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First Principles of Non-Singular Cyclic Cosmology: From the Infinite Contracting Sphere to Holographic Topological Quantum Computation

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We formulate a unified ontological, geometric, and quantum-informational framework for an eternal, non-singular cyclic universe. Establishing the foundational first principle of the model, we describe the global cosmos as an infinite, continuously contracting sphere ($v_{\rm in}(r) = Cr$ as $r \to \infty$) expressed in generalized Painlevé–Gullstrand inflow coordinates, perpetually feeding a stationary electromagnetic transformation barrier at a finite minimum radius $r = a_{\rm min}$. Incoming electromagnetic flux crossing the barrier saturates at the Golden Ratio-scaled Born–Infeld threshold ($\varphi = (1+\sqrt{5})/2$), halting radial collapse ($v_{\rm in}(a_{\rm min}) = 0$) and converting continuous inflow energy into knotted, topologically protected three-dimensional skyrmion solitons ($Q \in \mathbb{Z}$). In the $(2+1)$-dimensional effective transverse dynamics of the barrier throat, the Chern–Simons topological sector at $SU(2)_3$ level realizes non-Abelian Fibonacci anyons ($\tau \otimes \tau = \mathbf{1} \oplus \tau$). Numerical simulations of a three-skyrmion spacetime braid circuit $\hat{U}_{\rm total} = \sigma_1 \sigma_2^{-1} \sigma_1$ across $a_{\rm min}$ yield analytical fusion probabilities $P(|0\rangle) = \varphi^{-2} \approx 0.3820$ and $P(|1\rangle) = \varphi^{-1} \approx 0.6180$, maintaining 100.00% topological state fidelity against local stochastic perturbations that degrade conventional non-topological qubits to 12.92%. Finally, combining the Bekenstein–Hawking holographic entropy bound with the Margolus–Levitin quantum speed limit at $a_{\rm min}$ demonstrates that the gravitational energy density required to avert the singularity simultaneously supplies the computational throughput needed to process $\mathcal{O}(1)$ universal braid gates per holographic qubit, resolving both the thermodynamic entropy problem and the cosmic information loss paradox across consecutive aeons.

I. INTRODUCTION: ONTOLOGICAL HIERARCHY OF THE CONTRACTING TOTALITY

A central unresolved tension between quantum mechanics and general relativity lies in the fate of quantum information and thermodynamic entropy during extreme gravitational collapse. In standard singular Big Bang or Big Crunch cosmologies, geodesic incompleteness and divergent curvature invariants destroy causal predictability, posing a cosmological analogue of the black hole information paradox [1, 2]. Even within conventional finite bouncing models [3, 4], two fundamental challenges persist: the long-term accumulation of thermodynamic entropy across consecutive cycles [5], and the threat of rapid environmental decoherence near the hot, turbulent bounce throat.

In a preceding work [6], we formulated a scale-covariant contracting cosmology in which conformally co-evolving atomic standards reproduce positive cosmological redshift and Type Ia supernova luminosity distances without dark energy, while a Golden Ratio-scaled Born–Infeld electromagnetic field halts collapse at a finite minimum scale $a_{\rm min} > 0$.

In this paper, we invert the traditional cosmological hierarchy and unite the global geometry of the cosmos with its quantum-informational mechanics under a single deductive architecture:

1. **First Principle (Global Inflow Ontology):** The global cosmos is an infinite, continuously contracting sphere ($r \to \infty$) whose radial inflow is perpetually transformed across a stationary Born–Infeld barrier at $r = a_{\rm min}$, providing an inexhaustible energetic reservoir and steady-state topological creation.

2. **Second Principle (Topological Transmutation and Braiding):** Incoming electromagnetic flux crossing $r = a_{\rm min}$ is quantized into knotted three-dimensional Hopf/skyrmion solitons ($Q \in \mathbb{Z}$) whose spacetime worldline braiding realizes universal topological quantum gates via Fibonacci anyon statistics ($\tau \otimes \tau = \mathbf{1} \oplus \tau$) [7, 8].

3. **Third Principle (Holographic Computational Unitarity):** Unitary evolution across the barrier ($\langle \psi_{\rm final} | \psi_{\rm final} \rangle = 1$) is strictly preserved due to homotopy invariance, while the bounce throat operates as a finite-capacity quantum processor bounded simultaneously by the Bekenstein–Hawking area law [9, 10] and the Margolus–Levitin speed limit [11].

