Photon Tunneling and Entropy-Neutral Conduits in the Space-Time Fluid Model

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Posted Date: 27 June 2025

doi: 10.20944/preprints202506.2279.v1

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 doi:10.20944/preprints202506.2279.v1

Article

Photon Tunneling and Entropy-Neutral Conduits in the Space-Time Fluid Model

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Abstract

We propose that photons propagate through space-time not by traversing the medium itself, but via transient, self-generated entropy-neutral tunnels. These pressure-free conduits allow photons to bypass gravitational curvature, entropy gradients, and fluid tension—preserving the constancy of the speed of light across all reference frames. Unlike massive objects, which displace the space-time fluid and generate curvature through persistent pressure gradients, photons form dynamically maintained, null-time tunnels that leave no trace or deformation in the surrounding medium. This model provides a mechanistic basis for null geodesic behavior, reconciling light-speed invariance with a compressible, thermodynamic fluid interpretation of space-time. It further explains the coherence, entanglement, and phase stability of photons in curved space-time by treating the tunnel interior as causally flat and entropy-isolated. We show how this tunneling structure parallels wormhole physics and aligns with the ER=EPR framework, suggesting a geometric origin for entanglement. Observable predictions include curvature-induced birefringence, quantized spectral phase shifts, and gravitational lensing anomalies—all of which are experimentally testable. This work advances a unified, fluid-dynamical description of light propagation, causal structure, and quantum coherence.

Keywords: space-time fluid model; photon tunneling; entropy-neutral conduit; wormhole analog; light-speed invariance; entanglement geometry; ER=EPR; null geodesic; gravitational lensing; quantum coherence

1. Introduction

The foundational premise of the space-time fluid model is that all gravitational, thermodynamic, and quantum behaviors emerge from the pressure, tension, and entropy dynamics of a compressible space-time medium. In this framework, mass generates localized depressions in the fluid — displacing the medium, slowing entropy flow, and curving trajectories. This has been shown to reproduce gravitational attraction, relativistic time dilation, and orbital mechanics with high fidelity.

However, photons — unlike massive particles — propagate at a constant speed regardless of gravitational curvature, fluid density, or relative motion. This raises a core question: how does a photon maintain velocity c in a medium that resists and curves under the influence of energy?

We propose a refinement to the fluid model by introducing the concept of entropy-neutral conduits: transient, self-generated pressure-free tunnels through which photons travel without interacting with the surrounding medium. Unlike masses, which impose persistent stress on the fluid, photons momentarily carve a self-contained path — eliminating drag, avoiding curvature, and bypassing entropy divergence.

This paper formalizes the structure, behavior, and implications of such tunnels, reconciling photon propagation with fluid dynamics and demonstrating how light maintains constant velocity in a deformable medium.

Motivation: Why Photons Require a Separate Mechanism

 doi:10.20944/preprints202506.2279.v1

In the fluid model, all motion and interaction are mediated by pressure gradients and entropy flow. Massive objects displace the fluid, resulting in inward tension — perceived as gravity. As shown in prior work, this displacement persists and induces curvature, which slows time via entropy suppression.

Yet photons, which carry energy but no rest mass, experience none of the following:

- No acceleration due to gravity (they follow null geodesics)
- No time passage (proper time along the path is zero)
- No rest frame (velocity is invariant and absolute)

If photons behaved like fluid-bound wave packets, they would slow in high-curvature zones due to increased fluid tension. But empirical evidence — from gravitational lensing, redshift consistency, and quantum interference — shows that photons maintain their speed and coherence even near black holes.

Therefore, their motion cannot be modeled as propagation through a resistive fluid, nor as curvature-induced deviation alone. Instead, we postulate that the photon *modifies* the fluid medium differently: not by bending or compressing it, but by temporarily nullifying it — tunneling through a cavity of zero pressure and entropy flux.

This conduit is:

- Directional and transient
- Entropy-neutral ($\nabla \cdot \vec{S} = 0$)
- Closed behind the photon, leaving no trace or deformation

In effect, the photon does not traverse curved space-time — it bypasses it through an instantaneously self-created wormhole-like tunnel. This model preserves all known optical behaviors while eliminating inconsistencies with fluid drag or entropy interaction.

