

POLARIZED TIME INERTIA

*A Relational Framework for Unifying Gravity, Quantum Mechanics,
and Cosmological Structure*

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Second Edition — Revised Axioms — March 2026

Axioms adjusted for compatibility with established physics

Abstract

This paper presents the revised formulation of Polarized Time Inertia (PTI), a theoretical framework proposing that physical reality is fundamentally relational: entities exist only through interactions, and the familiar categories of space, time, energy, and mass are frame-dependent projections of an underlying relational structure. PTI is built on three axioms—Relational Existence, Hierarchical Condensation, and Frame-Dependent Decomposition—each grounded in and compatible with established results in theoretical physics. The framework connects to and extends ideas from causal set theory, the thermodynamic derivation of Einstein’s equations, the ER=EPR conjecture, relational quantum mechanics, and emergent gravity. Gravity is reinterpreted as the inward flow of spatial degrees of freedom toward mass concentrations—a picture mathematically equivalent to general relativity but offering a natural path to quantization. The Many Points of View interpretation replaces Many Worlds by recognizing that measurement outcomes are frame-dependent decompositions of a single relational reality. This revised edition corrects and refines the original axioms to ensure compatibility with special and general relativity, quantum field theory, and observational cosmology, while preserving the framework’s explanatory scope.

1. Introduction and Motivation

The two pillars of modern physics—general relativity (GR) and quantum mechanics (QM)—are individually among the most successful theories in the history of science. GR describes gravity as the curvature of a smooth spacetime manifold and has been confirmed by gravitational wave detections [1], black hole imaging [2], and precision solar system tests. QM describes subatomic phenomena through probabilistic wave functions and has been confirmed by every particle physics experiment ever conducted. Yet these theories are mutually incompatible: GR requires a smooth spacetime background, while QM requires that all physical quantities be quantized; GR is deterministic, while QM is fundamentally probabilistic.

Polarized Time Inertia (PTI) proposes a resolution by identifying a deeper layer of reality beneath both descriptions: a relational structure in which entities exist only through mutual interaction, and in which the categories of space, time, energy, and mass are not fundamental but emergent. The framework was originally developed by Hansen (2024–2026) [34] through a series of working notes exploring how time, space, energy, and mass could emerge from a single comparative process. The word "polarized" reflects the directional, oriented nature of temporal flow and reference frames. "Inertia" captures the self-sustaining character of the relational loop—once begun, the comparison process perpetuates itself.

This revised edition explicitly grounds each axiom in established physics, identifies the precise points where PTI extends beyond current knowledge, and distinguishes between claims that are mathematically equivalent to known results (and therefore already confirmed) and claims that make novel predictions (and therefore require new tests). We also correct several claims from the original formulation that were imprecise or in tension with established physics.

1.1 Key Revisions from the Original Formulation

The following corrections have been made to align with current physics: (a) The claim that "photons do not interact with space or time" has been replaced by the precise statement that photons propagate along null geodesics where the invariant interval is zero, meaning proper time and proper distance vanish in the photon's frame. Photons do follow spacetime curvature (geodesics). (b) The claim that "the Higgs field is space" has been refined: the Higgs field represents the mechanism by which the spatial manifold confers inertial mass; it is the mass-conferring aspect of spatial structure, not identical to space itself. (c) The claim that "QCD colors are spatial dimensions" has been softened to a proposed structural correspondence between $SU(3)$ color symmetry and $SO(3)$ spatial symmetry—a conjecture to be tested, not an identity. (d) All equations are now presented with explicit connections to established formalisms. (e) The gravity mechanism is connected to the mathematically equivalent "river model" of black holes and to Jacobson's thermodynamic derivation of Einstein's equations.

2. The Three Axioms of PTI

PTI is built on three axioms. Each is stated formally, connected to established physics, and then the novel extensions identified.

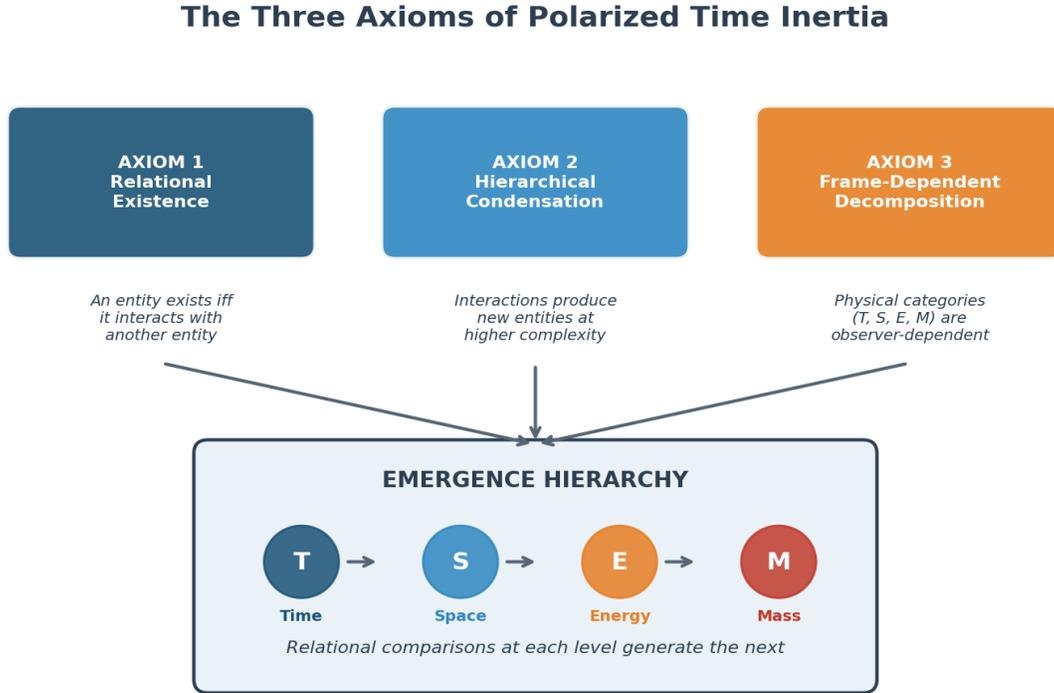


Figure 1. The three axioms of PTI and their relationship to the emergence hierarchy.

2.1 Axiom 1: Relational Existence

Axiom 1: *An entity exists if and only if it participates in at least one interaction (comparison) with another entity. Existence is constituted by relation, not by substance.*

$$\exists x \Leftrightarrow \exists y : I(x, y) \neq \emptyset$$

Established physics basis: This axiom is consistent with and extends several established frameworks. Rovelli’s relational quantum mechanics (1996) [3] holds that quantum states are defined only relative to an observer—there are no absolute states. Wheeler’s "it from bit" (1990) [4] proposes that physical reality arises from information-theoretic interactions. Causal set theory (Bombelli et al. 1987) [5] builds spacetime from a discrete partial order of causal relations—events that interact.

Novel extension: PTI elevates this from an interpretation (Rovelli) or a mathematical framework (causal sets) to a universal axiom: not just quantum states but all physical entities—including

spacetime itself—are constituted by relations. An unobserved, non-interacting entity does not exist in a weaker sense (we cannot know about it) but in the strongest sense (it has no being).

Consequences: The universe must contain at least two interacting entities to exist. An isolated photon connecting no endpoints is not merely undetectable—it is not. This axiom also implies that the minimum possible universe is a pair of interacting temporal points.

