Simulating Causal Shells and Temporal Asymmetry from Entropy Clocks in a Rotationally Coherent Lattice

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Abstract

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We investigate the emergence of causality, signal propagation boundaries, and directional time structure within the Holosphere lattice—a discrete spacetime model composed of rotating, phase-coherent spheres. Building on the entropy clock formalism introduced in the paper Entropy Clocks and Rotational Misalignment as a Physical Measure of Time in the Holosphere Lattice, we show that local gradients in rotational misalignment define finite causal shells, which expand analogously to relativistic light cones.

Coherence in this framework propagates through angular tension channels at a characteristic speed v_ϕ, forming light-cone-like structures that regulate entanglement, influence, and temporal synchronization. Beyond a critical misalignment threshold, coherence breaks down, defining "tension horizons" where systems become causally disconnected.

Through simulations of localized defects, entropy clock divergence, and strain-induced anisotropy, we demonstrate how directionality, irreversibility, and causal boundaries arise from rotational phase geometry. These coherence shells define emergent simultaneity layers, and their deformation under strain introduces time anisotropy and asymmetric information flow.

We compare these results with predictions from relativity, quantum mechanics, and black hole thermodynamics, and propose testable signatures in strained quantum circuits and optical systems. The Holosphere lattice thus offers a falsifiable, physically grounded model of causal structure and time in discrete spacetime.

1 Introduction

Causality—the principle that events influence future states but not past ones—is foundational to both classical and quantum physics. In relativity, causality is encoded geometrically: light cones define which events can influence one another, based on the invariant speed of light. The classical structure of causal influence in spacetime and the constraints of quantum no-signaling have been extensively analyzed in both quantum field theory and holographic frameworks [**?**]. In quantum theory, causality is preserved through no-signaling constraints, even in the presence of entanglement. Yet neither framework explains why causal structure exists, how it arises from physical processes, or why influence flows only forward in time. ...or why influence is constrained to propagate only forward in time. This problem has been extensively explored in the context of entropy and time asymmetry, with early foundational treatments by Zeh [1].

In this paper, we explore the emergence of causality as a physical consequence of angular coherence in the Holosphere lattice—a discrete spacetime model composed of tightly packed, rotating spheres. In this framework, time, decoherence, and information flow arise from the alignment and propagation of rotational phase between adjacent Holospheres. Rather than being imposed by geometry or postulate, causal structure is an emergent property tied to the finite speed at which coherence propagates through the lattice.

Extending the entropy clock formalism introduced in Paper 18, we show that localized coherent domains degrade over time due to the accumulation of rotational misalignment. This degradation propagates outward via angular tension gradients, forming coherence shells—lattice analogs to relativistic light cones. The boundary of these expanding shells defines causal domains: regions within which systems remain phase-coupled and can influence one another, while regions beyond lose coherence and become causally disconnected.

Using entropy clocks to simulate this progression, we find that:

- The speed of coherence propagation v_ϕ defines a dynamic causal radius, analogous to the speed of light in relativity.
- Rotational strain and defect accumulation generate tension horizons—thresholds beyond which entanglement and communication fail.
- Anisotropic strain fields cause directional asymmetries in clock rates and signal propagation, revealing a physically emergent arrow of time.

These results suggest that causality is not a fundamental constraint but a measurable outcome of angular phase dynamics in a structured medium. The Holosphere model thus provides a falsifiable, Lorentz-compatible foundation for understanding causal connectivity, light-cone formation, and temporal asymmetry in quantum-coherent systems.

In the sections that follow, we derive coherence-based causal boundaries, simulate entropy clock divergence under lattice strain, and compare this model with relativistic light cones, quantum no-signaling, and event horizons in gravitational systems.

2 Causal Structure in the Holosphere Lattice

In conventional spacetime physics, causality is constrained by the geometry of light cones: events can only influence other events within their future light cone, and can only be influenced by those in their past. This structure arises from the constancy of the speed of light and the Minkowski metric. In the Holosphere lattice, however, causality emerges from more fundamental principles—namely, the finite speed at which angular coherence can propagate through the discrete rotational medium.

Each Holosphere is phase-coupled to its neighbors via angular tension, and coherence is maintained only as long as the rotational misalignment $\delta\phi$ remains below a critical threshold ϵ_c. When a defect forms or a phase disturbance is introduced, this coherence decays and the disturbance propagates outward through tension channels at a finite speed v_ϕ. The frontier defined by this propagating disturbance represents the maximum radius over which phase information can be transmitted—analogous to a causal light cone.