2. Distinction Between Mass and Photonic Interaction with Space-Time

In the fluid dynamics model of space-time, all physical interactions are reinterpreted as local or non-local responses of the medium to embedded structures. To unify gravity, thermodynamics, and quantum behavior, it is essential to classify how different entities — mass-bearing objects and massless photons — interact with this fluid substrate.

Mass and photons both influence the space-time fluid, but they do so in categorically distinct ways:

- Mass persistently displaces the fluid, creating long-lived depressions in pressure and curvature that warp nearby flow lines.
- Photons do not compress, bend, or leave a wake in the fluid. Instead, they open zero-entropy tunnels through which they propagate without resistance or deformation.

This distinction is critical not only for reconciling light-speed invariance with fluid dynamics but also for understanding causality, entropy, and non-local quantum effects in a unified physical framework.

2.1. Mass: Persistent Curvature and Fluid Displacement

A massive object, whether a planet or particle, acts as a static void in the space-time fluid. Its presence pushes the medium outward, resulting in:

- A radial inward pressure gradient
- A surrounding flow of the fluid into the hollow
- A stable curvature field, generating gravitational attraction

This behavior is well-characterized by the equation:

$$\vec{a} = -\frac{1}{\rho}\nabla p$$

 doi:10.20944/preprints202506.2279.v1

where:

- $\vec{a}$ is the gravitational acceleration experienced by nearby objects,
- ρ is the local fluid density,
- ∇p is the spatial pressure gradient.

In this formulation, gravity is the manifestation of the fluid's mechanical response to displaced volume — it is not a force of intrinsic attraction but a pressure restoration process [Jacobson, 1995] [4]. The hollow created by mass also disrupts entropy flow, slowing time locally. This matches the observed gravitational time dilation and curvature dynamics from general relativity.

Masses, therefore, induce sustained modifications in both pressure and entropy geometry of the space-time medium.

2.2. Photons: Instantaneous Tunneling and Zero Displacement

Photons, in contrast, do not displace or deform the fluid in a persistent way. They carry energy but no rest mass, and their passage through the medium does not leave a curvature trace. The key observations motivating a distinct mechanism are:

- Photons move at the same speed in all reference frames
- They follow null geodesics with zero proper time [Einstein, 1915] [1]
- Their trajectories bend near mass, but without acceleration or time loss
- They are immune to entropy suppression, despite traveling through curved zones

We resolve this behavior by proposing that photons do not traverse the medium in the traditional sense. Instead, they:

1. Create a transient, narrow tunnel in the fluid
2. This tunnel is a pressure-neutral, entropy-free channel
3. The photon exists entirely within this tunnel during its motion
4. Once passed, the tunnel collapses without residue

The entropy flux across the tunnel walls is zero:

$$\nabla \cdot \vec{S} = 0$$

where $\vec{S}$ is the entropy current vector. This ensures that time does not "flow" for the photon — it bypasses entropy evolution entirely, consistent with its null time experience.

The tunnel is not a deformation of the fluid but a temporary void — a microscopic wormhole with no gravitational potential, no drag, and no interaction with surrounding flow. Unlike mass, the photon's tunnel is self-contained, coherent, and erases itself as the photon advances.

2.3. Summary Table: Mass vs. Photon Fluid Interaction

Property	Mass	Photon
Fluid Interaction	Displaces fluid	Tunnels through fluid
Pressure Effect	Creates sustained gradient	Carves zero-pressure channel
Curvature	Generates persistent curvature	Experiences no intrinsic curvature
Entropy Divergence	Positive ∇·S → Time slows	Zero ∇·S → No time passage
Wake or Deformation	Yes	None
Light Speed Influence	Slows due to tension/drag	Maintains constant c

3. Tunneling Mechanism of Photon Propagation

 doi:10.20944/preprints202506.2279.v1

If photons are to remain consistent with the fluid-dynamic interpretation of space-time, their propagation must be re-expressed not as movement through a resistive medium, but as a traversal via a self-generated, entropy-free tunnel. This section develops a precise model for that tunneling behavior and its consequences.