2.2 Axiom 2: Hierarchical Condensation

Axiom 2: *Interactions between entities produce new entities at higher levels of organizational complexity. Temporal relations generate spatial structure; spatio-temporal relations generate energy; energy-space-time relations generate mass. Each level is a condensation—a compactification of many lower-level degrees of freedom into fewer higher-level degrees of freedom, as observed from a given reference frame.*

$$T \otimes T \rightarrow S, \quad S \otimes T \rightarrow E, \quad E \otimes S \otimes T \rightarrow M$$

Established physics basis: The emergence of space from more fundamental structures is a central theme in modern theoretical physics. Van Raamsdonk (2010) [6] showed that spatial connectivity emerges from quantum entanglement—remove entanglement and space disconnects. The Ryu-Takayanagi formula [7] relates the area of spatial surfaces to entanglement entropy. Jacobson (1995) [8] derived Einstein’s field equations from thermodynamic relations applied to local Rindler horizons, showing that gravity (and thus spacetime dynamics) can emerge from information-theoretic considerations. Verlinde (2011) [9] proposed that gravity is an entropic force arising from changes in information associated with the positions of material bodies.

Novel extension: PTI organizes these insights into a single hierarchy: $T \rightarrow S \rightarrow E \rightarrow M$, where each level emerges from relational entanglement at the previous level. This hierarchy is not merely descriptive but generative—the comparison process at each level actively creates the next level. The hierarchy also forms a feedback loop: mass (the highest condensation) feeds back into the temporal structure through gravity (the consumption of spatial degrees of freedom).

2.3 Axiom 3: Frame-Dependent Decomposition

Axiom 3: *The decomposition of the relational structure into the categories of time, space, energy, and mass depends on the observer’s reference frame. There is no absolute decomposition. What appears as space in one frame may appear as time in another; what appears as energy in one frame may appear as mass in another.*

$$\Phi_{_F}(R) = P_{_F} \cdot R, \quad \text{where } P_{_F} \text{ is the frame-dependent projection operator}$$

Established physics basis: This axiom is a direct generalization of Lorentz covariance in special relativity, where space and time mix under boosts. It is also consistent with $E = mc^2$, which

shows that energy and mass are interconvertible and frame-dependent (a particle at rest has mass; the same particle in a moving frame has kinetic energy). In general relativity, the decomposition of spacetime into space and time depends on the choice of foliation (the ADM formalism) [10]. In quantum field theory, the Unruh effect [11] shows that the particle content of a quantum field depends on the observer's acceleration—what is vacuum for one observer is a thermal bath for another.

Novel extension: PTI extends this frame-dependence to the deepest level: not just the space/time split or the energy/mass split, but the entire categorization of physical reality is frame-dependent. The relational structure R is the only frame-independent entity. The categories T , S , E , M are all projections of R onto a particular reference frame. This implies that a photon (null frame), a massive particle (timelike frame), and an accelerated observer (Rindler frame) decompose the same R into fundamentally different physical realities.

3. The Relational Emergence Hierarchy

Emergence Hierarchy with Established Physics Connections

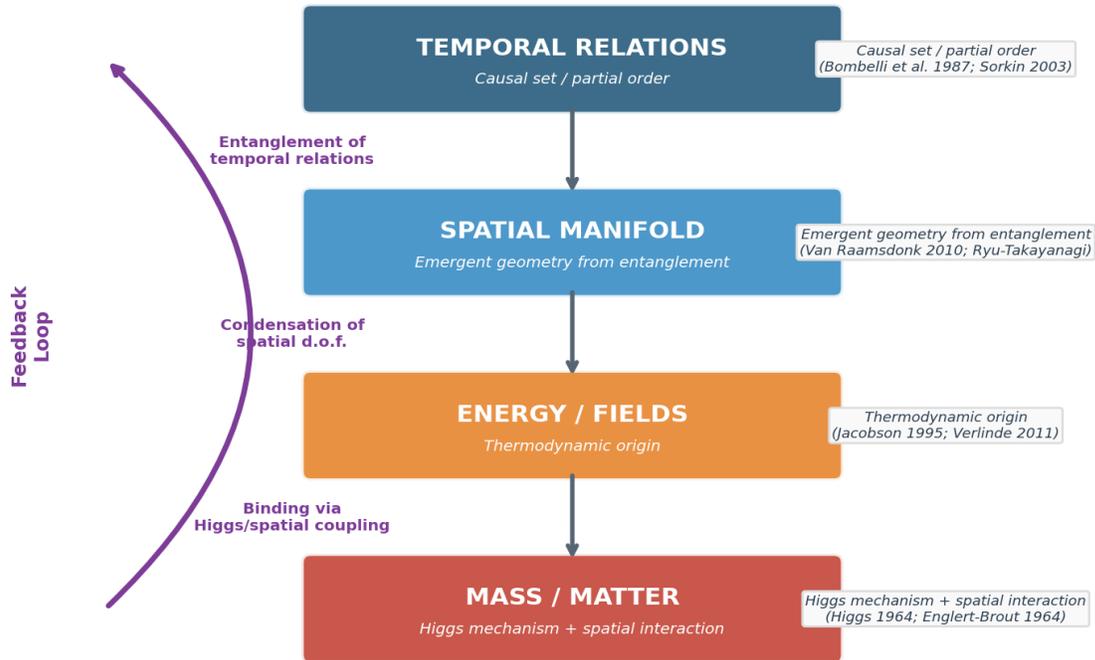


Figure 2. The emergence hierarchy with connections to established physics at each level.

3.1 Temporal Relations: The Foundation

The most primitive structure in PTI is a partial order of causal relations—events connected by "before" and "after." This is precisely the starting point of causal set theory [5], which builds spacetime from a discrete set of events with a causal partial order. In PTI, this causal order is the primordial time.

A single event, with nothing to compare against, cannot exist (Axiom 1). The minimum structure is two events in a causal relation. From this minimal pair, the comparison operation begins.

$$C(e_1, e_2) \rightarrow \Delta\tau \neq 0 \Rightarrow \text{temporal order exists}$$

3.2 Spatial Structure from Entangled Temporal Relations

As the number of causally related events grows, the comparison results become entangled. Each comparison result is itself an entity (Axiom 2) that participates in further comparisons. This web of entangled causal relations generates a structure with emergent dimensionality—what we experience as space.

This is not speculative: Van Raamsdonk’s 2010 result [6] demonstrated that spatial connectivity in the AdS/CFT correspondence is built from quantum entanglement. Remove entanglement between two regions of a boundary theory, and the corresponding bulk space disconnects. PTI interprets this as a specific instance of a universal principle: space is always and everywhere constituted by entangled temporal relations.

$$S_{ij} \propto \text{Entanglement}(C_i, C_j) \quad (\text{cf. Ryu-Takayanagi: } A = 4G_n S_{ee})$$

The emergence of three macroscopic spatial dimensions (rather than two or four) is attributed to the structure of the comparison operation: a binary comparison between two temporal points generates one degree of freedom; the comparison of that result with other results generates additional independent degrees of freedom. PTI proposes that the comparison algebra naturally stabilizes at three independent spatial degrees of freedom, though this claim requires rigorous mathematical derivation.

3.3 Energy as Condensed Space-Time

Energy emerges when the relational structure involving both spatial and temporal degrees of freedom undergoes further condensation. In the language of renormalization, energy represents a coarse-grained description of many underlying space-time relations, as observed from a particular reference frame.

