Beyond the Horizon: A Universe Within (Part I)

Causal Horizons and Cosmogenesis in a VSL Framework

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June 2025

Abstract

We propose a conceptual cosmological model in which the interior of a black hole constitutes a complete universe governed by a variable speed of light (VSL) framework. In this scenario, the speed of light approaches zero at the event horizon and increases toward the interior. This behavior reinterprets the horizon as a temporal boundary condition analogous to the Big Bang, offering a resolution to the flatness and horizon problems without invoking inflation. Furthermore, continued accretion from the parent universe manifests as accelerated expansion within the interior universe, providing a geometric alternative to dark energy. While formal development remains future work, we outline the key physical consequences and cosmological implications of this conceptual framework.

1 Introduction

Modern cosmology typically assumes that fundamental constants, such as the speed of light c, are fixed across space and time. However, Variable Speed of Light (VSL) theories have emerged as alternatives to inflation in addressing early-universe puzzles [1, 2]. Simultaneously, the physics of black hole interiors remains an open frontier, particularly regarding causal structure, entropy, and singularity resolution.

In this work, we explore a synthesis of these ideas by proposing that the interior of a black hole is itself a universe, where causal and thermodynamic behavior is governed by a radially varying speed of light. Inspired by Brans–Dicke-type scalar–tensor theories [3] and VSL cosmologies [5, 4], we emphasize a geometric transition in causal structure induced by the variation of $c(r)$, especially near the event horizon. Our approach builds on speculative models such as Smolin's cosmological natural selection [6] and Popławski's torsion bounce cosmologies [7], while introducing a new mechanism based on the collapse of lightcones.

This conceptual framework developed from an initial idea by the author through collaborative refinement with an AI model (ChatGPT), which contributed to equation structuring, physical analogies, and editorial coherence. All physical claims and interpretations remain author-driven. This work is intended as a self-contained starting point for further theoretical exploration, with formal mathematical development reserved for future work.

2 Horizon as a Cosmological Boundary

We propose that the radial variation of the speed of light defines a causal boundary at the event horizon. The simplest ansatz assumes an exponential suppression near the horizon:

$$c(r) = c_0 \exp\left(-\alpha |r - r_H|^n\right), \quad \alpha > 0,\ n > 0, \tag{1}$$

where c_0 is the asymptotic speed of light far from the horizon r_H. As r approaches r_H, the speed of light drops sharply, effectively collapsing lightcones and enforcing causal disconnection between the interior and exterior. Because thermodynamic quantities such as entropy scale with inverse powers of c (e.g., $S \sim A/c^3$), this results in a suppression of entropy at the horizon, suggesting a natural low-entropy initial condition. We note, however, that this interpretation conflicts with the Bekenstein-Hawking entropy relation $S \sim \frac{A}{4}$, raising the possibility that conventional thermodynamic assumptions may break down near causal boundaries. This apparent conflict may signal a deeper inconsistency between thermodynamic assumptions and causal boundary dynamics in VSL regimes, potentially requiring a reformulation of entropy accounting in such contexts.

The steep gradient in $c(r)$ near the horizon modifies the local causal structure dramatically. Although not implying a literal divergence, the relative change in c over small intervals becomes large, and this can be interpreted as contributing to rapid interior expansion—an effect reminiscent of inflation. Furthermore, unlike traditional singularity theorems, the interior geometry remains regular, as the curvature remains bounded and geodesic completeness is maintained near $r = 0$.

To make this formulation coordinate-independent, a covariant generalization can be introduced using curvature invariants. Specifically, we propose:

$$c(r) = c_0 \exp(-\alpha |\nabla K|), \tag{2}$$

where $K = R_{\mu\nu\rho\sigma} R^{\mu\nu\rho\sigma}$ is the Kretschmann scalar. Since $|\nabla K|$ peaks near the event horizon, this version reinforces the interpretation of the horizon as a geometric and causal boundary surface.

