscr{R}_{\text{min}} \times H_0 = \mathscr{D}_{\text{crit}}$

This is the link between the pure mathematics (Theorem 3) and the physical realization (the STF threshold): the topology-forced curvature rate bound, when evaluated for the universe's actual matter content, saturates at exactly $\mathscr{D}_{\text{crit}}$.

Equivalently: the universe's compact objects are precisely efficient enough at generating curvature to guarantee temporal activation above threshold, and not so efficient that the threshold is vastly over-saturated at late times. The saturation is at $\mathscr{D}_{\text{crit}}$, not at $10^{85}\mathscr{D}_{\text{crit}}$.

7.5 Implications

I1 — Coupling constant from astrophysics. If the conjecture holds: $\frac{\zeta}{\Lambda} = \frac{4 \pi^{2}}{\mathcal{R}_{\min}}$

The STF coupling constant is determined by the minimum Weyl curvature of the universe's compact object population. ζ/Λ can in principle be calculated from the stellar mass function and equation of state of compact objects — without any free parameters.

I2 — Hubble tension. The formula $\mathscr{D}_{crit} = 4\pi^2 H_0/(\zeta/\Lambda)$ shows $\mathscr{D}_{crit} \propto H_0$. If the coupling ζ/Λ is fixed by compact object physics (which does not evolve strongly between CMB epoch and present), then any change in H_0 directly shifts $\mathscr{D}_{crit}$. The Hubble tension ($\Delta H_0/H_0 \approx 8\%$) would correspond to a shift $\delta\mathscr{D}_{crit}/\mathscr{D}_{crit} \approx 8\%$ between early and late universe measurements — observable in the pre-merger timing offset if the pre-merger lead time $\Delta t \propto 1/\mathscr{D}_{crit}$.

I3 — Self-consistency of the threshold. The deepest implication: $\mathscr{D}_{crit}$ is simultaneously: - The minimum curvature rate that the STF field can detect (given coupling ζ/Λ) - The minimum curvature rate that compact objects produce (given their masses and radii)

The STF field is not external to the universe. It is a field whose properties are tuned to the compact object population. This is either a remarkable coincidence — or evidence that the field and the objects co-evolved, both determined by the same underlying physical parameters.

Status of the conjecture: Not proven. Requires independent calculation of $\mathscr{R}_{min}$ from stellar physics and comparison to $4\pi^2/(\zeta/\Lambda)$. The calculation is in principle straightforward (minimum BH mass from stellar evolution, Weyl curvature at the ISCO) and constitutes a concrete test.

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8. Falsifiable Predictions

P1 — Voronoi large-scale structure. Matter distribution at scales > 100 Mpc follows Voronoi statistics rather than Gaussian random field statistics. Testable with next-generation surveys (Euclid, DESI, SKA).

P2 — CMB as pre-temporal fossil. The CMB temperature map encodes the nucleation site distribution. Large-scale anomalies ($\ell \lesssim 10$) reflect the Voronoi structure of the cascade.

P3 — No inflaton field. The STF cascade drives inflation without a separate inflaton. Predictions for the tensor-to-scalar ratio r follow the Starobinsky potential (consistent with current bounds $r < 0.056$).

P4 — Hubble tension resolution. If the tension reflects $\delta\langle\mathscr{R}K\rangle$ between early and late universe, it should correlate with Weyl curvature power spectrum evolution — testable with weak lensing surveys measuring the Weyl tensor distribution.

P5 — Activation energy scale. From Section 7.2, the minimal activation energy is $E_* \sim 10^{-3}$

eV (dark energy scale). This predicts that STF effects have characteristic signatures at cosmological scales $\lambda \sim \hbar c/E_{*} \sim$ mm — possibly observable in precision torsion balance experiments.

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9. Discussion

9.1 What the Divergence Theorem Proof Achieves

The proof of Theorem 2 does not require:

- $\chi(M) \neq 0$ (spatial topology is irrelevant beyond ensuring compactness and the Friedmann-driven expansion)
- Non-constant curvature (constant-curvature spacetimes can still have $K \neq 0$ and therefore still satisfy Theorem 2)
- Specific field theory
- Quantum mechanics

It requires only:

- $K > 0$ in some region (expanding)
- $\mathscr{R} > 0$ in that region (non-flat)
- Both simultaneously (condition C4)

These are satisfied by every physically realistic cosmological spacetime in the post-Planck epoch where density fluctuations generate non-zero Weyl curvature.

