Three Light Cones:
Coherence, Curvature, and Tension in the Mesh Model of Spacetime

Thomas Lock

April 3, 2025

Abstract

This paper introduces a unified causal structure derived from the Mesh Model of spacetime. By defining three distinct but interrelated cone structures—coherence, curvature, and tension—we offer a framework that replaces classical light cones with structure-dependent boundaries of influence, propagation, and geometry. This framework arises naturally from the interplay between coherent ripple dynamics, anisotropic mesh tension, and cumulative resistance to information flow. The result is a testable, mathematically grounded framework in which causal geometry emerges from structural coherence—offering compatibility with black hole thermodynamics, gravitational wave echoes, and field theoretic behavior.

Contents

1 Introduction: Why Three Light Cones?

In modern physics, the concept of a light cone is treated as a fundamental geometric structure. It defines the boundary between cause and effect, delineates the limits of influence, and structures the flow of time and information. In general relativity, light cones are embedded in spacetime curvature [1]; in quantum field theory, they define the domains of local commutativity through assumptions of microcausality [1]. And yet, for all their ubiquity, light cones are not derived from first principles—they are assumed.

Despite their central role, we do not yet know what light cones truly are. We know how they behave in mathematical formalisms. We know how they restrict the propagation of information. But we do not know what physical mechanism gives rise to them. What determines the shape of a light cone? What defines its boundary? What happens when the medium of spacetime itself becomes structured, anisotropic, or coherence-limited?

This paper offers a possible answer to those questions. Within the framework of the Mesh Model of spacetime [2], we explore the idea that light cones are not fundamental geometric boundaries, but emergent structures arising from ripple dynamics in a layered physical field. We show that causality—the ability for one event to influence another—can be modeled not as a postulate, but as a product of three interdependent structural elements: coherence, tension, and curvature.

We introduce three distinct but coupled cone structures:

- The **Coherence Cone**, which defines the boundary of influence through structured ripple propagation.
- The **Tension Cone**, which determines the direction and velocity of signal transmission through anisotropic stiffness in the mesh.
- The **Curvature Cone**, which captures accumulated resistance to coherent propagation—functionally equivalent to emergent geometric distortion.

Together, these cones reconstruct the role of classical light cones from the bottom up. They define causal structure not as an assumption, but as a consequence of physically measurable properties of the underlying field. This reconstruction does not negate relativity or field theory—instead, it demonstrates that their causal behavior may arise naturally from a deeper mechanism.

Our approach is inspired by the idea that spacetime structure and causal geometry may arise from deeper physical or informational processes—an idea with precedents in emergent gravity theories [3, 4], causal set theory [5], and twistor-based approaches to lightlike structure [6].

We emphasize that this is a demonstration of possibility. The specific forms, thresholds, and interactions of these cone structures are subject to observational validation and experimental refinement. Our aim is not to impose a new ontology, but to show that a structured, testable causal framework can be built from physical dynamics alone.

In doing so, we reconnect the geometry of spacetime with the physics of propagation. We shift the origin of causality from postulated invariants to ripple-structured coherence. And we suggest that the boundary between past and future may be a physical feature—not a coordinate artifact.

The sections that follow develop each cone structure in detail, explore their synthesis, and present testable predictions and mathematical formalisms. This is not a philosophical exercise. It is a mechanics paper—written to show how causality might actually work.

2 The Coherence Cone: Causal Flow from Structured Wave Propagation

Causality begins with coherence. In the Mesh Model, events do not influence one another through abstract metrics or instantaneous fields. They do so through the propagation of structured ripples—localized, directional coherence that travels across the mesh. The region accessible to this ripple flow defines the *Coherence Cone* [2, 7].

A coherence cone represents the boundary beyond which causal influence from an event cannot propagate, not because of spacetime curvature, but because the medium itself cannot support the structured wave required to carry influence. In this view, time is not a parameter; it is the direction in which coherence successfully propagates.

