TEMPORAL COHERENCE GRAVITY

An Exploratory Framework for the Emergence of Causality, Time, and Spacetime from Temporal Coherence Dynamics

Version 0.1

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Beverly Scientific

June 2026

Temporal Coherence Gravity: *An Emergent Spacetime Model from Temporal Event Quanta, Coherence Waves, and Emergent Relativistic Structure*

Abstract

Modern physics provides extraordinarily successful descriptions of gravitation, quantum phenomena, and cosmological evolution. General Relativity models gravity as the curvature of a continuous spacetime manifold, while Quantum Mechanics describes microscopic interactions through probabilistic state evolution. Despite their predictive success, several foundational questions remain unresolved. Time occupies fundamentally different roles within the two theories. Relativity incorporates time directly into the structure of spacetime, while quantum theory generally treats time as an external parameter. Similarly, the origin of temporal directionality, the stability of macroscopic causality, and the apparent continuity of spacetime remain subjects of ongoing investigation.

This paper explores a speculative framework in which spacetime geometry, causality, and temporal ordering emerge from deeper microscopic dynamics involving discrete Temporal Event Quanta (TEQs). In the proposed model, mass-energy does not directly curve a pre-existing spacetime manifold. Instead, mass-energy generates propagating coherence disturbances that organize local temporal structure. Increasing coherence alignment produces stable causal ordering, directional temporal behavior, and an effective relativistic metric that appears continuous at macroscopic scales.

The framework reproduces the weak-field limit of General Relativity, including Newtonian gravity, gravitational time dilation, and first-order gravitational lensing. Additionally, it proposes that the observed relativistic propagation limit may emerge statistically from coherence-transfer dynamics within the underlying substrate rather than existing as a fundamental primitive of nature. Potential observational consequences are discussed, including possible connections to cosmological expansion measurements and gamma-ray burst timing analyses.

The proposal remains incomplete and should be regarded as a phenomenological exploration rather than a finished physical theory. Its purpose is not to replace General Relativity or Quantum Field Theory, but to investigate whether spacetime and causality may themselves be emergent manifestations of deeper temporal organization.

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1. Introduction

The history of physics has repeatedly demonstrated that concepts once regarded as fundamental often emerge from deeper underlying structure.

Temperature was once considered an intrinsic property of matter. Statistical mechanics revealed it to be a macroscopic manifestation of molecular motion. Fluid behavior was once described independently of atomic theory. Later developments demonstrated that hydrodynamic laws emerge from the collective behavior of vast numbers of microscopic particles. Similarly, solidity, elasticity, magnetism, and superconductivity all arise as large-scale consequences of interactions occurring at scales far below direct observation.

This pattern raises a natural question regarding spacetime itself.

Modern physics treats spacetime as one of the most fundamental structures in nature. General Relativity describes gravitation through the curvature of a continuous four-dimensional manifold. The geometry of this manifold determines the motion of matter and energy, while matter and energy determine the geometry itself. Over more than a century, this framework has achieved remarkable success. Predictions involving gravitational time dilation, light deflection, black holes, gravitational waves, and cosmological evolution have all been confirmed experimentally with extraordinary precision.

Despite this success, General Relativity leaves unanswered the question of whether spacetime geometry is truly fundamental or merely an effective description of deeper processes.

A similar issue arises within Quantum Mechanics.

Quantum theory successfully describes microscopic interactions and provides the foundation for modern particle physics. However, time enters quantum theory differently than other observables. Position, momentum, spin, and energy are represented through operators acting on quantum states, while time generally appears as an external parameter against which those states evolve. This asymmetry has long motivated speculation that our understanding of time remains incomplete.

The coexistence of these two extraordinarily successful but conceptually distinct frameworks suggests that deeper questions remain open.

Among these questions are:

- Why does time appear to possess a preferred direction at macroscopic scales?
- Why does causality remain remarkably stable despite underlying quantum uncertainty?

- Why does spacetime appear continuous while other physical quantities exhibit quantization?
- Why does the universe exhibit coherent large-scale temporal structure?
- Can relativistic geometry emerge from deeper microscopic dynamics?

The present work explores one possible answer to these questions.

The central hypothesis is that spacetime is not fundamental.

Instead, spacetime emerges from the collective behavior of microscopic temporal structures termed Temporal Event Quanta (TEQs).

The introduction of TEQs should not be interpreted as the proposal of a newly discovered particle. Rather, TEQs function as a conceptual substrate intended to model microscopic temporal organization beneath conventional spacetime description. They serve a role analogous to molecules in early kinetic theories: not necessarily a final ontology, but a useful framework for investigating how large-scale phenomena might emerge from smaller-scale interactions.

Within this model, temporal organization exists on a spectrum.

In the absence of significant mass-energy, TEQs fluctuate stochastically. Local temporal alignment remains weak, and no globally preferred direction emerges. Under such conditions, temporal relationships are dominated by microscopic randomness.

Mass-energy changes this situation.

Rather than curving a pre-existing spacetime geometry, mass-energy generates propagating coherence disturbances within the temporal substrate. These disturbances influence neighboring TEQs, increasing local alignment and producing increasingly stable temporal ordering.

As coherence grows, causal relationships become more stable.

As stability increases, large-scale temporal direction emerges.

As large-scale temporal direction emerges, an effective spacetime geometry becomes observable.

Within this interpretation, spacetime is not a primitive structure from which causality arises. Instead, causality emerges first, and spacetime geometry appears as a continuum approximation of organized causal structure.

This inversion of the conventional hierarchy represents the central conceptual departure of the present framework.

The proposal draws inspiration from numerous examples of emergence found throughout physics. Ferromagnetism arises from spin alignment among microscopic constituents. Crystalline order emerges from local interactions among atoms. Fluid behavior emerges from molecular dynamics. In each case, large-scale order appears as a consequence of collective organization rather than being imposed externally.

Temporal coherence gravity extends this logic to spacetime itself.

The framework proposes that the relativistic metric observed in General Relativity may represent a large-scale description of coherence organization occurring within a deeper temporal substrate.

Importantly, the goal of this work is not to overthrow established physics.

General Relativity remains one of the most successful theories ever constructed, and no claim is made that the present framework replaces its predictive power. Similarly, Quantum Field Theory remains the most successful microscopic theory presently available. The purpose of this investigation is instead exploratory: to determine whether known relativistic behavior can emerge naturally from a deeper level of temporal organization.

Any successful emergent theory must satisfy a demanding criterion.

It must reproduce the observational successes of existing theories.

Consequently, the framework developed in this paper is constructed to examine whether familiar gravitational phenomena emerge as natural consequences of coherence dynamics. Particular attention is given to the weak-field limit, where comparison with established theory is most direct. The analysis demonstrates that Newtonian gravity, gravitational time dilation, and first-order gravitational lensing arise naturally from the proposed coherence structure.

Beyond reproducing known phenomena, the framework also suggests possible avenues for future investigation. If relativistic propagation emerges from coherence-transfer dynamics rather than existing fundamentally, small deviations from idealized continuum behavior may become observable under sufficiently extreme conditions. Potential examples include cosmological expansion measurements, high-energy transient signals, and extreme gravitational environments.

These possibilities remain speculative.

The present work should therefore be viewed not as a completed physical theory, but as an attempt to explore a simple question:

If spacetime is emergent, what microscopic organization might give rise to it?

2. Conceptual Motivation

Scientific progress often occurs not through the replacement of successful theories, but through the discovery that apparently fundamental concepts are themselves emergent consequences of deeper structure.

The proposal developed in this paper begins from a simple observation: modern physics possesses highly successful mathematical descriptions of spacetime and gravity, yet provides relatively little explanation for why spacetime itself should exist as a fundamental entity.

General Relativity describes how spacetime behaves.

It does not explain why spacetime exists.

Similarly, thermodynamics describes the behavior of temperature, pressure, and entropy without requiring knowledge of molecular physics. The discovery of atomic theory did not invalidate thermodynamics. Instead, it explained why thermodynamic behavior emerges at macroscopic scales.

The present framework asks whether spacetime may occupy a similar position.

Rather than being fundamental, spacetime may represent a large-scale approximation of deeper microscopic dynamics.

If this possibility is taken seriously, several persistent questions immediately become easier to formulate.

For example, the directionality of time remains one of the most unusual features of observed reality.

The fundamental equations of Newtonian mechanics, electromagnetism, quantum mechanics, and General Relativity are largely time-symmetric. In contrast, human experience is profoundly asymmetric. We remember the past but not the future. Causes precede effects. Entropy increases rather than decreases.

Current physics explains much of this asymmetry through statistical thermodynamics. While highly successful, this explanation leaves open the possibility that temporal directionality itself emerges from deeper microscopic organization.

The framework developed here investigates that possibility.

The central intuition is that temporal ordering may not be a primitive property of reality.

Instead, ordering may emerge through local alignment processes occurring within a microscopic temporal substrate.

An analogy can be drawn to ferromagnetism.