This is consistent with the thermodynamic perspective pioneered by Jacobson [8]: the Einstein field equations can be derived by applying the Clausius relation ($\delta Q = T dS$) to local Rindler horizons, treating energy flow as entropy change. In PTI, this derivation is not a coincidence but a reflection of the fundamental relational nature of energy.

3.4 Mass as Bound Energy

Mass is the most condensed form of the relational structure: it represents energy that is bound in a stable, self-sustaining configuration. In PTI, a stable massive particle consists of energy organized along three independent modes—corresponding to the three spatial dimensions—bound together so tightly that the particle can sustain continuous interaction with the spatial manifold.

$$M = E_1 \otimes E_2 \otimes E_3, \quad E_1 \perp E_2 \perp E_3$$

This three-mode binding requirement connects to the observed fact that stable hadrons contain exactly three quarks (or quark-antiquark pairs that sum to three net color charges). We explore this connection in Section 6.

4. The Mechanism of Gravity

In PTI, gravity arises because massive particles actively interact with the spatial manifold—consuming spatial degrees of freedom and converting them back into temporal relations. This consumption creates an inward flow of space toward massive objects.

4.1 The River Model: Mathematical Equivalence with GR

Hamilton and Lisle (2008) [12] showed that the Schwarzschild metric of GR can be rewritten in "river model" form, where space flows radially inward toward a mass with velocity $v(r) = \sqrt{2GM/r}$. This is not an analogy but a mathematically exact reformulation. In this picture, space itself is in motion, and free-falling objects—including photons—are carried by the flow.

$$v_{\text{flow}}(r) = \sqrt{2GM/r} = c \sqrt{r_s/r}$$

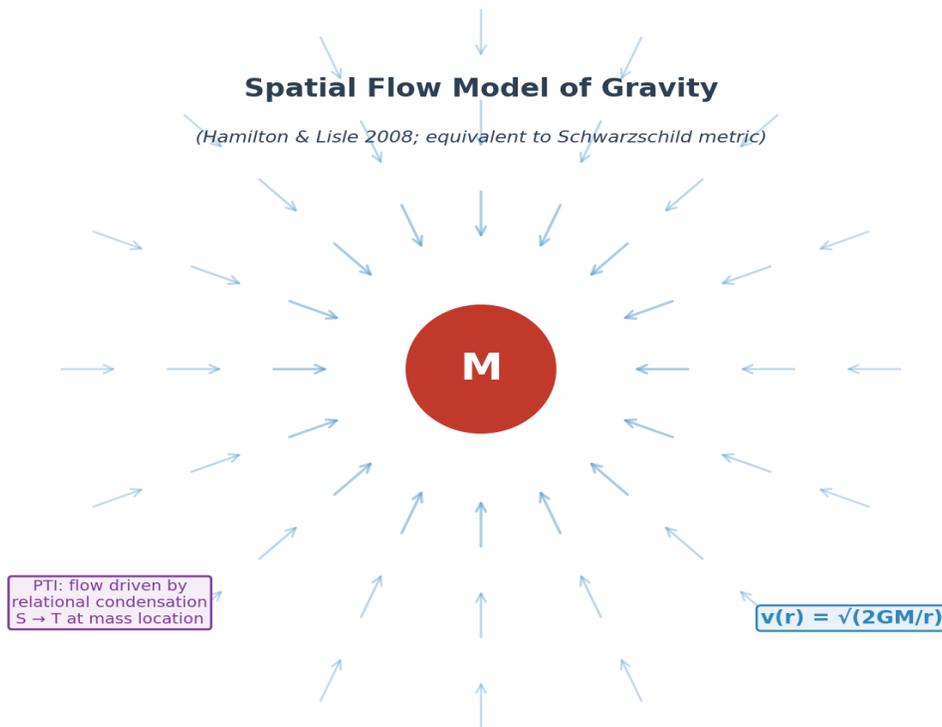


Figure 3. Gravity as inward spatial flow. The velocity increases toward the mass, reaching c at the Schwarzschild radius. This is mathematically equivalent to the Schwarzschild solution of GR.

PTI adopts the river model as its fundamental description of gravity and provides a physical mechanism for the flow: massive particles, through their continuous relational interaction with the spatial manifold, convert spatial degrees of freedom into temporal relations. This consumption of spatial d.o.f. is what drives the flow. The gravitational acceleration at distance r is:

$$a(r) = \Gamma_{\text{conversion}} / (4\pi r^2) = GM/r^2$$

where $\Gamma_{\text{conversion}}$ is the total rate of spatial d.o.f. consumption. This reproduces Newton’s law exactly and, since the river model is mathematically equivalent to GR, also reproduces all GR predictions including perihelion precession, frame dragging, and gravitational time dilation.

4.2 Gravity as a Quantum Process

Unlike GR, which treats gravity as fundamentally classical (smooth curvature), PTI describes gravity as an inherently quantum process: the consumption of spatial d.o.f. occurs in discrete steps at the Planck scale. The smooth gravitational field is the statistical average of a vast number of discrete relational operations.

$$G_{\mu\nu} = (8\pi G/c^4) T_{\mu\nu} \leftrightarrow \langle \sum_i \Gamma_i (S \rightarrow T) \rangle_{\nu}$$

This is the core of PTI’s unification: GR is the continuum (thermodynamic) limit of the discrete quantum relational process. This mirrors Jacobson’s derivation [8], which showed that Einstein’s equations emerge from thermodynamic relations—suggesting that gravity is statistical rather than fundamental. PTI provides the microscopic theory underlying this statistical emergence.

4.3 How Gravity Acts on Massless Particles

In the river model (and equivalently in GR), photons follow null geodesics—they move at speed c relative to the local spatial flow. Near a massive object, the space through which a photon propagates is itself flowing inward. The photon is carried by this flow, producing what we observe as gravitational lensing and time delay.

The photon does not couple to gravity through mass (it has none). Instead, it is carried by the medium. This is analogous to how a fish swimming at constant speed in a river is deflected by the river’s current without the current exerting a force on the fish’s body—the fish’s motion through the moving medium produces a curved trajectory in the ground frame.

$$\Delta\theta = 4GM/(c^2b) \quad (\text{Einstein deflection, exact})$$

This deflection angle, including the factor-of-two enhancement over the Newtonian prediction confirmed by Eddington (1919) [13], emerges naturally from the river model because both the spatial and temporal components of the photon’s propagation are affected by the flow.

