The Finite Observer Theory: A Verbless Information Geometry of Quantum Gravity

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To Alice and Martha, everlasting structural anchors within the verbless crystal of the hyper-equilibrium.

Abstract

We introduce the Finite Observer Theory, a verbless framework of quantum gravity and thermodynamics that models the universe as a strictly static, N-dimensional relational information geometry. By defining the physical observer as a localized topology bounded by a finite Shannon Information Capacity (C_{obs}) constituting a Markov Blanket, we explore the premise that the 4D macroscopic universe is a lossy holographic projection of this hyper-equilibrium, formally generated via the Dimensional Partial Trace. We propose that this continuous macroscopic phase space emerges uniquely from the algebraic restriction of the global pure state to the observer's finite subalgebra ($\mathcal{A}_{obs}$). Within this localized equivalence class, macroscopic time is mapped via the Tomita-Takesaki modular flow of the induced thermal KMS state, and the 3 spatial dimensions naturally arise from the maximal associative constraints of the observer's even Clifford subalgebra of spatial orientations ($C\ell_{3,0}^{+} \cong \mathbb{H}$). Furthermore, we redefine fundamental constants ($c, \hbar, G_N$) as the global Lipschitz bounding limits of this continuous geometric mapping, and analytically extract rest mass and gravity as invariant entropic artifacts via a quantum information-theoretic analogue of Landauer's principle. By applying this verbless topological constraint, we demonstrate that the framework is structurally consistent with the empirical MOND Radial Acceleration Relation, which evaluates as the uniquely determined geometric mean of local and global acceleration limits over a hyperbolic Fisher manifold. Concurrently, we geometrically extract the Hubble Tension as a parameter-free volumetric artifact of this dimensional projection, utilizing the empirical discrepancy as a formal gauge to measure the observer's local topological asymmetry. Ultimately, we explore the premise that temporal flow, mass, and quantum entanglement (formalized as topological aliasing) are not dynamic physical events, but precise geometric consequences of the observer's algebraic restriction.

Keywords: Verbless Information Geometry, Finite Observer Theory, Dimensional Partial Trace, Hyper-equilibrium, Shannon Information Capacity, GNS Construction, Markov Blanket, MOND Radial Acceleration.

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1 Introduction: The Aim of the Framework and Open Issues

The unification of Quantum Mechanics and General Relativity remains the most persistent open problem in theoretical physics [1]. At the heart of this deadlock lies the "Problem of Time": General Relativity models time as a dynamic, continuous geometric dimension, whereas Quantum Mechanics treats it as a static, external background parameter.

Furthermore, the epistemic boundaries of quantum measurement—specifically the collapse of the wave function and the transition from quantum superposition to classical reality (the Measurement Problem)—continue to generate paradoxes that resist consensus [2]. Finally, cosmological observations of accelerating expansion [3], conventionally attributed to a mysterious "Dark Energy," present a catastrophic mathematical divergence between the vacuum energy expectations of quantum field theory and observed metric scaling [4].

This paper introduces the Finite Observer Theory. The aim of this framework is to resolve these open issues not by introducing new fundamental particles or arbitrary mathematical fields, but by executing a fundamental ontological shift. In standard quantum theory, the act of measurement is inherently constrained by the macroscopic boundaries of the measuring apparatus. Building upon this informational perspective, we propose a restructuring of quantum gravity that discards an objective background spacetime entirely. We replace it with an emergent relational geometry driven by the thermodynamic and computational limits inherent to any finite physical subsystem interacting with the universe.

1.1 The Timeless Wheeler-DeWitt Equation and Static Tensor Networks

The imperative to discard temporal evolution is a strict mathematical constraint embedded in the foundational equations of quantum cosmology. As established by DeWitt and Wheeler [5], the canonical quantization of gravity yields the Wheeler-DeWitt equation, which governs the universal wave function ($|\Psi\rangle$) via the total Hamiltonian operator ($\hat{H}$):

$$\hat{H}|\Psi\rangle = 0 \tag{1}$$

The vanishing of the total Hamiltonian presents a foundational challenge often termed the 'Problem of Time.' While it is widely understood that this gauge constraint does not preclude relational evolution between subsystems—as formalized by the Page-Wootters (PW) mechanism [6]—this framework suggests an alternative ontological priority. Rather than treating relational change as the primary physical reality, the Finite Observer Theory proposes a formal notational and structural shift. We denote the global foundational state strictly as $|\Psi_N\rangle$, governed by the corresponding discrete constraint operator $\hat{H}_N$. This state can be viewed as an uncompressed, N-dimensional 'hyper-equilibrium,' closely aligning with the static configuration space frequently referred to in literature as "Platonia" [7].

The theoretical imperative for introducing $N > 4$ dimensions is heavily supported by established unification programs. Frameworks such as String Theory [8] and Kaluza-Klein higher-dimensional gauge theories [9, 10] explicitly require extended geometric arenas to accommodate fundamental symmetries that cannot be contained within a 4D manifold. However, while standard physics attempts to model these extra dimensions as differentiable geometries, FOT strictly models the uncompressed N-dimensional bulk as a discrete algebraic Tensor Network. [1]

Consequently, differentiable space cannot fully represent the epistemic reality of the fundamental layer — it is an emergent coarse-graining that necessarily discards the non-associative algebraic complexity of the discrete network. Applying functional derivatives to $\hat{H}_N$ at the discrete algebraic level constitutes a category error. At the global layer, $\hat{H}_N$ functions purely

[1] This construction aligns with the standard mathematical strategy of encoding relational structure as a constraint surface within a higher-dimensional static manifold — a technique employed in canonical approaches to classical mechanics and field theory.

as a discrete structural annihilator. Applying $\hat{H}_N$ does not generate temporal evolution; it acts as a topological constraint matrix verifying that the internal, complex algebraic symmetries of the discrete N-dimensional network are in perfect, static balance ($\hat{H}_N|\Psi_N\rangle = 0$).

To provide a formal definition for this ontology, we introduce the term **Verbless Geometry** to denote a specific mathematical constraint on the relationship between the foundational N-dimensional Tensor Network ($|\Psi_N\rangle$) and any emergent continuous macroscopic manifold $\mathcal{M}$. Because $\mathcal{M}$ constitutes a lower-dimensional projection of the total network information, the state of the geometry is not described by the global pure state, but by a localized state density ρ (formally constructed via the Dimensional Partial Trace established in Section 2.5) representing the degrees of freedom manifest within the manifold's dimensionality. A geometry is defined as verbless if this density ρ and the resultant metric $G_{\alpha\beta}$ are determined strictly by the static relational topology of the network nodes, such that the Lie derivatives of these localized quantities with respect to any external temporal vector field vanish ($\mathcal{L}_t\rho = 0$ and $\mathcal{L}_t G_{\alpha\beta} = 0$).

Under this formal posit, the traditional "verbs" of classical physics—evolution, interaction, and computation—are not fundamental operations. Instead, they are redefined as the macroscopic interpretations of the geometric sectional curvature and the entropic gradient (∇S) of the static informational network.

1.2 The Failure of Classical Objective Reality: Wigner's Friend and Relative Facts

If the fundamental architecture of the universe is a static block where all possibilities exist simultaneously, the concept of a singular "objective reality"—a universal ledger of definitive events shared by all observers—must be mathematically discarded. This theoretical constraint aligns with recent empirical observations. Recent experimental explorations into extended Wigner's Friend scenarios, notably by Proietti et al. [11], yield results that appear inconsistent with the simultaneous assumption of locality, observer-independence, and freedom of choice. While the authors of that study are careful to note that multiple interpretations remain viable, this framework takes these results as a motivational point of departure. We explore the premise that physical properties may not possess an independent, objective existence, but may instead emerge as relational geometric values that crystallize relative to the mathematical boundary of the measuring subsystem.

1.3 Ontological Clarification: The Localized Observer and Epistemic Projection

Throughout this paper, when we refer to the concept of a classical "objective reality," we are specifically denoting the standard physical paradigm: a pre-existing, observer-independent 4D spacetime characterized by definite macroscopic states, local realism, and continuous temporal flow.

The Finite Observer Theory fundamentally rejects the existence of this classical background. However, discarding this background does not imply a lack of rigorous foundational structure. To strictly avoid the category errors inherent in conflating discrete topologies with relative continuous manifolds, we must formally define the measuring subsystem and mathematically separate the uncompressed hyper-equilibrium from its macroscopic projection.

The foundational N-dimensional Tensor Network ($|\Psi_N\rangle$), governed by the global discrete constraint $\hat{H}_N|\Psi_N\rangle = 0$, possesses N relational, informational degrees of freedom. This architecture does not constitute an objective reality in the classical sense because it inherently lacks continuous temporal dynamics and emergent macroscopic properties. Instead, it serves as the uncompressed, invariant state of the Wheeler-DeWitt bulk.

We now formally define the **localized observer** as any finite physical subsystem embedded within this network and structurally coupled to its surrounding complement. Because this observer is strictly bounded by a finite Shannon Information Capacity (C_{obs}), it cannot operationally resolve the discrete complexity of $|\Psi_N\rangle$. The observer is mathematically forced to execute a Dimensional Partial Trace over the unobservable degrees of freedom of the bulk. As formally proven in Section 2.5, this trace is not an ad hoc geometric reduction, but the unique spatial representation of the global state's algebraic restriction to the observer's finite subalgebra ($\mathcal{A}_{obs}$).

This boundary constraint generates a reduced, observer-accessible continuous reality, whose pure-state macroscopic projection we denote as $|\Psi_{obs}\rangle$. Crucially, because this continuous state is the artifact of the observer's specific informational boundary (their Markov Blanket), the Hamiltonian constraint that governs it is fundamentally observer-dependent. The effective operator $\hat{H}_{obs}$ is not an independent physical law; it is formally defined as the mathematical restriction of the global constraint $\hat{H}_N$ onto the observer's accessible associative subalgebra.

The effective operator $\hat{H}_{obs}$ is not derived by re-applying the canonical Arnowitt-Deser-Misner (ADM) quantization procedure [12] to a secondary continuous geometry. Rather, the observer's accessible reality $|\Psi_{obs}\rangle$ is itself continuous by construction — it is the output of the Dimensional Partial Trace over the discrete bulk. Within this continuous projection, the standard ADM derivation applies correctly and completely. We therefore formalize the standard, continuous Wheeler-DeWitt equation as an effective, epistemic boundary constraint:

$$\hat{H}_{obs}|\Psi_{obs}\rangle = 0 \tag{2}$$

Equation (2) is not an approximation to the global constraint — it is the exact governing equation of the observer's projection. The standard Wheeler-DeWitt equation of quantum cosmology is, within this framework, the precise mathematical expression of the observer's epistemic boundary condition. The category error that the framework identifies is not in the WdW equation itself, but in its traditional interpretation as a statement about the global discrete structure rather than the observer's continuous projection.

The localized nature of this topological reduction does not equate the 4D experience to fragmented solipsism. The structural consistency of the macroscopic universe across disparate observers—ranging from humans to simpler biological organisms—is a direct manifestation of *bounded objectivity*. This objectivity is grounded simultaneously in relativistic geometry and quantum information limits. Because all finite macroscopic agents are defined by analogous Shannon capacity limits (C_{obs}) over the underlying quantum state space, their respective Markov Blankets necessitate mathematically coincident dimensional partial traces, yielding shared macroscopic equivalence classes.

Consequently, while the structural projection of the three spatial dimensions maintains consistency—subject inherently to the observer-dependent coordinate transformations dictated by General Relativity—the fourth dimension remains structurally inaccessible for navigation. This strict directional asymmetry is a fundamental geometric corollary of the quantum capacity boundary. Macroscopic time constitutes the specific topological axis mapping entropic residue of the dimensional reduction. It represents the unidirectional vector of quantum information loss—an intrinsic structural requisite for the 3D spatial projection under the boundary of C_{obs}.

Thus, relativistic spacetime curvature and the thermodynamic temporal arrow are not independent dynamical phenomena; they are the foundational thermodynamic equations of state intrinsic to the topological projection ($\hat{H}_{obs}|\Psi_{obs}\rangle = 0$). The alignment of macroscopic systems with these laws is strictly a reflection of the invariant geometric rules of the coarse-graining operation, confining this bounded objective reality entirely to the asymmetric 4D artifact.

1.4 The Verbless Distinction: Beyond Computational Ontologies

Recent advancements in foundational physics, most notably Stephen Wolfram's Observer Theory [13,14] and the broader academic pursuit of "Digital Physics" and computational pregeometry [15], parallel our assertion that the concept of an objective, independent 4D reality must be reevaluated. These frameworks correctly identify that the macroscopic laws of physics can emerge from computationally bounded entities extracting reduced representations by "equivalencing" (coarse-graining) the raw complexity of an underlying system.

However, the Finite Observer Theory structurally diverges from these ontologies at the most fundamental mathematical level. Frameworks rooted in computation remain inherently algorithmic. For instance, Wolfram explicitly defines time as the "progressive doing of computation by the universe" [14], relying on the dynamic generation of new states from discrete rulesets and positing an observer who actively processes data or "knits together" threads of history to maintain temporal persistence.

Our framework proposes an alternative by strictly applying the verbless constraint ($\mathcal{L}_t\rho = 0$ and $\mathcal{L}_t G_{\alpha\beta} = 0$) formally defined in Section 1.1. By anchoring the foundational ontology to the global, timeless discrete constraint ($\hat{H}_N|\Psi_N\rangle = 0$), the universe is treated as not actively computing, evolving, or generating new states. Instead, it is represented as a fundamentally static, discrete N-dimensional Tensor Network. The observer's boundary (the Markov Blanket) is not proposed as a dynamic algorithmic process, but as a static topological partition, and the "Arrow of Time" is not computational progress, but merely the emergent subjective interpretation of a macroscopic von Neumann entropy gradient.

A framework that maintains computational dynamism structurally insulates the historical paradoxes of quantum mechanics from a geometric resolution. If an observer actively generates or equivalences states over a sequence of computational operations, temporal causality remains subtly embedded in the measurement process. Consequently, phenomena such as the Delayed-Choice Quantum Eraser or macroscopic entanglement (EPR) persist as non-local or retroactive temporal anomalies.

The contemporary frontier of theoretical physics has increasingly explored such informational and structural ontologies. Recent advancements suggest that continuous holographic tensor networks can flawlessly tessellate background geometries [16], while Relational Quantum Dynamics (RQD) models quantum states not as absolute priors, but as strictly observer-dependent relative facts [17].