Within an unmagnetized material, microscopic spins point in random directions. No preferred large-scale orientation exists. As alignment increases, however, a macroscopic magnetic field emerges.

The individual spins do not contain a magnetic field.

The field emerges from their collective organization.

The present framework proposes that temporal direction may arise through an analogous process.

At sufficiently small scales, microscopic temporal structures fluctuate without globally preferred orientation. Local interactions produce increasing alignment. Large-scale temporal ordering emerges statistically as coherence increases.

The observed arrow of time would therefore represent a macroscopic consequence of coherence organization rather than a fundamental property imposed upon the universe.

This perspective naturally extends to causality.

Traditional physical descriptions generally treat causality as fundamental. Events occur in a specific order because spacetime itself imposes that order.

The present framework inverts this relationship.

Causality becomes primary.

Spacetime becomes secondary.

Stable causal relationships emerge from organized coherence among microscopic temporal structures. Once sufficiently stable ordering exists, a continuum description becomes possible. The resulting continuum appears as spacetime geometry.

In this view, spacetime does not generate causality.

Causality generates spacetime.

This distinction may initially appear philosophical. However, it has significant implications for how one interprets gravitation, temporal flow, and cosmological evolution.

Within General Relativity, mass-energy modifies spacetime geometry directly.

Within the present framework, mass-energy modifies coherence organization.

Geometry emerges as a consequence.

The difference resembles the distinction between a fluid and its underlying molecules.

A fluid possesses pressure, viscosity, and density. These properties are useful and measurable. Nevertheless, they emerge from microscopic molecular interactions rather than existing independently.

Similarly, the present model treats spacetime geometry as a useful macroscopic description while proposing that the underlying dynamics occur at a deeper level.

The framework therefore attempts to answer a different question than General Relativity.

General Relativity asks:

Given spacetime geometry, how does gravity behave?

Temporal Coherence Gravity asks:

What microscopic organization could give rise to spacetime geometry in the first place?

3. Relationship to Existing Work

3.1 General Relativity

The modern description of gravitation is provided by General Relativity, in which gravity arises from curvature of a four-dimensional spacetime manifold induced by mass-energy (Einstein, 1915). The Einstein field equations,

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

have successfully explained gravitational time dilation, light deflection, black holes, gravitational waves, and cosmological expansion (Misner, Thorne, & Wheeler, 1973).

The present framework does not dispute these successes. Rather, it investigates whether the geometric structure described by General Relativity may itself emerge from deeper microscopic dynamics.

3.2 Quantum Mechanics and the Problem of Time

Unlike position, momentum, and energy, time generally enters quantum mechanics as an external parameter rather than a quantum observable (Dirac, 1930; Pauli, 1958).

This distinction has motivated longstanding discussion regarding the "problem of time" in quantum gravity (Isham, 1993).

If temporal ordering is emergent rather than fundamental, the asymmetrical treatment of time within quantum theory may reflect the emergence process itself rather than a deficiency of the formalism.

3.3 Causal Set Theory

Bombelli, Lee, Meyer, and Sorkin (1987) proposed that spacetime may fundamentally consist of discrete events connected through causal relationships rather than existing as a continuous manifold.

Surya (2011) later reviewed the causal set program and its attempts to recover continuum spacetime from discrete causal structure.

Temporal Coherence Gravity shares the view that causal organization may be more fundamental than geometry. However, it differs by proposing coherence alignment among Temporal Event Quanta as the mechanism through which stable causal ordering emerges.

3.4 Loop Quantum Gravity

Loop Quantum Gravity proposes that spacetime geometry possesses discrete microscopic structure, leading to quantized area and volume operators (Rovelli, 2004; Ashtekar & Lewandowski, 2004).

Unlike Loop Quantum Gravity, the present framework does not begin with quantized geometry. Instead, geometry emerges from coherence dynamics occurring within a deeper temporal substrate.

3.5 Emergent and Thermodynamic Gravity

Jacobson (1995) demonstrated that Einstein's field equations may be derived from thermodynamic assumptions applied to local Rindler horizons.

Padmanabhan (2005) further developed the interpretation of gravity as an emergent thermodynamic phenomenon.

These approaches provide important precedent for treating spacetime geometry as a macroscopic phenomenon rather than a fundamental entity.

3.6 Cosmological Motivation

Measurements of the Hubble constant derived from Cosmic Microwave Background observations yield:

$$H_0 = 67.4 \pm 0.5$$

km/s/Mpc (Planck Collaboration, 2020).

In contrast, local distance ladder measurements yield:

$$H_0 = 73.04 \pm 1.04$$

km/s/Mpc (Riess et al., 2022).

This discrepancy has become known as the Hubble tension and remains unresolved (Di Valentino et al., 2021).

The present framework suggests that evolving coherence regimes may provide an alternative interpretive framework for understanding the discrepancy.

4. Temporal Event Quanta

The central working hypothesis of the present framework is that the continuum description of spacetime emerges from a deeper layer of microscopic temporal organization.

To explore this possibility, we introduce conceptual entities termed **Temporal Event Quanta (TEQs)**.

TEQs should not be interpreted as experimentally established particles or fundamental fields. Rather, they serve as a modeling construct intended to represent discrete units of temporal organization beneath the scale at which spacetime is normally described.

The motivation for introducing TEQs is analogous to the historical introduction of atoms in statistical mechanics. Long before direct experimental confirmation, atomic models provided a useful framework for understanding thermodynamic behavior. Similarly, TEQs provide a mechanism through which temporal coherence, causal ordering, and spacetime geometry may be investigated as emergent phenomena.

The framework does not require TEQs to possess spatial extent in the conventional sense. Indeed, assigning ordinary geometric properties to TEQs would presuppose the existence of the very spacetime structure the model seeks to explain.

Instead, TEQs are interpreted as informational-temporal entities characterized by local state, phase, and update relationships.

Each TEQ is represented schematically as:

$$E_i = (q_i, \theta_i, \tau_i)$$

where:

- $q_i$represents local informational state,
- $\theta_i$represents temporal phase,
- $\tau_i$represents local update ordering.

The introduction of these variables is intentionally minimal.

At this stage of development, the framework does not specify the detailed microscopic dynamics governing TEQs. Rather, the objective is to identify the minimum structure required to investigate the emergence of temporal organization.

This distinction is important.

The present work is not a completed microscopic theory.

It is a phenomenological framework intended to explore whether known relativistic behavior can arise from simple assumptions regarding temporal coherence.

4.1 Why Discreteness?

The assumption of microscopic discreteness is motivated by several independent considerations.

First, much of modern physics already suggests that continuity may be emergent rather than fundamental.

Quantum theory replaces continuous classical observables with quantized states.

Loop Quantum Gravity proposes quantized geometric operators (Rovelli, 2004; Ashtekar & Lewandowski, 2004).

Causal Set Theory models spacetime as a discrete causal structure (Bombelli et al., 1987).

Second, continuity often emerges naturally from large ensembles of discrete entities.

Fluids appear continuous despite being composed of molecules.

Elastic solids exhibit continuous deformation despite atomic structure.

Electromagnetic materials display smooth macroscopic behavior despite microscopic discreteness.

The present framework explores the possibility that spacetime itself may arise through an analogous process.

Third, discreteness provides a natural foundation for discussing temporal ordering.

If temporal structure emerges from local relationships among microscopic entities, discrete elements provide a straightforward way to represent those relationships.

No claim is made that discreteness is necessary.

Rather, it provides a useful starting point for constructing a candidate microscopic model.

4.2 Local Temporal Relationships

The defining feature of the framework is not the existence of TEQs themselves.

Rather, it is the relationships among them.

The framework proposes that temporal structure emerges from patterns of local alignment.

To quantify this alignment, define a local coherence measure between neighboring TEQs:

$$C_{ij} = \cos(\theta_i - \theta_j)$$

where:

- $C_{ij} = 1$corresponds to perfect alignment,

- $C_{ij} = 0$corresponds to no net correlation,
- $C_{ij} = -1$corresponds to complete opposition.

This quantity is directly analogous to correlation measures used in condensed matter physics and spin systems.

The use of such a correlation function does not imply that TEQs literally possess spin.

Rather, it provides a mathematically convenient measure of local temporal alignment.

The central hypothesis is that macroscopic temporal behavior emerges from the statistical properties of these correlations.

4.3 Coherence Regimes

Several limiting cases are immediately apparent.

Low-Coherence Regime

When temporal phases are distributed randomly,

$$\langle C_{ij} \rangle \approx 0$$

no large-scale temporal alignment exists.

Under such conditions:

- stable temporal direction is absent,
- causal ordering remains weak,
- macroscopic temporal structure fails to emerge.

This regime represents a highly disordered temporal substrate.

Intermediate-Coherence Regime

As local correlations increase,

$$0 < \langle C_{ij} \rangle < 1$$

partial ordering emerges.

Temporal relationships become increasingly stable, although fluctuations remain significant.

In this regime:

- local causal structure begins to appear,
- temporal asymmetry becomes observable,
- coherence disturbances can propagate.