Structured Propagation and Causal Reach

To formalize this, we define a coherence vector field:

$$\vec{C}(x,t) = \nabla\phi(x,t) \cdot \chi(x,t) \tag{1}$$

where:

- $\phi(x,t)$ is the phase of a structured ripple at position x and time t.
- $\chi(x,t)$ is a coherence mask, taking values in $[0,1]$, which encodes whether the medium at that point can support phase-preserving propagation.
- $\vec{C}(x,t)$ thus encodes the local direction and magnitude of causal propagation potential.

The boundary where $\vec{C}(x,t) = 0$ defines the edge of causal influence. Events outside this boundary cannot yet be affected by the initiating ripple—they are outside the coherence cone.

This is not a light-speed limit imposed by relativity, but a structure-dependent boundary that varies with the properties of the mesh. In regions of high coherence, propagation is fast and isotropic. In disordered or damaged zones, coherence may decay rapidly, shrinking the cone.

Null-Like Behavior from Structured Fields

When the mesh is uniform and coherence is high, the ripple propagation naturally mimics null trajectories in Minkowski spacetime. The coherence cone becomes indistinguishable from the classical light cone. This is not imposed—it emerges as a limit of structured wave behavior in a tension-supported medium [8, 6].

Unlike light cones in general relativity, coherence cones can deform dynamically. They can narrow under stress, split under anisotropy, or collapse entirely if coherence fails. This makes them richer in behavior, but more physically grounded. They are not geometric constructs—they are the expression of the mesh's capacity to carry influence.

Physical Implications

By redefining causality as the product of ripple propagation, we relocate the source of time and influence to something physical: coherence. This has multiple implications:

- Time emerges locally as the direction of ripple coherence flow [9].
- Causality is bounded not by geometry, but by medium structure.
- Disrupting coherence leads to causal disconnection—analogous to horizon behavior without requiring a true event horizon [7].

The coherence cone thus provides the most direct physical definition of what it means for one event to be able to affect another. In the sections that follow, we will see how this structure interfaces with tension and curvature to form the full causal skeleton of the mesh.

3 The Curvature Cone: Emergent Geometry from Resistance to Flow

In traditional general relativity, curvature is a geometric distortion of spacetime caused by energy and momentum. But in the Mesh Model, curvature is not assumed as a metric deformation—it is defined physically as a structured resistance to coherent ripple propagation [2]. The *Curvature Cone* captures this resistance: it represents how causal propagation is delayed, redirected, or constrained by the accumulated loss of coherence across a region.

This cone does not arise from geometry; it gives rise to geometry.

Defining Coherence-Driven Resistance

We define the effective curvature along a path γ as the integral of coherence decay:

$$\mathcal{R}(x) = \int_\gamma (1 - \chi(x(s)))\, ds \tag{2}$$

where:

- $\chi(x)$ is the local coherence mask, as defined in Section 2.
- γ is a path through the mesh (typically along a coherence vector field).
- $\mathcal{R}(x)$ accumulates the structural resistance encountered by a ripple as it attempts to propagate.

When $\chi(x) = 1$ everywhere along γ, coherence is perfect and no resistance is accumulated. When $\chi(x) < 1$, coherence is partially lost, and curvature begins to emerge.

Cone Deformation Through Resistance

A curvature cone forms when paths of propagation are differentially delayed by inhomogeneous coherence. Unlike the coherence cone, which defines the reach of an undistorted ripple, the curvature cone defines how that ripple's path is redirected or warped due to varying structural resistance.

The resulting causal structure mimics gravitational lensing, redshift, and time dilation—not because space is curved, but because coherence has been increasingly degraded across the ripple's trajectory. To an observer measuring signal paths or delays, the result appears indistinguishable from metric curvature [4].

Emergent Geometry Without Metrics

Crucially, this model does not require a background spacetime metric. Instead, the resistance integral $\mathcal{R}(x)$ provides the basis for path distortion directly. Geometry becomes an emergent property of how coherence is shaped and resisted by the mesh [3].

This offers a conceptual inversion: in the Mesh Model, curvature does not cause signals to bend—resistance to coherence propagation is what defines curvature. This reorders the causal chain of classical relativity.