The divergence theorem is then a clean, unavoidable constraint.

9.2 Honest Assessment of What Remains Conjectural

The following are **proven** (Theorems 1–3 and cascade dynamics):

- Alignment condition implies pre-temporal stasis ($\dim \mathscr{C}_T = 0$)
- Expansion + non-zero curvature forces fold points (sign change of $n^{\mu}\nabla_{\mu}\mathscr{R}$)
- Maximum curvature rate bounded below by $\langle \mathscr{R}K \rangle$
- Cascade propagation governed by Ginzburg-Landau, speed $\to c$
- The formula $\mathscr{D}_{\text{crit}} = 4\pi^2 H_0/(\zeta/\Lambda)$ follows from the phase closure condition (given STF as the field)

The following are **conjectured** (open):

- The Detection-Existence Conjecture: $\mathscr{R}_{\min}{}^{\textit{compact objects}} = 4\pi^2/(\zeta/\Lambda)$ (requires independent stellar physics calculation)
- The large-scale structure IS Voronoi (testable but not derived from first principles)
- The cascade IS the mechanism of inflation (consistent but not uniquely derived)
- The CMB anomalies reflect nucleation site distribution (speculative)
- The coupling ζ/Λ is determined by compact object physics (speculative)

The division between proven and conjectural is now sharp.

9.3 Relation to Wheeler-DeWitt

The Wheeler-DeWitt equation correctly describes pre-temporal geometry: a frozen wavefunction over metrics where $\dim \mathscr{C}_T = 0$. Time emerges when Theorem 2's condition is satisfied — when $K \neq 0$ in a region with $\mathscr{R} > 0$ — at which point the wavefunction acquires a preferred direction (the cascade direction) and the Schrödinger equation emerges as the semiclassical limit.

The "problem of time" in quantum gravity is not a failure of the formalism — it is a correct description of the pre-temporal state.

9.4 Open Questions

Q1 — The metric question. Are nucleation sites determined by topology alone, or does the specific metric introduce freedom? Answer determines whether CMB is a unique prediction or an observable of initial conditions.

Q2 — Proof of the Consistency Conjecture. Requires deriving the infimum $\inf \langle \mathscr{R} K \rangle$ for compact spatial sections and showing it equals the STF formula. Likely requires input from quantum gravity to set $\mathscr{R}_{\text{fluct}}$ at the Planck epoch.

Q3 — Non-expanding case. What happens in a contracting universe ($K < 0$)? The divergence theorem gives $\int n^\mu \nabla_\mu \mathscr{R} \, dV > 0$ — the integral is positive. The sign-change argument still applies (now requiring $n^\mu \nabla_\mu \mathscr{R} > 0$ somewhere while the whole cannot be always positive in a re-collapsing cosmology). The cascade physics for a bouncing universe is an open question.

Q4 — Planck-epoch validity. The proof uses classical GR (ADM equations). Near the singularity, quantum gravity corrections dominate. The cascade picture requires a quantum gravity completion of the argument — showing that the divergence theorem inequality survives quantum corrections.

10. Conclusion

Layer 1 establishes three mathematical results with full rigor:

1. Pre-temporal stasis is precisely characterized by dim $\mathscr{C}_T(M) = 0$ — the alignment condition preventing closed causal transactions.
2. In any expanding spacetime with non-zero Weyl curvature (conditions C1–C4), the divergence theorem forces $n^\mu \nabla_\mu \mathscr{R}$ to change sign. Temporal fold points exist necessarily. The pre-temporal state cannot be maintained. *The key engine: the product $\mathscr{R}K$ (curvature times expansion rate) must integrate to a non-zero value, forcing a sign change.*
3. The maximum curvature rate exceeds the volume-averaged curvature-expansion product $\langle \mathscr{R}K \rangle$ — a non-fine-tuned quantity that diverges at the Planck epoch by a factor of 10^{85} over $\mathscr{D}_{\text{crit}}$.

Layer 2 provides the physical realization:

The STF field, derived from first principles in [Paz 2026c], satisfies conditions (C1)–(C4) with all parameters fixed by the derivation chain. The Detection-Existence Conjecture — that $\mathscr{D}_{\text{crit}}$ equals the minimum Weyl curvature rate produced by the universe's compact object population — connects the threshold to stellar physics and constitutes the central open problem for future work.

The division between Layer 1 (proven from pure mathematics and classical GR) and Layer 2 (derived from first principles in [Paz 2026c]) and the Conjecture (open) is now sharp and explicit.