The photon is proposed not as a particle embedded in the fluid, nor as a wave traversing a tensioned lattice, but rather as an autonomous conduit — a fleeting, zero-pressure hollow that extends in its direction of motion. This structure does not bend the medium but briefly removes it, forming a tunnel with the following key properties:

- No net displacement of fluid
- No friction, resistance, or curvature accumulation
- Entropy flow divergence equals zero throughout the conduit
- Tunnel structure collapses instantly behind the photon

This concept is neither metaphorical nor purely analogical. It represents a physical claim: that the photon's motion is enabled by a transient wormhole-like structure — a self-generated cavity within the space-time fluid that nullifies the usual effects of curvature and tension.

3.1. Conceptual Basis of the Tunnel

Analogy: Bubble vs. Tunnel

To visualize the difference between massive and massless motion in the fluid, consider a liquid medium (e.g., water):

- A rock placed in the fluid displaces volume, creating a stable depression; nearby objects roll inward due to the surrounding fluid pressure — this is how mass creates gravity.
- A photon, on the other hand, is like a narrow, elongated bubble that appears just ahead of its position and vanishes immediately after — it doesn't disturb the surrounding fluid beyond the minimal path it consumes.

The bubble analogy breaks down in three ways that the tunnel analogy fixes:

1. A bubble rises due to buoyancy — the photon does not.
2. A bubble displaces fluid volume — the tunnel leaves no residual curvature.
3. A bubble can persist — the photonic tunnel is purely dynamic and collapses instantly.

The better analogy is that of a *quantum wormhole throat* or *Planck-scale pressure void* — a momentary conduit that exists only as long as the photon propagates.

3.2. Mathematical Constraint: No Net Fluid Displacement

Let us define the local fluid pressure as $p(x,t)$, and assume the tunnel has a core radius r_0 and length ℓ, moving at velocity c. For a stable, entropy-neutral conduit, we require:

$$\int_V \nabla \cdot \vec{v}\, dV = 0 \Rightarrow \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

Given the photon leaves no residual curvature or energy gradient in the fluid, we enforce:

$$\frac{\partial p}{\partial x} = 0, \nabla \cdot \vec{S} = 0$$

Thus, no net force, mass, or entropy is displaced across the tunnel volume. The photon's movement becomes a *topological transition* in the fluid — a zero-volume, zero-divergence conduit propagating at constant speed.

3.3. Entropy Flow and Null Time Evolution

 doi:10.20944/preprints202506.2279.v1

Time, in the fluid model, arises from entropy divergence. For the photon, the entropy current $\vec{S}$ remains entirely parallel to the motion vector, and its divergence vanishes:

$$\nabla \cdot \vec{S} = 0 \Rightarrow \frac{d\tau}{dt} = 0$$

This matches the behavior of a null geodesic in general relativity — zero proper time — but now with a mechanistic explanation: the photon does not experience time because it does not *generate* entropy. The tunnel has no entropy exchange, no irreversible deformation, and thus no clock ticks internally.

This entropy-neutral mechanism also ensures causal preservation: the photon cannot transfer information within its own frame because its tunnel has no internal thermodynamic history.

3.4. Tunnel Collapse and Reinstatement of the Medium

As the photon advances, the tunnel it forms collapses behind it. This collapse must be frictionless and reversible to prevent energy dissipation. The process is governed by:

- Instantaneous restoration of fluid pressure
- Closure of entropy pathlines
- Re-embedding of surrounding flow field with zero memory

This is not unlike the behavior of quantum wavefunction collapse — the spatial domain reverts to baseline once the quantum packet has moved through. Similarly, the photon leaves behind no gravitational wake, no entropy deformation, and no disturbance of nearby particles — unless directly absorbed or scattered.

4. Energy, Pressure, and the Null Structure of the Tunnel

In the fluid dynamics framework of space-time, energy is not simply a scalar quantity but an active agent that shapes and modulates the behavior of the fluid. Mass-energy curves the medium via pressure displacement, while entropy flow governs temporal dynamics. The photonic tunnel challenges this picture by representing a form of energy propagation that neither compresses the medium nor generates time.

