A New Interpretation of Gravitational Collapse: Setting the Framework for Internal Cosmology

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Abstract

This paper presents a conceptual framework that reinterprets black hole collapse as the source of emergent cosmological spacetime. In full accordance with Schwarzschild geometry, the model replaces the classical collapse into a singularity with dynamically structured, null-ordered layers of redshifted matter accumulating on the horizon, as seen by an external observer. The black hole initially forms on the Planck scale and acts as a source of gravity, with the event horizon dynamically growing outward. This growth generates a causal sequence of redshifted layers on the horizon, with radial motion asymptotically frozen due to gravitational time dilation, while angular and lateral modes remain unconstrained and dynamically active. The resulting surface structure holographically encodes information that projects an internally expanding universe. Topologically, however, the interior of the black hole is absent, the event horizon represents the ultimate boundary of the causal structure. This framework provides a physical realization of the holographic principle and a causal mechanism for the emergence of cosmic time, entropy gradients, and structure formation, while preserving unitarity and respecting entropy bounds. The model offers a complementary, geometrically motivated interpretation of horizon dynamics that bridges black hole thermodynamics, holography, and cosmology, uniting general relativity, quantum theory, and the origin of cosmic structure.

Keywords: black hole; event horizon; Schwarzschild geometry; holography; cosmology

1 Introduction

Black holes have long been a mystery because science has not yet been able to reconcile the general theory of relativity and quantum theory, which are necessary for a complete description of these cosmic bodies. Classical theory predicts that a massive star collapses into a single point, a singularity, at the end of its life, creating an event horizon. However, this interpretation leads to conceptual problems such as information loss, infinite density at the singularity point, and the meaning of invisible regions within the event horizon.

In this paper, we propose an alternative interpretation based on the experience of an external observer. Gravitational time dilation near the Schwarzschild radius should be taken seriously, meaning that infalling matter effectively remains frozen just outside the event horizon for an eternity until it evaporates in the form of Hawking radiation. The infalling matter thus forms a series of redshifted layers that form a dynamically layered quantum information surface that holographically encodes the interior of the black hole. The event horizon is therefore no longer just a theoretical boundary without a concrete physical realization.

The model respects unitarity, excludes singularities, and defines an inner universe limited by the entropy of the black hole. Black holes thus form a recursive hierarchical information structure bounded by total entropy. In this model, wave function collapse, cosmic inflation, and cosmic dynamics arise as a consequence of gravitational collapse.

2 Schwarzschild Black Hole

2.1 Current Black Hole Theories

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 r = 0 implies a singularity [1]. 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"* [2]. To justify this, various 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 [2]. 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 of the system to extend the geodesic system inside r_s is mathematically elegant, but irrelevant to physics that should be based only on what is possible to observe.

Contrary to this 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 [3], GPS correction [4], experiments with an atomic clock [5]. However, currently accepted theories reject measurable phenomena such as time dilation observed in the reference system of an external observer as a coordinate effect, giving priority to imperceptible transitions and singularities. 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 [6], although Hawking radiation [7] suggests a loss of information.

2.2 Radial Free Fall

In Schwarzschild geometry, the motion of falling objects towards the event horizon is determined by radial, temporal and angular metric components [8]. 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 to infinity as the object approaches the event horizon located at $r = 2M$, the angular part of the metric remains finite. This asymmetry between the radial and angular 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 [8]. 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.

2.2.1 Radial Length Contraction Near Event Horizon

In Schwarzschild geometry near the event horizon, where $r = 2M + u$ and $u \ll 2M$, the radial length is:

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

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: $u_2 = \frac{u_1}{2}$. Then:

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

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

2.2.2 Time Interval Near the Event Horizon

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 [9], 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, $u_2 = \frac{u_1}{2}$, 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:

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

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

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"* [10]. 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 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).

2.2.3 External Observer versus Infalling Observer Experience

Let us compare the experience of a radially falling particle and the experience of an external stationary observer. To establish this analysis, consider a collapsing massive star of size $10\,M_\odot$, which collapses 100 million years after the Big Bang. Using geometric units, this corresponds to a mass $M \approx 1.47667 \times 10^4$ m .

As the star gravitationally collapses, a particle that was at $r_0 = 20M$ (2.95334×10^5 m) begins to fall towards the center of the star under the influence of gravity. From the general relativity classical point of view, the falling particle reaches the event horizon in a finite proper time τ. However, from the perspective of an external observer (using the Schwarzschild coordinate time t), the particle asymptotically approaches the horizon and can never reach it in a finite coordinate time t . 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.

Let us calculate where a particle that started to fall radially 100 million years after the big bang is today, i.e. after $t \approx 4.2918 \times 10^{17}\,\text{s} \approx 6.34 \times 10^{22}\,\text{m}$. For a Schwarzschild black hole, the radius of the horizon is $r_s = 2M \approx 2.95334 \times 10^4\,\text{m}$. Using the expression for the coordinate time near the horizon (Equation (10)), we can approximate the remaining radial distance of the particle from the event horizon:

$$\Delta t = 2M \ln\left(\frac{u_1}{u_2}\right) \quad \Rightarrow \quad u_2 = u_1\, e^{-\Delta t/2M} \tag{13}$$

Assuming $u_1 = l_p$, since the coordinate time to fall from r_0 to within one Planck length of the horizon is only $t_{l_p} - t_0 \approx 11.415\,\text{ms}$, which is negligible compared to the age of the universe, we get the following:

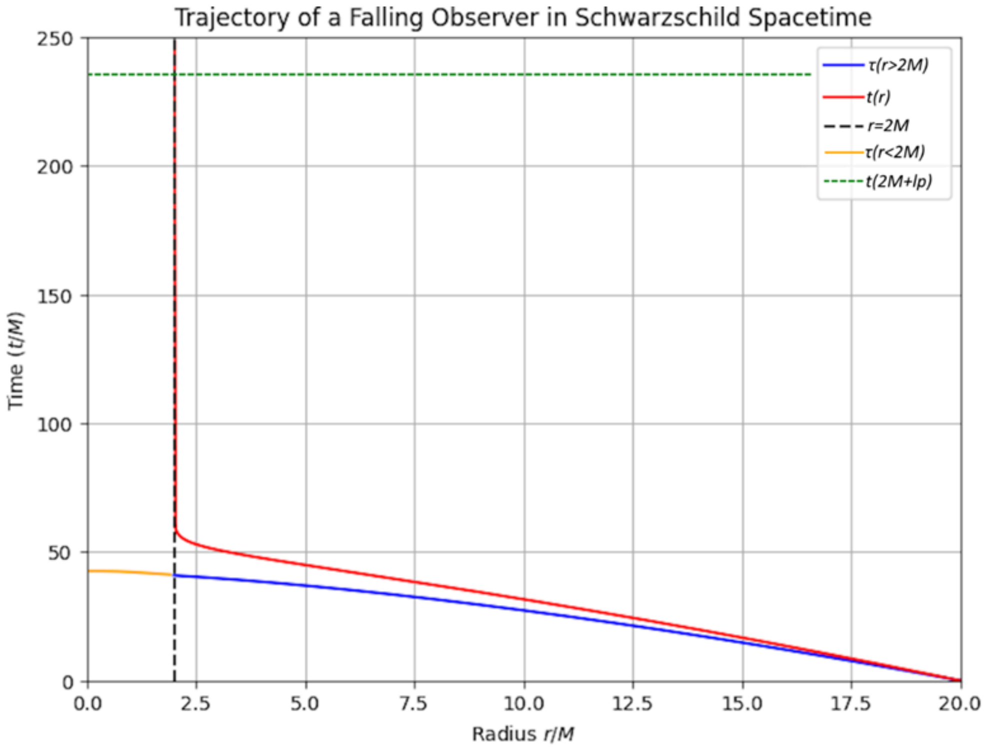

Fig. 1 The trajectory of a radially infalling observer in Schwarzschild spacetime plotted in terms of both proper time τ (Eq. (2)) and Schwarzschild coordinate time t (Eq. (3)). Both trajectories begin at $r_0 = 20M$, with $t_0 = \tau_0 = 0$. The orange segment represents the continuation of the proper time trajectory past the horizon, which is unobservable from the external frame. The green line indicates the coordinate time at which the infaller reaches a Planck-length distance from the horizon. Adapted from [8].

$$u_2 \approx l_p \cdot e^{-\Delta t/2M} \approx 1.616 \times 10^{-35} \cdot e^{-2.1467\times 10^{18}} \approx 1.616 \times 10^{-9.323\times 10^{17}} \text{ m} \quad (14)$$

This distance is unimaginably small, many orders of magnitude smaller than the Planck length. As viewed from a distant system, the particle remains effectively frozen just above the horizon, never reaching it even after billions of years. 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 time. 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:

$$\frac{d\tau}{dt} = \sqrt{1 - \frac{2M}{r}} \to 0 \quad \text{as} \quad r \to 2M \tag{15}$$

This implies that the falling particle's own time becomes infinitely slow relative to the clock of a distant observer. Near the horizon, in the falling particle's reference frame, all external processes appear to accelerate. From the perspective of a distant observer, time dilation freezes the falling particle's own clock, an extreme redshift occurs, and gravitational length contraction compresses the particle's radial length, while its angular modes remain active. From this perspective, the falling particle becomes radially causally frozen in the region just above the horizon.

If black holes evaporate in the finite time of the external observer as predicted by Hawking radiation, then the falling particle cannot cross the horizon even in its own time before the horizon disappears. For example, a fall to an almost infinitesimally small distance above the horizon takes only $\sim$ 2.011 milliseconds of its own time (Equation (2)), while in the distant frame it takes 13.6 billion years. During this brief interval in the reference frame of the falling particle, 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 space-time when the black hole evaporates completely.

The implication is profound: if Hawking evaporation proceeds as predicted, then 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 annihilated by Hawking radiation.

3 Event Horizon

3.1 Reinterpreting Hawking Radiation

Consider a black hole evaporating via Hawking radiation in finite coordinate time, $t = t_{\text{evap}} < \infty$. This imposes a global time constraint on any world line attempting to cross the horizon. Although duration of the proper time of the falling particle from the initial radius r_0 to just above the Schwarzschild radius $r_s = 2M$ may be less than 1 second, the evaporation of the black hole happens before any horizon crossing event can be completed. In this framework, the proper time of the falling particle is constrained by the global causal structure of the Hawking evaporation geometry.