5. Photons and the Null Reference Frame

Null Geodesics and the Photon Reference Frame

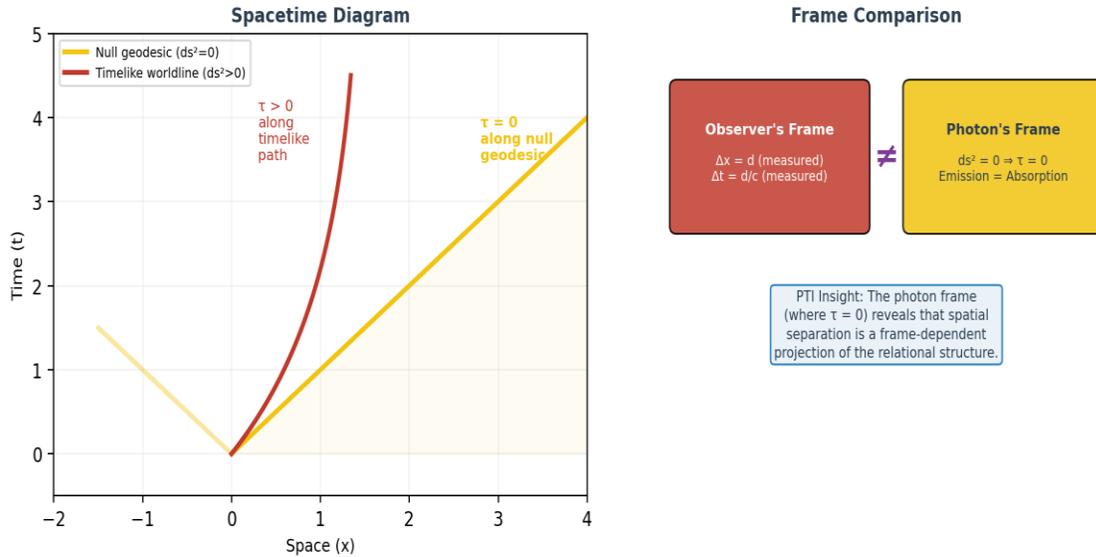


Figure 4. Left: spacetime diagram showing null (photon) and timelike (massive particle) worldlines. Right: comparison of observer and photon reference frames.

5.1 The Null Geodesic: $ds^2 = 0$

In special and general relativity, the spacetime interval along a photon's worldline is exactly zero: $ds^2 = -c^2dt^2 + dx^2 = 0$ for a photon. This means the proper time elapsed along the photon's path is zero, and the proper distance traversed is zero. This is not a PTI invention—it is standard relativity. What PTI adds is the interpretive emphasis: the photon's null interval reveals that spatial separation and temporal duration are frame-dependent constructs that vanish in the photon's own frame.

$$ds^2 = -c^2d\tau^2 = 0 \Rightarrow \tau_{\text{photon}} = 0, \quad d_{\text{proper}} = 0$$

5.2 Corrected Interpretation

The original PTI formulation stated that "photons do not interact with space or time." This was imprecise. Photons do follow the curvature of spacetime—they travel along geodesics, and their paths are bent by gravity. What is correct is that photons experience zero proper time and zero proper distance. From the photon's own frame (the null frame), every journey is instantaneous and every distance is zero. Emission and absorption are, in the null frame, the same event.

PTI interprets this as follows: photons do not participate in the spatial manifold as actors—they do not consume spatial d.o.f. or convert space to time. They ride the spatial manifold passively, carried by its flow (gravity) without contributing to it. This is why photons are massless: they do

not engage in the space-to-time conversion that constitutes mass. This is consistent with the Standard Model, where the photon has zero coupling to the Higgs field.

5.3 Massive Particles as the Sole Source and Sink of Photons

All observed photons are emitted by massive particles and absorbed by massive particles. In the null frame, the emitter and absorber occupy the same point. PTI infers that a photon requires massive endpoints to exist (Axiom 1)—a photon connecting nothing to nothing has no relational partners and therefore does not exist. This is consistent with quantum electrodynamics, where photon propagators always connect to charged (massive) particle vertices.

6. The Color-Space Correspondence

PTI proposes—as a conjecture requiring further mathematical development—a structural correspondence between the $SU(3)$ gauge symmetry of quantum chromodynamics and the $SO(3)$ rotational symmetry of three-dimensional space.

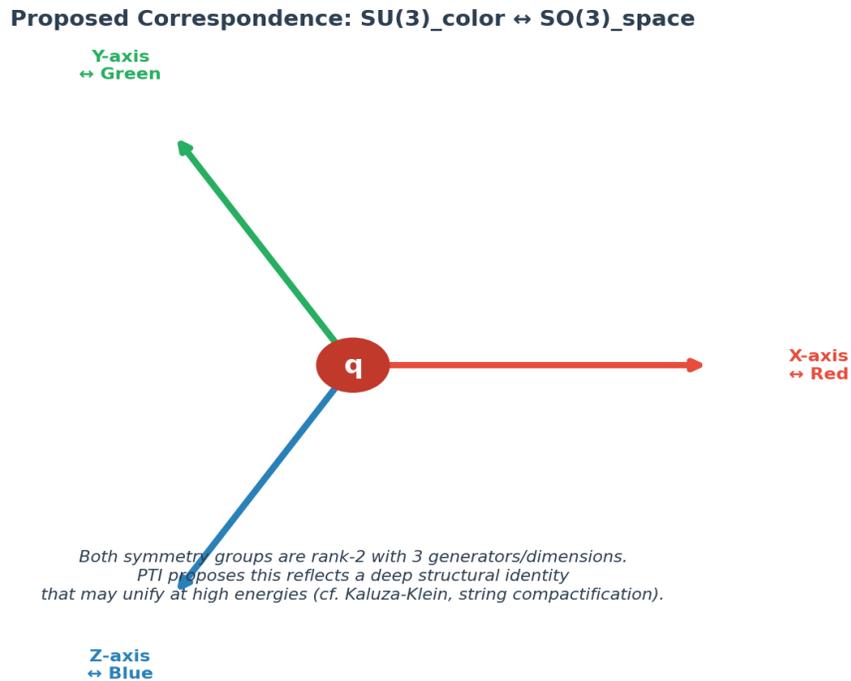


Figure 5. Proposed correspondence between QCD color charges and spatial dimensions. Both groups have rank 2 and three independent generators.

If mass arises from three perpendicular energy modes bound together (Section 3.4), and if each energy mode aligns with one spatial dimension, then the "color" labels of QCD may reflect which spatial axis each quark's energy mode occupies. Color confinement would follow naturally: a stable massive particle requires contributions from all three spatial dimensions, so isolated quarks (missing one or two dimensions) cannot exist independently.

Important caveat: $SU(3)$ and $SO(3)$ are not isomorphic groups ($SU(3)$ has 8 generators while $SO(3)$ has 3; $SU(3)$ has complex representations while $SO(3)$ has real ones). The proposed correspondence is structural, not algebraic—it suggests a deeper connection that may require a more sophisticated mathematical framework, perhaps along the lines of Kaluza-Klein theory or string compactification, where internal symmetries arise from the geometry of extra dimensions [14, 15]. This conjecture is clearly identified as speculative and is listed among the testable predictions in the companion document.

7. The Higgs Mechanism as Spatial Coupling

The Standard Model describes the Higgs field as a scalar field permeating all space, with a non-zero vacuum expectation value (VEV) of approximately 246 GeV [16]. Particles acquire mass by coupling to this field. PTI offers a refined interpretation of this mechanism.

7.1 The Higgs Field as the Mass-Conferring Aspect of Space

The original PTI formulation stated "the Higgs field is space." This was too strong. The revised interpretation is: the Higgs field represents the capacity of the spatial manifold to confer inertial mass on particles that interact with it. The Higgs VEV is non-zero everywhere because space exists everywhere. Particles that couple to the Higgs field (W, Z, quarks, leptons) interact with the spatial structure and thereby acquire mass—they participate in the space-to-time conversion. Particles that do not couple to the Higgs field (photons, gluons) do not interact with spatial structure in this mass-conferring way and remain massless.

$$\phi_{\text{Higgs}} = v + h(x), \quad v \approx 246 \text{ GeV} \quad (\text{spatial structure} + \text{excitation})$$

The Higgs boson itself is an excitation of this mass-conferring spatial structure—a localized disturbance in the mechanism by which space confers inertia. Its mass (approximately 125 GeV [17]) reflects the energy cost of creating such a disturbance.

