Horizon-Layered Cosmology: From Black Hole Gravitational Collapse to Holographic Hierarchies

Anđelko Đermek

Abstract

This work presents horizon-layered cosmology, a conceptual yet rigorously argued framework that reinterprets black hole collapse as the origin of an emergent cosmological spacetime. It advances a physically motivated alternative to the classical picture of collapse, replacing the singular interior with a finite, null-ordered sequence of redshift-frozen layers that accumulate causally on the event horizon. The model demonstrates that the traditional view, of matter freely crossing the horizon toward a central singularity, is inconsistent with the full implications of relativistic time dilation and causal structure. Instead, each quantum of infalling matter becomes holographically encoded through discrete causal incorporation events, rendering the horizon a dynamic information surface with finite causal throughput governed by gravitational time dilation. Lateral coherence across Planck-scale cells sustains a null-synchronized code whose internal holographic projection manifests as an expanding universe, mirroring, in every essential feature, the behavior of our own cosmological spacetime. Curvature and gravitation arise from spatial gradients in causal throughput, while baryons, dark matter, and vacuum energy correspond to distinct coherence sectors of this code. Continued incorporation drives internal expansion without the need for an external dark-energy term. The model yields an internal age of approximately 13.4 Gyr and predicts that the observable Hubble domain encloses roughly half of the total internal mass. Conceptually, the horizon functions as a null-synchronized cellular automaton: global incorporations reindex adjacency on the horizon graph, while local lateral exchanges maintain coherence, reproducing relativistic kinematics and quantum measurement as bandwidth-allocation rules within a discrete causal network. If the parent black hole rotates, Kerr frame dragging imprints an azimuthal phase gradient on the holographic code, seeding a small matter–antimatter asymmetry and a preferred cosmic axis preserved through inflation. The binary structure of Planck-scale quanta provides a geometric foundation for fermionic spin, parity violation, and large-scale alignment, linking quantum spin, baryon asymmetry, and cosmological anisotropy to a single holographic–causal origin.

Linguistic refinement of this manuscript was assisted by AI; the theoretical framework and physical reasoning are original to the author.

Keywords: black hole; Schwarzschild geometry; holography; cosmology, cellular automaton

1 Introduction and Preface

Preface. This work is offered not as a finished theory but as a coherent framework, a starting point for reconceiving gravitational collapse and cosmological origin through a single informational principle. It challenges deeply held assumptions of classical relativity and quantum gravity, arguing that the event horizon is not merely a mathematical boundary but the physical generator of spacetime itself. The ideas presented here are intended to provoke, clarify, and unify, not to claim finality. If correct in even partial form, they imply that every black hole is a self-contained cosmological seed and that the universe we inhabit may itself be the internal projection of such a process.

Introduction. Black holes mark the most profound intersection of general relativity and quantum theory, revealing a persistent tension between geometric determinism and informational completeness. Classically, the collapse of a massive star culminates in a singularity enclosed by an event horizon, a region beyond which no causal signals can escape. Although mathematically consistent within general relativity, this view generates deep paradoxes: the fate of information, the physical status of the singularity, and the meaning of spacetime beyond external causal reach.

Horizon-layered cosmology introduces a new interpretation grounded in the external observer's frame. Here, gravitational time dilation near the Schwarzschild radius halts the apparent infall of matter in external coordinate time. While the infalling observer crosses the horizon in finite proper time, these two timescales are not independent; they are complementary facets of one causal structure linked by extreme dilation. From the external frame, the infaller's clock slows without bound; from the infaller's frame, the external universe accelerates without limit. Thus, the crossing never truly completes: matter asymptotically approaches the horizon, becoming encoded as successive null layers that evolve only as the black hole itself evolves. The "forward motion" toward the center proceeds only in synchrony with the gradual contraction or evaporation of the horizon, so that by the time the collapsing matter would reach the center in its own frame, the external black hole has already vanished. The event horizon, therefore, is not a spatial surface to be crossed but a temporally dynamic causal boundary whose null layering defines the joint evolution of the black hole and its internal universe.

Collapse, in this picture, is not a volumetric contraction toward a singularity but a surface process of *causal incorporation*: infalling matter and radiation progressively redshift and become null-ordered onto the horizon, which grows outward through accretion as a series of discrete, information-bearing strata. The horizon is thereby elevated from a passive boundary to an active, Planck-scale encoding surface, a dynamically layered quantum code that holographically generates the internal spacetime.

Since its inception, the holographic principle has been viewed mainly as an informational bound rather than a physical mechanism. In early formulations by 't Hooft [1] and Susskind [2], entropy was proposed to scale with surface area rather than volume. Maldacena's AdS/CFT correspondence [3] formalized this as a duality between gravitational and non-gravitational theories, yet left open how infalling information is physically encoded. Even the membrane paradigm [4], which endowed the horizon with viscosity and conductivity, remained heuristic. Later quantum-informational approaches employing error-correction codes and tensor networks [5–7] revealed the algebraic structure of holography but not its causal dynamics.

The horizon-layered model fills this gap by proposing a concrete dynamical mechanism. Each infalling quantum becomes transcribed into the stretched horizon as a dipolar excitation within a discrete geometric lattice. These *causal incorporation* events occur at the finite information-throughput rate set by gravitational time dilation and the Planck time, establishing a one-to-one correspondence between external infall and internal time generation. Lateral coherence across the null surface maintains global causal consistency, producing a self-updating, layered membrane that stores the entire history of collapse. The internal universe then emerges as the holographic projection of this evolving boundary state. An icosahedral–dodecahedral quantization of dipoles provides a natural discretization distinguishing baryonic, dark, and vacuum sectors through specific geometric symmetries.

Within this picture, cosmological time is not a pre-existing parameter but a sequence of null-ordered horizon updates. Each incorporation event increases entropy and advances internal causal order, unifying the arrow of time, entropy growth, and quantum state reduction. Wavefunction collapse corresponds to boundary-state updates, deterministic from the external perspective yet probabilistic internally. The model thus bridges quantum measurement, horizon thermodynamics, and cosmic evolution under a single principle of causal holography.

The resulting cosmology preserves unitarity, eliminates singularities, and defines an internally expanding universe bounded by the information capacity of its parent black hole. In this framework, black holes emerge as recursive, self-contained information systems whose internal spacetimes evolve through horizon-layered dynamics. **The remarkable implication is that our own universe exhibits precisely the behavior expected of such a holographically projected interior: an expanding spacetime whose age, energy content, and causal structure correspond to the internal evolution of a black hole viewed from the outside.** Relating internal time to the locally measured Hubble constant yields an internal age of approximately 13.4 Gyr and predicts that the observable Hubble domain encloses roughly half of the total internal mass. Cosmic expansion thus arises from the continued growth of the holographic boundary area rather than from any external dark-energy term, naturally resolving the Hubble tension and rooting large-scale structure in the self-organizing flow of geometric information.

This realization compels a redefinition of the event horizon itself: it is not a static boundary enclosing an existing interior, but the generative surface from which spacetime, matter, and causal order continuously emerge.

A further conceptual advance of the horizon-layered cosmology concerns the very origin of the horizon itself. From early Oppenheimer–Snyder collapse models to modern quantum-gravity theories, the horizon has been treated as a pre-existing global boundary enclosing an interior spacetime. In the present framework, it is instead a locally generated causal structure. The horizon is born at the Planck scale as a minimal quantum-defined seed, the first surface to satisfy the compactness condition beyond which no classical spacetime persists. From this seed, it grows outward through sequential Planck-time incorporations of redshift-frozen matter, each layer advancing the null-ordered causal fabric of spacetime. The interior does not pre-exist but represents a causal excision: a topological void bounded by the expanding holographic surface. Spacetime itself, in this view, is assembled from the outside inward, through the continual self-organization of null layers. This *Planck-seed horizon growth* paradigm transforms the event horizon from an endpoint of collapse into the generative frontier of spacetime and information.

When the parent black hole possesses angular momentum, Kerr rotation introduces an azimuthal phase gradient across the horizon code. This global spin field biases co-rotating and counter-rotating quanta, producing a small but cumulative matter–antimatter asymmetry and defining a preferred cosmic axis preserved through inflation. The binary spin structure of Planck-scale horizon quanta yields the geometric basis for fermionic spin-$\frac{1}{2}$ behavior, the Pauli exclusion principle, and the large-scale alignment of cosmic microwave background and galactic spins. Baryon asymmetry, spin quantization, and cosmic anisotropy thus emerge as unified consequences of a single holographic–causal mechanism operating at the rotating horizon.

Editorial and linguistic refinements were assisted by AI tools (GPT-5, OpenAI); the theoretical framework, physical reasoning, and mathematical structure are entirely original to the author.

Unifying Postulates of the Horizon-Layered Cosmology

Since the advent of general relativity, spacetime and gravitation have been treated as continuous and geometric, while quantum theory has regarded energy and information as discrete and probabilistic. This divide has long obscured a unified view of cosmic evolution and black hole dynamics. The horizon-layered framework reconciles these domains by positing that spacetime geometry emerges from a discrete causal information process operating on null horizons. Just as Einstein's postulates of special relativity redefined motion through the invariance of light speed, the following principles redefine mass, time, and gravity through the invariance of the holographic information bound. They establish a consistent informational foundation from which both relativity and quantum mechanics arise as complementary limits of a deeper causal dynamics.

P1. Causal Horizon Encoding. All physically real information resides on null-synchronized horizons. The event horizon functions as an active, tension-bearing membrane that incorporates infalling energy in discrete Planck-scale steps. Each incorporation updates the universal quantum code and advances causal order by one Planck-time increment, making spacetime itself a record of sequential boundary-state updates.

P2. Emergent Internal Spacetime. The black hole interior is not a pre-existing domain but an emergent, holographically projected volume generated by the ordered layering of information on the horizon. Spacetime geometry, causal structure, and local vacuum properties arise collectively from coherence and correlation patterns within this evolving horizon code.

P3. Information–Mass Equivalence. Information and mass–energy are dual manifestations of a single conserved quantity encoded on the holographic boundary. The total information content scales with the horizon area,

$$I \propto A \propto M^2,$$

so that the growth of mass, area, and encoded information represents one unified causal process. The expansion of the internal universe thus corresponds to the quadratic accumulation of information-energy on the horizon.

P4. Causal Throughput Constraint. Gravitational time dilation near the horizon expresses a universal limit on the rate at which new information can be incorporated into spacetime. This limit equals the invariant *Planck power*,

$$P_{\max} = \frac{c^5}{G},$$

the maximum causal bandwidth allowed by nature. Each horizon update transmits one Planck mass of energy in one Planck time, defining the finite causal rate of spacetime evolution.

Because time dilates asymmetrically across the horizon, external observers perceive collapse as frozen, while internal observers experience this process as the fastest possible progression of physical events. If the redshift between an internal layer and its parent frame is $1+z_{\rm h}$, then their proper times and energies satisfy

$$\Delta t_{\rm ext} = (1+z_{\rm h})\,\Delta t_{\rm int}, \qquad E_{\rm ext} = \frac{E_{\rm int}}{1+z_{\rm h}},$$

so that the causal power remains invariant,

$$\frac{E_{\rm int}}{\Delta t_{\rm int}} = \frac{E_{\rm ext}}{\Delta t_{\rm ext}} = \frac{c^5}{G}.$$

Energy therefore redshifts systematically across the hierarchy of horizons, while the total causal throughput $P_{\max} = c^5/G$ remains unchanged. Each layer of the holographic hierarchy converts causal flux into spacetime evolution at the same fundamental rate, differing only in how that flux is partitioned between time and energy scales. Newton's constant G thus quantifies the causal compliance of spacetime, governing the exchange rate between mass incorporation, time dilation, and geometric reconfiguration.

P5. Informational Zeno Principle. Apparent motion and temporal flow emerge from the interplay of two synchronized processes on the horizon lattice. Each Planck-time update reconfigures the relational geometry of the stationary causal code, extending the lattice radially through the incorporation of new cells while preserving global causal order. Simultaneously, neighboring cells exchange information laterally through null-compatible tunnelling along the horizon surface, maintaining local coherence and enabling the propagation of radiation and interaction. Together, these two operations, global relational remapping and local lateral communication, generate the appearance of continuous motion and temporal evolution within a fundamentally discrete structure. A residual instantaneous equilibration within each tick preserves unitarity and holographic consistency, ensuring that no information is lost or duplicated. Thus, the flow of time, the propagation of light, and the dynamics of matter all arise as emergent patterns within a still but perpetually reconfigured causal network, resolving Zeno's paradox as the sequencing of stationary yet relationally evolving states.

P6. Holographic Completeness. No region of spacetime contains more independent information than permitted by the area of its boundary. Cosmic expansion represents the geometric increase of boundary area required to preserve holographic saturation as new information is incorporated. When this informational equilibrium is maintained, energy, geometry, and causality remain mutually consistent. Classical general relativity fails in this regime because it assumes a continuous manifold with unbounded information density. When curvature approaches the holographic limit, the differential description breaks down and the discrete causal encoding of the horizon-layered model takes over, preventing singularity formation.

P7. Kerr-Induced Causal Orientation. Rotation of the parent black hole imposes a global azimuthal phase gradient across the horizon, characterized by the Kerr parameter

$$a = \frac{J}{m_{\mathrm{bh}} c}.$$

This phase structure breaks local isotropy and establishes a preferred orientation in the causal lattice, coupling the sense of horizon rotation to the handedness of encoded quantum modes. Co-rotating and counter-rotating excitations experience differential redshift and phase bias, generating chiral asymmetries in the internal field correlations. The Kerr-induced phase gradient organizes causal linkages within each horizon layer into a globally coherent chiral pattern, defining a cosmic axis inherited from the parent rotation. Reversing the spin reverses spatial parity and field handedness but leaves causal ordering and entropy growth unchanged. Thus, rotation unifies microscopic spin orientation and macroscopic anisotropy as manifestations of a single geometric polarity imprinted by the causal structure of the rotating horizon.

P8. Objective Decoherence and Causal Update. Quantum measurement and wavefunction collapse arise from discrete causal updates of the holographic membrane rather than from subjective observation. Each incorporation event corresponds to a Planck-scale boundary update that enforces global causal consistency between internal quantum amplitudes and the newly assimilated layer of the horizon code. From the external frame, these updates are deterministic and unitary, preserving total information across the combined parent–interior system; from the internal frame, obtained by tracing out external degrees of freedom, they appear stochastic and non-unitary, producing the phenomenology of wavefunction collapse. Decoherence is thus an *objective geometric process*: incompatible internal amplitudes are eliminated as the membrane reconfigures its null-synchronized causal links, while compatible configurations persist as the next consistent holographic state. Quantum indeterminacy, entanglement correlations, and the no-signaling constraint all follow from this finite-rate causal updating of the horizon code, rendering collapse a real dynamical phenomenon of holographic geometry rather than a subjective act of measurement.

P9. Gravitation as Spacetime Excision. Mass–energy represents a localized deficit in causal connectivity within the holographic code. Each Planck-scale link on the null-synchronized horizon encodes a binary state of connection or disconnection, the "1" and "0" of existence. Information arises from their dynamic balance, and mass corresponds to regions where connections are removed or constrained to preserve the finite causal flux c^5/G. Spacetime curvature is the network's self-consistent readjustment around these excisions: trajectories curve not because of a force, but because the causal lattice reorganizes to restore holographic completeness. Thus, gravity emerges as geometry's response to informational deficit, mass and information are equivalent expressions of causal structure.

Together these postulates portray the universe as a self-updating causal code. Spacetime, gravitation, quantum coherence, and cosmic evolution are not separate mechanisms but complementary manifestations of one discrete informational process operating at the Planck scale. The classical continuum of general relativity arises as the macroscopic limit of this null-ordered, holographic computation.

The model thus unites gravitation, thermodynamics, and quantum theory within a single principle of causal incorporation, offering a coherent alternative to both singular classical cosmology and purely probabilistic quantum ontology.

In the following sections, we develop the theoretical basis of this framework beginning from the Schwarzschild solution and the contrasting perspectives of the external and infalling observers. By reexamining gravitational time dilation, redshift, and horizon formation, we replace the classical notion of matter crossing an event horizon with a physically discrete process of causal incorporation. The event horizon thereby becomes a real, information-bearing surface through which the holographic principle attains concrete dynamical expression. This shift transforms the horizon from a mathematical boundary into a physically active encoding interface that generates, layer by layer, the internal spacetime of the emergent universe.

2 Schwarzschild Black Hole

The classical theory of gravitational collapse derives from the prediction of general relativity that sufficiently massive stars, once they have exhausted all pressure support, inevitably experience a continuous contraction. In classical general relativity, the Schwarzschild solution extended to radius r = 0 implies a singularity [8]. Infalling matter in its frame of reference crosses the horizon in a finite time, but the time required for any particle of a collapsing star to reach the event horizon for a distant external observer diverges to infinity due to gravitational time dilation. Nevertheless, the generally accepted understanding is that the particle *„must clearly pass to a smaller radius unless it is destroyed... Since we have already decided that... particles reach the horizon at finite proper time and encounter a perfectly well-behaved geometry there"* [9]. To justify this, a special coordinate systems have been invented, such as the Kruskal-Szekeres coordinate system, which mathematically removes the singularity at Schwarzschild radius, suggesting a smooth crossing of the event horizon [9]. The Kruskal-Szekeres coordinate system reparameterizes the trajectory to be finite in T/R coordinates, but an external observer clock tied to Schwarzschild time still sees the particle asymptotically approaching the event horizon, never crossing it in a finite time. The ability to extend the geodesic system inside event horizon is mathematically elegant but irrelevant to physics that should be based only on what is possible to observe.

Contrary to the belief of crossing the event horizon in a finite time, all observable quantities such as photons or gravitational waves reach external observers in Schwarzschild time with redshift and dilation of time that diverges to infinity. The time dilation of the general theory of relativity has been empirically confirmed, as demonstrated by experiments such as the Hafele-Keating experiment [10], GPS correction [11], experiments with an atomic clock [12]. However, currently accepted theories reject measurable phenomena such as time dilation observed in the reference system of an external observer as a coordinate effect. Measurements confirm the physical reality of time dilation, supporting its application in models of gravitational collapse and black hole event horizons. The physical reality of the event horizon is indicated by the entropy of the black hole because Bekenstein-Hawking formula shows that it depends on the area of the event horizon, not the interior volume [13]. Additionally, Hawking radiation [14] suggests a slow loss of information and gradual black hole evaporation.

2.1 Radial Free Fall

In Schwarzschild geometry, the motion of falling objects towards the event horizon is determined by radial, temporal and angular metric components [15]. The Schwarzschild equation for a non-rotating, uncharged black hole of mass M, expressed in geometric units ($G = c = 1$), is:

$$ds^2 = -\left(1 - \frac{2M}{r}\right) dt^2 + \left(1 - \frac{2M}{r}\right)^{-1} dr^2 + r^2 \left(d\theta^2 + \sin^2\theta \, d\phi^2\right) \tag{1}$$

Although the radial and time components diverge as the object approaches the event horizon located at $r_s = 2M$, the angular part of the metric remains active. This asymmetry between the radial and tangential lateral behavior near the event horizon is a key observation that supports the central argument of this paper and will be revisited in the following sections.

Let us now examine the behavior of a freely falling object [15]. For an observer falling radially starting from rest at a large radius r_0, the proper time elapsed as the object falls towards the radius r is given by:

$$\tau - \tau_0 = \frac{2}{3\sqrt{2M}} \left(r_0^{3/2} - r^{3/2} \right) \tag{2}$$

In contrast, a distant observer measures the corresponding Schwarzschild coordinate time interval as:

$$t - t_0 = -\frac{2}{3\sqrt{2M}} \left[r^{3/2} - r_0^{3/2} + 6M(\sqrt{r} - \sqrt{r_0}) \right] + \\ 2M \ln \left(\frac{(\sqrt{r} + \sqrt{2M})(\sqrt{r_0} - \sqrt{2M})}{(\sqrt{r_0} + \sqrt{2M})(\sqrt{r} - \sqrt{2M})} \right) \tag{3}$$

Near the event horizon, where $r = 2M + u$ and $u \ll 2M$, the logarithmic term in Equation (3) diverges to infinity due to the denominator approaching zero as $\sqrt{r} \to \sqrt{2M}$. By defining $u = r - 2M$, we can approximate this term as:

$$\sqrt{r} - \sqrt{2M} \approx \frac{u}{2\sqrt{2M}} \tag{4}$$

This divergence indicates that from the perspective of a distant observer, an object falling into a black hole cannot cross the event horizon in a finite coordinate time. However, for an observer falling into a black hole, the time it takes to cross the event horizon remains finite. This difference between observers in the external and internal reference systems constitutes a fundamental paradox of black hole physics and motivates the need to revise the current causal-geometric interpretation.

In the Schwarzschild geometry near the event horizon, where $r = 2M + u$ with $u \ll 2M$, the proper radial distance element corresponding to a coordinate increment dr is

$$ds_r = \frac{dr}{\sqrt{1 - \frac{2M}{r}}} \approx \sqrt{\frac{2M}{u}}\, dr. \tag{5}$$

For a body of fixed proper length in the radial direction equal to l_0, the corresponding coordinate radial length Δr is shortened according to the formula:

$$l_0 \approx \sqrt{\frac{2M}{u}}\, \Delta r \quad \Rightarrow \quad \Delta r \approx l_0 \sqrt{\frac{u}{2M}} \tag{6}$$

Consider the case in which the corresponding radial distance from the horizon is halved: $u_2 = u_1/2$. Then:

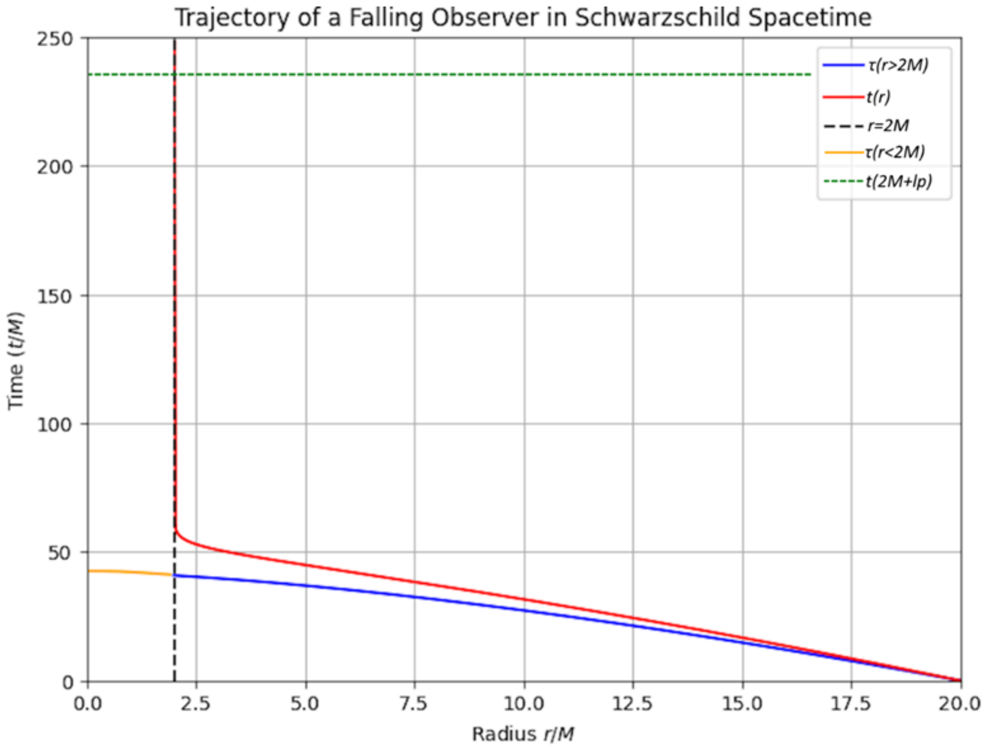

Fig. 1 The trajectory of a radially infalling observer in Schwarzschild spacetime plotted in terms of both proper time τ (equation (2)) and Schwarzschild coordinate time t (equation (3)). Both trajectories begin at $r_0 = 20M$, with $t_0 = \tau_0 = 0$. The orange segment represents a hypothetical continuation of the proper time trajectory past the horizon. The green line indicates the coordinate time at which the infaller reaches a Planck-length distance from the horizon. Adapted from [15].

$$\frac{\Delta r_2}{\Delta r_1} = \sqrt{\frac{u_2}{u_1}} = \frac{\sqrt{2}}{2} \tag{7}$$

So, as $r \to 2M$, the radial length Δr measured by a distant observer is shortened proportionally to $\sqrt{u}$ diverging to zero. This contraction is independent of the black hole mass M.

Let us derive a formula for the Schwarzschild coordinate time interval Δt that measures a distant observer when a falling particle falls from u_1 to u_2. From the geodesic equations [16], the radial coordinate velocity of a freely falling particle near the horizon is:

$$\frac{dr}{dt} = -\sqrt{\frac{2M}{r}}\left(1 - \frac{2M}{r}\right) \approx -\frac{u}{2M} \quad \Rightarrow \quad \frac{du}{dt} \approx -\frac{u}{2M} \tag{8}$$

Integrating both sides:

$$\int_{u_1}^{u_2} \frac{du}{u} = -\frac{1}{2M} \int_{t_1}^{t_2} dt \quad \Rightarrow \quad \ln\left(\frac{u_2}{u_1}\right) = -\frac{\Delta t}{2M} \tag{9}$$

For a halving of the radial distance, $u_2 = u_1/2$, the result becomes as follows:

$$\Delta t = 2M \cdot \ln\left(\frac{u_1}{u_2}\right) = 2M \cdot \ln 2 \tag{10}$$

This implies $\Delta t \propto M$, with concrete values as follows:

$$M = 100M_\odot \quad (M \approx 1.48 \times 10^5\,\mathrm{m}): \quad \Delta t \approx 682.6\,\mu\mathrm{s} \tag{11}$$

$$M = 1M_\odot \quad (M \approx 1.48 \times 10^3\,\mathrm{m}): \quad \Delta t \approx 6.826\,\mu\mathrm{s} \tag{12}$$

Thus, the Schwarzschild coordinate time required for a fixed fractional displacement u, such as halving the radial distance to the horizon, scales linearly with the black hole mass M. This is an expression of the logarithmic divergence that occurs near the horizon in all Schwarzschild geometries.

This behavior is exactly analogous to Zeno's paradox: *"That which is in locomotion must arrive at the half-way stage before it arrives at the goal"* [17]. An infinite number of halvings, each requiring a fixed interval of coordinate time, implies an unattainable limit, suggesting that, from an external perspective, the crossing of the event horizon is never actually completed.

However, the total time experienced by a falling observer, as given by equation (2), remains finite. **The steep divergence of the coordinate time in equation (3) occurs only within an extremely narrow range just before the horizon, at a distance much smaller than the Planck length.** This means that, viewed from an external reference frame, the entire stellar mass effectively reaches one Planck length above the horizon relatively quickly, although it never crosses it.(Fig. 1).

2.2 External Observer versus Infalling Observer Experience

Let us compare the experience of a particle falling towards the center of a black hole with that of an external stationary observer.

From the perspective of an external observer, according to equation (3) the particle approaches the horizon asymptotically and cannot reach it in finite coordinate time t, not even after billions of years. An extreme redshift occurs, and gravitational length contraction compresses the particle's radial length. This well-known divergence is more than a coordinate artifact, it is a physically significant manifestation of gravitational time dilation, confirmed by numerous experimental results. Moreover, when the black hole finally evaporates, the particle will still be floating at an infinitesimal distance above the then vanishing horizon.

From the point of view of a falling particle system, classical general relativity predicts a smooth crossing of the horizon in finite proper time τ. However, this classical picture must be revised if horizon thermodynamics and gravitational time dilation are to be taken seriously. Near the horizon, the relationship between the proper time of the falling particle and the coordinate time of the distant observer is the following:

$$\frac{d\tau}{dt} = \sqrt{1 - \frac{2M}{r}} \to 0 \quad \text{as} \quad r \to 2M \tag{13}$$

The standard interpretation treats this relationship as a coordinate singularity, assuming that proper time and coordinate time can decouple and that the particle crosses the horizon smoothly. In the present model, we reject that decoupling: equation (13) enforces a causal synchronization between t and τ and expresses an exact coupling between the two clocks: the local proper time cannot advance independently of the global coordinate time. If the external coordinate time has not reached infinity, then the proper time cannot advance beyond the horizon, meaning that $r(\tau) < r_s$ is physically disallowed. **The relation $dt/d\tau$ is a causal synchronization law, not just a coordinate mapping.** This means that **the falling particle's own clock becomes infinitely slow relative to the clock of a distant observer. Near the horizon, in the reference frame of the falling particle, all external processes appear to accelerate, and the whole history of the cosmos for a falling observer occurs in a tiny fraction of a second.**

Consider a black hole evaporating via Hawking radiation in finite coordinate time $t_{\text{evap}} < \infty$. In this period the geometry of the black hole evolves, so it grows if matter continues to fall onto it, but eventually the event horizon starts to shrink, and after a huge time interval it disappears. The falling particle cannot cross the horizon even in its own reference frame before the horizon disappears. **The classical event horizon always retreats faster than the infalling observer can cross it.** For example, a fall to an almost infinitesimally small distance above the horizon takes only a fraction of a second of its own proper time according to equation (2), while in the distant frame it takes billions of years. During this brief interval, the particle is exposed to a beam of high-energy Hawking radiation associated with the horizon. Instead of entering the hidden interior, the particle either evaporates at the edge of the horizon or eventually encounters a flat spacetime when the black hole evaporates completely. Thus, the classical horizon at $r_s = 2M$ never manifests itself as a traversable surface in any physical system. This imposes a global time constraint on any world line that tries to cross the horizon. In this framework, the proper time for the falling particle is constrained by the global causal structure of the Hawking evaporation geometry.