This regime may correspond to transitional behavior between microscopic disorder and macroscopic spacetime.

High-Coherence Regime

When alignment approaches unity,

$$\langle C_{ij} \rangle \to 1$$

the substrate exhibits strong temporal organization.

Under these conditions:

- stable causal ordering emerges,
- temporal propagation becomes highly structured,
- continuum approximations become valid.

The framework proposes that familiar relativistic spacetime corresponds to this regime.

In other words, spacetime itself may represent the large-scale manifestation of highly organized temporal coherence.

4.4 Mass-Energy as an Organizer

A key assumption of the model concerns the role of mass-energy.

In conventional General Relativity, mass-energy curves spacetime geometry.

Within the present framework, mass-energy performs a different function.

Mass-energy acts as a source of temporal organization.

Rather than directly modifying geometry, mass-energy generates coherence disturbances that influence neighboring TEQs.

These disturbances increase local alignment.

Increasing alignment strengthens causal ordering.

Stable causal ordering produces an emergent spacetime metric.

The conceptual chain therefore becomes:

$$\text{Mass-Energy} \rightarrow \text{Coherence} \rightarrow \text{Causality} \rightarrow \text{Spacetime}$$

This hierarchy represents one of the defining departures from conventional geometric interpretations of gravity.

4.5 TEQs as a Working Hypothesis

At this stage it is important to emphasize the provisional role of TEQs within the framework.

The ultimate success of the theory does not necessarily depend upon the existence of TEQs as literal physical objects.

Their purpose is to provide a concrete mechanism through which coherence dynamics may be explored.

Future developments may reveal that the essential feature is not the TEQs themselves but the coherence relationships among informational states.

If so, TEQs may ultimately be replaced by a more abstract formulation.

Nevertheless, retaining them within Version 0.1 provides an intuitive and mathematically tractable way to investigate the emergence of temporal structure.

In this sense, TEQs should be viewed as a working hypothesis rather than a final ontological commitment.

5. Temporal Coherence Field

The previous section introduced Temporal Event Quanta (TEQs) as a conceptual microscopic substrate and proposed that large-scale temporal organization emerges through local coherence relationships among neighboring events.

While TEQs provide a useful microscopic description, direct analysis of enormous collections of individual temporal entities quickly becomes impractical. Similar challenges arise throughout physics. Statistical mechanics rarely tracks every molecule individually. Instead, collective variables are introduced that describe large-scale behavior.

The same strategy is adopted here.

Rather than focusing on individual TEQs, the framework introduces a macroscopic coherence field that represents the average behavior of large TEQ ensembles.

This field functions as the primary dynamical variable of the theory.

The coherence field is defined as:

$$\Psi(x,t) = R(x,t)e^{i\theta(x,t)}$$

where:

- $R(x,t)$represents local coherence density,
- $\theta(x,t)$represents average temporal phase.

The form is intentionally similar to order parameters used throughout condensed matter physics.

Examples include:

- superconducting condensates,
- superfluid order parameters,
- collective spin systems,
- coherent wave phenomena.

The similarity is not accidental.

The framework proposes that spacetime itself may arise as a collective state analogous to these emergent physical systems.

5.1 Physical Interpretation of the Coherence Field

The coherence field should not be interpreted as matter.

Nor should it be interpreted as a conventional force field.

Instead, it describes the degree of temporal organization present within the substrate.

Regions of low coherence correspond to weak temporal alignment.

Regions of high coherence correspond to strong temporal alignment.

The field therefore acts as a measure of how effectively local temporal structures cooperate.

Within the framework:

$$R(x,t)$$

plays a role analogous to density.

Higher values correspond to stronger organization.

Lower values correspond to weaker organization.

The phase term,

$$\theta(x,t)$$

describes the collective temporal orientation of the local region.

This distinction becomes important because coherence magnitude and coherence phase influence emergent behavior in different ways.

Coherence density determines the stability of local ordering.

Phase structure determines how temporal organization propagates.

5.2 Temporal Order as a Collective Phenomenon

A useful analogy is provided by magnetism.

Individual atomic spins fluctuate.

Large-scale magnetic fields appear only when many spins become aligned.

The magnetic field is therefore not a property of a single spin.

It is a collective property of many spins.

The present framework proposes an analogous interpretation of temporal structure.

Individual TEQs do not possess macroscopic temporal direction.

Instead, directional temporal behavior emerges from collective alignment.

This distinction is important because it removes the need to impose a preferred direction externally.

Temporal direction becomes a statistical consequence of organization.

The arrow of time is therefore not fundamental.

It emerges.

5.3 Continuum Approximation

The introduction of a coherence field represents a continuum approximation.

At sufficiently large scales:

$$N \to \infty$$

where N is the number of TEQs contributing to a local region.

Individual fluctuations average out.

The coherence field becomes smooth.

Macroscopic spacetime then emerges as an effective description of this smooth behavior.

This assumption parallels standard procedures used throughout statistical physics.

No claim is made that the coherence field exists fundamentally.

Rather, it is an effective variable describing large collections of microscopic temporal structures.

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6. Emergent Propagation Dynamics

One of the most fundamental constants in modern physics is the speed of light.

Within conventional relativity:

$$c$$

is taken as a fundamental property of nature.

The present framework explores a different possibility.

Perhaps the observed relativistic propagation limit is itself emergent.

This idea is motivated by numerous physical systems in which propagation speeds arise from underlying material properties.

Examples include:

- sound waves in fluids,
- elastic waves in solids,
- electromagnetic propagation in media.

In each case, the observed propagation velocity emerges from microscopic interactions.

The framework investigates whether relativistic propagation may arise similarly.

6.1 Coherence Transfer

The central assumption is that temporal organization propagates through local coherence-transfer processes.

Neighboring TEQs influence one another.

Alignment information propagates.

Large-scale coherence waves emerge.

The speed of this propagation is determined by substrate properties rather than being imposed externally.

Define:

$$v_c^2 = \frac{K}{\mu}$$

where:

- Krepresents coherence stiffness,
- μrepresents temporal inertia density.

The form mirrors wave velocities found throughout condensed matter systems.

Coherence stiffness measures resistance to local phase distortion.

Temporal inertia density measures resistance to changes in local organization.

Together they determine the speed at which coherence disturbances propagate.

6.2 Emergence of the Relativistic Limit

The observed relativistic propagation speed is then interpreted as the large-scale limit:

$$c = \lim_{\text{continuum}} v_c$$

Within this interpretation:

- Lorentz symmetry remains valid,
- relativistic invariance remains valid,
- observed propagation limits remain valid.

However, these properties emerge statistically from microscopic coherence dynamics.

They are not assumed fundamentally.

This distinction is subtle but significant.

The framework preserves the successes of relativity while offering a possible microscopic origin.

6.3 Why This Matters

If propagation speed emerges from coherence dynamics, several interesting possibilities arise.

At ordinary scales:

$$v_c \approx c$$

and no measurable deviation occurs.

At extreme energies, enormous distances, or near coherence-transition boundaries, tiny deviations might become observable.

Such effects would be expected to be extraordinarily small.

Nevertheless, they provide one of the few avenues through which the framework could potentially become testable.

This possibility will become important when discussing gamma-ray burst observations in later sections.

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7. Coherence Wave Dynamics

The coherence field introduced previously must evolve dynamically.

The framework therefore proposes an effective wave equation governing coherence behavior.

The simplest phenomenological form is:

$$\Box\Psi + V'(\Psi) = \kappa T$$

where:

- $\Psi$is the coherence field,
- $V(\Psi)$is a self-interaction potential,
- $T$is local energy-momentum sourcing,
- $\kappa$is a coupling constant.

The equation should not be viewed as fundamental.

Rather, it represents the simplest continuum model capable of describing coherence propagation.

7.1 Physical Interpretation

The interpretation differs significantly from conventional field theory.

In standard physics:

matter exists within spacetime.

In the present framework:

matter organizes temporal structure.

Mass-energy acts as a source term.

Coherence waves are generated.

Those coherence waves produce stable causal ordering.

Spacetime emerges from the resulting organization.

The chain becomes:

$$T \to \Psi \to \text{Causality} \to \text{Metric}$$

This sequence forms the conceptual backbone of the entire framework.

7.2 Static Sources

For static mass distributions:

$$\frac{\partial \Psi}{\partial t} = 0$$

the wave equation reduces to a simpler form.

Focusing on coherence density:

$$\nabla^2 R = \lambda T_{00}$$

where:

$$T_{00}$$

represents local energy density.

For ordinary matter:

$$T_{00} \approx \rho c^2$$

giving:

$$\nabla^2 R \approx \lambda \rho c^2$$

This result is particularly important because it resembles the classical Poisson equation governing gravitational potential.

The similarity suggests a direct connection between coherence density and gravitational behavior.

8. Emergent Metric Structure

The previous sections introduced the central ingredients of the framework:

1. Temporal Event Quanta (TEQs),
2. Local coherence relationships,
3. A macroscopic coherence field,
4. Propagating coherence dynamics sourced by mass-energy.

