Emergent Spacetime and Quantum Fields from Coexisting Time Arrows: An Axiomatic Framework

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Abstract

We propose an axiomatic framework, termed Coexisting Time Arrows (CTA), in which spacetime geometry, matter, energy, and quantum phenomena are investigated as potential emergent consequences of the local coexistence of two oppositely oriented temporal sectors, τ_+ and τ_-.

The framework extends the cosmological motivation of the CPT-symmetric universe proposed by Boyle, Finn, and Turok (Phys. Rev. Lett. 121, 251301, 2018) toward a local field-theoretic description in which temporal degrees of freedom are treated as fundamental, while spatial geometry is regarded as an induced structure.

A central mathematical result concerns the construction of a four-dimensional Lorentzian metric from temporal scalar fields. We demonstrate that a bilinear metric constructed from a single pair of scalar-field gradients has rank at most two and is therefore necessarily degenerate in four dimensions.

We introduce a multimode generalization and prove that at least three pairs of temporal modes are necessary to obtain Lorentzian signature $(-+++)$ within the proposed metric ansatz.

An explicit construction with three mode pairs reproduces the Minkowski metric. The resulting geometry admits an interpretation as an induced metric in an auxiliary six-dimensional flat space with signature $(3, 3)$.

The framework further proposes that the gravitational effects attributed to dark matter may originate from a CPT-symmetric baryonic sector, while cosmic acceleration may admit an interpretation based on temporal geometry rather than a fundamental dark-energy component.

Electric charge is hypothesized to arise from local asymmetry between oppositely oriented temporal sectors, and quantum behavior is explored through an operator description of temporal degrees of freedom.

The representation of general curved spacetimes, recovery of Einstein dynamics, derivation of gauge interactions, and quantitative cosmological predictions remain open problems.

CTA thus provides a mathematically explicit realization of flat Lorentzian geometry from temporal fields, together with a broader axiomatic research program for investigating the possible emergence of physical structure from coexisting time arrows.

The multimode construction establishes that three pairs of temporal scalar fields are the minimum required to realize a four-dimensional Lorentzian metric within the proposed bilinear ansatz.

An explicit configuration reproduces Minkowski spacetime and admits an interpretation as an induced metric in an auxiliary flat space of signature $(3, 3)$.

Beyond this geometric result, CTA proposes a unified research framework in which dark matter, cosmic acceleration, electric charge, and quantum phenomena may be investigated as consequences of the interaction between oppositely oriented temporal sectors.

The extension to curved spacetime, the recovery of gravitational dynamics, and the derivation of quantitative observational predictions constitute the principal directions for further development.

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1 Introduction

The nature of time, space, and their relation to matter and quantum phenomena is one of the deepest and most enduring questions in fundamental physics. Traditional cosmology and quantum theory often treat spacetime as a fixed background or as emergent from quantum fields; however, the fundamental origin of temporal directionality and the interplay between the flow of time and geometry remains unclear. Recent theoretical proposals, notably the CPT-symmetric universe scenario introduced by Boyle, Finn, and Turok [7], suggest that the universe may possess a dual temporal structure with two oppositely directed arrows of time. This bold idea offers a fresh perspective on long-standing cosmological puzzles, such as the arrow of time and matter-antimatter asymmetry. A key insight derived from these discoveries is that such emergent CPT-symmetric universes can interact only gravitationally and via weak interactions. This observation raises the question whether what we call dark matter and dark energy might, in a Platonic sense, be merely reflections or projections of these fundamental inter-universal relations that we observe and label as "dark" phenomena. Building on these ideas, we propose a rigorous axiomatic model in which time is a fundamental ontological category. We postulate the local coexistence of two opposite arrows of time within a purely baryonic universe, consisting of two CPT-symmetric, coexisting baryonic sectors, from which spacetime geometry, matter, and quantum phenomena naturally emerge. Our approach treats time as eternal and fundamental, avoiding singular creation events like the Big Bang. In this work, we develop the conceptual, mathematical, and physical foundations of this theory. We explore its implications for gravity, quantum mechanics, dark matter, and cosmology, aiming to establish a coherent and minimal foundation that challenges traditional assumptions and opens new avenues for theoretical and experimental research.