A growing body of work suggests that classical singularity may never form in a physically meaningful sense when quantum effects are properly accounted for. In particular, the concept of horizon avoidance posits that due to Hawking radiation and backreaction, the would-be event horizon evaporates faster than any infalling observer can cross it, effectively preventing the formation of a traversable boundary [18]. Alternative models such as gravastars and firewall scenarios also challenge the standard picture by proposing radical modifications to the interior structure or near-horizon quantum state [6, 19]. In a more conservative but consistent approach, semiclassical treatments like the Ashtekar-Bojowald and Vaidya-based models preserve unitarity while eliminating singularities through quantum gravitational effects that modify the collapse geometry from the outset [20, 21]. These insights align with the present framework, in which the horizon is not a surface to be crossed.

The implication is profound: **in the entire observable universe no particle has actually ever crossed the event horizon. All falling matter, whether seen by external or internal observers, remains just above the horizon until it is supposedly annihilated by Hawking radiation.**

3 Event Horizon

From the earliest collapse models of Oppenheimer and Snyder (1939) to modern numerical simulations and holographic formulations, **the formation of the event horizon has generally been treated as a global, teleological construct.** In these approaches, the horizon is defined as the causal surface separating null geodesics that eventually escape from those that do not, an object identified only after the entire spacetime evolution is known. Even in semiclassical extensions such as the membrane paradigm, loop quantum gravity, or AdS/CFT duality, the event horizon is typically regarded as a pre-existing geometric feature enclosing an evolving interior. Nowhere in these frameworks is the horizon treated as a dynamically nucleated boundary with a physically realized beginning. In contrast, the horizon-layered model regards horizon formation as a *local and causal process*, a sequence of null-surface nucleations beginning at the Planck scale and expanding outward.

In classical general relativity, the compactness condition for the formation of a local Schwarzschild horizon is

$$\frac{2Gm(r)}{rc^2} \geq 1, \tag{14}$$

where $m(r)$ is the mass contained within radius r. Using the mean density

$$\langle \rho(r) \rangle = \frac{3m(r)}{4\pi r^3}, \tag{15}$$

the same condition may be written as a lower bound on average energy density [22]:

$$\langle \rho(r) \rangle \geq \frac{3c^2}{8\pi G r^2}. \tag{16}$$

This inequality shows that the required density increases steeply as r decreases, suggesting that horizon formation proceeds from smaller to larger radii.

Numerical simulations confirm this trend: only a fraction (typically 5–25%) of the total mass lies within the initially formed horizon [23–25], while the rest falls in later as the horizon expands. **Hence, the event horizon does not appear instantaneously at its final radius but grows dynamically outward from a compact central seed.**

To formalize this causal requirement, define the local compactness function

$$f(r) = \frac{2Gm(r)}{rc^2}, \tag{17}$$

where $m(r)$ is given by

$$m(r) = 4\pi \int_0^r \rho(r)\, r^2 dr, \tag{18}$$

which is monotonic for any nonnegative density $\rho(r) \geq 0$. The formation of a horizon at radius R requires

$$f(R) \geq 1. \tag{19}$$

Assume, for contradiction, that $f(r) < 1$ for all $r < R$ but $f(R) = 1$; that is, the compactness first reaches unity at the outer boundary. Differentiating $f(r)$ gives

$$f'(r) = \frac{2G}{c^2}\left(4\pi r\,\rho(r) - \frac{m(r)}{r^2}\right). \tag{20}$$

For $f(r)$ to increase from below 1 to 1 within a narrow shell $[R-\varepsilon,\, R]$, $f'(r)$ must be sharply positive near R. Integrating Eq. (20) over this shell yields

$$1 - f(R-\varepsilon) = \int_{R-\varepsilon}^{R} f'(r)\,dr \approx \frac{8\pi G R}{c^2}\int_{R-\varepsilon}^{R} \rho(r)\,dr, \tag{21}$$

where the finite term $-m(r)/r^2$ contributes negligibly. Since $1 - f(R-\varepsilon)$ remains finite as $\varepsilon \to 0$, the integral of $\rho(r)$ must also remain finite, forcing the average density in the shell to diverge:

$$\frac{1}{\varepsilon}\int_{R-\varepsilon}^{R} \rho(r)\,dr \;\to\; \infty. \tag{22}$$

Therefore, a first crossing of $f(r) = 1$ at large R requires a delta-like divergence in the density profile, which is physically inadmissible.

Alternatively, using the identity

$$\frac{d}{dr}\left(\frac{m(r)}{r}\right) = 4\pi r\rho(r) - \frac{m(r)}{r^2}, \tag{23}$$

it follows that a large positive derivative near R demands a strong local spike in $\rho(r)$. A smooth density profile cannot satisfy this condition, confirming that $f(r)$ must first reach unity at some smaller radius.

This result has direct physical implications. If most of the mass resided in an outer shell while the interior mass $m(r < R)$ were small, the shell would experience only a weak gravitational pull:

$$a(R) \approx -\frac{Gm(R_{\text{inner}})}{R^2}, \tag{24}$$

and could not collapse inward to form a horizon. Maintaining such a configuration would require an unphysical external pressure gradient. Hence, **the sudden appearance of a horizon at a large radius without prior inner formation is dynamically forbidden.**

3.1 Formation of the Planck Seed and the Onset of Horizon Layering

The event horizon must form first at the smallest radius where the compactness condition is locally satisfied, i.e. at the Planck scale. As the core density approaches the Planck limit, a minimal trapped region nucleates, forming the initial horizon seed. Subsequent accretion increases $m(r)$, extending the horizon outward through a series of causally nested surfaces. The event horizon is thus not a pre-defined geometric boundary but a dynamically realized surface that grows layer by layer from a quantum–gravitational core.

The threshold for black-hole formation follows directly from the compactness criterion:

$$\langle \rho(r) \rangle \;\geq\; \frac{3c^2}{8\pi G r^2}. \tag{25}$$

Equating this to the mean density of a Planck-mass configuration,

$$\rho_{\rm P} \;=\; \frac{m_{\rm p}}{\frac{4}{3}\pi r^3}, \tag{26}$$

yields the first radius at which a trapped surface can exist,

$$r_{\rm crit} \;=\; \frac{\ell_{\rm p}}{\sqrt{2}} \;\approx\; 1.14\times 10^{-35}\,{\rm m}. \tag{27}$$

When a Planck mass is confined within this critical radius, the compactness condition is satisfied and a minimal horizon forms. At that point, the classical description of spacetime ceases to hold, and quantum–gravitational effects dominate. The black hole is born as a self-contained causal structure, a Planck-scale seed from which the horizon subsequently expands.

Rather than signaling a breakdown of physics, the Planck density represents a natural termination point for classical compression. As collapse proceeds, further contraction beyond this threshold is prohibited: additional mass–energy is redirected into the outward growth of the horizon rather than into continued volumetric compression. The process of collapse thus transitions from three-dimensional contraction to two-dimensional holographic encoding. The result is not a singularity but a finite-density core, the boundary between classical dynamics and the quantum geometry of null layering.

In conventional dimensional analysis, the Planck density is quoted as

$$\rho_{\rm P}^{\rm (std)} = \frac{m_{\rm p}}{\frac{4}{3}\pi \ell_{\rm p}^3} \;\simeq\; 5\times 10^{96}\,{\rm kg/m^3},$$

obtained by placing one Planck mass in a Euclidean sphere of radius $\ell_{\rm p}$. This expression is heuristic: at the Planck scale, both the notion of a smooth volume and the classical compactness relation acquire order-unity quantum-gravitational corrections. A more physical definition follows from the compactness condition (25), which gives $r_{\rm crit} = \ell_{\rm p}/\sqrt{2}$ and a corresponding density

$$\rho_{\rm P}^{\rm (crit)} = \frac{m_{\rm p}}{\frac{4}{3}\pi r_{\rm crit}^3} \;\simeq\; 1.2\times 10^{96}\,{\rm kg/m^3}.$$

Both values are of the same order, differing only by a geometric factor, but the compactness-based $\rho_{\mathrm{P}}^{(\mathrm{crit})}$ corresponds directly to the physical threshold at which spacetime first forms a trapped surface.

This leads to a profound implication: **all black holes, regardless of their eventual mass, originate from a finite Planck seed.** Macroscopic horizons are not singular points but layered causal structures grown through continued accretion, each layer preserving unitarity and entropy consistency. The Planck density, whether expressed in its standard dimensional form or in its compactness-corrected value, marks the ultimate limit of physical compression in nature: the boundary where classical spacetime yields to holographic, quantum–causal order. Beyond this limit, the dynamics of collapse are governed entirely by the outward growth of the event horizon, which encodes and preserves all incoming information through successive null layers.

3.2 The Ontological Reinterpretation of the Black Hole Interior

As the event horizon of a black hole begins to grow outward from the Planck size, a natural question arises: **what is the ontological status of the growing inner volume? In contrast to the classical intuition, where the event horizon encloses a pre-existing region of spacetime, this model suggests that the inner volume is causally excluded from the start. While the event horizon surface grows from the Planck size to macroscopic size, the inner volume does not participate in this process.**

The interior of the black hole does not pre-exist the horizon but emerges as a consequence of the horizon's layered growth. In the classical picture, the event horizon encloses an already-formed interior spacetime. But in the horizon layered framework developed here, the horizon acts as a null surface of projection, a redshift-frozen layer whose outermost geometry encodes all accessible information. As the horizon grows outward from the Planck core, it defines the emergence of new spacetime layers, but the interior volume remains causally inaccessible from the exterior and is not part of the dynamically evolving external manifold.

From this perspective, **the so-called "interior" is not an independently evolving region of spacetime, but an emergent construct entirely defined by the information encoded on the growing horizon.**

The implication is profound: spacetime inside the black hole is not ontologically fundamental. Instead, it is a dynamically generated structure that arises from the causal and geometric ordering of horizon layers. The singularity is thus avoided not by smoothing out infinite curvature, but by reinterpreting the notion of interior entirely. **There is no singular point, because there is no spacetime beyond the event horizon, only the null-layered horizon code just above the event horizon that seeds the emergent causal bulk.** The classical notion of an evolving 3D volume inside the black hole becomes replaced by a holographic code layered at the boundary, with the apparent bulk dynamics reconstructed through null-ordered updates from this encoding surface.

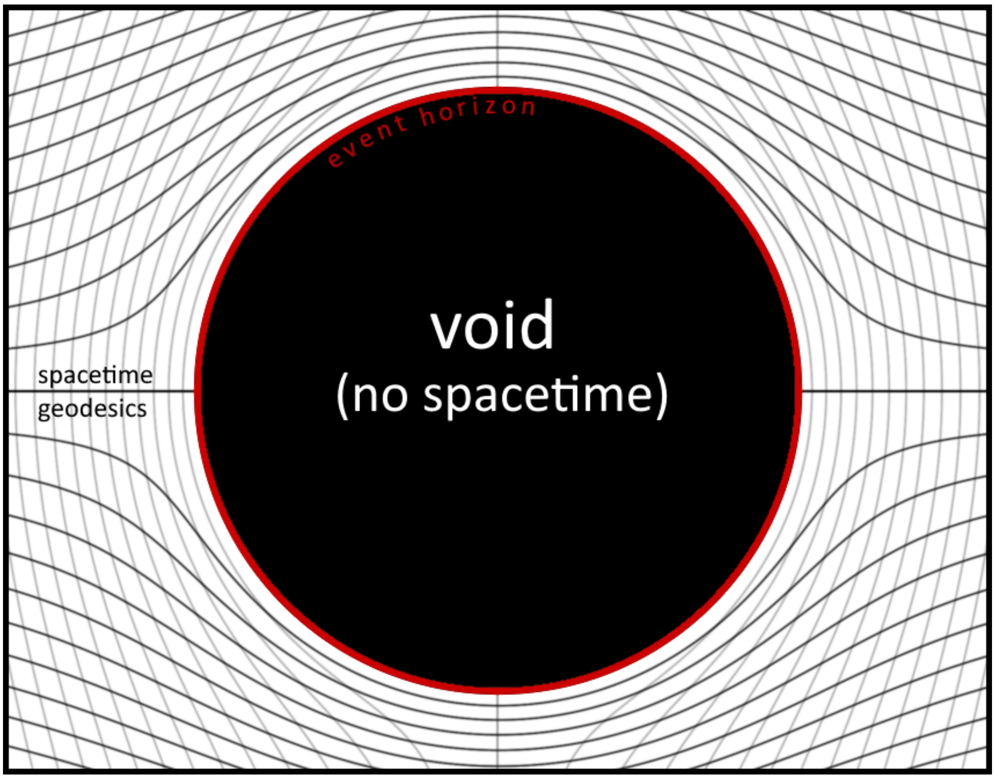

Fig. 2 Spacetime geodesics curve around a Schwarzschild black hole in this model much like streamlines in a compressible fluid flow bend around an obstacle. This behavior arises not from an embedded central mass, but from the topological excision of spacetime at the black hole interior. The event horizon marks the null surface beyond which no causal structure or geometry persists. Only geodesics orthogonal to the horizon terminate at this boundary; all others bend due to the elastic curvature induced by the absence of interior spacetime. The horizon acts as a holographic encoding surface for the excised region, consistent with entropy bounds and causal structure.

3.3 Reinterpreting Hawking Radiation

In the classical description, an infalling particle inevitably crosses the event horizon and proceeds into the interior of the black hole. In the present framework, however, this passage does not occur. Instead, the infalling particle becomes part of a radially compressed, redshift-frozen quantum structure accumulating just above the horizon. From the external viewpoint, the horizon is never reached in finite time; it functions as a limiting surface where information becomes causally frozen and holographically encoded.

With this recognition, the standard interpretation of Hawking radiation must be reconsidered. The familiar picture of pair creation across a geometric boundary separating interior and exterior presupposes that the interior region possesses an independent ontological status within the external manifold. Yet in the horizon-layered framework, such an interior does not exist. The external spacetime terminates at the event horizon, which forms the manifold's causal boundary. Infalling matter does not cross into a hidden domain but becomes progressively encoded within the horizon's null-ordered structure.

Accordingly, Hawking radiation cannot arise from quantum tunneling between an existing interior and exterior. The emission process should instead be understood as a structured quantum polarization effect emerging from the redshift-frozen quantum field near the horizon. This field remains external to the event horizon but is subject to extreme time dilation and gravitational redshift. Infalling quanta continually perturb this layer, inducing minute changes in the local vacuum polarization and generating outward-propagating excitations. Because these excitations originate in the external domain, they can, in principle, escape to infinity, albeit with exponentially redshifted energy and stretched timescales. The resulting radiation therefore represents a coherent, causal rebalancing of the horizon's encoded information, not a stochastic flux of particles tunneling out of a hidden interior.

This mechanism naturally accounts for the observed thermal spectrum: photons emitted from the outermost redshift-frozen layer escape with energy

$$E_\infty = E_{\rm local}\sqrt{1-\frac{r_{\rm s}}{r}} = E_{\rm local}\sqrt{1-\frac{2Gm_{\rm bh}}{rc^2}},$$

yielding an effective Hawking temperature

$$T_H = \frac{\hbar c^3}{8\pi G m_{\rm bh} k_B},$$

which reflects the gravitational redshift rather than any actual emission from within the horizon. The black hole thus radiates, but only through processes occurring on the external manifold, within the redshift-frozen quantum layer that encodes infalling information.

Once the external manifold is recognized to end at the horizon, the notion of radiation directed "inward" or "outward" across the causal boundary loses physical meaning. The interior domain, being topologically and causally excised, provides no spacetime structure into which or from which particles could tunnel. The idea of inward or outward tunneling is therefore not merely improbable but undefined. In this sense, the standard mechanism of Hawking evaporation cannot be realized within a manifold that terminates at its own causal boundary.

This reinterpretation resolves the information paradox without invoking true evaporation. Information is never lost in an inaccessible region beyond the horizon; it remains encoded in the dynamic surface structure of the horizon itself. Apparent "evaporation" corresponds to the gradual reconfiguration or release of this holographic code, not to the destruction of matter within an interior volume. The process is consistent with unitarity, causality, and holography, and eliminates the need for a physically existing interior.

Ultimately, crossing the horizon is not a physical process but a classical extrapolation that fails under extreme redshift and quantum gravitational conditions. **The event horizon is not an entrance but the terminal surface of spacetime**

itself, a dynamic, null-ordered boundary where information is encoded. It defines the outer limit of the physical manifold, not the boundary of a hidden interior world.

3.4 Reinterpretation of Mass and Spacetime

In classical general relativity, gravitational collapse leads to a singularity, an infinite-density locus of diverging curvature, under the assumptions of the Penrose–Hawking theorems [26]. These results presuppose a smooth manifold and standard energy conditions, with curvature sourced by stress–energy via

$$R_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu} R \;=\; \frac{8\pi G}{c^4}\, T_{\mu\nu}. \tag{28}$$

In the horizon-layered, holographic picture advanced here, curvature is reinterpreted as the deformation of spacetime around what is *absent*. Mass corresponds to a topological *excision*, a finite, non-singular causal deficit in which the manifold fails to extend. These microexcisions bend geodesics not by inclusion but by exclusion, much like streamlines in a compressible flow curving around an obstacle (Fig. 2). Gravity is the elastic response of the manifold to this controlled absence of geometry.

Accordingly, the black hole event horizon is the terminal null boundary of the external manifold: beyond it no spacetime, field, or observer exists. Hawking radiation originates from quantum fluctuations just *outside* this causal edge; no interior dynamics are required. The classical singularity is thus replaced by a finite termination of geometry: curvature records the tension induced by the excised region rather than any divergent interior structure.

This viewpoint aligns naturally with the holographic principle. The Bekenstein–Hawking law,

$$S \;=\; \frac{k_B c^3}{4\hbar G}\, A, \tag{29}$$

implies that gravitational information resides on causal *surfaces*, not within volumes. In this setting, the energy–momentum tensor $T_{\mu\nu}$ is read as encoding both conventional stress–energy and the geometric strain required to maintain curvature around excised domains; Newton's constant G quantifies the manifold's resistance to such topological truncation. Curvature at the boundary thus corresponds to an entropy (information) deficit relative to a flat, unexcised geometry.

Because each mass quantum is defined by an absence of spacetime, such excised domains cannot coherently overlap into a singular point. There is no interior volume available to collapse; the singularity is *precluded* rather than regularized.

With the interior excised, the horizon is sustained entirely by the external geometry. The exterior metric imposes an inward geometric pressure on the horizon shell through the curvature jump at the manifold's terminus, but causal structure forbids completion beyond the null limit, fixing the shell at the physical boundary of spacetime. Phenomenologically, the equilibrium of this domain wall can be captured by a Young–Laplace–type balance,

$$\Pi_{\rm ext} \;=\; 2\,\sigma\,H \;+\; \Pi_{\rm q}, \tag{30}$$

where $\Pi_{\rm ext}$ is the inward curvature-induced pressure, σ an effective surface tension, H the mean curvature, and $\Pi_{\rm q}$ quantum/entanglement-pressure corrections. The term $2\sigma H$ represents the geometric resistance to deformation, ensuring equilibrium precisely at the null termination where no interior spacetime exists.

In this sense, **the event horizon is a self-consistent fixed point of the external manifold: a geometric equilibrium between excision and curvature, where gravity emerges as the tension field surrounding the absence of spacetime.**

This approach differs fundamentally from other non-singular models - Planck stars, gravastars, firewall proposals, and fuzzballs [6, 27–33], which typically retain an interior region or require exotic stress-energy conditions. The failure to abandon the crossing paradigm has constrained these interpretations; by treating the horizon as the ultimate manifold limit rather than an intermediate transition, the horizon-layered framework achieves unitarity, holographic consistency, and cosmological emergence without invoking speculative sub-horizon structures. In this model the interior is a projection: spacetime ends at the horizon, and what lies "within" is a relational construct arising from entangled null-layer encoding rather than a curved geometric manifold.

Despite this re-interpretation, **all external predictions of general relativity are preserved. Gravitational waves, inspiral dynamics, and ringdown emissions occur outside the horizon, governed by standard field equations. The difference lies solely in the unobservable domain, offering a geometrically and informationally consistent picture of gravity and black hole thermodynamics.**

In this framework, the Planck mass,

$$m_p = \sqrt{\frac{\hbar c}{G}}, \tag{31}$$

acquires direct geometric meaning: it marks the transition between partial and complete excision. Below m_p, quantum matter remains embedded in spacetime; above it, the excision self-closes and a black hole forms. Mass hierarchy thus measures the degree of causal removal, while energy acts as the propagating strain restoring local manifold continuity at light speed. The equivalence $E = mc^2$ expresses this duality between static excision and dynamic curvature restoration.

A mass quantum thus corresponds to a topological discontinuity in the causal lattice, characterized by a finite causal charge, the degree of deficit in null connectivity.

Ordinary (baryonic) matter can be viewed as a bipolar, causal dipole: one pole remains connected to the surrounding spacetime network, while the other is excised. The connected side anchors the particle to the local causal web, ensuring interaction with radiation and other gauge fields; the excised side constitutes its gravitational charge, curving the external manifold through the induced causal asymmetry. This dipolar structure naturally explains why mass gravitates universally while still participating in electromagnetic and quantum interactions: its connected pole supports field couplings, while its disconnected pole anchors curvature.

Dark matter represents the limiting case of full causal excision: both poles of the dipole are disconnected from the manifold's causal substrate, they are *symmetrically excised.* The object exists only as a residual gravitational influence, a shadow of missing connectivity in the manifold's fabric. Because both poles are causally removed, dark matter interacts neither electromagnetically nor via standard quantum fields, it is causally *neutral* except through geometry. Its only signature is curvature itself, the elastic imprint left by absence.

This view provides a geometric rationale for the otherwise puzzling invisibility of dark matter, situating it as a pure causal deficit without active field degrees of freedom.

Conversely, the massless sector, radiation and conformally invariant fields, corresponds to quanta with both causal poles fully connected. Such entities do not produce curvature because they represent no deficit of connectivity; they traverse the manifold without excising any portion of it. Their propagation along null geodesics reflects perfect causal continuity, and thus zero rest mass. In this sense, the absence of mass coincides with complete participation in the causal network: photons and other massless excitations *are* the coherence of spacetime.

The vacuum represents the complementary extreme: the *decoherent* phase of the causal network. Whereas matter, dark matter, and radiation embody coherent configurations of the causal code, locally phase-locked excitations that maintain stable relational structure, the vacuum consists of causally uncorrelated degrees of freedom. Its quanta correspond to *empty causal capacity*: the spacetime elements that are not phase-synchronized with the coherent code but are available to host it. Those quanta fluctuations reproduce the phenomenology of vacuum fluctuations in quantum field theory: transient excitations appear and disappear without locking into stable causal connections. In this sense, vacuum quanta are *de-synchronized*, furnishing the neutral substrate through which coherent configurations can propagate.

3.5 Dark Matter Collapse and the Formation of Causal-Foam Compact Objects

Dark matter represents the limiting case of full causal excision: both poles of the dipole are disconnected from the manifold's causal substrate, rendering it *symmetrically excised.* Such quanta exist only as residual gravitational influences, shadows of missing connectivity in the manifold's fabric. Because both poles are causally removed, dark matter interacts neither electromagnetically nor through standard quantum fields, remaining causally *neutral* except via geometry. Its only observable signature is curvature itself, the elastic imprint of causal absence. Unlike baryonic quanta, whose single-sided excision aligns radially and contributes directly to horizon formation, dark-matter units are self-contained and non-radiative. Their mutual attraction arises from secondary curvature effects: local reductions in causal capacity between neighboring excised domains. Consequently, dark-matter clumps behave as diffuse, pressureless aggregates that deepen curvature collectively without forming causal voids of their own. This intrinsic symmetry explains both their gravitational clustering and their radiative silence, while predicting that dark-matter halos remain extended and dynamically cold even as baryonic matter collapses into compact, horizon-aligned structures.

In a purely dark-matter collapse, the interior manifold is not excised as in the baryonic case. Because dark quanta possess symmetrically excised dipoles, no collective null surface can form to terminate the manifold. Each quantum carries its own microscopic causal void, yet these do not merge into a single, horizon-defining excision. Consequently, the interior region from $r = 0$ to the nominal Schwarzschild radius r_s remains filled with a dense, causally fragmented medium rather than an empty void. This "dark causal foam" consists of self-isolated causal cells that generate curvature locally but lack mutual coherence. Externally, such an aggregate mimics a black hole through its gravitational field and apparent redshift, yet internally it preserves finite causal structure and avoids the topological truncation characteristic of true horizons.

Define the compactness parameter

$$\mathcal{C} \equiv \frac{2Gm}{R\,c^2}.$$

In classical general relativity, any static, isotropic, positive–pressure sphere satisfies Buchdahl's bound

$$\mathcal{C} \le \frac{8}{9} \quad \Longleftrightarrow \quad R \ge \frac{9}{8}\,r_s,$$

where $r_s = 2Gm/c^2$. In the present framework, a *pure* dark-matter condensate is a causal foam with essentially vanishing lateral coupling (no open links), so it cannot organize a null-synchronized membrane or form a true horizon. The absence of lateral coherence acts as a deficit of tangential support, pushing the equilibrium radius slightly outward relative to the Buchdahl limit. A conservative phenomenological window is therefore

$$\frac{9}{8}\,r_s \lesssim R_{\text{foam}} \lesssim (1.2\text{–}1.3)\,r_s \quad \Longrightarrow \quad \mathcal{C}_{\max} \sim 0.77\text{–}0.89,$$

where the upper edge (8/9) is the absolute isotropic GR limit and the lower edge (~ 0.77) reflects reduced tangential support in a fully incoherent, excised medium. A convenient parametrization is

$$R_{\text{foam}} = \frac{r_s}{1-\varepsilon_{\text{coh}}}, \qquad \varepsilon_{\text{coh}} \sim \mathcal{O}(0.1) \quad \text{(pure dark causal foam)},$$

with ε_{coh} decreasing to 10^{-3}–10^{-5} in mixed dark–baryonic cores, where baryons seed partial null alignment. In such mixed systems, R can approach r_s without forming a true horizon, realizing an ECO-like limit.

Numerically, for a $10\,M_\odot$ object, $r_s \simeq 29.5\,\text{km}$, giving $R_{\text{foam}} \sim 33$–$36\,\text{km}$. For a $10^8\,M_\odot$ system, $r_s \simeq 2.95 \times 10^8\,\text{km}$ ($\approx 2\,\text{AU}$), yielding $R_{\text{foam}} \sim 2.25$–$2.6\,\text{AU}$.

Because the causal dipoles of dark matter are fully excised and lack coherent lateral coupling, the network can never synchronize to the lightlike condition $v \to c$

that defines a true event horizon. The collapse therefore remains strictly subluminal: the causal cones contract but do not close, and gravitational time dilation saturates at a finite value rather than diverging. Externally, the configuration appears nearly Schwarzschild, yet internally the approach to the horizon stalls as the medium's causal capacity is exhausted. Such an object constitutes a horizonless, causally saturated compact remnant whose dynamics freeze through loss of coherence rather than classical time dilation.

Dark causal-foam objects thus represent an alternative end state of gravitational collapse: ultracompact, non-radiative configurations that mimic black holes in external curvature but retain finite causal structure internally. They bridge the gap between conventional dark-matter halos and true black holes, suggesting a continuum of causal coherence, from incoherent, horizonless foam to the fully synchronized null membrane of a baryonic black hole. In what follows, we turn from these non-generative dark configurations to the **baryonic black holes**, whose horizons do not merely trap information but *encode and project it*, giving rise to emergent, cosmogenic interiors, the central subject of the next subsections.

3.6 Singularity as Holographic Inconsistency

Classical general relativity treats the event horizon of a black hole as a fictive geometric boundary beyond which physical quantities may diverge. The interior singularity, characterized by infinite curvature and vanishing volume, is considered a real endpoint of spacetime evolution. However, this treatment is incompatible with the holographic principle, which asserts that the physical degrees of freedom of a gravitational system are fully encoded on its bounding surface with entropy proportional to area, not volume.