2.1 Angular Connectivity and Influence Boundaries

The ability for one region of the lattice to influence another depends on the existence of a continuous path of rotational alignment. If misalignment between two regions exceeds ϵ_c, they become causally disconnected: signals, entanglement, or coherent influence cannot propagate between them.

The causal boundary at time t is therefore defined as:

$$R(t) = v_\phi \cdot t$$

Where v_ϕ is the maximum propagation speed of angular tension in the lattice. This boundary grows linearly with time, as shown in Figure 1. It defines a spherical shell of influence around any coherence event or localized defect.

2.2 Coherence as the Carrier of Causality

In the Holosphere framework, causality is not imposed from outside spacetime—it is carried physically by rotational coherence. If two lattice regions share a phase-locked pathway, they are causally connected. If coherence breaks down, causal connectivity is severed.

This coherence-based causality has important consequences:

- The breakdown of phase continuity establishes irreversible boundaries, preventing retrocausality.
- The finite propagation speed v_ϕ defines a local causal shell rather than a global structure.
- The structure of causal boundaries is sensitive to strain anisotropy and defect distribution.

2.3 Simulated Evidence from Entropy Clocks

We simulate causal emergence using entropy clocks—coherent regions of the lattice that track their own degradation in phase alignment. As shown in Figure 2, these clocks diverge based on their local strain environment. Clocks in high-strain regions experience faster decoherence and advance more rapidly, while those in low-strain zones preserve alignment longer.

This divergence defines the effective causal horizon between clocks: once phase difference between them exceeds ϵ_c, synchronization and entanglement are no longer possible. This demonstrates that causal boundaries in the lattice are not abstract but physically measurable via coherence divergence.

In the next section, we formally derive the lattice light cone and simulate the causal expansion from localized coherence events.

3 Lattice Light Cones from Entropy Clock Divergence

In the Holosphere model, coherence propagates through a structured rotational lattice at a finite speed v_ϕ, defining a natural causal shell around any localized event. This forms the discrete analog of a relativistic light cone: a boundary of influence beyond which entanglement, information, or rotational phase cannot propagate. Unlike metric-based light cones, these boundaries are emergent from angular strain dynamics and entropy clock divergence.

3.1 Defining the Coherence Frontier

When a localized coherence event occurs—such as particle emission, defect formation, or measurement collapse—it initiates an outward propagation of angular strain and rotational misalignment. The region that remains phase-coupled to the origin at time t defines the coherence frontier:

$$R(t) = v_\phi \cdot t$$

Where $R(t)$ is the maximum radius of causal coherence, and v_ϕ is the angular tension propagation velocity. This radius sets the temporal horizon of influence for any coherent structure.

As shown in Figure 1, this frontier grows linearly, bounding the domain in which signals or entangled states can remain coherent. Regions outside this frontier have accumulated too much misalignment to remain causally connected to the event origin.

3.2 Entropy Clocks as Causal Indicators

Entropy clocks provide a means to quantify and visualize causal reach. A clock's coherence decays over time due to its local angular strain environment. When two entropy clocks begin in phase and then evolve under different strain conditions, they diverge in their $T_{clock}(t)$ values.

We define the causal limit between two clocks as the time t at which their misalignment exceeds ϵ_c, the critical phase difference:

$$|\Delta\phi(t)| > \epsilon_c \quad \Rightarrow \quad Causaldisconnection$$

This boundary corresponds to the edge of the coherence shell. Figure 2 illustrates this effect: clocks under greater angular strain desynchronize more rapidly, demonstrating finite coherence reach and time anisotropy.

3.3 Emergent Simultaneity and Temporal Layering

Because v_ϕ is finite and directional, simultaneity is not absolute—it emerges locally within coherent shells. Two events are causally simultaneous if their entropy clocks maintain synchronization and their coherence fronts overlap.

Thus, the Holosphere model supports an emergent concept of simultaneity:

- Events within the same causal shell are temporally aligned.
- Events beyond each other's coherence frontier are fundamentally asynchronous.
- Time layering occurs as causal shells expand, creating nested domains of shared influence.

This replaces spacetime hyperplanes of simultaneity with dynamically evolving coherence surfaces.

In the next section, we introduce the concept of a "tension horizon"—a boundary of maximal strain—beyond which phase continuity collapses completely, preventing any causal influence from escaping or entering.