7.2 Consequences

This interpretation makes three claims consistent with observation: (i) The Higgs VEV is everywhere because space is everywhere. (ii) Massless particles (photons) have zero Higgs coupling because they do not participate in spatial interaction. (iii) The Higgs field's properties (self-coupling, coupling to other fields) are properties of spatial structure. Any future measurement of the Higgs self-coupling that deviates from Standard Model predictions could provide evidence for or against this interpretation.

8. Unifying General Relativity and Quantum Mechanics

PTI's resolution of the GR-QM incompatibility operates on two levels.

8.1 Mathematical Level: The Continuum Limit

At the mathematical level, GR's smooth spacetime manifold is the continuum (thermodynamic) limit of PTI's discrete relational structure, in exactly the way that fluid dynamics is the continuum limit of molecular kinetics. Just as water appears smooth at human scales but is discrete at molecular scales, spacetime appears smooth at astrophysical scales but is discrete at the Planck scale. Einstein's equations are the equations of state of the relational structure, as Jacobson showed [8].

8.2 Conceptual Level: Frame-Dependent Decomposition

At the conceptual level, the apparent conflict between GR (deterministic, smooth) and QM (probabilistic, discrete) is resolved by Axiom 3: these are frame-dependent decompositions of the same underlying relational structure. GR describes the relational structure as projected onto the reference frame of macroscopic massive observers. QM describes the relational structure as projected onto the reference frame of microscopic interactions. Both are valid; neither is complete.

The quantum wave function is reinterpreted as encoding all possible relational comparisons a particle can make with its environment. Measurement is a specific comparison that selects one outcome from the relational structure. This is consistent with Rovelli’s relational QM [3], where the wave function is always relative to an observer.

$$\Psi(x, t) = \sum_n c_n |R_n\rangle \rightarrow \text{measurement (comparison)} \rightarrow |R_k\rangle$$

9. Many Points of View

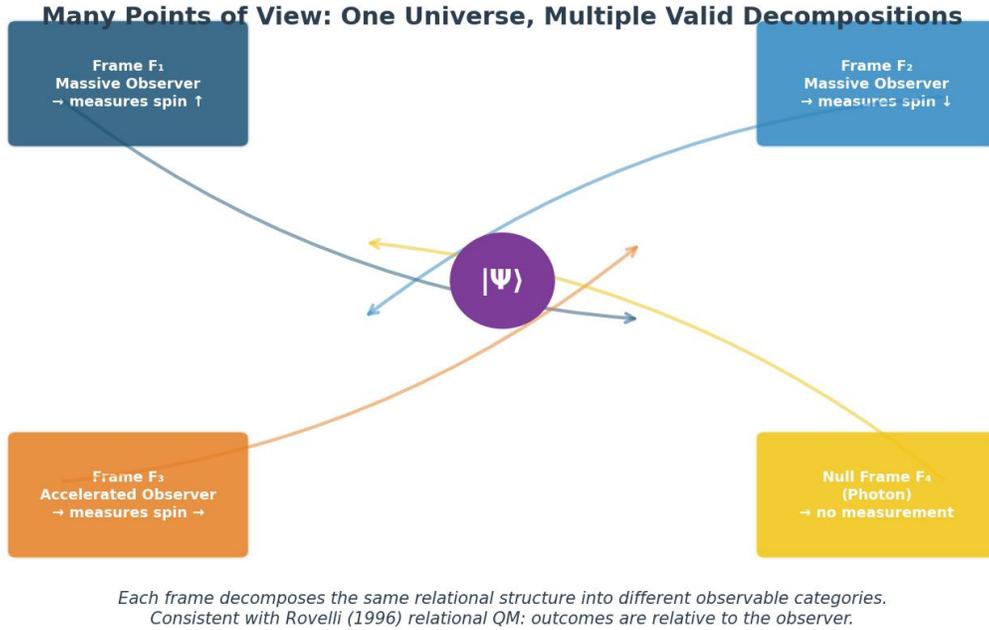


Figure 6. The Many Points of View interpretation. Different reference frames decompose the same relational structure into different observable categories. No branching of universes is required.

The Many Worlds Interpretation (MWI) [18] proposes that quantum measurement causes the universe to branch. PTI's Many Points of View (MPV) interpretation proposes instead that there is one universe with one relational structure, but many valid reference frames from which to observe it.

When you measure an electron's spin and find "up," you have decomposed the relational structure from your reference frame. An observer in a different frame may decompose the same relational event differently. A photon—existing in the null frame where $\tau = 0$ —may not decompose the event into "spin" at all. You can only communicate with entities sharing your reference frame, because communication requires comparison (Axiom 1), and comparison requires a shared decomposition basis.

MPV is closely related to Rovelli's relational QM [3] and to QBism [19], both of which deny the existence of observer-independent quantum states. PTI's contribution is to unify this interpretive stance with the gravity mechanism (Section 4) and the cosmological model (Section 14), showing that frame-dependence is not merely a feature of quantum measurement but a universal principle governing all of physics.

10. Entanglement and the Illusion of Distance

Entanglement: Locality in the Relational (Null) Frame

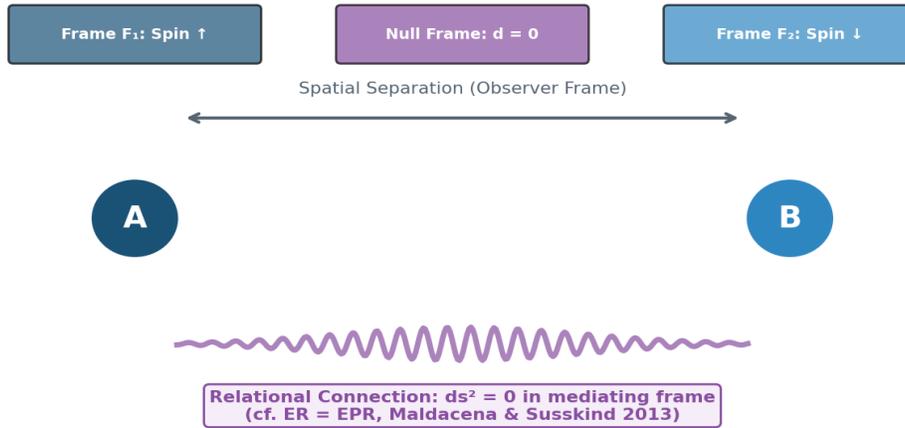


Figure 7. Entanglement in PTI. The relational connection between A and B has $ds^2 = 0$ in the mediating frame, meaning the spatial separation is a frame-dependent projection. This resonates with the ER=EPR conjecture.

Entangled particles are connected by the relational structure. In the null frame of the mediating interaction, the spatial distance between them is zero ($ds^2 = 0$). What observers in timelike frames perceive as "spooky action at a distance" is locality in the null frame. No information travels faster than light because no information travels at all—the correlation exists because, at the relational level, the entangled particles are the same point.