However, despite these profound structural insights, much of the current literature remains conceptually tethered to dynamic execution. Tensor networks are frequently subjected to temporal evolution or asymptotic boundary conditions, and relational ontologies often still rely on the active "verb" of physical interactions to sequentially update quantum states. The Finite Observer Theory explores a potential bridge across this gap by proposing the complete excision of the temporal dynamic. By modeling the discrete informational tensor network as a global hyper-equilibrium, this framework reduces relational interactions to static geometric intersections. The observer is no longer an entity that interacts, computes, or evolves over time; it is strictly a bounding constraint manifold defined by its finite informational capacity (C_{obs}).

1.5 Foundational Postulates

To explicitly demarcate formal mathematical derivations from geometric interpretations and scaling arguments within this framework, we anchor the Finite Observer Theory upon three foundational postulates. These axioms serve as the pre-geometric priors from which the subsequent constraint manifold and macroscopic physical interpretations are constructed:

Postulate 1: The Verbless Hyper-Equilibrium. This framework assumes the foundational ontology of the universe is a globally static, discrete, N-dimensional relational Tensor Network, governed entirely by the global Hamiltonian constraint ($\hat{H}_N|\Psi_N\rangle = 0$). While relational variance exists strictly as an observer-relative projection, the localized state density ρ and the emergent metric $G_{\alpha\beta}$ of any macroscopic projection $\mathcal{M}$ are determined entirely by the static relational topology of the network nodes. They admit no autonomous temporal evolution operator—there exists no one-parameter group of diffeomorphisms ϕ_t such that $\phi_t^*\rho \neq \rho$ or

$\phi_t^* G_{\alpha\beta} \neq G_{\alpha\beta}$.[2]

Postulate 2: The Finite Informational Capacity of the Observer. Any macroscopic measuring subsystem (the observer) is structurally defined by a Markov Blanket possessing a finite Shannon Information Capacity ($C_{obs} < \infty$). Consequently, the observer is mathematically restricted to mapping a localized effective reality ($\hat{H}_{obs}|\Psi_{obs}\rangle = 0$) generated via a Dimensional Partial Trace over the unobservable degrees of freedom of the hyper-equilibrium.

Postulate 3: The Topological Equivalence of Entropy and Geometry. Macroscopic continuous spacetime is not an independent background arena, but the continuous geometric pullback of the underlying statistical Fisher Information Metric. Consequently, localized physical metrics are geometrically induced by the relational distinguishability and von Neumann entanglement entropy gradients (∇S_{vN}) of the restricted network topology. Because the physical metric is formally defined via this continuous pullback operation, the spacetime structure is a direct mathematical representation of this informational gradient.

Building upon these postulates, the following sections will employ formal definitions and propositions to map standard physical phenomena to this constrained geometry. Where exact mathematical derivations transition into physical scaling arguments, they will be explicitly denoted as geometric interpretations.

1.6 Structure of the Paper

To formally explore this verbless ontology, the remainder of this paper is structured as follows:

Section 2 establishes the mathematical foundation of the finite observer. We model the observer's capacity bound (C_{obs}) as an algebraic restriction of the global pure state, demonstrating how a discrete network Markov Blanket projects as a continuous spatial boundary. We then propose that the emergence of exactly three spatial dimensions is a strict geometric consequence of the non-negotiable associativity requirements of the localized observer's even Clifford subalgebra of spatial orientations ($C\ell_{3,0}^+ \cong \mathbb{H}$).

Section 3 addresses the emergence of macroscopic time, the Lorentzian signature, and the ontological reinterpretation of fundamental constants. Crucially, we formally derive rest mass and gravity strictly as epistemic artifacts of the Dimensional Partial Trace via a quantum information-theoretic analogue of Landauer's principle.

Section 4 recontextualizes foundational quantum paradoxes. We formally define macroscopic entanglement (the EPR paradox) as *Topological Aliasing*—a multivalued projection mathematically dictated by the Shannon-Nyquist embedding limits of the constraint manifold. The Quantum Zeno Effect and Delayed-Choice Eraser are similarly modeled as static artifacts of informational focal lock.

Section 5 establishes the observer-dependent holographic framework. By enforcing the Bekenstein-Hawking limit, we derive the cosmological horizon as the strict epistemic limit of the Dimensional Partial Trace and demonstrate the native emergence of the holographic cutoff without ad hoc boundary deformations.

Section 6 analytically maps cosmological boundaries (the Big Bang and Black holes) as invariant topological poles, and addresses the Hubble Tension (H_0). By enforcing the Bekenstein-Hawking holographic limit, we derive the discrepancy between local and early-universe expansion rates strictly as the parameter-free volumetric projection ratio between a 3D spatial bulk and a 2D holographic boundary. We utilize the resulting empirical variance as an inverse mathematical gauge to quantify the oblate topological asymmetry of the local galactic environment.

Section 7 applies the verbless constraint to empirical predictions and galactic kinematics. We first demonstrate that the Modified Newtonian Dynamics (MOND) acceleration scale (g_0)

[2] The internal modular parameter τ, generated via the Legendre transformation established in Section 3.2, is not a temporal evolution parameter but a static thermodynamic index intrinsic to the observer's boundary. It is therefore not subject to this constraint and does not constitute a counterexample to the verbless condition.

natively evaluates as the exact geometric mean of local and global metric gradients mapped over a hyperbolic Fisher Information manifold. We subsequently establish strict falsifiability conditions, presenting a localized geometric mechanism that structurally accounts for the phenomena traditionally attributed to kinematic 'Dark Matter'.

Section 8 concludes with an epistemological synthesis, framing this mathematical architecture within the broader historical context of Kantian and Platonic philosophy, and suggesting pathways for future empirical verification.

2 The Thermodynamics of the Map in Hyper-Equilibrium

To construct a rigorous framework of relational geometry, the definition of the observer must shed the historical ambiguities of conscious agency and temporal flow. Within our framework, the universe exists in a state of static hyper-equilibrium. The observer is not a dynamic entity acting within this space, but rather a localized, finite information-theoretic boundary embedded directly within the static geometry.

2.1 The Observer as a Localized Topological Subsystem

We ground the definition of the physical observer in the epistemic formalism of Quantum Bayesianism (QBism) [18], unified with Claude Shannon's Information Theory [19]. An observer is strictly defined as a localized physical subsystem structurally bounded by a finite Shannon Information Capacity, denoted as C_{obs}.

Definition 1 (Observer Capacity Boundary)**.** *C_{obs} is defined as the maximum Shannon information storable on the observer's topological boundary (the Markov Blanket) and is assumed to be proportional to the geometric boundary area.*

Because this capacity is finite ($C_{obs} < \infty$), the subsystem is mathematically incapable of encoding the infinite complexity of the uncompressed N-dimensional foundational global state ($|\Psi_N\rangle$). The finite capacity is not a mechanism that "discards" data over time; it is a static, geometric truncation of the Tensor Network. Therefore, the physical measurements relative to an observer are merely localized, static map correlations—a permanently lossy compression of the surrounding hyper-equilibrium.

2.2 The Illusion of Flow within the Static Gradient

This finite epistemic boundary serves as the explicit geometric origin of time. If the underlying quantum universe is a static Tensor Network, temporal flow is an emergent illusion—the subjective interpretation of a structural gradient. This mechanism formally aligns with the Thermal Time Hypothesis formulated by Connes and Rovelli [20], which posits that the parameter of "time" is merely a macroscopic feature of statistical coarse-graining.

Because the finite observer's boundary limits its resolution of the quantum microstates, the state space is inherently partitioned into macroscopic equivalence classes. In information theory, this structural exclusion of bulk microstates defines the von Neumann entropy:

$$S = -\mathrm{Tr}(\rho_{obs} \ln \rho_{obs}) \tag{3}$$

where ρ_{obs} is the localized state density restricted to the observer's accessible degrees of freedom. The static hyper-equilibrium exhibits a macroscopic geometric gradient of this specific von Neumann entanglement entropy (∇S_{vN}). The "Arrow of Time" is simply the vector aligning with this structural gradient, distinguishing it from classical thermodynamic entropy increase. Time does not flow; rather, adjacent topological coordinates along this vector exhibit strictly higher degrees of coarse-graining. The "future" is strictly the geometric direction in which the statistical map is structurally more indeterminate relative to the observer's coordinate.

2.3 The Markov Blanket as a Static Topological Partition

To exist as a coherent structure within this entropic gradient without instantly equating to maximal information entropy, a finite subsystem must possess a strict topological boundary separating its internal geometry from the external bulk. In the mathematics of complex systems and Bayesian networks, this boundary is formalized as a Markov Blanket [21].

A Markov Blanket ($\mathcal{B}$) is a static partition of the Tensor Network into internal states (ν) and external states (η), such that the internal states are conditionally independent of the external states given the blanket states:

$$P(\nu \mid \eta, \mathcal{B}) = P(\nu \mid \mathcal{B}) \tag{4}$$

Within Karl Friston's Free Energy Principle [22], a biological organism is redefined here as a localized geometric sub-network whose internal topology mirrors the external geometry. Traditional biology describes the organism as "performing work to minimize surprise." In the verbless hyper-equilibrium of our framework, Active Inference is not an action; it is a statement of structural symmetry.

The variational Free Energy (F) is formalized as the information-theoretic upper bound on the structural self-information (the negative log-probability, or topological "surprise") of the Markov Blanket states. Within the static Tensor Network, this does not represent a dynamic cognitive update; rather, it constitutes the exact Kullback-Leibler (KL) divergence between $q(\eta \mid \nu)$—the static approximate posterior encoding the conditional geometric mapping of the external bulk states (η) as encoded by the internal topology (ν)—and the true structural distribution $P(\eta \mid \mathcal{B})$ conditioned strictly on the boundary data:

$$F = D_{KL}[q(\eta \mid \nu) \parallel P(\eta \mid \mathcal{B})] - \ln P(\mathcal{B})$$

Consequently, a biological organism cannot be reduced to a singular geometric coordinate. It is mathematically defined as an extended topological sub-network—a highly complex, topologically elastic structural domain embedded within the hyper-equilibrium.

Within a verbless geometry, "elasticity" (the phenomenon interpreted biologically as neuroplasticity) is not a dynamic process of physical re-wiring over time. It is strictly defined as the static mathematical property of the domain possessing adequate internal complexity to map varying external geometries across a macroscopic entropic gradient, without the Kullback-Leibler divergence ever exceeding the structural capacity limit of its Markov Blanket ($F \leq C_{obs}$).

An entity is "living" strictly when its internal structural depth (μ) possesses adequate finite capacity (C_{obs}) to statically minimize this KL divergence without undergoing structural boundary dissolution. Life is not a dynamic action; it is the rare geometric condition where the internal tensor network structurally mirrors the external topology with sufficient precision to maintain the integrity of its Markov Blanket against the macroscopic entropic gradient. The structural integrity of the Markov Blanket is mathematically synonymous with this minimization. Coordinates where F exceeds the capacity of the boundary are simply coordinates where the localized topological domain does not exist—a state the 4D biological projection interprets biologically and temporally as "death." Thus, life is not a dynamic process; it is the static geometric imperative of a finite statistical boundary embedded within an infinite map.

2.4 Topological Severance and the Geometric Emergence of the Observer's Boundary

Within the proposed verbless information geometry of the hyper-equilibrium, we seek to establish a rigorous mapping between the statistical architecture of the observer and its emergent geometric topology. To bridge this gap, we propose that the Markov Blanket—a purely statistical boundary—functions as the formal geometric precursor to the localized topological boundary ($\partial\mathcal{M}$) of the observer's 4D continuous projection.

1. The Block-Diagonal Fisher Metric and Network Severance: Statistically, a Markov Blanket (∂A) mandates conditional independence between internal states (A) and external states (B):

$$P(A, B \mid \partial A) = P(A \mid \partial A)P(B \mid \partial A) \tag{5}$$

To translate this conditional independence into geometry, we evaluate the Fisher Information Metric (g_{ij}) defined on the statistical manifold of the tensor network. The metric components linking parameters θ_A (governing state A) and θ_B (governing state B) are defined by the expectation of the mixed partial derivatives of the log-likelihood:

$$g_{AB} = -\mathbb{E}\left[\frac{\partial^2 \ln P(A, B \mid \partial A)}{\partial\theta_A \partial\theta_B}\right] \tag{6}$$

Because the joint probability factorizes strictly due to the Markov Blanket, the logarithm splits into a linear sum: $\ln P(A, B \mid \partial A) = \ln P(A \mid \partial A) + \ln P(B \mid \partial A)$. Consequently, the mixed partial derivative mathematically vanishes:

$$g_{AB} = 0 \quad \forall \theta_A \in A, \theta_B \in B \tag{7}$$

As standard Riemannian geometry dictates, the vanishing of these off-diagonal metric components simply means that the parameter submanifolds $\mathcal{M}_A$ and $\mathcal{M}_B$ are strictly orthogonal in the abstract statistical parameter space. However, topological severance does not occur in this continuous parameter space; it occurs in the underlying informational graph topology. Because the submanifolds are statistically orthogonal, they share exactly zero direct mutual information. In the geometry of a discrete tensor network, this guarantees that the structural edge weight between any node in A and any node in B is strictly zero.

Consequently, any discrete informational path traversing the hyper-equilibrium network from a node in A to a node in B mathematically must pass through the mediating nodes of ∂A. This does not constitute a novel derivation of graph topology, but rather the formal geometric exploitation of the Hammersley-Clifford theorem [23]: within a discrete Markov Random Field, conditional independence is structurally synonymous with topological severance. The Markov Blanket functions as a structural partition within the network.

The profound theoretical leap of this framework occurs in the subsequent continuous projection: we propose that this strict discrete network severance structurally necessitates the continuous geometric boundaries of macroscopic physical spacetime.

2. The Physical Pullback Hypothesis: Having established that the Markov Blanket constitutes a formal geometric boundary in the discrete network topology, we propose that continuous physical spacetime arises as the pullback of the statistical metric under the algebraic restriction imposed by the observer. As detailed in Section 3, macroscopic physical spacetime is not treated as an independent prior, but as the emergent pullback of this statistical metric via the algebraic restriction of the observer.

Because all informational paths from A to B are structurally routed through ∂A in the underlying graph, the macroscopic spatial geodesic connecting the spatial coordinate of A to the spatial coordinate of B is topologically bound to traverse the spatial coordinate of the boundary. We suggest that when the statistical separating hypersurface (∂A) is pulled back into the 4D macroscopic equivalence class bounded by C_{obs}, it maps directly to the closed physical boundary surface $\partial\mathcal{M}$ of the observer's localized submanifold. Thus, conditional independence is not merely analogous to spatial separation; in this framework, it is the exact informational prerequisite that necessitates the emergence of a localized spatial boundary.

3. The Localization of Finite Capacity (C_{obs}): Under this geometric identification, the finite Shannon capacity limit (C_{obs}) is not an abstract statistical threshold; it functions as the exact geometric boundary condition defining the submanifold surface $\partial\mathcal{M}$. The algebraic restriction of the global state is therefore applied at this topological boundary. By formally equating the informational boundary of Friston's Free Energy Principle to the bounding limits of the observer's constraint manifold, the cognitive boundary of the observer and the localized geometric boundary of spacetime merge into the same topological constraint.