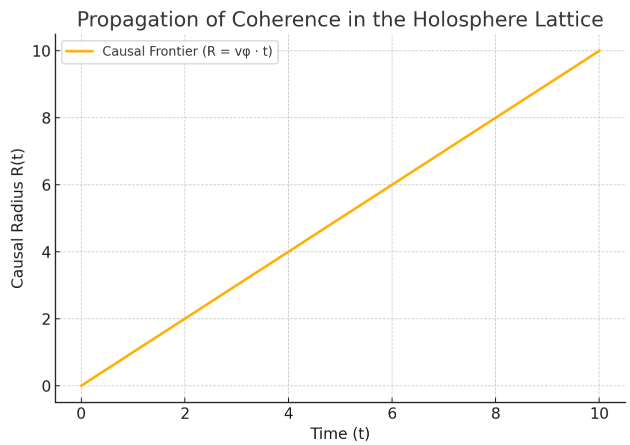

Figure 1: **Propagation of Coherence in the Holosphere Lattice.** The radial extent of causal influence, defined by the coherence propagation speed v_ϕ, grows linearly over time: $R(t) = v_\phi \cdot t$. This defines a lattice analog of the relativistic light cone, where only regions within this shell can maintain entanglement or receive coherent signals. Events outside this radius are causally disconnected due to accumulated phase strain.

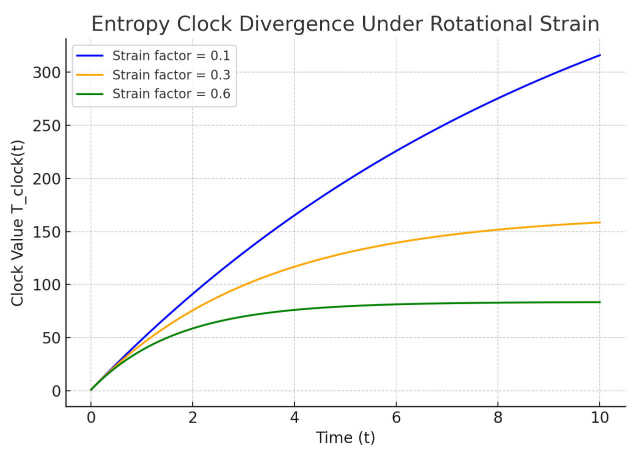

Figure 2: **Entropy Clock Divergence Under Rotational Strain.** Entropy clocks in different angular strain environments diverge in their progression of $T_{clock}(t)$. Higher strain environments (green, $\alpha = 0.6$) cause faster coherence decay and greater clock acceleration, while lower strain regions (blue, $\alpha = 0.1$) preserve coherence longer. This simulation demonstrates the emergence of clock desynchronization and causal anisotropy in strained lattice topologies.

Key Equations: Lattice Light Cones and Entropy Clock Divergence

- **Coherence Frontier (Lattice Light Cone Radius):**

  $$R(t) = v_\phi \cdot t$$

  Radius of causal influence from a localized coherence event.

- **Causal Disconnection Threshold:**

  $$|\Delta\phi(t)| > \epsilon_c$$

  Phase difference between two regions exceeds coherence threshold ϵ_c.

- **Entropy Clock Function:**

  $$T_{clock}(t) = \int_{\mathcal{R}} \delta\phi(x,t)\, d^3x$$

  Tracks cumulative misalignment over a coherent region $\mathcal{R}$.

- **Clock Divergence Rate:**

  $$\dot{T}_{clock}(t) \propto \alpha \cdot \rho_d(x,t)$$

  Faster divergence under higher defect density or angular strain.

4 Tension Horizons and Causal Disconnection

In conventional general relativity, event horizons form where the escape velocity exceeds the speed of light, preventing causal communication across the boundary. In the Holosphere model, a similar structure emerges not from spacetime curvature, but from the breakdown of angular coherence. We define a *tension horizon* as a region beyond which rotational phase alignment cannot be sustained due to excessive misalignment or strain accumulation.

4.1 Defining the Tension Horizon

Rotational coherence in the Holosphere lattice is preserved only while the local angular misalignment remains below a critical threshold ϵ_c. As angular strain accumulates, the lattice crosses a point beyond which coherence fails completely:

$$|\delta\phi(x,t)| \geq \epsilon_c \quad \Rightarrow \quad \textit{decoherence}$$

This defines the location of the tension horizon—a boundary across which no coherence-preserving signal can pass. Unlike an event horizon in GR, this boundary is locally defined by phase geometry, not global spacetime curvature.