This section formalizes the properties of the photonic conduit — a structure defined by zero internal pressure, null entropy flow, and constant velocity — and shows how it carries energy without disturbing the surrounding space-time fluid.

4.1. Energy Without Compression

Photons carry energy given by:

$$E = h\nu \qquad \text{[Planck, 1900] [2]}$$

Yet in the fluid model, energy is typically associated with curvature, stress, or tension in the medium. The photon, however, transmits energy without curvature — it transfers no pressure to the surrounding fluid. This leads us to a remarkable conclusion:

$$\frac{dp}{dE} = 0 \text{(within the tunnel)}$$

That is, the photon's energy does not map onto pressure-induced curvature or fluid compression. Instead, energy in this case exists as a *topological configuration* — a null-entropy state that moves through the fluid while keeping it locally unperturbed.

 doi:10.20944/preprints202506.2279.v1

In conventional terms, this is equivalent to saying the photon carries energy in a way that cannot be "felt" by the fluid unless it is absorbed. The tunnel's boundary is insulated from entropy gradients and does not conduct force — only internal coherence.

4.2. Tunnel Interior: Zero Pressure and Tension-Free Geometry

The internal structure of the tunnel is governed by two boundary conditions:

1. Pressure-free constraint:

$$p_{\text{interior}} = 0$$

2. Entropy flux cancellation:

$$\nabla \cdot \vec{S} = 0$$

These conditions ensure that:

- No inward tension exists along the tunnel axis
- No entropy accumulates within the tunnel
- The geometry of the tunnel is flat (Minkowskian) regardless of external curvature

This structure is dynamically maintained by the photon as it propagates. From the viewpoint of the fluid medium, the tunnel is indistinguishable from a transient cavity of *zero causal depth* — no information enters or leaves across its boundaries except at the entry and exit points.

4.3. Null Vector Structure: Photon as a Self-Contained Propagator

In general relativity, the photon follows a null geodesic defined by:

$$g_{\mu\nu}k^{\mu}k^{\nu} = 0$$

In the fluid model, this null property emerges as a result of the tunnel's pressure and entropy configuration. The tunnel is a self-propagating entity where:

- The 4-velocity of the photon cannot be locally defined (no rest frame)
- The energy-momentum tensor inside the tunnel satisfies:

  $T^{\mu\nu}_{\text{tunnel}} = 0$

  (except at boundary points of interaction)

Thus, the photonic tunnel is null in every thermodynamic and geometric sense:

- No mass
- No tension
- No entropy exchange
- No internal curvature

This explains why the photon cannot be slowed, diverted by drag, or decohered by turbulence in the fluid. It does not interact with the fluid — it bypasses it.

4.4. Energetic Coherence and Wave Properties

While the tunnel lacks pressure and entropy, it does support internal coherence — the oscillatory structure of the electromagnetic wave:

$$E(t) = E_0 \sin(2\pi\nu t), B(t) = B_0 \sin(2\pi\nu t)$$

These fields are not propagated *through* the fluid but *within* the tunnel. This preserves polarization, frequency stability, and phase coherence even in regions of high external curvature — aligning with observed behavior of light near massive bodies.

Because the tunnel's refractive index is effectively unity regardless of ambient curvature, light always moves at c, without frequency shift due to local drag. Redshift and blueshift arise only from entry/exit point differentials — not from the tunnel's interior, which remains causally flat.

 doi:10.20944/preprints202506.2279.v1

4.5. Summary: Null Conduit as Carrier of Energy Without Geometry

In this model, the photon's energy travels without mass, pressure, or entropy cost. The tunnel it generates is a topologically null, tensionless, entropy-free path through space-time fluid — distinct from curvature-based paths of mass or field gradients.

This resolves longstanding paradoxes about how photons maintain constant speed and coherence in a dynamic, curved, and potentially dissipative medium.

5. Implications for Light-Speed Constancy

One of the most counterintuitive features of modern physics is the invariance of the speed of light across all inertial reference frames. Special relativity postulates this as a fundamental axiom, and it has been confirmed in numerous experiments — from the Michelson–Morley interferometer [Michelson & Morley, 1887] [3] to modern-day particle accelerators and GPS synchronization.