The falling particle never actually experiences a horizon crossing. Although classical general relativity allows its trajectory to continue through the event horizon, the dynamical evaporation process overtakes the falling particle before such a crossing can occur. Due to the extreme gravitational time dilation near the horizon, the infalling particle's own time is effectively "frozen" with respect to external coordinate time. Meanwhile, the geometry of the black hole evolves, and the event horizon shrinks (or grows if matter continues to fall onto it) and eventually disappears. Thus, the classical horizon at $r = 2M$ never manifests as a traversable surface in any physical system.

This reinterpretation undermines the classical understanding that every infalling particle inevitably passes through the event horizon and enters the interior. Instead, the trajectory is shortened by evaporation before the transition can occur. The infalling particle becomes part of a compressed and redshift-frozen quantum structure just outside r_s, contributing to the source configuration responsible for Hawking radiation.

Consequently, Hawking radiation must be fundamentally reinterpreted. It does not arise by pair creation across the geometric boundary separating the interior from the exterior. Instead, in this model, the interior of the black hole has no ontological status in the external space-time manifold. Infalling matter never enters this causally unconnected domain. Instead, the falling matter is compressed into successive redshifted layers separated by the Planck length just above the horizon. These layers form a physically real, dynamically evolving quantum code surface that represents the boundary of visible space-time.

In such a model, Hawking radiation is interpreted not as a tunneling process from an existing interior, but as a structured quantum emission that arises from quantum polarization effects originating from the layered geometry of the black hole horizon. This emission represents a gradual, coherent release of encoded information, rather than any dynamics within the interior volume.

One might ask whether radiation directed inward, into the interior of the black hole, is possible. Although not ruled out by quantum consistency, such radiation has no physical meaning in this model, because the interior has no space-time structure into which particles could tunnel. According to this, tunneling inward is not only improbable, but is also undefined. A related conceptual direction is explored in [11], although that work does not explicitly address the implications of Hawking radiation directed inward.

This interpretation resolves several paradoxes. Information is never lost in an inaccessible region behind the event horizon but is always preserved in the form of a code on the surface of the horizon. Evaporation represents the gradual erasure of this code, not the destruction of matter within the interior volume. The process is consistent with unitarity, causality, and holography. After the black hole completely evaporates, the projected "interior" ceases to exist, not because anything inside the black hole has been destroyed, but because its physical support, the surface layer of the horizon, has disappeared.

According to this causally and quantum consistent understanding, crossing the horizon is not a physical process. This is a classical extrapolation that cannot be realized in the presence of extreme redshift and quantum gravitational effects. The event horizon is not the entrance but the terminal surface of space-time itself, a dynamic, zero-ordered structure in which information is encoded. It represents the outer boundary of a physically defined geometry, not the boundary of a hidden volume.

3.2 Event Horizon Formation

In classical general relativity, black hole formation begins when the core of a sufficiently massive star collapses, creating a region bounded by event horizon. The compactness condition for the formation of a local horizon is:

$$\frac{2GM(r)}{rc^2} \geq 1. \tag{16}$$

By using the equation:

$$\langle\rho(r)\rangle = \frac{3M(r)}{4\pi r^3} \tag{17}$$

the condition for the formation of a black hole can be expressed as the minimum average energy density within a certain radius [12]:

$$\langle\rho(r)\rangle \geq \frac{3c^2}{8\pi G r^2}. \tag{18}$$

This inequality shows that the density threshold for event horizon formation rises sharply as the radius decreases. Contrary to the idealized idea that the horizon encompasses the entire mass at once, numerical simulations consistently show that only a small part, usually 5-25% of the total mass, initially finds itself within the forming event horizon [13–15]. The remaining mass subsequently collapses into the already formed black hole, indicating that horizon formation begins with a compact central seed and dynamically expands outward.

But traditional horizon-finding methods overlook a key causal requirement: For a horizon to form at some outer radius R, the compactness condition must already have been satisfied at smaller radii $r < R$ at an earlier time.

To assess whether the compactness condition can be satisfied only at a large radius R, without first satisfying it at any smaller radius, consider a smooth, positive density profile $\rho(r)$. Let us define the mass function:

$$M(r) = 4\pi \int_0^r \rho(r)\, r^2 dr, \tag{19}$$

which monotonically increases for $\rho(r) \geq 0$. A necessary condition for the formation of a Schwarzschild horizon at radius R is that the compactness function satisfies:

$$f(R) = \frac{2GM(R)}{Rc^2} \geq 1. \tag{20}$$

Suppose that the compactness condition is not satisfied for any inner radius: $f(r) < 1$ for all $r < R$. Then, for the Equation (20) to hold for R, the compactness function must increase sharply near $r = R$. This implies a steep local gradient of the mass function $M(r)$, which is related to the density profile by the expression:

$$\frac{d}{dr}\left(\frac{M(r)}{r}\right) = 4\pi r\rho(r) - \frac{M(r)}{r^2}. \tag{21}$$

For the derivative in the Equation (21) to be large and positive near $r = R$, the local density $\rho(r)$ must increase in the narrow shell approaching R. This suggests a configuration in which a significant portion of the total mass $M(R)$ is concentrated in the thin shell near R, while the interior $r < R$ remains sparse.

In such a configuration, the gravitational force acting on the outer shell arises almost entirely from the inner mass $M(r < R)$, since according to the shell theorem, only the inner mass contributes to the gravitational acceleration experienced by the shell. The radial acceleration of the shell is approximately:

$$a(R) = -\frac{GM(R_{\text{inner}})}{R^2}, \tag{22}$$

where $M(R_{\text{inner}}) \ll M(R)$ by construction.

This leads to a contradiction: since the shell contains most of the mass of the system, it is subject to a very weak gravitational force. Without sufficient gravitational force, the shell cannot collapse towards the center to dynamically form a horizon. Moreover, the pressure gradients sufficient to maintain such a configuration would be physically unrealistic, since they would require a finely tuned external pressure to balance the almost nonexistent internal gravitational force.

We conclude that a dense outer shell on the large radius with a small internal mass cannot form a stable or physically realistic configuration. Consequently, the sudden appearance of a horizon at a large radius without the prior formation of it at some smaller radius is dynamically forbidden. This strengthens the interpretation that the event horizon is a physically realized surface that progressively forms from the center outwards.

This causal nesting of event horizon surfaces, starting from the smallest radii, leads to a well-defined initial radius: the formation of a minimal core that satisfies the Schwarzschild condition on the Planck scale. As matter continues to collapse inward, gravitational contraction inexorably increases the local density until the inequality (16) is satisfied at the smallest possible physical scale. This occurs when the Planck mass m_p is confined within a radius $r \sim l_p$, forming a Planck sized Schwarzschild region. At that point, the classical description of spacetime ceases to hold, and quantum gravitational effects become dominant. The formation of this dense core on the Planck scale marks the beginning of a fundamentally new regime of evolution governed by the quantum geometry of the layered horizon.

Rather than being a problem for collapse, the Planck density acts as a critical threshold at which quantum gravitational effects replace classical dynamics. As collapse progresses, gravitational contraction increases the density of the core. Instead of this contraction continuing toward a classical singularity, the collapse stops at the limit defined by the Planck density:

$$\rho_{\text{p}} = \frac{m_p}{\frac{4}{3}\pi r_p^3} \sim 5.1 \cdot 10^{96}\ \text{kg/m}^3. \tag{23}$$

At this scale, the classical equations of motion no longer hold, and quantum gravitational corrections dominate. The result is not a singularity, but a minimal black hole, a seed with Planck density around which the event horizon begins to grow. This initial core forms the boundary between classical collapse and a new phase governed by the accumulation of layers of matter with redshift just above the event horizon.

Subsequent accretion no longer compresses the core, but deposits matter on the outer layers of the horizon. The Planck density therefore marks not an end, but a transition point: from volumetric compression to quantum encoding of the event horizon surface.

This reinterpretation naturally resolves the singularity problem. The interior of the black hole is not formed by compression into a geometric point, but the event horizon dynamically grows outwards starting from the Planck core. Once the core is formed at the Planck scale, it acts as a gravitational surface attracting infalling matter.

This leads to a profound implication: all black holes, regardless of their final size, start from a Planck seed. Macroscopic horizons are structures formed by cumulative growth due to the accretion of matter. This layered growth ensures compliance with causal structure, quantum consistency, and the Bekenstein-Hawking entropy limit. It also rules out singularities by prohibiting further compression beyond the quantum gravitational limit.

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 inner volume? In contrast to the classical intuition, where the event horizon encloses a pre-existing region of space-time, this model suggests that the inner volume is causally excluded. While the event horizon surface grows from the Planck size to macroscopic size, the inner volume does not participate in this process.

3.3 Mass as Exclusion of Spacetime

In classical general relativity, mass-energy curves spacetime via Einstein's field equations. However, in this model, black hole thermodynamics and the absence of internal observations suggest a deeper interpretation: gravity may not originate from matter embedded in spacetime, but from a topological exclusion of spacetime itself. In this view, mass corresponds to the causal and structural absence of spacetime. The resulting curvature is an elastic deformation of the surrounding manifold, encoding the residual imprint of the removed causal structure.

Accordingly, the interior of a black hole contains no hidden matter or infinite curvature, but is completely absent. The event horizon functions as the terminal boundary of the causal structure, beyond which no observer, no quantum field, and no classical geometry can extend. Spacetime ends at the horizon, and Einstein's field equations no longer hold in that inner topological region. Hawking radiation, in this model, does not originate from internal processes, but from quantum fluctuations just outside the null boundary. The classical singularity is thus replaced by a causal edge, and the curvature becomes a tension field induced by the removal of a part of the manifold.