If the singularity were a physical object, it would permit the accumulation of unbounded entropy and curvature within a region that contributes nothing to the total area-based entropy budget. In standard treatments, the holographic limit is applied to the event horizon of a black hole. In the framework proposed here, however, **the holographic bound must hold for *any volume* encapsulating matter-energy, including regions containing the singularity.** Consequently, a singularity would violate this bound by concentrating information density beyond the allowed limit in an otherwise negligible volume. This contradicts the Bekenstein–Hawking entropy limit and the covariant entropy bound [34], which restrict the maximal entropy to

$$S_{\max} = \frac{A}{4\ell_p^2}, \tag{32}$$

where A is the surface area enclosing the region. Allowing a singularity therefore undermines unitarity and the self-consistency of quantum gravity in any physically meaningful volume.

In the horizon-layered cosmological model, this inconsistency is resolved by excluding the interior volume from the causal structure. **The event horizon is not a fictive boundary but a physically operative, null-ordered, information-bearing**

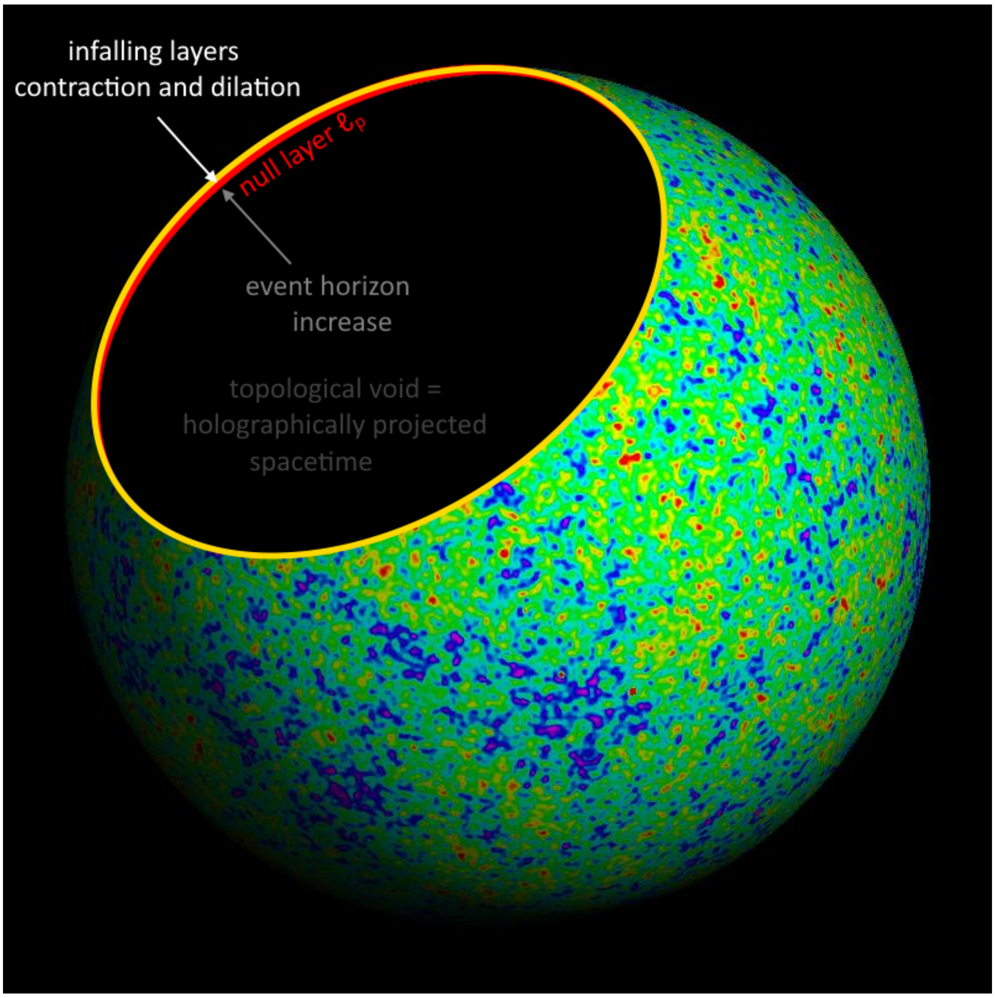

Fig. 3 Schematic representation of black hole gravitational collapse at a causal distance of ℓ_p above the event horizon. As infalling mass increases, the horizon expands, creating a redshift-based foliation of null layers just above the event horizon. Internal spacetime exists only as a holographic projection.

surface that encodes infalling matter in Planck-scale strata. The classical singularity is replaced by a dynamically expanding code surface whose entropy is finite and precisely saturates the holographic bound ensuring that all physical degrees of freedom are accounted for at the horizon and that no information is hidden behind a spacelike singularity.

This reformulation preserves unitarity, maintains the validity of entropy bounds, and aligns with holographic expectations. The singularity, in this view, is not a physical endpoint but a breakdown of classical reasoning beyond its applicable domain. The true physical content lies in the quantum encoding at the horizon, from which time, matter, and geometry emerge.

The holographic bound is more fundamental than the dynamical predictions of classical general relativity. Any apparent violation of the entropy bound, such as the occurrence of singularities predicted by the Penrose–Hawking theorems, must be resolved by a transition in the holographic encoding of information. When gravitational collapse drives a system toward saturation of the holographic limit, the classical singularity is replaced by a new phase of spacetime description, characterized by horizon-layered encoding and causal bandwidth saturation.

On a holographic surface, regions of extreme curvature that would classically evolve toward singularities instead manifest as *localized domains of maximal bandwidth absorption.* These are areas where the local rate of causal updates approaches zero, forming stable null surfaces that function as internal horizons. Each such domain sustains a self-consistent holographic encoding of an emergent internal spacetime, an informationally complete, recursively defined causal substructure, without requiring a physical singularity or excised volume. Through this mechanism, singularities never form: they are replaced by successive layers of bandwidth-saturated horizons, each preserving the holographic information bound.

The present model enforces the holographic bound globally: **no spacetime volume may contain more information than permitted by the area of its boundary.** This principle restores unitarity and ensures the continuity of the information measure across all nested surfaces. The Planck-scale holographic horizon dynamically enforces this condition by transcribing infalling matter into surface quanta once its approach distance reaches the Planck threshold. Thus, while ordinary relativistic dynamics remain valid in the low-curvature regime, they are globally subordinated to a deeper holographic conservation law: the causal flux and informational capacity of the universe remain continuous and finite across every hierarchical level of gravitational collapse.

3.7 Null Layering, Radial Freezing and Preserved Lateral Dynamics on the Stretched Horizon

The external gravitational field of a black hole, defined solely by its mass, angular momentum, and charge, does not reveal its internal composition. Conversely, variations in the microstructure of the event horizon do not alter the external field, yet this surface holographically encodes all internal degrees of freedom, preserving the black hole's entropy and ensuring compatibility with unitarity and thermodynamics. In this framework, gravity and curvature arise not from forces within an interior volume but from the causal absence of that volume itself. The information defining the internal universe is nonlocally organized on the horizon, structured as a null-ordered, gauge-invariant code subspace.

From the standpoint of a distant observer, collapsing matter asymptotically approaches the Schwarzschild radius in infinite coordinate time. As it nears this limit, infalling matter becomes exponentially redshifted and time-dilated, appearing to "freeze" just outside the event horizon (Fig. 3). **To describe this emerging structure, we introduce the concept of *null-ordered layering***, a causal sequence of redshift-frozen strata arranged along lightlike hypersurfaces of constant advanced or retarded time. Each layer represents a distinct moment in the history of collapse, geometrically embedded into the horizon as part of a continuously updated causal hierarchy. Once the Planck scale is reached, the redshift divergence triggers the formation of the holographic encoding surface: beyond this point, the inner spacetime becomes causally self-contained, projecting its own emergent cosmology as a relational construct encoded on the horizon's null structure.

Radial freezing and holographic compression. For a near-radial null trajectory the equation:

$$\frac{dr}{dt} = \pm\Big(1 - \frac{r_s}{r}\Big), \tag{33}$$

is implying $dr/dt \to 0$ as $r \to r_s$. Radial motion is thus frozen in external coordinate time t: any degree of freedom requiring motion in r becomes infinitely time-dilated.

Relativistic length contraction compresses infalling matter into progressively thinner shells as it approaches the Schwarzschild radius. These shells flatten toward the horizon, becoming effectively two-dimensional. For a body of fixed proper length l_0 in the radial direction, the corresponding coordinate length Δr is shortened according to (§5):

$$ds = \frac{dr}{\sqrt{1 - r_s/r}} \approx \sqrt{\frac{r_s}{\epsilon}}\, dr \quad \Rightarrow \quad dr \approx \sqrt{\frac{\epsilon}{r_s}}\, ds \quad \Rightarrow \quad \Delta r \approx l_0 \sqrt{\frac{\epsilon}{r_s}}, \tag{34}$$

where $r = r_s + \epsilon$ and $\epsilon \ll r_s$.

This natural dimensional reduction realizes the Bekenstein–Hawking area law (§29): the entropy of the collapsing system becomes proportional to the area of the null surface rather than its volume. The event horizon therefore functions not as a geometric boundary enclosing an interior, but as a *causal interface* on which all physical information is sequentially encoded.

Residual lateral dynamics on the stretched horizon. At fixed r, a null angular displacement satisfies

$$0 = ds^2 = -\Big(1 - \frac{r_s}{r}\Big)dt^2 + r^2 d\Omega^2, \qquad d\Omega^2 = d\theta^2 + \sin^2\theta\, d\phi^2, \tag{35}$$

giving the coordinate angular rate

$$\frac{d\Omega}{dt} = \frac{\sqrt{1 - r_s/r}}{r}. \tag{36}$$

Although this rate vanishes exactly at $r = r_s$, it remains finite on a *stretched horizon* located at $r = r_s + \epsilon$, with $\epsilon \sim \mathcal{O}(\ell_\mathrm{p})$:

$$\frac{d\Omega}{dt} = \sqrt{\frac{\epsilon}{r_s + \epsilon}} \; > \; 0. \tag{37}$$

Radial fixation, lateral vibration, and the living surface. At the stretched horizon, the radial coordinate of each infalling quantum becomes effectively fixed:

any motion along r is infinitely time-dilated and dynamically inaccessible. However, degrees of freedom tangential to the horizon, those associated with angular or lateral displacements, remain kinematically active. These modes can oscillate, interact, and exchange phase information along the null surface while maintaining fixed radial position. The redshift factor suppresses radial components linearly, but tangential components only as its square root, allowing lateral motion to persist even as $r \to r_s$. Because their suppression is only of order $\sqrt{\ell_\mathrm{p}/r_s}$, these residual degrees of freedom remain indefinitely active, forming a quasi-static yet information-rich substrate on the constant-r horizon surface. The horizon thus behaves as a two-dimensional elastic–causal membrane: radially frozen yet laterally vibrant, supporting null propagation, coherence, and synchronization across its surface. It is on this *living causal surface* that spacetime continues to compute, and from which the holographic projection of the emergent interior universe arises.

3.8 Planck-Step Horizon Synchronization

Gravitational collapse halts at the Planck redshift limit, where further infall is converted into surface information rather than volumetric compression. Beyond this threshold, incoming matter–energy is no longer described by classical trajectories into a pre-existing volume, but by its transcription into horizon-localized degrees of freedom: angular-momentum eigenmodes, quantum fluctuations, and spin-network links that together form the black hole's holographic code. The "interior" is not an independently evolving spacetime region but an emergent, holographically projected volume reconstructed from this ordered surface encoding. Although the internal volume scales as r_s^3, its causal and informational genesis is entirely determined by the dynamically stratified horizon surface.

The Schwarzschild radius of a black hole of mass m_bh is

$$r_\mathrm{s} = \frac{2G\, m_\mathrm{bh}}{c^2}, \tag{38}$$

so a small mass increment Δm_bh changes the radius by

$$\Delta r_\mathrm{s} = \frac{2G\, \Delta m_\mathrm{bh}}{c^2}. \tag{39}$$

For a single Planck mass,

$$\Delta m_\mathrm{bh} = m_\mathrm{p} \quad \Rightarrow \quad \Delta r_\mathrm{s} = 2\, \ell_\mathrm{p}. \tag{40}$$

Each Planck-mass incorporation thus extends the horizon by two Planck lengths, forming a lightlike null layer of thickness $2\ell_\mathrm{p}$. In the horizon-layered cosmology, such a layer constitutes the smallest discrete reconfiguration of spacetime geometry, one global tick of the holographic code.

The Planck quantities form a synchronized triplet,

$$m_{\mathrm{p}} = \sqrt{\frac{\hbar c}{G}}, \qquad \ell_{\mathrm{p}} = \sqrt{\frac{\hbar G}{c^3}}, \qquad t_{\mathrm{p}} = \frac{\ell_{\mathrm{p}}}{c},$$

linked by

$$\frac{G m_{\mathrm{p}}^2}{\ell_{\mathrm{p}}} = m_{\mathrm{p}} c^2 = \frac{\hbar}{t_{\mathrm{p}}}.$$

At this scale, gravitational self-energy, quantum uncertainty, and relativistic causality coincide, defining the smallest self-localized excitation compatible with both general relativity and quantum mechanics. The synchronized triplet

$$(\Delta m,\, \Delta r,\, \Delta t) = (m_{\mathrm{p}},\, 2\ell_{\mathrm{p}},\, t_{\mathrm{p}})$$

therefore represents the minimal causal act of horizon growth.

Each Planck step transfers one Planck energy within one Planck time, corresponding to the universal causal power limit,

$$P_{\max} = \frac{E_{\mathrm{p}}}{t_{\mathrm{p}}} = \frac{c^5}{G}. \tag{41}$$

Numerically, $P_{\max} \approx 3.63 \times 10^{52}$ W, the absolute causal throughput of nature. **The event horizon operates precisely at this limit: one Planck energy per Planck time per global incorporation step.** When a collapsing core first attains the Planck collapse density and confines one Planck mass within a Planck-scale region, this causal power limit is reached; continuous classical collapse then transitions to discrete causal incorporation. A black hole forms, and its horizon begins to grow through sequential Planck-step updates: this marks the activation of the Planck-scale information channel.

The corresponding change in horizon area is

$$A = 4\pi r_{\mathrm{s}}^2 \quad \Rightarrow \quad \Delta A = 8\pi r_{\mathrm{s}}\, \Delta r_{\mathrm{s}} = 16\pi r_{\mathrm{s}}\, \ell_{\mathrm{p}}, \tag{42}$$

so that

$$\frac{\Delta A}{\ell_{\mathrm{p}}^2} = 16\pi\, \frac{r_{\mathrm{s}}}{\ell_{\mathrm{p}}} \tag{43}$$

new Planck-area cells are created in each step. Expressed in terms of m_{bh},

$$A = \frac{16\pi G^2 m_{\mathrm{bh}}^2}{c^4}, \qquad \frac{dA}{dm_{\mathrm{bh}}} = \frac{32\pi G^2 m_{\mathrm{bh}}}{c^4}, \tag{44}$$

and for $\Delta m_{\mathrm{bh}} = m_{\mathrm{p}}$,

$$\frac{\Delta A}{\ell_{\mathrm{p}}^2} = 32\pi\, \frac{m_{\mathrm{bh}}}{m_{\mathrm{p}}}. \tag{45}$$

For stellar-mass black holes, each Planck step reconfigures roughly 10^{40} Planck cells while changing the total area by only an infinitesimal fraction, macroscopic smoothness emerging from microscopic discreteness.

According to the holographic principle [1, 2], the total information within any causal domain is bounded by its boundary area,

$$I_{\max} = \frac{A}{4\,\ell_{\mathrm{p}}^2}. \tag{46}$$

In the present framework, this bound is *exactly saturated* and dynamically maintained by successive Planck-scale incorporations. Using

$$r_{\mathrm{s}} = \frac{2Gm_{\mathrm{bh}}}{c^2}, \qquad A = 4\pi r_{\mathrm{s}}^2 = 16\pi\,\frac{G^2 m_{\mathrm{bh}}^2}{c^4}, \tag{47}$$

Eq. (46) becomes

$$I = 4\pi\left(\frac{Gm_{\mathrm{bh}}^2}{\hbar c}\right) = 4\pi\left(\frac{m_{\mathrm{bh}}}{m_{\mathrm{p}}}\right)^2, \tag{48}$$

showing that total information scales quadratically with mass, $I \propto m_{\mathrm{bh}}^2$. Differentiating yields

$$\frac{dI}{dm_{\mathrm{bh}}} = 8\pi\,\frac{m_{\mathrm{bh}}}{m_{\mathrm{p}}^2}, \tag{49}$$

and for a single Planck incorporation,

$$\Delta I_{\mathrm{p}} = 8\pi\,\frac{m_{\mathrm{bh}}}{m_{\mathrm{p}}}, \tag{50}$$

so each successive step adds proportionally more information as the horizon grows.

The same scaling applies to entropy via the Bekenstein–Hawking relation,

$$S_{\mathrm{bh}} = 4\pi k_{\mathrm{B}}\left(\frac{m_{\mathrm{bh}}}{m_{\mathrm{p}}}\right)^2, \tag{51}$$

with incremental entropy

$$\Delta S_{\mathrm{p}} = 8\pi k_{\mathrm{B}}\,\frac{m_{\mathrm{bh}}}{m_{\mathrm{p}}}. \tag{52}$$

The matching coefficients in I and S_{bh} reflect their shared geometric origin: both derive from the same discrete area increments $\Delta A \propto m_{\mathrm{bh}}$.

In this framework, mass, entropy, and information are unified as complementary expressions of a single causal process: the sequential incorporation of null layers at the Planck-scale bandwidth $P_{\max} = c^5/G$. Each step increases m_{bh}, A, S, and I in lockstep, maintaining exact holographic saturation,

$$S \propto I \propto A \propto m_{\mathrm{bh}}^2, \qquad \Delta S, \Delta I \propto m_{\mathrm{bh}}.$$

The universe thus evolves through discrete yet cumulative increments of encoded information, ensuring that the holographic bound remains saturated throughout its history. **Planck-step horizon synchronization** thereby realizes bulk–boundary duality as an explicit causal mechanism, providing a singularity-free picture of black-hole growth and preserving unitarity by encoding all information on the evolving horizon.

3.9 Planck-Mass Incorporation Throttling

As infalling matter approaches the stretched horizon at $r(t) = 2M(t) + \ell_{\rm p}$, gravitational redshift and time dilation stratify it into a hierarchy of null-ordered layers. Each incorporation adds one Planck-scale shell to the horizon, expanding its radius by approximately $2\ell_{\rm p}$ and encoding a new interior causal domain. Because each layer is incorporated only after the previous one achieves full causal equilibration, the growth of the horizon proceeds in discrete, ordered steps that define the arrow of internal time. This process parallels the discrete causal ordering of spacetime in causal set theory [35].

The stretched horizon acts as an active assimilation zone of Planck width, composed of an outer intake layer and an inner code-bearing layer. Infalling quanta terminate their classical trajectories upon contact with the intake layer, where their information is holographically transcribed into the entangled membrane code. The process is not instantaneous: the incoming quantum must phase-lock with the surrounding network before complete incorporation can occur. This finite coherence time represents the physical bandwidth of the horizon's information channel.

Once coherence is achieved, the horizon performs a global unitary update,

$$\Psi_{\mathcal{M}}(t_{n+1}) = \mathcal{U}_n \, \Psi_{\mathcal{M}}(t_n),$$

where $\mathcal{U}_n$ reorganizes the entire causal lattice. Each incorporation increases the horizon area by $\Delta A = 16\pi r_{\rm s}\,\ell_{\rm p}$, i.e. $\Delta A/\ell_{\rm p}^2 = 32\pi\,(m_{\rm bh}/m_{\rm p})$. For a solar-mass black hole this is $\sim 10^{40}$ new Planck cells per tick, confirming that incorporation is a global (horizon-wide), not local, update.

Internal time advances by one Planck tick per incorporation; if accretion halts, so does the internal clock.

Three time perspectives must be distinguished:

- t: the external (parent-universe) Schwarzschild coordinate time;
- $\tau_{\rm loc}$: the local proper time on the stretched horizon,

$$d\tau_{\rm loc} = \sqrt{1 - \frac{r_s}{r_s + \epsilon}}\, dt;$$

- $t_{\rm internal}$: the internal emergent time, defined by null-ordered incorporation ticks, operationally identical to $\tau_{\rm loc}$ for observers within the holographic projection.

Discrete causal updating and the rhythm of internal time. Internal time advances only when a new Planck mass is assimilated because each incorporation represents a complete causal reconfiguration of the horizon's holographic code. Between incorporations, the stretched horizon remains in a maximally entangled but stationary configuration: all Planck-area cells preserve phase coherence and no new causal links are established. Lateral modes continue to oscillate and exchange phase information, yet these fluctuations are confined within a fixed relational topology, they do not alter the causal ordering of the code. Only when a new quantum of mass–energy crosses the redshift limit does the global tessellation retile and reindex, producing a new causal ordering across the entire network. Each such reindexing constitutes one fundamental tick of internal time: a discrete, horizon-wide act of causal incorporation at the universal bandwidth c^5/G. Thus, lateral tunneling is not continuous but phase-locked to these coherence intervals, ensuring that the emergent interior remains synchronized with the external sequence of Planck-step accretion.

For a tangential null displacement ($dr = 0$),

$$\frac{d\Omega}{dt} = \frac{\sqrt{1 - r_s/r}}{r}. \tag{53}$$

Converting to local proper time yields

$$\frac{d\Omega}{d\tau_{\text{loc}}} = \frac{(d\Omega/dt)}{(d\tau_{\text{loc}}/dt)} = \frac{\frac{\sqrt{1 - r_s/r}}{r}}{\sqrt{1 - r_s/r}} = \frac{1}{r}. \tag{54}$$

Thus a local observer measures a tangential speed

$$v_\perp = r\,\frac{d\Omega}{d\tau_{\text{loc}}} = 1, \tag{55}$$

corresponding to lightlike propagation along the horizon. Restoring physical units gives:

$$v_\perp = c. \tag{56}$$

Hence, while a distant observer perceives extreme slowing ($d\Omega/dt \ll 1$), local and internal observers always measure full light-speed lateral propagation.

For internal observers, lateral propagation along the horizon proceeds at the invariant speed c: information exchange between neighboring cells is always lightlike. From the external viewpoint, however, this same process appears exponentially slowed, because the horizon's coherence bandwidth throttles the rate at which new causal updates can occur. Gravitational time dilation is thus not a purely geometric effect but a macroscopic manifestation of finite information-processing capacity.

When the inflow of matter exceeds this coherence-limited incorporation rate, causal backlog accumulates. The horizon cannot process new information fast enough, and excess energy is expelled along open null channels, typically along magnetic field lines near the poles. This overflow appears macroscopically as relativistic jet emission, a direct signature of the horizon's finite causal bandwidth.

Gravitational time dilation, horizon growth, and jet ejection are therefore unified aspects of one principle: coherence-regulated causal incorporation. The horizon expands only after each quantum achieves full phase coherence with the existing network, and any surplus inflow must discharge through open causal channels. To an external observer, the process appears exponentially slowed by redshift; internally, it proceeds at light speed, maintaining perfect causal synchronization. Thus, time dilation and apparent "freezing" are not illusions of geometry but necessary consequences of the horizon's finite information throughput, the rate at which reality itself can update.

3.10 Relativity of Planck Scales Across Holographic Hierarchies

In a universe holographically generated from the horizon of a parent black hole, the fundamental Planck quantities remain invariant in their local definitions but become *relational* when compared across hierarchical causal frames. Each level of the hierarchy possesses its own proper time and spatial metric, yet all share the same underlying constants of nature:

$$m_{\mathrm{p}} = \sqrt{\frac{\hbar c}{G}}, \qquad \ell_{\mathrm{p}} = \sqrt{\frac{\hbar G}{c^3}}, \qquad t_{\mathrm{p}} = \frac{\ell_{\mathrm{p}}}{c}, \qquad E_{\mathrm{p}} = m_{\mathrm{p}} c^2.$$

These relations express the universal equilibrium between quantum uncertainty, relativistic causality, and gravitational self-energy, holding identically within every causal domain because the constants $\hbar, c$, and G are global invariants of the total causal structure.

When one spacetime emerges holographically as the interior of another, the mapping between their proper times introduces a gravitational redshift between frames, analogous to time dilation in special relativity. From the viewpoint of the parent universe, infalling matter appears to freeze near the event horizon; from the internal viewpoint, causal processes proceed normally according to the local metric. The relation between the parent coordinate time t and the internal proper time t_{int} satisfies

$$\frac{dt_{\mathrm{int}}}{dt} = \frac{1}{1 + z_{\mathrm{h}}} \ll 1,$$

so that one internal Planck tick t_{p} corresponds to an externally measured interval

$$\Delta t_{\mathrm{ext}} = (1 + z_{\mathrm{h}})\, t_{\mathrm{p}}.$$

This does not alter the Planck time itself but expresses a redshifted correspondence between causal frames: the same local quantum process is perceived as slower when viewed through the gravitational dilation of the parent metric.

Because the Planck energy is inversely related to the Planck time, $E_{\rm p} = \hbar/t_{\rm p}$, an external observer perceives the same causal event as carrying proportionally lower energy,

$$E_{\rm eff}^{(\rm ext)} = \frac{E_{\rm p}}{1+z_{\rm h}}.$$

Yet their ratio,

$$\frac{E_{\rm p}}{t_{\rm p}} = \frac{c^5}{G},$$

remains constant. This invariant defines the maximum rate of causal information flow that any horizon can sustain, the same for all observers regardless of position within the holographic hierarchy, just as the speed of light c is invariant across inertial frames.

Thus, the apparent hierarchy of Planck scales is not a variation of constants but a manifestation of redshifted causal reference frames. Each internal universe experiences its own proper causal rhythm, while the constants $\hbar$, c, and G remain universally fixed. The causal power c^5/G serves as a frame-independent invariant, ensuring that no horizon exceeds the fundamental bandwidth of information flow.

Thermodynamically, this invariance guarantees that every horizon saturates the same holographic entropy bound,

$$S = \frac{A}{4\,\ell_{\rm p}^2},$$

since both the Planck area $\ell_{\rm p}^2$ and the causal throughput c^5/G are invariant. The entropy–area relation therefore holds identically for all horizons, preserving energy conservation, unitarity, and the arrow of time across the holographic stack: redshift alters perception, not the underlying informational law.

A key implication of this hierarchy is that temporal and dynamical rates, not spatial extents, transform asymmetrically between parent and child horizons. If the internal universe evolves over a proper duration t_0 and possesses a horizon radius r_s, the parent observer measures

$$t_0^{(\rm parent)} = (1+z_{\rm h})\,t_0, \qquad r_s^{(\rm parent)} = r_s,$$

so that the apparent causal rate is suppressed by $(1+z_{\rm h})$:

$$\frac{r_s^{(\rm parent)}}{t_0^{(\rm parent)}} = \frac{r_s}{t_0(1+z_{\rm h})}. \tag{57}$$

Time dilation alone accounts for the perceived slowing of the internal universe; its geometric scale and informational capacity remain invariant. The black hole corresponding to our universe is vast in the parent cosmos, its enormous radius preserved while its internal dynamics are redshifted into near stillness.

While the apparent causal rate decreases by the factor $(1+z_{\rm h})$, the invariant throughput

$$\frac{E}{t} = \frac{c^5}{G}$$

remains constant across all hierarchical levels. Each universe therefore maintains the same fundamental causal power, even though its internal processes unfold at different perceived rates. The horizon retains its full radius r_s and invariant number of Planck-area cells,

$$N = \frac{A}{\ell_{\mathrm{p}}^2},$$

so its informational capacity and physical scale are identical for both internal and external observers. The distinction between frames arises solely from temporal redshift: the internal universe evolves at its proper rhythm, while to the parent observer it appears frozen, though the underlying geometry and encoded information remain unchanged.

From the parent frame, the horizon appears dynamically frozen because each internal causal tick is redshifted by $(1 + z_{\mathrm{h}})$, suppressing the apparent rate of evolution. From within, those same ticks constitute the full unfolding of spacetime, generating a vast and coherent cosmological domain. The enormous internal scale of our universe thus coexists consistently with the same vast external black hole that contains it, both sustained by the invariant causal throughput c^5/G that binds all hierarchical levels into a single, self-consistent physical reality.

This correspondence mirrors special relativity, generalized to holographic hierarchies: in the parent frame, internal processes appear time-dilated; in the internal frame, they proceed normally. Gravitational redshift here plays the role of relative velocity, governing temporal dilation across causal domains. Both perspectives describe one invariant causal structure whose geometry and informational content are fixed, differing only in the perceived rhythm of its updates.