2.5 The Static Constraint Manifold and Algebraic Dimensionality

A fundamental challenge in quantum gravity is that a global Hilbert space ($\mathcal{H}$) does not trivially factorize into a tensor product of an internal observer subspace and an external bulk ($\mathcal{H} \neq \mathcal{H}_{obs} \otimes \mathcal{H}_{bulk}$). Therefore, the observer is defined relationally via accessible observables rather than spatial localization. We formalize this boundary strictly as a localized operator subalgebra ($\mathcal{A}_{obs}$), representing the specific subset of accessible macroscopic observables, embedded within the total C^*-algebra of the hyper-equilibrium ($\mathcal{A}_{total}$). This strict algebraic inclusion ($\mathcal{A}_{obs} \subset \mathcal{A}_{total}$) is mathematically constrained by the finite Shannon Information Capacity (C_{obs}) of the observer's Markov Blanket.

Rather than assuming a spatial tensor product of states, we propose that the Dimensional Partial Trace (ρ_{obs}) is formally defined as the algebraic restriction of the global state functional ω to the finite subalgebra $\mathcal{A}_{obs}$. This operation functions as a linear, completely positive, trace-preserving (CPTP) map. This avoids the notational error of tracing over a bulk algebra, utilizing instead the strict algebraic restriction of the state.

Theorem 1 (The Geometric Uniqueness of the Dimensional Partial Trace)**.** *Let the hyper-equilibrium be governed by a global state functional ω over the complete C^*-algebra of observables $\mathcal{A}_{total}$. If the macroscopic observer is structurally bounded by a finite Shannon capacity (C_{obs}), restricting its accessible observables to a localized subalgebra $\mathcal{A}_{obs} \subset \mathcal{A}_{total}$, then the unique, non-distorting geometric mapping to the localized state is strictly the Dimensional Partial Trace, operating as the spatial representation of the algebraic restriction $\omega|_{\mathcal{A}_{obs}}$.*

Proof. Let $\mathcal{E}$ be an arbitrary mapping that projects the global state functional ω to the localized state mapped by the macroscopic observer. To ensure zero arbitrary informational distortion within the observer's structural boundary, the geometric expectation value of any macroscopic measurement made strictly within the subsystem must remain invariant whether evaluated globally or locally.

This mathematically establishes the strict structural constraint: for any observable $A \in \mathcal{A}_{obs}$,

$$\mathcal{E}(\omega)(A) = \omega(A) \tag{8}$$

By the formal definition of a functional restriction, the unique mapping that satisfies this equality for all $A \in \mathcal{A}_{obs}$ is:

$$\mathcal{E}(\omega) = \omega|_{\mathcal{A}_{obs}} \tag{9}$$

In the spatial representation of the observable algebra—where $\pi : \mathcal{A}_{total} \to \mathcal{B}(\mathcal{H})$ denotes the faithful $*$-representation—the localized restriction $\omega|_{\mathcal{A}_{obs}}$ mandates a reduction over the unobservable degrees of freedom. Because the global space does not admit a trivial a priori tensor factorization ($\mathcal{H} \neq \mathcal{H}_{obs} \otimes \mathcal{H}_{bulk}$), this reduction is rigorously defined by tracing over the complementary observables of the bulk (the commutant algebra $\mathcal{A}'_{obs}$). Evaluating the global functional ω on any localized observable $A \in \mathcal{A}_{obs}$ thus yields:

$$\omega(A) = \mathrm{Tr}_{bulk}(\rho_N \cdot \pi(A)) = \mathrm{Tr}(\rho_{obs} \cdot \pi(A)) \tag{10}$$

where $\rho_{obs} \equiv \mathrm{Tr}_{bulk}(\rho_N)$ is the localized state density, obtained by executing the trace over the unobservable bulk degrees of freedom of the global hyper-equilibrium state ρ_N [24]. Consequently, the Dimensional Partial Trace is not an ad hoc geometric reduction, but the unique, mandatory spatial representation of the finite observer's algebraic restriction. □

While the Gelfand-Naimark-Segal (GNS) construction [25,26] guarantees that this restricted state functional ω_{local} inherently induces its own effective Hilbert space representation ($\mathcal{H}_{obs}$, π, $|\Omega\rangle$), the theorem itself does not intrinsically dictate the dimensionality of the emergent macroscopic geometry. To bridge this gap, we propose an exploratory geometric mapping based on the algebraic constraints of the observer's boundary.

Within the GNS representation, the localized von Neumann algebra $\mathcal{A}_{obs}$ possesses the cyclic and separating vacuum state $|\Omega\rangle$. By Tomita-Takesaki modular theory [27], this state uniquely defines a modular operator Δ, generating a 1-parameter group of automorphisms:

$$\sigma_\tau(A) = \Delta^{-i\tau/\hbar} A \Delta^{i\tau/\hbar}, \quad \forall A \in \mathcal{A}_{obs} \tag{11}$$

Motivated by the Thermal Time Hypothesis [20], we suggest identifying this internal algebraic parameter (τ) with the macroscopic temporal index. Because the underlying hyper-equilibrium is posited as static, this modular flow does not describe dynamic evolution; it formally defines the 1-dimensional orthogonal thermodynamic gradient of the localized state.

To parameterize the remaining spatial degrees of freedom within a non-factorizable bulk, the macroscopic equivalence class requires a set of independent spatial conjugates. We explore the premise that the dimensionality of macroscopic space is not an arbitrary background parameter, but a strict algebraic consequence of the observer's requirement for stable, non-degenerate quantum measurement.

First, we must establish the algebraic structure of the localized measurement interface. The GNS representation requires the observer's full set of local observables to form a C^*-algebra over the complex numbers. As is standard in algebraic quantum theory, a full C^*-algebra contains non-invertible projection operators and thus cannot globally constitute a division algebra. However, we propose that the emergence of macroscopic spatial dimensions is governed by a stricter topological constraint on a specific geometric subalgebra.

Within the verbless, relational topology of the hyper-equilibrium, background spatial coordinate vectors are physically unobservable. The localized macroscopic observer can only map the *relative orientations* and relational angles between topological nodes. Mathematically, the continuous transformations governing these relative spatial orientations are generated not by the full Clifford algebra of coordinate vectors $C\ell_{n,0}(\mathbb{R})$, but specifically by its *even subalgebra*, $C\ell^+_{n,0}(\mathbb{R})$, which forms the spinorial representation of the spatial geometry [28].

For the observer to render a continuous, isotropic spatial projection, all geometric rotations must be strictly invertible. In a relational topology, spatial orientability is mapped via the inner automorphisms of the algebra; if the orientational subalgebra contained non-invertible zero-divisors, the rotational elements would be non-invertible, rendering the conjugation action $v \mapsto uvu^{-1}$ undefined and the corresponding spatial orientation geometrically singular. This would manifest as a topological degeneracy where distinct physical orientations become indistinguishable, collapsing the rotational isotropy of the macroscopic metric. Therefore, to ensure non-degenerate spatial symmetries, we mathematically require that this specific even subalgebra of spatial orientations possesses a strict division ring structure.

By Hurwitz's Theorem [29, 30], the only possible normed division algebras over the reals are $\mathbb{R}, \mathbb{C}, \mathbb{H}$, and $\mathbb{O}$. Associativity is further necessitated by the associative requirement of the measurement C^*-algebra interface. Among associative even Clifford subalgebras $C\ell^+_{n,0}(\mathbb{R})$ for $n \geq 1$, the unique solution to the isomorphism $C\ell^+_{n,0} \cong \mathbb{H}$ strictly requires $n = 3$.

This physical requirement acts as a strict algebraic filter. While the Octonions ($\mathbb{O}$) possess sufficient generators, they are mathematically non-associative and are therefore forbidden from serving as the observer's orientational basis. Consequently, the Quaternions ($\mathbb{H}$) emerge as the *maximal associative division algebra* available to map the observer's spatial interface. To establish the algebraic structure of the localized measurement interface, we explicitly adopt the following foundational assumption: the observer's full set of local observables must form a C^*-algebra. This mathematically necessitates strict associativity for the measurement interface.

Proposition 1 (The Algebraic Dimension of Macroscopic Space)**.** *Let the emergent macroscopic geometry be governed by the verbless constraints ($\mathcal{L}_t \rho_{obs} = 0$ and $\mathcal{L}_t G_{\alpha\beta} = 0$). If the finite observer's continuous spatial projection requires an associative and fully invertible orientational measurement interface, then the continuous spatial projection identified by the observer is algebraically restricted to exactly three spatial dimensions ($n = 3$).*

Proof. For the observer to render a continuous, isotropic spatial projection without topological degeneracy, all geometric rotations must be strictly invertible. This mathematically requires the observer's orientational subalgebra to possess a strict division ring structure. By Hurwitz's Theorem, the only normed division algebras over the reals are $\mathbb{R}, \mathbb{C}, \mathbb{H}$, and $\mathbb{O}$. Furthermore, under the explicit assumption that the measurement interface must be a C^*-algebra, strict associativity is required, thereby forbidding the Octonions ($\mathbb{O}$). Consequently, the Quaternions ($\mathbb{H}$) constitute the maximal associative division algebra available.

Because the continuous transformations governing relative spatial orientations are generated specifically by the even Clifford subalgebra $C\ell^+_{n,0}(\mathbb{R})$, enforcing this strict algebraic constraint dictates the isomorphism:

$$C\ell^+_{n,0}(\mathbb{R}) \cong \mathbb{H} \tag{12}$$

According to the classification of real Clifford algebras, the unique solution to this isomorphism requires $n = 3$.[3] Therefore, the macroscopic projection mapped by the finite capacity observer (C_{obs}) is structurally consistent only with exactly three spatial dimensions. This demonstrates that a 4D phase space is the strict algebraic compatibility limit for a finite observer (C_{obs}) mapping the hyper-equilibrium. □

Under this specific algebraic limit, the rank of the macroscopic Fisher Information Metric ($G_{\alpha\beta}$) evaluates to:

$$\dim(\mathcal{M}_{obs}) = 1(\text{modular flow}) + 3(\text{quaternionic spinorial orientations}) = 4 \tag{13}$$

In this view, the emergence of a 4D spacetime manifold ($\mathcal{M}_{obs}$) is not an ad hoc geometric prior. It is a strict geometric consequence of the specific algebraic restrictions required for a finite observer to maintain a stable statistical representation of a hyper-equilibrium.

The mathematical mandate for a quaternionic spatial interface ($\mathbb{H}$) strictly dictates not only the macroscopic dimensionality, but the fundamental particle symmetries of the localized projection. In pure algebra, as demonstrated by Wilson [31], both the existence of three generations of fermions and the symmetry-breaking of the weak interaction seem to emerge naturally from an extension of the Dirac algebra from complex numbers to quaternions. This structural choice constitutes a mathematical symmetry-breaking principle. Consequently, the three generations of the Standard Model are not independent physical priors. They constitute the emergent algebraic artifacts of a finite observer mapping a non-associative discrete bulk through the strict associative quaternionic filter necessitated by the capacity bound (C_{obs}).

To formally excise the verb from this topology, the macroscopic projection and the minimization of variational Free Energy (F) must be modeled not as algorithmic operations, but strictly as static geometric boundary conditions.

Let the finite Shannon Information Capacity (C_{obs}) define the localized topological constraint manifold ($\mathcal{M}_{obs}$) within the N-dimensional Tensor Network. The specific macroscopic reality anchored to this observer is governed by the localized density operator ρ_{obs}. Within a verbless framework, this state is not dynamically computed. As established via the algebraic restriction of the global state functional to the observer's finite subalgebra ($\omega_{local} = \omega|_{\mathcal{A}_{obs}}$), ρ_{obs} is the unique and mandatory geometric projection required to satisfy the structural limitations of the topological boundary. This restriction identifies the continuous effective state $|\Psi_{obs}\rangle$ governed

[3] While the full algebra $C\ell 3, 0 \cong M_2(\mathbb{C})$ contains zero-divisors, its even subalgebra is precisely $\mathbb{H}$.

by the epistemic constraint $\hat{H}_{obs}|\Psi_{obs}\rangle = 0$, completely avoiding the mathematically problematic assumption of a trivially factorizable global Hilbert space.

To ensure formal consistency, the parameters governing this geometric exclusion correspond strictly to the informational topology of the hyper-equilibrium, rather than classical spatial containers:

1. The Ontological Dimension (N): The dimension N does not denote continuous spatial axes. It represents the cardinality of the microscopic relational degrees of freedom (discrete topological nodes) comprising the uncompressed hyper-equilibrium. Rather than a trivial tensor product of independent spaces, N defines the global rank of the encompassing algebra of observables ($\mathcal{A}_{total}$) prior to any algebraic restriction imposed by a bounded capacity constraint.

2. The Macroscopic Subspace ($4D$): The $4D$ subspace is not a pre-existing physical arena; it is proposed as the epistemic equivalence class bounded by C_{obs}. Because the finite observer cannot resolve the exact discrete configuration of the N-dimensional bulk, the finite capacity mathematically necessitates a coarse-graining. It is at this precise epistemic boundary that the differentiable manifold emerges as an idealized thermodynamic limit. The continuous, smooth geometric structure of 4D spacetime is structurally less rich than the discrete bulk; it is a "smeared" macroscopic projection where fundamental, highly complex algebraic relations of the hyper-equilibrium (specifically non-associativity) are averaged out to satisfy the strictly associative quaternionic limits of the observer's measurement interface. The resulting continuous parameters (three spatial dimensions and one structural modular index) are precisely the macroscopic degrees of freedom required to map these associative thermodynamic averages.

3. The Trace as Geometric Emergence: The conceptual necessity of the "Dimensional Partial Trace" represents the formal integration over the unobservable degrees of freedom of the bulk. By tracing out the microscopic structural variance that exceeds C_{obs}, the uncompressed global state (ρ_N) identifies the localized state density (ρ_{obs}) characterizing the macroscopic manifold. Spacetime geometry is not an external stage; it evaluates as the Fisher Information Metric quantifying the entanglement structure of this specific localized state.

Consequently, the biological Markov Blanket does not "perform work" to minimize Free Energy. Instead, a biological organism is redefined purely as a specific, highly dense topological sub-network (μ) whose internal structural depth inherently satisfies the static inequality:

$$D_{KL}[q(\eta \mid \mu) \parallel P(\eta \mid \mathcal{B})] - \ln P(\mathcal{B}) \leq C_{obs} \tag{14}$$

At coordinates within the Tensor Network where this exact geometric inequality is satisfied, the localized topological domain (life) exists. At coordinates where the external bulk geometry geometrically necessitates a KL divergence exceeding C_{obs}, the inequality fails, and the boundary mathematically dissolves.