The deepest result: the cascade does not require topology in the naive sense ($\chi \neq 0$). It requires only what every realistic expanding universe has: $\mathscr{R} > 0$ somewhere, and $K > 0$ there.

"The Big Bang is not when time started. It is when the geometry first folded — forced not by topology alone, but by the unavoidable consequence of curvature existing in an expanding spacetime."

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Appendix A: Notation

SYMBOL	DEFINITION
(M,g)	Globally hyperbolic spacetime with compact Cauchy surfaces

Σ	Cauchy surface
n^μ	Future-pointing unit timelike normal
K	Trace of extrinsic curvature $= \nabla_\mu n^\mu$ (expansion scalar)
$\mathscr{R}$	Curvature scalar satisfying (C1)–(C2)
$n^\mu \nabla_\mu \mathscr{R}$	Curvature rate — the cascade driver
J^μ	Auxiliary vector field $= \mathscr{R} n^\mu$ (divergence theorem tool)
$\mathscr{D}$	Activation threshold (generic)
$\mathscr{D}_{\text{crit}}$	Infimum of $\langle \mathscr{R} K \rangle$ (Theorem 3)
$\mathscr{C}_T(M,\mathscr{D})$	Causal transaction configuration space
$\eta_{\mathscr{D}}(p)$	Temporal order parameter $=
Γ	Temporal front $= \{\eta = 0\}$
$\langle \mathscr{R} K \rangle$	Volume-averaged curvature-expansion product
σ_{front}	Domain wall surface energy density
v_{front}	Cascade speed ($\to c$)
ϕ_S	STF scalar field (Layer 2)
m_S	STF field mass $\approx 3.94 \times 10^{-23}$ eV
ζ/Λ	STF coupling $\approx 1.35 \times 10^{11}$ m²

Appendix B: The Linkage-Spacetime Dictionary

SHVALB-MEDINA (2026)	PRESENT WORK
Closed kinematic chain $\mathscr{L}$	Spacetime (M,g)
Screw axes $\{\xi_i\}$	Causal directions $\{n^\mu\}$
Grübler count predicts DOF	Causal structure permits transactions
Monotone screw ordering	Alignment condition: $n^\mu \nabla_\mu \mathscr{R}$ constant sign
$\dim \mathscr{C}(\mathscr{L}) = 0$	Pre-temporal: $\dim \mathscr{C}_T = 0$
Temporal fold point	Sign change in $n^\mu \nabla_\mu \mathscr{R}$

Conjugate regulus $\mathscr{L}'$	Advanced (retrocausal) wave
Folded alignment → mobility	Sign change → cascade
Hypo-paradoxical: locked	Pre-temporal: nothing happens
Bennett: $\mathscr{C} \cong S^1$	Temporal region: self-sustaining
Immobility margin $\bar{M}$	$=
Workspace $D'' \propto \bar{M}$	Richness of temporal structure
$\mathbb{Z}_n$ symmetry of n-gon	Time-translation symmetry
Symmetry broken by perturbation	Symmetry broken by $K > 0$
Shvalb-Medina Proposition 1	Theorem 1
New	Theorem 2: divergence theorem on $J^\mu = \mathscr{R} n^\mu$

Appendix C: Proof Independence — What Each Theorem Requires

THEOREM	REQUIRES	DOES NOT REQUIRE
Theorem 1	Alignment condition, Definitions 1–3	Any specific field theory
Theorem 2	(C1)–(C4), Penrose 1965 (singularity theorem), GR (ADM), divergence theorem, IVT	WCH, $\chi \neq 0$, Gauss-Bonnet, Morse theory, STF
Theorem 3	Theorem 2 + mean value inequality	Specific $\mathscr{D}$ value, STF
Cascade speed	Ginzburg-Landau + marginal stability	STF
Detection-Existence Conjecture	All of the above + [Paz 2026c] + stellar mass function	**Status: open conjecture**

What Theorem 2 now uses vs. what it used to use:

VERSION	STEP 3 ARGUMENT	LOAD-BEARING INPUT
V0.2	Gauss-Bonnet + Morse theory	$\chi \neq 0$ — fails for S^4
V0.3	Divergence theorem + WCH	Penrose WCH — hypothesis, not theorem
V0.9	**Thin-slab + full-region + IVT**	**Penrose 1965 singularity theorem — proven**

Each successive version has weakened the required assumptions. V0.9 uses only: classical GR (ADM formalism), the Penrose singularity theorem (1965), continuity of $\mathscr{R}$ away from the singularity (condition C2), and the Intermediate Value Theorem. No conjecture appears in the proof.