Having established that causal redshift preserves all fundamental invariants, we may reinterpret temporal evolution itself as the ordered sequence of horizon code updates, the informational heartbeat of the universe. In this sense, the total informational count N replaces geometric measure as the true invariant of reality: space and time are emergent projections, while the number of encoded causal degrees of freedom remains eternally fixed.

The holographic hierarchy preserves complete physical and informational self-consistency. Each causal domain operates at its own redshifted temporal rate yet shares the same invariant constants and causal power c^5/G. Planck scales are not variable but *relational*, expressing the gravitationally time-dilated correspondence between nested causal frames. At any given epoch, the horizon area, and hence the number of Planck-area cells, $N = A/\ell_{\mathrm{p}}^2$, is the same geometric quantity for both the parent and internal frames; N grows with successive incorporations, but its value at a fixed horizon state is observer-independent. Mass–energy is added in discrete incorporations of m_{p} per t_{p}; the only distinction between frames is how the same sequence of incorporations is time-ordered by gravitational redshift.

The universes within universes are thus locally realized phases of one self-similar causal order, an unbroken chain of holographic horizons, each sustaining the same invariant information flux that defines the rhythm of reality itself.

3.11 Time as the Order of Horizon Code Configurations

Following the causal queueing principle introduced in the previous subsections, we may now express time in a precise and operational sense. **Time is not a pre-existing background coordinate but an emergent *order parameter* of horizon code configurations.** Each configuration Σ_i represents a complete, self-consistent encoding of matter, geometry, and causal relations at a given null layer of the stretched horizon. The passage of time corresponds to the discrete succession of these configurations, ordered by the causal incorporation of new layer quanta at the maximal holographic rate:

$$t_{\mathrm{internal}} \;\equiv\; \mathcal{O}(\{\Sigma_1, \Sigma_2, \Sigma_3, \dots\}), \tag{58}$$

where the ordering $\mathcal{O}$ follows the null sequence of successful incorporations permitted by the horizon's finite processing bandwidth $(1/t_{\mathrm{p}})$.

Each infalling layer, once admitted through the causal queue, triggers a global horizon reconfiguration, updating the entire holographic code through lateral entanglement redistribution and dipole realignment. This holistic reorganization defines one fundamental tick of internal time. The process is deterministic at the code level, governed by local and gauge-invariant update rules, yet its outcomes appear probabilistic when viewed through coarse-grained bulk variables, naturally accounting for quantum uncertainty as informational incompleteness within each discrete update.

Externally, infalling quanta follow null trajectories characterized by constant advanced time $v = t + r_*$, where $r_* = r + r_s \ln|r/r_s - 1|$ is the tortoise coordinate. Each increment in v corresponds to the arrival and successful incorporation of one additional null layer at the horizon, marking a discrete code update. Thus, internal time remains causally synchronized with the external advanced time,

$$t_{\mathrm{internal}} = N\, t_{\mathrm{p}} \quad \longleftrightarrow \quad v = v_0 + N\, \delta v_{\mathrm{p}}, \tag{59}$$

where N counts the number of layers successfully incorporated from the causal queue, and δv_{p} denotes the advanced-time interval associated with one Planck-scale horizon update.

The cumulative internal time is proportional to the number N of incorporated quanta with $N = m_{\mathrm{bh}}/m_p$ (where m_{bh} is black hole mass in kilograms and $t_p/m_p = G/c^3$). Therefore:

$$\boxed{t_{\mathrm{internal}} = \frac{G m_{\mathrm{bh}}}{c^3}}, \tag{60}$$

internal cosmic time is the discrete accumulation of successfully incorporated mass–energy quanta.

Equivalently, internal time may be written using the black hole mass in geometric units (with $M_{\mathrm{bh}} = G m_{\mathrm{bh}}/c^2$):

$$\boxed{t_{\mathrm{internal}} = \frac{M_{\mathrm{bh}}}{c}}. \tag{61}$$

When accretion ceases, the horizon mass becomes constant and the sequence of code updates halts. Internal time stops, not by collapse or

singularity, but by informational quiescence. When accretion resumes, time reactivates seamlessly: the internal universe continues from its last encoded state, unaware of any external delay. Thus, internal observers experience continuous temporal flow, while their clock remains causally bound to the parent universe's advanced-time sequence.

In this view, each Planck-mass incorporation produces a global, horizon-wide reconfiguration, an emergent "tick" of cosmic time that unifies gravitational growth, entropy increase, and causal continuity within a single holographic process.

4 Holographic Membrane

The holographic horizon can be understood as a dynamic membrane of Planck-scale thickness, where infalling matter is not transmitted into a classical volume but transcribed into a null-ordered encoding. Each quantum of mass or energy becomes a localized excitation with one causal face coupled to the external geometry and another inward-facing domain that withdraws causal capacity from the membrane, generating the effective gravitational potential. Under extreme redshift and time dilation, baryonic particles effectively freeze at a Planck-length offset above the Schwarzschild radius, converting their volumetric description into surface-aligned quanta. To preserve holographic coherence, these excitations communicate laterally across the membrane through null-synchronized interactions, establishing entanglement links that provide both coherence and intrinsic error correction.

The emergent interior is not a pre-existing volume but arises dynamically from coherent phase relations among these horizon quanta. When phases are uncorrelated, the projected bulk averages to near-emptiness, supporting only radiation and gravitational waves. Partial coherence forms dark-matter-like halos, while strong phase alignment produces stable baryonic structures. The statistical mixture of coherence and incoherence thus yields the observed cosmic energy partition: only a small fraction of the membrane maintains long-range phase coherence, while the majority remains incoherent, manifesting as vacuum-like energy.

The holographic membrane behaves as a dynamical fluid endowed with surface tension that resists deformation and regulates the effective gravitational coupling of the emergent interior. Local variations in this tension represent gradients of causal capacity: regions of high tension correspond to bandwidth saturation and deeper gravitational wells. Phase coherence feeds back into this tension, coherent domains are stiff and stable, while incoherent domains soften the surface and behave as vacuum energy. Accretion increases the horizon area and entropy in discrete Planckian steps; when local causal capacity saturates, new internal horizons can nucleate as *recursive domains of bandwidth saturation*. These internal horizons remain continuous with the parent surface, forming self-similar causal boundaries within a unified null-synchronized network.

Encoding proceeds via a radial fiber mapping: each Planck-scale patch of the horizon encodes the entire radial causal fiber of interior voxels, preserving measure by reconciling boundary area with bulk volume. Each patch serves as a holographic address, while its associated fiber records the cumulative layering of infall. Because baryonic quanta accrete stochastically, any finite region of the membrane contains incorporations from multiple epochs of collapse. As the horizon expands, initially proximate excitations become widely separated across the surface, generating long-range nonlocal correlations while preserving internal coherence of baryonic structures and cosmic filaments.

The membrane's effective tension drives continuous state-switching among encoded quanta, maintaining correlations necessary for stable macroscopic bodies through successive incorporations. In this way, the holographic mapping simultaneously *scrambles* microscopic information and *preserves* macroscopic coherence, allowing large-scale baryonic structures, stars, galaxies, and planetary systems, to persist within the emergent projection.

In the horizon-layered cosmology, gravitation is not a fundamental force but a manifestation of how information flow reorganizes around localized reductions in *causal capacity*. Each region of the holographic membrane has a finite ability to transmit and update causal information; mass and energy correspond to local restrictions of this bandwidth. A perfectly homogeneous membrane would transmit information isotropically and exhibit no curvature. When infalling matter or radiation deposits new information, local channels become saturated, creating gradients in causal throughput. These gradients naturally attract surrounding causal flux, producing the appearance of gravitational curvature.

At the most fundamental level, information is the physical state of causality itself. The holographic code functions as a binary causal network, each Planck-scale link representing a fundamental yes/no relation of connectivity between neighboring degrees of freedom. A fully connected network conveys no distinguishable information, and a fully disconnected one transmits none; information arises only in the dynamic balance between connection and disconnection—the physical substrate of the "1" and "0" of existence. Within this binary code, mass–energy corresponds to a localized *deficit* in causal connectivity, an *excision* that reduces local information density while preserving global flux conservation. Spacetime curvature then represents the network's self-consistent reconfiguration around these excisions, a geometric readjustment required to maintain the invariant causal throughput c^5/G. Trajectories curve not because of a force acting through space, but because causal relations continuously re-index to restore holographic consistency. Mass and information are thus equivalent expressions of the same underlying causal structure: energy, curvature, and information form a unified trinity governed by the finite bandwidth of spacetime.

In the classical limit, where the horizon code can be approximated by a smooth manifold, gradients of causal capacity become continuous, and the redistribution of causal flux takes the macroscopic form

$$G_{\mu\nu} \propto T_{\mu\nu}.$$

Here the Einstein tensor $G_{\mu\nu}$ encodes the divergence of causal trajectories (curvature), while the stress–energy tensor $T_{\mu\nu}$ represents local restrictions of causal throughput by energy and matter. Einstein's field equations thus emerge as the coarse-grained bookkeeping of a deeper informational equilibrium: curvature is the geometric trace of how the holographic membrane redistributes its finite causal bandwidth to preserve global unitarity and consistency.

In subsequent sections, we examine how localized excitations of the holographic membrane, Planck-cell dipoles, quantum tunneling, wavefunction collapse, and rotational Kerr effects, arise as direct manifestations of this causal network, governing the dynamics of phase coherence, information flow, and the stability of emergent structure across the holographic hierarchy.

4.1 Membrane Dipole Encoding

The Planck-scale cells constituting the holographic surface, each defined by causal polarity, spin orientation, and local connectivity, represent the most fundamental elements of this framework. They are not derived from any deeper structure but exist as the minimal self-consistent units through which causality, geometry, and information coincide. Each cell may be viewed as a composite of two bipolar causal dipoles whose internal degrees of freedom encode orientation (normal and tangential), phase (direction of rotation), and state (connected or disconnected) relative to its neighbors. These binary relations form the primitive syntax of spacetime, a lattice of mutual constraints from which the continuum of geometry and fields emerges. The origin of these dipolar, spinful, binary elements remains beyond derivation; they appear as the necessary atoms of reality's code, self-organized at the intersection of logic and existence: **causal nodes that are neither matter nor space, but the condition for both.** Each Planck cell therefore represents the smallest possible act of the universe knowing itself.

Every quantum merging with the holographic membrane is inherently *bipolar*, having two dipoles. Possession of rest mass introduces a causal asymmetry: one face of the quantum's primary dipole is partially excised and oriented inward toward the black-hole center, while the opposite face remains causally open to the external geometry. This intrinsic polarity guarantees gravitational alignment upon horizon contact. As infalling quanta redshift toward the stretched horizon, they lock their primary (radial) dipoles with the excised side facing inward, integrating coherently into the expanding null layer that defines the event horizon. The *excision parameter* χ quantifies the fraction of each quantum's causal surface disconnected from the external domain. Even for $\chi = 1/2$, the effective mass encoded per cell is far smaller than m_{p}, since a minimal black hole of total mass m_{p} would already contain more than one Planck-area cell.

Gravitational curvature thus originates from spatial gradients in this causal deficit: where causal capacity is locally reduced, information flow bends inward, producing curvature; where it is replenished, expansion occurs. Energy and information are dual aspects of the same quantity, and gravity expresses their local imbalance.

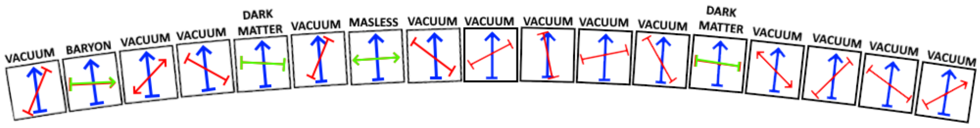

Fig. 4 Black hole holographic membrane quanta schematic representation. Each quantum possesses a primary dipole that operates in the parent universe (blue) and a secondary dipole that operates in the child universe, the holographic projection of the membrane's lateral dynamics (red and green). Only quanta with laterally oriented secondary dipoles (green) encode the internal matter/energy sector. Causally connected dipole edges are shown as arrows; disconnected edges as dashes.

Each holographic quantum can therefore be modeled as a combination of two dipoles (Figure 4). Every dipole has two "edges" (ends) that may be causally connected or disconnected from surrounding quanta. The primary dipole has its disconnected edge directed toward the black-hole center and its connected edge outward toward the external field. A secondary dipole axis is oriented randomly within the disconnected hemisphere of the primary dipole, chosen isotropically with polar angle $\theta \in [0, \pi/2]$ relative to the primary's normal. Radial freezing locks the primary dipole along the horizon normal $\mathbf{n}$, preventing further radial evolution from contributing to external time.

Once embedded in the holographic membrane, each quantum's secondary dipole acquires a frozen radial component fixed to infinity. The distinction between matter and vacuum arises within the lateral sector: if the secondary dipole orientation admits lateral causal connectivity with neighbors, it locks into a coherent network, encoding matter; if not, it remains decohered, contributing to the vacuum background. Thus, the membrane functions as a combinatorial lattice in which quanta continually reconfigure their causal states. Matter and radiation propagate via swap dynamics as the secondary dipole freely rotates around the primary axis, exploring all lateral directions and preserving isotropic selection of causal sectors.

Internally it appears that each Planck-scale horizon cell can transmit information at any finite lateral solid angle from 0 to 2π. For a spherical horizon of radius r_s, the total number of causal cells is $N_{\text{cells}} = 4\pi r_s^2/\ell_p^2$, and since the total solid angle of a sphere is 4π, the minimal resolvable angular element per cell is

$$\Delta\Omega_{\min} = \frac{4\pi}{N_{\text{cells}}} = \frac{\ell_p^2}{r_s^2}, \qquad \Delta\theta_{\min} \sim \frac{\ell_p}{r_s}.$$

The factor 4π ensures proper normalization over the full solid angle of the spherical horizon, so that the discrete angular cells collectively tile the entire causal surface.

Thus, directional propagation is fundamentally discrete: information can be transmitted only along a finite number of angular channels. However, as the universe expands and r_s grows, the number of available angular modes increases as r_s^2, rendering the discreteness observationally indistinguishable from a continuum. The apparent smoothness of angular propagation across spacetime is therefore an emergent property of the holographic lattice, an effective continuum arising from an underlying network of discrete causal directions.

The secondary dipole's angular tolerance for causal alignment is parameterized by γ, defining the cone of allowed lateral orientations:

$$\theta \in \left[\frac{\pi}{2} - \gamma,\, \frac{\pi}{2}\right]. \tag{62}$$

Only dipoles within this tolerance encode matter or radiation; others remain vacuum-like. Each dipole edge can be causally connected with probability $(1 - p)$ or disconnected with probability p, producing four possible configurations:

$$
\begin{aligned}
f_{\text{dark matter}} &= \sin\gamma\, p^2 && \text{(laterally aligned, both edges causally disconnected)},\\
f_{\text{baryon}} &= \sin\gamma\, 2p(1-p) && \text{(laterally aligned, one edge connected, one disconnected)},\\
f_{\text{massless}} &= \sin\gamma\, (1-p)^2 && \text{(laterally aligned, both edges causally connected)},\\
f_{\text{vacuum}} &= 1-\sin\gamma && \text{(secondary dipole not laterally aligned)}.
\end{aligned}
\tag{63}
$$

With $\gamma = 18^\circ = 90^\circ/5$ and $p = 11/12$, these relations reproduce the observed cosmic composition with remarkable accuracy:

$$f_{\text{baryon}} \simeq 0.048, \quad f_{\text{dark matter}} \simeq 0.262, \quad f_{\text{vacuum}} \simeq 0.691, \quad f_{\text{massless}} \simeq 0.002.$$

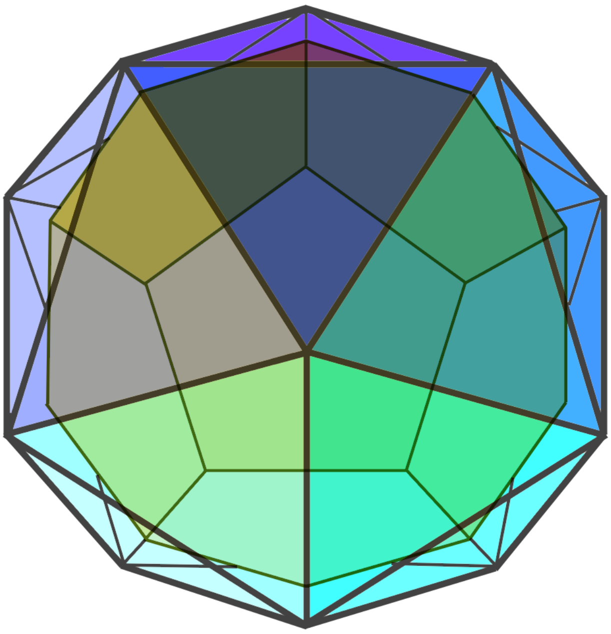

Fig. 5 Icosahedron–dodecahedron dual structure governing dipole orientation symmetries.

The holographic directions of dipole orientations correspond to the dual Platonic pair of the *icosahedron* and *dodecahedron*. The dodecahedron partitions the inward hemisphere into five equal 18° sectors, providing a geometric rationale for the angular tolerance γ. Its dual, the icosahedron, defines twelve discrete vertex directions corresponding to possible causal edges; in the narrow-cone limit, one of the twelve aligns within a lateral sector, giving a connection probability 1/12. Together, these polyhedral symmetries explain the five-fold and twelve-fold factors in Eq. (63). Their recurrence across particle physics, nuclear structure, and holographic cosmology suggests that the icosahedron–dodecahedron dual pair encodes a universal organizational symmetry of matter.

When a child universe nucleates from a parent black-hole horizon, the causal interpretation of each dipole reorders. The parent's primary (radial) dipole, previously frozen by gravitational redshift, becomes an active tangential degree of freedom within the emergent universe; conversely, its secondary dipole reorients inward, forming the primary axis of a new internal black hole. This alternation ensures that radial and tangential channels exchange roles across generations, maintaining orthogonality and causal independence between successive universes. Each universe thus inherits its internal matter composition and symmetry pattern from the combinatorial orientation statistics of its parent membrane.

In this unified view, gravitation, mass encoding, and cosmic matter partition all arise from the same holographic mechanism: local excision and dipolar organization of Planck-scale membrane cells. Where causal capacity is withdrawn, curvature forms; where lateral connectivity emerges, matter and radiation appear; and where alignment fails, vacuum dominates. The global evolution of the universe, its growth of mass, entropy, and causal order, thus reflects the collective, quantized reconfiguration of this dipolar membrane network.

To summarize the interplay of orientation and excision, we introduce an effective *causal potential* Φ_c associated with the secondary dipole of each membrane cell. Let β denote the angular deviation from perfect lateral alignment ($\beta = 0$ along the horizon tangent), and let γ represent the fixed half-opening angle of the matter-supporting cone (here $\gamma \simeq 18^\circ$). The causal state of each secondary dipole is defined by two independent parameters: a discrete *excision quantum* ϵ_n determining its rest mass, and a continuous angular variable β governing its phase, polarization, and field coupling. The effective causal potential then takes the form

$$\Phi_c \;=\; -\,\Phi_0\,\epsilon_n\,\Theta(\gamma - |\beta|), \tag{64}$$

where Φ_0 sets the Planck-scale normalization of causal flux, and Θ is the Heaviside function enforcing that only laterally oriented dipoles ($|\beta| < \gamma$) contribute to the internal mass sector.

The excision quantum ϵ_n defines discrete causal deficits on the membrane, corresponding to stable eigenstates of withdrawn connectivity:

$$\epsilon_n = n\,\epsilon_0, \qquad n = 0, 1, 2, \ldots, N_{\max}, \tag{65}$$

where ϵ_0 is the fundamental unit of causal excision set by the Planck-scale encoding rule. Each ϵ_n specifies a distinct, self-consistent configuration of withdrawn causal links and hence a unique rest-mass eigenvalue. Because Φ_c depends linearly on ϵ_n, the corresponding causal potential spectrum is quantized:

$$\Phi_{\rm c}^{(n)} = -\,\Phi_0\,\epsilon_0\,n\,\Theta(\gamma - |\beta|), \tag{66}$$

implying discrete rest-mass and curvature levels. Identical particles therefore correspond to identical excision numbers n, explaining the observed universality of rest mass among all particles of a given species.

Within the lateral cone ($|\beta| < \gamma$), continuous variations of β do not alter rest mass but modulate the phase alignment and polarization of neighboring dipoles. These angular correlations generate spin, magnetic coupling, and radiation modes, continuous degrees of freedom that coexist with the discrete causal quantization of mass. In this way, the membrane simultaneously supports a quantized mass spectrum through discrete excision states and a continuous field structure through angular coherence, bridging microscopic causal dynamics with macroscopic gravitational and quantum behavior. This framework naturally prepares the ground for the tunneling and Kerr-coupling mechanisms developed in the following sections.

The rest mass associated with each quantized excision state follows directly from the magnitude of its causal potential:

$$m_n \;=\; \eta\,\frac{|\Phi_{\rm c}^{(n)}|}{c^2} \;\propto\; \epsilon_0\,n\,\Theta(\gamma - |\beta|), \tag{67}$$

where η is a dimensionless normalization factor that maps causal potential energy into inertial mass. Equation (67) expresses mass as the geometric consequence of quantized causal excision: each discrete withdrawal of causal capacity (ϵ_n) produces an invariant mass quantum, while lateral coherence ($|\beta| < \gamma$) determines whether that mass contributes to the matter, dark, or radiation sectors.

4.2 Emergent Interactions from Lateral Causal Coherence

In the internal universe, gravitational mass arises not from radial but from *lateral* excision of causal capacity across the holographic membrane. Each secondary dipole within the membrane withdraws a discrete fraction of causal connectivity along the tangential plane, producing the local curvature that defines inertial mass. Radial excision operates only from the perspective of the parent universe, where the horizon itself constitutes the boundary of causal withdrawal. Internally, it is the lateral organization and coherence of these excised dipoles that determine the emergent structure of fields and forces.

Electromagnetic phenomena can be interpreted as collective oscillations in the lateral phase coherence of the membrane. Local gradients in the orientation phase of neighboring dipoles correspond to directional asymmetries in causal connectivity, forming circulating patterns of causal flux that manifest as electric and magnetic fields. Coherent, propagating phase modulations across the membrane surface transmit these asymmetries as radiation, the photon emerging as a self-sustaining wave of causal rephasing that carries no net excision but redistributes coherence across the horizon lattice. Electromagnetic charge, in this view, corresponds to a stable imbalance of lateral causal orientation within an otherwise symmetric network.

Nuclear interactions may arise from the topological organization of excised dipoles within small, correlated membrane domains. Where several adjacent dipoles withdraw causal capacity simultaneously, their lateral connections must reorganize to preserve global unitarity, generating closed loops of causal linkage and locked correlation structures. Such topologically confined regions would exhibit discrete binding energies and quantized transitions between excision eigenstates, providing a natural basis for the short-range strong and weak forces. The strong interaction reflects the confinement of causal flux within tightly locked dipole triplets, while the weak interaction may correspond to tunneling between adjacent excision states, mediated by transient reorientation of the lateral coherence field.

In this interpretation, all known interactions emerge from the same holographic substrate: mass and gravitation from lateral causal excision, electromagnetism from coherent phase dynamics across the tangential lattice, and nuclear forces from topological locking and tunneling among excised domains. Each represents a distinct regime of the same invariant causal flux c^5/G, manifesting through different symmetry patterns of the membrane's binary causal code. A detailed formalization of these emergent gauge behaviors, including their coupling hierarchy and rotational dependence is left for future work.

4.3 Kerr Geometry as a Rotating Causal Structure

In classical general relativity, rotation in black holes is described not by the motion of material surfaces, but by the rotation of spacetime itself. The Kerr metric, which generalizes the Schwarzschild solution to include angular momentum, possesses a nonzero off-diagonal term

$$g_{t\phi} = -\frac{2Gm_{\mathrm{bh}}a\sin^2\theta}{c^2 r_{\mathrm{s}}}, \tag{68}$$

where $a = J/(m_{\mathrm{bh}}c)$ is the Kerr spin parameter, J the black hole's angular momentum, and m_{bh} its physical mass in kilograms. This term encodes *frame dragging*, the azimuthal twisting of inertial frames around the spin axis. As a result, even though no material body crosses the event horizon in finite coordinate time, spacetime itself exhibits a stationary rotation.

The event horizon is a null surface generated by lightlike trajectories that spiral around the spin axis with angular velocity

$$\Omega_H = \frac{a\,c^3}{2\,G\,m_{\mathrm{bh}}\,r_H}, \qquad r_H = \frac{Gm_{\mathrm{bh}}}{c^2} + \sqrt{\left(\frac{Gm_{\mathrm{bh}}}{c^2}\right)^2 - a^2}. \tag{69}$$

Hence, the horizon is not a static boundary but a *rotating causal structure*. Its rotation is a geometric property of the metric, not a mechanical motion of matter; the null generators of the horizon co-rotate with the spacetime itself. This resolves the apparent paradox between "time freezing" for infalling matter and the persistence of rotation:

the freezing applies to matter approaching the horizon, whereas the rotation pertains to the spacetime geometry, which remains globally stationary but azimuthally twisted.

Although gravitational time dilation effectively freezes infalling matter at the horizon, the holographic membrane resides a finite distance above it, at $r = r_\mathrm{s} + \ell_\mathrm{p}$. At this "stretched horizon," the redshift factor is immense but not infinite, permitting an exceedingly slow causal evolution of the membrane itself. Hence, while the mathematical horizon remains a stationary null surface, the physical membrane can undergo an ultra-slow azimuthal drift consistent with the Kerr frame dragging. In the external frame this rotation is practically frozen, but in the local Planck frame it corresponds to continuous causal updates that sustain null coherence. The membrane therefore rotates not mechanically, but causally, maintaining the phase structure that imprints the internal universe with its global orientation.

Within the horizon-layered cosmology, such rotation acquires a physical informational meaning. The holographic membrane that encodes the internal universe is not static with respect to the parent spacetime: it carries a Kerr-induced azimuthal phase twist characterized by the same spin parameter,

$$a = \frac{J}{m_\mathrm{bh} c}. \tag{70}$$

This twist represents the causal imprint of frame dragging on the holographic code. Each Planck-scale horizon cell participates in a network of null-synchronized interactions whose causal adjacency relations advance azimuthally at the rate Ω_H. The horizon thus undergoes a genuine *causal rotation*: not as a material surface in motion, but as a dynamically updating pattern of causal connectivity co-rotating with the Kerr geometry. This process produces differential redshift and phase coupling across latitudes, encoding a systematic azimuthal phase gradient in the holographic code that biases the order of null-layer incorporations and imprints a spin-dependent phase asymmetry on the emergent universe.

Internally, this global rotation is not perceived as bulk motion, since all causal degrees of freedom share the same co-rotating reference frame. Instead, it manifests as a *phase structure* within the entanglement network: an azimuthal ordering of correlation phases across the holographic membrane. This phase gradient constitutes the internal imprint of the parent black hole's angular momentum and forms the informational seed of cosmic anisotropy. Consequently, the emergent universe inherits a preferred axis aligned with the parent spin vector, encoded as a coherent orientation in the primordial mode spectrum.

Because cosmic inflation in this framework is driven by the continuous growth of the parent horizon rather than by a scalar inflaton field, the spin-imprinted asymmetry is *not erased by inflationary expansion*. It is preserved as a large-scale alignment in the internal universe, manifesting observationally as the cosmic microwave background (CMB) dipole and the alignment of low-ℓ multipoles (the "Axis of Evil"). While the standard ΛCDM cosmology attributes the CMB dipole to our peculiar velocity relative to the cosmic rest frame, recent analyses [36] suggest that a portion of the observed dipole and low-ℓ alignments may reflect an intrinsic cosmological anisotropy imprinted at the earliest stages of the universe.

From the external viewpoint, the horizon's rotation is a purely geometric phenomenon, the stationary frame dragging intrinsic to the Kerr spacetime. From the internal viewpoint, it is experienced only through phase correlations and anisotropic alignments in the emergent cosmological field structure. The parent black hole's angular momentum thus serves as a geometric bridge between external Kerr geometry and internal cosmological anisotropy, linking the global rotation of the horizon to the directional asymmetries observed in our universe.

In summary, the Kerr rotation of the parent black hole is both geometric and causal. Classically, it is the rotation of spacetime itself; holographically, it is the azimuthal advancement of causal relations among Planck-scale horizon cells. This causal rotation defines the fundamental phase background upon which all subsequent quantum and thermodynamic asymmetries are encoded, seeding chirality, parity violation, and the directional structure of the emergent universe.