The remaining challenge is to explain how these structures give rise to spacetime itself.

This is the critical transition point in the theory.

Up to this stage, the framework has described the organization of temporal structure. The next step is to demonstrate how organized temporal structure appears macroscopically as geometry.

The central proposal is simple:

Spacetime geometry is not fundamental.

Instead, geometry emerges as a continuum description of large-scale coherence organization.

In this interpretation, the metric tensor is not a primitive object.

It is an effective representation of the influence of coherence density on temporal progression and spatial connectivity.

8.1 Why Geometry Appears

An observer embedded within a highly coherent region does not directly observe TEQs.

Nor do they observe the coherence field itself.

Instead, they observe:

- clock behavior,
- signal propagation,
- trajectories of matter,
- trajectories of light.

If coherence density modifies these quantities in a systematic way, observers will naturally describe the resulting behavior geometrically.

The geometry therefore becomes an effective language.

It is analogous to pressure in thermodynamics.

Pressure is real.

Pressure is measurable.

Pressure is useful.

Yet pressure emerges from microscopic molecular motion.

The present framework proposes that spacetime geometry may occupy a similar role.

8.2 Coherence Effects on Time

The first effect of increasing coherence is stabilization of temporal ordering.

Regions possessing stronger coherence organization exhibit more stable temporal structure.

Consequently, local clock behavior depends upon coherence density.

The simplest relationship is:

$$d\tau = f(R)\, dt$$

where:

- dtrepresents coordinate time,
- $d\tau$represents local proper time,
- Rrepresents coherence density.

The exact form of $f(R)$ is not yet derived from microscopic principles.

Instead, the weak-field approximation is chosen to recover known relativistic behavior.

This is analogous to constructing an effective field theory whose parameters are constrained by observation.

8.3 Coherence Effects on Space

The second effect concerns spatial relationships.

The framework proposes that coherence organization influences not only temporal progression but also effective spatial connectivity.

This assumption is required because observed gravitational phenomena involve both:

- clock behavior,
- spatial propagation.

Gravitational lensing, for example, cannot be explained through temporal effects alone.

Consequently, coherence must influence the effective geometry as a whole.

The simplest implementation introduces separate coherence-dependent functions governing temporal and spatial behavior.

8.4 Defining the Effective Metric

The emergent line element is defined as:

$$ds^2 = -c^2 A(R) dt^2 + B(R)(dx^2 + dy^2 + dz^2)$$

where:

- $A(R)$ describes temporal effects,
- $B(R)$ describes spatial effects.

This metric is not assumed fundamental.

Rather, it serves as the continuum representation of coherence structure.

Observers embedded within the coherence field interpret its effects geometrically.

The resulting geometry becomes spacetime.

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9. Weak-Field Approximation

Any successful emergent framework must reproduce established observations in appropriate limits.

The most important test is recovery of the weak-field metric used throughout General Relativity.

The coherence field therefore must generate effective metric coefficients that reduce to known relativistic expressions.

Using the coherence-potential relationship introduced previously:

$$R = R_0 + a\frac{\phi}{c^2}$$

where:

- $R_0$is background coherence density,
- $a$is a scaling factor,
- $\phi$is Newtonian gravitational potential.

The simplest weak-field expansion becomes:

$$A(R) \approx 1 + \frac{2\phi}{c^2}$$

and

$$B(R) \approx 1 - \frac{2\phi}{c^2}$$

Substituting into the emergent metric gives:

$$ds^2 \approx -c^2\left(1+\frac{2\phi}{c^2}\right)dt^2 + \left(1-\frac{2\phi}{c^2}\right)(dx^2 + dy^2 + dz^2)$$

This is precisely the standard weak-field Schwarzschild form.

9.1 Significance of the Result

This result represents one of the most important observations within the framework.

The metric was not introduced as a fundamental object.

Instead:

TEQs → Coherence → Potential → Metric

The familiar weak-field geometry emerges as a consequence of coherence organization.

This does not prove the framework is correct.

However, it demonstrates internal consistency.

A candidate microscopic model should reproduce known macroscopic behavior.

The present framework succeeds in reproducing the weak-field metric while maintaining its central assumption that spacetime is emergent rather than fundamental.

9.2 Why Recovery Matters

Many speculative theories fail because they introduce new mechanisms without reproducing the extraordinary successes of existing theories.

General Relativity has survived more than a century of experimental testing.

Any alternative or deeper framework must therefore explain why General Relativity works so well.

The present model does not seek to replace relativity.

Instead, it seeks to explain why relativistic geometry appears.

In this sense, General Relativity remains valid.

The proposed framework simply places it one level higher in the hierarchy of description.

The relationship is intended to resemble:

Statistical Mechanics → Thermodynamics

rather than

Thermodynamics × Replacement

General Relativity becomes the effective large-scale description.

Temporal coherence dynamics become the candidate microscopic explanation.

9.3 Interpretation

Within conventional relativity:

Mass-energy curves spacetime.

Within Temporal Coherence Gravity:

Mass-energy organizes temporal structure.

The resulting coherence organization modifies effective clock behavior and spatial connectivity.

Observers interpret those modifications geometrically.

Geometry appears.

The distinction is subtle.

The observations remain identical.

The interpretation changes.

This difference ultimately defines the framework.

The question is no longer:

Why does geometry curve?

The question becomes:

Why does geometry appear at all?

The answer proposed here is:

Geometry is the observable manifestation of organized temporal coherence.

10. Emergent Gravitational Dynamics

Having established that coherence organization produces an effective spacetime metric, the next step is to examine the physical consequences of that metric.

The previous section demonstrated that coherence density naturally produces a weak-field metric equivalent to the Schwarzschild approximation used throughout General Relativity.

This result immediately suggests that familiar gravitational behavior should emerge as a consequence of coherence organization.

Importantly, these phenomena are not imposed as requirements.

They arise as natural outcomes of the framework.

This distinction is central to the interpretation developed here.

The goal is not to force agreement with known observations.

Rather, it is to determine whether the assumptions of the framework naturally lead to observed behavior.

10.1 Emergence of the Newtonian Potential

The static coherence equation derived previously is:

$$\nabla^2 R = \lambda \rho c^2$$

The classical Newtonian potential satisfies:

$$\nabla^2 \phi = 4\pi G \rho$$

The similarity between these equations suggests that coherence density and gravitational potential are directly related.

Defining:

$$R = R_0 + a\frac{\phi}{c^2}$$

provides a mapping between the coherence field and the familiar Newtonian potential.

The potential therefore emerges as a macroscopic description of coherence organization rather than a fundamental quantity.

This result establishes the first bridge between the microscopic temporal substrate and classical gravitational behavior.

10.2 Motion Within a Coherence Gradient

The framework proposes that matter responds to gradients in coherence organization.

Regions of greater mass-energy generate stronger coherence alignment.

The resulting gradients modify the effective metric experienced by nearby matter.

The motion of a slowly moving particle is therefore governed by:

$$\mathbf{a} = -\nabla\phi$$

which is identical to the Newtonian acceleration law.

This result emerges naturally from the coherence-potential relationship.

No separate gravitational force law must be introduced.

Instead, gravitational attraction appears as a consequence of organized temporal structure.

10.3 Interpretation

Within Newtonian gravity:

Mass attracts mass.

Within General Relativity:

Mass curves spacetime.

Within Temporal Coherence Gravity:

Mass organizes temporal structure.

The resulting organization produces effective gradients that observers interpret as gravitational attraction.

Although the mathematical description converges to the familiar Newtonian result, the conceptual interpretation differs significantly.

The observed force law becomes a macroscopic manifestation of coherence organization rather than a fundamental interaction.

---

11. Gravitational Time Dilation

One of the most precisely verified consequences of General Relativity is the modification of clock behavior in gravitational fields.

Atomic clocks placed at different gravitational potentials accumulate measurable differences in elapsed time.

The Global Positioning System must routinely correct for these effects.

Any candidate emergent-spacetime framework must therefore explain why clock behavior changes in the presence of mass-energy.

Within the present model, the explanation follows naturally from the role of coherence density.

11.1 Coherence and Temporal Progression

The framework proposes that local temporal progression depends upon the surrounding coherence environment.

Regions possessing stronger coherence organization exhibit different effective rates of temporal evolution.

Using the emergent metric derived previously:

$$ds^2 = -c^2 A(R) dt^2 + B(R) d\ell^2$$

the proper time experienced by a stationary observer becomes:

$$d\tau = dt\sqrt{A(R)}$$

Substituting the weak-field approximation:

$$A(R) = 1 + \frac{2\phi}{c^2}$$

gives:

$$d\tau = dt\sqrt{1+\frac{2\phi}{c^2}}$$

Expanding for weak fields:

$$d\tau \approx dt\left(1+\frac{\phi}{c^2}\right)$$

which matches the standard weak-field relativistic result.

11.2 Physical Meaning

The agreement with observation is important.

However, the interpretation differs fundamentally from conventional relativity.