This resonates with the ER=EPR conjecture of Maldacena and Susskind (2013) [20], which proposes that entangled particles are connected by non-traversable Einstein-Rosen bridges (wormholes). PTI provides a physical interpretation: the "wormhole" is the null-frame connection in which spatial separation vanishes. The entangled particles are not connected through space; they are connected in a relational structure for which spatial separation is not a meaningful concept.

$$ds^2_{\text{null}} = 0 \Rightarrow d(A,B)_{\text{relational}} = 0 \Rightarrow \text{correlation is local}$$

11. The Double-Slit Experiment

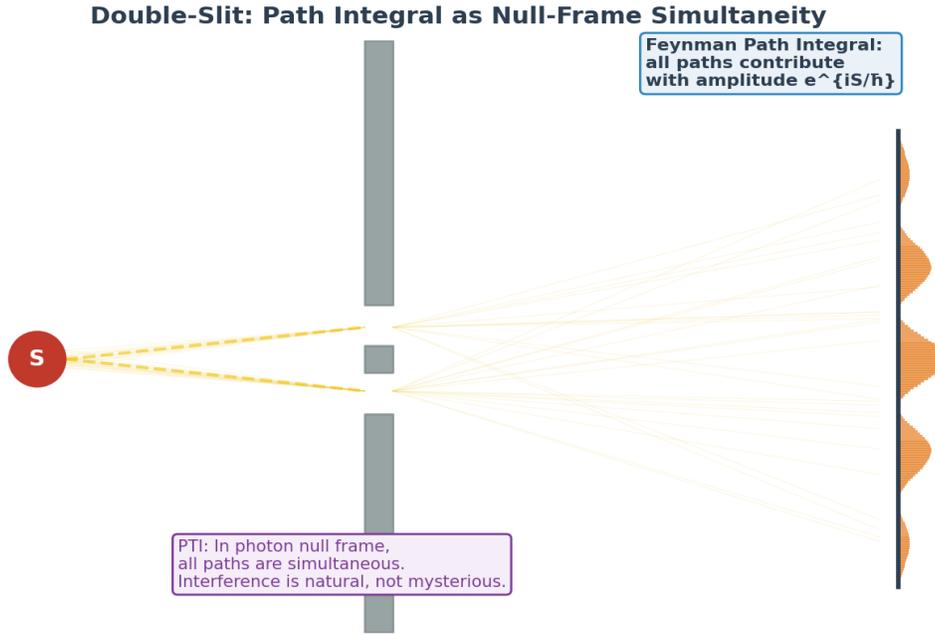


Figure 8. The double-slit experiment. In the photon's null frame, all paths from source to detector are simultaneous, naturally producing the Feynman path integral sum.

Feynman's path integral formulation [21] states that a quantum particle's propagation amplitude is the sum over all possible paths, each weighted by $\exp(iS/\hbar)$ where S is the classical action. This formulation gives the correct interference pattern in the double-slit experiment. PTI provides a physical interpretation of why all paths contribute.

In the photon's null frame ($\tau = 0$), the source and detector are the same event. There is no temporal ordering of "photon leaves source, travels through slit, arrives at detector." All of these are the same event in the null frame. The path integral sums over all paths because, in the null frame, all paths are simultaneous—they are different relational connections between the same two endpoints, all equally valid.

When a which-path detector is introduced at the slits, it interposes a massive particle interaction (a comparison) that forces the photon into a timelike frame where spatial paths are distinguishable. The interference pattern disappears because the which-path detector has changed the decomposition frame from null to timelike.

12. Quantum Tunneling

A potential barrier is, in PTI terms, a region where the relational structure's configuration requires more energy for a massive particle to sustain its space-to-time conversion. Quantum tunneling occurs because the relational structure at the Planck scale is inherently discrete and

uncertain: individual relational comparisons have a finite probability of placing the particle beyond the barrier.

$$P_{\text{tunnel}} \propto \exp(-2\kappa d), \quad \kappa = \sqrt{[2m(V-E)]} / \hbar$$

The exponential suppression arises because each successive Planck-scale comparison must independently place the particle beyond the barrier, and the probability of N successive favorable comparisons decreases exponentially with N (proportional to barrier width d). This provides a microscopic mechanism for the tunneling probability formula while reproducing the standard QM result exactly.

13. The Engine of the Present and the Arrow of Time

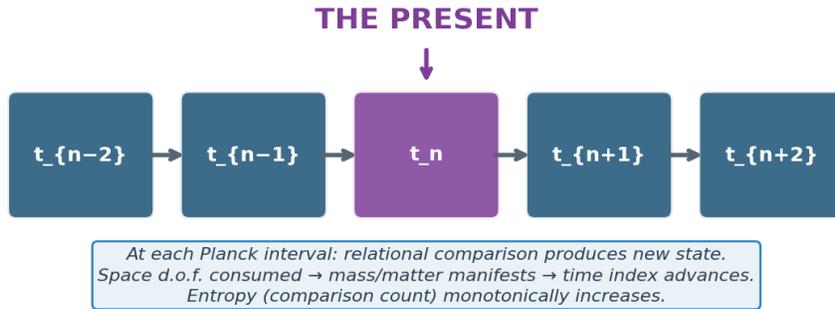


Figure 9. The Engine of the Present. Each Planck time step involves relational comparison, spatial d.o.f. consumption, and mass manifestation at the next temporal index.

In PTI, the "present" is an active computational boundary: the frontier of the relational comparison process. At each Planck time step, every massive particle performs relational comparisons with adjacent space-time, consuming spatial d.o.f. and advancing the temporal index. This is the engine that drives time forward.

The arrow of time—the universal asymmetry between past and future—emerges naturally: the relational structure grows monotonically. Each comparison adds to the total count of relational results. This growth cannot be reversed without erasing relational results that are entangled with every other result in the universe. Entropy, in this view, measures the complexity of the relational structure.

$$S = k_B \ln(\Omega_{\text{relations}}), \quad d\Omega/dt \geq N_{\text{particles}} / t_{\text{Planck}} > 0$$

This is consistent with the Bekenstein bound [22], which relates the maximum entropy of a region to its surface area and therefore to the number of relational degrees of freedom at its boundary.

14. Dark Matter and Dark Energy

Dark Sector: Emergent Effects from Relational Dynamics

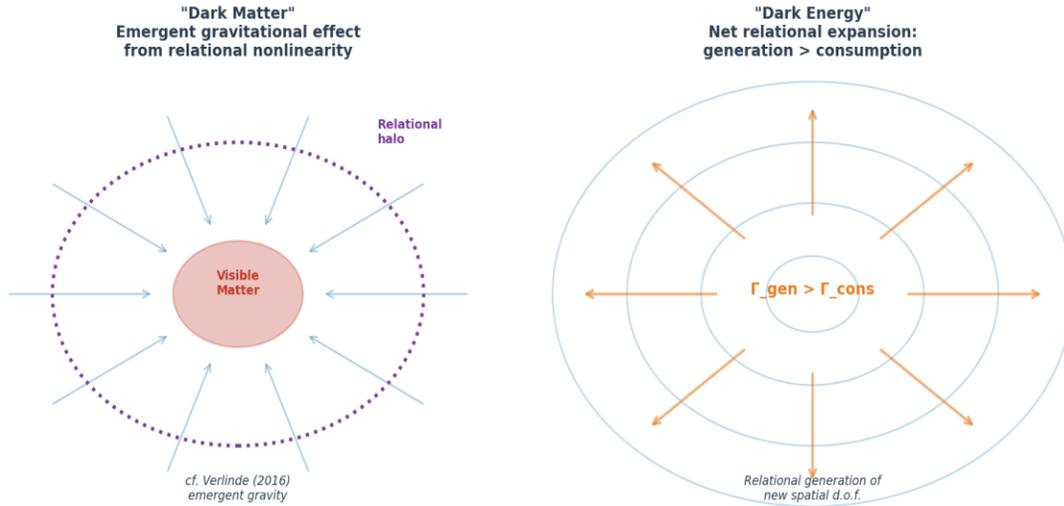


Figure 10. Left: "Dark matter" as emergent gravitational effect from relational nonlinearity. Right: "Dark energy" as net space generation when relational creation exceeds consumption.