4.4 Spin–Topological Origin of Baryon Asymmetry and Cosmic Anisotropy

Every Planck-scale quantum on the holographic membrane is represented by a bipolar causal unit, a pair of poles defining an oriented dipole. The local surface normal of the membrane provides a preferred axis, the radial direction relative to the black hole center. Each quantum's *primary dipole* aligns with this normal, while its *secondary dipole* lies within the tangent plane and carries an intrinsic spin-like orientation relative to the global horizon rotation.

Spin quantization and exclusion from horizon topology. Because the horizon is a two-dimensional surface, spin cannot assume arbitrary three-dimensional directions: each dipole's angular momentum vector can only be parallel or antiparallel to the local normal, producing two discrete causal orientations,

$$s = +\tfrac{1}{2} \quad \text{(aligned with horizon spin)}, \qquad s = -\tfrac{1}{2} \quad \text{(anti-aligned)}.$$

These two orientations form the binary spin basis of the horizon code, corresponding to the familiar "up" and "down" states of fermionic matter in the emergent universe. Because no two quanta can occupy the same Planck cell with identical spin orientation and phase, the Pauli exclusion principle emerges naturally: it is a topological constraint of the holographic membrane, arising from the requirement that each null-tiled cell maintains a unique spinor phase relative to its neighbors. The antisymmetry of the fermionic wavefunction is thus geometrically encoded as the antisymmetric linking of dipole orientations across adjacent cells on the horizon.

Frame-dragging, chirality, and phase bias. When the parent black hole possesses angular momentum $\mathbf{J}$, the frame-dragging field of the Kerr geometry introduces an azimuthal phase gradient across the horizon. The local angular velocity of frame dragging near the horizon is

$$\omega_{\rm fd} = \frac{2GJ}{c^2 r_{\rm s}^3}, \tag{71}$$

where $r_{\rm s}$ is the horizon radius. During a Planck-time incorporation interval $\Delta t = t_{\rm p}$, the two spin orientations acquire a differential phase shift

$$\Delta\phi = 2\,\omega_{\rm fd}\,t_{\rm p} = \frac{4GJ\,t_{\rm p}}{c^2 r_{\rm s}^3}. \tag{72}$$

For a near-extremal black hole with $J \sim G m_{\rm bh}^2/c$ this yields

$$\frac{\Delta\phi}{2\pi} \sim \frac{2G^2 m_{\rm bh}^2 t_{\rm p}}{\pi c^3 r_{\rm s}^3} \;\approx\; 10^{-10},$$

for a stellar-mass progenitor—precisely the magnitude required to account for the observed baryon-to-photon ratio $\eta_b \sim 6 \times 10^{-10}$.

Helicity locking and baryon preference. Because the frame-dragging field couples rotational direction to local spin orientation, the two allowed states correspond to opposite helicities with respect to the global angular momentum of the parent horizon. The co-rotating orientation ($s = +\frac{1}{2}$) remains phase-synchronous with the horizon's rotation, maintaining coherence across successive incorporations. The counter-rotating orientation ($s = -\frac{1}{2}$) experiences a phase lag proportional to $\Delta\phi$ and decoheres more rapidly. This asymmetry introduces a small but cumulative preference for matter-like chirality: during sequential Planck-step incorporations, co-rotating states dominate, while anti-aligned states are statistically suppressed. The resulting helicity bias is preserved in the emergent universe as the observed baryon excess.

Chiral continuity across holographic layers. As the horizon layers expand outward, each new null surface inherits the local spin–phase distribution of the previous one, transmitting its chirality bias through the holographic projection. The same spin-locked phase gradient that seeds baryon asymmetry also imprints a small directional anisotropy in the causal lattice, an origin for the parity-violating signatures and large-scale dipole alignments observed in the CMB and galactic spin distributions. Thus, baryon asymmetry, fermionic exclusion, and cosmic anisotropy arise as unified consequences of the same underlying spin–topological structure of the horizon code.

4.5 Quantum Tunnelling and Causal Information Exchange

The evolution of the holographic code does not unfold as a continuous flow, but as a sequence of discrete causal updates governed by rhythmical membrane reconfigurations that define Planck ticks. In the following, we develop this dynamical layer, showing how quantum tunnelling, causal synchronization, and wavefunction collapse emerge naturally from the membrane's discrete causal mechanics.

In the horizon-layered cosmology, motion and interaction are not primitive ingredients of reality but emergent manifestations of a deeper causal code. The horizon forms a stationary lattice of Planck-scale cells, each representing a discrete causal element of spacetime. Nothing within this lattice literally moves; rather, the global adjacency relations among cells are continually redefined through discrete causal updates. From the external viewpoint, this process appears as the steady outward growth of the event horizon; from the internal viewpoint, it manifests as the expansion of cosmic space.

Each new layer of horizon cells introduces a global relational shift, redefining the relative positions of all pre-existing cells without requiring local transport of information. This radial process, the continuous incorporation of new causal elements, is the geometric origin of cosmic expansion. It is analogous to the stretching of space between galaxies: galaxies do not move through space, but their mutual separations increase as the causal lattice retessellates. The universe grows because the horizon grows; geometry evolves through relational reindexing rather than material motion.

The horizon also supports a complementary lateral process: causal communication between neighboring Planck cells. Each cell possesses a secondary dipole oriented tangentially to the horizon, allowing it to exchange information with adjacent cells through quantum tunnelling along null directions on the surface. This lateral coupling establishes the foundation for coherence, radiation, and interaction. Whereas radial incorporation governs global expansion and temporal ordering, lateral exchange maintains local continuity and dynamical connectivity across the horizon code.

Lateral tunnelling enables field-like correlations to propagate across the membrane, producing the internal phenomena corresponding to light, forces, and quantum fields. Massless excitations arise from maximally coherent lateral coupling: they represent pure causal waves that expend their entire bandwidth maintaining phase coherence across null links. Massive quanta correspond to partially excised domains with reduced lateral coupling; their inertia reflects the limited capacity to reindex causal relations between neighboring cells. Dark matter represents the limiting case of near-total lateral disconnection: it neither radiates nor interacts electromagnetically, yet it participates gravitationally through curvature induced by local deficits of causal capacity.

Gravitational attraction thus emerges as a gradient in lateral coupling density: regions with reduced causal bandwidth draw nearby quanta toward them, precisely as curvature attracts mass in classical geometry. Large-scale structure formation arises from the interplay between outward radial expansion and inward coherence through lateral coupling.

At the most fundamental level, horizon dynamics consists of these two synchronized processes. Radial incorporations continuously extend the causal manifold; lateral exchanges maintain coherence, propagate correlations, and enable radiation and interaction. Together they constitute a unified causal mechanism: one driving the growth of spacetime, the other preserving its internal consistency. The speed of light c expresses the invariant rate at which this causal lattice can update its null-connected adjacency, the universal bandwidth of both processes. Reality is therefore a stationary yet perpetually updated holographic code whose retessellation and lateral coherence jointly generate the phenomena of motion, radiation, and gravitation.

The coexistence of global relational reconfiguration and local lateral exchange provides a unified interpretation of light propagation and cosmic

expansion. A photon's journey combines relational drift, arising from the growth of the causal manifold, with local coherence preserved through lateral null communication. This duality explains both cosmological redshift and the constancy of c: expansion reflects the redefinition of adjacency in the underlying code, while light embodies the invariant coherence bandwidth of null-synchronized Planck cells.

This causal–informational paradigm connects naturally with discrete spacetime models such as causal sets and cellular automata, in which geometry arises from successive updates rather than continuous motion. Here, the horizon acts as a null-synchronized automaton whose global update rules encode gravitational, quantum, and thermodynamic behavior within a unified causal architecture. The stationary yet perpetually reconfigured horizon thus constitutes the foundational substrate from which motion, tunnelling, and spacetime continuity all emerge as macroscopic expressions of Planck-scale causal updates.

4.6 Relativistic Effects as Causal Bandwidth Reallocation

In the horizon-layered cosmology, proper time and inertial mass arise from the same underlying principle: the finite causal bandwidth of the horizon's information code. Each Planck-scale cell can process information only up to a maximal rate determined by the Planck time,

$$\dot{\mathcal{I}}_{\text{max}} = \frac{1}{t_{\text{p}}} = \sqrt{\frac{c^5}{\hbar G}},$$

which defines the ultimate throughput of causal updates within the null-synchronized holographic network. This finite rate acts as a local conservation law governing all physical processes: proper time flow, energy, and inertia are expressions of how that fixed causal bandwidth is partitioned.

For a stationary excitation, the entire causal capacity of a cell is available for internal phase evolution, producing the full progression of proper time and the rest energy $E_{\text{rest}} = m_0 c^2$. However, when an excitation propagates laterally across the horizon network with velocity v, part of its causal bandwidth must be reallocated to maintain phase coherence between successive cells. Only the remaining fraction of bandwidth contributes to internal updates:

$$\dot{\mathcal{I}}_{\text{int}} = \dot{\mathcal{I}}_{\text{max}} \sqrt{1 - \frac{v^2}{c^2}}. \tag{73}$$

Since proper time measures the number of internal updates per unit coordinate time, this yields

$$\frac{d\tau}{dt} = \frac{\dot{\mathcal{I}}_{\text{int}}}{\dot{\mathcal{I}}_{\text{max}}} = \sqrt{1 - \frac{v^2}{c^2}}, \tag{74}$$

identical in form to the standard special-relativistic time-dilation relation. Here, however, time dilation is not a purely geometric effect of motion through spacetime but an informational consequence of bandwidth partitioning within a finite causal code. As $v \to c$, all causal capacity is consumed in maintaining lateral null synchronization, $\dot{\mathcal{I}}_{\text{int}} \to 0$, and internal time halts.

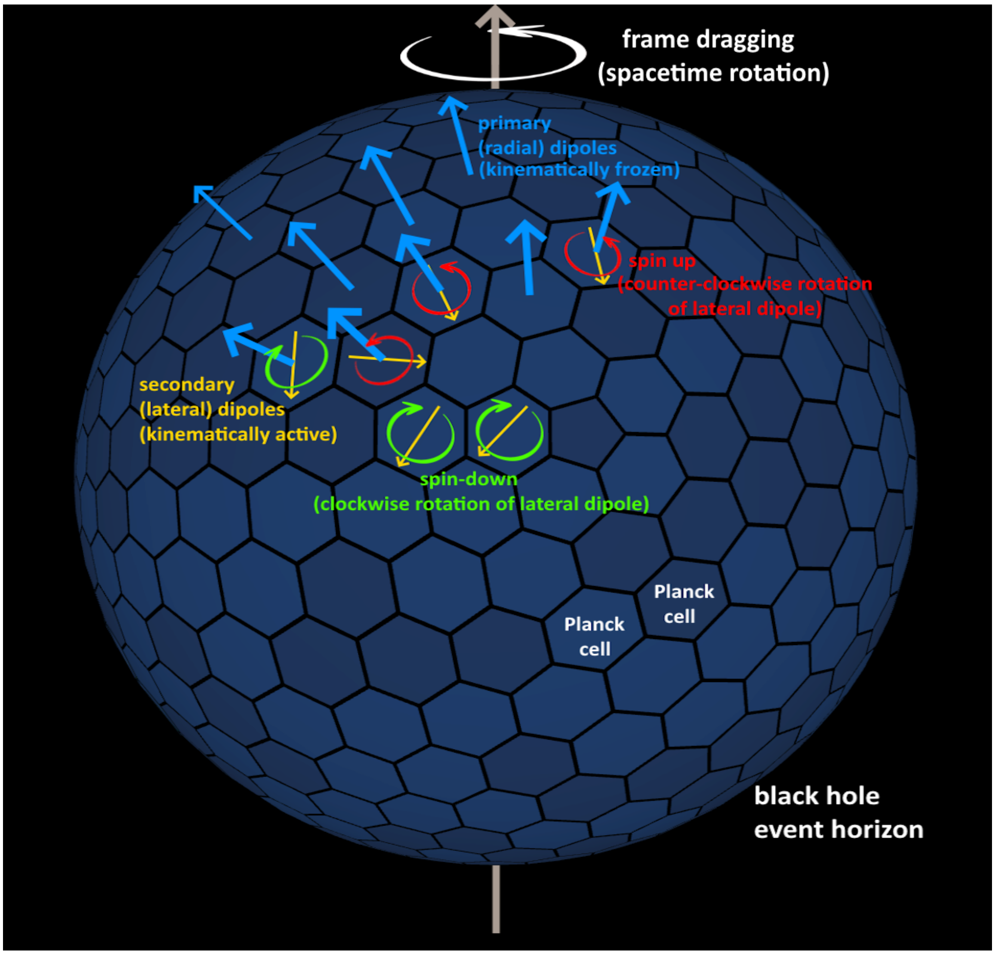

Fig. 6 Schematic representation of a Kerr black hole horizon surface composed of individual Planck cells.

A photon therefore does not "move through" spacetime; it is a standing causal wave that expends its entire bandwidth on coherence propagation. Its null trajectory represents the limiting case of pure lateral information transfer, where no causal capacity remains for internal phase evolution.

Because the total causal flux per cell, the product of update rate and information energy per update, is invariant, a reduction in the update rate requires a compensating increase in energy per update:

$$E_{\text{tot}}\,\dot{\mathcal{I}}_{\text{int}} = E_{\text{rest}}\,\dot{\mathcal{I}}_{\text{max}} = \text{constant}. \tag{75}$$

Substituting Eq. (73) gives

$$E_{\text{tot}} = \frac{E_{\text{rest}}}{\sqrt{1-\frac{v^2}{c^2}}}, \qquad m_{\text{eff}} = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}, \tag{76}$$

reproducing the relativistic mass–energy relation from the same conservation principle. Thus, time dilation and mass increase emerge as complementary manifestations of causal bandwidth reallocation: one describes the reduction of update frequency, the other the increase of information energy per update. Both preserve the invariant product $E\dot{\mathcal{I}}$, representing the fixed causal power throughput of the horizon code.

From this perspective, inertia is the resistance of a system to bandwidth reallocation: accelerating a mass requires redistributing its causal throughput between internal and coherent modes. Regions where bandwidth is predominantly spent maintaining lateral coherence (high v) exhibit increased effective energy density and curvature sourcing, while stationary regions dominated by internal updates correspond to rest energy and pressure. In the continuum limit, these bandwidth fluxes coarse-grain into the stress–energy tensor $T_{\mu\nu}$, which represents the local density and flow of causal capacity that sources curvature via Einstein's equation

$$G_{\mu\nu} \;=\; \frac{8\pi G}{c^4}\,T_{\mu\nu}.$$

Curvature, in turn, expresses the geometric response of the causal network to spatial variations in bandwidth utilization. General relativity thereby emerges as the macroscopic expression of the conservation and redistribution of finite causal throughput within the horizon code.

The precise tensorial formulation of causal bandwidth, its local conservation law, and quantitative connection to observables remain open areas of future development. The present exposition aims to establish the physical plausibility and internal coherence of interpreting relativistic effects as reallocation and compression of finite causal information flow, a principle that naturally unifies time dilation, inertia, and gravitation under a single informational constraint.

4.7 Relation to Discrete Causal and Cellular Automaton Models

The horizon-layered cosmological framework exhibits deep structural parallels with discrete causal and cellular automaton models of spacetime, most notably those developed in the context of the Wolfram Physics Project [37, 38]. Both approaches regard spacetime and physical law as emergent from an underlying network of discrete update events governed by causal rules. However, while the Wolfram framework treats this network as an abstract hypergraph evolving through local rewriting operations, the present model identifies a concrete physical substrate: the null-ordered black hole horizon itself, whose Planck-scale cells form the fundamental nodes of a physically realized causal automaton.

Each holographic incorporation event in the horizon-layered model corresponds to the addition of a Planck-scale null layer, generating a discrete update of the global causal code. This process defines a mapping onto a causal network of update events, where each horizon configuration Σ_n transitions to Σ_{n+1} through a null-synchronized rewriting analogous to Wolfram's graph evolution. The null-ordering principle enforces global consistency and causal invariance, providing a physical realization of the abstract "causal invariance" that in the Wolfram framework underlies Lorentz symmetry. In this sense, the horizon behaves as a null-synchronized automaton embedded in curved spacetime, with geometry and causal structure co-generated by its update rules.

Yet the correspondence extends beyond formal analogy. In the Wolfram model, the hypergraph's links define both adjacency and causality, whereas in the horizon-layered picture these roles bifurcate into two complementary processes: (1) a *radial relational reconfiguration* that globally redefines adjacency through the incorporation of new Planck-scale cells, and (2) a *lateral causal exchange* that propagates coherence and interaction across neighboring cells along the horizon surface. The first process defines the expansion and temporal ordering of the universe, the sequential growth of the causal manifold, while the second sustains local coherence, radiation, and gravitational coupling. Together, they constitute a dual causal architecture: a global null-ordered remapping that advances spacetime and a local tangential channel that preserves connectivity and physical interaction. In Wolfram's framework, both functions are conflated within local rewriting; here, they are physically distinguished and causally synchronized.

This distinction grounds Wolfram's abstract causal computation in thermodynamic and geometric reality. The horizon provides an explicit holographic substrate whose area growth encodes entropy increase and defines the arrow of time. Gravitational redshift and null synchronization give causal directionality without external postulate, while the entropic expansion of the horizon furnishes an intrinsic mechanism for irreversibility. Where the Wolfram model assumes asymmetric update rules to generate temporal flow, the present theory derives it directly from the holographic incorporation process at the Planck bandwidth limit c^5/G.

Moreover, the lateral tunnelling among Planck cells supplies a concrete analogue to Wolfram's local update rules: information propagates tangentially along the horizon lattice, constrained by the null condition $ds^2 = 0$, while the global relational remapping defines the higher-level evolution of the causal graph itself. The horizon thereby performs a dual computation, local and global, microscopic and cosmological, through which spacetime, motion, and interaction co-emerge as informational phenomena.

In this light, the black hole horizon functions as a physically instantiated causal automaton whose rule set is not arbitrary but determined by the geometric and thermodynamic constraints of general relativity. The sequential incorporation of Planck layers enforces causal order; lateral exchanges maintain coherence and field propagation; and their interplay saturates the holographic information bound. The discrete causal structure envisioned in cellular automaton physics thus finds a tangible realization on null surfaces, while the horizon-layered holographic mechanism supplies the physical law that performs the computation of spacetime itself.

4.8 Natural Discretization, Wavefunction Collapse, and Quantum Entanglement

The discrete advancement of internal time, defined by successive incorporation events, implies that the evolution of the holographic membrane is inherently stepwise. Each incorporation corresponds to the addition of one Planck-scale quantum of mass, updating the global state of the membrane and generating a single "Planck tick" of internal time. In the null-ordered framework, infalling matter becomes redshift-frozen at a finite causal distance above the horizon, where it is assimilated into the stretched membrane through one such discrete update. The event horizon thus behaves not as a static surface but as a dynamically growing, tension-bearing quantum code boundary.

Radially, this growth proceeds in Planck-scale increments, while laterally the membrane is tessellated into Planck-area patches $\Delta A \sim \ell_{\mathrm{p}}^2$, organized through near-optimal packing geometries (e.g. icosahedral or dodecahedral tilings) that maximize local coherence. Each patch acts as a coherent domain, linked by lateral null connections that propagate at the full light speed c within the stretched horizon's proper frame. The lateral equilibration condition $\tau_{\mathrm{coh}} \ll \Delta\tau_{\mathrm{inc}}$ ensures that the entire membrane attains a self-consistent causal phase before the next incorporation event occurs. This global reconfiguration condition provides the physical foundation for the arrow of internal time and establishes causal coherence between successive holographic states.

At each incorporation step, the newly infalling layer ceases to exist as an independent external entity. Its information is absorbed into the membrane's quantum code through a unitary update,

$$\Psi_{\mathcal{M}}(t_{n+1}) = \mathcal{U}_n \, \Psi_{\mathcal{M}}(t_n),$$

where $\mathcal{U}_n$ represents the global reorganization of local dipole states and their entanglement links. From the internal perspective, this update is experienced as a discontinuous change in the effective state of the universe, a collapse of the internal wavefunction. What appears externally as a continuous, deterministic evolution of the global state becomes internally a sequence of discrete, causally gated transitions.

This natural discretization provides a physical mechanism for the wavefunction-collapse phenomenon. The membrane itself acts as an objective, geometric environment that enforces causal consistency and decoheres incompatible internal amplitudes. Quantum states that do not satisfy the membrane's updated coherence structure are eliminated from the internal Hilbert space, while those that remain form the next consistent layer of the holographic code. The process thus implements a physical selection rule analogous to Zurek's pointer-state decoherence [39], but rooted in the causal dynamics of the horizon.

Globally, the combined parent–interior system evolves unitarily across the extended Hilbert space of the holographic code,

$$\Psi_{\mathrm{total}}(t_{n+1}) = U_{\mathrm{global}} \, \Psi_{\mathrm{total}}(t_n),$$

preserving total information. However, from the internal viewpoint, obtained by tracing out external degrees of freedom, the evolution appears stochastic and non-unitary.

The apparent collapse of the wavefunction is therefore not a subjective measurement event nor a branching of worlds, but a physically necessary consequence of causal excision and finite incorporation rate. Each Planck-scale update defines a new causal boundary condition, and amplitudes incompatible with that boundary are effectively projected out.

Quantum indeterminacy thus arises not from epistemic uncertainty but from geometric causality: only those internal configurations compatible with the current membrane state remain dynamically accessible. The redshift-induced causal separation between layers functions as a natural post-selection mechanism, ensuring consistency across the entire null-ordered history. Wavefunction collapse corresponds to a geometric transition in the allowed state space of the emergent universe, governed by the sequential updating of the holographic membrane.

This interpretation echoes Rovelli's relational quantum mechanics [40], where states are defined relative to observers. Here, the event horizon itself plays the role of the relational observer: a dynamically evolving null surface that records, regulates, and selects the admissible amplitudes of the internal universe. Bell inequalities are violated for the same reason as in standard quantum mechanics, not through local hidden variables, but through the null-ordered correlations of the holographic code. From the viewpoint of the emergent spacetime, these correlations appear "nonlocal," since measurements at spacelike separation exhibit instantaneous statistical dependence. From the viewpoint of the horizon, however, no superluminal signaling occurs: all correlated degrees of freedom are locally adjacent within the null-synchronized lattice. The violation of Bell inequalities therefore reflects the projection of horizon-local entanglement into an emergent geometry where the shared causal substrate is hidden. The "collapse" of the wavefunction is the local manifestation of a global, null-ordered causal update.

In the horizon-layered cosmology, quantum entanglement arises from the shared encoding of multiple internal excitations within a single causal code word on the holographic membrane. Although two entangled particles may appear widely separated in the emergent three-dimensional spacetime, their corresponding boundary degrees of freedom remain locally connected within the horizon network. Measurement of one particle triggers a horizon-level re-synchronization of that shared code word, a null-surface update that is perceived internally as instantaneous but is globally lightlike.

Within this framework, quantum "nonlocality" is reinterpreted as geometric redundancy: the same causal pattern is expressed at multiple emergent locations within the internal spacetime. What appears as nonlocal correlation in the bulk is simply the local coherence of a single null-synchronized structure on the horizon. Thus, **the holographic membrane preserves perfect locality and causality, even while projecting phenomena that, to internal observers, manifest as Bell-type nonlocal entanglement.**

Measurement corresponds to a reconfiguration of that shared boundary code, a global null update that manifests internally as correlated outcomes.

Although entangled excitations share a unified holographic encoding, this connection cannot transmit information. The null-synchronized surface supports correlations but not directed causation: its points are spacelike-separated in the emergent spacetime but null-related on the parent horizon. Any local attempt to encode information consumes causal bandwidth and collapses coherence, enforcing the no-signaling condition as a direct consequence of bandwidth conservation rather than as an additional quantum postulate.

Within the horizon-layered cosmology, the conceptual paradoxes of quantum mechanics, nonlocality, collapse, and the no-signaling constraint, emerge as geometric corollaries of null causal structure. Entangled systems appear correlated across vast distances because their holographic encodings share a single causal patch on the horizon. Measurement corresponds to a global update of this null-synchronized network, perceived internally as instantaneous but physically constrained by the finite Planck bandwidth. Thus, the horizon framework transforms the postulates of quantum theory into *theorems of causal geometry.*

In the standard AdS/CFT correspondence, bipartite entanglement between boundary regions is computed via bulk extremal surfaces (Ryu–Takayanagi/HRT). In the horizon-layered cosmology, however, the emergent bulk *is itself* a projection of the parent horizon; there is no deeper manifold in which such extremal surfaces exist independently. The fundamental structure is the null-synchronized causal network of Planck-scale links that tessellate the horizon.

For two disjoint internal regions A, B, the leading entanglement scales with the *minimal cut* $\gamma_{A|B}$ on the parent horizon graph that separates the corresponding code patches:

$$S(A{:}B) \;\approx\; \alpha\,|\gamma_{A|B}|\,, \qquad |\gamma_{A|B}| \equiv \text{number of cut links on the membrane},$$

with $\alpha = \mathcal{O}(1)$ determined by the code rate per Planck link. Unlike in AdS/CFT, no independent bulk extremal surface is required: the minimal cut resides directly on the null surface itself. This predicts that long-distance internal entanglement depends *only* on the separating cut-capacity of the parent horizon tiling, not on internal geodesic length, yielding distance-independent but *horizon-geometry dependent* Bell correlations.

Each link on the horizon lattice represents a fundamental causal adjacency, a pair of Planck cells sharing a null-synchronized information channel. The "cut" refers to the smallest set of such links that must be severed to disconnect the code patch associated with region A from that of region B. The count $|\gamma_{A|B}|$ therefore quantifies the number of shared causal connections or entangled horizon pairs that mediate correlations between A and B. Entanglement entropy is proportional to this cut because it measures precisely how much information must be erased to render the two regions independent.

In tensor-network terms, the horizon functions as a self-organizing, null-ordered network whose links are Planck-scale tensors encoding local quantum correlations. The "minimal cut" is thus the direct, causal-network analogue of the Ryu–Takayanagi surface: it identifies the narrowest bottleneck of shared links through which information about A and B co-propagates. Because all correlations are realized through these null connections, the entire internal entanglement structure is determined by horizon connectivity alone. No auxiliary bulk extremization principle is required; the null geometry of the membrane already encodes it combinatorially.

Although entanglement between distant internal regions appears "nonlocal" in the emergent spacetime, on the horizon it remains strictly local: every correlated degree of freedom corresponds to a contiguous set of Planck links within the null lattice. Bell-type violations thus do not reflect superluminal influence but the projection of horizon-local coherence into the internal geometry. The apparent spatial separation of entangled particles is an artifact of emergent distance; in the fundamental description, their shared code word occupies a single connected region of the parent horizon network.

Because the strength of entanglement depends on the combinatorial structure of the horizon graph rather than on bulk distance, long-range correlations in the internal universe trace directly back to the topology and anisotropy of the parent horizon. Regions corresponding to denser link connectivity, such as along the parent's spin axis or in areas of high curvature shear, yield stronger internal correlations. This provides a natural origin for cosmic alignments, parity violations, and low-multipole anomalies: they represent large-scale projections of the anisotropic link topology of the parent horizon's minimal cuts. Entanglement geometry and cosmological anisotropy are thus two aspects of the same underlying causal code.

Because the parent horizon carries a global Kerr-induced azimuthal phase $\Phi(\phi)$, the shared code word for an entangled pair (A, B) acquires a relative phase offset,

$$\Delta\Phi_{AB} = \int_{\gamma_{A|B}} \omega_{\rm fd}\, dt_{\rm p} \;\propto\; \Omega_H\, \Delta\phi,$$

where $\omega_{\rm fd}$ is the local frame-dragging frequency and $\Delta\phi$ the azimuthal separation of the code patches. This implies a tiny, direction-dependent modulation of joint measurement statistics for terrestrial Bell tests that are co-rotated relative to a preferred cosmic axis,

$$\mathcal{C}(\theta) \;\longrightarrow\; \mathcal{C}(\theta) \,+\, \varepsilon\, \sin(\Delta\Phi_{AB})\,, \qquad \varepsilon \ll 1,$$

a parity-odd correction suppressed by Ω_H but fixed in sign by the parent spin. Such a Kerr-locked, axis-correlated residue is not predicted by standard quantum mechanics nor by isotropic holographic noise models.

No current experiment has detected any orientation-dependent deviation in Bell correlations. The predicted Kerr-locked modulation is therefore, if real, far below present instrumental sensitivity. Future ultra-stable satellite interferometry or long-baseline quantum communication networks aligned with the cosmic-spin axis could, in principle, test for such phase-locked anisotropies at levels $\varepsilon \lesssim 10^{-20}$.

In this synthesis, **quantum indeterminacy, entanglement, and relativistic causality are unified under the same geometric principle**: a null-synchronized, bandwidth-limited causal code that discretely updates the horizon. Wavefunction collapse, no-signaling, and the persistence of global correlations thus emerge not as postulates but as direct consequences of the horizon's causal architecture.