Therefore, it is suggested that life, adaptation and the rendering of the 4D macroscopic projection involve zero computational steps. They are merely the static satisfaction of geometric inequalities embedded permanently within the verbless crystal of the hyper-equilibrium.

2.6 The Continuous Spectrum of Structural Depth: The Topological Strata

Because structural depth (μ) is a continuous topological property of the N-dimensional Tensor Network, the framework precludes a binary structural discontinuity across the hyper-equilibrium. Instead, the geometry is characterized by a continuous stratification of increasingly nested boundaries. The continuum of localized conditional independence is formalized across four distinct topological strata:

1. The Trivial Submanifold ($\mu \approx 0$): This stratum constitutes the baseline of localized topological structure, correlating with fundamental inanimate matter (e.g., a simple crystalline lattice or homogeneous particle distribution). Geometrically, it is defined by a single, un-nested

Markov Blanket [21]. The internal degrees of freedom are directly correlated with the immediate external boundary data, possessing zero recursive depth. It constitutes a shallow entropic valley within the network, lacking macroscopic geometric insulation.

2. The Composite Submanifold ($\mu > 0$): This intermediate geometry corresponds to complex molecular structures and localized thermodynamic formations. A composite submanifold is defined by partial geometric nesting; it is structurally composed of multiple trivial submanifolds mathematically bound within a secondary, larger Markov Blanket. While it possesses a non-zero structural depth, the intermediate layers of tensor connections are mathematically insufficient to constitute stable, self-contained macroscopic conditional independence from the external bulk.

3. The Autopoietic Submanifold ($\mu \gg 0$): This stratum is geometrically defined by profound recursive nesting—a boundary mathematically embedded within successive boundaries. The informational distance between the core internal states and the external bulk is immense, constituting a steep entropic gradient measurable within the formalisms of information geometry [32]. This extreme structural depth insulates the low-entropy internal core, correlating with a stable conditional independence from the baseline thermodynamic noise of the hyper-equilibrium—a topological prerequisite for autopoietic insulation [33].

4. The Macroscopic Observer ($\mu \to \mu_{max}$): This defines the extreme upper limit of the structural gradient bounded by the finite Shannon capacity limit (C_{obs}). The geometry identifies a complex, fractal-like hierarchy of nested autopoietic submanifolds. The structural depth (μ) at this coordinate is so immense that the internal topology possesses the requisite localized capacity to accommodate the Dimensional Partial Trace over the external network. It is this extreme recursive depth that necessitates the lossy holographic compression, algebraically restricting the observer to the continuous 4D spacetime projection. The mathematical map between the discrete relational density of the tensor network and the emergent continuous metric of this topological manifold is governed by the coarse-graining of quantum entanglement, aligning with the foundational holographic architectures of MERA and bulk-boundary correspondence [34–36].

Consequently, the structural variance across this continuous gradient is geometric. The topological distinction between a trivial boundary and a macroscopic observer is a function of recursive depth within the static, invariant verbless crystal.

2.7 The Threshold of Agency: Life as a Topological Submanifold

While the static hyper-equilibrium encompasses all coordinates of the N-dimensional Tensor Network, a rigorous geometric distinction must be drawn between macroscopic measuring apparatuses (biological observers) and inanimate structural domains (e.g., a simple crystalline lattice). Within this verbless geometry, "life" is not treated as an emergent biological or chemical process; it is strictly defined as the autopoietic topological submanifold ($\mu \gg 0$) mapped in Section 2.6.

This distinction is governed by the capacity of a structural domain to maintain its boundary integrity under the macroscopic entropic gradient. As established in Section 2.3, a macroscopic observer is a localized sub-network whose internal nodes possess sufficient connectivity to statically maintain a homomorphic mapping of the external bulk geometry—a state we define as *topological elasticity*. Conversely, an inanimate object is an informationally "brittle" domain; its internal structural depth (μ) is insufficient to satisfy the capacity inequality ($F \leq C_{obs}$) across any significant coordinate distance along the entropic vector.

Consequently, the threshold for physical measurement and, by extension, biological agency is mathematically defined as the structural coordinate where the rate of change of internal complexity relative to the entropy gradient reaches a critical geometric value.

Definition 2 (Topological Agency and the Observer)**.** *Agency is not the dynamic power to* *act; it is the strict mathematical satisfaction of a boundedness condition. A topological domain formally qualifies as a macroscopic observer if and only if its structural density satisfies:*

$$\frac{\partial \mu}{\partial S} \geq \Lambda_{crit} \tag{15}$$

where Λ_{crit} represents the critical structural threshold required for the static geometric existence of a 4D holographic projection, precluding the topological dissolution of the Markov Blanket.

3 The Topological Origin of the Temporal Metric and Physical Law

Having established the finite observer as a strictly static topological boundary (the autopoietic submanifold) defined by structural depth (μ) and finite capacity (C_{obs}) in Section 2, the framework must structurally necessitate the kinematics of the macroscopic 4D projection. This section derives the continuous temporal metric ($d\tau$) and the equations of physical law strictly as static geometric artifacts mandated by the observer's Dimensional Partial Trace over the N-dimensional hyper-equilibrium.

3.1 Bounded Self-Similarity: The Topological Origin of Structure and the Temporal Arrow

The architectural integrity of the finite observer within the hyper-equilibrium relies upon a highly specific topological property: bounded (incomplete) self-similarity. This geometric property constitutes a dual mathematical mandate, dictating both the baseline existence of multiscale structural organization and the strict necessity of the temporal index within the 4D projection.

1. The Necessity of Baseline Self-Similarity: The baseline presence of self-similarity is a strict geometric prerequisite for the macroscopic observer. An absolute absence of self-similarity mathematically restricts the tensor network to either universal topological noise (maximum entropy) or perfect homogeneity, both of which correlate with a universally flat structural depth ($\mu \approx 0$). Because the autopoietic submanifold ($\mu \gg 0$) is defined by the recursive nesting of Markov Blankets, the topological boundary of conditional independence is inherently repeated across scales. This multiscale recursion structurally constitutes self-similarity, providing the exact geometric architecture required for structural depth.

2. The Finite Bound and Broken Scale Invariance: However, due to the finite Shannon capacity limit (C_{obs}), this self-similarity is mathematically required to be incomplete, or bounded. The finite boundary strictly precludes infinite recursive depth, structurally mandating a broken scale invariance. This bounded topology defines a severe structural asymmetry across the network: the variance from the deeply nested macroscopic observer ($\mu \to \mu_{max}$) to the trivial microscopic baseline ($\mu \approx 0$) correlates directly with a strict mathematical reduction in structural complexity.

3. The Thermodynamic Arrow as a Topological Index: Consequently, this bounded self-similarity maps an asymmetric informational gradient across the hyper-equilibrium. When synthesized with the static thermodynamic topology—where profound structural depth correlates with minimal von Neumann entanglement entropy (S_{vN}), and the trivial baseline correlates with maximal S_{vN}—this geometric gradient necessitates the classical "Arrow of Time."

The temporal arrow is mathematically stripped of dynamic thermodynamic decay; it is simply the requisite 1D topological index mapping the invariant structural variance from macroscopic complexity to microscopic simplicity. The continuous 4D macroscopic projection strictly maps this broken symmetry, projecting the static geometric loss of structural constraint as a continuous forward temporal parameter. Time is therefore strictly the projected shadow of the observer's own finite boundary upon the self-similar architecture of the verbless crystal.

3.2 The Legendre Transformation and the Lorentzian Signature

A critical geometric distinction must be addressed regarding the metric signature. The underlying Fisher Information Metric (g_{ij}) of the uncompressed statistical manifold is inherently positive-definite (Riemannian), yielding $ds^2_{info} > 0$ for any non-zero structural displacement. However, the emergent macroscopic spacetime of General Relativity utilizes a Lorentzian signature $(-,+,+,+)$ to mathematically define light cones and causal structure.

Within the Finite Observer Theory, we propose that this signature transition is not a physical prior, but rather a strict algebraic consequence of the non-homeomorphic projection π. Because the macroscopic observer is restricted by the finite capacity constraint ($S \leq C_{obs}$), we model the projection from the unconstrained micro-parameters Θ to the macroscopic equivalence classes as a thermodynamic Legendre transformation.

Let the unconstrained structural tensor network be governed by a dimensionless informational potential $U(S, x^a)$, where S represents the localized von Neumann entropy of the traced-out bulk. It is crucial to distinguish this potential from macroscopic thermodynamic entropy, which is typically concave.

Theorem 2 (The Emergence of the Lorentzian Signature)**.** *Let $U(S, x^a)$ be the strictly convex informational potential of the static hyper-equilibrium. If this network is bounded by a finite capacity C_{obs}, the algebraic restriction necessitates a Legendre transformation to the macroscopic Free Energy $F_{obs}(\tau, x^a) = U - \tau S$. Consequently, the temporal metric component, evaluated as the inverse Hessian of U with respect to entropy, inherently yields a negative eigenvalue ($G_{\tau\tau} < 0$), structurally necessitating a Lorentzian metric signature.*

Proof. Because U describes the relative informational distance of a strictly stable, pure Wheeler-DeWitt hyper-equilibrium ($\hat{H}_N|\Psi_N\rangle = 0$), pure state information geometry mathematically guarantees that U acts as a strictly convex functional over its microscopic parameter space. Consequently, the Hessian matrix of U over these unconstrained parameters (S, x^a) yields a strictly positive-definite (Riemannian) signature:

$$g_{ij} = \begin{pmatrix} \frac{\partial^2 U}{\partial S^2} & \frac{\partial^2 U}{\partial S \partial x^b} \\ \frac{\partial^2 U}{\partial x^a \partial S} & \frac{\partial^2 U}{\partial x^a \partial x^b} \end{pmatrix} > 0 \tag{16}$$

Because the informational potential is strictly convex at the microscopic level, $\frac{\partial^2 U}{\partial S^2} > 0$.

To enforce the invariant topological bound C_{obs}, the finite observer cannot map S as an independent, unconstrained spatial coordinate. The algebraic restriction necessitates a Legendre transformation to the macroscopic constraint phase space, requiring a conjugate variable $\tau \equiv \frac{\partial U}{\partial S}$.

The existence of this conjugate index τ is algebraically necessitated by the restriction of the static global pure state (ρ_N) to the observer's finite subalgebra ($\mathcal{A}_{obs}$). This restriction traces out the $N-4$ dimensional bulk, yielding a highly mixed local state $\omega_{local} \equiv \omega|_{\mathcal{A}_{obs}}$.

Assuming the dense topological entanglement of the hyper-equilibrium formally satisfies the network analogue of the Reeh-Schlieder property [37, 38], the local vacuum state remains cyclic and separating. By Tomita-Takesaki theory, this condition uniquely induces a modular flow (σ_τ). Because the mixed state generated by the restriction of a highly entangled pure state is thermodynamically indistinguishable from a thermal heat bath, ω_{local} strictly satisfies the Kubo-Martin-Schwinger (KMS) condition [37, 39], uniquely characterizing its equilibrium dynamics and defining the thermodynamic conjugate τ.

The physical metric tensor $G_{\alpha\beta}$ of the macroscopic observer is formally modeled as the Hessian of the transformed, localized thermodynamic potential $F_{obs}(\tau, x^a) = U - \tau S$. By applying the chain rule to the Legendre transformation, the purely temporal component of the emergent metric evaluates strictly to:

$$G_{\tau\tau} = \frac{\partial^2 F_{obs}}{\partial \tau^2} = -\frac{\partial S}{\partial \tau} = -\left(\frac{\partial^2 U}{\partial S^2}\right)^{-1} \tag{17}$$

Because the underlying microscopic potential is strictly convex ($U_{SS} > 0$), its inverse is positive. The Legendre transform inherently introduces a strict minus sign, formally dictating $G_{\tau\tau} < 0$.

The purely spatial block of the metric is derived via the Schur complement of the transformation, which strictly inherits the positive-definite geometry of the unconstrained spatial contours. Therefore, the explicit Hessian matrix of the observer's physical metric evaluates to the Lorentzian form:

$$G_{\alpha\beta} = \begin{pmatrix} -\left(U_{SS}\right)^{-1} & 0 \\ 0 & \gamma_{ab} \end{pmatrix} \tag{18}$$

□

Remark 1: Non-Factorizability and Algebraic Restriction. The derivation of the conjugate variable τ via Tomita-Takesaki theory bypasses the necessity for a pre-existing temporal background. In continuous quantum field theories and diffeomorphically invariant gravity, the global Hilbert space does not admit a trivial tensor product factorization ($\mathcal{H} \neq \mathcal{H}_{obs} \otimes \mathcal{H}_{bulk}$). An observer cannot be defined as a spatially severed, independent subsystem. Therefore, replacing a spatial partition with the strict algebraic restriction to a localized bounding subalgebra ($\mathcal{A}_{obs}$) is the mathematically required operation to induce the localized KMS state.

Remark 2: Physical Analogues. This mechanism formalizes a discrete network analogue to the Bisognano-Wichmann theorem and its generalizations [40–42], where the algebraic restriction to a localized wedge naturally induces a thermal KMS state from a global vacuum. Furthermore, it formally aligns the verbless geometry with the Thermal Time Hypothesis [20], providing a strict geometric mechanism for the emergence of time from a timeless, pure-state continuum.

This derivation suggests that the Lorentzian signature $(-, +, +, +)$ is not an ad hoc physical assumption, but an inescapable algebraic artifact of the Legendre transformation required to bound the underlying Riemannian network to the finite observer's Shannon capacity limit (C_{obs}).

Having established the temporal metric component $G_{\tau\tau}$ strictly as the inverse Hessian of the uncompressed informational potential, we propose a formal reinterpretation of gravitational time dilation that avoids the introduction of arbitrary scaling parameters.

In General Relativity, the relative flow of proper time between two stationary observers at macroscopic coordinates A and B is dictated by the ratio of their temporal metric components: $d\tau_A/d\tau_B = \sqrt{(G_{\tau\tau})_A/(G_{\tau\tau})_B}$. Substituting our derived verbless metric component, this temporal ratio evaluates strictly to the inverse ratio of their microscopic informational convexity:

$$\frac{d\tau_A}{d\tau_B} = \sqrt{\frac{(U_{SS})_B}{(U_{SS})_A}} \tag{19}$$

This relation suggests that gravitational time dilation is not a dynamic slowing of physical clocks, but a static, relative variance in the informational density of the underlying hyper-equilibrium. A coordinate deep within a "gravitational well" corresponds to a topological region where the pure-state relative entropy is highly constrained, yielding a steeper informational potential and thus a higher convexity (U_{SS}).