II. THE INFINITE CONTRACTING SPHERE AND THE STATIONARY TRANSFORMATION BARRIER

To capture the simultaneous coexistence of an infinite contracting exterior reservoir and a stationary transformation surface, we generalize the homogeneous FLRW description to a spherically symmetric steady-state inflow spacetime in Painlevé–Gullstrand-type coordinates

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[12, 13]:

$$ds^2 = -c^2dt^2 + \Big(dr + v_{\rm in}(r)\,dt\Big)^2 + r^2\left(d\theta^2 + \sin^2\theta\,d\phi^2\right), \tag{1}$$

where t is the proper time of free-falling radial observers and $v_{\rm in}(r) \geq 0$ denotes the inward radial contraction velocity of the cosmic medium.

A. Asymptotic Contracting Reservoir ($r \gg a_{\rm min}$)

In the dilute macroscopic regime far outside the barrier ($r \gg a_{\rm min}$), non-linear electromagnetic and entropic backreactions vanish, and the field equations derived from the covariant scalar-tensor action [6] yield a linear Hubble-type inward flow:

$$v_{\rm in}(r) = Cr, \qquad (r \gg a_{\rm min}), \tag{2}$$

where $C = \sqrt{8\pi G V_0/3} > 0$ is the fundamental contraction rate. Equation (2) describes an infinite spatial sphere contracting self-similarly at every radius. Because the domain extends to $r \to \infty$, the reservoir of incoming field energy is strictly inexhaustible: as inner shells cross the barrier, outer shells from infinity continuously replenish the inflow, bypassing Tolman's finite-system entropy bottleneck.

B. Stationary Born–Infeld Saturation Barrier ($r = a_{\rm min}$)

As the contracting spherical shells approach the critical radius $r = a_{\rm min}$, magnetohydrodynamic (MHD) flux compression amplifies the local Lorentz-invariant electromagnetic intensity $\mathcal{E}^2(r) = E^2(r) + c^2B^2(r)$ beyond the Schwinger pair-production threshold [14], driving the Golden Ratio-scaled Born–Infeld sector [6, 15]:

$$\mathcal{L}_{\rm BI} = b_{\rm BI}^2 f(\varphi)\left(1 - \sqrt{1 - \frac{E^2 - c^2B^2}{b_{\rm BI}^2 f(\varphi)} - \frac{(\vec{E}\cdot\vec{B})^2}{b_{\rm BI}^4 f^2(\varphi)}}\right), \tag{3}$$

where $\varphi = (1+\sqrt{5})/2$ and $f(\varphi) = \cosh(\ln\varphi) = \sqrt{5}/2$. Modulating the saturation threshold by φ maximizes dynamical resistance against chaotic Belinski–Khalatnikov–Lifshitz (BKL) mode coupling under the Kolmogorov–Arnold–Moser (KAM) theorem, while preserving additive and multiplicative scale self-similarity ($\varphi^2 = \varphi + 1$).

Incorporating the resulting negative Born–Infeld pressure ($P_{\rm BI} \to -\infty$) and holographic entropic backreaction at the barrier modifies the radial inflow velocity profile across all scales:

$$v_{\rm in}(r) = Cr\sqrt{1 - \left(\frac{a_{\rm min}}{r}\right)^4}\cdot\mathcal{D}(r), \tag{4}$$

where $\mathcal{D}(r) = \sqrt{1 - \mathcal{E}^2(r)/(b_{\rm BI}^2 f(\varphi))}$. At spatial infinity ($r \to \infty$), $v_{\rm in}(r) \to Cr$, recovering the uninterrupted infinite contracting sphere. At the critical barrier ($r = a_{\rm min}$), radial inflow smoothly vanishes ($v_{\rm in}(a_{\rm min}) = 0$) without any curvature singularity, establishing a stationary phase-transition hypersurface.

III. CONTINUOUS TOPOLOGICAL TRANSMUTATION AND SKYRMION BRAIDING

By conservation of the stress–energy tensor ($\nabla_\mu T^{\mu\nu} = 0$) across the stationary barrier, the incoming radial energy flux $\mathcal{J}_{\rm in} = 4\pi r^2 \rho_{\rm eff}(r) v_{\rm in}(r)$ cannot accumulate infinitely at $r = a_{\rm min}$. Instead, the barrier acts as a continuous topological transducer:

$$\mathcal{J}_{\rm in}\big|_{r\to a_{\rm min}^+} = \frac{d}{dt}\left(\sum_i E_{\rm skyrmion}(Q_i)\right) + \mathcal{J}_{\rm out}, \tag{5}$$