But within a fluid framework, where all entities are embedded in and interact with a medium, this presents a challenge: how can light maintain a constant speed, regardless of fluid tension, pressure gradients, or observer motion?

The photonic tunnel model provides a mechanistic answer: photons do not travel through the fluid; they tunnel across it via entropy-free conduits that render local conditions irrelevant. These tunnels, being pressure-neutral and tensionless, ensure the velocity of light remains constant — not as an arbitrary rule, but as a structural consequence of the tunnel's topology.

5.1. Independence from Ambient Pressure or Flow

In classical fluid mechanics, a wave or object traveling through a medium will interact with that medium, leading to:

- Resistance due to viscosity
- Refraction due to density gradients
- Speed dependence on compressibility

However, the photon bypasses these effects by carving a path that removes the fluid from its trajectory. This ensures:

$$v_{\text{photon}} = c = \text{constant}, \forall\, \rho(x), p(x), v_{\text{fluid}}(x)$$

Thus, the speed of light is independent of:

- The observer's velocity relative to the fluid
- The local fluid density or pressure
- The curvature or tension field surrounding the photon

This explains why gravitational lensing affects the *path* but not the *speed* of light: the photon's tunnel redirects its endpoint via entry/exit angle, but within the tunnel, the velocity remains invariant.

5.2. Entropy Isolation and Temporal Decoupling

Since time in this model is the divergence of entropy ($\nabla \cdot \vec{S}$), any system isolated from entropy exchange is temporally inert. For the photon tunnel:

$$\nabla \cdot \vec{S} = 0 \Rightarrow \frac{d\tau}{dt} = 0$$

This not only prevents time passage within the tunnel, but also ensures there is no external time gradient influencing the photon's motion. From this, we conclude:

- No Doppler effect arises within the tunnel itself — shifts occur only at emission or detection points

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- The photon does not "age" or accumulate history
- Tunnel geometry enforces causality without temporal inertia

5.3. Lorentz Invariance as a Fluid-Tunnel Symmetry

In special relativity, Lorentz invariance implies that the laws of physics — including the speed of light — are the same in all inertial frames. In our model, this emerges naturally from the tunnel's construction:

- The tunnel is entropy-neutral: no thermodynamic gradient can define a preferred frame
- The tunnel's structure is topologically null: it does not alter space-time metrics
- The photon always moves at c relative to the endpoints of the tunnel, which are embedded in the fluid

This implies that Lorentz symmetry is not a geometric property of space-time per se, but a dynamical constraint enforced by the photon's interaction with the fluid: the tunnel formation selects only those paths that preserve c as an invariant.

5.4. Compatibility with Experimental Results

This model reproduces key observational facts:

- In GPS satellites, time dilation is applied to massive clocks; photons used for communication require no such adjustment — they remain consistent across frames
- In LIGO interferometry, gravitational waves stretch the arms of the detector, but light within those arms maintains constant phase velocity — again consistent with a fluid-free conduit
- In gravitational redshift (Pound–Rebka), the frequency shifts at emission and absorption — not during propagation, consistent with boundary-effect tunneling [Pound & Rebka, 1959] [8]

Hence, all empirical phenomena that appear to "assume" light's invariance are now explained mechanically as effects of a pressure-free, entropy-neutral, self-generated tunnel in the space-time fluid.

6. Link to Wormhole Physics and ER=EPR

The concept of photons tunneling through self-generated, entropy-neutral conduits closely parallels another foundational idea from modern theoretical physics: that of wormholes, or Einstein–Rosen bridges. In general relativity, a wormhole is a topological shortcut connecting two distant regions of space-time. In quantum gravity, this idea has taken on a new role — particularly in the ER=EPR conjecture — where entanglement and geometric connection are deeply intertwined.

In this section, we demonstrate how the photonic tunnel can be interpreted as a micro-wormhole-like structure — not just metaphorically, but geometrically and causally. We also explore its implications for quantum entanglement, teleportation, and information flow in curved space-time.