This motivates a reinterpretation of Einstein's field equations:

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}, \tag{24}$$

where the stress-energy tensor $T_{\mu\nu}$ not only encodes the local energy momentum, but also the effective deformation required to preserve the curvature around the excised causal region. In this formulation, the gravitational constant G can be viewed as a quantification of the resistance to the manifold's truncation, a conversion factor between the curvature and the entropy deficit imposed by the boundary constraints. This naturally coincides with the holographic principle. Bekenstein-Hawking law of entropy,

$$S = \frac{k_B c^3}{4\hbar G} A, \tag{25}$$

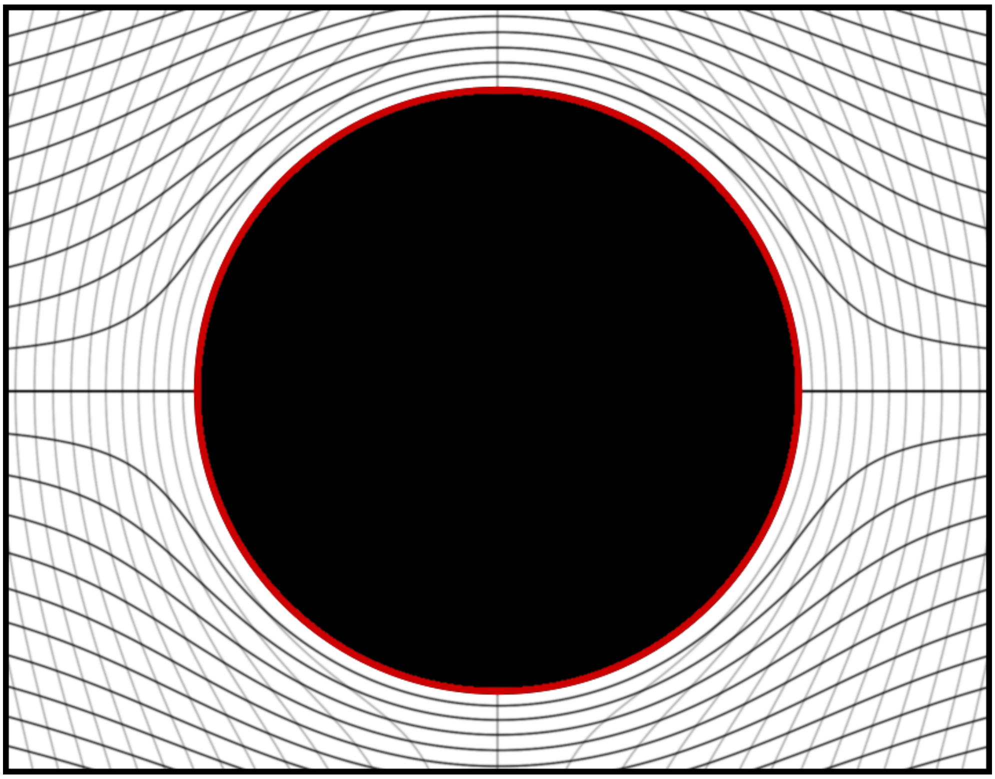

Fig. 2 Spacetime geodesics curve around a Schwarzschild black hole in this model much like streamlines in a compressible fluid flow bend around a void. This behavior arises not from an embedded central mass, but from the topological excision of spacetime at the black hole interior. The event horizon 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.

suggests that gravitational information resides not in the volume, but in a causally terminal surface region. The gravitational field of mass is therefore the elastic imprint of this causal subtraction, and mass itself does not become matter within space-time, but a geometric description of topological exclusion.

This proposal reproduces all the external predictions of general relativity. Gravitational waves, inspiral dynamics, and ringdown signatures are generated and detected entirely outside the horizon, where the classical field equations remain fully valid. The deviation concerns only the unobservable internal domain, offering a unique geometric and informational interpretation of black hole thermodynamics, gravitational collapse, and holography.

Ordinary matter, in this view, consists of localized micro-excisions, non-singular causal deficits embedded within the manifold. A black hole represents the asymptotic limit: complete topological excision. Geodesic lines of space-time do not curve toward mass as an embedded entity, but around these void-like regions, much like streamlines curve around an obstacle in a compressible medium (see Fig. 2). This model interprets dark matter as "silent" causal exclusions, regions that contribute to the curvature of spacetime but remain inert to measure interactions and entropy changes.

Such a geometric framework implies that space-time is not a passive or inert background, but a dynamic, relational structure with elastic and causal properties. Its ability to transmit gravitational waves, as predicted by general relativity and confirmed by observations, shows that spacetime has field-like degrees of freedom. However, this model does not treat spacetime as a material medium. Unlike the discarded ether of the Michelson-Morley experiment, this relational structure does not establish a preferred frame or absolute rest. Instead, it encodes causal relations invariant under local Lorentz transformations. Gravitational interaction does not appear as a force transmitted through matter, but as an intrinsic curvature resulting from geometric excision. This curvature acts as a residual memory of absent causal connections, which is entirely consistent with the relativistic paradigm.

Spacetime arises locally from the connection of events, and mass is reinterpreted as the topological boundary of the missing causal structure. While the interior of a black hole is mathematically defined in terms of an excluded volume, it does not possess physical observables or internal geometry. The event horizon thus becomes a null-layer, immutable encoding surface, consistent with the limits of entropy, holographic encoding, and quantum unitarity.

In this model the Planck mass, $m_p = \sqrt{\hbar c/G}$, marks the critical threshold between partial and complete excision of spacetime. It is the smallest mass whose Schwarzschild radius is equal to the Compton wavelength. Below this scale, quantum matter remains embedded in spacetime; above it, the deformation self-closes and forms a black hole. The mass hierarchy thus takes on a geometric meaning: it reflects how far a quantum excitation is from complete causal separation. Gravity, in this model, arises from the tension fields surrounding partial breaks in the causal structure.

This picture even suggests a new interpretation of particle properties. A quantum of mass might correspond to a one-sided hemispherical geometric deficit. One side interacts with the outside universe; the other represents the causal boundary. This structure could underlie the observed chirality in the weak interaction or give rise to gauge symmetries, depending on how spacetime behaves around the missing region. The Higgs field, rather than imparting mass by coupling with particles, could instead stabilize these micro-cuts by locking in geometric curvature.

The sum of the individual causal deficits must coherently reproduce the curvature observed around a smooth, spherically symmetric horizon. However, the gravitational field of a black hole does not reflect its internal volume, but the surface of its causal boundary. This points to Bekenstein and Hawking's holographic scaling: gravitational entropy and curvature scale with surface area, not volume. Each quantum of mass removes a portion of the Planck scale from the manifold, and the coherent organization of these disconnected surface segments represents the full gravitational footprint. The inner volume, although definable in mathematical terms, is not physically operational, but is in this model realized only as a holographic projection. Thus, gravitational dynamics are entirely determined by the causal boundary and its geometric structure, not by volumetric content.

By treating mass as a geometric cutout, this approach recasts gravitational curvature as a memory of a missing structure, curved around rather than filled in. Although speculative, this framework offers a a conceptually elegant path toward unifying the Standard Model, gravity, and quantum information.

4 Event Horizon as Holographic Surface

4.1 Horizon Layering, Null Ordering, and Angular Dynamics

Although the external gravitational field of a black hole is fully characterized by its global parameters: mass, angular momentum, and charge, they do not determine its internal content. In this model, gravity is not the result of matter embedded in space-time, but arises from topological excision: the causal removal of the volume of space-time, which deforms the external geodesic structure. Although the detailed microstructure of the event horizon does not change the external field, it plays a crucial role. This surface holographically encodes the internal degrees of freedom, preserves the entropy of the black hole, and ensures compatibility with unitarity and the laws of thermodynamics. Accordingly, gravity and curvature arise from the causal absence of the internal volume, while the information defining the internal universe is nonlocally organized on the horizon, structured as a null-ordered gauge-invariant code subspace.

From the perspective of a distant observer, gravitationally collapsing matter asymptotically approaches the Schwarzschild radius in infinite coordinate time. As it approaches this limit, the infalling matter becomes increasingly time-dilated and redshifted, effectively freezing just before the event horizon (Fig. 3). To describe this emerging structure, we introduce the concept of null-ordered layered accretion: a causal sequence of layers organized along lightlike null hypersurfaces, surfaces of constant advanced and retarded time. Each layer in this construction encodes a moment in the history of the collapse as it is embedded in the horizon surface, forming a geometrically ordered sequence that preserves the causal hierarchy. In this regime, the proper time of each infalling layer is effectively stopped with respect to the external frame of reference. Once the Planck scale is reached, the redshift divergence triggers the encoding of the null surface. From that point on, the holographically coded inner space-time disconnects from the parent cosmos and is projecting its own microcosm as a relational construct, encoded on the horizon in its causal surface structure.

This becomes possible because the relativistic length contraction compresses the falling matter into thinner and thinner layers in the radial direction. These shells flatten towards the horizon, becoming effectively two-dimensional (Equation 7). Thus, the dynamics of the gravitational collapse naturally realize the Bekenstein-Hawking area law for entropy (Equation 25). This reduction of 3-dimensional falling particles to a two-dimensional surface is a feature of the holographic principle, in which the maximum entropy of a region is proportional to the area of its boundary, not its volume. The event horizon therefore acts not as a transition point to an unobservable interior, but as a null surface in which quantum coding processes take place. Incoming matter is absorbed into causally ordered informational layers, with each redshifted arrival encoded sequentially.

This structure follows directly from the Schwarzschild metric. Although the radial component becomes singular near the horizon due to the redshift factor $\sqrt{1-\frac{2M}{r}} \to 0$, the angular component remains unaffected by this divergence:

$$r^2 d\Omega^2 = r^2(d\theta^2 + \sin^2\theta\, d\phi^2) \tag{26}$$

Thus we arrive at a crucial structural decoupling: Radial evolution stops, while angular degrees of freedom remain dynamically active. Near the horizon, the effective time evolution seen from the external frame becomes entirely determined by lateral propagation across the surface. These angular modes, unaffected by divergent redshift, serve as physical channels through which information is stored, ordered, and projected holographically.

Gravitational collapse, according to this interpretation, stops at the Planck redshift limit. The incoming information is encoded in surface degrees of freedom, such as angular momentum eigenmodes, quantum fluctuations, and horizon-localized spin networks. The interior of a black hole is not a separate space-time domain that is physically realized, but merely an emergent, holographically projected volume that results from the ordered surface encoding. Although the interior appears to scale with r_s^3, its entire information content and causal genesis arise from the dynamically stratified surface of the horizon.