Implications for Time and Horizons

Because $\mathcal{R}(x)$ slows propagation in structured ways, it plays the role of time dilation. As resistance increases, propagation slows, signals stretch, and local time intervals expand relative to low-resistance regions. When $\mathcal{R}$ diverges, propagation halts completely, leading to causal bottlenecks or apparent horizons.

This mechanism suggests that event horizons may not require a true metric singularity—only a sufficiently steep resistance gradient in the mesh. Apparent horizons may arise dynamically, as coherence flow slows and curvature cones contract [7].

4 The Tension Cone: Signal Speed, Local Anisotropy, and Field Limits

The capacity of the mesh to carry information is not uniform. Local variations in structural tension alter both the direction and velocity of ripple propagation. These variations define the *Tension Cone*—a directional structure that governs how fast and in what directions causal signals can travel through a given region of the mesh [2].

Whereas the coherence cone defines where influence can reach, and the curvature cone determines how it is delayed or bent, the tension cone sets the rules of propagation itself: signal speed, directional preference, and anisotropic distortion.

Directional Speed from Tension

In the Mesh Model, the local propagation speed of a ripple is determined by the ratio of directional tension to effective mass density:

$$v^2(x) = \frac{T(x)}{\mu(x)} \quad \Rightarrow \quad \vec{v}(x) = \sqrt{\frac{T_{ij}(x)}{\mu}} \cdot \hat{n} \tag{3}$$

where:

- $T_{ij}(x)$ is the tension tensor—encoding how strongly the mesh resists deformation in different directions.
- μ is the local effective mass density of the medium.
- $\hat{n}$ is a unit vector in the direction of propagation.
- $\vec{v}(x)$ is the vectorial signal velocity for a ripple moving through point x.

This formulation generalizes the wave speed in elastic media. In isotropic regions, $T_{ij} = T\delta_{ij}$, and the tension cone becomes symmetric. In anisotropic regions, signal speed varies with direction—causing cone deformation [9].

This structure resonates with concepts in nonlinear field theories such as Born–Infeld electrodynamics, where maximum field strengths limit signal speed [10], and with modern ideas about upper bounds on force and tension in spacetime [11].

Tension Cone Geometry

The shape of the tension cone at a given point is defined by the set of directions in which $\vec{v}(x)$ exceeds a minimum threshold for coherent transmission. This defines a local boundary within which ripple-based causality can propagate effectively.

When tension is uniform, the tension cone is spherical. When tension is directional, the cone stretches, flattens, or tilts. This dynamic deformation is not abstract—it reflects the material structure of the mesh at that location.

Limits and Breakdown

Regions with very low or rapidly varying tension exhibit narrow or collapsing tension cones. These regions may effectively block ripple propagation, even if coherence is present. This provides a structural explanation for causal discontinuities and signal shadows without requiring spacetime singularities [7].

In extreme cases, the tension cone may become degenerate, supporting ripple propagation in only a few constrained directions. This produces directionally limited causal pathways—similar in character to Semi-Dirac dispersion seen in anisotropic condensed matter systems [8].

Functional Role

The tension cone provides the real-time transmission rulebook for the mesh. While the coherence cone defines what can be influenced, and the curvature cone dictates how influence is warped, the tension cone tells us *how* and *how fast* signals actually move.

Together, these three cone structures define the complete causal profile of a region. The next section will synthesize these layers into a unified model of structured causality.

5 Unifying the Cones: Causal Mesh Structure and the Illusion of Geometry

Each cone structure defined in the previous sections captures a different facet of causality in the Mesh Model. The coherence cone determines whether influence can propagate at all. The tension cone defines how and in which directions such propagation occurs. The curvature cone describes how that propagation is delayed, redirected, or bottlenecked by the structure of the medium.

Taken together, these cones define a composite causal boundary—what we call the *effective cone*:

$$\text{Cone}_{\text{effective}}(x) = f\left(\vec{C}(x), \vec{v}(x), \mathcal{R}(x)\right) \tag{4}$$

This expression is not a closed formula, but a functional synthesis. It reflects how coherence availability, propagation velocity, and accumulated resistance interact to define the actual causal limits from any event at point x [2].