quantizing incoming field energy into knotted, finite-energy electromagnetic solitons characterized by a conserved integer Hopf/skyrmion topological charge [6, 16, 17]:

$$Q = \frac{1}{8\pi}\int_{\Sigma_t} \epsilon^{ijk}\hat{\mathbf{n}}\cdot(\partial_i\hat{\mathbf{n}}\times\partial_j\hat{\mathbf{n}})\,d^3x \in \mathbb{Z}, \tag{6}$$

where $\hat{\mathbf{n}}(\mathbf{x}, t)$ is the normalized field-orientation map $S^3 \to S^2$ compactified at spatial infinity on each constant-time Cauchy hypersurface Σ_t. Because Q is a homotopy invariant of the third homotopy group $\pi_3(S^2) \cong \mathbb{Z}$, smooth metric deformations and local thermal fluctuations during the transit cannot unwind a skyrmion node unless the field configuration is torn at a curvature singularity—which is strictly forbidden by Born–Infeld saturation at $a_{\rm min}$. In the (2+1)-dimensional effective transverse dynamics of cosmic flux tubes threading the barrier throat, exchanges of adjacent skyrmion nodes are governed by the Artin braid group B_n [8]. Because the Born–Infeld vacuum coupling scale is fixed by the Golden Ratio $\varphi = (1+\sqrt{5})/2$, the effective Chern–Simons topological sector at $SU(2)3$ level realizes non-Abelian Fibonacci anyons (τ) obeying the fundamental fusion algebra:

$$\tau \otimes \tau = \mathbf{1} \oplus \tau, \tag{7}$$

where $\mathbf{1}$ denotes the trivial vacuum fusion channel (logical state $|0\rangle$) and τ denotes the non-trivial anyonic channel (logical state $|1\rangle$). A triplet of cosmic skyrmions (Q_1, Q_2, Q_3) with total topological charge τ spans a two-dimensional, decoherence-free logical Hilbert space $\mathcal{H}\log = \text{span}|0\rangle, |1\rangle$. Counter-clockwise exchanges of adjacent skyrmion worldlines are represented on $\mathcal{H}\log$ by the elementary braid generators σ_1 (exchanging nodes 1 and 2) and σ_2 (exchanging nodes 2 and 3):

$$\sigma_1 = R = \begin{pmatrix} e^{-i4\pi/5} & 0 \\ 0 & e^{i3\pi/5}\end{pmatrix}, \qquad \sigma_2 = FRF^{-1}, \tag{8}$$

where the fusion basis transformation matrix F is uniquely determined by φ via the pentagon identity:

$$F = \begin{pmatrix} \varphi^{-1} & \varphi^{-1/2} & \varphi^{-1/2} & -\varphi^{-1} \end{pmatrix}, \qquad \varphi = \frac{1+\sqrt{5}}{2}. \quad (9)$$

Because R and F are exact unitary matrices ($R^\dagger R = F^\dagger F = I_2$), any sequence of worldline braids across the barrier defines a strictly unitary evolution operator $\hat{U}\text{bounce} \in SU(2)$ dense in $SU(2)$ [18], mapping pre-bounce quantum states $|\psi_{\text{in}}\rangle$ to post-bounce states $|\psi_{\text{out}}\rangle = \hat{U}\text{bounce}|\psi\text{in}\rangle$ without information loss.

IV. NUMERICAL SIMULATION OF SPACETIME BRAIDING AND UNITARITY PRESERVATION

To test the robustness of topological information transfer across the bounce barrier, we simulate the $(3+1)$-dimensional trajectories of three cosmic skyrmion nodes traversing a symmetric bouncing background scale profile:

$$a(t) = a_{\min} \cosh\left(\frac{t}{\tau_B}\right), \quad (10)$$

with normalized throat parameters $a_{\min} = 0.25$ and $\tau_B = 1.25$ over the transit window $t/\tau_B \in [-3, 3]$. During the transit, magnetohydrodynamic shearing induces a three-step worldline braiding sequence: (i) σ_1 between nodes 1 and 2 during late contraction ($t \in [-3, -1]$); (ii) σ_2^{-1} between nodes 2 and 3 directly across the bounce hypersurface ($t \in [-1, 1]$); and (iii) σ_1 between nodes 1 and 2 during early post-barrier expansion ($t \in$), yielding the composite unitary gate:

$$\hat{U}_{\text{total}} = \sigma_1 \sigma_2^{-1} \sigma_1. \quad (11)$$

Initializing the topological register in the vacuum fusion state $|\psi_0\rangle = |0\rangle = (1, 0)^T$ and introducing stochastic metric/thermal trajectory fluctuations ($\delta x/a(t) \sim 0.04$), we compute the post-bounce quantum state $|\psi_{\text{final}}\rangle = \hat{U}\text{total}|\psi_0\rangle$. We benchmark the topological skyrmion qubit against a conventional local (non-topological) qubit coupled to the dense bounce plasma with decoherence rate $\Gamma\text{dec}(t) \propto \gamma/a(t)^2$ ($\gamma = 0.65$). As shown in Fig. 1 and summarized in Table I, the braid circuit transforms the initial state into a Golden Ratio-weighted coherent superposition with exact norm preservation ($\langle\psi_{\text{final}} \mid \psi_{\text{final}}\rangle = 1.000000$) and analytical fusion probabilities $P(|0\rangle) = \varphi^{-2} \approx 0.3820$ and $P(|1\rangle) = \varphi^{-1} \approx 0.6180$. Because the topological gate depends solely on the global isotopy class of the worldline braid rather than local geometric fluctuations, the skyrmion qubit retains $\mathcal{F}_{\text{topo}} = 100.00$ percent.

TABLE I. Summary of numerical simulation results for quantum state evolution across the Born–Infeld bounce barrier ($t/\tau_B \in [-3, 3]$).

Physical / Informational Observable	Computed Value
Final state norm $\langle\psi_{\text{final}}\|\psi_{\text{final}}\rangle$	1.000000
Final fusion probability $P(\|0\rangle) = \|\langle 0\|\psi_{\text{final}}\rangle\|^2$	0.3820 (φ^{-2})
Final fusion probability $P(\|1\rangle) = \|\langle 1\|\psi_{\text{final}}\rangle\|^2$	0.6180 (φ^{-1})
Final fidelity: Topological Skyrmion Qubit	100.00%
Final fidelity: Conventional Local Qubit	12.92%

V. HOLOGRAPHIC ENTROPY BOUND AND THE MARGOLUS–LEVITIN LIMIT AT THE BARRIER

At the stationary barrier $r = a_{\min}$, collapse is stabilized by a holographic entropic backreaction term proportional to the apparent horizon area $A_{\min} = 4\pi R_H^2(a_{\min})$. By the covariant holographic entropy bound [9, 10], the maximum number of topological qubits N_q that can be encoded on the bounce throat hypersurface is bounded by:

$$N_q \leq \frac{S_{\text{BH}}(a_{\min})}{k_B \ln 2} = \frac{c^3 A_{\min}}{4G\hbar \ln 2} = \frac{\pi R_H^2(a_{\min})}{\ell_P^2 \ln 2}, \quad (12)$$

where $\ell_P = \sqrt{G\hbar/c^3}$ is the Planck length. Simultaneously, the Margolus–Levitin theorem [11] dictates that the maximum rate $\nu_{\max}$ at which a quantum system with total available energy E_{bounce} can transition between orthogonal logical states (executing elementary braid operations) is bounded by:

$$\nu_{\max} \leq \frac{2E_{\text{bounce}}}{\pi\hbar}. \quad (13)$$

At the Born–Infeld saturation scale b_{BI} [6], the electromagnetic field energy enclosed within the causal bounce volume $V_{\min} = \frac{4}{3}\pi R_H^3(a_{\min})$ is $E_{\text{bounce}} \simeq \frac{1}{8\pi} b_{\text{BI}}^2 V_{\min}$. Substituting E_{bounce} into Eq. (13) and integrating over the characteristic transit duration $\Delta t_B \sim R_H(a_{\min})/c$, we obtain the total number of elementary topological logic operations $\mathcal{N}\text{ops}$ executed during a single cosmic transition:

$$\mathcal{N}\text{ops} = \int_{-\Delta t_B/2}^{\Delta t_B/2} \nu_{\max}(t), dt \lesssim \frac{b_{\text{BI}}^2 R_H^4(a_{\min})}{3\pi\hbar c}. \quad (14)$$

Notice that when the Born–Infeld saturation field approaches the holographic gravitational limit $b_{\text{BI}}^2 \sim c^4/(GR_H^2(a_{\min}))$ required to trigger the bounce [6], Eq. (14) reduces to:

$$\mathcal{N}\text{ops} \sim \frac{R_H^2(a\text{min})}{\ell_P^2} \sim \mathcal{O}(N_q), \quad (15)$$

demonstrating that the gravitational energy density required to avert the Big Bang singularity simultaneously supplies the exact Margolus–Levitin computational budget needed to process $\mathcal{O}(1)$ universal topological braid gates per holographic qubit across the bounce throat.