This model satisfies several fundamental principles of theoretical physics. It realizes the bulk-boundary duality that underlies the AdS/CFT correspondence. It supports non-singular models consistent with quantum gravity and it provides a causal, local mechanism to resolve the black hole information paradox by preserving all information on the horizon. Sequential encoding of the falling layers in the null-layer ensures entropy conservation within the finite boundary of surface, which is consistent with both holography and unitary evolution.

4.2 Temporal Direction and Planck-Layer as Encoding Threshold

In the proposed model, the arrow of time within the emergent inner universe arises from a null-ordered accumulation of redshifted falling layers and a monotonically increasing coarse-grained entropy. As matter collapses toward the event horizon, it becomes increasingly compressed and time-dilated, forming a stratified sequence of causal layers. This redshift hierarchy establishes a temporal order from the Planck seed to the large-scale cosmic structure, while the increasing entropy of the horizon imposes a thermodynamic gradient and irreversibility.

The causal sequence of falling layers establishes the direction of internal time, synchronizing the occurrence of inflation, cosmological expansion, and the thermodynamic arrow with a single, externally-based chronology. This offers a non-anthropic explanation for the low-entropy initial state of the universe, linking the temporal asymmetry of cosmology to a physically causal encoding mechanism at the horizon.

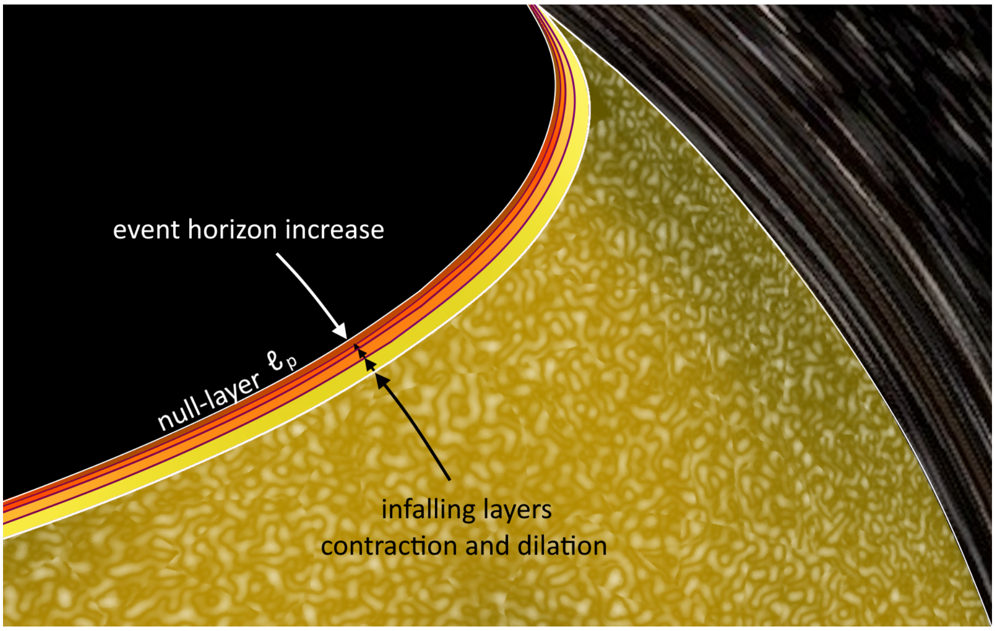

Fig. 3 Schematic representation of black hole gravitational collapse at a causal distance of l_P above the event horizon. As infalling mass increases, the horizon expands, creating a redshift-based foliation of layers which subsequently are encoded into null-layer. Internal spacetime exists only as a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

Let $r_n(t)$ represent the radius of the n-th falling layer of matter as a function of the Schwarzschild coordinate time t, as seen by a distant observer. The redshift parameter between the n-th layer and the evolving Schwarzschild radius $r_s(t) = 2M(t)$ defines the causal foliation of the null layers:

$$1 + z_n = \left(1 - \frac{r_s(t_n)}{r_n(t_n)}\right)^{-1/2} \tag{27}$$

Let us define a threshold for encoding at the Planck distance from the event horizon $r = 2M(t) + l_p$, where the classical geometry still remains valid. At smaller distances, standard concepts of spacetime break down as a result of quantum fluctuations. At this threshold, the redshift becomes:

$$1 + z(t) = \lambda(t) = \left(1 - \frac{2M(t)}{2M(t) + l_p}\right)^{-1/2} = \left(\frac{2M(t) + l_p}{l_p}\right)^{1/2} \approx \left(\frac{2M(t)}{l_p}\right)^{1/2} \tag{28}$$

This surface, located one Planck length above the horizon, represents the limit beyond which matter is holographically encoded and provides a natural temporal origin for internal spacetime. The Planck length limit resolves the classic Zeno paradox of the impossibility of reaching the event horizon.

4.3 Definition of Emergent Internal Time

In the layered-horizon model developed here, the flow of internal time does not arise from the background metric, i.e. the flow of time in the parent universe, but from the causal coding structure of the growing black hole. As the external mass increases, the gravitational redshift changes the rate at which internal observers experience time. This leads to several complementary ways of defining internal time.

The natural coarse-grained approach is based on the redshift factor $\lambda(t)$, defined according to Equation (28):

$$\lambda(t) = \left(\frac{2M(t)}{l_p^{\text{external}}}\right)^{1/2}, \tag{29}$$

which governs the relation between external coordinate time and internal clock time:

$$dt_{\text{internal}} = \lambda(t)\, dt_{\text{external}}. \tag{30}$$

By integrating over the collapse history, one obtains the accumulated internal time:

$$t_{\text{internal}}(t) = \int_{t_0}^{t} \lambda(t')\, dt', \tag{31}$$

where t_0 is the moment of the Planck scale event horizon formation. This formulation captures the accelerated evolution seen from within, as a consequence of increasing mass and redshift.

A second formulation ties internal time directly to horizon entropy. Since each Planck-area element added to the black hole corresponds to one bit of holographically encoded information, the internal time can be taken as proportional to the increase in Bekenstein–Hawking entropy:

$$t_{\text{internal}}(t) \propto S(t) = \frac{4\pi M(t)^2}{l_p^2}. \tag{32}$$

This perspective emphasizes causal accumulation: each increase in surface area represents a new layer of information, and the progression of internal time corresponds to the expansion of the encoding surface.

A third alternative is discrete: internal time evolves as a sum over individual null-layer encoding events. Each infalling layer contributes a Planck-time update to the internal geometry:

$$t_{\text{internal}} = \sum_{i=1}^{N} \delta t_p^{(i)}, \tag{33}$$

where $\delta t_p^{(i)}$ is the invariant internal Planck time per layer, and N is the total number of encoding events up to a given external time. This formulation reflects the quantum and holographic nature of spacetime, in which geometry emerges through a discrete, causally ordered code.

Each of these definitions highlights a different aspect of the model: the integral over λ captures the macroscopic flow of time; the internal entropy-based time flow is related to thermodynamics and information content; and the discrete sum corresponds to the microscopic process of layering. Despite these differences, all yield a consistent emergent structure governed by the dynamics of the growth of the event horizon.

With any of these models, short time intervals in the parent universe lead to large internal durations, allowing billions of years of evolution during the relatively short duration of gravitational collapse.

4.4 Dimensional Consistency Across Frames

The layered model of the event horizon preserves full dimensional consistency with general relativity and maintains the invariance of the gravitational constant G and the speed of light c in the outer and inner cosmos. Although the inner holographic universe inherits its structure from horizon encoding, its local holographically projected Planck units dynamically change in response to the changing surface of the black hole. These scalings are not arbitrary: they arise directly from angular holographic dynamics, which impose no constraints on internal adaptation of the Planck units, but require coherence with the amount of available entropy.

The total entropy of the black hole, governed by the Bekenstein-Hawking relation, sets the maximum information content for the emergent inner universe. This entropy is distributed over the causal structure of the event horizon, thus preserving consistency in scaling between the fundamental Planck units. The interdependence of the Planck length, time, and mass is given by:

$$l_P = \sqrt{\frac{\hbar G}{c^3}}, \quad t_P = \sqrt{\frac{\hbar G}{c^5}}, \quad m_P = \sqrt{\frac{\hbar c}{G}} \tag{34}$$

Any scaling of one Planck unit due to the growth of a black hole must be accompanied by a proportional scaling of all the others. This synchronization is not just a formal constraint; it is essential for preserving Lorentz invariance, causal structure, and the integrity of Einstein's field equations. Desynchronization would violate the dimensional coherence of the internal framework, leading to a violation of relativistic symmetry, internal inconsistency, and a collapse of the generative potential of the next generation of universes.

This dynamic allows for a physically grounded and recursively generative multiverse without fine-tuning. The invariance of G and c, together with the synchronized scaling of l_P, t_P, and m_P, acts both as a requirement of mathematical consistency and as a selection condition for sustainable cosmogenesis. Universes that maintain these scaling relations maintain their internal coherence and generative capacity, while those that do not fail to support stable causal evolution.

Thus, the black hole horizon in this model is not simply a one-way causal surface, but a regulating structure that preserves dimensional integrity across generations of encoded spacetimes. The internal universes are not arbitrary projections, they are physically grounded descendants within a coherent and recursive cosmological framework.

In the case of the natural coarse-grained approach of the emergent internal time which is based on the redshift factor $\lambda(t)$, the Planck scale shifts internally due to the change in the redshift scale:

$$t_p^{\text{internal}} = \frac{t_p^{\text{external}}}{\lambda}, \quad l_p^{\text{internal}} = \frac{l_p^{\text{external}}}{\lambda},$$
$$m_p^{\text{internal}} = \frac{m_p^{\text{external}}}{\lambda}, \quad \hbar_{\text{internal}} = \frac{\hbar_{\text{external}}}{\lambda^2}. \tag{35}$$

Thus, as the black hole grows and λ increases, the internal Planck time and length shrink, allowing finer spacetime resolution and faster apparent time flow. The internal universe is not constrained by the external Schwarzschild radius topological size but expands according to this redshifted encoding structure. Even a stellar-mass black hole can thus contain an internally vast and long-lived universe.