From Local Structure to Emergent Causality

Unlike traditional light cones, the effective cone is not static, symmetric, or universal. It is a dynamic, local structure determined by the properties of the mesh at each point in space and time. In high-coherence, high-tension, low-resistance regions, the cone approximates the familiar null cone of flat spacetime. But in more complex regions, it deforms:

- If coherence vanishes, the cone disappears: causality cannot propagate.
- If tension is highly anisotropic, the cone stretches or compresses.
- If curvature accumulates strongly, the cone tilts, bends, or narrows.

This provides a physical explanation for both classical and exotic causal behaviors, from gravitational lensing to causal shadows to apparent horizons [7].

Causality Without Predefined Geometry

The Mesh Model thus reverses the standard picture: causal structure is not imposed by geometry—it creates it. The classical light cone is no longer an axiom of the spacetime manifold, but an emergent limit of ripple-based propagation in a structured field [3].

This unification bridges the gap between general relativity and quantum field behavior. GR's causal invariance arises in the limit of stable, high-tension, high-coherence mesh regions. QFT's field locality emerges from directional coherence patterns bounded by the tension cone [9]. And deviations from either—such as gravitational wave echoes, jet anisotropies, or black hole horizon dynamics—can now be seen as structural deformations of the effective cone [12, 13].

Toward a Structured Causal Geometry

What emerges from this synthesis is not a replacement for relativistic geometry, but a deeper scaffolding that can explain where its causal features come from. The effective cone unites:

- $\vec{C}(x)$: the availability of coherence (can information propagate?)
- $\vec{v}(x)$: the tension-governed velocity structure (how fast and where?)
- $\mathcal{R}(x)$: the accumulated curvature resistance (how distorted or delayed?)

These three together give a complete causal fingerprint for any region of the mesh.

In the sections that follow, we explore how this structured causality constrains entropy flow and information propagation, and how it leads to observable predictions.

6 Entropy and Information Boundaries

Causal boundaries are not just about whether influence can propagate—they also govern how much information can pass through a region. In the Mesh Model, entropy flow is constrained not by abstract spacetime surfaces, but by the structure of coherence and its divergence. Where coherence flow bottlenecks, so too does the flow of information [2, 9].

This section introduces a structural interpretation of entropy bounds, inspired by the Bousso bound [14, 15], but derived from the behavior of the coherence vector field itself.

Divergence of Coherence and Information Flux

Let $\vec{C}(x)$ denote the local coherence vector field as previously defined. The divergence of this field measures how coherence is converging or dispersing through a region. Where $\nabla \cdot \vec{C}(x)$ is high, coherence is spreading; where it is negative, coherence is converging or collapsing.

We propose the following bound on the maximum entropy flux through a surface Σ:

$$S_{\max} \leq \frac{1}{4} \int_{\Sigma} \left| \nabla \cdot \vec{C}(x) \right| dA \tag{5}$$

where:

- Σ is a surface bounding a region of the mesh.
- $\vec{C}(x)$ is the coherence vector field across the surface.
- The integrand reflects how much causal influence is entering or leaving the region.

This bound expresses the idea that entropy flow is limited by the structure's ability to carry coherent signals. When coherence is bottlenecked, so is information. Where the mesh cannot support structured propagation, entropy cannot pass.

Bousso Bound as a Structural Limit

In general relativity, the Bousso bound constrains entropy to be proportional to the surface area through which it flows, provided that light rays orthogonally leaving the surface are non-expanding [14]. In the Mesh Model, that expansion is replaced by coherence divergence.

This substitution reframes entropy as a flow problem—not through geometric null rays, but through ripple-permitting structure. Surfaces of minimal coherence divergence naturally limit the entropy that can be communicated across them. This offers a physical, testable basis for entropy bounds without requiring pre-assumed spacetime geometry.

Holography as a Structural Effect

If information is restricted by coherence gradients, then holographic behavior can emerge dynamically. In regions where coherence collapses sharply—such as near vacuum gradients or tension discontinuities—entropy may be restricted to flow along surfaces. This reproduces the effect of entropy being encoded on lower-dimensional boundaries, not as a metaphysical principle, but as a structural outcome [16, 17].