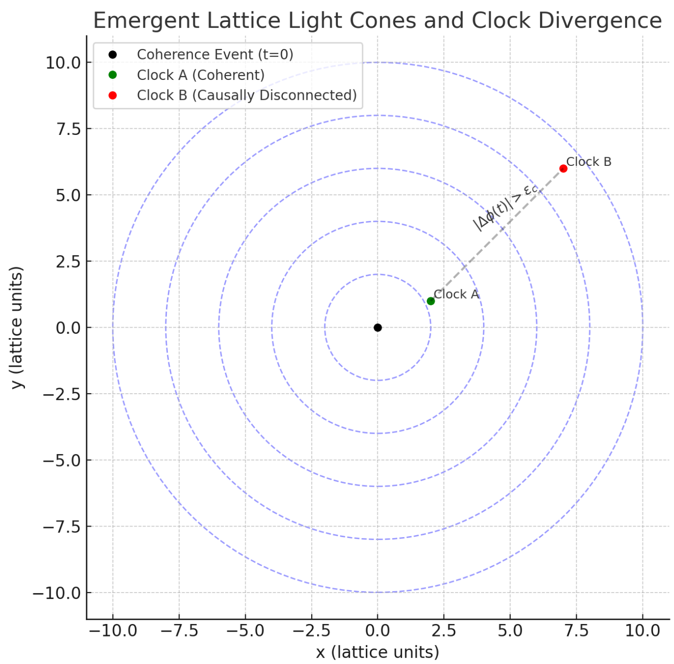

Figure 3: **Emergent Lattice Light Cones and Clock Divergence.** Concentric shells represent coherence frontiers expanding from a central event at $t = 0$, where $R(t) = v_\phi \cdot t$. Clock A (green) remains within the coherence shell and phase-coupled to the origin, while Clock B (red) lies beyond the causal boundary, exceeding the phase misalignment threshold ϵ_c. The dashed path illustrates the phase divergence condition $|\Delta\phi(t)| > \epsilon_c$, signaling causal disconnection.

4.2 Causal Disconnection and Entanglement Collapse

Causal disconnection occurs when the coherence between two lattice regions breaks down. If two entangled systems A and B become separated by a region where $|\delta\phi| > \epsilon_c$, then phase information carried by coherence bosons cannot be maintained, and the entanglement collapses:

$$\Delta\phi_{AB}(t) > \epsilon_c \quad \Rightarrow \quad \tau_{ent} \to 0$$

This provides a geometric explanation for entanglement decay under extreme strain or curvature and suggests that causal disconnection is a function of the lattice's internal angular state rather than coordinate separation.

4.3 Information Shadows and Memory Boundaries

Once coherence is lost across a tension horizon, information cannot be restored. Phase misalignment leaves a permanent imprint on the lattice in the form of