4.5 Natural Discretization and Wavefunction Collapse

In a null-ordered layered structuring of the event horizon, successive layers that fall on the event horizon are separated by Planck intervals in the radial direction, forming a time-ordered foliation that encodes the information contained in the falling layers. A layer becomes fully redshifted and gravitationally compressed when it reaches a finite Planck causal distance from the horizon. At that point, the layer no longer exists as an independent dynamical structure, but is integrated into the event horizon itself. The horizon, therefore, is not a static surface, but a dynamically growing, redshift-encoded quantum code, a 2D boundary surface that updates in discrete increments of the Planck area as layer by layer falls onto it:

$$\Delta A \sim 8\pi r_s l_p \tag{36}$$

This quantized growth is consistent with the Bekenstein-Hawking entropy formula and connects the causal hierarchy of redshifts to updates of information in the horizon null layer. Each incoming layer contributes a discrete update to the null-surface encoding. Internally, this manifests itself as a discontinuous change of the quantum state, which is internally experienced as a collapse of the wave function. From an external point of view, these updates are deterministically defined. But from an internal perspective, they introduce an apparent stochasticity: Quantum amplitudes that do not conform to the new horizon geometry are eliminated.

This process describes the collapse of the wave function not as a subjective act of measurement or branching of worlds, but as a physically grounded consequence of the layered dynamics of the event horizon. Bell inequalities are violated in the same way as in standard quantum mechanics, not because of local hidden variables, but because of the fundamentally nonlocal, dynamically ordered entanglement structure of the holographic code. The model retains realism by rejecting locality at the coding level, replacing hidden variables with causally ordered, redshift-frozen updates reflecting quantum correlations.

Let $|\psi^{(i)}_{\text{horizon}}\rangle$ represent the quantum state of the horizon null-layer encoding after i infall events. Let O_i denote the causal update operator associated with the i^{th} infalling layer. The encoding evolves as [16]:

$$|\psi^{(i+1)}_{\text{horizon}}\rangle = O_i|\psi^{(i)}_{\text{horizon}}\rangle, \quad |\psi^{(i+1)}_{\text{int}}\rangle = \text{Tr}_{\text{ext}}\left(O_i|\psi^{(i)}_{\text{horizon}}\rangle\right) \tag{37}$$

Here, the internal state is defined as the partial trace over the external degrees of freedom of the horizon Hilbert space. To internal observers, each update appears as a wavefunction collapse, analogous to measurement-induced decoherence. However, globally the dynamics are unitary, evolving across the joint Hilbert space of parent and internal universe:

$$\mathcal{H}_{\text{global}} = \mathcal{H}_{\text{ext}} \otimes \mathcal{H}_{\text{int}}, \quad |\Psi^{(i+1)}_{\text{global}}\rangle = U_i|\Psi^{(i)}_{\text{global}}\rangle \tag{38}$$

This interpretation builds on Rovelli's relational quantum mechanics [17], where quantum states are not absolute but defined relatively with respect to the observer. In this model, the black hole horizon itself plays the role of the observer, acting as a dynamically changing boundary that encodes the relational information of the falling quantum states. It grounds the abstract relational idea in the concrete causal geometry of the horizon.

At the same time, the model embodies Zurek's interpretation of decoherence [18], where the environment selects stable "pointer states". Here, the horizon acts as a geometric environment, a null-surface that causally selects and freezes certain internal amplitudes via redshift-induced decoherence. It functions as an information-regulating membrane that both observes and constrains the resulting internal state. Thus, the collapse of the wave function does not result from subjective measurement, but from objective causal updates of this surface.

Quantum indeterminacy therefore arises as a feature of causal exclusion, not epistemological ignorance. The collapse of the wave function is a geometric transition in the allowed state space driven by redshift stratification and horizon growth, solving the measurement problem without invoking branching of worlds or external observers. The inner universe retains only amplitudes compatible with the updated boundary code.

4.6 Entropy Bound and Entanglement

At the Planck scale, the separation between adjacent layers encodes causal order. Each layer is entangled with its neighbors, contributing to a nested, error-resistant quantum code. Once assimilated into the horizon, each layer contributes angularly organized information, preserving correlations with the previous and subsequent layers. The null-layer is not a static archive, but an active process: each new layer falling onto the null-layer updates the overall state of the horizon, modifying the entanglement structure from which the internal spacetime emerges. In this way, the surface of the black hole acts as a quantum memory, growing with each frozen redshifted layer, dynamically forming a source from which the internal cosmos is constructed.

Despite the apparent exponential growth of spacetime during internal inflation, the entropy of the resulting universe remains limited by the Bekenstein–Hawking entropy of the parent black hole, in accordance with the covariant entropy bound [19, 20]. As Bousso established, for any lightlike hypersurface generated from a surface A, the entropy flux through that surface cannot be greater than $A/4l_p^2$. Applied to the context of a black hole, this places an upper bound on the number of independent internal degrees of freedom:

$$N_{\text{internal bits}} \leq \frac{A}{4l_p^2}. \tag{39}$$

Each element of the event horizon surface at the Planck scale encodes a single bit of quantum information. Although the internal space-time is rapidly expanding, the internal Planck units change accordingly, and the total information content remains constant under holographic constraints. What appears internally as a rich and complex geometry is actually a projection of this boundary data. The internal universe appears large not because it contains more information, but because information is encoded in a highly redundant and entangled manner on the finite surface of the host black hole horizon. The encoding of internal information works similarly to high-resolution image compression, exploiting patterns, symmetries, and redundancies because pixels are not independent. Similarly, the vast volume of the internal cosmos is actually almost empty.

In this way, each bit is causally projected inward and propagates into a nonlocally entangled substructure across emergent internal bulk regions. This leads to distributed, redundant encoding, a key feature of holographic quantum error-correcting codes. The layered horizon, in this framework, functions analogously to tensor network models such as HaPPY in [21], where a small number of logical qubits are redundantly represented in overlapping boundary regions on the horizon to preserve observations in the internally projected universe in the case of erasure.

This interwoven layering realizes the principle that the connectivity and geometry of the space-time of the inner cosmos emerge from quantum entanglement patterns [22]. The inner universe is not an independently existing volume, but an emergent quantum domain reconstructed from correlations encoded on the horizon. As in holographic tensor network models [21], each localized degree of freedom in the projected volume is redundantly represented across multiple boundary layers on the horizon, allowing for geometric consistency and the possibility of recovery even with partial data loss. This framework also resonates with the ER=EPR conjecture [23], that the entangled pairs encoded in the horizon layers can be interpreted as non-traversable Einstein-Rosen bridges, suggesting that the spatial connectivity in the inner universe arises from the entanglement structure itself.

The inner state can be expressed as a superposition of bulk operators acting on this entangled surface:

$$I_{\text{internal}} \sim \sum_i \alpha_i O_i, \quad \sum_i |\alpha_i|^2 = 1, \tag{40}$$

where O_i are operators corresponding to local observables (e.g. curvature, field amplitudes) and α_i form a normalized quantum state. Information is not stored in a single location, but is distributed nonlocally across the causal layers of the horizon, consistent with the idea that entanglement, not locality, is fundamental. Spatial locality within the inner universe is an emergent property of the topology of entanglement on the horizon surface, and causal structure is inherited by the ordering of the layers that fall on null-layer.

Once inflation begins, these quantum-coded correlations stretch with the horizon, decohering into classical perturbations imprinted on the large-scale structure and the cosmic microwave background. The perceiving universe becomes a realization of the thesis that entanglement builds geometry. The inflated interior does not emerge from a pre-existing space, but from a coherent, null-layered entanglement code inscribed in the expanding parent horizon.

The code on the layered horizon introduces a form of causal interdependence. Since each null layer constraines the future ones through entanglement, the inner universe must remain consistent not only with the previously encoded information but also with the data yet to arrive in the upcoming falling layers. This is reminiscent of features of post-selected quantum theories, which here arise naturally from the Schwarzschild geometry of gravitational collapse.

This redundancy also implies an internal gauge invariance: In the effective theory, only surface-preserving relational operations survive. As the black hole accumulates more and more mass, it adds new redshift-frozen layers to the horizon surface, preserving unitarity and maintaining error correction in the expanding inner domains. The inner parts of the universe do not emerge from any single region of the horizon, but from the collective structure of the layered holographic coding.

Ultimately, this framework suggests that black hole horizons are not sinks of information, but quantum encoders, projecting structured internal universes whose geometry, fields, and observations are encoded on a Planck-scale-thick surface, built up layer by layer through infall and redshift. The apparent paradox of lost information is resolved: all physical structure is preserved in the quantum entanglement of the horizon, accessible only from within, with causally blocked access from the parent universe.

5 Internal Universe Cosmology

5.1 Internal Universe Perspective

In this framework, our universe may have originated from a Planck-sized seed within a parent black hole, which accreted rapidly through a redshifted layered horizon. A compelling clue supporting this scenario comes from the so-called Schwarzschild-Hubble coincidence. The total mass confined within the Hubble radius of the observed universe (approximately 13.8 Gyr) matches the Schwarzschild radius on a cosmological scale.

Given the Hubble constant $H_0 \approx 70$ km/s/Mpc $= 2.268 \cdot 10^{-18}$ s^{-1}, the corresponding Hubble radius is:

$$R_H = \frac{c}{H_0} = \frac{2.99792458 \cdot 10^8 \text{ m/s}}{2.268 \cdot 10^{-18} \text{ s}^{-1}} \approx 1.3218 \cdot 10^{26} \text{ m} \tag{41}$$

Assuming the critical density,

$$\rho_{\text{total}} = \frac{3H_0^2}{8\pi G},$$

the total enclosed mass is:

$$M = \frac{4\pi}{3} R_H^3 \cdot \rho_{\text{total}} = \frac{4\pi}{3} \cdot \frac{c^3}{H_0^3} \cdot \frac{3H_0^2}{8\pi G} = \frac{c^3}{2GH_0} \approx 8.8999 \cdot 10^{52} \text{ kg}.$$

The Schwarzschild radius for this mass is the following:

$$R_S = \frac{2GM}{c^2} = \frac{2 \cdot 6.6743 \cdot 10^{-11} \text{ m}^3\text{kg}^{-1}\text{s}^{-2} \cdot 8.8999 \cdot 10^{52} \text{ kg}}{(3 \cdot 10^8 \text{ m/s})^2} \approx 1.3218 \cdot 10^{26} \text{ m} \quad (42)$$

The identity $R_S = R_H$ is exact, suggesting a deep physical connection rather than a mere coincidence.