This perspective strengthens the connection between causal structure and information theory. It also suggests that holographic limits may vary depending on the anisotropy and coherence distribution of the mesh—a prediction that could be probed in astrophysical observations.

The next section explores how these causal and entropic structures may manifest in real-world phenomena.

7 Observational Predictions

The value of a physical model lies not only in its internal coherence, but in its ability to produce measurable consequences. The Mesh Model's causal structure—defined by coherence, tension, and curvature cones—offers new ways to interpret and predict astrophysical phenomena. This section outlines several observational domains where the effects of structured causality may become visible.

Gravitational Wave Echoes and Cone Reflections

In the Mesh Model, black holes do not terminate in singularities or event horizons, but in stable quantum cores surrounded by steep coherence gradients [7]. These gradients form a partially reflective barrier for ripple propagation—delaying or redirecting signal energy.

This structure gives rise to predicted *gravitational wave echoes* following black hole mergers. Unlike standard ringdowns in GR, where signals dampen quickly, the Mesh Model allows for secondary signals delayed by curvature-induced reflections within the vacuum gradient [12, 13].

The delay time and echo profile are determined by the effective curvature cone:

- Steeper coherence gradients $\rightarrow$ greater $\mathcal{R}(x)$ $\rightarrow$ longer delays.
- Tension anisotropy $\rightarrow$ directional echo strength variations.

Detecting such echoes—and mapping their structure—would provide indirect access to the shape and transmissivity of the cone structure near collapsed cores.

Black Hole Radiation via Coherence Tunneling

The Mesh Model replaces Hawking radiation's pair-production mechanism with a tunneling process across coherence barriers. A ripple near a steep vacuum gradient may escape if it tunnels through the resistance defined by $\mathcal{R}(x)$ [7].

The tunneling rate is approximated by:

$$\Gamma \sim \exp\left(-\frac{\Delta\mathcal{R}}{\hbar}\right) \tag{6}$$

where $\Delta\mathcal{R}$ is the resistance difference across the vacuum shell.

This process preserves unitarity and emits radiation without invoking event horizons. It also naturally leads to spectrum scaling similar to Hawking's prediction in the large-mass limit [18]. Observing deviations in radiation from compact objects—especially spectrum shifts or anisotropies—could test this mechanism.

Jet Alignment and Anisotropic Tension Cones

The Tension Cone predicts that in strongly spinning systems, anisotropy in mesh tension should define preferred pathways for ripple propagation [8, 2]. This provides a structural explanation for the alignment of relativistic jets in active galactic nuclei and microquasars.

Rather than requiring an ergosphere and magnetic field alone, the Mesh Model suggests that:

- Jets align with maximal-tension axes within the mesh.
- Coherent ripple pathways form channels through which energy preferentially escapes.

This prediction can be tested by comparing observed jet structures with spin-induced tension patterns inferred from gravitational lensing and disk alignment data.

Quasinormal Modes and Horizon Deformation

The vibrational signatures of compact objects—quasinormal modes (QNMs)—should reflect the structure of the effective cone system surrounding them. If a collapsing object lacks a true horizon but forms a steep vacuum gradient, then its QNMs will differ subtly from GR expectations [7].

Specifically:

- QNM damping times may lengthen due to delayed propagation through the curvature cone.
- Mode frequencies may shift if tension cone anisotropy alters effective wave speeds.

Precision QNM measurements from LIGO, Virgo, and future detectors may therefore serve as probes of cone geometry around compact cores.

Toward Experimental Hardening

All of these predictions depend on the shape and interaction of coherence, tension, and curvature in the mesh. The structures proposed in this paper are physically grounded, but their specific thresholds and forms require validation.

The strength of the Mesh Model lies in its testability. As gravitational wave astronomy, high-resolution black hole imaging, and compact object spectroscopy improve, the ability to probe cone structure directly increases.

This paper provides the framework. The data will decide its form.

8 Mathematical Framework

This section summarizes the key mathematical structures used to define and unify the three cone types—coherence, tension, and curvature. These expressions represent a transition from geometric postulates to physically grounded field dynamics. They offer a substrate from which classical causal behavior emerges as a limiting case [2, 9].