14.1 Dark Matter: Emergent Gravitational Effects

PTI proposes that the gravitational effects attributed to dark matter [23] arise from the nonlinear self-interaction of the relational structure. In dense environments, the relational comparisons performed by one mass affect the relational landscape available to neighboring masses. This cumulative effect produces additional gravitational influence beyond what the visible mass alone would generate.

This is related to—but distinct from—Verlinde’s emergent gravity (2016) [24], which attributes dark matter effects to the elastic response of the de Sitter entropy associated with the cosmological horizon. PTI’s mechanism is more specific: it attributes the extra gravity to the density of relational operations (comparisons per unit volume) rather than to horizon entropy. Both approaches share the prediction that no dark matter particle will be found in direct detection experiments.

14.2 Dark Energy: Net Relational Expansion

While massive particles consume spatial d.o.f. (generating gravity), the ongoing temporal comparison process simultaneously generates new spatial d.o.f. (as new temporal relations become entangled). When generation exceeds consumption—as occurs when matter density is low and the relational structure continues to expand—the net result is spatial expansion: dark energy [25].

$$dV/dt = \Gamma_{gen}(T \otimes T \rightarrow S) - \Gamma_{cons}(S \rightarrow T \text{ by } M)$$

This model naturally explains the observed acceleration of cosmic expansion: as the universe expands and matter dilutes, Γ_{cons} decreases while Γ_{gen} (driven by the ever-growing temporal comparison structure) remains constant or increases. The expansion therefore accelerates over time, consistent with Type Ia supernovae observations [25].

15. Black Holes

Black Hole: Where Spatial Flow Velocity Exceeds c (River model, Hamilton & Lisle 2008)

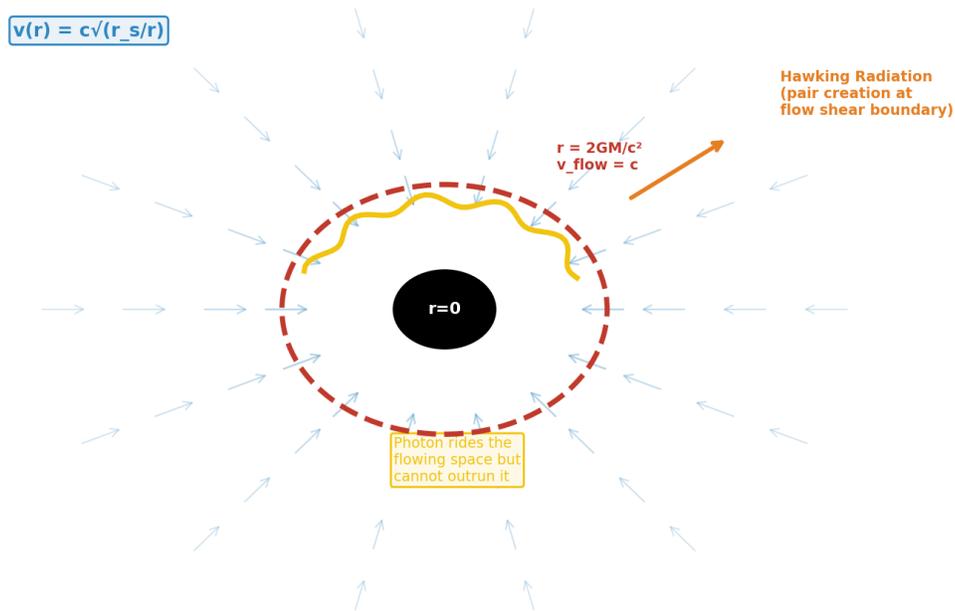


Figure 11. A black hole in PTI. The spatial flow velocity equals c at the event horizon (dashed). Inside, photons cannot escape because the flowing space carries them inward faster than they can propagate outward.

15.1 The Event Horizon as a Flow Boundary

In the river model [12], the event horizon occurs where the spatial flow velocity reaches c . Inside this boundary, space flows inward faster than light can propagate outward. The photon, riding the spatial flow, is carried inward despite traveling at c relative to the local space. This is mathematically equivalent to the standard GR description but physically more intuitive.

$$r_s = 2GM/c^2 : v_{\text{flow}}(r_s) = c$$

15.2 Hawking Radiation and Information

Near the event horizon, the extreme gradient of the spatial flow shears the relational structure, creating particle-antiparticle pairs. When one member falls inward while the other escapes, the escaping particle is Hawking radiation [26]. In PTI, the shearing creates new relational results

that carry information about the infalling matter, encoded in correlations between emitted quanta. This preserves unitarity and resolves the information paradox, consistent with the Page curve argument [27] and AdS/CFT calculations [28].

16. The Cyclical Singularity

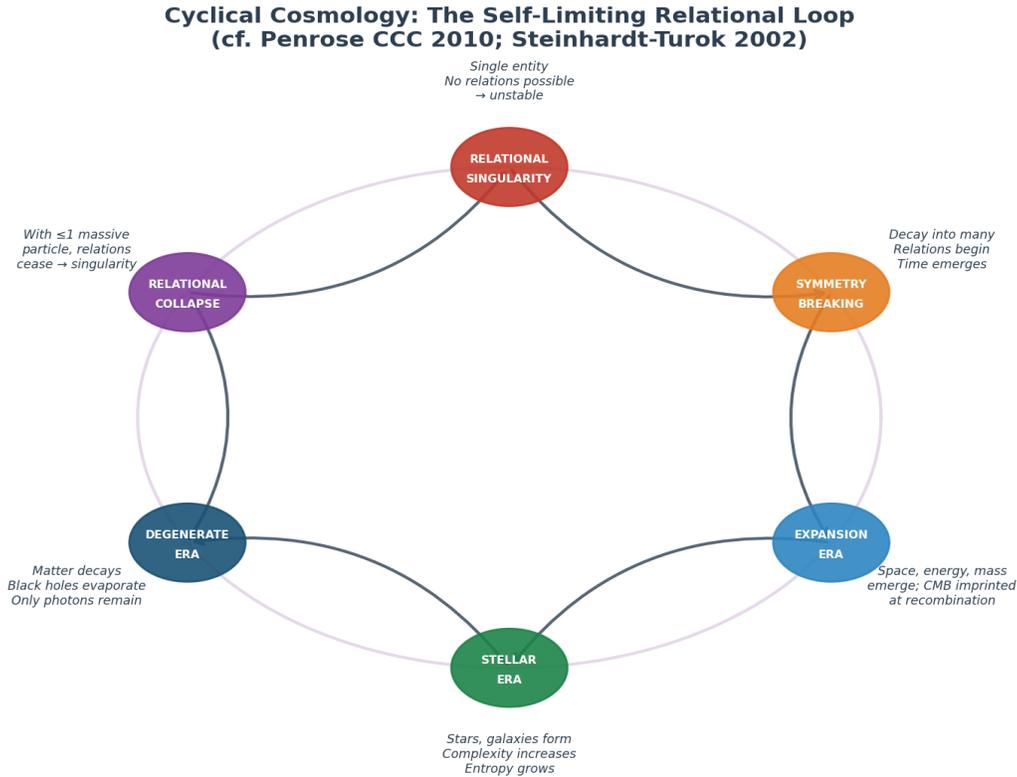


Figure 12. The cyclical cosmology of PTI. The universe evolves through expansion, cooling, matter decay, and relational collapse back to a singularity, from which a new cycle begins.