Scope of the Framework. The purpose of this work is to introduce an axiomatic framework and investigate its mathematical and physical consequences, rather than to claim a complete replacement of general relativity, quantum field theory, or the Standard Model. e distinguish results established within the proposed mathematical construction from physical hypotheses and predictions requiring independent derivation and observational verification.

Executive Summary

1. **Fundamental Primacy of Time**: Time is the only absolute and fundamental entity; space and geometry are emergent consequences.

2. **Dual Time Arrows**: The universe contains two coexisting temporal flows (τ_+ and τ_-) with opposite directions, forming a CPT-symmetric structure.

3. **Emergent Geometry**: The interplay of these time arrows induces an emergent spacetime metric $g_{\mu\nu}$ from which classical gravity arises.

4. **Matter as Necessary Consequence**: Matter and energy naturally emerge as necessary manifestations of time and its capacity for change.

5. **Resolution of Dark Matter**: "Dark matter" is interpreted as the CPT-symmetric baryonic sector (τ_-), invisible electromagnetically but gravitationally active.

6. **No Need for Dark Energy**: The apparent cosmic acceleration is a geometric projection, removing the need for a cosmological constant or dark energy.

7. **Emergent Speed of Light**: The value of c arises as a geometric consequence of $g_{\mu\nu}$, not as a fundamental constant.

8. **Quantum Mechanics from Temporal Operators**: Quantum behavior emerges from the operator nature of $\hat{\tau}_{\pm}$, providing a natural unification of quantum mechanics and general relativity.

9. **Particles as Geometric Oscillations**: Standard Model particles are hypothesized as localized topological or oscillatory solutions of the temporal fields.

10. **Unified Ontological Foundation**: All physical phenomena—including matter, geometry, energy, quantum effects, and possibly consciousness—emerge from the minimal axiomatic basis rooted in fundamental time and dual temporal flows.

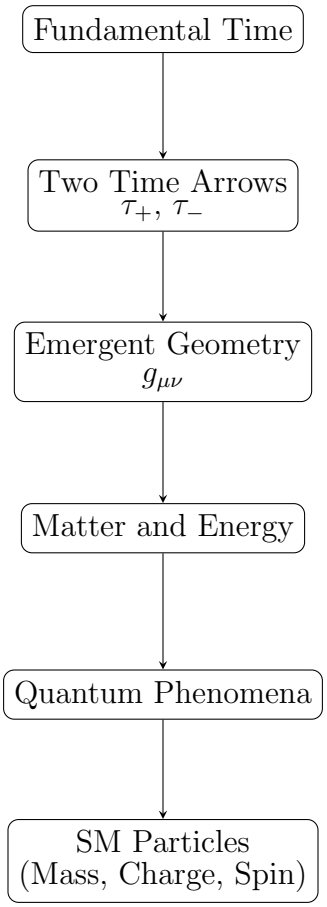


Figure 1: Logical emergence chain: from fundamental time to Standard Model particle parameters.

Mathematical Summary

- **Fundamental temporal sectors:** Two oppositely oriented temporal sectors, τ_+ and τ_-, represented in the multimode construction by scalar fields

$$\tau_+^a, \tau_-^a : M \to \mathbb{R}, \qquad a = 1, \ldots, N.$$

- **Emergent metric:**

$$g_{\mu\nu} = \frac{1}{2} \sum_{a=1}^{N} \left(\partial_\mu \tau_+^a \partial_\nu \tau_-^a + \partial_\mu \tau_-^a \partial_\nu \tau_+^a \right).$$

- **Algebraic minimality:** A single temporal mode pair yields $\mathrm{rank}(g) \leq 2$. Within the proposed bilinear ansatz, at least three mode pairs are required to realize Lorentzian signature $(-+++)$.

- **Flat-spacetime realization:** Three mode pairs are sufficient to reproduce the Minkowski metric through an explicit configuration of temporal scalar fields.

- **Geometric interpretation:** The multimode metric is an induced metric in an auxiliary flat space with signature (N, N). For $N = 3$, the ambient signature is $(3, 3)$.

- **Dynamics:** A complete dynamical formulation consistent with the multimode metric remains under investigation. The previously proposed gravitational and temporal-field equations require re-examination in this formulation.

- **Quantum formulation:** Temporal fields may be promoted to operators, $\hat{\tau}_\pm^a(x)$, with conjugate momenta $\hat{\pi}_{\pm a}(x)$. A consistent canonical quantization and its physical consequences remain to be established.