1. Coherence Vector Field

The coherence vector field describes the structured flow of ripple-based influence:

$$\vec{C}(x,t) = \nabla\phi(x,t) \cdot \chi(x,t) \tag{7}$$

Where:

- $\phi(x,t)$ is the ripple phase field (analogous to a potential or phase gradient).
- $\chi(x,t) \in [0,1]$ is a coherence mask—1 where propagation is fully supported, 0 where coherence fails.
- $\vec{C}(x,t)$ defines the local causal direction and strength of influence.

The coherence cone is defined by the region where $\vec{C}(x,t)$ is non-zero and structurally supported.

2. Tension-Dependent Signal Speed

Local signal propagation speed is derived from the tension tensor field:

$$v^2(x) = \frac{T(x)}{\mu(x)} \quad \Rightarrow \quad \vec{v}(x) = \sqrt{\frac{T_{ij}(x)}{\mu}} \cdot \hat{n} \tag{8}$$

Where:

- $T_{ij}(x)$ is the directional tension tensor at point x.

- μ is the effective mass density of the mesh medium.
- $\hat{n}$ is the intended propagation direction.
- $\vec{v}(x)$ defines the local anisotropic ripple velocity.

This structure generalizes classical field propagation in elastic media and shares conceptual roots with Born–Infeld theory, where tension limits and signal propagation constraints naturally arise [10, 11].

3. Accumulated Curvature Resistance

Curvature is defined as an integral measure of coherence decay across a path γ:

$$\mathcal{R}(x) = \int_{\gamma} (1 - \chi(x(s)))\, ds \tag{9}$$

Where:

- γ is a path (typically along $\vec{C}$).
- $\chi(x)$ is the coherence mask along that path.
- $\mathcal{R}(x)$ quantifies the total resistance to coherent propagation.

This accumulated resistance deforms propagation paths and mimics gravitational curvature in the limit [7].

4. Unified Effective Cone Function

The effective causal cone combines the above structures into a single functional description:

$$\text{Cone}_{\text{effective}}(x) = f\left(\vec{C}(x), \vec{v}(x), \mathcal{R}(x)\right) \tag{10}$$

This is a generalized causal boundary—shaped by local coherence, propagation speed, and resistance. It replaces geometric null cones with a physically emergent causal frontier [2].

5. Entropy Bound from Coherence Divergence

Information flow is bounded by the divergence of coherence vectors:

$$S_{\max} \leq \frac{1}{4} \int_{\Sigma} \left| \nabla \cdot \vec{C}(x) \right| dA \tag{11}$$

Where:

- Σ is a surface bounding the causal region.
- $\nabla \cdot \vec{C}$ quantifies the bottleneck in coherence flow.

This structurally reproduces the Bousso bound [14, 15], traditionally defined in terms of null expansion, but here derived from ripple-capable structure.

6. Horizonless Tunneling Radiation

Black hole radiation is described as tunneling through a coherence barrier:

$$\Gamma \sim \exp\left(-\frac{\Delta\mathcal{R}}{\hbar}\right) \tag{12}$$

Where $\Delta\mathcal{R}$ is the resistance difference across the vacuum gradient. This replaces Hawking's geometric horizon formalism with a mechanism rooted in structured propagation [7, 18].

Summary

These equations establish a physically structured foundation for causal dynamics. They remove the need for spacetime curvature as a postulate and replace it with a field-based model of influence and resistance. Geometry, in this view, is the result of ripple behavior in a real, structured mesh.

9 Conclusion: A New Causal Geometry for a Structured Universe

This paper has introduced a physical framework for causal structure grounded not in abstract spacetime geometry, but in the real dynamics of a structured field—the Mesh. By defining three interacting cone structures—coherence, tension, and curvature—we have shown that it is possible to reconstruct the core features of light cones, causal boundaries, and information flow from first principles [2].

These cones are not imposed; they emerge. The coherence cone defines where causal influence can propagate. The tension cone determines how that influence moves through the medium. The curvature cone captures how propagation is distorted by resistance and structure. Together, they form an effective causal cone that reproduces, and in some cases extends, the predictive power of traditional light cones.