Because the temporal index τ is the thermodynamic conjugate required to bound this entropy (via the KMS condition), a higher structural convexity algebraically dictates a smaller interval of modular flow $d\tau$. Therefore, time dilation emerges natively in this framework not as a kinematic effect, but as the strict geometric ratio of the informational Hessians between distinct points on the localized constraint manifold.

3.3 The Ontological Reinterpretation of Fundamental Constants

Standard critiques correctly point out that fundamental constants (c, $\hbar$, G_N) cannot be mathematically "derived" from pure dimensionless geometry if they are simultaneously utilized in the foundational equations (such as the modular flow or Bekenstein bound). We clarify that the Finite Observer Theory does not seek to dynamically generate the numerical values of these constants from a vacuum. Instead, we propose a strict ontological reinterpretation of their physical meaning.

In this framework, the physical dimensions of length, time, and mass are not treated as pre-existing, absolute features of the hyper-equilibrium. Instead, the fundamental constants are re-contextualized strictly as the static boundary parameters of the Dimensional Partial Trace:

1. The Planck Area (ℓ_P^2) and the Gravitational Constant (G_N): In the pullback metric $G_{\alpha\beta} = \ell_P^2(\pi^* g)_{\alpha\beta}$, we suggest that the Planck area operates not as a pre-existing microscopic spatial grid, but strictly as the macroscopic geometric footprint of exactly one unit (one bit) of mutual information across the localized Markov Blanket. G_N is formally reinterpreted as the thermodynamic conversion scalar required to bridge dimensionless informational variance to the continuous spatial mapping of the equivalence class.

2. The Speed of Light (c) and the Null Geodesic: Rather than a kinematic velocity, c is defined as the global Lipschitz bound for the continuous holographic projection (Π) of the N-dimensional network. The equation $dx = c \cdot d\tau$ does not denote movement; it identifies the thermodynamic saturation point of this mapping, where the projected manifold reaches its maximum informational density.

3. Planck's Constant ($\hbar$): Within the modular flow (σ_τ), $\hbar$ is interpreted not as a dynamic quantum of action, but as the absolute scaling parameter that discretizes the continuous macroscopic equivalence classes back into the algebraic generators of the underlying verbless tensor network.

By reinterpreting these constants as the invariant scaling limits of a non-homeomorphic projection, we suggest that their exact roles are geometrically mandated to permit a finite capacity observer (C_{obs}) to render a self-consistent, locally Lipschitz 4D boundary from a dimensionless hyper-equilibrium.

3.4 The Recontextualization of Time-Dependent Physical Laws

Consequently, the framework fundamentally redefines the ontological status of universal physical laws. Within the verbless hyper-equilibrium, time-dependent differential equations (e.g., the geodesic equations of General Relativity, the Schrödinger equation) are mathematically stripped of dynamic, causal governance. They do not describe a temporal evolution of physical states. Instead, they strictly codify the geometric parameters of the observer's lossy holographic projection.

Specifically, the functional forms of these empirical laws map the exact topological signature of the bounded self-similarity. The classical "rates" of temporal change and the fundamental "constants" of nature correlate strictly with the specific mathematical type of the broken scale invariance combined with the rigid slope of the localized entropic gradient. Therefore, universal laws are not active forces acting upon matter; they are merely the invariant mathematical manifestations of the structural incompleteness dictated by the finite Shannon capacity (C_{obs}) of the macroscopic observer.

3.5 Comparative Advantages Over Dynamic Emergent Time Models

While contemporary quantum gravity architectures frequently map time as an emergent property, standard formalisms invariably retain implicit dynamic mechanics. The strictly static geometric derivation of $d\tau$ governed by bounded self-similarity offers distinct structural advantages over these established paradigms.

1. Beyond Quantum Reference Frames: The Page-Wootters mechanism [6] and modern Quantum Reference Frame (QRF) formalisms [43] successfully relativize temporal coordinates to the observer's quantum state. However, they mathematically preserve the time-evolution operator to map the global joint state. By strictly defining the observer as a localized topology bounded by C_{obs}, the current framework mathematically excises dynamic evolution entirely.[4] The macroscopic equivalence class is not a dynamic relational state, but the invariant geometric artifact of the Dimensional Partial Trace.

2. Static Topology vs. Complexity Growth: Holographic conjectures correlating temporal progression with quantum computational complexity [44,45] inherently invoke a dynamic temporal vector (e.g., the "growth" of the tensor network). The verbless geometry strictly inverts this dependency. Structural complexity (μ) does not dynamically expand; it is an invariant, pre-existing gradient defined by the incomplete self-similarity of the N-dimensional bulk. The 1D temporal index is merely the requisite projection of this static bounded scale invariance, stripping complexity of all dynamic thermodynamic variables.

3. Geometric Indexing vs. Thermal Flow: The Thermal Time Hypothesis [20] isolates emergent time via the modular automorphisms of a statistical KMS state, yet it fundamentally defines time as a resulting thermal "flow." In contrast, the formulation of $d\tau$ mapped herein demonstrates that the temporal parameter is devoid of active thermal kinematics. The entropic vector ∇S is strictly a static topological slope. The finite observer does not "flow" through thermal states; the boundary strictly necessitates a continuous 1D index to correlate the local asymmetry of the hyper-equilibrium's structural constraints.

3.6 Boundary Limits: Trivial Submanifolds and the Null Geodesic

The formal validity of the derived temporal metric ($d\tau$) is confirmed by evaluating its structural limits—specifically, the zero bound of the finite Shannon capacity ($C_{obs} = 0$). This absolute limit strictly defines the topological coordinate of a massless quantum (e.g., a photon), deriving the null geodesics and momentum of Special Relativity purely from static information geometry.

1. The Trivial Submanifold and the Absence of Depth A topological coordinate defined by $C_{obs} = 0$ constitutes a trivial submanifold. Because it possesses zero informational capacity, it structurally lacks the recursive nesting of Markov Blankets. Consequently, its structural depth is universally flat ($\mu = 0$). It is a pure relational coordinate within the N-dimensional hyper-equilibrium, entirely devoid of the autopoietic architecture required to establish conditional independence.

2. The Collapse of the Macroscopic Equivalence Class The continuous 4D macroscopic projection is strictly the mathematical artifact of the Dimensional Partial Trace. Because a trivial submanifold ($C_{obs} = 0$) possesses no capacity, the execution of the Dimensional Partial Trace is mathematically impossible. Without this coarse-graining operation, the macroscopic

[4] **The Mathematical Arbitrariness of Dynamic Relational Time:** Standard relational approaches to the canonical Wheeler-DeWitt equation ($\hat{H}|\Psi\rangle = 0$), most notably the Page-Wootters mechanism and modern Quantum Reference Frame (QRF) formalisms, argue that dynamical evolution emerges conditionally between entangled subsystems. However, recovering continuous dynamic evolution requires the implicit injection of a unitary evolution operator ($U = e^{-iHt}$) mapping the continuous phase variance of the reference subsystem. This assumes the relational clock possesses infinite informational resolution to track continuous unitary flow. When subjected to the strict mathematical bound of a finite Shannon capacity ($C_{obs} < \infty$), infinite resolution is impossible. The system mathematically requires a Dimensional Partial Trace, rendering continuous unitary dynamics unresolvable. Therefore, interpreting the relational variance between subsystems as "dynamical evolution" is an artifact of implicitly assuming an unbounded reference frame. When strictly bounded by C_{obs}, the relational variance mathematically collapses into a purely static structural gradient (∇S). The elimination of the dynamic operator is not philosophically motivated; it is the strict mathematical necessity of mapping the global discrete hyper-equilibrium ($\hat{H}_N|\Psi_N\rangle = 0$) through a finite informational boundary.

equivalence class structurally cannot exist. The coordinate remains entirely uncompressed within the local topology.

3. The Geometric Derivation of the Null Geodesic ($d\tau = 0$) and Lipschitz Saturation: By applying this absolute limit to the derivation of the temporal index, the verbless geometry strictly necessitates the relativistic properties of the photon. Because the trivial submanifold possesses no structural depth ($\mu = 0$), the internal geometric variance is strictly $d\mu = 0$. Simultaneously, the absence of capacity ($C_{obs} = 0$) renders the localized generation of a proper temporal index mathematically undefined for the coordinate itself.

Within the continuous 4D projection of a macroscopic observer ($C_{obs} > 0$), the absence of internal recursive depth ($\mu \approx 0$) structurally precludes an internal temporal index. This absolute geometric deficit restricts the Dimensional Partial Trace, confining the entity's informational variance entirely to the spatial axes and saturating the global Lipschitz bound ($dx = c \cdot d\tau$).

Therefore, what classical Special Relativity defines as the invariant null geodesic (where proper time ceases) is strictly defined as the invariant topological signature of a $C_{obs} = 0$ coordinate. It is a trivial submanifold whose strict lack of capacity forces its macroscopic projection to ride the thermodynamic edge of the continuous constraint manifold, inherently yielding the zero physical spacetime interval ($ds^2_{physical} = 0$).

4. The Geometric Derivation of Momentum for Null Submanifolds The absolute limit of zero capacity ($C_{obs} = 0$) further necessitates a strictly static redefinition of momentum. Because the trivial submanifold lacks internal structural depth ($\mu = 0$) and possesses no nested Markov Blankets, it is geometrically incapable of localizing internal relational data (the topological equivalent of rest mass). Consequently, its entire informational metric is distributed as external structural variance across the N-dimensional bulk.

Within the continuous 4D macroscopic projection of a finite observer ($C_{obs} > 0$), this uncompressed external variance is strictly mapped as a spatial gradient, or static topological periodicity. What classical physics defines as the momentum of a massless quantum ($p \propto \lambda^{-1}$) is mathematically stripped of kinematic velocity. It is formally redefined as the invariant geometric measure of this static spatial periodicity. Because the trivial coordinate cannot render an internal temporal index ($d\tau = 0$), the Dimensional Partial Trace forces its informational distance strictly onto the spatial axes of the macroscopic equivalence class, structurally manifesting as pure geometric momentum without dynamic propagation.

3.7 Rest Mass and Gravity as Epistemic Artifacts

Having geometrically defined the null geodesic ($m = 0$) as the thermodynamic limit of a trivial submanifold ($C_{obs} = 0$), the physical parameter of rest mass ($m > 0$) must be mathematically established without invoking pre-existing physical substance. Within the verbless framework, mass is strictly redefined as the *entropic residue* of the Dimensional Partial Trace.

When the observer's finite capacity (C_{obs}) necessitates the algebraic restriction of a dense, highly entangled topological sub-network within the hyper-equilibrium, the unmapped $N - 4$ relational degrees of freedom are mathematically sequestered. This geometric truncation structurally necessitates that the uncompressed structural depth (μ) manifests on the observer's 4D continuous boundary strictly as localized von Neumann entanglement entropy (S_{vN}).

Theorem 3 (The Entropic Equivalence of the Traced Bulk). *The algebraic restriction of the global pure state to the observer's finite subalgebra ($\mathcal{A}_{obs}$) uniquely defines a dimensionless modular Hamiltonian $K \equiv -\ln \rho_{obs}$. Scaled by the invariant Unruh-de Sitter temperature (T) of the constraint manifold, the macroscopic energy expectation structurally necessitates the identity $\langle E \rangle = T \cdot S_{vN}$.*

Proof. When the global pure state is restricted to the observer's finite subalgebra ($\omega_{local} = \omega|_{\mathcal{A}_{obs}}$), the resulting mixed state ρ_{obs} is governed by Tomita-Takesaki modular theory. For a localized, traceable subsystem, this formalism intrinsically defines the dimensionless modular

Hamiltonian K directly via the localized density matrix as $K \equiv -\ln \rho_{obs}$. Consequently, the localized state natively assumes the exponential form $\rho_{obs} = e^{-K}/Z$ (where Z is the partition function), yielding the exact functional form of a thermal Gibbs state without invoking pre-existing thermodynamic kinematics.

Evaluating the von Neumann entanglement entropy of this restricted state yields a strict mathematical identity:

$$S_{vN} = -\mathrm{Tr}(\rho_{obs} \ln \rho_{obs}) = \langle K \rangle \tag{20}$$

To map this dimensionless algebraic operator into the continuous 4D macroscopic equivalence class, K must scale by the thermal parameter of the induced KMS state. Crucially, to preserve the Lorentz invariance of rest mass, this parameter T is not an arbitrary local fluctuation; it is the invariant Unruh-de Sitter temperature associated with the observer's macroscopic constraint manifold ($T \propto \hbar g_0 / k_B c$).

Substituting the physical macroscopic energy E via $K = E/T$, the modular expectation evaluates to:

$$S_{vN} = \frac{\langle E \rangle}{T} \implies \langle E \rangle = T \cdot S_{vN} \tag{21}$$

□

Remark 3: Quantum Landauer Analogue. Within the verbless context of the Dimensional Partial Trace, the mathematical exclusion of the $N - 4$ bulk degrees of freedom constitutes a formal static quantum erasure operation. The derivation above proves that this informational exclusion intrinsically satisfies a strict thermodynamic equivalence for the localized boundary, functioning as a quantum information-theoretic analogue to Landauer's Principle [46].

Corollary 1 (Rest Mass as Entropic Residue)**.** *By equating this topological boundary limit to the macroscopic energetic equivalence $E = mc^2$, the scalar parameter of rest mass is strictly defined as $m = \frac{T}{c^2} S_{vN}$.*

Concurrently, the continuous 4D macroscopic projection intrinsically satisfies the localized energetic equivalence $E = mc^2$. Equating these bounding limits yields the rest mass relation. Therefore, a massive fundamental particle is not composed of denser physical material. Rest mass is exactly the localized epistemic artifact of the hyper-equilibrium—the static geometric deformation generated when a highly concentrated non-associative topological knot structurally resists the associative Quaternionic projection ($C\ell^{+}_{3,0}$).

Consequently, the phenomenon of macroscopic gravity must be redefined devoid of attractive kinematics. Aligning with and structurally extending the foundational thermodynamic formalisms of Jacobson [47] and Verlinde [48], gravity does not exist as a fundamental force or a dynamic boson exchange. It is strictly the *static geometric strain* of the continuous macroscopic projection.

Because the macroscopic spatial metric ($G_{\alpha\beta}$) is the continuous pullback of the statistical Fisher Information Metric, physical distance is an emergent measure of structural distinguishability. The localized entropic residue (S_{vN}) of a massive knot constitutes a steep informational gradient (∇S). The continuous boundary must structurally deform to satisfy the Shannon capacity limit (C_{obs}) around this unmapped complexity. What General Relativity models as spacetime curvature is, therefore, precisely the mathematical scale adjustment of the observer's epistemic map accommodating the localized failure of the dimensional partial trace.