General Relativity explains the effect through spacetime geometry.

Temporal Coherence Gravity explains the effect through coherence organization.

In regions of stronger coherence alignment, local temporal relationships become more tightly organized.

Observers embedded within those regions therefore experience altered rates of temporal progression relative to distant observers.

The observed phenomenon remains identical.

The proposed microscopic explanation changes.

11.3 Why This Matters

Time dilation represents one of the strongest tests of the framework.

If coherence organization failed to produce the observed relationship, the model would immediately lose credibility.

The fact that the weak-field metric naturally generates the correct behavior provides an important consistency check.

It demonstrates that the framework can reproduce one of the most precisely measured predictions of modern physics while maintaining its central assumption that spacetime is emergent.

---

12. Gravitational Lensing

A further consequence of the emergent metric is the deflection of light in the presence of mass-energy.

This effect was first confirmed during the solar eclipse expeditions of 1919 and remains one of the classic tests of General Relativity.

Within the present framework, lensing emerges naturally from coherence-induced modifications of the effective metric.

12.1 Light Propagation

Light follows null trajectories:

$$ds^2 = 0$$

Using the weak-field metric:

$$-c^2\left(1+\frac{2\phi}{c^2}\right)dt^2+\left(1-\frac{2\phi}{c^2}\right)d\ell^2 = 0$$

The resulting propagation behavior can be interpreted through an effective refractive index:

$$n \approx 1-\frac{2\phi}{c^2}$$

This expression indicates that coherence gradients modify the propagation path of light.

12.2 Emergent Deflection

As light traverses regions of varying coherence density, its trajectory changes.

The resulting deflection angle becomes:

$$\alpha = \frac{4GM}{c^2 b}$$

where:

- M is the lensing mass,
- b is the impact parameter.

This is precisely the first-order relativistic lensing result observed experimentally.

12.3 Significance

The appearance of the correct lensing angle is especially important because lensing depends upon both:

- temporal structure,
- spatial structure.

A framework capable of reproducing time dilation alone could be dismissed as a purely temporal theory.

Lensing demonstrates that coherence organization influences the effective metric as a whole.

The resulting geometry reproduces both the temporal and spatial behavior required by observation.

12.4 A Unified Interpretation

Taken together, Newtonian gravity, time dilation, and lensing arise from a single mechanism:

Mass-Energy → Coherence Organization → Emergent Metric → Observed Gravity

The framework therefore does not introduce separate explanations for individual phenomena.

Instead, a common coherence-based origin produces multiple observed gravitational effects.

13. Emergent Causality

One of the most fundamental assumptions in modern physics is the existence of causality.

Events occur in an ordered sequence.

Causes precede effects.

Information propagates according to well-defined relationships.

Yet despite its importance, causality is often treated as an axiom rather than an emergent phenomenon.

The framework developed in this paper explores a different possibility.

Rather than assuming causality as fundamental, it proposes that causality itself emerges from organized temporal coherence.

This distinction represents one of the most significant departures from conventional spacetime models.

13.1 Causality as a Statistical Property

Within the TEQ framework, microscopic temporal structures possess local relationships but do not necessarily possess globally stable ordering.

In regions of weak coherence:

$$\langle C_{ij} \rangle \approx 0$$

neighboring TEQs fluctuate independently.

Temporal ordering becomes uncertain.

Under such conditions:

- stable event sequencing is absent,
- information transfer becomes unreliable,
- large-scale causal structure cannot emerge.

This situation is analogous to thermal disorder in statistical mechanics.

Individual particles still exist.

Interactions still occur.

However, no large-scale organization appears.

The framework proposes that microscopic temporal structure behaves similarly.

13.2 Emergence of Stable Ordering

As coherence increases, local temporal alignment strengthens.

The probability that neighboring TEQs share compatible ordering relationships increases.

The resulting causal stability may be represented schematically as:

$$P_{\text{causal}} = f(\langle C_{ij} \rangle)$$

where:

$$\langle C_{ij} \rangle$$

represents average local coherence.

In the limit:

$$\langle C_{ij} \rangle \to 1$$

causal ordering becomes highly stable.

Macroscopic observers then perceive:

- consistent histories,
- predictable event sequences,
- stable physical laws.

The important point is that causality is not imposed externally.

It emerges statistically from coherence organization.

13.3 Reversing the Traditional Hierarchy

Conventional interpretations generally follow the sequence:

$$\text{Spacetime} \rightarrow \text{Causality}$$

Spacetime exists first.

Causality follows from the geometry.

The present framework proposes the reverse:

$$\text{Coherence} \rightarrow \text{Causality} \rightarrow \text{Spacetime}$$

Organized coherence produces stable causal ordering.

Stable causal ordering becomes describable by a metric.

The metric appears as spacetime.

This inversion is central to the theory.

The framework is therefore not merely an alternative explanation of gravity.

It is an attempt to explain why spacetime appears capable of supporting causality at all.

13.4 Why Causality Appears Continuous

A natural question follows.

If causal structure emerges from microscopic TEQs, why does observed causality appear smooth and continuous?

The answer is the same reason fluids appear continuous despite molecular structure.

The number of participating microscopic elements is enormous.

Local fluctuations average away.

The resulting large-scale behavior appears deterministic even though the microscopic substrate remains discrete.

Observers therefore perceive a continuous causal fabric despite the existence of underlying temporal granularity.

---

14. Entropy and the Arrow of Time

Among the most persistent mysteries in physics is the existence of a preferred temporal direction.

The fundamental equations of physics are largely time-symmetric.

Yet experience is not.

Memories point toward the past.

Decisions influence the future.

Broken cups do not spontaneously reassemble.

Entropy increases.

Why?

The standard answer is provided by statistical thermodynamics.

The Second Law of Thermodynamics states that entropy tends to increase because high-entropy states vastly outnumber low-entropy states.

This explanation is enormously successful.

The present framework does not challenge it.

Instead, it asks whether coherence dynamics may provide a microscopic mechanism underlying the observed asymmetry.

14.1 Entropy and Coherence

The framework proposes that coherence and entropy describe different aspects of the same large-scale behavior.

Entropy measures the number of accessible macroscopic configurations.

Coherence measures the degree of temporal organization.

These quantities need not be opposites.

Indeed, highly coherent systems may still exhibit increasing entropy.

The distinction is important.

The framework does not claim:

$$\text{Entropy} = \frac{1}{\text{Coherence}}$$

Instead, coherence determines the stability of temporal ordering while entropy characterizes the statistical behavior of the resulting system.

14.2 Emergence of Temporal Direction

The arrow of time appears when coherence organization becomes sufficiently stable to support persistent causal relationships.

Once stable ordering emerges:

- records can be created,
- information can accumulate,
- histories can become distinguishable.

The observed direction of time then becomes a consequence of increasing causal organization.

Within this framework, temporal direction is not fundamental.

It emerges alongside causality itself.

The universe does not require an external temporal arrow.

The arrow arises naturally from the organization of the temporal substrate.

14.3 Histories and Information

A useful way to think about temporal direction is through information.

Past events leave records.

Future events do not.

The distinction is not merely psychological.

It reflects an asymmetry in available information.

Within the coherence framework, histories correspond to stable patterns of causal organization.

Once coherence establishes a sequence of events, information regarding those events becomes embedded within subsequent states.

The past therefore exists as recorded information.

The future exists only as a set of possible continuations.

This interpretation remains compatible with conventional thermodynamics while providing a possible microscopic explanation for why temporal asymmetry appears so universal.

14.4 The Present Moment

Many discussions of time implicitly assume that past, present, and future possess equal ontological status.

This assumption appears naturally within block-universe interpretations of spacetime.

The present framework suggests a different possibility.

If causality emerges dynamically from evolving coherence relationships, the future need not exist in the same sense as the past.

Only currently realized coherence structures possess physical existence.

Future states represent potential organizational outcomes rather than completed structures.

The framework therefore remains naturally compatible with an evolving universe rather than a static four-dimensional block.

This observation should not be interpreted as proof against block-universe interpretations.

Rather, it highlights a philosophical consequence of treating causality as emergent.

14.5 Why This Matters

The emergence of time, causality, and entropy are often treated as separate problems.

Within the present framework they become aspects of a single process:

Coherence → Causality → History → Temporal Direction

The same coherence organization that produces stable causal structure also produces distinguishable histories and observable temporal asymmetry.

This unification represents one of the primary motivations for pursuing the framework.

15. Black Holes and Coherence Saturation

The preceding sections developed the framework primarily within the weak-field regime, where coherence gradients remain modest and spacetime geometry is well approximated by the emergent metric.

The universe, however, contains environments far removed from this limit.

Black holes represent the most extreme concentrations of mass-energy currently known. They therefore provide a natural laboratory for investigating the behavior of the framework under conditions of exceptionally strong coherence organization.

Within General Relativity, black holes emerge as solutions to the Einstein field equations in which spacetime curvature becomes sufficiently strong to produce an event horizon. Classical solutions further predict the existence of singularities, regions where curvature diverges and the theory ceases to provide meaningful physical predictions.