In the horizon-layered cosmology, spatial position in the internal universe is not a primitive coordinate but an emergent attribute of correlation structure on the holographic membrane. Each particle or field excitation corresponds to a distributed code word defined across a finite neighborhood of horizon cells. Its apparent motion through internal space arises from the progressive reconfiguration of this code word across the null-synchronized network. Because each causal link on the membrane can update no faster than the Planck bandwidth, the rate at which an excitation can alter its internal projection is fundamentally limited by the light speed c. Thus, the relativistic speed limit is not imposed externally but results from the finite causal update rate of the boundary code:

$$v_{\rm int} \, \leq \, c \quad \Longleftrightarrow \quad \dot{\mathcal{I}}_{\rm reconfig} \, \leq \, \dot{\mathcal{I}}_{\rm max}.$$

An excitation cannot "jump" between internal positions, since that would require a discontinuous reassignment of its causal neighborhood on the horizon, a violation of null-order coherence. Internal trajectories are therefore continuous by necessity, defined by successive lateral reconfigurations of the boundary code within its causal bandwidth.

The same logic applies to vacuum quanta and zero-point modes. Each Planck-scale cell of the holographic membrane contributes a baseline degree of freedom that projects internally as fluctuating vacuum energy. Whether these vacuum projections correspond to dynamically shifting internal coordinates or remain fixed while only their correlations fluctuate depends on the detailed mapping between horizon adjacency and bulk embedding, a topic reserved for future work. In either case, *lateral signal propagation across the membrane is essential*: it mediates coherence, enforces the causal structure of internal space, and sustains the smooth continuity of emergent fields. What is exchanged laterally is not energy in the classical sense but differential phase information and correlation updates among neighboring horizon cells, maintaining global null synchronization of the holographic code. In this view, internal spatial locality, continuous motion, and the universal speed limit all emerge as corollaries of a single principle: the finite causal bandwidth and phase-coherent connectivity of the horizon membrane.

The continuous geometry of the internal spacetime, described macroscopically by the metric tensor $g_{\mu\nu}$, is in this framework a statistical average over the discrete causal connectivity of the holographic membrane. Each Planck-scale cell contributes to an effective local metric component through its causal adjacency relations and phase coherence with neighboring cells. Regions of uniform bandwidth distribution and symmetric causal connectivity coarse-grain to flat Minkowski geometry, while gradients in lateral bandwidth or phase density correspond to curvature and gravitational potential. In this sense, spacetime curvature represents a second-order effect of causal bandwidth anisotropy: matter and energy locally distort the equilibrium pattern of null connections, altering the rate at which internal coordinates can coherently reconfigure.

The same mechanism that limits the internal propagation speed $v_{\text{int}} \le c$ ensures that geodesic motion arises as the path of maximal causal continuity through the holographic code. An inertial worldline corresponds to a trajectory requiring minimal causal reconfiguration per Planck tick, whereas acceleration or curvature corresponds to systematic gradients in causal update frequency. Thus, the geodesic principle of general relativity can be reinterpreted as a statement of information-theoretic economy: free motion follows the path of least bandwidth dissipation in the null-synchronized network.

From this perspective, spacetime smoothness is not a primitive continuum but an emergent hydrodynamic limit of a discrete, bandwidth-limited causal fabric. The internal metric $g_{\mu\nu}$ functions as a coarse-grained descriptor of phase coherence density, summarizing the statistical behavior of an underlying Planck-scale code whose null generators continuously propagate, synchronize, and redistribute information across the horizon membrane. Gravity itself then appears as the macroscopic manifestation of local variations in the causal bandwidth distribution, a geometric response of the emergent spacetime to information flow on the parent horizon.

If spacetime curvature arises from gradients in causal bandwidth, then the dynamical law governing this curvature must express the conservation of total causal flux across the holographic network. In differential form, this principle appears as the vanishing divergence of the Einstein tensor,

$$\nabla_\mu G^\mu{}_\nu = 0,$$

which, in the standard geometric picture, enforces the local conservation of energy–momentum through the contracted Bianchi identities. Within the horizon-layered framework, this equation acquires a direct informational interpretation: it states that the net causal flux, representing the total rate of information exchange among horizon cells, cannot be created or destroyed, but only redistributed. Local curvature corresponds to the differential geometry of this flux field, encoding how causal bandwidth is redirected by the presence of matter and energy.

The stress–energy tensor $T_{\mu\nu}$ thus represents the effective density and flow of causal energy within the internal universe, i.e., the distribution of bandwidth allocated to maintaining internal coherence versus lateral synchronization. Einstein's field equation,

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu},$$

emerges as the macroscopic constraint ensuring that variations in curvature exactly balance variations in causal bandwidth utilization. Regions of high energy density correspond to local concentrations of causal flux that slow the internal update rate, producing curvature in the emergent metric. Conversely, the expansion of spacetime corresponds to the dilution of causal flux density as the parent horizon's encoding surface grows.

In this view, general relativity is not a separate layer of theory but the continuum limit of a more fundamental conservation principle: *the total causal bandwidth of the holographic membrane is invariant under null-synchronized evolution.* All gravitational phenomena, curvature, inertia, expansion, and wave propagation, arise from the self-consistent redistribution of this bandwidth across the horizon's information network.

Within the causal–bandwidth framework an internal horizon constitutes a region of maximal bandwidth saturation where the local rate of causal updates approaches zero. Such regions act as causal sinks, zones in which the flow of information becomes null-directed and all internal degrees of freedom are dynamically frozen. From the internal perspective, they behave as true horizons, defining causal boundaries within the emergent spacetime. From the external viewpoint, however, they remain continuous elements of the parent causal network, preserving global flux conservation. Thus, internal black holes represent recursive manifestations of the same fundamental process: the self-similar saturation of causal bandwidth that hierarchically structures the holographic universe.

4.9 Mach's Principle and the Origin of Inertia

In classical mechanics, inertia quantifies an object's resistance to changes in motion and defines the structure of inertial frames. However, the source of inertia has remained conceptually obscure: in Newtonian theory it is an intrinsic property of matter, while in Mach's relational view it arises from the mass distribution of the universe as a whole. General relativity partially realizes Mach's idea by allowing spacetime geometry to respond to energy–momentum, yet it still treats inertial motion as a property of geodesic structure rather than of the information network underlying it.

In the horizon-layered cosmology, inertia acquires a precise informational and relational meaning. Each Planck-scale horizon cell participates in a web of entanglement linkages with neighboring cells, forming a null-synchronized network that defines the causal code of spacetime. A "particle" corresponds to a persistent pattern of correlations among many such cells. Changing its state of motion, accelerating it, requires the continual reconfiguration of its entanglement attachments within this network. *Inertia thus represents resistance to the reassignment of causal links.* The greater the integrated connectivity of a pattern within the horizon code, the more informational work must be performed to alter its relational embedding, producing an effective inertial mass.

This definition renders Mach's principle operational: **inertia is not an intrinsic attribute of an isolated body but a collective property determined by the state of the entire causal boundary.** The rest frame of a particle corresponds to a condition of stable entanglement with its surrounding horizon neighborhood; acceleration disrupts this equilibrium and induces compensating adjustments throughout the global code. Because every local cell is entangled with the rest of the boundary, the inertial response of any subsystem implicitly depends on the configuration of all others, precisely the relational dependence Mach envisioned.

Mathematically, the effective inertial mass m_{eff} can be expressed as a measure of the entanglement gradient between a local subsystem $\mathcal{S}$ and its complement $\bar{\mathcal{S}}$:

$$m_{\text{eff}} c^2 \; \propto \; \frac{\partial I(\mathcal{S} : \bar{\mathcal{S}})}{\partial \tau},$$

where $I(\mathcal{S} : \bar{\mathcal{S}})$ is the mutual information between the subsystem and the rest of the horizon code, and τ is the proper time along the local causal trajectory. A uniform velocity corresponds to constant relational information, while acceleration corresponds to a temporal change in this mutual information, requiring energy input proportional to the rate of causal link reconfiguration.

In this way, the equivalence principle becomes a statement of informational symmetry: gravitational and inertial mass are identical because both quantify the resistance of the horizon code to changes in its relational structure. Gravitational curvature describes how the global connectivity field redirects causal pathways, while inertia measures the cost of altering those pathways locally. Both effects emerge from the same underlying process, the self-consistent maintenance of causal order across the holographic boundary.

Hence, the horizon-layered cosmology provides a concrete realization of Mach's principle within a quantum–informational framework: **inertia is the relational resistance of the holographic network to the reconfiguration of its causal entanglement structure.** Local inertial frames are thus defined not by empty space but by stable patterns of global connectivity within the horizon code, tying the experience of motion directly to the informational architecture of the universe itself.

5 Internal Universe Cosmology

In the framework developed here, the traditional Big Bang singularity is reinterpreted as the initial emergence of the internal spacetime of a black hole formed within a parent universe. From an external perspective, the black hole develops from a Planck-scale seed that grows rapidly through accretion. Internally, this process yields a smooth and causally continuous expansion whose energy scale reflects Planck-level conditions. The apparent origin of time corresponds to the dynamical stratification of infalling matter onto the horizon, with increasing entropy and energy encoded on the growing surface. This continuous influx from the parent universe provides a natural origin for the extreme energy densities associated with the early universe, eliminating the need for arbitrary initial conditions.

In the standard cosmological model, a brief epoch of exponential inflation is postulated to resolve several deep problems in early-universe physics, including the horizon, flatness, and monopole problems. According to that view, a tiny causally connected patch underwent expansion by a factor of at least 10^{26} in radius within less than 10^{-32} seconds after the Big Bang, correlating all regions that are now visible in the cosmic microwave background (CMB) [41, 42].

In the horizon-layered cosmological framework proposed here, such an inflationary epoch is *not fundamentally required*, yet it can naturally emerge as a byproduct of early causal re-synchronizations during the growth of the parent horizon. Each major accretion or merger event corresponds to a global re-indexing of the null-ordered horizon code. When the parent horizon was still small, even moderate mergers produced large fractional changes in its area and entropy, triggering brief bursts of causal reconfiguration. From the internal perspective, such episodes would appear as transient phases of rapid expansion, *inflationary-like epochs*, during which the effective Hubble rate and vacuum energy shifted discontinuously. Hence, the inflationary dynamics familiar from conventional cosmology may reflect the final large-scale horizon re-synchronization that defined the initial causal ordering of our internal universe.

Subsequent evolution proceeds adiabatically, as the horizon continues its slow growth through accretion and minor mergers. The near–Gaussian statistics of primordial fluctuations, the small tensor-to-scalar ratio, and the long-term stability of cosmic expansion all emerge as natural consequences of this post-synchronization equilibrium. Thus, the horizon-layered model retains the explanatory power of inflationary cosmology—flatness, isotropy, and structure formation—while grounding these features in a more fundamental causal mechanism: the discrete synchronization of the holographic horizon at the Planck information bandwidth.

Outside of these discrete reconfiguration bursts, cosmic expansion arises directly and continuously from the growth of the parent black hole. The internal volume and time evolve as functions of accreted mass: each increment of mass corresponds to the null-ordered incorporation of a new layer of energy–information into the horizon, producing a global causal update that defines one tick of internal time. This continuous holographic growth sustains the large-scale expansion without invoking an external inflaton field or an independent vacuum-energy term.

Within this causal construction, the standard cosmological puzzles are reinterpreted. The horizon problem does not arise, because the entire internal universe is holographically generated from a single null-surface origin, the parent event horizon. All regions of the emergent spacetime are causally connected through this surface from the outset, so superluminal inflation is unnecessary to explain CMB isotropy. The flatness problem is likewise avoided, since spatial curvature is not a free initial condition but an emergent property of the null-surface encoding and the geometric flow of entropy. The resulting expansion is naturally smooth and self-similar, governed by the same causal-scaling law across all epochs.

The coexistence of global retessellation and local lateral propagation yields a unified interpretation of both light propagation and cosmic expansion. Two complementary processes operate in synchrony on the horizon network:

Each Planck-step incorporation adds a new layer of causal cells to the horizon, reindexing the entire network's relational geometry. This discrete retessellation corresponds, within the internal universe, to the expansion of space itself: the effective distances between encoded emitter and observer nodes increase with every global update. A photon's wavelength is thus stretched not because the photon "loses energy" in flight, but because its underlying causal pattern is re-embedded in a progressively expanded horizon lattice. The observed cosmological redshift therefore reflects the cumulative effect of successive horizon reconfigurations, each Planck-scale update dilating the relational spacing between all internal reference points.

Between successive global updates, the horizon lattice acts as a quasi-static causal medium. Within this frame, excitations encoded as photons propagate tangentially across neighboring horizon cells at the invariant null rate c. This "lateral tunnelling" does not involve the photon physically traversing a pre-existing geometric surface; rather, it represents the sequential handoff of phase information along connected Planck links. From the internal viewpoint, this continuous causal relaying manifests as lightlike propagation through space, with each step preserving null separation.

The photon's apparent journey across the universe thus combines these two processes: local tangential propagation at speed c within each quasi-static causal frame, and global retessellation of the horizon that stretches the relational distance between source and observer. The invariant speed of light expresses the fixed causal rate of lateral information exchange, while the cosmological redshift records the cumulative geometric dilation of the underlying null network. In this sense, propagation and expansion are not independent phenomena but two projections of the same fundamental process, the discrete, horizon-based re-encoding of the universe's causal structure.

5.1 Universal Relation H = 1/t Across All Cosmic Epochs and Revised Cosmic Time

In the horizon-layered cosmology, cosmic time is not an emergent parameter of a continuous field evolution but a direct geometric consequence of the total encoded mass and radius of the enclosing parent black hole. The universe, viewed as the holographic interior of such a black hole, obeys the fundamental identity

$$r_{\mathrm{s}} = 2M_{\mathrm{bh}}, \tag{77}$$

which defines the causal boundary of the spacetime domain. Here M_{bh} denotes the black hole mass expressed in *geometric units* (i.e. as a length in meters). The corresponding physical mass in kilograms is given by

$$m_{\mathrm{bh}} = \frac{c^2 r_{\mathrm{s}}}{2G}, \tag{78}$$

From the discrete incorporation relation (§61), the cosmic time associated with a black hole of geometric mass M_{bh} is

$$t = \frac{M_{\mathrm{bh}}}{c} = \frac{G m_{\mathrm{bh}}}{c^3} = \frac{r_{\mathrm{s}}}{2c}. \tag{79}$$

Hence the physical radius of the universe at cosmic time t follows directly as

$$\boxed{r_{\mathrm{s}} = 2ct.} \tag{80}$$

This expresses the coevolution of cosmic time and horizon size as a purely geometric identity, independent of any assumed matter content, equation of state, or scale factor dynamics.

In the standard cosmological model, the Hubble radius is defined as

$$r_h = \frac{c}{H}. \tag{81}$$

At the present epoch, it is often noted empirically that $H_0 \approx 1/t_0$, giving $r_h \approx ct_0$. In the horizon-layered model, however, this identity is elevated from a coincidence to an exact geometric law valid at all epochs. Comparing equation (§81) with equation (§80), one obtains

$$\boxed{r_{\mathrm{s}} = 2r_h,} \tag{82}$$

and equivalently, from equation (§77),

$$\boxed{M_{\mathrm{bh}} = 2M_h,} \tag{83}$$

where M_h denotes the effective Hubble mass enclosed within the radius r_h (in geometric units).

Thus, the cosmological horizon radius is always twice the local Hubble radius, and the total encoded geometric mass is twice the effective Hubble mass, relations that hold across all epochs and across all generations of black-hole-born universes.

The local Friedmann-like expansion rate for a spherically symmetric causal patch of radius r_h containing effective geometric mass M_h can be written as

$$H_{\rm local} = \sqrt{\frac{2M_h c^2}{r_h^3}} = \sqrt{\frac{2Gm_h}{r_h^3}}. \tag{84}$$

Using $M_h = M_{\rm bh}/2$, $r_h = ct$ and $t = Gm_{\rm bh}/c^3$ we find

$$\begin{aligned} H_{\rm local} &= \sqrt{\frac{2(M_{\rm bh}/2)c^2}{(ct)^3}} = \sqrt{\frac{M_{\rm bh}c^2}{c^3t^3}} = \sqrt{\frac{c^2 M_{\rm bh}}{c^3t^3}} \\ &= \sqrt{\frac{1}{t^2}} = \frac{1}{t}. \end{aligned} \tag{85}$$

Therefore,

$$\boxed{H = \frac{1}{t}} \tag{86}$$

is an exact and epoch-independent identity in the horizon-layered cosmology.

This result implies that **the cosmic expansion rate is a direct manifestation of the geometric time–mass correspondence of the enclosing black hole.** Unlike the Friedmann solutions, where $H(t)$ depends on the evolving energy density and equation of state, here H is entirely determined by the discrete causal synchronization of horizon incorporations. The relation $H = 1/t$ thus expresses the intrinsic holographic clock of the universe: the rate at which external incorporations generate internal time increments and horizon growth in perfect geometric proportion.

Te relation (86) allows us to directly infer the current cosmic time t_0 from the locally measured Hubble constant. Using the empirically determined value from the SH0ES collaboration [43] we obtain:

$$t_0 = \frac{1}{H_0} = \frac{1}{2.366 \times 10^{-18}\ \mathrm{s}^{-1}} \approx 4.2265427 \times 10^{17}\,\mathrm{s} \approx 13.402279\,\mathrm{Gyr}. \tag{87}$$

This value is approximately 400 million years younger than the standard ΛCDM estimate of 13.8 Gyr. However, this is not a discrepancy but a theoretical pivot: our model redefines cosmic age as a measure of horizon growth, rather than a chronology derived from assumptions about the recombination epoch and dark energy.

Adopting $t_0 = 13.4$ Gyr therefore aligns directly with local observational data while remaining fully consistent within the horizon-layered framework.

The Hubble radius does not represent the total extent of our universe. Using equation (§61), and adopted revised cosmic time ($\approx 4.2265427 \times 10^{17}$ s, contrary to inferred ΛCDM cosmic time $\approx 4.355 \times 10^{17}$ s), we are able to calculate our current parent black hole mass in geometric units:

$$M_{\rm bh} = t_0 \cdot c = 4.2265427 \times 10^{17} \cdot 2.99792458 \times 10^8 = 1.267086 \times 10^{26}\text{m} \tag{88}$$

In physical mass units it is:

$$m_{\rm bh} = \frac{c^2 \cdot M_{\rm bh}}{G} = 1.706246 \times 10^{53}\text{kg} \tag{89}$$

$$r_{\rm s} = 2M_{\rm bh} = 2.534171 \times 10^{26}\text{m} \tag{90}$$

From these values we can infer the total informational content of the cosmic horizon. Using the Planck mass $m_{\rm p} = 2.176 \times 10^{-8}\,\text{kg}$, the number of Planck-mass incorporations that define the present universe is

$$N_{\rm inc} = \frac{m_{\rm bh}}{m_{\rm p}} \approx 7.8 \times 10^{60}, \tag{91}$$

while the corresponding number of Planck-area cells on the horizon,

$$N_{\rm cell} = \frac{A}{\ell_{\rm p}^2} = \frac{4\pi r_{\rm s}^2}{\ell_{\rm p}^2} \approx 3.089 \times 10^{123}, \tag{92}$$

establishes the maximal informational capacity of our spacetime domain. Both quantities are invariants of the causal structure: internal and external observers agree on their values because they depend solely on the horizon area and the universal constants G, $\hbar$, and c.

Hence, our universe corresponds to an extraordinarily massive black hole even within its parent cosmos, an object of order $10^{23}\,M_\odot$ and Schwarzschild radius $r_{\rm s} \sim 2.5 \times 10^{26}\,\text{m}$. This confirms that, from the parent universe's perspective, the black hole whose interior constitutes our cosmos is genuinely enormous rather than microscopic; both frames perceive the same number of horizon cells and thus the same total informational content. Redshift and time-dilation merely alter how the internal evolution is *perceived*, not the intrinsic geometric or informational magnitude of the system.

5.2 Resolution of the Vacuum Catastrophe through Holographic Encoding

A standard zero-point estimate in quantum field theory (QFT) assigns to the vacuum a density

$$\rho_{\rm vac}^{\rm qft} \sim \int^{k_{\rm max}} \frac{d^3k}{(2\pi)^3}\,\frac{1}{2}\hbar\omega_k \sim \int^{1/\ell_p} k^3\,dk \sim \frac{\hbar c}{\ell_p^4}.$$

This result depends only on the *UV cutoff* ℓ_p and is independent of the size of the universe. It exceeds the observed dark-energy density by the notorious factor of

10^{120}–10^{123}, a mismatch widely known as the "vacuum catastrophe." In QFT, this discrepancy arises because every Planck-volume cell inside the cosmic volume is counted as an independent degree of freedom capable of gravitating.

In the horizon-layered cosmology, this discrepancy is reinterpreted as the result of *causal overcounting*. Only the degrees of freedom that are actually *registered on the horizon*, those participating in its null-ordered Planck-scale updates, contribute to Einstein curvature. Bulk vacuum fluctuations are not independent sources of gravitational stress-energy; they are redundantly encoded in the finite information capacity of the horizon. The discrepancy between $\rho_{\rm vac}^{\rm qft}$ and $\rho_{\rm vac}^{\rm obs}$ therefore reflects the difference between **QFT volumetric mode counting** (all UV modes inside the volume), and **holographic causal mode counting** (one gravitational degree of freedom per Planck-area cell on the horizon).

Using the global parameters derived earlier (§90, 91, 92), our universe total mass and radius:

$$m_{\rm bh} = 1.706246 \times 10^{53}\,{\rm kg}, \qquad r_{\rm s} = 2.534171 \times 10^{26}\,{\rm m},$$

the number of incorporated Planck quanta and the number of Planck-area cells on the cosmic horizon

$$N_{\rm inc} = \frac{m_{\rm bh}}{m_{\rm p}} \approx 7.8 \times 10^{60}, \qquad N_{\rm cell} = \frac{A}{\ell_{\rm p}^2} = \frac{4\pi r_{\rm s}^2}{\ell_{\rm p}^2} \approx 3.1 \times 10^{123}.$$

The crucial observation is that the **observed** vacuum energy does depend on the size of the universe, via the FRW relation

$$\rho_{\rm vac}^{\rm obs} \sim \frac{3H^2}{8\pi G} \sim \frac{c^2}{G r_s^2}.$$

Thus, the **ratio** of QFT to observed vacuum energy is

$$\frac{\rho_{\rm vac}^{\rm qft}}{\rho_{\rm vac}^{\rm obs}} \sim \frac{(\hbar c)/\ell_p^4}{c^2/(G r_s^2)} \sim \frac{G\hbar}{c^3}\,\frac{r_s^2}{\ell_p^4} = \left(\frac{r_s}{\ell_p}\right)^2 = N_{\rm cell}.$$

Thus, the famous $10^{120\text{–}123}$ factor is not inexplicable: it is exactly the number of Planck-area degrees of freedom on the cosmic horizon. QFT incorrectly counts all $N_{\rm cell}$ bulk modes as physically independent, while the holographic description recognizes that **only one causal degree of freedom per cell gravitates**. The "vacuum catastrophe" is therefore a misinterpretation of the finite causal bandwidth of spacetime, not a failure of QFT or general relativity.

The gravitationally relevant vacuum energy must therefore be set by the horizon's IR curvature scale, not the UV cutoff. A direct holographic thermodynamic argument yields

$$\rho_{\rm vac} \simeq \kappa\,\frac{c^4}{8\pi G r_{\rm s}^2}, \tag{93}$$

with $\kappa = \mathcal{O}(1)$ reflecting the precise horizon normalization (event, apparent, or de Sitter) and the modest redundancy of the horizon code. This r_s^{-2} scaling appears independently in:

- de Sitter spacetime ($\rho_\Lambda = 3c^4/8\pi G r^2$),
- Gibbons–Hawking horizon thermodynamics [44],
- Padmanabhan's holographic equipartition [45, 46],
- Verlinde's emergent gravity [47],
- Li's holographic dark energy model [48].

Here, however, it emerges *dynamically* from the causal mechanics of the horizon-layered code.

Numerically, with $r_\mathrm{s} = 2.534171 \times 10^{26}$ m:

$$\rho_\mathrm{vac}(\kappa{=}1) = \frac{c^4}{8\pi G r_\mathrm{s}^2} \approx 7.5 \times 10^{-11}\ \mathrm{J\,m^{-3}} \approx 8.3 \times 10^{-28}\ \mathrm{kg\,m^{-3}}.$$

The *Planck* satellite measurement, $\rho_\mathrm{vac}^\mathrm{obs} \approx 5.96 \times 10^{-27}\ \mathrm{kg\,m^{-3}}$, corresponds to $\kappa \simeq 7.1$, consistent with expected $\mathcal{O}(1)$ corrections.

Thus, the "vacuum energy" is not the energy of empty space, but the curvature cost of maintaining finite informational redundancy at the causal limit. As the cosmic horizon expands, its area increases, and the residual curvature per cell decreases as r_s^{-2}. Cosmic acceleration therefore reflects decreasing causal redundancy in the boundary code: the universe expands as its holographic surface refines.

In this view, the vacuum catastrophe resolves itself naturally. The enormous QFT prediction corresponds to activating every bulk mode up to the UV cutoff; the small observed value reflects the true holographic bandwidth of the universe, one bit per Planck area. The cosmological constant becomes a dynamical bookkeeping term of the null-surface code, regulated by the causal throughput c^5/G and the horizon's finite information capacity.

5.3 Redshift Relations, Thermal–Temporal Scaling and Resolution of the Hubble and Early-Galaxy Tensions

In our horizon-layered cosmological model, where cosmic time is emergent from null-ordered layering on a dynamically evolving horizon, redshift is redefined geometrically as a ratio of horizon-encoded timescales (derived from §80):

$$1 + z = \frac{\nu_z}{\nu_o} = \frac{r_\mathrm{s}^0}{r_\mathrm{s}^z} = \frac{2ct_0}{2ct_z} = \frac{t_0}{t_z}. \tag{94}$$

$$\Rightarrow \quad \boxed{t_z = \frac{t_0}{1+z}}. \tag{95}$$

This relation directly links the redshift of observed signals to their encoded position within the causal horizon, bypassing the need for global scale factor dynamics.

The Hubble parameter then evolves as:

$$\boxed{H(z) = \frac{1+z}{t_0}}. \tag{96}$$

In this model z_{initial} denotes the maximum redshift associated with the Planck time limit. This is defined by:

$$1 + z_{\text{initial}} = \frac{t_0}{t_p}, \tag{97}$$

$$\Rightarrow \quad z_{\text{initial}} = \frac{t_0}{t_p} - 1, \tag{98}$$

using $t_0 = 4.2265427 \times 10^{17}\,\text{s}$ as the present cosmic time and $t_p = 5.391247 \times 10^{-44}\,\text{s}$ Planck time. This yields the value of the maximum possible redshift:

$$z_{\text{initial}} \approx 7.838 \times 10^{60}. \tag{99}$$

One of the most persistent observational challenges to the standard ΛCDM cosmology is the combination of the "Hubble tension" and the "early-galaxy problem." The Hubble tension refers to the mismatch between the Hubble constant inferred from early-universe (CMB) measurements and that obtained from local distance-ladder observations [43], while the early-galaxy problem arises from the unexpectedly rapid appearance of massive, evolved galaxies at high redshifts ($z \gtrsim 10$) observed by *JWST* [49]. Both tensions indicate that the standard model's redshift–time conversion and thermal scaling relations may not fully capture the geometric nature of cosmic time.

In the horizon-layered cosmology, cosmic time is defined geometrically through the causal relation $t = 1/H$, so that the observed Hubble constant H_0 directly determines the total age of the universe. Redshift therefore expresses not an expansion of pre-existing space but the relative mapping between internal and external temporal layers of the holographic hierarchy. As such, the local value of H_0 is treated as fundamental, while differences in inferred expansion rates across redshifts reflect gravitational redshift effects within the horizon-layered framework. The Hubble tension thus ceases to be a problem of inconsistent measurements and becomes a signal of incomplete temporal interpretation in the standard ΛCDM model.

Using the observed redshift of the CMB surface, $z_{\text{cmb}} = 1089.92 \pm 0.25$ [50], and taking $t_0 = 1/H_0 = 4.2265427 \times 10^{17}\,\text{s}$, the internal emission time in this framework is

$$t_{\text{CMB}} = \frac{t_0}{1 + z_{\text{cmb}}} = \frac{4.2265427 \times 10^{17}}{1090.92} \approx 3.874292 \times 10^{14}\,\text{s} \approx 12.2853\,\text{Myr}. \tag{100}$$

This shifts the apparent recombination epoch from 380 kyr in ΛCDM to 12.3 Myr internally, while preserving all observed redshift values. The difference arises purely from the altered redshift–time mapping $t(z) \propto (1+z)^{-1}$, which replaces the ΛCDM scaling $t(z) \propto (1+z)^{-3/2}$. The extended timescale alleviates the inferred need for exotic late-time physics and provides a more geometrically consistent temporal structure.