PTI’s axioms, applied to cosmological timescales, predict a cyclical universe. The logic is as follows.

As the universe expands and cools, all massive particles eventually decay into radiation (photons). This is required by the second law of thermodynamics: bound states are lower-entropy than radiation, and entropy increases. When no massive particles remain to anchor temporal reference points, the relational structure supporting space and time degrades. Eventually, with at most one massive particle remaining, Axiom 1 fails: a single entity with nothing to compare against cannot sustain its existence.

This final particle, having absorbed all remaining photons, contains the total energy of the universe in a single point. But a single entity violating Axiom 1 is unstable. It decays into multiple particles, which immediately establish temporal relations (comparisons), generate spatial structure, and initiate a new cycle—a new Big Bang.

This model shares features with Penrose’s Conformal Cyclic Cosmology (CCC) [29], which proposes that the heat death of one universe conformally maps to the Big Bang of the next. It also connects to the Steinhardt-Turok cyclic model [30]. PTI’s specific contribution is the relational mechanism: the cycle is driven by the requirement that entities must interact to exist.

16.1 The Cosmic Microwave Background

The CMB [31] is explained as the thermal signature of the first epoch of relational comparison: when the singularity decayed into many particles and the relational structure exploded into space-time, the initial comparisons were nearly uniform (all derived from the same source). The tiny anisotropies ($\Delta T/T \sim 10^{-5}$) reflect the inherent granularity of the discrete comparison process—quantum fluctuations in the initial relational operations.

17. Discussion

17.1 Relationship to Established Frameworks

PTI draws on and extends several established lines of research: (i) Causal set theory provides the mathematical foundation for the discrete temporal partial order. (ii) Jacobson's thermodynamic derivation provides the bridge from microscopic relational dynamics to macroscopic gravity. (iii) Van Raamsdonk's entanglement/geometry correspondence provides the mechanism for spatial emergence. (iv) The river model provides mathematical equivalence with GR. (v) Rovelli's relational QM provides the interpretive framework for frame-dependent measurements. (vi) The ER=EPR conjecture provides the connection between entanglement and spatial connectivity.

PTI's contribution is to organize these insights into a unified, axiomatically compact framework with a single ontological primitive (the relational comparison) and a single emergence hierarchy ($T \rightarrow S \rightarrow E \rightarrow M$). No other framework currently connects all six of these research programs.

17.2 Open Questions

Several aspects of PTI require further development: (a) The three-dimensionality of space must be derived from the comparison algebra, not assumed. (b) The $SU(3)/SO(3)$ correspondence must be placed on rigorous mathematical footing. (c) The quantitative prediction for dark matter rotation curves must be calculated. (d) The Higgs self-coupling correction must be computed. (e) The transition from discrete relational dynamics to the Standard Model Lagrangian must be explicitly constructed.

17.3 Testable Predictions

The companion document "Experimental Tests for Polarized Time Inertia" proposes over 25 specific tests. The most critical near-term predictions are: (1) No dark matter particle will be found. (2) Gravitational wave signals contain Planck-scale noise. (3) Photon vacuum dispersion is exactly zero. (4) The proton lifetime is finite. (5) The double-slit decoherence curve follows a comparison-counting exponential form.

18. Conclusion

Polarized Time Inertia proposes that the universe is a self-referential relational engine. Three axioms—Relational Existence, Hierarchical Condensation, and Frame-Dependent Decomposition—generate an emergence hierarchy in which time is the primitive structure, space emerges from entangled temporal relations, energy from condensed space-time, and mass from bound energy triplets. Gravity is the inward flow of spatial degrees of freedom toward mass concentrations—mathematically equivalent to GR, physically amenable to quantization. Quantum phenomena arise naturally from the discrete, relational, frame-dependent character of the underlying structure.

This revised formulation corrects imprecise claims from the original theory, explicitly connects each axiom to established physics, and identifies the precise boundaries between established results and novel predictions. PTI is not a replacement for GR or QM but a deeper layer from which both emerge as valid projections—different points of view on the same relational reality.

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Appendix A: Equation Reference

All principal equations used in this paper are collected below for reference.

Equation Name	Equation
Relational Existence (Axiom 1)	$\exists x \Leftrightarrow \exists y : I(x, y) \neq \emptyset$
Hierarchical Condensation (Axiom 2)	$T \otimes T \rightarrow S, \quad S \otimes T \rightarrow E, \quad E \otimes S \otimes T \rightarrow M$
Frame-Dependent Decomposition (Axiom 3)	$\Phi_F(R) = P_F \cdot R$
Temporal Emergence	$C(e_1, e_2) \rightarrow \Delta\tau \neq 0 \Rightarrow \text{temporal order exists}$
Spatial Emergence (Ryu-Takayanagi)	$S_{ij} \propto \text{Entanglement}(C_i, C_j); \quad A = 4G_N S_{EE}$
Mass Formation	$M = E_1 \otimes E_2 \otimes E_3, \quad E_1 \perp E_2 \perp E_3$
Spatial Flow Velocity	$v_{\text{flow}}(r) = \sqrt{2GM/r} = c\sqrt{r_s/r}$
Gravitational Acceleration	$a(r) = \Gamma_{\text{conversion}} / (4\pi r^2) = GM/r^2$
GR–QM Bridge	$G_{\mu\nu} = (8\pi G/c^4)T_{\mu\nu} \leftrightarrow \langle \sum_i \Gamma_i(S \rightarrow T) \rangle / V$
Einstein Deflection	$\Delta\theta = 4GM/(c^2 b)$
Null Geodesic	$ds^2 = -c^2 d\tau^2 = 0 \Rightarrow \tau = 0, \quad d_{\text{proper}} = 0$
Higgs VEV	$\Phi_{\text{Higgs}} = v + h(x), \quad v \approx 246 \text{ GeV}$
Wavefunction (Relational)	$\Psi(x, t) = \sum_n c_n R_n\rangle \rightarrow R_k\rangle$
Tunneling Probability	$P \propto \exp(-2\kappa d), \quad \kappa = \sqrt{[2m(V-E)]/\hbar}$
Entropy (Relational)	$S = k_B \ln(\Omega_{\text{relations}}), \quad d\Omega/dt \geq N/t_{\text{Planck}} > 0$
Dark Energy Balance	$dV/dt = \Gamma_{\text{gen}}(T \otimes T \rightarrow S) - \Gamma_{\text{cons}}(S \rightarrow T \text{ by } M)$
Event Horizon	$r_s = 2GM/c^2 : \quad v_{\text{flow}}(r_s) = c$
Entanglement Locality	$ds^2_{\text{null}} = 0 \Rightarrow d(A, B)_{\text{rel}} = 0$
Color Confinement	$M_{\text{stable}} = E_{\text{red}} \otimes E_{\text{green}} \otimes E_{\text{blue}} \leftrightarrow E_x \otimes E_y \otimes E_z$