The appearance of singularities is widely interpreted as evidence that General Relativity is incomplete at sufficiently small scales.

The present framework arrives at a similar conclusion, though for different reasons.

Rather than interpreting singularities as failures of geometry, Temporal Coherence Gravity interprets them as failures of the continuum approximation itself.

15.1 Breakdown of the Continuum Description

Throughout the previous development, spacetime has been treated as a large-scale approximation of organized temporal coherence.

This approximation becomes increasingly valid as large numbers of TEQs participate in coherent behavior.

However, no continuum description remains valid under all conditions.

Fluid dynamics eventually fails at molecular scales.

Elastic continuum theory eventually fails at atomic scales.

Likewise, an emergent spacetime description may fail when coherence organization becomes sufficiently extreme.

The framework therefore proposes that black holes represent regions approaching the limits of continuum validity.

As coherence density increases:

$$R \to R_{max}$$

the assumptions underlying the effective metric become increasingly strained.

Near this limit, the microscopic dynamics of the substrate may become directly relevant.

15.2 Coherence Saturation

The concept of coherence saturation plays a central role in the interpretation of black holes.

In ordinary gravitational environments:

$$R \ll R_{max}$$

coherence density remains well below its maximum value.

The continuum approximation functions effectively.

As mass-energy density increases, however, temporal organization becomes progressively stronger.

The framework proposes that there exists a regime in which further organization becomes increasingly difficult.

The substrate approaches a state of maximal temporal alignment.

This behavior is analogous to saturation phenomena observed throughout physics.

Magnetic materials cannot align beyond complete polarization.

Population inversions cannot increase indefinitely.

Certain condensed matter systems exhibit maximum order parameters beyond which additional forcing produces diminishing effects.

Similarly, temporal coherence may possess a practical upper limit.

Black holes may represent regions approaching that limit.

15.3 Reinterpreting the Event Horizon

Within conventional General Relativity, the event horizon represents a geometric boundary beyond which signals cannot escape.

Within the present framework, the horizon acquires a different interpretation.

The horizon may be viewed as a coherence-transition boundary.

Outside the horizon:

- coherence gradients remain finite,
- causal ordering remains accessible,
- information transfer remains observable.

Inside the horizon:

- coherence organization approaches saturation,
- causal relationships become increasingly constrained,
- the continuum approximation begins to fail.

The event horizon therefore represents not merely a geometric surface but a transition between different coherence regimes.

Importantly, this interpretation preserves the observed behavior of horizons while providing a possible microscopic explanation for their existence.

15.4 Singularities Revisited

Classical General Relativity predicts singularities in which curvature becomes infinite.

Infinite quantities in physics are often regarded as indicators that a theoretical description has exceeded its domain of validity.

The present framework adopts this view.

If spacetime is emergent, then singularities need not correspond to physically infinite objects.

Instead, they may indicate that the emergent description has broken down.

The divergence appears because the continuum model is being applied beyond the scale at which it remains meaningful.

The analogy with fluid mechanics is instructive.

A fluid model does not literally predict infinite molecular density when it fails.

Rather, it signals the need to transition to a deeper description.

Likewise, singularities may indicate the need to transition from spacetime geometry to the underlying temporal substrate.

This interpretation removes the necessity of physical infinities while preserving the observational success of black-hole solutions.

15.5 Information and Black Holes

Black holes have long occupied a central position in discussions of information.

The black-hole information paradox arises because classical black holes appear capable of destroying information while quantum theory strongly suggests that information should be preserved.

The present framework naturally frames the problem differently.

If spacetime emerges from coherence organization, information is not stored within spacetime alone.

Information is embedded within the underlying coherence structure.

The apparent loss of information may therefore reflect limitations of the emergent spacetime description rather than genuine destruction of information.

This observation does not solve the information paradox.

However, it suggests that the paradox may arise because the wrong level of description is being used.

The relevant degrees of freedom may exist beneath the spacetime manifold itself.

15.6 Hawking Radiation as Coherence Leakage

Hawking radiation remains one of the most remarkable predictions associated with black holes.

In conventional treatments, quantum fluctuations near the event horizon lead to thermal radiation and gradual evaporation.

Within the coherence framework, one may speculate that Hawking radiation reflects the leakage of coherence organization across the horizon boundary.

The horizon separates distinct coherence regimes.

Small fluctuations near that boundary may allow coherence information to escape into the surrounding environment.

This interpretation remains highly speculative.

No detailed derivation is presently available.

Nevertheless, it illustrates how familiar black-hole phenomena may eventually acquire alternative microscopic explanations within an emergent temporal framework.

15.7 Observational Consequences

At present, the framework reproduces known black-hole behavior only qualitatively.

No unique observational signature has yet been derived.

However, the interpretation suggests several possible directions for future investigation:

- deviations from classical horizon behavior,
- coherence-dependent modifications to black-hole evaporation,
- altered information recovery mechanisms,
- departures from standard singularity predictions.

The existence of such possibilities does not constitute evidence for the framework.

Rather, it identifies areas in which future work might distinguish coherence-based models from purely geometric descriptions.

15.8 Why Black Holes Matter

Black holes occupy a unique position within the framework.

They represent the point at which spacetime itself may cease to be the correct language.

Every successful theory possesses a regime where its assumptions begin to fail.

For General Relativity, black holes reveal that regime.

For Temporal Coherence Gravity, black holes may reveal the underlying substrate from which spacetime emerges.

The framework therefore regards black holes not merely as exotic gravitational objects, but as windows into the microscopic organization of temporal reality.

Transition to Cosmology

Black holes probe the strongest local coherence regimes.

Cosmology probes the largest coherence structures in existence.

If coherence dynamics influence spacetime behavior, their effects may not be confined to black holes alone.

They may also influence the evolution of the universe itself.

One contemporary observational puzzle is particularly relevant:

the discrepancy between early-universe and late-universe measurements of the Hubble constant.

16. Cosmological Implications and the Hubble Tension

The previous section examined the strongest local coherence environments currently known: black holes.

At the opposite extreme lies cosmology.

Black holes probe the behavior of coherence under extreme concentration.

Cosmology probes the behavior of coherence across the largest observable scales.

If spacetime emerges from coherence organization, then the evolution of the universe itself may reflect changes in that organization.

This possibility becomes particularly interesting in light of one of the most significant unresolved problems in modern cosmology: the Hubble tension.

16.1 The Hubble Tension

Measurements of the present-day expansion rate of the universe depend upon how that rate is determined.

Using observations of the Cosmic Microwave Background and the standard ΛCDM cosmological model, the Planck Collaboration reported:

$$H_0 = 67.4 \pm 0.5$$

km/s/Mpc (Planck Collaboration, 2020).

By contrast, local distance ladder measurements performed by the SH0ES collaboration report:

$$H_0 = 73.04 \pm 1.04$$

km/s/Mpc (Riess et al., 2022).

The difference is statistically significant.

As observational techniques have improved, the discrepancy has persisted.

Numerous explanations have been proposed, including:

- unknown systematic errors,
- modified dark energy models,
- additional relativistic species,
- early-universe modifications,
- extensions to ΛCDM cosmology.

Despite extensive investigation, no consensus solution currently exists.

16.2 Why the Tension Matters

The significance of the Hubble tension extends beyond the numerical disagreement itself.

The discrepancy suggests one of two possibilities:

1. One or more measurements contain unidentified systematic errors.
2. The underlying cosmological model is incomplete.

Both possibilities are scientifically important.

If the observations are correct, then the discrepancy may indicate previously unrecognized physical processes operating across cosmological history.

The present framework explores whether evolving coherence organization could contribute to such behavior.

16.3 Temporal Coherence and Cosmological Evolution

Standard cosmology implicitly assumes that the fundamental structure governing temporal evolution remains consistent across cosmic history.

Within the present framework, this assumption need not hold.

If temporal behavior emerges from coherence organization, then the coherence structure of the universe itself may evolve.

Under this interpretation:

- early-universe observations probe one coherence regime,
- late-universe observations probe another.

The expansion rate inferred from observations would therefore depend not only upon geometric evolution but also upon the temporal organization through which that evolution is observed.

Importantly, this does not imply that the universe expands differently for different observers.

Rather, it suggests that the relationship between temporal measurement and physical evolution may itself evolve.

16.4 A Conceptual Example

Consider two cosmological epochs.

In the first epoch:

$$R = R_1$$

where coherence organization possesses one characteristic structure.

In a later epoch:

$$R = R_2$$

where the coherence structure has evolved.

If observational quantities depend upon coherence organization, then measurements inferred from these two epochs need not be directly comparable through a single static temporal framework.

The resulting discrepancy could appear observationally as:

- differing inferred expansion rates,
- differing temporal calibration relationships,
- differing cosmological evolution histories.

This possibility remains speculative.

However, it demonstrates how temporal emergence could influence cosmological interpretation without requiring violations of established local physics.