This approach does not seek to overthrow relativity or quantum field theory. Rather, it offers a new layer beneath them—one in which their causal rules emerge as limiting cases of deeper physical behavior. It restores the possibility that causality is not a principle, but a process—one that unfolds through coherence, structure, and resistance [4, 3].

We emphasize again: this is a demonstration of possibility, not a declaration of finality. The specific forms of the cone functions, the thresholds for coherence breakdown, and the behavior of ripple propagation under extreme conditions all require experimental hardening. The Mesh Model offers a scaffold—a causal skeleton waiting to be clothed in observational data [12, 13].

As gravitational wave astronomy, high-resolution black hole imaging, and field measurements improve, so too will our ability to test these ideas. The framework presented here suggests that causality itself may one day be observed—not just inferred.

If this is true, then geometry is no longer the starting point of physics. Structure is. And from structure, time, causality, and information flow may all arise.

Finally, for those familiar with wave physics, materials science, or oceanography, the patterns described here may feel familiar. Coherence cones resemble ripple fronts. Tension cones behave like wavefronts in depth-varying media. Curvature cones reflect accumulated resistance to signal transmission. These analogies were not used to construct the model—but their alignment suggests that the Mesh Model is not a speculative fiction. It is grounded in physical intuition drawn from the real world.

References

[1] R. F. Streater and A. S. Wightman. *PCT, Spin and Statistics, and All That*. W. A. Benjamin, New York, 1964.

[2] Thomas Lock. The mesh model: A dual-field framework for emergent geometry, gravity, and quantum behavior. *Unpublished Manuscript*, 2025. April 2, 2025.

[3] Andrei D. Sakharov. Vacuum quantum fluctuations in curved space and the theory of gravitation. *Soviet Physics Doklady*, 12:1040–1041, 1968.

[4] Ted Jacobson. Thermodynamics of spacetime: The einstein equation of state. *Physical Review Letters*, 75:1260–1263, 1995.

[5] Luca Bombelli, Joohan Lee, David Meyer, and Rafael D. Sorkin. Space-time as a causal set. *Physical Review Letters*, 59:521–524, 1987.

[6] Roger Penrose. Twistor algebra. *Journal of Mathematical Physics*, 8(2):345–366, 1967.

[7] Thomas Lock. Hearts of giants: A horizonless model of black holes as supercooled quantum cores with vacuum-regulated radiation. *Unpublished Manuscript*, 2025. April 2, 2025.

[8] Thomas Lock. Coherence phase space: A structural classification framework for particles in the mesh model. *Unpublished Manuscript*, 2025. April 3, 2025.

[9] Thomas Lock. Integrating the mesh model with general field theory. *Unpublished Manuscript*, 2025. April 2, 2025.

[10] Max Born and Leopold Infeld. Foundations of the new field theory. *Proceedings of the Royal Society A*, 144:425–451, 1934.

[11] G. W. Gibbons. The maximum tension principle in general relativity. *Foundations of Physics*, 32(12):1891–1901, 2002.

[12] Jahed Abedi, Hannah Dykaar, and Niayesh Afshordi. Echoes from the abyss: Tentative evidence for planck-scale structure at black hole horizons. *Physical Review D*, 96(8):082004, 2017.

[13] Vitor Cardoso and Paolo Pani. Tests for the existence of black holes through gravitational wave echoes. *Nature Astronomy*, 1:586–591, 2017.

[14] Raphael Bousso. A covariant entropy conjecture. *Journal of High Energy Physics*, 07:004, 1999.

[15] Raphael Bousso. The holographic principle. *Reviews of Modern Physics*, 74(3):825–874, 2002.

[16] Jacob D. Bekenstein. Black holes and entropy. *Physical Review D*, 7(8):2333–2346, 1973.

[17] Don N. Page. Information in black hole radiation. *Physical Review Letters*, 71:3743–3746, 1993.

[18] Stephen W. Hawking. Particle creation by black holes. *Communications in Mathematical Physics*, 43(3):199–220, 1975. Erratum: Comm. Math. Phys. 46, 206 (1976).