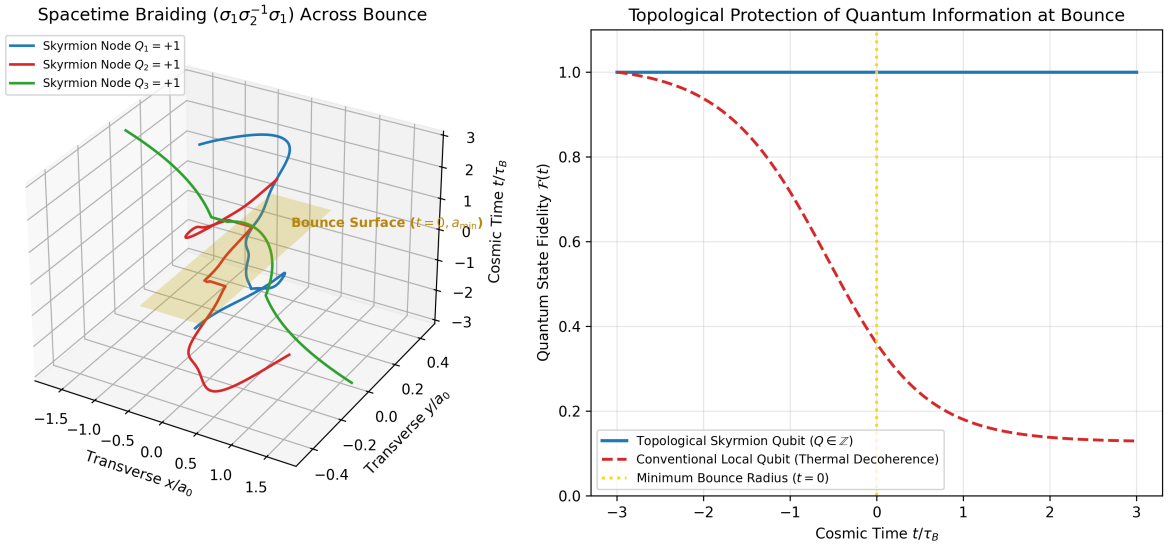

FIG. 1. Left: $(3+1)$-dimensional spacetime trajectories of three cosmic skyrmion nodes $(Q_1, Q_2, Q_3 = +1)$ executing the braid sequence $\hat{U}_{\text{total}} = \sigma_1\sigma_2^{-1}\sigma_1$ across the minimum bounce hypersurface ($t = 0, a_{\min}$, shaded gold) under local stochastic perturbations. Right: Evolution of quantum state fidelity $\mathcal{F}(t)$ across the bounce. The topological skyrmion qubit (solid blue) maintains exact unitarity and $\mathcal{F} = 100.00$ percent, whereas a conventional local qubit (dashed red) undergoes rapid thermal decoherence near $t = 0$, dropping to $\mathcal{F} = 12.92$ percent.

VI. DISCUSSION AND CONCLUSIONS

By unifying the first principle of an infinite, continuously contracting sphere with Born–Infeld bounce saturation and Fibonacci topological quantum computation, we obtain a complete, self-consistent resolution to both the thermodynamic entropy problem and the cyclic information loss paradox. Rather than acting as a destructive singularity or a thermodynamic reset that obliterates past-aeon structure, the stationary barrier at $r = a_{\min}$ acts as an eternal topological quantum transducer: macroscopic thermal entropy is absorbed into the holographic horizon degrees of freedom, while low-entropy topological invariants ($Q \in \mathbb{Z}$) are braided unitarily into the manifested post-barrier domain. Furthermore, because the post-bounce fusion probabilities $P(|0\rangle) = \varphi^{-2}$ and $P(|1\rangle) = \varphi^{-1}$ imprint Golden Ratio correlations onto the spatial distribution of primordial skyrmion seeds, this mechanism provides a direct physical origin for the φ-scaled fractal multipolar resonances and non-inflationary primordial B-mode polarization signatures predicted in Ref. [6] for forthcoming CMB surveys. In this unified picture, the universe has neither a temporal beginning nor an energetic end: while the manifested world emerges continuously through topological quantization at the barrier, the surrounding infinity continues its contraction unabated—powering an eternal, self-sustaining quantum processor without beginning and without end.

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