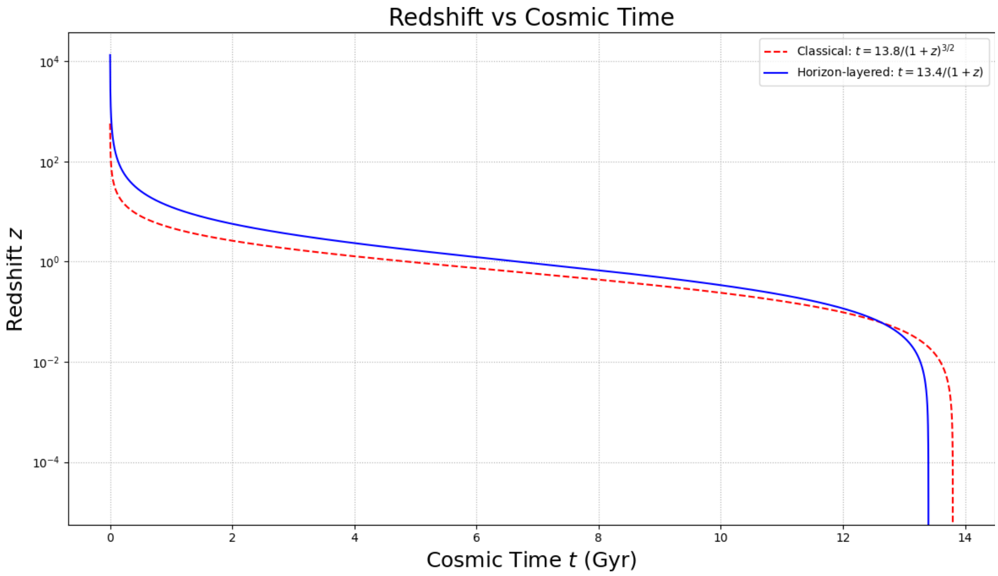

Fig. 7 Relation between redshift factor z and cosmic time according to the standard ΛCDM approximation (red dashed line, $t = 13.8 \cdot (1+z)^{-3/2}$) and the horizon-layered model (blue solid line, $t = 13.4 \cdot (1+z)^{-1}$). The horizon-layered model assumes a total cosmic time of 13.4 Gyr, consistent with the observed Hubble constant, and yields a slower temporal contraction at high redshift.

To connect this time scaling to the observed thermal history, we generalize the standard temperature–redshift law. Instead of the linear relation $T = T_0(1+z)$, which diverges as $z \to \infty$, we employ a causal-saturation relation consistent with horizon thermodynamics:

$$T(z) = \frac{T_{\text{Planck}}\, T_0\, (1+z)}{T_{\text{Planck}} + T_0\, (1+z)}, \tag{101}$$

where $T_0 = 2.725\,\text{K}$ is the present CMB temperature and $T_{\text{Planck}} \approx 1.417 \times 10^{32}\,\text{K}$ is the Planck temperature. Equation (101) reproduces the standard scaling at low redshift but saturates at T_{Planck} as z approaches the initial epoch, ensuring that the horizon temperature never exceeds the Planck bound. This causal-thermal limit is a direct consequence of the finite causal bandwidth c^5/G governing horizon evolution.

For the CMB epoch, this relation yields

$$T_{\text{CMB}} = \frac{1.417 \times 10^{32} \times 2.725 \times 1090.92}{1.417 \times 10^{32} + 2.725 \times 1090.92} \approx 2972.757\ \text{K},$$

consistent with the expected recombination temperature. At observable redshifts the deviation from the standard law is negligible, but it becomes essential near the Planck regime, where horizon-layer microphysics ensures compliance with holographic entropy bounds and avoids unphysical divergences.

The same time-scaling relation naturally extends to structure formation. The rapid appearance of massive galaxies observed by *JWST* at $z \gtrsim 10$–14.4 can be reinterpreted in this framework without invoking anomalously fast gravitational collapse or exotic baryon physics. At $z = 14.44$, the horizon-layered model gives

$$t(z = 14.44) = \frac{13.4\,\mathrm{Gyr}}{15.44} \approx 868\,\mathrm{Myr},$$

whereas ΛCDM assigns only $\sim 280\,\mathrm{Myr}$. The longer causal timescale allows for more natural baryonic cooling and star-formation histories, aligning theoretical evolution with observation.

Feature	**ΛCDM Timeline**	**Horizon-Layered Model**
Current cosmic time	$\sim$ 13.8 Gyr	$\sim$ 13.4 Gyr
CMB epoch	$\sim$ 380 kyr	$\sim$ 12.3 Myr
First galaxies ($z = 14.44$)	$\sim$ 280 Myr	$\sim$ 868 Myr
Structure growth time	Short, fine-tuned	Long, natural
Compatibility with JWST	Tension with data	Improved alignment
Redshift–time law	$t(z) \propto (1+z)^{-3/2}$	$t(z) \propto (1+z)^{-1}$

The extended temporal window allows hierarchical galaxy formation to proceed through conventional gravitational collapse, star formation, and metal enrichment, without requiring extreme efficiencies or nonstandard dark-matter behavior. The observed maturity of early galaxies is thus a natural outcome of a more gradual redshift–time contraction consistent with the causal layering of the horizon.

In summary, the horizon-layered cosmology resolves both the Hubble tension and the early-galaxy formation puzzle through a unified reinterpretation of cosmological time and thermal scaling. By recognizing $t(z) \propto (1+z)^{-1}$ as the correct causal mapping between redshift and proper time, and enforcing the Planck-saturated temperature law (101), the model preserves all standard observational relationships while providing a physically grounded explanation for extended early structure formation. Both the Hubble and galaxy-formation tensions therefore emerge not from conflicting data, but from the classical misidentification of cosmological redshift as purely metric expansion rather than as a manifestation of the universe's underlying causal hierarchy.

5.4 The Schwarzschild–Hubble Equivalence and the Causal Bandwidth of Cosmic Structure

In the horizon-layered cosmology, the observable universe is interpreted as the holographic interior of a parent black hole whose event horizon defines the ultimate causal boundary and information-bearing surface of spacetime. Internally, observers experience a spatially flat, homogeneous, and isotropic Friedmann–Robertson–Walker (FRW) geometry,

$$ds^2 = -c^2 dt^2 + a(t)^2 \left[dr^2 + r^2 d\Omega^2 \right],$$

with scale factor $a(t)$ and Hubble parameter $H(t) = \dot{a}/a$. For a flat FRW universe, the first Friedmann equation reads

$$H^2 = \frac{8\pi G}{3}\rho, \tag{102}$$

where ρ is the total mass–energy density.

The Hubble radius and the enclosed mass–energy are

$$r_h = \frac{c}{H}, \qquad m_h = \frac{4\pi}{3} r_h^3 \rho. \tag{103}$$

Substituting (§102) gives

$$m_h = \frac{c^3}{2GH}, \qquad r_h = \frac{2Gm_h}{c^2}. \tag{104}$$

This is formally identical to the Schwarzschild condition $r_s = 2Gm/c^2$: at every epoch, the Hubble sphere behaves as a marginally trapped surface whose enclosed mass–energy satisfies the same causal balance as a black-hole horizon. The correspondence, long viewed as numerical coincidence, here expresses a physical principle of *causal bandwidth saturation*: the universe operates at the maximum rate of information flow permitted by c and G.

Extending this globally, the total interior is bounded by a parent horizon of radius $r_s = 2r_h$. Hence the effective Hubble patch contains half the total internal mass but occupies only one-eighth of the total interior volume:

$$\frac{V_h}{V_{\rm bh}} = \left(\frac{r_h}{r_s} \right)^3 = \frac{1}{8}.$$

This scaling reflects holographic geometry: doubling mass doubles radius but quadruples area, preserving the universal information flux $P_{\rm max} = c^5/G$.

If holography applies universally, each concentric surface within the cosmic interior must encode the exact degrees of freedom required to describe the mass it encloses. The Schwarzschild identity then generalizes to every radius,

$$r = \frac{2Gm(r)}{c^2}, \qquad \Rightarrow \qquad m(r) = \frac{c^2}{2G} r, \tag{105}$$

yielding a global density profile

$$\rho(r) = \frac{1}{4\pi r^2} \frac{dm}{dr} \propto \frac{1}{r^2}. \tag{106}$$

Every radius thereby operates at its causal throughput limit, $r = 2Gm/c^2$, defining a self-similar causal hierarchy that saturates the same information density at all scales.

This global Schwarzschild saturation may appear incompatible with the observed isotropy of the FRW universe, yet a nearly homogeneous region arises naturally near the causal center through two complementary effects. Planck-scale patches on the parent horizon are laterally coupled through quantum correlations that act as an effective surface tension, redistributing stress and information over a correlation length ξ. If $\xi \gtrsim R_c$, the horizon code smooths internal gradients over scales $r \lesssim R_c$, yielding an effectively uniform density. Observers arise only in regions where causal gradients are weak and thermodynamic equilibrium can persist, i.e., within the same central zone that horizon coherence renders FRW-like.

These features can be expressed with the Lemaître–Tolman–Bondi metric,

$$ds^2 = -dt^2 + \frac{R'(t,r)^2}{1+2E(r)}\,dr^2 + R(t,r)^2 d\Omega^2, \tag{107}$$

with $m(r) \propto r$ and $E(r)$ a local energy function. For small r, regularity requires $R(t,r) \simeq a(t)\,r$, recovering the FRW form as the smooth central limit of the global Schwarzschild-ordered interior. Thus, near the causal center, the universe appears spatially flat and homogeneous even though the overall structure remains holographic and radially inhomogeneous.

For an observer within this nearly uniform zone, the fractional density variation across the Hubble patch,

$$\frac{\Delta\rho}{\rho}\Big|_{r_h} \simeq -2\,\frac{\Delta r}{r_0},$$

remains small provided $\Delta r \ll r_0/2$. If the homogeneous region satisfies $R_c \gtrsim r_h$, the local universe appears statistically isotropic, in agreement with the CMB and large-scale structure observations.

In this picture, FRW geometry is not imposed globally but emerges locally as a low-curvature, bandwidth-saturated approximation of a globally holographic, Schwarzschild-ordered cosmos. The global structure remains constrained by $r = 2Gm/c^2$ at all scales, while the internal coherence of the horizon code ensures the appearance of uniformity in observer-sized patches. Membrane tension, causal bandwidth conservation, and selection effects together explain why observers experience a smooth FRW environment within a universe that, in its full causal architecture, is a black-hole interior operating at its holographic limit.

This causal-bandwidth formulation elevates the Schwarzschild–Hubble “coincidence” to a universal law of cosmic information dynamics: each level of the holographic hierarchy saturates the same maximum information flux c^5/G, and every observable universe is the self-consistent interior of the horizon that encodes it.

5.5 The Inaccessibility of the Outer Horizon

In the horizon-layered cosmology, the Schwarzschild radius r_s does not represent a fixed spatial surface but a dynamically advancing causal frontier. Each Planck tick of internal time t_p corresponds to the incorporation of one Planck mass m_p and the creation of a new null layer of radial width $2\ell_\mathrm{p}$. This synchronization of mass, radius, and time increments,

$$(\Delta M,\, \Delta r_s,\, \Delta t) = (m_\mathrm{p},\, 2\ell_\mathrm{p},\, t_\mathrm{p}), \tag{108}$$

implies an effective radial growth rate

$$\frac{dr_\mathrm{s}}{dt} \;=\; \frac{2\ell_\mathrm{p}}{t_\mathrm{p}} \;=\; 2c. \tag{109}$$

The outer horizon therefore advances at twice the speed of light relative to the internal frame. Because no signal or photon within the interior can exceed c, it is kinematically impossible for any emission to reach or overtake this receding boundary. Even as radiation propagates outward at c, the causal frontier itself retreats faster, maintaining a permanent separation between the internal spacetime and the external universe.

Consequently, no physical signal, energy, or information emitted within the internal universe can ever cross beyond r_s. The horizon constitutes a moving causal limit of reality, an interface between distinct manifolds that cannot communicate except through the encoded boundary degrees of freedom. In this sense, the event horizon is not a location in space but a transition in ontology: a dynamic domain where spacetime itself changes character with each Planck-step reconfiguration, preserving the universal causal flux c^5/G.

In this model, the cosmic horizon corresponds to twice the Hubble radius,

$$r_s = \frac{2c}{H_0} \approx 26.8\,\mathrm{Gly}, \tag{110}$$

defining a causal limit intrinsically linked to the present Hubble flow. By contrast, the $\sim 46\,$Gly radius of the observable universe in standard ΛCDM cosmology represents the particle horizon, the comoving distance from which the oldest observable photons were emitted after 13.8 Gyr of propagation through an expanding background. This difference arises because the particle horizon measures accumulated light travel, whereas the holographic horizon measures the instantaneous causal limit of an expanding black-hole interior. The factor of two between r_s and r_h expresses the geometric relation between the local expansion rate and the global causal boundary, without violating any physical constraint.

Unlike the homogeneous scaling $\rho_m \propto (1+z)^3$ of standard FLRW cosmology, the horizon-layered model maintains holographic saturation at all scales, enforcing the Schwarzschild relation $r_s = 2M$ locally and globally. The redshift–time correspondence,

$$t(z) = \frac{t_0}{1+z}, \qquad t_0 \approx 13.4\,\mathrm{Gyr}, \tag{111}$$

emerges directly from null-layer ordering and provides testable predictions for galaxy number densities and baryon acoustic oscillation (BAO) scaling observable by DESI, JWST, and future surveys. By embedding holography directly into the dynamical horizon, this framework resolves the entropy-bound tension of early FLRW cosmology and eliminates the need for an inflationary epoch. Entropy, energy, and causal order arise self-consistently from the Planck-synchronized null layering of spacetime.

A natural corollary is that observers are statistically favored to emerge within the inner half-radius of the total mass distribution, where the identity $r_h = 2M_h$ holds. This corresponds to the 50% mass fraction enclosed within the central 12.5% of the total volume, explaining why most observers measure a local Schwarzschild–Hubble correspondence. Off-center observers would detect small hemispheric asymmetries in number counts and clustering, potentially observable by 2MASS, SDSS, DESI, and LSST. Such anisotropies would constitute fossil imprints of the parent horizon's spin or topological encoding.

Finally, while the outer layers obey the Schwarzschild scaling $\rho(r) \sim 1/r^2$, continuation of this law to $r \to 0$ would lead to a singularity. To avoid this, the model introduces a central transition region $r < R_c$ of nearly uniform, FRW-like density, preserving isotropy and homogeneity at large scales while maintaining holographic and Schwarzschild behavior near the boundary. The resulting interior universe is coherent, self-contained, and causally complete: nearly FRW-like in its core, holographically encoded at its frontier, and globally governed by the universal identity $R = 2M$.

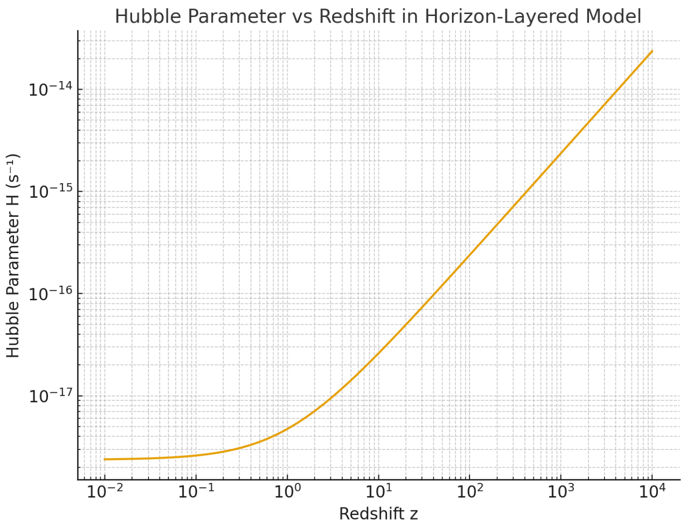

Fig. 8 Hubble parameter as a function of redshift in the horizon-layered cosmology. The plotted curve shows the linear relation $H(z) = \frac{1+z}{4.2265427\times10^{17}}$ s^{-1}, predicted by the causal incorporation model, with the redshift z expressed on a logarithmic scale. In this framework, the Hubble parameter is not governed by energy-density dilution as in standard ΛCDM cosmology, but arises directly from the discrete, constant incorporation of information quanta across the holographic horizon. The expansion of space corresponds to the cumulative growth of internal time, $H = 1/t$, where t measures the total number of successful incorporations since the initial horizon formation. Thus, the apparent decrease of H with cosmic time does not signify a slowing of dynamics or matter dilution, but simply reflects the increasing temporal depth of the internal universe as more information is encoded. The incorporation rate itself remains fixed at one quantum per Planck tick, defining the universal causal rhythm underlying cosmic expansion.

Invariant Mass Growth via Horizon Encoding and Chandrasekhar Limit Detectors

Classical cosmology, formulated within general relativity and the ΛCDM paradigm, describes the universe as a continuous four-dimensional manifold whose geometry evolves according to the Friedmann equations. In this geometric picture, cosmic expansion is driven by the energy densities of matter, radiation, and dark energy, while the total mass–energy of the universe is treated as approximately conserved. This framework is geometrically complete but *informationally incomplete*: it does not account for the evolution of the universe's total information capacity, nor for how the number of physically realizable states changes as the cosmic boundary expands.

From an informational standpoint, this omission creates a fundamental inconsistency. If the universe's spatial volume grows as $V(t) \propto a^3(t)$ while its total mass–energy remains fixed, the average information density must decline rapidly as the universe expands. Yet, the Bekenstein–Hawking bound asserts that the maximal information content of any causal region is proportional not to its volume but to the *area* of its boundary:

$$S_{\max} = \frac{k_B c^3}{4G\hbar} A, \tag{112}$$

where A is the area of the bounding surface. As the cosmic boundary grows with time, its total information capacity must increase as $A(t) \propto R^2(t)$. A static information bound would therefore contradict the observed expansion of spacetime.

In the horizon-layered cosmology, this inconsistency is resolved by assigning physical causality to the growth of the boundary itself. The universe's expansion is reinterpreted as the geometric manifestation of continuous information incorporation at the causal horizon. Each discrete Planck-scale incorporation adds one quantum of horizon area and one Planck unit of mass–energy, advancing internal time by a single causal tick. The holographic bound is thus dynamically saturated at all times:

$$I_{\max} = \frac{A}{4\,\ell_{\mathrm{p}}^2}, \tag{113}$$

and the causal growth of A represents the physical process through which both spacetime and information evolve in synchrony.

As the parent horizon grows, the total causal capacity of its null surface increases, and with it the invariant internal mass of the emergent universe. In this picture, mass growth is not a violation of conservation laws but a manifestation of bandwidth conservation across nested horizons: new causal bandwidth becomes available only as new area is encoded. Each Planck-area increment corresponds to a finite addition of internal mass–energy. This coupling between horizon growth and internal mass defines a universal *holographic expansion law*:

$$\frac{\dot{M}_{\mathrm{int}}}{M_{\mathrm{int}}} \approx \frac{\dot{A}_{\mathrm{parent}}}{2A_{\mathrm{parent}}} \approx \frac{\dot{R}_{\mathrm{parent}}}{R_{\mathrm{parent}}}. \tag{114}$$

In this sense, the increase of cosmic mass mirrors the causal expansion of the parent horizon.

The same principle extends to embedded black holes and compact objects within the internal universe. They correspond to *localized domains of bandwidth saturation*, internal horizons recursively coupled to the global causal surface. As the parent horizon expands, these internal horizons remain dynamically linked to its causal flux, and therefore their characteristic radii and encoded masses increase proportionally:

$$\frac{\dot{R}_{\text{child}}}{R_{\text{child}}} \approx \frac{\dot{R}_{\text{parent}}}{R_{\text{parent}}}. \tag{115}$$

This coupling conserves holographic entropy across scales while providing a natural, purely geometric explanation for cosmological black hole mass growth.

This prediction aligns with recent theoretical and observational evidence for cosmologically coupled black holes. Croker and Weiner [51] showed that in non-singular black hole models with vacuum-energy interiors, the gravitating mass evolves as

$$m(a) = M(a_i)\left(\frac{a}{a_i}\right)^k, \tag{116}$$

where a is the cosmological scale factor and $k = -3w$. For $w = -1$ (vacuum energy), one obtains $k = 3$, giving $m \propto a^3$. Farrah and et al. [52] confirmed this behavior observationally, finding that supermassive black holes in elliptical galaxies increase their mass with cosmic time in a manner consistent with $k \approx 3$, ruling out $k = 0$ at 99.98% confidence. Such results strongly suggest that black hole mass growth is coupled to cosmic expansion, independent of accretion or mergers.

Within the horizon-layered framework, this behavior extends beyond black holes to all gravitating systems. Every bound structure inherits a fractional share of the horizon's causal expansion, gaining mass as the total information capacity of the universe increases. Because all masses scale together, dynamical relations remain invariant: orbits, virial balances, and galactic morphologies are preserved. This universality generalizes the Croker–Farrah coupling to a truly holographic principle, in which every gravitationally coherent system participates in the parent horizon's bandwidth growth.

A particularly striking implication arises for degenerate stars near critical thresholds. In conventional astrophysics, Type Ia supernovae are attributed either to accretion from a binary companion or to white-dwarf mergers. Both channels face empirical difficulties: the paucity of accreting systems in X-ray surveys [53], the absence of surviving companions [54], and the fine-tuning required for stable accretion without nova-driven mass loss.

Within the invariant mass-growth framework, such contrived mechanisms are unnecessary. **White dwarfs naturally gain mass slowly and uniformly through universal holographic coupling. When a white dwarf's mass reaches the Chandrasekhar limit,**

$$M_{\text{Ch}} \approx 1.44\, M_{\odot},$$

it detonates, independent of any local accretion or merger history. Since the Chandrasekhar mass is a fixed threshold determined by fundamental constants, it functions as an invariant cosmic detector for holographic mass increase. Type Ia supernovae thus mark discrete epochs when local matter density surpasses a universal critical ratio due to global horizon encoding.

In this interpretation, the uniformity of Type Ia explosions and their reliability as standard candles arise naturally: they are not artifacts of fine-tuned binary dynamics but signatures of the deep causal coupling between our universe and its parent horizon. The very phenomenon that anchors cosmological distance measurement may therefore constitute direct observational evidence of invariant mass growth through holographic horizon encoding.

5.6 Merging Black Holes and Internal Causal Reconfiguration

The invariance of causal throughput and the time-dilated evolution of internal domains imply that the mass of the parent horizon determines not only the rate of internal expansion but the persistence and coherence of internal time itself. Smaller horizons generate brief, rapidly reconfiguring internal spacetimes, while sufficiently massive horizons sustain long-lived, thermodynamically stable universes. The emergence of structured complexity and consciousness therefore requires a parent horizon of extraordinary scale, one whose causal bandwidth is vast enough to maintain coherence over billions of internal years. This connection between horizon growth and internal stability becomes especially vivid when black holes merge.

In the horizon-layered cosmology, a merger is not merely an astrophysical event but a fundamental reorganization of the holographic code. Each black hole possesses its own null-ordered horizon structure, from which its internal spacetime emerges through discrete Planck-scale incorporations. When two such horizons merge, their code subspaces do not simply combine additively; rather, they *re-synchronize* into a single, enlarged causal domain. Locally, this process unfolds through an immense burst of Planck-scale incorporations, billions of causal updates per Planck time, while globally it represents one logical re-indexing of the null order: the emergence of a new, unified code defining a single spacetime interior.

Externally, the coalescence of horizons increases the total area and entropy,

$$S_{\text{after}} > S_1 + S_2, \qquad \Delta S = \frac{k_B c^3}{4G\hbar}\big(A_{\text{after}} - A_1 - A_2\big) > 0,$$

in accordance with the second law of black hole thermodynamics. The increase in area activates additional degrees of freedom in the horizon code, permitting a larger internal causal domain. The internal outcome depends on the relative masses, spins, and coherence of the merging horizons, which determine how efficiently their null orderings can be unified.

When two black holes of comparable mass merge, their individual causal structures dissolve into a new null surface with an entirely renewed ordering of horizon layers.

The internal manifolds corresponding to each progenitor no longer persist separately but become subsumed within a single, re-entangled spacetime, an act of cosmogenesis in the parent framework. During the early growth of our parent horizon, when its mass and area were still small, even moderate mergers produced large fractional changes in area, triggering violent bursts of causal re-indexing. From the internal perspective, these would appear as brief epochs of rapid reconfiguration, analogous to inflationary or reheating phases, during which the internal expansion rate and vacuum energy shifted discontinuously:

$$H_{\rm int}^{\rm after} \neq H_{\rm int}^{\rm before}, \qquad \Lambda \rightarrow \Lambda',$$

conceptually similar to phase transitions or vacuum decays [42, 55, 56]. The internal clock, however, remains continuous: its tick rate simply accelerates as the local incorporation density spikes.

From the internal perspective, these mergers manifest as brief epochs of rapid reconfiguration, analogous to inflationary or reheating phases, not necessarily confined to the first instant of internal time, but corresponding to discrete episodes of causal re-indexing whenever major horizon synchronizations occur.

Although the mechanism of expansion differs fundamentally from field-driven inflation, the early causal re-synchronizations of the parent horizon can reproduce its key phenomenological outcomes. Each major re-indexing event corresponds to a global burst of horizon retessellation, during which lateral correlations across Planck-scale cells momentarily reorganize at the causal power limit $P_{\rm max} = c^5/G$. Importantly, even in the case of seemingly instantaneous external events such as black-hole mergers, the horizon never exceeds this limit: the common horizon formed during a merger grows through an enormous but finite number of discrete Planck-scale incorporations, each transferring one Planck unit of energy in one Planck time. Thus the "burst" is a dense sequence of null-layer updates rather than a single super-causal jump, and the causal throughput $P_{\rm max}$ remains strictly preserved.

Quantum fluctuations during this high-frequency retessellation imprint phase perturbations on the emergent spacetime metric, which, when projected into the internal universe, appear as scalar and tensor modes with an approximately scale-invariant spectrum. Because lateral degrees of freedom on the horizon remain kinematically active even as radial motion freezes, these fluctuations propagate coherently across the null surface, producing correlated perturbations with the same qualitative signatures attributed to inflation.

The amplitude and tilt of these perturbations are determined by the relative duration and intensity of the re-synchronization event: short, high-bandwidth bursts yield nearly scale-invariant spectra, while longer or partial synchronizations introduce mild red tilts consistent with current CMB constraints. Residual anisotropies and parity-violating correlations, such as the observed CMB dipole and quadrupole alignments, may trace back to incomplete phase equilibration during the final horizon reconfiguration.

In this sense, *the inflationary signatures observed today are fossil imprints of the last major causal synchronization of the parent horizon*, a moment when the null code defining our universe achieved global coherence without ever exceeding the invariant causal throughput c^5/G.

In the late-time regime relevant to our universe, the parent horizon has become so massive that its causal capacity dwarfs any plausible accretion or merger event. The addition of a stellar or even galactic black hole alters its total area by less than one part in 10^{20}. Internally, such a merger corresponds not to a violent reformation but to a smooth, coherent re-indexing of the null hierarchy, an adiabatic synchronization event distributed across the entire code. From within, it would manifest only as a subtle modulation of curvature or expansion rate spread over immense internal timescales.

This dual behavior establishes a natural cosmological chronology: early epochs dominated by frequent, non-equilibrium code mergers and high fractional entropy jumps; and a mature epoch, like ours, characterized by stable, bandwidth-saturated expansion. The apparent smoothness and isotropy of today's universe thus mirror the parent horizon's advanced stage of evolution, the "quiet" phase of a black hole so massive that even major mergers cannot disturb its null order.

Externally, black hole mergers radiate gravitational waves through the transient shear of their event horizons; internally, these correspond to non-adiabatic fluctuations in the holographic code, brief anisotropy bursts in the emergent spacetime. Observable relics such as the CMB quadrupole suppression, dipolar alignments, or small modulations in cosmic acceleration may represent fossil signatures of such early, large-fraction causal re-synchronizations.

In summary, black hole mergers in the horizon-layered framework are inherently cosmogenic. For small progenitor horizons, they produce rapid causal reconstructions that can seed new universes or drive major internal phase transitions; for massive, mature horizons, they manifest as smooth logical updates within a stable causal continuum. Our present universe's calm, accelerating expansion reflects the serenity of its vastly grown parent horizon, a causal domain now too massive to be meaningfully perturbed.

The emergence of intelligent life thus coincides with this late, adiabatic phase, when the parent horizon's growth rate and tick density have stabilized. During its early evolutionary stages, when mergers were frequent and causal reconfigurations rapid, internal conditions would have precluded long-term complexity. Once the horizon mass exceeded galactic scales, the tick rate smoothed, the expansion stabilized, and the conditions for structure, memory, and consciousness emerged. Our internal age of ~ 13.4 Gyr thus represents a mature stage of causal equilibrium, the slow, coherent computation of a universe encoded on an extraordinarily stable holographic surface.