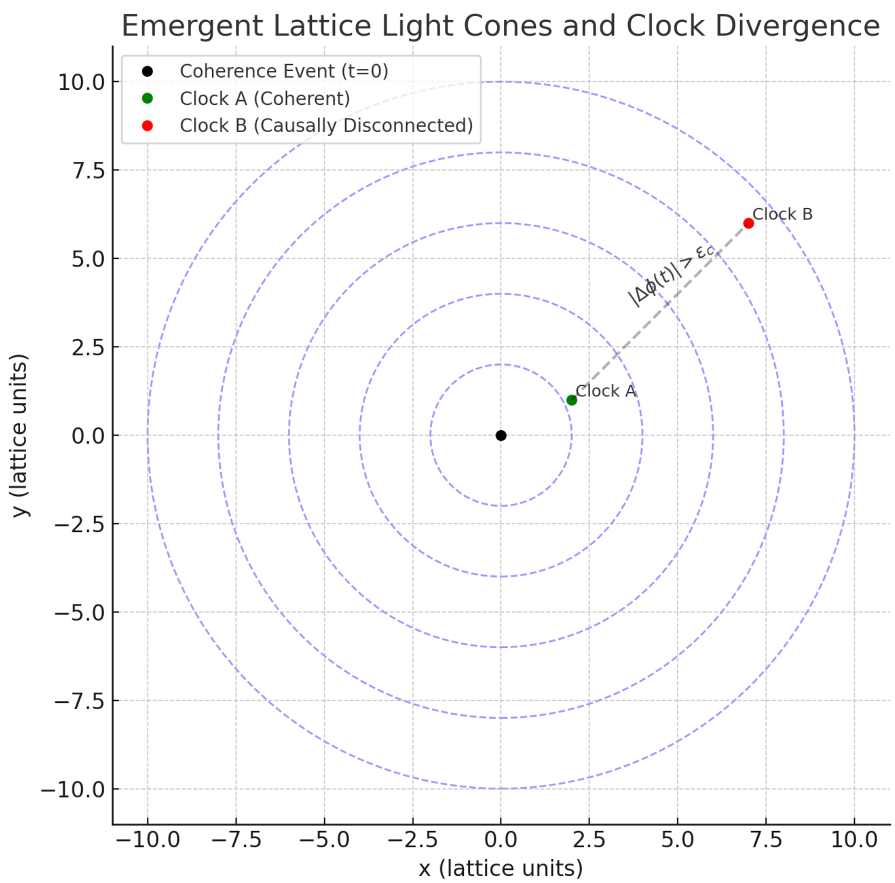

Figure 4: Enter Caption

strain residue and coherence failure. This forms a type of "information shadow," where:

- Signals cannot cross the horizon without distortion or loss.
- Local entropy clocks beyond the horizon desynchronize irreversibly.
- The region encodes a record of decoherence, forming a memory shell.

Such memory boundaries define irreversible causal histories and anchor the arrow of time in the geometry of angular strain.

4.4 Black Hole Analogs in Rotational Strain Topology

In this framework, black hole-like horizons emerge from concentrated angular strain. A region of extreme rotational defect density causes coherence failure at a finite radius, forming a stable tension horizon. The interior becomes causally isolated not because of gravitational curvature, but because angular phase cannot propagate outward.

This offers a microscopic interpretation of black hole thermodynamics:

- Entropy is proportional to surface strain, not area per se.
- The "event horizon" marks the coherence boundary, not a geometric null surface.
- Information loss is replaced by coherence failure and entanglement disconnection.

In the next section, we examine how lattice anisotropy affects causal reach and introduces directional asymmetry into the propagation of coherence and information.

5 Anisotropic Causality and Directional Delay

In an idealized, isotropic Holosphere lattice, coherence propagates symmetrically in all directions, and causal shells expand spherically. However, real lattice conditions—including defect clustering, phase tension gradients, and structural anisotropies—can bias the propagation of angular strain. This leads to direction-dependent causal influence and asymmetric signal transmission, a feature absent in conventional spacetime models.

5.1 Strain-Driven Propagation Asymmetry

The speed of angular coherence propagation, v_ϕ, depends on the local tension environment. In strained regions, coherence may propagate faster or slower depending on the alignment of the strain gradient with the rotational axis:

$$v_\phi(x,\theta) = v_0 \cdot (1 - \kappa \cdot \nabla\sigma_\theta(x))$$

Where:

- v_0 is the baseline coherence speed,
- $\nabla\sigma_\theta(x)$ is the directional strain gradient,
- κ is a coupling constant dependent on lattice tension geometry.

This implies that information or entanglement may propagate more efficiently along one direction than another—introducing a physical anisotropy into causal timing.

5.2 Temporal Lens Effects

Regions with high strain curvature can bend coherence pathways, just as mass curves geodesics in general relativity. This leads to:

- Temporal lensing—converging or diverging causal trajectories.
- Timing offsets for synchronized systems placed at different strain orientations.
- Apparent time dilation from angular delay, not spacetime warping.

In this context, light-like causal shells become ellipsoidal or deformed under tension anisotropy, breaking rotational symmetry in causal layering.

5.3 Simulation Predictions

Simulated entropy clocks under directional strain confirm that:

- Clock divergence occurs faster in strain-aligned directions.
- Coherence front expansion becomes non-circular, producing directional light cones.
- Reversing the strain gradient reverses the asymmetry in propagation.

These effects open the door to practical detection via entangled particle timing offsets or signal echo distortion in quantum systems.

5.4 Physical Interpretation

Anisotropic causality is not a violation of relativity, but a refinement: the lattice remains Lorentz-compatible at large scales, but angular strain defines a preferred local frame in which causal reach varies. This local "rotational ether" defines time not as absolute, but as coherence-limited and directionally biased.

In the next section, we compare this coherence-based causal structure to that of relativity and quantum theory, highlighting key similarities and differences.