6.1. Einstein–Rosen Bridges as Topological Shortcuts

In classical general relativity, Einstein and Rosen (1935) showed that the Schwarzschild metric contains a second asymptotically flat region, connected by a throat-like geometry — a non-traversable wormhole [Einstein & Rosen, 1935] [5]. Later, solutions involving exotic matter suggested the possibility of traversable wormholes, albeit with stability and causality issues.

In our fluid model, the photon tunnel:

- Has zero proper length internally (null geodesic)
- Connects two space-time events causally
- Allows energy transfer without traversing curved external geometry
- Requires no exotic matter — the tunnel exists only transiently and self-annihilates

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Therefore, the photonic conduit is a *natural, entropy-neutral, transient wormhole* that preserves causality and resolves light-speed invariance by short-circuiting curved geometry without violating energy conditions.

6.2. ER=EPR and Quantum Entanglement

The ER=EPR conjecture, proposed by Maldacena and Susskind (2013) [Maldacena & Susskind, 2013] [6], posits that two entangled particles are connected by a non-traversable wormhole. In this view, entanglement is not merely an abstract Hilbert space correlation, but a literal geometric bridge in space-time.

This aligns well with the photon tunnel model:

- Entangled photons may co-generate overlapping or conjugate tunnels
- These tunnels maintain zero-entropy, non-local correlation despite spatial separation
- The geometric bridge (tunnel) enforces coherence without information transfer through classical space

Thus, entanglement becomes a manifestation of *synchronized tunnel geometry*, where two endpoints share boundary conditions of an extended entropy-neutral structure. Collapse of one tunnel endpoint (via measurement) instantaneously resolves the entire structure, not due to faster-than-light signaling, but because the tunnel is causally unified.

6.3. Implications for Quantum Teleportation

Quantum teleportation experiments — in which the state of one particle is transmitted to another via entanglement [Scully et al., 1991] [14] and classical communication — require:

1. Pre-established entanglement
2. A Bell-type measurement
3. Collapse and reconstruction of quantum state elsewhere

If photon tunnels are wormhole-like structures, then teleportation can be reinterpreted as:

- Collapse of one end of an entropy-neutral tunnel
- Classical signal triggering the opening of a compatible tunnel endpoint elsewhere
- The state re-emerging without having traveled through space-time fluid

This model allows us to explain quantum teleportation in purely geometric-fluid terms, without invoking paradoxes of information transfer through curved or noisy media.

6.4. Causality, Tunneling, and Temporal Consistency

One might worry that tunneling structures allowing instantaneous communication could violate causality. However, the photon tunnel adheres to:

- Local light cones at endpoints (entry/exit occurs at classical c)
- Internal structure being null (no proper time, no space)
- Entropy conservation across full process

Therefore, there is no violation of relativistic causality. The tunnel simply bypasses entropy-rich space-time by invoking a path where entropy and curvature vanish — a mechanism already latent in the null geodesic formalism.

6.5. Micro-Wormholes and Topological Foam

In quantum gravity (e.g., Wheeler's space-time foam model) [Wheeler, 1957] [7], the fabric of space-time is thought to be riddled with Planck-scale wormholes. The photonic tunnel model fits into this paradigm as:

- A macroscopic expression of transient topological defects
- An entropy-invariant path through Planck-scale curvature

 doi:10.20944/preprints202506.2279.v1

- A dynamically regulated foam throat that opens and closes with each photon event

Thus, photons may be nature's only known example of stable, reversible, entropy-free wormhole traversal — explaining their invariance, coherence, and non-local entanglement behaviors.

7. Observable Predictions

A scientific theory gains robustness when it leads to falsifiable predictions. The fluid-dynamic tunnel model of photon propagation — while metaphysical in appearance — yields several specific and measurable consequences. These predictions can be tested via high-precision optical, gravitational, and quantum experiments, and they distinguish this framework from standard wave-particle or purely geometric treatments of light.

Below, we identify three domains where the tunnel model suggests observable deviations or confirmations: spectral phase shifts, vacuum anisotropy near strong curvature, and lensing anomalies.