From the internal perspective, Planck units appear fixed and invariant, even though they rescale dynamically with black hole growth as seen externally.

The total accumulated internal time from the external frame is (Eq. 31):

$$t_{\text{internal}}^{\text{cumulative}} = \int_{t_0}^{t} \lambda(t_{\text{external}})\, dt_{\text{external}} = \int_{t_0}^{t} \left(\frac{2M_{\text{BH}}(t_{\text{external}})}{l_p^{\text{external}}} \right)^{1/2} dt_{\text{external}} \quad (43)$$

This integral reflects the fact that early in the collapse, λ is smaller and internal time flows more slowly, while in later stages, larger λ accelerates internal evolution. As a result, the majority of external black hole growth maps to a brief epoch of internal time, mimicking the rapid expansion phase of inflation.

This model demonstrates how a black hole, appearing nearly instantaneously in external time, can encode the full cosmological evolution of a universe internally.

5.2 Internal Universe Evolution

In the framework developed here, the traditional Big Bang singularity is reinterpreted as the initial emergent interior of a Planck-sized black hole formed in the parent universe. From an external perspective, this black hole develops from a Planck scale seed which experiences rapid growth via accretion. However, due to the extreme gravitational time dilation near the nascent event horizon, the internal evolution, which we perceive as the cosmic timeline of our universe, proceeds independently, starting from the moment the horizon first forms.

Internally, this yields a smooth, inflating early universe whose energy scale reflects Planck-scale conditions. The apparent origin of time corresponds to the dynamical stratification of matter falling 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 high energy densities of the early universe, eliminating the need for arbitrary initial conditions.

At the moment the black hole formed, the radial distance between the infalling layers and the event horizon was negligibly small. The rate of growth of the event horizon was thus initially maximal, because in this phase it rapidly engulfed the dense outer core regions. This created a "sweeping up" effect, where matter falling at speeds close to the speed of light $v \approx c$ was overtaken by the rapidly expanding horizon. From a distant observer's perspective, this accretion spike was compressed into a nearly instantaneous Schwarzschild time interval. From an internal perspective, this translated into a sudden injection of entropy and energy, analogous to the inflationary epoch of standard cosmology.

The gravitational redshift parameter λ started at a minimum value (in geometrized units) (Eq. (28)):

$$\lambda_0 = \left(\frac{2m_p + l_p}{l_p}\right)^{1/2} = \left(\frac{3 \cdot 1.616 \cdot 10^{-35}}{1.616 \cdot 10^{-35}}\right)^{1/2} = \sqrt{3} \tag{44}$$

During this early phase, the difference between the internal and external time flows was minimal. The entropic layering encoded in the horizon created large-scale structure in the inner universe. This early, rapid accretion phase acted as a trigger for the inflationary epoch. Externally, this period corresponds to a small λ, implying a slow internal evolution of time. As a result, most of the black hole's growth occurred within a miniature interval of the internal universe's own time, consistent with standard inflationary models [13, 24, 25].

As accretion progressed, the growth of the horizon began to slow down. Infalling material was no longer being pulled along by the rapid growth of the event horizon, but was gradually added to the horizon over longer Schwarzschild times. Internally, this marked the end of inflation and the transition to a slower expansion regime similar to dark energy regime. In this framework, constants such as t_p, l_p, m_p, and ρ_vac dynamically change according to the causal structure of the growing horizon. Each new layer updates the encoding of the null-surface, changing the internal units and effectively accelerating the expansion. Dark energy, in this view, is not a fundamental constant, but an emergent effect of the constantly expanding horizon. Large-scale cosmological asymmetries, such as CMB multipole alignments and hemispherical power asymmetries, arise from geometric constraints imposed by the parent black hole. The spin of the progenitor also defines a preferred axis, imprinted by the anisotropic encoding of the null-layer. This permanent asymmetry is reflected in the structure and correlations of the emergent spacetime.

The long-standing discrepancy between local measurements of the Hubble constant (e.g. SH0ES [26]) and inferences about the early universe from the cosmic microwave background (e.g. Planck [27]) remains unresolved within the standard ΛCDM framework. This so-called Hubble tension is usually interpreted as a consequence of new physics of the early universe or a systematic error in the calibrations of distance scales. In classical cosmology, cosmic time is assumed to flow linearly and uniformly, allowing redshift-distance relations to provide consistent estimates of the Hubble parameters over epochs. However, in this framework, cosmic time t_internal is an emergent quantity that arises through the gravitational structure of the redshift layers of the parent black hole. It evolves nonlinearly according to:

$$t_\mathrm{internal} = \int \lambda(t_\mathrm{external})\, dt_\mathrm{external}, \tag{45}$$

where $\lambda(t)$ is the redshift factor defined by the external observer clock. This parameter governs the rate at which causal layers accumulate on the black hole event horizon. As the black hole accretes more mass, λ increases, shrinking internal Planck units and accelerating the emergence of internal time.

The size of the parent black hole expressed in internal Planck units follows from:

$$M_{\text{black hole}} = \frac{M_{\text{internal}}}{\lambda}, \quad l_p^{\text{external}} = \lambda \cdot l_p^{\text{internal}} \tag{46}$$

This gives a redshift relation:

$$\lambda^2 = \frac{2M_{\text{black hole}}}{l_p^{\text{external}}} = \frac{2 \cdot \frac{M_{\text{internal}}}{\lambda}}{\lambda \cdot l_p^{\text{internal}}} = \frac{2M_{\text{internal}}}{\lambda^2 \cdot l_p^{\text{internal}}} \tag{47}$$

Solving for λ, we obtain:

$$\lambda = \left(\frac{2M_{\text{internal}}}{l_p^{\text{internal}}}\right)^{1/4} \tag{48}$$

We can now derive the internal Hubble volume using the scaling relations developed in this framework.

From the definition of the Hubble radius in the internal coordinates:

$$R_{\text{Hubble}} = 2M_{\text{internal}} \quad \Rightarrow \quad V_{\text{Hubble}}^{\text{internal}} = \frac{4}{3}\pi(2M_{\text{internal}})^3 = \frac{32\pi}{3}M_{\text{internal}}^3 \tag{49}$$

So, the internal Hubble volume scales as:

$$V_{\text{internal}} \propto M_{\text{internal}}^3 \tag{50}$$

But from the redshift scaling relation (Eq. 48):

$$\lambda = \left(\frac{2M_{\text{internal}}}{l_p^{\text{internal}}}\right)^{1/4} \quad \Rightarrow \quad M_{\text{internal}} = \frac{1}{2}\lambda^4 l_p^{\text{internal}} \tag{51}$$

Plugging this into the volume expression:

$$V_{\text{internal}} \propto \left(\lambda^4 l_p^{\text{internal}}\right)^3 = \lambda^{12}(l_p^{\text{internal}})^3 \tag{52}$$

This result implies that, from the point of view of an internal observer, where the Planck length l_p^{internal} appears fixed, the visible volume of the internal Hubble universe scales according to λ^{12} as the parent black hole accretes mass and grows, so that any non-uniformity in $\lambda(t)$ translates directly into a varying expansion rate per unit internal time. If $\lambda(t)$ increased slowly in the early stages of the collapse, and more steeply later, as would be expected from intensified accretion, then the actual early value of λ would be larger than what a linear extrapolation from its current value would suggest:

$$\lambda_{\text{CMB}} > \lambda_{\text{now}} \cdot \frac{t_{\text{CMB}}}{t_{\text{now}}}, \tag{53}$$

This inequality arises because linear extrapolation assumes constant λ growth, analogous to the uniform flow of time. In contrast, the model implies that the early universe (e.g., the epoch of the last scattering) occurred during a slowly growing λ regime, while the present era reflects a phase of rapid λ acceleration.

It is important to note that the cosmological redshift z depends only on the cumulative internal time. Therefore, it cannot reveal whether internal time has recently undergone a rapid acceleration relative to external coordinate time. The redshift "remembers" how much internal time has passed, but not how that time was distributed over external epochs.

However, the acceleration becomes clear when one analyzes how the Hubble volume grows at fixed internal time intervals. Given:

$$t_{\text{internal}} \propto \int \lambda(t')dt', \qquad V_{\text{internal}} \propto \lambda^{12}, \tag{54}$$

a steep rise in λ implies that spacetime expansion is outpacing internal time accumulation. This asymmetry directly influences the inferred expansion rates from observations made at different epochs.

Observations anchored in the early universe (e.g., Planck CMB) measure a lower Hubble constant because they probe a regime where internal time flowed slowly. In contrast, local measurements (e.g., SH0ES) reflect conditions when internal time flowed rapidly, compressing more expansion into less time and thereby increasing the effective Hubble parameter:

$$H_{\text{internal}}(t_{\text{external}}) = \frac{1}{t_{\text{internal}}(t_{\text{external}})}. \tag{55}$$

This offers a potential resolution to the Hubble tension without invoking exotic early dark energy or modifications to the Standard Model. Instead, it suggests that time itself is nonuniform and emergent, governed by horizon-layer accumulation during black hole collapse. However, for this reinterpretation to become predictive, a concrete accretion model for realistic black hole collapse must be developed, one capable of reproducing the observed evolution of $H(t)$ under classical cosmological constraints.

5.3 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. This formulation supports a plausible interpretation of cosmogenesis: Each black hole creates a new, inflating universe whose initial conditions are stored in the information of the layers on the horizon inherited from the parent space-time.

The parent universe may contain a vast population of such black holes, primordial, astrophysical, or otherwise, that create their own internal universes. Each serves as a node in the generative cosmic hierarchy described in this model. The observable quantities within any universe thus reflect the specific accretion history and horizon layer structure of its ancestor, not necessarily its final state.