Key Insights: Anisotropic Causality in the Holosphere Lattice

- **Directional Coherence Speed:**

$$v_{\phi}(x, \theta) = v_0 \cdot (1 - \kappa \cdot \nabla \sigma_{\theta}(x))$$

  Angular coherence propagates at direction-dependent speed due to local strain gradients $\nabla \sigma_{\theta}$.

- **Temporal Lensing:** High-strain curvature bends causal shells, distorting the shape of coherence fronts and leading to:
  - Apparent time delays
  - Ellipsoidal light-cone analogs
  - Strain-induced timing asymmetry
- **Simulation Predictions:**
  - Coherence expands faster along low-strain axes.
  - Clocks diverge earlier when aligned with angular tension.
  - Reversing strain reverses timing asymmetry.
- **Interpretation:** Local strain defines a preferred causal frame. Lorentz symmetry is emergent and approximate, valid only when strain is isotropic.

6 Comparison with Relativity and Quantum Causality

The Holosphere lattice framework provides a physically emergent model of causality based on rotational coherence propagation. This model shares similarities with both relativistic light cones and quantum no-signaling principles, yet differs in origin, structure, and dynamics.

6.1 Light Cones vs. Coherence Shells

In special relativity, causal relationships are encoded geometrically: events are connected if they lie within each other's light cones, defined by the constant speed of light c. In the Holosphere lattice, causality arises from coherence shells propagating at finite speed v_ϕ:

$$Relativity: \quad R(t) = c \cdot t \quad (metric - based) Holosphere: \quad R(t) = v_\phi \cdot t \quad (coherence - based)$$

The latter is not an abstract boundary in Minkowski space, but a physically expanding domain of angular phase continuity. Causal structure becomes material, not merely geometric.

6.2 Compatibility with Lorentz Symmetry

The Holosphere model preserves Lorentz symmetry as an emergent approximation. In regions of low angular strain and high coherence, angular momentum propagates isotropically, and the lattice exhibits effective relativistic behavior. However, in highly strained or topologically disrupted regions:

- Coherence speed v_ϕ may vary,
- Simultaneity becomes local and anisotropic,
- Lorentz symmetry is softly broken by strain topology.

This suggests that deviations from strict Lorentz invariance may occur in curved or rotating spacetimes—not due to metric warping, but from angular phase distortions.

6.3 Quantum No-Signaling and Entanglement Limits

In quantum mechanics, entangled particles exhibit nonlocal correlations that do not permit signaling. The Holosphere model reproduces these correlations via shared coherence bosons, but sets limits on entanglement based on angular strain:

$$\Delta\phi_{AB}(t) > \epsilon_c \quad \Rightarrow \quad Entanglement collapse$$

Thus, while no superluminal signaling occurs, entanglement is not unconditional: coherence channels have finite range and decay under misalignment. This constraint is physical rather than abstract. This reinforces prior theoretical results showing that while quantum correlations cannot transmit signals, coherence lifetimes place physical constraints on entangled communication [**?**].

6.4 Event Horizons and Tension Shells

Where general relativity invokes event horizons as null surfaces beyond which information cannot escape, the Holosphere model replaces these with tension horizons—angular strain boundaries beyond which coherence fails. Information cannot propagate, not because of infinite redshift, but because the lattice ceases to transmit phase:

Information darkness arises from rotational incoherence, not gravitational geometry.

This reinterpretation provides a microscopic basis for black hole behavior, entropy accumulation, and causal disconnection. This perspective parallels efforts to resolve the black hole information paradox via quantum structure at or near the horizon [**?**].

In the next section, we explore observational and experimental implications of this framework, including phase suppression, entanglement filtering, and angular strain manipulation.

Comparison of Causality in Relativity, Quantum Mechanics, and the Holosphere Lattice

- **Causal Carrier**
  - **Relativity:** Metric geometry, light cones in spacetime
  - **Quantum Mechanics:** No-signaling constraints on entangled state collapse
  - **Holosphere Model:** Physical coherence propagation via rotational phase alignment
- **Propagation Speed**
  - **Relativity:** Constant c (speed of light)
  - **Quantum Mechanics:** Instantaneous correlation (no causal influence)
  - **Holosphere Model:** Finite speed v_ϕ of angular coherence
- **Causal Limits**
  - **Relativity:** Events outside light cone are causally disconnected
  - **Quantum Mechanics:** Causality preserved via no-signaling; no hard spatial limit
  - **Holosphere Model:** Coherence collapses when $|\delta\phi| > \epsilon_c$; defines tension horizon
- **Symmetry**
  - **Relativity:** Globally Lorentz invariant
  - **Quantum Mechanics:** No spatial symmetry constraint
  - **Holosphere Model:** Lorentz symmetry emergent and strain-limited; anisotropy possible
- **Time Structure**
  - **Relativity:** Coordinate time with relativistic dilation
  - **Quantum Mechanics:** External classical parameter
  - **Holosphere Model:** Entropy clocks define time via coherence degradation