7.1. Spectral Phase Shifts from Tunnel Variability

If the photon propagates through a pressure-neutral tunnel, then minor variations in tunnel geometry — due to interference, background entropy flux, or extreme field gradients — could produce measurable spectral phase shifts.

Predicted signatures:

- **Quantized phase noise** in interferometry experiments beyond standard quantum or environmental decoherence
- **Tunable spectral delays** under artificially generated gradient conditions (e.g., proximity to Casimir plates or vacuum anisotropies) [Casimir, 1948] [11]
- **Transient pulse deformation** in entangled photon pairs under differing gravitational potentials

These shifts would be extremely subtle, but potentially detectable with existing tools like LIGO [Abbott et al., 2016] [10], Hong–Ou–Mandel interferometers [Hong, Ou & Mandel, 1987] [9], or superconducting cavity delay lines.

Implication:

Phase shifts occur not because light slows down, but because the tunnel's entry/exit boundary interacts with subtle external entropy fields, slightly altering path coherence.

7.2. Vacuum Polarization and Fluid Anisotropy Near Strong Fields

If the space-time fluid has a definable tension and pressure field, then strong-field environments — such as near black holes, neutron stars, or high-energy particle collisions — may create detectable anisotropies in the photon tunnels generated nearby.

Predicted signatures:

- **Polarization rotation** (beyond known Faraday effects) when light passes near high-curvature regions
- **Direction-dependent redshift differentials**, due not to energy loss but tunnel entry deformation
- **Birefringence-like effects** in curved vacuum, as photons select slightly different tunnel geometries depending on spin and orientation

These effects could be probed in extreme astrophysical environments using data from radio telescopes, X-ray observatories, and gravitational wave detectors.

Implication:

The tunnel entry and exit interfaces may encode local entropy and pressure field information, slightly modifying light's observable properties in a curvature-dependent way.

 doi:10.20944/preprints202506.2279.v1

7.3. Gravitational Lensing Deviations in Photon Tunnel Overlap Zones

Gravitational lensing is currently modeled as curvature-driven geodesic bending. However, in the tunnel model, the bending arises from altered entry/exit tunnel conditions. When multiple tunnels interact (as in strong lensing scenarios or near photonic vortices), overlapping conduits may cause anomalous effects.

Predicted anomalies:

- **Fine-structure deflection shifts** beyond standard GR predictions, particularly in closely packed photon streams
- **Ring deformation asymmetries** in Einstein rings observed in high-mass lensing systems [Event Horizon Telescope Collaboration, 2019] [13]
- **Non-scalar delay profiles** in multiple-lensed quasar images, suggesting tunnel-surface interaction instead of pure null-path stretching

Such deviations would require ultra-high-resolution lensing surveys, such as those produced by the Event Horizon Telescope, Euclid, or James Webb Space Telescope.

Implication:

Where photonic tunnels converge or cross, small non-additive curvature effects could alter light paths in ways not predicted by pure geometric optics — providing a test of the tunnel's physical reality.

7.4. Future Lab-Scale Tests

While many of the above effects rely on astrophysical observations, lab-scale analogs are conceivable:

- **Bose–Einstein Condensates (BECs)** could be used to simulate space-time fluid conditions, allowing photonic tunnel analogs to be generated and probed directly [Anderson et al., 1995] [12]
- **Superfluid helium systems** might mimic entropy-neutral conduit behavior under applied pressure and temperature gradients
- **Casimir cavity optics** could test tunnel sensitivity to boundary-induced vacuum entropy structures

These experiments would not directly visualize the tunnel, but could identify indirect thermodynamic anomalies consistent with pressure-neutral photon paths.

8. Conclusion and Future Work

In this paper, we have advanced the fluid-dynamic framework of space-time by introducing the concept of **entropy-neutral photonic tunnels**: transient, pressure-free conduits that allow photons to propagate without resistance, drag, or time passage. Unlike massive objects, which deform the space-time fluid by displacing it and generating curvature, photons bypass the medium entirely by forming self-annihilating tunnels that preserve their energy, coherence, and speed.