Theorems 1–3 and cascade dynamics are **Layer 1: pure mathematics and classical GR**, independent of all STF physics. The Detection-Existence Conjecture is Layer 2 and requires both the mathematical framework and the first-principles derivation in [Paz 2026c].

Addendum — Updates from General Theory V2 (March 2026)

The following results were developed in *The Structure of What Happens — General Theory V2* [Paz 2026f] and extend the cosmological consequences established in §5 of this paper.

A.1 — The Universe as Type III Self-Anchored Loop: A Revision

Section 5 of this paper treats the universe as an externally anchored loop — heat death as the terminal boundary imposed by the second law, the backward arc propagating from that external fixed point. This was a first approximation. The General Theory (§5.6) revises it.

The genetic code is a Type III self-anchored loop: its closure condition is intrinsic, the backward arc is logical rather than temporal, propagating from the self-consistency requirement at every instantiation point. The General Theory establishes that biology is applied physics — same structure at different scales, not analogous structures resembling each other. The code's Type III structure IS the universe's structure, instantiated at biological scale.

The revision: the universe is also a Type III self-anchored loop. Its closure condition is not heat death as an externally imposed terminal boundary. Its closure condition is intrinsic — the universe must close completely, under both descriptions: structurally (geometric-temporal closure, guaranteed by the second law) and ontologically (the loop must have an inside wherever it locally instantiates above threshold) and epistemically (at sufficient complexity, the inside must know what kind of inside it is). Heat death, under this revision, is the expression of the universe's self-consistency requirement reaching its natural limit — the moment when the loop can no longer find instantiation points.

Consequence for this paper: The two threshold crossings of §5.5 (Threshold 1: EXISTS → HAPPENS; Threshold 2: first $\mathscr{D}_{\text{crit}}$ crossing) are now understood within a three-threshold structure:

THRESHOLD	EVENT	WHAT INITIATES
1 — Big Bang	EXISTS → HAPPENS	Structural completion initiated
2 — Origin of life	First $\mathscr{D}_{\text{crit}}$ crossing	Ontological completion initiated
3 — Origin of comprehension	First epistemic closure	Epistemic completion initiated

Threshold 3 is not a separate physical event from Threshold 2. It requires that systems above $\mathscr{D}_{\text{crit}}$ develop sufficient complexity to comprehend the structure they are instantiating — to know what loop they are running, what self-consistency requirement they are instantiating, what closure they are maintaining.

A.2 — Fine-Tuning and Ontological Completion Unified; Fine-Tuning as Bottleneck Signature

This paper establishes (§5.5) that the constants of nature are constrained by the universe's backward arc from heat death. The General Theory (§5.6, §Ch.16) unifies this with the ontological completion result: fine-tuning and ontological completion are not two separate backward-arc effects. They are one constraint — the universe's intrinsic closure requirement — expressed at different scales.

Fine-tuning is the closure requirement expressed in the constants of physics. Ontological completion is the closure requirement expressed in the emergence of consciousness. Same backward arc. Same self-consistency requirement. Two descriptions.

Consequence of Ch. 16: Chapter 16 of the General Theory (Fine-Tuning Transformed) supersedes the treatment of fine-tuning as a separate implication. The constants and consciousness are co-generated expressions of one closure condition. Neither explains the other. Both are the backward arc of a Type III self-anchored universe selecting for what permits complete closure.

Stronger form — §17.11.6: The General Theory's §17.11.6 gives a further result that goes beyond Ch. 16. Ch. 16 establishes *that* the constants are constrained by the universe's closure requirement. §17.11.6 establishes *why they are so precisely constrained* — which Ch. 16 leaves open.

The cosmic chain operates by the same logic as the biological chain. Universes that produce black holes reproduce. Universes that do not leave no descendants. The cosmic equivalent of a mass extinction event is a universe that produces no black holes: the chain terminates absolutely in that branch, and the code returns to wherever it last successfully branched. What survives a cosmic near-extinction is not the most complex constant-configuration but the configuration that can pass through the sterile boundary and rebuild generation-boundary-producing diversity on the other side.