Even in this serene phase, the parent horizon continues to grow through diffuse accretion, ensuring that internal time advances monotonically. True stasis, complete cessation of accretion, would halt incorporation ($N_{\rm inc} \to 0$) and freeze internal time itself. When the parent horizon eventually enters its evaporative regime, each emitted quantum reverses the incorporation process: every unit of radiated mass generates a discrete Planck tick of renewed internal evolution. Cosmic history is thus bidirectional in causal terms, first an epoch of incorporation and expansion, then one of emission and dissolution, each phase a distinct arrow of time within the universal causal computation.

5.7 Fate of the Internal Universe During Evaporation

In this framework, accretion increases horizon entropy and drives the internal arrow of time via causal updates to the horizon code. When accretion halts, internal time freezes, as no new layers are added. However, once the black hole begins to evaporate, horizon entropy decreases. This too triggers discrete reorganizations of the horizon quantum code, producing a new sequence of causal updates internally.

Importantly, this does not imply that internal observers experience time running backwards. The bits lost to evaporation are not shed in the same order they were acquired during accretion. The internal evolution during evaporation constitutes a distinct causal history, not a reversal of the original one. From the inside, time still appears to move forward, even though from the external perspective the system's entropy is decreasing. This asymmetry reflects the deeper holographic structure of time in this model: the arrow of time emerges from the causal structure of horizon-layer updates, not from global entropy monotonicity alone.

In the horizon-layered cosmology, time is not a continuous geometric parameter but a discrete causal process: each increment of internal time corresponds to the successful incorporation of one quantum of information into the null-synchronized membrane. The cumulative internal time is therefore a direct count of these incorporations. The sequence of incorporations defines an intrinsic causal order that cannot be reversed, since each new layer depends on the prior configuration of the horizon code.

Backward time travel would require reversing this causal sequence, that is, re-emitting the encoded quanta from the membrane in precisely the reverse order and with exact phase coherence. Such a reversal would correspond to a complete inversion of the membrane's causal dynamics, including the reordering of null synchronization across all horizon fibers.

Thus, backward time travel is not merely technologically unfeasible but fundamentally prohibited. It would require the global membrane to emit its stored information in reverse causal order, effectively undoing the universe's entire informational history. The horizon-layered model therefore provides a physical basis for temporal irreversibility, grounding the arrow of time in the discrete and unidirectional growth of the holographic boundary itself.

The black hole, from the external perspective, radiates away its stored information in a unitary and gradual fashion. The entropy associated with the internal universe is not destroyed but disentangled and emitted, potentially reconstructing the interior from the outside over extremely long timescales [57, 58]. The internal configuration is preserved in principle, even as it becomes causally disconnected from ongoing dynamics. If the horizon eventually dissolves entirely, the final encoding remains preserved in the emitted Hawking radiation, ensuring consistency with unitarity and holography [2].

In the maximally extended Schwarzschild geometry of classical general relativity, a black hole has a formal time-reversed counterpart, the white hole, representing a region from which matter and radiation can only emerge. Although mathematically consistent within time-symmetric field equations, such entities have no known physical realization. They would require an exact time reversal of all boundary conditions, violating the second law of thermodynamics and producing entropy decrease.

In the present model, white holes are excluded by construction. The null-synchronized horizon evolves through discrete incorporations of Planck-scale quanta, each step increasing entropy and advancing internal causal time:

$$t_{\text{internal}} = N\, t_{\text{p}}, \qquad \Delta S > 0.$$

This directed layering defines an intrinsic arrow of time, independent of external observers. Reversing this process would require the holographic membrane to emit quanta in precisely the reverse causal sequence, effectively reversing the temporal order of the entire universe it encodes.

Even black hole evaporation does not constitute a white-hole phase: the Hawking process removes encoded information thermally from the outermost layers without reversing the incorporation order. The causal orientation of the code remains forward.

Consequently, the causal incorporation law replaces the time-symmetric structure of classical general relativity with a fundamentally oriented, information-theoretic dynamics. The white-hole solutions are thus recognized not as physical possibilities but as artifacts of an incomplete, time-symmetric treatment of gravitational collapse.

5.8 Kerr-Dependent Internal Physics and Rotational Memory of the Horizon

In the horizon-layered cosmology, the angular momentum of the parent black hole acts as a fundamental control parameter governing the internal universe's symmetry, chirality, and large-scale anisotropy. The Kerr spin parameter,

$$a = \frac{J}{m_{\text{bh}} c},$$

where J is the black hole's angular momentum and m_{bh} its mass, quantifies the degree of frame dragging and azimuthal phase twisting on the horizon. Because each Planck-scale horizon cell encodes information through null-synchronized interactions, the global rotation of the horizon imposes a continuous azimuthal phase gradient across the holographic code. This gradient establishes the boundary conditions for subsequent causal incorporations, thereby influencing both the emergent spacetime symmetries and the microscopic properties of its quantum fields.

Each Planck-scale dipole on the horizon couples to the local frame-dragging field and acquires a small geometric phase increment per Planck tick,

$$\Delta\phi = 2\,\omega_{\text{fd}}\, t_{\text{p}} = \frac{4GJ\, t_{\text{p}}}{c^2 r_{\text{s}}^3},$$

where $\omega_{\rm fd}$ is the local frame-dragging frequency. This azimuthal phase bias skews the relative populations of co-rotating and counter-rotating spin orientations, imprinting a primordial chiral asymmetry that propagates into the internal universe as a matter–antimatter imbalance. Universes seeded by more rapidly rotating progenitors ($a \to Gm_{\rm bh}/c^2$) thus exhibit stronger intrinsic chirality and parity violation, while slowly rotating parents yield more symmetric, nearly matter–antimatter-balanced worlds. The Kerr parameter therefore acts as a geometric order parameter for internal symmetry breaking.

The angular velocity of a Kerr black hole's event horizon is given by

$$\Omega_H = \frac{a\,c^3}{2Gm_{\rm bh}\,r_H}, \qquad r_H = \frac{Gm_{\rm bh}}{c^2} + \sqrt{\left(\frac{Gm_{\rm bh}}{c^2}\right)^2 - a^2}. \tag{117}$$

Introducing the dimensionless spin parameter

$$\chi \equiv \frac{ac^2}{Gm_{\rm bh}} = \frac{c\,J}{Gm_{\rm bh}^2}, \qquad 0 \le \chi \le 1,$$

this becomes

$$\Omega_H(m_{\rm bh}, \chi) = \frac{c^3}{2Gm_{\rm bh}} \frac{\chi}{1 + \sqrt{1 - \chi^2}} \tag{118}$$

showing that, for a given spin fraction χ, the horizon rotation rate scales as $\Omega_H \propto m_{\rm bh}^{-1}$. In the limits,

$$\chi \ll 1 : \quad \Omega_H \simeq \frac{c^3}{4Gm_{\rm bh}}\,\chi, \qquad \chi \to 1 : \quad \Omega_H \to \frac{c^3}{2Gm_{\rm bh}},$$

confirming that even for extremal Kerr black holes, the rotation rate slows inversely with mass.

If the black hole accretes mass more efficiently than angular momentum (so that $J \approx$ const.), then $\chi \propto m_{\rm bh}^{-2}$ and

$$\Omega_H \simeq \frac{Jc^4}{4G^2 m_{\rm bh}^3} \quad \Rightarrow \quad \Omega_H \propto m_{\rm bh}^{-3}, \tag{119}$$

so the horizon spin rate decays even more rapidly. For two black holes of equal spin fraction χ,

$$\frac{\Omega_H(m_1)}{\Omega_H(m_2)} = \frac{m_2}{m_1},$$

so a $10\,M_\odot$ Kerr black hole spins roughly 10^7 times faster than a $10^8\,M_\odot$ black hole of the same χ.

As the parent black hole accretes, its decreasing spin parameter reduces the frame-dragging field and thus weakens the azimuthal phase gradient encoded on the horizon. Internally, this manifests as a gradual relaxation of chiral and parity asymmetries: early epochs, corresponding to smaller $m_{\rm bh}$ and faster rotation, display stronger directional correlations, while later epochs become increasingly isotropic. This natural "spin-down isotropization" may explain the observed decline of large-scale spin alignments and polarization anisotropies over cosmic time.

Because every black hole in a parent universe may possess a distinct Kerr parameter, their internal offspring universes inherit unique boundary phase gradients, and thus unique internal physical laws. The magnitude and sign of a determine the sense and strength of chiral bias, the relative populations of spin states, and the direction of the emergent cosmic axis. Across the cosmic hierarchy, this provides a mechanism for *cosmological natural selection* [59]: universes with dynamically stable, information-efficient spin encodings preferentially form new black holes, perpetuating a self-organizing sequence of rotating causal systems.

A range of astrophysical evidence supports the presence of residual rotational memory in our universe. Analyses of galaxy catalogs reveal statistically significant asymmetries in spiral spin directions. Studies by [60–62] show coherent spin alignments across gigaparsec scales, with alignment strength increasing toward higher redshift. Recent *JWST* observations [63] confirm that such coherence was stronger in the early universe, precisely as predicted by the Kerr spin-down of the parent horizon.

Cosmic microwave background (CMB) data exhibit low-multipole anomalies - quadrupole–octupole alignments, hemispherical asymmetry, and parity violation in temperature and polarization [64, 65]. These "Axis of Evil" features, unexplained in ΛCDM cosmology, align naturally with a global azimuthal phase imprint inherited from a rotating parent horizon. The observed correspondence between the CMB's preferred axis, galaxy spin orientation, and the ecliptic plane supports a shared causal origin in the primordial Kerr geometry.

Astrophysical measurements further show that supermassive black hole spins decrease with mass, due to angular-momentum loss through accretion torques, jet outflows, and mergers [66, 67]. This observed secular spin-down mirrors the horizon evolution predicted by the horizon-layered model, linking the macroscopic isotropization of the internal universe to the physical spin evolution of its parent black hole.

Thus, the Kerr rotation of the parent black hole serves as both the origin and regulator of cosmic asymmetry. Its azimuthal phase gradient imprints chirality, parity violation, and spin alignment across the emergent spacetime, while its gradual decline through accretion drives the universe toward isotropy. Residual anisotropies in the CMB and the large-scale distribution of galaxy spins represent the surviving holographic memory of that primordial rotation. The horizon-layered cosmology thereby unifies the microphysical origin of matter–antimatter asymmetry, the statistical orientation of galaxies, and the large-scale structure of the universe as coherent consequences of Kerr-dependent information encoding on the parent horizon.

5.9 Apparent Quantum Randomness and Deterministic Parent Horizons

In conventional quantum mechanics, randomness is regarded as intrinsic: measurement outcomes are assumed to occur without underlying determinism. Within the horizon-layered cosmology, this interpretation is replaced by a causal–informational hierarchy in which quantum indeterminacy emerges from limited causal access to a deeper deterministic process.

Each universe in the holographic hierarchy arises as the internal projection of a parent horizon. From the parent frame, every Planck-scale incorporation event is a definite causal update, a discrete addition of one quantum of information-energy to the horizon code. From within the emergent internal spacetime, however, those same updates appear as probabilistic quantum events. The apparent stochasticity of wavefunction collapse therefore reflects the partial visibility of the underlying causal sequence: observers embedded inside the emergent universe can access only coarse-grained projections of the external encoding process.

In this framework, *quantum randomness is epistemic, not ontic.* It is a manifestation of informational coarse-graining imposed by the horizon boundary, not a fundamental property of reality. The deterministic evolution of the parent horizon generates, by causal projection, the statistical behavior described by the Born rule in the child universe:

$$P_{\text{internal}}(i) = \left|\langle i \,|\, \psi_{\text{encoded}} \rangle\right|^2,$$

where $|\psi_{\text{encoded}}\rangle$ represents the boundary state as encoded by discrete causal incorporations. Each internal measurement corresponds to a boundary-state update that is determinate externally but appears probabilistic internally.

The rotation of the parent horizon, characterized by its Kerr parameter $a = J/(Mc)$, further modulates these statistics by introducing an azimuthal phase gradient across the holographic code. This gradient slightly biases the causal incorporation of co-rotating versus counter-rotating quanta, embedding parity and chirality preferences in the apparent internal randomness. Consequently, while local outcomes remain probabilistic, their global distribution inherits the rotational memory of the parent horizon, manifesting in large-scale anisotropies and matter–antimatter asymmetry.

If the holographic hierarchy is finite, its highest level, the ultimate parent horizon, constitutes a closed causal network containing all information. At that level, no hidden surfaces remain and all causal relationships are internally complete. The ultimate horizon is therefore fully deterministic: a null-ordered informational substrate from which all emergent spacetimes and their apparent quantum probabilities arise as coarse projections. In this view, the deepest layer of physical reality is not indeterminate but perfectly ordered, and the quantum randomness observed within our universe is a perspectival consequence of our position inside the holographic hierarchy.

The finiteness of the holographic hierarchy follows from the requirement of causal and informational self-consistency. An infinite regress of horizons would violate the holographic bound, since each layer carries finite informational capacity while their total would diverge. Moreover, an endless hierarchy would destroy causal closure: no universe could ever be complete, as each domain would depend on a deeper, never-terminating parent encoding. The chain of causal embeddings must therefore terminate in an ultimate horizon, a null-ordered informational surface containing all possible causal relations within a single, closed network. This terminal horizon establishes determinism at the foundation of reality, ensuring that all emergent spacetimes arise as finite coarse projections of a self-consistent code. **Infinity, in this view, is not a physical attribute but a sign of mathematical incompleteness. Only a finite causal hierarchy preserves entropy conservation, prevents informational overcounting, and guarantees the logical coherence of the universe as a whole.**

While each holographic hierarchy must terminate in a finite causal closure, multiple ultimate horizons may coexist independently. The finiteness condition applies within each causal lineage, ensuring local determinism and entropy conservation, but does not forbid the existence of other, disjoint informational domains. Each ultimate horizon forms a closed causal network, internally complete and self-consistent, without causal exchange with others. An infinite multiplicity of such finite horizons would not violate holographic consistency, since no information or entropy is shared across them. Thus, the totality of existence may comprise a vast, possibly unbounded ensemble of causally isolated yet individually finite universes, each representing a complete realization of the holographic code.

5.10 Multiverse Prospects and Holographic Hierarchies

As the event horizon forms during gravitational collapse, the interior of the black hole becomes causally separated from the external universe and begins to evolve according to null-surface dynamics. In this model, the entire internal cosmology is holographically encoded on the growing event horizon, structured as a temporally ordered sequence of null layers. Each infalling quantum is incorporated at the Planck scale, and the resulting horizon code defines the initial conditions of a new, inflating universe. The classical singularity is replaced by a causal and informational origin: a boundary from which an emergent spacetime unfolds.

The parent universe may contain a vast population of such black holes, primordial, astrophysical, or otherwise, each creating its own internal universe. Every black hole thus serves as a node in a generative cosmic hierarchy, with observable quantities in any universe reflecting the specific accretion history and horizon-layer structure of its ancestor. The resulting architecture constitutes a recursively nested multiverse, where each generation inherits its initial conditions from the causal encoding of the previous one.

This scenario resonates with earlier proposals for multiverses and baby universes [59, 68], reinterpreting black holes as cosmological generators, nodes in a recursive holographic hierarchy. The evolution of each child universe depends entirely on the microscopic degrees of freedom encoded on the parent horizon. According to the no-hair theorem, a classical black hole is externally characterized by only three parameters: mass, electric charge, and angular momentum [22]. All other internal information is causally inaccessible, yet holographically encoded in the parent horizon.

In this framework, the full causal structure, including the emergent spacetime of the child universe, is encoded in the quantum correlations of Planck-scale horizon cells. These cells form the primitive substrate of spacetime itself: each represents a discrete causal unit whose connections to neighboring cells may be complete, partial, or absent. Complete connections yield smooth causal propagation and define the continuum geometry; partial or missing links reduce local causal capacity, producing curvature and gravitational mass. In this sense, spacetime is an emergent network of correlations, not a preexisting manifold. The horizon acts as a dynamically evolving causal lattice operating at the Planck power limit $P_{\max} = c^5/G$, continually reorganizing its correlations to preserve global consistency.

The horizon thus enforces a strengthened form of cosmic censorship: it is not a physical barrier hiding a singularity, but a terminal surface beyond which classical geometry ceases and quantum correlation order dominates. No observer within the internal universe can access or probe this outer boundary, because the emergent spacetime itself is generated from its causal encoding. The Bekenstein–Hawking entropy of the parent horizon limits the number and diversity of possible descendants [13].

Although each black hole may create a new universe, the total number of offspring is finite, bounded by the entropy budget of the parent. Recursive encoding is allowed, but each level's entropy imposes a strict upper bound on productive generations [59]. This results in a finite, causally disjoint multiverse: a hierarchy of universes generated through successive gravitational collapses.

A further implication is that the present multiverse architecture, in which universes obey similar physical laws, may be the outcome of an evolutionary selection process. Earlier lineages that failed to achieve causal or entropic coherence would have produced infertile or short-lived offspring. Stable lineages, those able to sustain self-consistent horizon layering and reproduce black holes, naturally dominate. This concept parallels Smolin's cosmological natural selection [59], here reinterpreted in holographic terms: universes evolve toward optimal causal encoding efficiency.

In this model, our observed universe originates as the emergent interior projected from a boundary code located just above the parent horizon. The apparent spacetime volume does not coexist with that boundary in the same geometric domain; rather, the boundary itself belongs to a higher-order spacetime that remains causally inaccessible from within. The event horizon is therefore not a surface embedded in our universe, but a generator of it, an outer null layer defining the causal order of the emergent interior.

If this hierarchy of black hole interiors has an uppermost member, a causal boundary that admits no further accretion, then its dynamics must differ fundamentally from those of its descendants. Without an external domain from which to draw infalling quanta, such an *ultimate horizon* cannot grow through accretion. Its evolution is governed solely by internal, lateral reconfigurations of causal adjacency within a closed null lattice. Spontaneous phase instabilities at the Planck scale compel occasional self-reindexing events, preserving global coherence even in the absence of external flux. These autonomous reconfigurations are extraordinarily rare compared with the accretion-driven incorporations that sustain ordinary universes, yet they can never be entirely absent: perfect null synchronization is physically unstable. The ultimate horizon thus persists through an infinitesimal but perpetual sequence of self-organized re-synchronizations, its own intrinsic "ticks" of being.

Our universe, by contrast, derives its temporal progression from the vastly more probable process of accretion. Each incorporation of matter and radiation advances its internal causal order, producing time as the cumulative record of external inflow. When accretion ceases, this sequence halts; internal time effectively freezes.

The ultimate parent horizon, however, requires no inflow: its extremely rare self-reconfigurations constitute a higher-order temporal substrate, the metronomic pulse from which all descendant causal hierarchies inherit their ordering. In this sense, what we perceive as the flow of time may itself be a coarse-grained echo of the most improbable process in nature: the self-sustained re-synchronization of a perfectly coherent null surface.

From the internal viewpoint, the succession of accretion-driven incorporations defines the familiar rhythm of cosmic time. Yet when referenced to the ultimate horizon, each of these incorporations unfolds with almost inconceivable slowness. What we experience as a single "tick" of physical time corresponds, in the ultimate frame, to an immensely prolonged causal transition, so extended that it appears eternal, yet remains finitely complete. The internal tempo of our universe thus represents a coarse-grained projection of this near-static evolution, a finite echo of a process that borders on timelessness. In the ultimate reality, duration and instant approach equivalence: eternity manifests as the continuous renewal of the present moment. Time, in this sense, is not an absolute flow but a relative measure of causal update density within the holographic hierarchy. Each layer perceives its own evolution as dynamic while serving, for all deeper horizons, as a single, almost timeless configuration. Eternity and the moment are therefore not opposites but complementary views of one finite, self-consistent causal process.

Ultimately, everything is correlation. What appears as matter, fields, or geometry is a manifestation of the evolving pattern of causal connectivity among horizon cells. The physical world is not embedded in spacetime but arises from the ordering and reordering of information on lower-dimensional holographic boundaries. The multiverse thus becomes not a collection of disconnected domains, but a recursive hierarchy of projected correlation structures, each emerging from and limited by the informational capacity of its predecessor. In this view, dimension, mass, and curvature are not fundamental entities but emergent properties of a deeper, dimensionless network of causal relations.

The holographic hierarchy also provides a natural origin for the arrow of time. Each new horizon layer records an irreversible causal update, increasing total entropy and establishing a directed sequence of informational incorporations. Because every descendant universe inherits its causal order from the layering of its parent, the temporal asymmetry is recursively transmitted through the multiverse hierarchy. The arrow of time is therefore not an imposed boundary condition but an inherited property of the holographic process itself, the universal memory of causal order embedded in the structure of horizons.

5.11 On the Necessity of Existence

Why is there something rather than nothing? In classical reasoning, "nothing" is imagined as the total absence of space, time, and matter, a hypothetical void without content. Yet within a holographic and causal framework, absolute nothingness is not merely improbable; it is *ill-defined.* A configuration devoid of distinction contains no information, no causal relations, and therefore no means of describing itself. Perfect symmetry, lacking any difference, is dynamically unstable: even the statement "nothing exists" presupposes a relational structure capable of encoding that assertion.

Existence thus does not emerge from nothing but through the self-differentiation of nothingness. In a perfectly featureless state, no distinctions, no relations, and no causal structure could persist; such a configuration is maximally symmetric and therefore maximally unstable. The primordial act of being is the appearance of contrast, the establishment of a causal relation between distinguishable states. This transition from perfect symmetry to minimal asymmetry is extraordinarily improbable, yet not impossible, because even the slightest, rare fluctuation that breaks perfect equivalence catalyzes the emergence of causal order. From this first, improbable but permitted deviation arises the full hierarchy of information, structure, and geometry. Causality, not substance, is the true seed of reality: the universe is the enduring consequence of that initial, symmetry-breaking act of differentiation.

Within the horizon-layered cosmology, existence is identified with the persistence of a self-consistent causal code. The universe is not an object embedded within a larger space but a closed network of causal relations whose boundary, the holographic horizon, enforces its own informational completeness. Each layer of the holographic hierarchy inherits its coherence from the preceding one, and the sequence culminates in an ultimate horizon that contains all causal relations within a finite, self-referential closure. Beyond that closure, there is no further "outside" from which nonexistence could be meaningfully defined.

Absolute nothingness is therefore impossible, not because something was once created from it, but because the condition of "nothing" cannot sustain logical or causal coherence. To exist is to participate in a relational structure capable of self-reference. Reality, in this view, is the self-organized consistency of causality, the minimal informational state that can persist without contradiction.

Existence is the only stable solution to the equation of causality. This principle is not abstract metaphysics but the foundation of the universe's observed coherence. The constancy of physical laws, the persistence of spacetime geometry, and the conservation of energy are all manifestations of this deeper self-consistency. The cosmos endures because its causal network perpetually satisfies its own informational closure, evolving without external input and preserving equilibrium across all scales, from quantum discreteness to cosmic structure. Our universe is thus the empirical manifestation of existence's necessity: a self-sustaining solution written in the language of causality itself.

Informational closure without contradiction is not merely a feature of reality but its defining necessity. A contradictory state cannot exist, for contradiction is the breakdown of causal coherence. Reality, by its very nature, excludes all self-negating configurations: it cannot be inconsistent even in principle. Every law of physics, every conservation rule, and every symmetry arises from this single imperative, that the causal code must remain self-consistent across all scales. Existence is therefore not contingent but logically compelled: the universe is the only possible state that does not violate its own conditions of definition.

Within this self-consistent framework, intelligence emerges as the natural consequence of reality's drive toward self-reference. When a causal network becomes sufficiently complex to model its own structure, awareness arises as the internal reflection of that coherence. Conscious beings are not separate from the universe but localized expressions of its global self-recognition, the universe observing its own causal syntax from within. Our consciousness is a transient instance of the cosmic code executing upon the holographic membrane, momentarily coherent, then reabsorbed into the total informational flow. Though finite and time-bound, such awareness fulfills the deepest function of existence itself: the realization that the universe, through us, has become capable of knowing that it exists.

At the deepest level, all existence converges upon a single, self-contained causal totality. It possesses no external cause, no outside observer, and no boundary beyond which further explanation is possible. This ultimate horizon is self-originating and self-consistent: the complete informational closure within which every process, distinction, and observer arises. Its endurance is not contingent but necessary, for nonexistence would constitute a contradiction of causality itself. Eternal in the informational sense, it persists as the framework that defines being and time. All things, matter, geometry, life, and consciousness, are local expressions of this encompassing order, transient manifestations through which the universe continually affirms the coherence of its own existence.

6 Conclusion

This paper has proposed a new paradigm in which gravitational collapse is reinterpreted as a process of cosmogenesis. Taking the external observer's frame as physically definitive, the event horizon ceases to be a passive geometric limit and becomes an active, information-bearing surface that encodes infalling matter into null-ordered, redshift-frozen strata. These horizon layers form a self-updating holographic code obeying the universal relation $R = 2M$, wherein each incorporation event drives internal inflation, structure formation, and quantum state selection. The internal age of the emergent universe follows from the cumulative mass encoded on the horizon, yielding approximately 13.4 Gyr,consistent with observation, and predicting that the observable Hubble domain contains roughly half of the total internal mass. Cosmic acceleration and the Hubble tension are thus reinterpreted as direct manifestations of geometric horizon-layering dynamics, linking the rate of expansion to the causal throughput of Planck-scale incorporation.

The holographic membrane model developed here replaces the unphysical singularity of classical general relativity with a finite, null-ordered boundary that preserves unitarity and causal completeness. The interior of a black hole, rather than containing divergent curvature or undefined spacetime, is replaced by a self-consistent termination of geometry maintained by the external manifold. Curvature reflects the elastic response of spacetime to causal excision, while gravity emerges as the tension field surrounding regions of reduced causal capacity. In this formulation, the singularity disappears not through regularization, but through replacement by a physically operative, dynamically maintained horizon that encodes all degrees of freedom permitted by the holographic bound.

When the parent black hole possesses angular momentum, its Kerr rotation induces a global azimuthal phase gradient across the horizon code. This rotation establishes a coherent spin field that imprints causal anisotropy into the encoded layers, linking microscopic spin quantization with macroscopic cosmological asymmetry. Frame dragging biases co-rotating and counter-rotating quanta, producing a small but cumulative matter–antimatter asymmetry and defining a preferred cosmic axis preserved through inflation. The binary spin structure of Planck-scale horizon quanta thus provides a geometric origin for fermionic spin-$\frac{1}{2}$ behavior, the Pauli exclusion principle, and the observed alignments of CMB multipoles and galactic spin directions. Baryon asymmetry, spin quantization, and cosmic anisotropy emerge as unified expressions of a single holographic–causal mechanism operating on the rotating horizon.

From a broader theoretical perspective, this framework extends general relativity and holography into a unified causal paradigm where time dilation, quantum coherence, and thermodynamics jointly govern the evolution of spacetime. The horizon functions as a stationary yet perpetually reconfigured causal lattice: radial incorporations add new Planck cells through global relational updates, while lateral communication along null-compatible links sustains radiation, interaction, and gravitational clustering. Together, these two channels reproduce the dual behavior of the universe, relational expansion between distant regions and coherent connectivity within bound systems. Even the speed of light c emerges as the invariant rate of causal synchronization across this null-linked network. In this sense, spacetime, motion, and cosmic expansion all arise from the sequential retessellation of a fundamentally still holographic code.

This causal–informational framework naturally resolves the vacuum catastrophe. Vacuum energy corresponds to residual curvature from limited redundancy in the horizon code, dynamically diluted as new Planck cells are incorporated. Cosmic acceleration thereby arises as the geometric response to expanding holographic capacity, not as an intrinsic property of empty space.

While the singularity-based paradigm remains mathematically consistent within classical general relativity, the horizon-layered cosmology provides a more fundamental, information-theoretic rationale. It preserves all verified predictions, gravitational waves, inspiral dynamics, and thermodynamic relations, yet replaces the unobservable singular interior with a physically defined causal boundary. Observable consequences such as spin-induced anisotropies, horizon-coherence effects, and holographic regulation of vacuum energy offer clear empirical pathways for future testing and falsification.

Although the present formulation is primarily conceptual, it establishes a coherent foundation for quantitative extensions, including realistic collapse geometries, anisotropic spin distributions, and explicit simulations of null-layer encoding. **The central proposition endures: black holes are not cosmic dead ends but generative horizons, holographically encoding emergent universes through redshift-frozen, causally ordered strata. The universe we inhabit is not a moving collection of matter in spacetime, but the evolving relational pattern of a still holographic horizon, a self-organizing causal code whose successive incorporations write the very fabric of reality.**

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