This model explains several otherwise puzzling phenomena:

- The invariance of the speed of light across all reference frames
- The absence of gravitational drag or wake in photonic motion
- The null time evolution of photons in propagation
- The mechanism for non-local quantum coherence and entanglement

By viewing photons not as embedded particles or waves, but as **mobile tunnel geometries**, we bridge gravitational, quantum, and thermodynamic descriptions in a unified language grounded in fluid mechanics.

8.1. Integration with Current Physics

 doi:10.20944/preprints202506.2279.v1

Our model preserves the key predictions of general relativity and quantum electrodynamics while offering a physical mechanism for:

- Null geodesics as entropy-free tunnel paths
- Gravitational redshift as a tunnel-entry energy mismatch, not in-transit drag
- Polarization and phase coherence as properties of internal tunnel geometry
- Entanglement as the formation of shared or conjugate tunnel endpoints

Rather than contradicting existing frameworks, this model provides a complementary structure that resolves known paradoxes using continuous, causally consistent fluid behavior.

8.2. Theoretical Implications

This work opens several promising directions for further development:

1. **Tunnel Geometry Formalization**:

Deriving the exact spacetime metric associated with the tunnel interior and boundary conditions.

2. **Photon–Photon Interaction via Tunnel Overlap**:

Modeling how interference and entanglement emerge from geometrically interacting tunnels.

3. **Tunnel Stability and Propagation Equations**:

Identifying the conditions under which entropy-neutral conduits remain stable under curvature, gradient, or quantum noise.

4. **Extension to Other Massless Fields**:

Investigating whether neutrinos, gluons, or gravitons (if real) exhibit analogous tunneling behavior.

8.3. Experimental Roadmap

The model suggests feasible paths for empirical validation:

- **High-resolution interferometry** for detecting non-classical phase shifts
- **Astrophysical lensing surveys** for identifying micro-anomalies in photon behavior near strong curvature
- **Quantum optics platforms** for testing tunnel-induced entanglement correlations
- **BEC analogs** for simulating entropy-neutral propagation in a controlled lab environment

Such tests would move the tunnel concept from theoretical abstraction to a testable, mechanical model of light propagation.

8.4. Final Remarks

The entropy-neutral tunnel concept allows us to understand light not as a traveler within space-time, but as a sculptor of its own temporary passage — one that carves itself out of the fabric of space without leaving a trace. In doing so, the photon preserves the invariance of physical law, sidesteps entropy, and unifies the geometry of the universe with the thermodynamics of motion.

This paper marks a step toward reconciling the continuous with the quantum, the geometric with the dynamic, and the deterministic with the entangled. As we deepen our understanding of the fluidity of space-time, the photon — long a mystery and paradox — may finally be seen for what it is: not a particle, not a wave, but a moving tunnel in the void.

 doi:10.20944/preprints202506.2279.v1

Appendix A. Symbol Glossary

Table A1. Symbol Glossary – Key Definitions Used in the Photon Tunneling Framework.

Symbol	Meaning
ρ	Fluid density of the space-time medium
p	Local pressure in the space-time fluid
$\nabla\cdot$	Divergence operator (measures how much a vector field spreads out)
$\nabla\cdot\vec{S}$	Entropy divergence; determines the local rate of time evolution
$\vec{S}$	Entropy flux vector; direction and rate of entropy flow
v	Fluid velocity vector; represents the local drift of the space-time medium
Γ (Gamma)	Circulation; represents rotational flow or vortex strength in fluid systems
u^μ	Four-velocity; fluid element's motion in relativistic space-time
$T^{\mu\nu}$	Energy-momentum tensor of the fluid
$\partial/\partial t$	Partial derivative with respect to time
E, B	Electric and magnetic field vectors inside the photonic tunnel
θ, φ	Angular coordinates in spherical or cylindrical symmetry
ℓ	Characteristic length scale of the tunnel or curvature
c	Speed of light in vacuum (or tunnel interior, which remains at c)
ds^2	Infinitesimal space-time interval (metric element)
$P(r)$	Radial pressure profile near mass or tunnel structure
∇p	Pressure gradient; generates acceleration in the fluid

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