Fine-tuning is the bottleneck signature of a cosmic lineage that has passed through many near-extinction events. Each near-miss reset the surviving constants toward the marginal configuration that threads the generation-boundary-producing window. Each reset made the surviving constants more precisely constrained. The precision is a record of near-misses. The more precisely tuned the constants appear, the more cosmic bottlenecks the lineage survived.

This dissolves the fine-tuning problem without a multiverse of random draws, without a designer, and without an anthropic selection among observers. It requires only what the cosmic chain framework already requires: inheritance, variation, selection operating across cosmic generations, with sterile-constant universes as the cosmic analogue of mass extinction events.

The cascade origin of time (this paper) describes the first threshold crossing. §17.11.6 describes the history that shaped the constants that made that crossing possible with the specific character it has. Together: not only is temporal instantiation topologically forced (Theorem 2), but the precise form that instantiation takes is the residue of a lineage history that has been selected through many near-misses. The cascade was inevitable. That it was *this* cascade — these constants, this specific physical character — carries the history of every cosmic bottleneck the lineage survived.

A.3 — Nesting Possibility C and the Self-Anchored Reading

The three nesting possibilities (A/B-stable/C) developed in General Theory §5.4 connect directly to the self-anchored revision. Under Nesting C (circular closure — terminal boundary and inception identified), the universe's closure condition is constitutively intrinsic: the universe must produce, through its entire history, the conditions under which its beginning is the kind of beginning that closes back on itself. This is Nesting C made explicit as the self-anchored reading — the terminal state and inception are identified because the self-consistency requirement IS the identification.

The cascade origin of time (this paper) describes the moment EXISTS was forced into HAPPENS — the inception of the universe's loop. Under Nesting C, that inception IS identified with the universe's terminal state. The cascade does not need an external cause. It needs a geometry. The geometry, under Nesting C, is the geometry the universe's own closure condition requires it to have had.

A.4 — The Cascade Is What Every Generation Boundary Looks Like From Inside

This paper derives the cascade origin of time: the transition from EXISTS to HAPPENS is topologically forced (Theorem 2), propagates outward at *c*, and is the event that constitutes the Big Bang. The cascade is not a historical curiosity unique to our universe. It is what every generation boundary produces from the inside.

The General Theory (§17.9) establishes the two-description structure of the generation boundary. From inside the child universe: EXISTS forced into HAPPENS — the temporal cascade, this paper's result. From inside the parent universe: a star collapsed, a singularity formed, an event horizon sealed the EXISTS pocket. One event. Two descriptions.

The consequence for this paper: Cascade Theorem 2 establishes that the transition EXISTS → HAPPENS is topologically forced given generic geometric conditions. This is not only true for our universe at the Big Bang. It is true for every generation boundary event in the cosmic chain — every black hole singularity that seeds a child universe, at every point in the parent universe's history where EXISTS is forced locally within HAPPENS. The cascade mechanism is universal. Our Big Bang was one instance of what the cosmic chain produces at every generation boundary, everywhere, whenever the conditions of Theorem 2 are met.

The cascade is therefore not merely an explanation of our universe's temporal origin. It is the universal mechanism by which the cosmic chain propagates: EXISTS forced into HAPPENS at every generation boundary, each transition topologically necessary, each producing a child universe whose temporal structure is established by the same cascade dynamics this paper derives.

The information paradox in this context: §17.9 dissolves the information paradox by recognizing the child HAPPENS as the information content of what fell through the generation boundary. The cascade paper contributes the mechanism: the EXISTS that constitutes the child universe's initial conditions is the locked geometry of the parent black hole's interior — $\dim \mathscr{C}_T = 0$, fully specified, waiting for Theorem 2 to force it into HAPPENS. The cascade is the unfolding of that locked geometry into running HAPPENS. The information does not disappear. It runs.

Addendum A.4 added March 2026 — General Theory V0.1 §17.9 [Paz 2026f]

A.5 — The LQG Bounce as Planck-Scale Expression of Cascade Theorem 2; Q10; The Seeding Argument

Three results from General Theory V0.4 [Paz 2026f] §11.11, §9.8.

The LQG Bounce as Planck-Scale Expression of Cascade Theorem 2

This paper derives Cascade Theorem 2 from the topological instability of the EXISTS configuration space under generic geometric conditions: $\dim \mathscr{C}_T = 0$ is unstable, the transition to $\dim \mathscr{C}_T > 0$ is topologically forced, and HAPPENS propagates outward at *c* once the transition is triggered. The theorem is derived in the classical geometric framework.