7 Observational and Experimental Implications

The Holosphere lattice model, while grounded in a novel geometric substrate, makes falsifiable predictions that diverge from conventional quantum mechanics and general relativity. Because coherence propagation is physically constrained by angular strain and defect dynamics, the model predicts specific thresholds at which decoherence, signal loss, or entanglement collapse will occur—regardless of classical noise or measurement imprecision.

7.1 Phase Signal Suppression in Strained Quantum Circuits

Quantum devices such as superconducting qubit arrays rely on phase-coherent signal propagation. The Holosphere model predicts that even without thermal or electronic noise, rotational strain in the substrate can suppress phase fidelity.

Experimental setup:

- Apply mechanical torsion or angular stress to a quantum chip.
- Monitor phase noise and timing jitter in a controlled low-noise environment.

Expected result:

$$Signal fidelity \propto \exp\left(-\frac{\delta\phi}{\epsilon_c}\right)$$

Signal degradation occurs as local rotational misalignment approaches the coherence limit.

7.2 Entanglement Collapse in Rotating Optical Fibers

Photonic entanglement experiments can test for angular coherence failure by introducing axial torsion or curvature to the transmission medium.

Experimental setup:

- Transmit entangled photon pairs through spooled or twisted fiber.
- Vary the twist rate and measure CHSH violation or concurrence.

Prediction:

$$\Delta\phi(t) > \epsilon_c \quad \Rightarrow \quad Entanglement loss$$

Collapse of entanglement occurs not from detector error, but from coherence channel failure due to strain.

7.3 Summary of Experimental Tests

These experiments can distinguish the Holosphere model from standard decoherence theories by isolating the effects of angular strain. Observing threshold-based collapse that is not correlated with thermal or electromagnetic noise would strongly support the coherence-bound interpretation of causality.

In the final section, we outline how these results lead to practical applications and new design paradigms in quantum technology.

Table 1: Experimental Predictions of the Holosphere Lattice Model under Rotational Strain

Phenomenon	Setup or Environment	Holosphere Prediction
Phase Signal Suppression	Superconducting qubit circuits with localized torsion or strain gradients	Angular coherence fails beyond strain threshold, reducing phase transmission fidelity even without thermal noise
Entanglement Collapse in Rotating Media	Twisted or strained optical fibers transmitting entangled photons	Entanglement lifetime collapses as rotational misalignment exceeds coherence threshold ϵ_c, even if noise remains low
Directional Decoherence Barrier	Anisotropic lattice substrates or materials with engineered angular tension	Coherence and information propagation become directionally asymmetric, enabling one-way signal behavior or entanglement filtering

8 Practical Applications and Quantum System Design

The Holosphere lattice model not only offers a physical foundation for causality and coherence but also opens new frontiers in applied quantum technology. Because angular phase alignment directly governs entanglement, decoherence, and information flow, the ability to modulate rotational strain introduces a powerful control mechanism for engineered quantum systems.

These predictions make the Holosphere Theory falsifiable in near-term experimental setups and provide a blueprint for new device classes based on coherence geometry.

8.1 Angular-Coherence Engineering

By designing systems that maintain or deliberately disrupt phase continuity across Holosphere-like domains, quantum engineers can create environments where coherence is either preserved or intentionally suppressed. This gives rise to:

- Quantum routers that guide entangled states through stable coherence channels.
- Tunable coupling layers in superconducting or photonic lattices using rotational geometry.
- Strain-controlled quantum dot arrays with coherence-based gating.

8.2 Strain-Gated Entanglement Routers

The coherence boundary defined by $|\delta\phi| \approx \epsilon_c$ acts like a switch for quantum communication. By mechanically modulating local angular tension, one can:

- Turn entanglement "on" or "off" between spatially separated qubits.
- Construct quantum logic gates activated by rotational strain thresholds.
- Implement secure channels that decohere under unauthorized physical stress.