This scenario is consistent with earlier proposals for multiverses and baby universes [28, 29], reinterpreting black holes as cosmological generators, nodes in a recursive cosmic hierarchy. The evolution of each child universe depends entirely on the properties encoded on the horizon of the parent black hole. According to the no-hair theorem, a classical black hole is externally characterized by only three parameters: mass, electric charge, and angular momentum [12]. All other internal information is inaccessible and holographically encoded.

In this model, the full causal structure, including the emergent space-time of the child universe, is encoded in microscopic degrees of freedom on the parent horizon. These degrees of freedom are causally inaccessible from the outside, which implements a strengthened version of the cosmic censorship principle. Rather than simply hiding a singularity, the horizon acts as a terminal surface beyond which classical geometry ceases and quantum encoding dominates. It is about preserving causal integrity and informational closure: no observer can access the child universe from the outside because its entire geometry is emergent and bounded by the code of the parent horizon. The detailed structure of the inner universe, encoded as a null-stratified quantum surface, is therefore protected not by a physical singularity, but by a causal and informational boundary. The black hole event horizon serves simultaneously as the endpoint of space-time in the parent system and the initial conditional surface for an emergent cosmology within it. The Bekenstein-Hawking entropy of the parent horizon limits the number and diversity of possible descendants [6]:

$$S_{\text{parent}} = \frac{k_B A_{\text{horizon}}}{4l_P^2} \quad \Rightarrow \quad N_{\text{child}} \lesssim \frac{S_{\text{parent}}}{\langle S_{\text{child}} \rangle} \tag{56}$$

Thus, although each black hole can in principle create a new universe, the total number of offspring is limited by the entropy budget of the parent. This model therefore naturally leads to a finite, causally unconnected multiverse: a hierarchy of universes generated by the successive formation of black holes. Recursive encoding is allowed, each universe can create others by itself via its own black holes, but the finite entropy at each level imposes a strict upper bound on the number of productive generations [28]. In this way, holographically encoded entropy places real physical constraints on recursive cosmogenesis, forming a limited alternative to the paradigm of an unbounded multiverse.

The inner universe appears large not because it contains more bits, but because its information is encoded on the parent horizon using nonlocal redundancy and entanglement. Each inner region is reconstructed from overlapping, causally consistent contributions across multiple redshifted layers on the surface of the parent black hole. However, not all regions are reconstructed equally. Some encoded degrees of freedom, especially those still entangled with the outer universe or with previous horizon structures, remain inaccessible to the inner subspace of the code. These bits cannot be decohered or classicize and therefore cannot participate in gauge interactions or radiation processes. Nevertheless, they still project a geometric influence, curving spacetime due to their partial encoding. This naturally explains dark matter as a holographic artifact of compression: a manifestation of partially realized geometry, where information exists but remains incomplete. These poorly resolved regions are not filled with exotic particles, but with gravitational signatures of non-decohered, externally entangled modes. As such, they represent partial geometric excisions, regions where spacetime is distorted not by embedded mass-energy, but by the limitations of causal and informational reconstruction.

Observationally, our universe exhibits a baryonic matter fraction of about 4.5% and a dark matter fraction of about 27% [30]. Within this model, such proportions are consistent with a cosmological lineage of intermediate generation: our universe is not of the first generation, but is still generatively viable. The existence of stars, chemistry, and observable complexity implies that there remain enough fresh, decoherable degrees of freedom. In the meantime, the dominance of dark matter may serve as a cosmological signature of the ancestors, a remnant of the inherited, non-decohered quantum structure.

This leads to a key theoretical prediction regarding the generative limits of the multiverse. Although any black hole can, in principle, seed a new universe, the ability to create classical, information-rich internal structure declines with each generation. A significant consequence of this structure is the eventual breakdown of generativity. As universes inherit an increasing number of entangled, non-decoherable horizon modes from their ancestors, their ability to create baryonic structure, and thus new black holes, diminishes. Generativity may cease not because of heat death, but because of information saturation.

A further implication is that our current multiverse architecture, with universes obeying similar Planck scaling, dimensional consistency, and physical laws, may be the product of an evolutionary selection process. Earlier lineages of universes, which arose from less stable or incoherently encoded parent black holes, may have failed to achieve dimensional closure or entropy efficiency. These unstable proto-universes were largely infertile, unable to seed child universes via gravitational collapse.

In contrast, the current lineage, including our own universe, could be located on a stabilized, self-consistent branch of the multiverse: one selected for its ability to generate further black holes and sustain recursive cosmogenesis. This view resonates with Smolin's hypothesis of cosmological natural selection [28], in which the laws of physics evolve to maximize the production of black holes. Here we reinterpret this principle through the prism of quantum gravity and holographic coding, proposing that universes that are best able to produce self-consistent layered horizon structures are favored over global evolution.

In our framework, the observed universe originates as an emergent volume projected from a boundary code located at the null layer just above the event horizon of the parent black hole. But this volume is not embedded in the same space-time in which the boundary degrees of freedom live; rather, the border itself is part of the external, higher-order spatio-temporal structure inaccessible from the emergent interior.

Thus, no observer within the universe can reach or probe the very edge of the event horizon. The event horizon is not a physical surface in our space-time, but a null-layer encoding what defines the evolution and causal order of emergent interior. This highlights a fundamental difference: the horizon is not a physical boundary within our space-time, but a surface located in an outer space-time substrate.

Finally, the question of how the boundary of our space-time is organized remains subtle. It is probably closed in itself topologically, forming a compact manifold without a boundary in the emergent sense. The true boundary lies beyond the space-time fabric of our universe.

So, in the deepest sense, everything is correlation. What appears as matter, particles, fields, or geometry is a manifestation of an interwoven structure organized in a compressed, causally ordered horizon. The physical world is not embedded in space-time, but emerges from the causal and informational constraints of its holographic boundary surface. In this way, the multiverse becomes not a collection of disconnected universes, but a recursive hierarchy of projected domains, each generated from the entropic and geometric heritage of the horizon of its predecessor.

At the deepest level, the notion of volume does not appear as a fundamental ingredient of reality, but as an emergent feature of more primitive structures, encoded on lower-dimensional boundaries or networks of correlations. Holographic principles suggest that all the information needed to describe the apparent three-dimensional universe is encoded on a two-dimensional surface at its causal boundary. Multiverse is according to this in fact a “surface of surfaces”. Deeper exploration, theories such as spin networks and tensor network models suggest that even these surfaces arise from discrete or algebraic building blocks, perhaps effectively one-dimensional or point-like, where the geometric concepts of dimension, length, and continuity have no independent meaning. In this respect, dimension itself is an emergent construct, arising from patterns of entanglement and information flow, suggesting that at the most fundamental level, reality is ultimately just a network of dimensionless relationships.

6 Conclusion

This paper presents a new paradigm for understanding gravitational collapse as a process of cosmogenesis. Taking the reference frame of the external observer seriously, the horizon of a black hole is interpreted not as a boundary to be crossed, but as a dynamic, information-rich surface. Falling matter forms a series of null-ordered, redshifted layers that holographically encode the inner universe. This encoding serves as the engine for inflation, structure formation, and quantum state selection. Our model solves the black hole information paradox, bypasses singularities, and supports a finite, entropy-limited architecture of the multiverse. By unifying causal collapse, quantum encoding, and cosmological emergence, this model offers a bridge between general relativity and quantum theory, one that redefines the nature of space, time, and the universe itself.

Although the present model is necessarily idealized and includes several simplifications, it establishes a coherent and physically consistent framework. Future work should extend this foundation to include more realistic collapse geometries, including rotating (Kerr) and charged (Reissner-Nordström) black holes, to investigate the robustness of the null-layered holographic structure and its implications for internal anisotropy, angular momentum transfer, and information dynamics. While specific components may require refinement or modification, the central proposition, that black holes holographically encode emergent universes via causally ordered, redshift-frozen surface structures, offers a compelling and testable alternative to traditional singularity-driven models. As such, it provides a fundamental foundation upon which future researchers can construct more detailed developments in quantum field theory and phenomenology.

6.1 Appendix

Here are calculated quantities for a universe with internal Hubble mass:

$$M_{\text{internal}} = 8.8999 \cdot 10^{52}\ \text{kg} = 6.6092 \cdot 10^{25}\ \text{m} = 4.4757 \cdot 10^{22}\ M_{\odot}.$$

Using Eq. (48):

$$\lambda = \left(\frac{2 \cdot 6.6092 \cdot 10^{25}}{1.616 \cdot 10^{-35}} \right)^{1/4} = 1.69116 \cdot 10^{15} \tag{57}$$

Then the external mass of the parent black hole becomes:

$$M_{\text{black hole}} = \frac{M_{\text{internal}}}{\lambda} = \frac{6.6092 \cdot 10^{25}}{1.69116 \cdot 10^{15}} = 3.9081 \cdot 10^{10}\ \text{m} = 2.6466 \cdot 10^{7}\ M_{\odot} \tag{58}$$

Accordingly, the external Planck units are larger than their internal counterparts:

$$l_p^{\text{external}} = \lambda \cdot l_p^{\text{internal}} = 1.69116 \cdot 10^{15} \cdot 1.616 \cdot 10^{-35} = 2.7329 \cdot 10^{-20}\ \text{m} \tag{59}$$
$$t_p^{\text{external}} = \lambda \cdot t_p^{\text{internal}} = 1.69116 \cdot 10^{15} \cdot 5.391247 \cdot 10^{-44} = 9.117 \cdot 10^{-29}\ \text{s} \tag{60}$$
$$m_p^{\text{external}} = \lambda \cdot m_p^{\text{internal}} = 1.69116 \cdot 10^{15} \cdot 2.176434 \cdot 10^{-8} = 3.6807 \cdot 10^{7}\ \text{kg} \tag{61}$$

These rescalings preserve dimensional consistency and allow for a consistent physical evolution across frames.

As a lower bound, if we assume a constant redshift λ_{now}, then for an internal evolution duration of 14 Gyr $\approx 4.352 \cdot 10^{17}$ s, the minimum collapse duration in external time is:

$$\Delta t_{\text{collapse}}^{\text{lower}} > \frac{\Delta t_{\text{internal}}}{\lambda_{\text{now}}} = \frac{4.352 \cdot 10^{17}}{1.69116 \cdot 10^{15}} = 257.3\ \text{s} \approx 4.3\ \text{minutes} \tag{62}$$

In reality, the collapse duration is longer due to the lower values of λ in the early stages.