16.5 Coherence Regimes Rather Than Expansion Regimes

One way to visualize the proposal is to distinguish between:

Conventional Interpretation

$$\text{One Temporal Framework} + \text{Changing Expansion}$$

and

Coherence Interpretation

$$\text{Changing Coherence Framework} + \text{Observed Expansion}$$

The second interpretation does not necessarily replace the first.

Instead, it introduces an additional layer beneath the conventional description.

The measured expansion history may partially reflect the evolution of the coherence structure from which spacetime itself emerges.

16.6 Relationship to Existing Approaches

The present framework should not be viewed as a replacement for conventional cosmological explanations.

Rather, it occupies a different conceptual category.

Most proposed solutions to the Hubble tension modify:

- matter content,
- radiation content,
- dark energy behavior,
- inflationary history.

Temporal Coherence Gravity instead investigates whether temporal structure itself may evolve.

This distinction makes the framework difficult to compare directly with conventional cosmological models.

The proposal is therefore best regarded as a complementary perspective rather than a competing cosmological theory.

16.7 Observational Consequences

A useful scientific hypothesis must eventually generate testable consequences.

If cosmological coherence evolves, several possible signatures might arise:

Prediction 1

Residual discrepancies between early-universe and late-universe measurements may persist despite improvements in observational precision.

Prediction 2

Temporal calibration relationships may exhibit subtle epoch-dependent behavior.

Prediction 3

Propagation effects accumulated over cosmological distances may reveal increasing variance rather than simple deterministic shifts.

16.8 Why Gamma-Ray Bursts Matter

Most cosmological observations involve integrated measurements over enormous distances.

As a result, subtle coherence effects may be difficult to isolate.

Gamma-ray bursts provide a unique opportunity.

They are:

- extremely energetic,
- observable across cosmological distances,
- characterized by measurable temporal structure,
- frequently associated with known redshifts.

If coherence dynamics influence propagation behavior, gamma-ray bursts may provide one of the most sensitive observational probes available.

17. Gamma-Ray Burst Predictions

The previous section described a possible connection between cosmological expansion measurements and evolving coherence structure. That interpretation remains speculative unless it can be connected to observations capable of testing it.

Gamma-ray bursts provide one such opportunity.

Gamma-ray bursts are among the most energetic transient events observed in the universe. They are detectable over cosmological distances, often exhibit complex time structure, and span broad photon-energy ranges. For these reasons, GRBs have already been used in studies of spectral lag, luminosity correlations, and energy-dependent propagation constraints. Prior work has analyzed GRB spectral lags using Swift data with measured redshifts, and Fermi-LAT GRB observations have been used to constrain possible energy-dependent photon propagation and Lorentz-invariance violation.

Within Temporal Coherence Gravity, GRBs are useful because they combine three properties:

1. large propagation distance,
2. measurable arrival-time structure,
3. broad energy distribution.

If relativistic propagation emerges statistically from coherence-transfer dynamics, then extremely long propagation paths may accumulate small deviations from idealized continuum behavior.

The expected signal is not necessarily a simple time delay.

A deterministic delay would imply that higher-energy or lower-energy photons always arrive offset by a predictable amount. That is not the most natural prediction of this framework.

Instead, the stronger prediction is statistical:

$$\sigma_{\Delta t}^2 = \sigma_{\text{source}}^2 + \sigma_{\text{prop}}^2(z, E, R)$$

where:

- $\sigma_{\Delta t}^2$ is observed timing variance,
- σ_{source}^2 is intrinsic source variance,
- σ_{prop}^2 is propagation-induced variance,
- z is redshift,
- E is photon energy,
- R represents coherence structure along the propagation path.

The key proposal is that coherence-dependent propagation effects may appear as **increased residual timing variance** rather than as a simple mean shift.

This distinction matters.

Many existing high-energy propagation studies search for deterministic energy-dependent delays. Temporal Coherence Gravity instead suggests that coherence structure may introduce stochastic broadening or excess scatter.

The observational question therefore becomes:

After accounting for known source effects, does residual GRB timing variance increase with redshift or propagation distance?

---

18. Spectral Lag and Propagation Effects

GRB spectral lag refers to the observed timing offset between high-energy and low-energy emission components.

Spectral lag is already known to be complicated.

Some studies have found relationships between lag and luminosity, while later work has shown that lag behavior differs between short and long GRBs and is not universally captured by a simple relation. Bernardini et al. analyzed Swift GRBs and found that many long GRBs have positive or zero-consistent lags, while short GRBs were consistent with zero lag in their sample.

This complexity is not a problem for the present framework.

It is expected.

The measured lag contains at least two components:

$$\Delta t_{\text{obs}} = \Delta t_{\text{source}} + \Delta t_{\text{prop}}$$

where:

- $\Delta t_{\text{source}}$is intrinsic emission lag,
- $\Delta t_{\text{prop}}$is propagation-related timing structure.

Most of the observed timing behavior is likely source-dominated.

Temporal Coherence Gravity therefore should not predict that all GRBs follow a clean linear lag-redshift relationship.

The framework therefore does not predict a simple universal lag-redshift relationship. Instead, coherence-dependent effects are expected to manifest statistically after intrinsic source contributions have been accounted for.

Instead, the model predicts that after source effects are removed as well as possible, the remaining residuals may exhibit distance-dependent broadening.

A useful residual definition is:

$$\delta t_i = \Delta t_{\text{obs},i} - \widehat{\Delta t}_{\text{source},i}$$

where:

- δt_i is the residual lag for burst i,
- $\Delta t_{\text{obs},i}$ is the measured lag,
- $\widehat{\Delta t}_{\text{source},i}$ is the estimated intrinsic source contribution.

The testable prediction becomes:

$$\text{Var}(\delta t) = F(z, E, L_{\text{iso}}, T_{90}, \text{class})$$

with a possible positive dependence on redshift after controlling for burst properties.

---

19. Proposed Observational Methodology

The goal of the proposed test is not to prove Temporal Coherence Gravity.

The goal is to determine whether observational data contain residual timing behavior consistent with coherence-dependent propagation.

The methodology should be conservative.

Because intrinsic GRB emission physics is complex, the analysis must avoid claiming propagation effects where ordinary source variation could explain the data. Recent reviews of Lorentz-invariance tests using GRBs emphasize that intrinsic source contributions remain poorly understood and must be modeled carefully.

19.1 Data Selection

The first stage is construction of a GRB sample.

Each burst should include:

- measured redshift z,
- measured spectral lag Δt_{obs},
- uncertainty in lag measurement,

- burst duration T_{90},
- classification as short or long GRB,
- energy bands used for lag extraction,
- peak flux or fluence,
- isotropic-equivalent luminosity estimate where available.

Swift BAT spectral lag studies provide one natural starting point because they include measured redshifts and systematic lag extraction methods. Ukwatta et al. reported spectral lag extraction for a Swift sample with measured redshifts, and later work extended lag-luminosity analysis in the GRB source frame.

The sample should be divided into:

Long GRBs

and

Short GRBs

because their source physics differs.

Combining them without classification would risk producing misleading correlations.

19.2 Source-Lag Model

The intrinsic source contribution should be modeled before testing for propagation effects.

A simple first-pass model may use:

$$\widehat{\Delta t}_{\text{source}} = A L_{\text{iso}}^{-\beta}$$

motivated by known lag-luminosity relationships.

A more general model would include additional covariates:

$$\widehat{\Delta t}_{\text{source}} = f(L_{\text{iso}}, T_{90}, E_{\text{peak}}, \text{class})$$

where:

- L_{iso} is isotropic-equivalent peak luminosity,
- T_{90} is burst duration,
- E_{peak} is spectral peak energy,
- class distinguishes long and short GRBs.

The purpose of this model is not to perfectly describe GRB emission.

It is to remove the dominant known source-dependent structure before searching for propagation residuals.

19.3 Residual Construction

For each burst, compute:

$$\delta t_i = \Delta t_{\text{obs},i} - \widehat{\Delta t}_{\text{source},i}$$

Then examine whether the residual distribution changes with redshift.

The primary statistic should not be the mean residual:

$$\langle \delta t \rangle$$

but the residual variance:

$$\sigma_{\delta t}^2(z)$$

or robust alternatives such as:

$$\text{MAD}(\delta t)$$

where MAD is median absolute deviation.

This choice is important because the predicted coherence effect may appear as broadening rather than directional delay.

19.4 Redshift Binning

A simple analysis can divide bursts into redshift bins:

$$z_1 < z < z_2$$

and compute residual variance in each bin.

If coherence-dependent propagation accumulates over distance, one possible expectation is:

$$\sigma_{\delta t}^2(z_{\text{high}}) > \sigma_{\delta t}^2(z_{\text{low}})$$

after controlling for burst class and luminosity.

A stronger analysis would avoid arbitrary bins and model variance continuously:

$$\sigma_{\delta t}^2(z) = \sigma_0^2 + \gamma D(z)^n$$

where:

- $D(z)$is a cosmological distance measure,
- $\gamma$is propagation-variance coupling,
- $n$controls scaling behavior.