8.3 Optical Rotation as Coherence Distortion

Holosphere theory offers a reinterpretation of optical effects in high-precision metrology:

- Angular rotation in fibers or materials introduces phase misalignment.
- Interferometric phase shifts may reflect not just path length but rotational strain. This coherence-based timing offset is analogous to the classical Shapiro delay in general relativity, where light experiences time delay in curved spacetime [**?**].
- Rotationally sensitive interferometers could detect coherence drift due to lattice anisotropy.

This reframes optical sensing as a probe of angular coherence—making interferometers useful for detecting coherence decay, not just classical displacement or phase delay.

8.4 Beyond Classical Decoherence Control

Traditional quantum error correction treats decoherence as stochastic noise. In contrast, the Holosphere model interprets decoherence as a geometric effect—providing a deterministic control lever. Future quantum systems may:

- Adjust coherence boundaries dynamically based on strain feedback.
- Encode logical states in rotationally phase-locked triplets immune to environmental perturbation.
- Develop topology-based protection schemes tied to angular strain invariants.

The model thus bridges the gap between foundational physics and experimental hardware, suggesting that geometry, strain, and coherence form the next frontier in quantum technology design.

In the concluding section, we summarize the key outcomes and outline future directions for simulation, falsification, and device implementation.

9 Conclusion

We have presented a coherence-based model of causality grounded in the Holosphere lattice framework, where spacetime is composed of discrete, rotationally coupled spheres. In this model, causal structure, temporal order, and entanglement dynamics emerge from the propagation of angular phase coherence and its degradation under strain.

Key contributions of this work include:

- The definition of *coherence shells*—light-cone analogs that expand at a finite speed v_ϕ, bounding causal influence via rotational alignment.
- The concept of *tension horizons* as boundaries of decoherence, providing a microphysical basis for information isolation and black hole-like behavior.
- Simulation-based prediction of anisotropic causal propagation, clock desynchronization, and directional time delays in strained lattice regions.
- Experimental proposals involving phase suppression and entanglement collapse under mechanical strain in superconducting circuits and optical systems.
- Practical applications such as angular-coherence quantum routers, strain-gated entanglement switches, and rotationally sensitive interferometry.

This coherence-driven perspective reframes time and causality not as abstract properties of spacetime geometry, but as measurable consequences of angular strain and phase connectivity. It offers a unified framework for explaining quantum decoherence, time asymmetry, and relativistic limits without requiring a continuous metric or nonlocal mechanisms.

Future work will focus on simulation of coherence propagation under varying topological constraints, development of entropy-clock synchronization metrics, and fabrication of prototype systems to test the strain-induced boundaries of quantum coherence. These directions will be explored in Papers 20–22, expanding the predictive power and experimental accessibility of the Holosphere model.

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Appendix A: Definitions and Terms

$\phi(x,t)$ Rotational phase of a Holosphere at position x and time t.

$\delta\phi(x,t)$ Rotational misalignment; the local angular phase gradient between adjacent Holospheres.

ϵ_c Critical phase misalignment threshold; coherence collapses when $\delta\phi \geq \epsilon_c$.

$\rho_d(x,t)$ Local density of rotational defects—topological disruptions in phase continuity.

v_ϕ Angular coherence propagation speed through the Holosphere lattice.

$T_{clock}(t)$ Entropy clock value; integrated rotational misalignment over a coherent region $\mathcal{R}$.

$\dot{T}_{clock}(t)$ Rate of entropy clock divergence; indicates local temporal density.

$R(t)$ Radius of causal coherence shell at time t; defines the lattice light cone.

$\vec{t}(x)$ Local arrow of time vector, defined by the steepest gradient of angular strain:

$$\vec{t}(x) = \frac{\nabla\delta\phi(x,t)}{|\nabla\delta\phi(x,t)|}$$

τ_{ent} Entanglement lifetime; time until phase drift exceeds coherence threshold between two sites.

γ Rotational diffusion coefficient; describes how angular strain equilibrates spatially.

α Defect amplification factor; governs misalignment growth due to ρ_d.

$\nabla\phi(x,t)$ Angular phase gradient field.

$\mathcal{R}$ Coherent spatial region over which entropy clocks or coherence integrals are evaluated.

Tension Horizon A boundary beyond which $\delta\phi \geq \epsilon_c$, and coherence propagation fails.

Coherence Shell Region of lattice within which phase continuity is preserved at time t; analog of a light cone.

Entropy Clock A localized subregion whose integrated misalignment T_{clock} tracks temporal progression.