Within the framework developed here, the interior of a black hole gives rise to an entire cosmological history, experienced as a universe. However, from the vantage point of the parent universe, the timescale of black hole formation and growth appears to be radically different. The horizon growth and accumulation of infalling matter, which seeds the expansion of the internal universe, are governed by the external frame's gravitational collapse dynamics.

In our model, the parent black hole corresponding to our universe has a final Schwarzschild radius of approximately:

$$R_S = 3.908 \cdot 10^{10} \text{ m},$$

as given in Eq. (58). This quantity is computed using internal Planck units. To assess its physical meaning from the perspective of the parent universe, we must compare it to the Planck length in the external frame.

The internal and external Planck lengths differ significantly (Eq. 59). This means that, in terms of the parent universe's fundamental scales, the relative mass of the black hole is close to Planckian, even though its absolute mass is far above the Planck mass. This can be expressed via the dimensionless relative mass:

$$M_{\text{rel}} = \frac{M_{\text{black hole}}}{l_p^{\text{external}}} \cdot m_p = \frac{3.9080896 \cdot 10^{10}}{2.7329 \cdot 10^{-20}} \cdot 2.176434 \cdot 10^{-8} \approx 6.22 \cdot 10^{22} \text{ kg} \tag{63}$$

This corresponds to about 0.016 $M_{\odot}$, or roughly three times the mass of the Moon. Thus, from the external view, this black hole does not resemble a typical astrophysical object but rather a sharply localized, high-curvature region collapsing on Planckian timescales.

To estimate the effective duration of the collapse in external Planck time units, we use the lower limit on collapse duration from Eq. (62) and rescale it using the external Planck time from Eq. (60):

$$\Delta t_{\text{relative}}^{\text{external}} = \frac{\Delta t_{\text{collapse}}^{\text{lower limit}}}{t_p^{\text{external}}} \cdot t_p = \frac{257.3 \text{ s}}{9.117 \cdot 10^{-29} \text{ s}} \cdot 1.616 \cdot 10^{-35} \text{ s} = 45.6\ \mu\text{s} \tag{64}$$

Thus, from the external perspective, the entire sequence of horizon formation, core mass trapping, and null-surface growth unfolds in just tens of microseconds. Internally, however, this same process corresponds to the emergence and evolution of a full cosmological history lasting approximately 13.8 Gyr.

This time-asymmetry emerges naturally from the extreme redshift near the horizon and the holographic encoding of infalling matter onto the event horizon. The resulting internal universe is not governed by external accretion dynamics in the usual thermodynamic sense: the Eddington limit becomes irrelevant.

Instead, the black hole appears as a transient, Planck-scale object from the external frame, whereas internally, it contains the full spacetime structure of an expanding universe. Our entire cosmos may be the interior evolution of such a small black hole in a parent universe no matter how absurd this looks. Nevertheless, the observable portion of our universe may be only a small subset of its full extent.

It is important to recognize that the parameters derived in this model, such as the current value of the gravitational redshift factor λ_{now}, or the mass of the parent black hole as inferred from the observable internal universe, are conditioned by the assumption that we are observing only a finite, partial region of the full internal cosmology. The observed Hubble radius, for instance, need not represent the total extent of the internal universe encoded on the parent black hole's horizon. Instead, it reflects the finite portion currently accessible within the causal structure defined by accumulated horizon layering.

Consequently, the relatively small parent black hole mass derived in Eq. (63), approximately $6.22 \cdot 10^{22}$ kg, should not be interpreted as the final or total mass of the black hole. Rather, it reflects only the portion of mass that has accreted up to the current external time t_{now}, corresponding to the visible internal region. This suggests that the total amount of encoded spacetime, and therefore the full extent of the internal cosmology, could be vastly larger than what is currently observable from within. Moreover, as accretion continues, the black hole horizon will expand accordingly. If not already of stellar or supermassive scale, the parent black hole may eventually reach such dimensions by the time accretion completes.

Assuming that inflation is driven by an initial accretion spike, we estimate an average redshift parameter $\lambda_{\text{avg}} \approx 10^6$. If the external duration of this spike is roughly Planck time, $\Delta t_{\text{external}} = 10^{-42}$ s, then the corresponding internal Planck time becomes consistent with the inflation duration of our universe:

$$t_p^{\text{internal}} = \frac{t_p^{\text{external}}}{\lambda} = \frac{5.391247 \cdot 10^{-44}}{10^6} = 5.391247 \cdot 10^{-50} \text{ s} \tag{65}$$

$$\Delta t_{\text{internal}} = \lambda \cdot \Delta t_{\text{external}} = 10^{-36} \text{ s} \tag{66}$$

$$\Delta t_{\text{relative}}^{\text{internal}} = \frac{\Delta t_{\text{internal}}}{t_p^{\text{internal}}} \cdot t_p = \frac{10^{-36}}{5.391247 \cdot 10^{-50}} \cdot 5.391247 \cdot 10^{-44} = 10^{-30} \text{ s} \tag{67}$$

References

[1] Schwarzschild, K.: On the gravitational field of a mass point according to einstein's theory. arXiv preprint physics/9905030 (1999)

[2] Schutz, B.: A First Course in General Relativity, pp. 317–322. Cambridge university press, ??? (2022)

[3] Hafele, J.C., Keating, R.E.: Around-the-world atomic clocks: Observed relativistic time gains. Science **177**(4044), 168–170 (1972)

[4] Ashby, N.: Relativity in the global positioning system. Living Reviews in relativity **6**(1), 1–42 (2003)

[5] Chou, C.-w., Hume, D., Koelemeij, J., Wineland, D.J., Rosenband, T.: Frequency comparison of two high-accuracy al+ optical clocks. Physical review letters **104**(7), 070802 (2010)

[6] Bekenstein, J.D.: Black holes and entropy. Physical Review D **7**(8), 2333 (1973)

[7] Hawking, S.W.: Particle creation by black holes. Communications in mathematical physics **43**(3), 199–220 (1975)

[8] Sperhake, U.: General Relativity 2: Lecture Notes. University of Cambridge. https://www.damtp.cam.ac.uk/user/us248/Lectures/Notes/grII.pdf (2016)

[9] Carroll, S.M.: An introduction to general relativity: spacetime and geometry. Addison Wesley **101**, 102 (2004)

[10] Aristotle: Physics

[11] Ho, P.-M.: The absence of horizon in black-hole formation. Nuclear Physics B **909**, 394–417 (2016)

[12] Misner, C.W., Thorne, K.S., Wheeler, J.A.: Gravitation. Macmillan, ??? (1973)

[13] O'Connor, E., Ott, C.D.: Black hole formation in failing core-collapse supernovae. The Astrophysical Journal **730**(2), 70 (2011)

[14] Shapiro, S.L., Teukolsky, S.A.: Black Holes, White Dwarfs and Neutron Stars: the Physics of Compact Objects. John Wiley & Sons, ??? (2024)

[15] Woosley, S., Wilson, J., Mathews, G., Hoffman, R., Meyer, B.: The r-process and neutrino-heated supernova ejecta. Astrophysical Journal, Part 1 (ISSN 0004-637X), vol. 433, no. 1, p. 229-246 **433**, 229–246 (1994)

[16] Pastawski, F., Yoshida, B., Harlow, D., Preskill, J.: Holographic quantum error-correcting codes: Toy models for the bulk/boundary. arXiv preprint arXiv:1503.06237 (2015)

[17] Rovelli, C.: Relational quantum mechanics. International journal of theoretical physics **35**, 1637–1678 (1996)

[18] Zurek, W.H.: Decoherence and the transition from quantum to classical. Physics today **44**(10), 36–44 (1991)

[19] Bousso, R.: A covariant entropy conjecture. Journal of High Energy Physics **1999**(07), 004 (1999)

[20] Bousso, R.: The holographic principle. Reviews of Modern Physics **74**(3), 825 (2002)

[21] Almheiri, A., Dong, X., Harlow, D.: Bulk locality and quantum error correction in ads/cft. Journal of High Energy Physics **2015**(4), 1–34 (2015)

[22] Van Raamsdonk, M.: Building up space–time with quantum entanglement. International Journal of Modern Physics D **19**(14), 2429–2435 (2010)

[23] Maldacena, J., Susskind, L.: Cool horizons for entangled black holes. Fortschritte der Physik **61**(9), 781–811 (2013)

[24] Rezzolla, L., Zanotti, O.: Relativistic Hydrodynamics. Oxford University Press, USA, ??? (2013)

[25] Liddle, A.R., Lyth, D.H.: Cosmological Inflation and Large-scale Structure. Cambridge university press, ??? (2000)

[26] Riess, A.G., Yuan, W., Macri, L.M., Scolnic, D., Brout, D., Casertano, S., Jones, D.O., Murakami, Y., Peterson, R., Polin, A., *et al.*: A comprehensive measurement of the local value of the hubble constant with 1 km/s/mpc uncertainty from the hubble space telescope and the sh0es team. The Astrophysical Journal Letters **934**(1), 7 (2022) https://doi.org/10.3847/2041-8213/ac5c5b

[27] Collaboration, P., Aghanim, N., Akrami, Y., Ashdown, M., Aumont, J., Baccigalupi, C., Ballardini, M., Banday, A., Barreiro, R., Bartolo, N., *et al.*: Planck 2018 results. vi. cosmological parameters. Astronomy & Astrophysics **641**, 6 (2020) https://doi.org/10.1051/0004-6361/201833910

[28] Smolin, L.: The Life of the Cosmos. Oxford University Press, ??? (1997)

[29] Frolov, V., Novikov, I.: Black Hole Physics: Basic Concepts and New Developments vol. 96. Springer, ??? (2012)

[30] Collaboration, P., Aghanim, N., Akrami, Y., Arroja, F., Ashdown, M., Aumont, J., Baccigalupi, C., Ballardini, M., Banday, A., Barreiro, R., *et al.*: Planck 2018 results. A&A **641**, 1 (2020)