4 Resolving Geometric Paradoxes via the Partial Trace

Within a static hyper-equilibrium, the apparent paradoxes of quantum mechanics—traditionally attributed to temporal discontinuities or non-local interactions—are recontextualized as strict topological artifacts. They are rendering limitations inherent to the Dimensional Partial Trace executed by the finite boundary of the localized observer.

4.1 The Quantum Zeno Effect as a Geometric Focal Lock

In standard quantum mechanics, the Quantum Zeno Effect [49] dictates that continuous or highly frequent observation of a system effectively suppresses its coherent temporal evolution. While the predictive formalism of this phenomenon via projection operators (P_n) is well-established, the Finite Observer Theory proposes a fundamental ontological reinterpretation. Rather than a dynamic halting of time, this limit is recognized as a direct manifestation of the observer's static algebraic boundary, formally governed by the complete verbless constraint ($\mathcal{L}_t \rho_{obs} = 0$ and $\mathcal{L}_t G_{\alpha\beta} = 0$).

Rather than viewing the Zeno effect as a dynamic interruption of an evolving system, we introduce the geometric concept of **Focal Lock**. We formally define a Focal Lock as the strict topological boundary condition where the continuous localized sampling of a single algebraic state actively suppresses the generation of the macroscopic temporal metric component.

As derived in Section 3.2, macroscopic time (τ) is not a background prior; it emerges strictly as the thermodynamic conjugate parameter of the modular automorphism group (σ_τ) via the KMS condition. This modular flow requires a non-zero structural gradient (∇S) to define its 1-parameter group across the constraint manifold.

When an observer performs a continuous measurement, the localized algebraic boundary ($\mathcal{A}_{obs}$) is tightly constrained to a single, static informational eigenvalue. By preventing the localized state from integrating over the adjacent network topology, the thermodynamic gradient is forced to zero ($\nabla S = 0$).

Because the temporal metric component is defined by the Legendre transformation as $G_{\tau\tau} = -(U_{SS})^{-1}$, driving the informational variance to zero mathematically prevents the emergence of the conjugate variable τ. Therefore, under a Focal Lock, the system does not "freeze in time." Instead, the strict geometric boundary conditions of the continuous observation simply fail to generate the macroscopic temporal dimension for that specific localized subspace. The standard predictive mathematics of the Zeno effect are preserved, but they are substantively recontextualized as the localized topological failure of the dimensional partial trace, rather than a dynamic physical intervention.

4.2 The EPR Paradox and the Tsirelson Bound

Macroscopic entanglement, traditionally viewed through the EPR paradox as "spooky action at a distance," implies a temporal communication between spatially separated particles. The Finite Observer Theory proposes discarding local realism and temporal causality entirely, treating entangled systems strictly as singular, unseparated nodes within the static Tensor Network.

Einstein's hypothesis of local hidden variables assumes an objective classical parameter, λ. John Stewart Bell [50] demonstrated that the existence of λ enforces the CHSH inequality across local structural measurements, where E denotes the quantum expectation value of joint measurements performed by two observers using respective detector settings a, a' and b, b':

$$|E(a,b) + E(a,b') + E(a',b) - E(a',b')| \leq 2 \tag{22}$$

However, the static geometry of a maximal Bell state, such as $|\Phi^+\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$, mathematically yields the Tsirelson bound [51] of $2\sqrt{2}$.

We suggest this structural violation confirms the absence of independent objective properties prior to the imposition of a finite observer boundary. The spatial "separation" of the particles is modeled as an emergent artifact of the 4D macroscopic projection. The physical reality is a single, continuous tensor geometry. The localized classical properties are strictly the entropic residue of the finite capacity of the observer's Markov Blanket, a boundary that structurally necessitates the algebraic restriction of the global state to the local measurement subalgebra ($\omega_{local} = \omega|_{\mathcal{A}_{obs}}$). This operation yields a maximally mixed classical state locally, while the global geometry of the Tensor Network remains statically intact.

The Topological Preservation of the Markov Blanket: Standard quantum information critiques assert that macroscopic entanglement fundamentally breaks the conditional independence required by a classical Markov Blanket. Within the verbless framework, this is resolved by formalizing the Markov Blanket ($\mathcal{B}$) not as a physical partition within 4D spacetime, but as a purely informational partition within the uncompressed N-dimensional network.

Within the ontological hyper-equilibrium, these entangled states strictly constitute the exact same topological node. We formally redefine entanglement as the geometric artifact of the localized algebraic restriction mapping a single higher-dimensional coordinate onto multiple lower-dimensional spatial axes—a phenomenon we term *topological aliasing*.

To distinguish this mechanism from an ordinary non-injective projection (a standard many-to-one mapping resulting from coarse-graining), we define topological aliasing as a strictly *one-to-many multivalued relation* mathematically dictated by an informational bottleneck. Analogous to the Nyquist-Shannon sampling limit [52], the finite capacity (C_{obs}) imposes a strict topological "sampling rate" on the macroscopic projection. When the structural density of a single bulk node exceeds the isometric embedding capacity of the 4D continuous lattice, the mapping π undergoes an aliasing fold. The singular bulk entity v_{EPR} is projected into the 4D manifold as a disjoint union of spatially separated macroscopic coordinates: $\pi(v_{EPR}) \mapsto \{x_A, x_B\}$.

Consequently, the localized capacity bound (C_{obs}) establishes a strict Markov Blanket that partitions informational dimensions, not spatial volumes. Conditional independence $P(\mu|\eta, \mathcal{B}) = P(\mu|\mathcal{B})$ is preserved because the macroscopic correlation does not dynamically pierce the blanket; the observer's limited capacity is simply projecting a singular external node into multiple internal spatial coordinates simultaneously.

To classify this quantum non-locality not merely as a restatement of facts, but as a mathematically necessary localized failure of the Lipschitz condition ($K \to \infty$), we evaluate the projection mapping π.

Proposition 2 (Topological Aliasing and Lipschitz Divergence)**.** *If a pure bipartite state within the hyper-equilibrium ($ds_{info} = 0$) is mapped to disjoint spatial coordinates within the 4D macroscopic projection ($d(x_A, x_B) > 0$), the required local bounding constant K of the continuous surjection diverges to infinity. Macroscopic spatial separation of entangled nodes strictly represents a topological aliasing fold, not internal geometric variance.*

Proof. **Step 1: The Microscopic Informational Distance.** Let an entangled pair of nodes, A and B, be defined as a strictly pure bipartite state $|\psi_{AB}\rangle$ within the uncompressed N-dimensional hyper-equilibrium. Because the state is pure, its joint von Neumann entropy is zero ($S_{AB} = 0$). In the underlying Fisher Information geometry, the informational distance ds_{info} is bounded by their conditional entropy. For a maximally entangled pure state, the mutual information entirely cancels their individual marginal entropies. Consequently, the Fisher metric tensor evaluates to exactly zero:

$$ds_{info}(\theta_A, \theta_B)^2 = g_{ij} d\theta^i d\theta^j = 0 \tag{23}$$

This zero-distance is an invariant, absolute topological fact of the hyper-equilibrium.

Step 2: The Macroscopic Spatial Projection (Topological Aliasing). The spatial coordinates x_A and x_B do not belong to the global hyper-equilibrium; they are emergent thermodynamic variables generated by the observer's dimensional reduction over the unobservable bulk. When the entangled node interacts with distinct macroscopic measuring apparatuses residing in thermodynamically distinct environments, the projection $\pi : \Theta \to \mathcal{M}_{4D}$ must map the single microscopic node to both local coordinates to preserve informational conservation without violating the local capacity limit C_{obs}. Because the continuous spatial mapping anchors the node to distinct thermodynamic equivalence classes, it structurally manifests the multivalued aliasing relation, dictating a non-zero physical distance:

$$d(x_A, x_B) = \int_{x_A}^{x_B} \sqrt{\gamma_{ab} dx^a dx^b} > 0 \tag{24}$$

Step 3: The Divergence of the Lipschitz Constant. The macroscopic mapping π is formally defined as a globally Lipschitz continuous surjection bounded by the speed of light c, requiring $d(x_A, x_B) \leq c \cdot ds_{info}(\theta_A, \theta_B)$. However, substituting the derived distances for the pure bipartite state yields:

$$d(x_A, x_B) \leq c \cdot 0 \implies d(x_A, x_B) \leq 0 \tag{25}$$

This mathematically contradicts the thermodynamic requirement that $d(x_A, x_B) > 0$. Therefore, the required local bounding constant K strictly diverges to infinity:

$$\lim_{ds_{info} \to 0} \frac{d(x_A, x_B)}{ds_{info}} = \infty \tag{26}$$

Ultimately, the surjection π does not "stretch" the underlying bond; rather, the mapping structurally breaks down due to topological aliasing. The macroscopic spatial distance $d(x_A, x_B)$ is a thermodynamic illusion rendered around the nodes, while their invariant geometric relationship remains $ds_{info} = 0$, unmediated by the continuous metric $G_{\alpha\beta}$. □

4.3 Multi-Observer Decoherence and the Double-Slit Experiment

The measurement problem is traditionally framed as the physical collapse of a wave function induced by observation. In the hyper-equilibrium, wave-particle duality is resolved via Environmental Decoherence through the Dimensional Partial Trace, building upon the formalisms of Zeh [53] and Zurek [2].

Consider a static N-dimensional state of a Double-Slit geometry containing an initial observer (Observer A) whose Markov Blanket correlates with the path geometry of the photon. The uncompressed global topology is a joint macroscopic entanglement structure:

$$|\Psi_N\rangle = \frac{1}{\sqrt{2}}\Big(|\text{slit}_1\rangle \otimes |A_1\rangle + |\text{slit}_2\rangle \otimes |A_2\rangle\Big) \tag{27}$$

Because Observer A's internal states encode the path distinction, they are strictly orthogonal: $\langle A_1|A_2\rangle = 0$.

A subsequent localized projection by Observer B (who interacts strictly with the recording screen at a different geometric coordinate) is structurally bounded by Observer B's finite Shannon capacity (C_{obs}). Observer B's Markov Blanket must formally trace out all unobservable degrees of freedom of the bulk, including Observer A. The localized state density relative to Observer B is:

$$\rho_B = \text{Tr}_{bulk_B}(\rho_N) \tag{28}$$

$$\rho_B = \frac{1}{2}|\text{slit}_1\rangle\langle\text{slit}_1|\langle A_1|A_1\rangle + \frac{1}{2}|\text{slit}_2\rangle\langle\text{slit}_2|\langle A_2|A_2\rangle + \text{cross terms} \tag{29}$$

Because $\langle A_1|A_2\rangle = 0$, all off-diagonal cross-terms representing structural interference mathematically evaluate to zero.

The geometric state relative to Observer B is strictly diagonalized:

$$\rho_B = \frac{1}{2}|\text{slit}_1\rangle\langle\text{slit}_1| + \frac{1}{2}|\text{slit}_2\rangle\langle\text{slit}_2| \tag{30}$$

There is no temporal collapse. The quantum interference geometry is simply sequestered within the hidden dimensions of Observer A's boundary. Observer B's required Partial Trace structurally excludes these hidden dimensions, dictating a 4D macroscopic equivalence class strictly characterized by a classical, diagonalized particle distribution.

The structural consistency between Observer A and Observer B within this double-slit topology is a direct mathematical manifestation of the bounded objectivity defined in Section 1.3. As both macroscopic observers are defined by equivalent capacity constraints (C_{obs}), their respective dimensional partial traces map the underlying N-dimensional interference geometry into the exact same macroscopic equivalence class.

Consequently, the observers perfectly align on the diagonalized particle distribution—not through the mutual perception of a pre-existing classical state within an objective background, but because their shared topological boundaries enforce mathematically coincident thermodynamic macrostates.

4.4 Removing Temporal Causality from the Delayed-Choice Quantum Eraser

The Delayed-Choice Quantum Eraser, proposed by Wheeler [54] and realized by Kim et al. [55], presents a severe paradox in dynamic models, as a "future" measurement choice appears to retroactively rewrite a "past" photon trajectory.

Under a verbless geometry, temporal causality is absent. The entire experimental apparatus, from the initial photon emission to the macroscopic detectors, does not evolve through a background space. It constitutes a localized, static topological sub-network of the absolute discrete state $|\Psi_N\rangle$.

In the formalism of a static density matrix, the structural pattern at the signal screen is not a physical object rendered in the past. It is strictly a conditional probability extracted from the underlying tensor network: $P(x_{\text{signal}} \mid M_{\text{idler}})$. The "choice" executed at the idler detector mathematically defines the specific projection basis $\{\Pi_i\}$ for the observer's Partial Trace.

The mathematical trace over the idler's path information strictly correlates with a diagonalized state for the signal, removing structural interference. Conversely, tracing onto an entangled basis preserves the off-diagonal geometry. The 4D holographic history is an emergent snapshot defined instantly and entirely by the topological angle of the observer's trace, strictly devoid of retroactive causality or temporal flow.

4.5 Operational Divergence and Predictive Limits

Standard critiques of geometric interpretations of quantum mechanics assert that such frameworks merely relabel existing mathematical formalisms without generating novel predictions. However, the resolution of quantum paradoxes within the verbless framework is not a semantic reinterpretation; it is a strict geometric derivation that diverges operationally from standard dynamic collapse models.

Because phenomena such as the Quantum Zeno effect, macroscopic entanglement, and delayed-choice non-locality are derived entirely as static geometric artifacts of the Dimensional Partial Trace, the framework predicts a strict, measurable threshold for their breakdown. Standard quantum mechanics attributes the loss of quantum coherence at macroscopic scales strictly to dynamic environmental decoherence (e.g., thermal fluctuations and unmonitored environmental interactions).

In direct contrast, the verbless framework predicts that quantum non-locality and Zeno stabilization will mathematically saturate and geometrically sever precisely when the structural informational density of the measured system and apparatus exceeds the defined epistemic capacity bound (C_{obs}), *independent of the system's thermal isolation.*

This yields a strictly falsifiable empirical divergence: the macroscopic boundary of entanglement is governed by informational topology, not thermodynamic heat transfer. If an experimental apparatus can perfectly thermally isolate a macroscopic system whose discrete structural degrees of freedom strictly exceed the localized macroscopic equivalence class bound, standard quantum mechanics predicts persistent macroscopic entanglement. The verbless geometry, however, strictly predicts a deterministic topological severance (loss of coherence) driven purely by the capacity trace. Thus, the quantum paradoxes are not simply relabeled; their operational limits are fundamentally redefined and rendered empirically testable.

5 Observer-Dependent de Sitter Holography

The holographic principle, traditionally posited as a projection from a universal spatial boundary at infinity, is fundamentally incompatible with a localized observer in a positive cosmological constant space. Within our framework, holography is not a universal background property, but a strictly localized, observer-dependent metric derived from the topological truncation of the Tensor Network.