3 Cosmological Evolution via Accretion

From the interior's perspective, continued accretion by the black hole in the parent universe corresponds to cosmological expansion. Let the interior scale factor $a(t)$ be proportional to the black hole radius $R(t)$, which in turn tracks the black hole mass $M(t)$:

$$a(t) \propto R(t) \propto M(t). \tag{3}$$

Then the Hubble parameter is

$$H(t) = \frac{\dot{a}}{a} = \frac{\dot{M}}{M}. \tag{4}$$

Under the VSL framework, the time-variation of c modifies this to:

$$H(t) \approx \frac{\dot{M}}{M} - 2\frac{\dot{c}}{c}, \tag{5}$$

where the second term dominates near the horizon due to the rapid decrease of c. This naturally yields inflation-like exponential behavior without requiring inflaton fields:

$$a(t) \propto e^{\gamma t}, \quad \gamma = -2\frac{\dot{c}}{c}. \tag{6}$$

This mechanism also provides a natural interpretation of dark energy: as the black hole continues to accrete mass from the parent universe, the resulting interior expansion mimics late-time cosmic acceleration. Unlike a cosmological constant, this acceleration is dynamic, sourced by the evolving horizon geometry and its associated causal structure.

4 Implications and Outlook

This model suggests that black holes act as seeds of new universes, with their horizons functioning as cosmological initial surfaces. Our universe could plausibly be the interior of such a structure. The vanishing of c at the horizon reproduces a low-entropy, causally-disconnected initial state, while the regularity of curvature near $r = 0$ suggests avoidance of classical singularities.

Moreover, this scenario offers a fresh lens on the black hole information paradox, causal structure evolution, and potential bridges between general relativity and quantum gravity. The reinterpretation of horizon dynamics as early-universe physics invites deeper exploration through both analytical and numerical methods.

We note that this model remains phenomenological and faces several open questions. The absence of a Lagrangian formulation limits its theoretical completeness, and the entropy tension at the horizon highlights the need for new thermodynamic principles in VSL contexts. Future work should focus on developing a self-consistent Lagrangian formulation and resolving the entropy-boundary tension. While detailed observational analysis lies beyond this conceptual treatment, potential signatures like large-scale CMB anisotropies from asymmetric accretion merit investigation through numerical simulations.

5 Conclusion

We have outlined a speculative but physically motivated model in which black hole interiors function as cosmological domains governed by a variable speed of light. The horizon emerges as a causal and thermodynamic boundary, mimicking a Big Bang without singularities. The model offers a geometric basis for early-universe inflation and late-time acceleration through ongoing mass accretion.

While formal mathematical completion awaits further development, this conceptual framework highlights the potential for black hole horizons to geometrize cosmological origins. Future work may numerically simulate accretion-driven expansion or seek observational signatures. If our universe indeed emerged from such a structure, asymmetric accretion patterns might imprint testable features in cosmological observables, providing pathways to evaluate this paradigm.

References

[1] A. Albrecht and J. Magueijo, *A time varying speed of light as a solution to cosmological puzzles*, Phys. Rev. D **59**, 043516 (1999).

[2] J. W. Moffat, *Superluminary universe: A possible solution to the initial value problem in cosmology*, Int. J. Mod. Phys. D **2**(3), 351–366 (1993).

[3] C. Brans and R. H. Dicke, *Mach's principle and a relativistic theory of gravitation*, Phys. Rev. **124**(3), 925 (1961).

[4] J. Magueijo, *New varying speed of light theories*, Rep. Prog. Phys. **66**(11), 2025 (2003).

[5] J. D. Barrow, *Cosmologies with varying light speed*, Phys. Rev. D **59**, 043515 (1999).

[6] L. Smolin, *The Life of the Cosmos*, Oxford University Press (1997).

[7] N. J. Popławski, *Cosmology with torsion: An alternative to cosmic inflation*, Phys. Lett. B **694**(3), 181–185 (2010).