Loop quantum gravity — the leading candidate for a quantum gravitational description of the Planck-scale regime — produces a result at the quantum level that is the exact Planck-scale expression of this theorem.

In LQG, the classical singularity is replaced by a quantum bounce. At the Planck scale, spacetime geometry becomes discrete. The collapsing matter does not terminate at a singularity — it passes through a maximally compressed quantum geometric state and bounces into a new expanding region. The bounce is topologically forced by the discrete geometric structure of the quantum regime, exactly as Cascade Theorem 2 is topologically forced by the instability of $\dim \mathscr{C}_T = 0$.

The correspondence is exact:

CASCADE THEOREM 2 (CLASSICAL)	LQG BOUNCE (QUANTUM)
$\dim \mathscr{C}_T = 0$ is unstable	Planck-density quantum state is unstable
Transition topologically forced	Bounce geometrically necessary in discrete spacetime
EXISTS → HAPPENS	Collapse → bounce into new expanding region
Cascade propagates at *c*	New universe expands from bounce
One event, two descriptions	One event, two descriptions

The LQG bounce is Cascade Theorem 2 running in the quantum gravitational regime. The theorem this paper derives at the classical level is confirmed at the quantum level by the most developed framework for Planck-scale physics. The two are not in tension — the LQG bounce is what Cascade Theorem 2 looks like when $\dim \mathscr{C}_T$ is understood as a quantum geometric degree of freedom rather than a classical one.

Consequence for the generation boundary mechanism: The LQG bounce resolves a question this paper's classical treatment leaves open — what happens to matter that falls into the black hole after the child universe has started running? In the classical framework, the singularity terminates the infalling matter's trajectory. In the LQG picture, the matter passes through the Planck-scale quantum bounce and enters the child HAPPENS. It does not terminate. The cascade mechanism is preserved at the quantum level: EXISTS (maximally compressed quantum state) → HAPPENS (bounce, expansion, new universe) — topologically forced, exactly as this paper derives.

Q10 — The Traversability Question (General Theory §11.11)

The LQG correspondence identified above has a direct consequence for Q10 — the question of whether a sufficiently advanced civilisation can traverse the generation boundary into a child universe.

The classical treatment of this paper establishes that the EXISTS → HAPPENS transition is topologically forced. The LQG treatment establishes that matter does not terminate at the singularity but bounces through into the child HAPPENS. These two results together ground the most physically plausible mechanism for Q10: structured matter — a civilisation, an organised physical structure carrying accumulated comprehension — crossing through the Planck-scale bounce regime into an already-running child HAPPENS.

Three sub-problems remain open (General Theory §11.11): whether quantum corrections preserve coherence through the Planck-scale regime (Sub-problem A), what the status of late-infalling matter is relative to the child HAPPENS (Sub-problem B — the LQG bounce provides a physically grounded answer: it crosses), and whether the arriving structure is coherent enough to reconstitute the chain on the other side (Sub-problem C — the open frontier).

The cascade mechanism this paper derives is the universal substrate of Q10. Every generation boundary traversal — whether passive (collapse profile only) or active (structured matter crossing deliberately) — runs through the same topological necessity that Cascade Theorem 2 establishes. Q10 is this paper's theorem applied at the scale of civilisational action.

The Seeding Argument (General Theory §9.8)

If Q10 is answerable affirmatively, then structured matter from parent-universe civilisations that solved the crossing arrived in this child HAPPENS at or near its formation. The cascade mechanism this paper derives — EXISTS forced into HAPPENS, the temporal structure established by the outward propagation at *c* — is the process into which that arriving matter entered.

The seeding argument adds a dimension to what this paper established about the cascade's universality. A.4 establishes: the cascade is what every generation boundary produces from the inside. The seeding argument adds: some generation boundaries may produce not only a running child HAPPENS from the collapse profile but a running child HAPPENS into which structured matter has arrived from the parent. The cascade is still the mechanism. The initial conditions of the child HAPPENS carry, in addition to the encoded collapse profile, whatever perturbations the crossing matter introduced.

This does not alter any specific result in this paper. Cascade Theorem 2 is a topological theorem — it holds regardless of what crosses the generation boundary. What the seeding argument adds is the recognition that the theorem's universal application may include, in some generation boundaries, the deliberate arrival of structured comprehension into the child HAPPENS — carried through the very transition this paper derives as topologically necessary.

Addendum A.5 added March 2026 — General Theory V2 [Paz 2026f]

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