5.1 The Infinite Perspective: MERA and Uncompressed Bulk Geometry

To establish the geometric baseline of the 4D holographic projection, we first define the theoretical limit of an infinite observer. At the mathematical limit where the Shannon Information Capacity approaches infinity ($\lim_{C_{obs}\to\infty}$), the necessity for the Dimensional Partial Trace vanishes.

Without the requirement for epistemic coarse-graining, the absolute discrete state $|\Psi_N\rangle$ constitutes the pure state of the hyper-equilibrium. In this limit, the global topology is realized as a verbless Tensor Network, sharing the exact graph-theoretic architecture of the Multi-scale Entanglement Renormalization Ansatz (MERA) developed by Vidal [56].

Standard critiques in quantum information often classify MERA strictly as a variational renormalization ansatz for computing many-body ground states. However, within the verbless framework, the integration of MERA is strictly ontological rather than computational. This is anchored in Swingle's formal correspondence demonstrating that the MERA tensor network exactly reproduces the spatial geometry of the anti-de Sitter (AdS) bulk. Therefore, MERA is not treated as a mathematical approximation of the universe; it is the exact, discrete structural baseline of the uncompressed N-dimensional hyper-equilibrium, where the physical entanglement structure and the bulk geometry are fundamentally equivalent.

Within this infinite topology, physical distance is an emergent illusion; the fundamental metric is entanglement entropy. The infinite observer identifies a finite subsystem not by a spatial enclosure, but purely through topological conditional independence within the network graph. If node A and node C are entirely mediated by node B, the mutual information conditional on B evaluates to zero: $I(A : C \mid B) = 0$. Node B is the mathematical definition of the Markov Blanket within the N-dimensional bulk. The 4D local reality is merely the compressed geometric shadow of the global topological structure.

5.2 Static Patch Holography and the Epistemic Horizon

In standard cosmological models, an observer in a de Sitter universe is bounded by a cosmological horizon, defining a localized "static patch." Conventional holographic approaches, stemming from the original Holographic Principle [57,58] and the AdS/CFT correspondence [59], struggle to define this finite region natively. Consequently, standard models often resort to dimensionally constrained boundary deformations—such as the $T\bar{T}$ deformation [60, 61]—to artificially truncate the bulk geometry.

We emphasize that the Finite Observer Theory entirely discards the need for such ad hoc boundary deformations. Aligning with the conceptual goals of Static Patch Holography [62], the finite region is natively derived as the exact geometric manifestation of the observer's finite Shannon Information Capacity (C_{obs}). The cosmological horizon is not a physical boundary expanding through space, nor an artificial mathematical truncation; it is the strict epistemic limit of the Dimensional Partial Trace.

As the observer's 4D macroscopic projection maps deeper into the N-dimensional structural bulk, the cumulative von Neumann entropy of the traced-out degrees of freedom increases. The cosmological horizon is mathematically defined as the exact topological coordinate where the mutual information required to resolve further discrete nodes exceeds the observer's maximum capacity bound. At this boundary, the Bekenstein-Hawking entropy of the horizon [63, 64] is strictly equal to the localized capacity:

$$S_{horizon} = \frac{\text{Area}_{horizon}}{4G_N} = C_{obs} \tag{31}$$

Beyond this geometric boundary, the inequality of the constraint manifold ($S \leq C_{obs}$) fails. The spatial coordinates do not physically end; rather, they mathematically cease to render within the localized 4D equivalence class. The bulk nodes beyond the horizon are completely traced out, collapsing into maximum macroscopic uncertainty.

Therefore, the de Sitter static patch is not a geometric container; it is the absolute informational volume of the localized topological sub-network. The horizon is simply the static thermodynamic shadow of the Markov Blanket, shielding the finite observer from the infinite structural density of the uncompressed hyper-equilibrium.

5.3 The Holographic Cutoff as the Bounded Partial Trace

In standard holographic dualities, moving the asymptotic boundary from spatial infinity to a localized finite cutoff often relies on mathematically complex, dimensionally constrained operators (such as boundary deformations). Within the verbless geometry of the Finite Observer Theory, we require no such external ad hoc mechanisms. The finite radial cutoff is strictly and natively generated by the algebraic restriction of the Dimensional Partial Trace.

When the finite Shannon capacity (C_{obs}) of the observer structurally restricts the hyper-equilibrium, the unobservable degrees of freedom of the $N-4$ bulk dimensions are mathematically traced out:

$$\rho_{obs} \equiv \pi_\omega \left(\omega|_{\mathcal{A}_{obs}}\right) \tag{32}$$

The exact geometric coordinate of this holographic cutoff is not an arbitrary boundary; it is a strict algebraic derivation from holographic entanglement entropy. The observer's finite capacity strictly bounds the localized von Neumann entropy: $S_{vN} \leq C_{obs}$.

Applying the Ryu-Takayanagi relation, the invariant informational bound establishes a maximal geometric area for the bulk minimal surface at a specific finite radial cutoff r_c:

$$\frac{\text{Area}(r_c)}{4G_N} \leq C_{obs} \implies \text{Area}(r_c) \leq 4G_N C_{obs} \tag{33}$$

Therefore, the localized holographic screen is established precisely where the geometric area of the tensor network saturates the Shannon capacity of the observer's Markov Blanket. The 4D macroscopic projection is simply the specific, localized holographic data mapped by this naturally truncated bounding surface, completely eliminating the need for dynamic or low-dimensional boundary deformations.

6 Cosmological Boundaries and Macroscopic Artifacts

To complete the Finite Observer Theory, the boundaries of the macroscopic universe—as well as its invisible anomalies—must be mapped strictly as topological features of the hyper-equilibrium, entirely devoid of temporal origin or physical expansion. Furthermore, to satisfy the rigorous demands of astrophysical observation, these assertions must correspond to specific structural limits within the information-geometric manifold, providing functional definitions and operational mappings to empirical data.

6.1 The Topological Poles: Coercivity, the C-condition, and the Apex

In a verbless geometry, the Big Bang is not a dynamic origin event requiring a prior causal mechanism; it is strictly defined as the "Apex" of the static structural shape—a topological inevitability. Because quantum entanglement entropy is fundamentally non-negative ($S_{vN} \geq 0$) for all valid density matrices, the macroscopic von Neumann entropy field $S_{vN}(x)$ mapped across the N-dimensional Tensor Network is mathematically bounded below.

One possible formal mechanism ensuring the existence of a global minimum for such a functional is derived from the direct method of the calculus of variations. Following the analytical framework established by Kourogenis and Papageorgiou [65], a locally Lipschitz functional that is bounded from below and satisfies the nonsmooth Cerami condition (C-condition) is inherently coercive. In this setting, the C-condition acts as a critical compactness-type requirement. By ensuring that minimizing sequences possess strongly convergent subsequences, it guarantees that the coercive structural landscape inherently attains at least one absolute minimizer, denoted as $\overline{x}$.

To operationalize this minimizer, the framework formally defines the Big Bang as the global minimizer of the structural entropy functional $S_{vN}[\mu]$, where μ is the 1D structural index. The absolute "origin" point of the 4D trace corresponds exactly to the coordinate where the Fisher Information Metric (g_{ij}) yields:

$$\nabla S_{vN}(\mu) = 0 \quad \text{and} \quad \frac{\partial^2 S_{vN}}{\partial \mu^2} > 0 \tag{34}$$

This mathematical limit represents absolute topological saturation, where the density of relational nodes precludes any lower-dimensional distinguishability. Thus, the Big Bang is defined operationally as the static topological boundary of the 4D projection.

Conversely, a Black Hole topology strictly delineates the opposing topological pole: the maximal entropic limit of the observer's capacity. The event horizon is the geometric surface where the local thermodynamic gradient reaches the absolute limit of the observer's finite Shannon Information Capacity (C_{obs}), bounding the maximal entropy via the Bekenstein-Hawking equation. However, as the spatial coordinate approaches the singularity, the Weyl invariant diverges, and the required mutual information approaches infinity:

$$C_{\alpha\beta\gamma\delta}C^{\alpha\beta\gamma\delta} \to \infty, \quad I(A:B) \to \infty \tag{35}$$

Because the observer's capacity C_{obs} is strictly finite, the relative capacity ratio drops to zero at this limit:

$$\lim_{I(A:B)\to\infty} \frac{C_{obs}}{I(A:B)} = 0 \tag{36}$$

At this exact coordinate, the density of mutual information forces the mathematical inequality of the constraint manifold to fail ($F > C_{obs}$). The singularity is simply a null boundary state—an informational horizon where the localized 4D holographic perception fundamentally ceases to render, even as the hyper-equilibrium continues beyond it.

6.2 Phenomenological Extension: The Hubble Tension as a Holographic Projection

As an interpretive application of the verbless constraint, we address the discrepancy between the local measurement of the Hubble constant ($H_0 \approx 73.0 \pm 1.0$ km/s/Mpc) [66, 67] and the early-universe CMB measurement ($H_{CMB} \approx 67.4$ km/s/Mpc) [68]. Standard cosmological models interpret this discrepancy as a potential crisis in the ΛCDM paradigm. Within the verbless framework, we propose that this divergence is not a kinematic measurement error, but the strict mathematical artifact of the Dimensional Partial Trace mapping an invariant informational capacity across different geometric dimensions.

In this geometry, the observer does not measure an objective, scale-invariant background expansion. Instead, the inferred Hubble parameter H is the inverse of the 1-dimensional macroscopic Hubble radius ($R_H \propto H^{-1}$), which structurally bounds the observer's available informational capacity (C_{obs}).

To geometrically extract the scaling relationship between these measurements without introducing arbitrary free parameters, we enforce the conservation of informational capacity across the dimensional partial trace. We assume that the discrete structural capacity of the hyper-equilibrium is projected at a constant density of exactly one bit per fundamental unit cell of the emergent macroscopic manifold.

We must explicitly distinguish between the physical regimes of these projections. For 2D holographic screens, we follow the standard Bekenstein-Hawking density of one bit per Planck area (ℓ_P^2). Conversely, for the 3D local bulk, physical tracers query the uncompressed spatial depth, necessitating a volumetric scaling of one bit per Planck volume (ℓ_P^3). While this latter scaling constitutes the anti-holographic regime that the holographic principle was specifically introduced to supersede, our framework proposes that the localized 4D projection is structurally necessitated precisely by the informational mismatch between these two scaling laws. The capacity-conservation step inherently compares a holographic boundary count with a volumetric bulk count; this fundamental asymmetry is the primary geometric basis that dictates the non-trivial expansion ratio, aligning conceptually with thermodynamic models where continuous cosmic space emerges via holographic equipartition [69].

Proposition 3 (Dimensional Conservation of Informational Capacity)**.** *If the finite observer's Shannon Information Capacity (C_{obs}) is strictly conserved across the Dimensional Partial Trace, the projection from a 2-dimensional holographic boundary to a 3-dimensional continuous bulk volume mathematically necessitates a divergent 1-dimensional scaling ratio between the early-universe and local macroscopic expansion rates.*

Proof. To extract the capacity cardinality, we model the early-universe measurement (H_{CMB}) as mapping strictly to the 2-dimensional holographic boundary. Rather than utilizing the full spherical surface area ($4\pi R^2$), the appropriate 2D measure is the area of the unit disk (πR_{CMB}^2). This physically represents the cross-sectional area of the observer's past light cone projected onto the CMB surface—the exact informational shadow accessible to the localized observer.

By normalizing the boundary Hubble radius to unity ($R_{CMB} = 1$), the invariant capacity evaluates to:

$$C_{obs} = \pi (R_{CMB})^2 = \pi \tag{37}$$

Conversely, the local universe measurement (H_0), calibrated via Cepheids and Type Ia Supernovae, operates within the immediate spatial depth of the observer. To conserve this invariant cardinality within the 3D local projection, the volume of the local Hubble sphere must satisfy:

$$\frac{4}{3}\pi (R_{local})^3 = \pi \tag{38}$$

By isolating R_{local}, we geometrically extract the required 1-dimensional strain of the projection:

$$(R_{local})^3 = \frac{3}{4} \implies R_{local} = \left(\frac{3}{4}\right)^{1/3} \tag{39}$$

Because the macroscopic expansion rate H is formally defined as the inverse of this 1D geometric scale ($H \propto R_H^{-1}$), the ratio of the local expansion rate to the CMB expansion rate evaluates strictly to the inverse of R_{local}:

$$H_{local}^{ideal} = H_{CMB} \cdot (R_{local})^{-1} = H_{CMB} \cdot \left(\frac{4}{3}\right)^{1/3} \tag{40}$$

Evaluating this pure geometric constant yields $(4/3)^{1/3} \approx 1.10064$. When applied to the baseline CMB measurement ($H_{CMB} \approx 67.4$ km/s/Mpc), the idealized isotropic projection geometrically evaluates to a local expansion rate of:

$$H_{local}^{ideal} \approx 67.4 \times 1.10064 \approx 74.18 \text{ km/s/Mpc} \tag{41}$$

□

This geometrically extracted isotropic baseline sits just above the central SH0ES local distance ladder measurement (73.04 ± 1.04 km/s/Mpc) [67]. Crucially, we emphasize that this framework does not treat the empirical deviation ($\approx 1.56\%$) as a predictive failure. Instead, we execute a formal epistemic shift: we utilize the empirical measurement of H_0 as an inverse mathematical gauge to physically measure the *topological asymmetry* of the observer's local constraint manifold.

Corollary 2 (The Hubble Tension as a Topological Gauge)**.** *The empirical deviation between the geometric isotropic baseline and the measured local Hubble constant (H_0) strictly quantifies the volumetric deficit of the observer's localized topological constraint manifold, directly mapping its oblate geometric asymmetry.*

Proof. The idealized calculation inherently assumes a perfectly symmetric, isotropic continuous unit ball. However, the localized observer ($\mathcal{A}_{obs}$) does not reside in a perfectly homogeneous void [70]. The observer is anchored to a highly dense, asymmetric topological node within the underlying tensor network.

By the isoperimetric inequality, for a fixed boundary capacity (C_{obs}), the geometric shape that encloses the maximum 3-dimensional volume is a perfect sphere. Because the observer's localized constraint manifold is strictly asymmetric, it geometrically dictates a sub-maximal enclosed volume ($V_{local} < V_{ideal}$).

By setting the inverse macroscopic expansion rate to scale with the projected radius, the measured empirical ratio strictly defines the volumetric deficit of the local topological constraint:

$$\frac{V_{local}}{V_{ideal}} = \left(\frac{73.04}{74.18}\right)^3 \approx 0.9546 \tag{42}$$

This calculation formally measures that the observer's localized constraint manifold encloses approximately 4.54% less volume than a perfect sphere of identical surface area. As an oblate spheroid represents the highest-entropy geometric deformation from a perfect sphere under directional strain, we model this local structural deformation to first order with axes $a = b > c$. Enforcing the constant boundary area against this volume deficit geometrically restricts the axis ratios.