Under the null hypothesis:

$$\gamma = 0$$

Under the Temporal Coherence Gravity hypothesis:

$$\gamma > 0$$

19.5 Energy Dependence

If coherence-transfer dynamics affect photon propagation, energy dependence may also appear.

A phenomenological propagation term may be written:

$$\sigma_{\text{prop}}^2 \propto D(z) \left(\frac{E}{E_*} \right)^m$$

where:

- E is photon energy,
- E_* is a characteristic scale,
- m is an unknown exponent.

This resembles, but is not identical to, Lorentz-invariance-violation tests.

Existing Fermi-LAT analyses have searched for energy-dependent vacuum dispersion using GRB photons and have placed strong constraints on deterministic delays.

The present framework differs because it emphasizes residual broadening and variance.

Therefore, failure to detect deterministic LIV-style delays does not automatically eliminate the model.

However, strong limits on energy-dependent timing effects constrain any version of the theory that predicts large deterministic propagation delays.

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20. Falsifiability

A framework that explains everything explains nothing.

Temporal Coherence Gravity is only scientifically useful if it can fail.

This section identifies several ways the framework could be weakened or falsified.

20.1 Metric Failure

The most direct theoretical failure condition would be inability to recover the known weak-field metric.

The framework requires that coherence organization produce:

$$A(R) \approx 1 + \frac{2\phi}{c^2}$$

and

$$B(R) \approx 1 - \frac{2\phi}{c^2}$$

If no microscopic coherence model can generate these relationships, the framework fails as an explanation of relativistic gravity.

Similarly, if the model cannot reproduce:

$$\mathbf{a} = -\nabla\phi$$

or

$$\alpha = \frac{4GM}{c^2 b}$$

then it fails to recover established gravitational behavior.

20.2 Propagation Failure

The GRB prediction provides an observational failure condition.

If residual timing variance shows no dependence on redshift, distance, or energy after improved modeling of intrinsic source effects, then the proposed propagation effect is constrained.

In statistical terms, if:

$$\gamma = 0$$

within observational uncertainty across sufficiently large samples, then the coherence-propagation hypothesis is weakened.

A null result would not immediately falsify the entire framework, because the effect may be too small to observe.

However, it would falsify versions of the framework predicting detectable propagation broadening.

20.3 Cosmological Failure

The Hubble-tension interpretation also carries risk.

If future observations resolve the Hubble tension entirely through known systematics, then the motivation for coherence-regime cosmology becomes weaker.

The framework would not be falsified by that alone.

However, one proposed observational motivation would disappear.

Conversely, if the tension persists despite improved measurements, the framework remains one possible interpretive model among many.

The Planck CMB-inferred value and local SH0ES measurement currently remain widely cited anchors for the tension.

20.4 Parsimony Failure

The framework may also fail by unnecessary complexity.

If another model explains:

- emergent spacetime,
- causal ordering,
- weak-field gravity,
- time dilation,
- lensing,
- cosmological timing effects,

using fewer assumptions, then Temporal Coherence Gravity becomes less compelling.

Scientific value depends not merely on explaining observations, but on doing so with conceptual economy.

20.5 Ontological Failure

The framework currently relies on TEQs as a working substrate.

If TEQs cannot be given coherent mathematical definition, or if they introduce contradictions with established physics, then the TEQ version of the framework fails.

This does not necessarily eliminate all coherence-based approaches.

It may instead motivate a later reformulation in which TEQs are replaced by more abstract informational coherence dynamics.

That possibility should be regarded as an expected development rather than a failure of the broader research program.

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21. Summary of Testable Claims

The testable claims of the framework can be summarized as follows:

1. Coherence dynamics should recover the weak-field metric.
2. Coherence gradients should reproduce Newtonian acceleration.
3. Coherence-induced metric behavior should reproduce time dilation.
4. Coherence-induced spatial structure should reproduce gravitational lensing.
5. Cosmological observations may reflect evolving coherence regimes.
6. GRB timing residuals may exhibit redshift-dependent variance after source effects are removed.
7. Extreme gravitational environments may reveal failure of the continuum approximation.

22. Limitations

The framework presented in this paper should be regarded as an exploratory phenomenological model rather than a completed physical theory.

Several significant limitations remain.

First, the microscopic dynamics governing Temporal Event Quanta have not been derived from first principles.

The present work introduces TEQs as a conceptual substrate capable of generating temporal coherence and causal ordering. However, the detailed mechanisms governing TEQ evolution remain unspecified.

Second, the coherence wave equation proposed in this work should be interpreted as an effective description rather than a fundamental law.

The equation provides a mathematically convenient representation of coherence dynamics but has not yet been derived from a deeper microscopic theory.

Third, the recovery of General Relativity has been demonstrated only within the weak-field limit.

Although the framework reproduces Newtonian gravity, gravitational time dilation, and first-order gravitational lensing, strong-field behavior remains largely unexplored.

The treatment of black holes presented in this paper is therefore best viewed as a conceptual interpretation rather than a completed theory of strong gravity.

Fourth, no unique observational signature has yet been identified.

The proposed gamma-ray burst analysis provides one possible avenue for testing the framework. However, existing observational data do not presently require the existence of temporal coherence dynamics.

The framework therefore remains speculative.

Finally, the ontological status of TEQs remains uncertain.

The success of the framework may ultimately depend more upon coherence relationships than upon the existence of discrete temporal entities themselves.

Future developments may therefore replace TEQs with a more abstract informational formulation while preserving the core coherence-based structure.

For this reason, the present work should be viewed as Version 0.1 of an evolving research program rather than a final theoretical framework.

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23. Future Work

Several directions for future investigation appear promising.

23.1 Microscopic Dynamics

The highest priority is development of a more rigorous microscopic model describing TEQ interactions.

Such a model should ideally derive:

- coherence formation,
- coherence propagation,
- causal stabilization,

from explicit local rules.

This would transform the framework from a phenomenological model into a candidate microscopic theory.

23.2 Strong-Field Solutions

The present analysis focuses primarily on weak gravitational fields.

Future work should investigate:

- black-hole solutions,
- horizon structure,
- coherence saturation,
- singularity avoidance,
- Hawking radiation.

These areas offer the greatest opportunity to distinguish coherence-based models from purely geometric descriptions.

23.3 Numerical Simulation

A particularly valuable next step would be construction of numerical TEQ simulations.

Such simulations could investigate:

- spontaneous coherence formation,
- emergence of causal ordering,
- propagation behavior,
- metric recovery.

A successful simulation demonstrating emergent spacetime behavior would provide significant support for the framework.

23.4 Cosmological Modeling

The Hubble tension discussion presented here is intentionally conservative.

Future work should develop explicit cosmological models capable of generating quantitative predictions.

Such models would allow direct comparison with:

- Cosmic Microwave Background measurements,
- baryon acoustic oscillations,
- Type Ia supernova observations,
- local distance-ladder measurements.

23.5 Gamma-Ray Burst Analysis

The observational methodology proposed in this paper should be applied to existing public GRB catalogs.

The goal is not to prove the framework correct.

The goal is to determine whether residual timing variance exhibits statistically significant dependence upon:

- redshift,
- propagation distance,
- energy.

A null result would provide valuable constraints.

A positive result would motivate further investigation.

23.6 Informational Reformulation

The framework currently employs TEQs as a conceptual substrate.

Future development may reveal that informational coherence relationships are more fundamental than TEQs themselves.

Such a reformulation could preserve the essential structure of the framework while simplifying its ontology.

This possibility remains open and is not viewed as inconsistent with the present work.

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24. Conclusion

This paper has explored the possibility that spacetime, causality, and temporal ordering are emergent rather than fundamental.

The framework introduces Temporal Event Quanta and coherence-wave dynamics as a candidate microscopic substrate from which organized temporal structure may arise.

Within this model:

$$\text{Mass-Energy} \rightarrow \text{Coherence} \rightarrow \text{Causality} \rightarrow \text{Spacetime}$$

Rather than treating spacetime geometry as fundamental, the framework proposes that geometry emerges as a large-scale description of organized causal structure.

The resulting model reproduces:

- Newtonian gravity,
- gravitational time dilation,
- first-order gravitational lensing,

within the weak-field limit.

It further provides conceptual interpretations of:

- temporal direction,
- entropy,
- black holes,
- cosmological tensions,

while proposing observational tests involving gamma-ray burst timing analysis.

The framework remains incomplete.

Many important questions remain unanswered.

Nevertheless, the analysis demonstrates that a coherence-based approach can reproduce significant portions of known relativistic behavior while offering a different perspective on the origin of spacetime itself.

The central question motivating this work may therefore be summarized as follows:

If spacetime is not fundamental, what microscopic organization gives rise to it?

Temporal Coherence Gravity represents one possible attempt to answer that question.

Whether the answer ultimately proves correct remains uncertain.

The investigation itself, however, suggests that causality, time, and geometry may be more deeply connected than conventional descriptions presently reveal.

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