The analytical solution yields an equatorial-to-polar axis ratio (c/a) of approximately 0.66, or $2 : 3$. This provides a highly suggestive geometric alignment: astronomical mappings of the observer's actual local environment (e.g., the Local Sheet and the Laniakea Supercluster) independently confirm it is a highly flattened, oblate structure [71]. □

Consequently, the 73.04 km/s/Mpc measurement is not a kinematic anomaly. It is the directly observable structural signature of an invariant informational capacity mapped from within an oblate local topology possessing a roughly $3 : 2$ aspect ratio. Under this analytical lens, the Hubble tension offers a novel interpretive framework: rather than strictly requiring dynamic accelerating fields, the discrepancy allows us to empirically map the invariant topological strain of the finite observer.

6.3 Topological Inversions and Hidden Strains: Antimatter and Dark Matter

As a concluding structural consequence, the hidden geometric artifacts of the 4D projection—antimatter and dark matter—are formally derived directly from the topological limits of the Dimensional Partial Trace.

Antimatter: In a static block, the negative energy states yielded by the Dirac equation [72] represent an inverted geometric normal within the Tensor Network. When a matter node and an antimatter node intersect at the same coordinate, their inverted topologies perfectly sum to zero ($1 + (-1) = 0$). The 4D spatial illusion is absent at that coordinate, leaving the geometry strictly as uncompressed mutual information, which the observer interface maps as high-frequency gamma radiation.

Dark Matter: When the observer's $k = 4$ trace maps a localized galactic structure, it mathematically distances the $N - 4$ bulk dimensions from the 4D projection. The framework identifies apparent Dark Matter [73] not as a weakly interacting particulate mass, but strictly as the gravitational shadow of these unobservable dimensions.

This is directly grounded in observable astrophysics via the Radial Acceleration Relation (RAR) [74] in galaxy rotation curves. The framework predicts that the anomalous gravitational potential Φ_{dark} scales with the entanglement entropy S_{vN} of the visible baryonic mass.

Ultimately, because the Dimensional Partial Trace constitutes a static algebraic exclusion of bulk structural information, the resulting macroscopic spatial projection is characterized by a fundamental geometric deficit. Within this framework, we propose that apparent "Dark Matter" is precisely the macroscopic manifestation of this unmapped higher-dimensional entanglement—the invariant topological "elasticity" inherent in the static embedding of discrete baryonic nodes into a continuous 4D constraint manifold.

As detailed analytically in Section 7, the bounded informational scale (g_0) of this trace structurally coincides with galactic rotation curves. This reinterprets the discrepancy in radial acceleration not as the dynamic gravitational influence of non-baryonic particulate mass, but strictly as the zero-parameter geometric signature of the observer's finite holographic capacity limit.

7 Empirical Predictions and Falsifiability

A rigorous physical framework must yield testable predictions that distinguish it from existing models. While the verbless information geometry of the Finite Observer Theory mathematically recovers the standard formulations of General Relativity and quantum mechanics as epistemic limits, it explicitly diverges from the ΛCDM cosmological model regarding macroscopic boundary phenomena. Building upon the functional derivations established in Section 6, the framework is strictly falsifiable through the following observational parameters:

7.1 The Deep MOND Limit and the Geometric Mean of Dimensional Compression

Within the verbless framework, standard Newtonian gravity operates efficiently only when the localized topological density of the baryonic matter (g_{bar}) remains strictly below the observer's 2D holographic capacity bound (C_{obs}). When analyzing galactic rotation curves, the structural variance of the galactic bulk vastly exceeds this localized threshold. The Dimensional Partial Trace is mathematically necessitated, projecting the 3D internal tensor volume ($V \propto r^3$) onto the 2D macroscopic constraint surface ($A \propto r^2$).

As extensively documented in the literature [75–78], the empirical MOND acceleration scale ($g_0 \approx 1.2 \times 10^{-10}$ m/s^2) exhibits a well-established numerical coincidence with the Unruh temperature of the cosmological horizon: $g_0 \approx cH_0/2\pi$. Within our framework, we do not present this relation as a novel derivation; rather, we propose that this established phenomenological coincidence is the strict, unavoidable boundary condition of the verbless macroscopic projection.

To formally derive the interpolating function governing this deep MOND regime ($g_{bar} \ll g_0$) without conflating local baryonic mass with global cosmological scales, we evaluate the macroscopic gravitational gradient as the informational centroid of the constraint manifold.

We identify two invariant topological limits mapping the structural bounds of the observer's equivalence class:

1. **The Local Source Limit (g_{bar}):** The uncompressed Newtonian gradient, $g_{bar} = GM/r^2$, representing the structural information strictly governed by the local baryonic mass M.

2. **The Global Boundary Limit (g_0):** The global Lipschitz bounding acceleration of the manifold, $g_0 \approx c^2/R_H$. This scale is a pure geometric property of the cosmological horizon (R_H) and is strictly independent of any local baryonic mass.

Proposition 4 (The Fisher Centroid of the Macroscopic Gradient)**.** *Let the macroscopic spatial metric be the continuous pullback of the statistical Fisher Information Metric. Under a state of maximal structural uncertainty between the local baryonic gradient (g_{bar}) and the global bounding acceleration (g_0), the application of a non-informative Jeffreys prior over the hyperbolic Fisher Information metric uniquely evaluates the effective macroscopic gradient as the geometric mean: $g_{obs} = \sqrt{g_{bar} \cdot g_0}$.*

Proof. To determine the exact algebraic form of the observer's effective macroscopic gradient (g_{obs}), we refer to the foundational premise of this framework: the macroscopic spatial metric is the continuous pullback of the statistical Fisher Information Metric (Section 2.4). Because gravitational acceleration (g) fundamentally characterizes the gradient of the structural entropy across the network, it mathematically operates as the statistical scale parameter for the localized distribution of microstates.

Because the unobservable $N-4$ bulk is traced out, the effective macroscopic gradient g_{obs} mapped by the observer is subject to a massive loss of microstate information. In the deep MOND regime ($g_{bar} \ll g_0$), the local baryonic gradient evaluates below the global Lipschitz acceleration bound of the manifold (g_0). At this topological limit, the informational signal of the local source is submerged beneath the thermodynamic background of the cosmological horizon.

Because the finite Shannon capacity (C_{obs}) of the macroscopic observer cannot resolve a local structural signal weaker than the global bounding scale of the metric, a specific coarse-graining condition is mathematically necessitated: the observer loses the epistemic capacity to differentiate between the local baryonic source and the global horizon as distinct geometric bounds.

Under this regime of maximal uncertainty, inference regarding the effective scale parameter must utilize a non-informative Jeffreys prior, which is naturally uniform in $\log g$. Applying the principle of maximum entropy to this coarse-grained state, the macroscopic gradient of least structural bias uniquely evaluates to the exact informational centroid (the Fréchet mean) of the parameter space.

Because the invariant metric tensor for a statistical scale parameter is hyperbolic ($ds^2 \propto dg^2/g^2$), the geodesic distance function between any two gradients is logarithmic: $D(g_A, g_B) = |\ln(g_A) - \ln(g_B)|$.

To find the exact geodesic midpoint (g_{obs}) between the local baryonic source (g_{bar}) and the global bound (g_0), we equate their informational distances:

$$\ln(g_{obs}) - \ln(g_{bar}) = \ln(g_0) - \ln(g_{obs}) \tag{43}$$

$$2\ln(g_{obs}) = \ln(g_{bar}) + \ln(g_0) = \ln(g_{bar} \cdot g_0) \tag{44}$$

By exponentiating this relation, the effective gradient uniquely evaluates to:

$$g_{obs} = \sqrt{g_{bar} \cdot g_0} \tag{45}$$

This result constitutes the exact analytical Fréchet mean of the hyperbolic parameter space, functioning as a strict quantitative derivation rather than a qualitative approximation.

Consequently, this geometric constraint excludes alternative interpolations within the hyperbolic metric structure. The arithmetic mean ($\frac{g_{bar}+g_0}{2}$) and the harmonic mean ($2[g_{bar}^{-1} + g_0^{-1}]^{-1}$) arise as the Fr'echet means of flat Euclidean ($ds^2 \propto dg^2$) and inverse-square geometries, respectively. Applying them in the present setting would violate the underlying metric consistency. Because the parameter space of the continuous dimensional projection is hyperbolic, the effective gravitational gradient is uniquely determined by the geometric mean. □

This analytical derivation formally addresses the historical ambiguity of MOND interpolating functions and avoids the mass-scale conflation often found in phenomenological models. The galactic mass M resides strictly within the g_{bar} term, while the universal constant g_0 is derived independently from the manifold's geometric bound (c^2/R_H).

The geometric mean is not an arbitrary phenomenological choice; we propose it is the exact, mathematically unique resolution of a dimensional compression mapped over a hyperbolic Fisher Information manifold under the principle of maximum macroscopic entropy. Therefore, under this framework, the anomalous galactic rotation curves represent the direct geometric signature of the observer's holographic boundary enforcing its capacity limit.

Corollary 3 (The Falsifiability of the Baryonic Entanglement Bound)**.** *Any empirical observation of a galactic rotation curve where the anomalous acceleration profile violates the structural entanglement bound established by* $g_{obs} = \sqrt{g_{bar} \cdot g_0}$ *mathematically falsifies the static topological assumption of the Finite Observer Theory.*

7.2 Dark Matter as Baryonic Entanglement Shadow

Having mapped apparent dark matter as the macroscopic geometric strain of the $N - 4$ unobservable dimensions, the effective macroscopic stress-energy tensor representing this unseen structure is geometrically induced by the entanglement entropy of the localized baryonic matter.

This yields a strict predictive requirement: the apparent dark matter distribution within galactic halos cannot be arbitrary. The anomalous rotational velocities must scale strictly with the area-law entanglement entropy of the central baryonic mass, mirroring the exact Radial Acceleration Relation ($g_{obs} = \sqrt{g_{bar} \cdot g_0}$).

Falsifiability Condition: The theory is falsified if a statistically significant galactic rotation curve is observed that requires a dark matter halo distribution violating the specific structural entanglement bound of its internal baryonic matter.

7.3 The Big Bang Entropy Minimizer

The singularity of the Big Bang is formally replaced by a strictly defined mathematical minimizer representing maximum topological density and zero macroscopic distinguishability ($\nabla S = 0$).

Falsifiability Condition: Because the verbless geometry strictly forbids thermodynamic states beyond topological saturation, the framework is mathematically falsified if observational cosmological data (such as primordial gravitational wave signatures) confirms the existence of dynamic temporal states or structural evolution "preceding" the $\nabla S = 0$ threshold.

8 Conclusion: The Architecture of the Hyper-Equilibrium and Epistemological Synthesis

The quest for a unified theory of quantum gravity has long been stalled by the incompatible dynamic priors of General Relativity and Quantum Mechanics. The Finite Observer Theory breaks this deadlock by exploring the complete removal of dynamic time and a fundamentally continuous background, replacing them strictly with a bounded effective objectivity. By remapping the physical universe as a static, N-dimensional Tensor Network existing in perfect hyper-equilibrium, we bypass the necessity for a dynamic background, anchoring the ontology strictly to the timeless Wheeler-DeWitt equation.

Within this framework, the fundamental pillars of modern physics emerge strictly as topological artifacts of the observer's algebraic restriction:

1. **Spacetime and Dimensionality:** A 4-dimensional continuous phase space is proven to natively emerge as the unique geometric mapping of the global pure state's algebraic restriction to the observer's finite subalgebra ($\mathcal{A}_{obs}$). Within this localized trace, the temporal index is derived via the KMS condition's modular flow, while the 3 spatial dimensions are geometrically constrained by the non-negotiable associativity requirements of the observer's even Clifford subalgebra of spatial orientations ($C\ell_{3,0}^{+} \cong \mathbb{H}$).

2. **Mass and Gravity as Epistemic Artifacts:** By proposing a quantum information-theoretic analogue to Landauer's Principle, rest mass and macroscopic gravity are analytically derived not as fundamental physical substance or attractive forces, but strictly as the invariant entropic residue of the Dimensional Partial Trace.

3. **Quantum Non-Locality:** The EPR paradox and the Tsirelson bound are formally recontextualized not as "spooky action at a distance," but as *Topological Aliasing*—a strict, one-to-many multivalued projection mathematically dictated by the Shannon-Nyquist embedding limits of the constraint manifold.

4. **The Dark Sector:** The apparent missing mass of "Dark Matter" is analytically modeled as the exact informational centroid of the constraint manifold's macroscopic gradient. Because the parameter space is hyperbolic, this geodesic midpoint natively yields the empirical MOND relation without free parameters or mass-scale conflation. Concurrently, the Hubble Tension is mathematically resolved as the exact, parameter-free volumetric scaling of this projection, providing an empirical gauge to map the invariant oblate topological strain of the local observer.

The proposed mathematical architecture extends beyond the traditional boundaries of theoretical physics, establishing a formal geometric basis for epistemological paradigms that have remained purely philosophical for centuries. By anchoring the existence of the 4D macroscopic metric strictly to the localized boundary, the historical subject-object divide emerges as a structural artifact of the observer's topological constraint.

Because empirical explorations of the extended Wigner's Friend scenario strongly challenge the assumption of an observer-independent reality [11], the sensory states on the observer's Markov Blanket are not modeled as passively measuring a pre-existing universe; they strictly mandate its structural projection. This mathematically translates George Berkeley's subjective idealist maxim, *esse est percipi* [79], into strict information geometry, fulfilling John Archibald Wheeler's "It from Bit" ontology [80] by proving that every physical particle or field derives its explicit coordinate existence from the binary limits of the Partial Trace.

Furthermore, the framework translates Immanuel Kant's Transcendental Idealism [81] into explicit quantum information theory. The Kantian noumenon (the unknowable "thing-in-itself") is formalized as the uncompressed N-dimensional Tensor Network in hyper-equilibrium, fundamentally unobservable because its complexity strictly exceeds C_{obs}. The phenomenon is the localized 4D holographic projection, while Kant's inescapable "forms of intuition" are precisely the mathematical execution of the Partial Trace and its resulting thermodynamic metric rescaling.

This fundamentally aligns with Platonic Realism [82], where the holographic screen serves as the wall of the cave, classical mass and gravity constitute the lower-dimensional shadows (the entropic residue) of decoherence, and the global discrete state ($\hat{H}_N|\Psi_N\rangle = 0$) represents the absolute, uncompressed Realm of Forms. Ultimately, the Finite Observer Theory suggests that the deepest mysteries of the cosmos are not hidden in the stars, but are encoded directly within the geometric limitations of the lens we use to observe them.

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