2 Hypothesis of Electromagnetic Decoupling Between CPT-Symmetric Sectors

2.1 Degeneracy of the original two-field construction

Consider the symmetric tensor constructed from two scalar temporal fields τ_+ and τ_-:

$$g_{\mu\nu}^{(1)} = \frac{1}{2} \left(\partial_\mu \tau_+ \partial_\nu \tau_- + \partial_\mu \tau_- \partial_\nu \tau_+ \right). \tag{1}$$

At each point of a four-dimensional manifold, this tensor is generated by at most two independent covectors. Consequently,

$$\mathrm{rank}\left(g^{(1)}\right) \leq 2. \tag{2}$$

It therefore cannot define a nondegenerate Lorentzian metric of signature $(-,+,+,+)$. This obstruction is algebraic and does not depend on the equations of motion.

2.1.1 Scope and Limitations of the Construction

The three-mode construction establishes that a nondegenerate Lorentzian metric can be generated from three pairs of scalar temporal fields within the proposed bilinear ansatz. The explicit Minkowski realization provides a constructive existence proof for flat four-dimensional spacetime. However, the construction does not establish that all physically relevant curved metrics can be represented in this way. In particular, compatibility with the Schwarzschild, Kerr, and FLRW geometries remains an open mathematical problem. Furthermore, the three temporal mode pairs are introduced as a model assumption. Their existence and number have not yet been derived from the fundamental CTA axioms. The projected gravitational field equations are not generally equivalent to the complete Einstein equations. Consequently, the recovery of general relativity, the propagation of gravitational waves, and the stability of the induced geometry require further investigation.

2.2 A multimode extension

To overcome this degeneracy, we introduce an additional model assumption: each temporal orientation is represented by N scalar modes,

$$\tau_+^a, \quad \tau_-^a, \qquad a = 1, \dots, N. \tag{3}$$

These modes are not postulated as independent physical time dimensions. They are additional scalar degrees of freedom associated with the two temporal orientations. The generalized metric ansatz is

$$\boxed{g_{\mu\nu} = \frac{1}{2} \sum_{a=1}^{N} \left(\partial_\mu \tau_+^a \partial_\nu \tau_-^a + \partial_\mu \tau_-^a \partial_\nu \tau_+^a \right).} \tag{4}$$

This extension is not derived from the original CTA axioms and must be regarded as a separate model assumption.

2.3 Minimal number of temporal modes

Define

$$X^a = \frac{\tau_+^a + \tau_-^a}{2}, \qquad T^a = \frac{\tau_+^a - \tau_-^a}{2}. \tag{5}$$

The metric becomes

$$g_{\mu\nu} = \sum_{a=1}^{N} \left(\partial_\mu X^a \partial_\nu X^a - \partial_\mu T^a \partial_\nu T^a \right). \tag{6}$$

The positive index of inertia of this quadratic form cannot exceed N, because its positive contribution is generated by only N covectors dX^a. A four-dimensional Lorentzian metric with signature $(-,+,+,+)$ requires three positive directions. Therefore,

$$\boxed{N \geq 3.} \tag{7}$$

This is a necessary algebraic condition within the specific ansatz of Eq. (4). The following construction establishes that $N = 3$ is sufficient for at least one nondegenerate Lorentzian geometry.

2.4 Explicit Minkowski construction

On $\mathbb{R}^4$, with coordinates (t, x, y, z), choose

$$\tau_+^1 = t + x, \qquad \tau_-^1 = -t + x, \tag{8}$$
$$\tau_+^2 = t + y, \qquad \tau_-^2 = -t + y, \tag{9}$$
$$\tau_+^3 = t + z, \qquad \tau_-^3 = -t + z. \tag{10}$$

Substitution into Eq. (4) gives

$$\boxed{g_{\mu\nu} = \mathrm{diag}(-3, 1, 1, 1).} \tag{11}$$

Its determinant is

$$\det(g_{\mu\nu}) = -3 \neq 0. \tag{12}$$

Introducing the rescaled coordinate

$$t_{\mathrm{M}} = \sqrt{3}\, t, \tag{13}$$

the line element becomes

$$\boxed{ds^2 = -dt_{\mathrm{M}}^2 + dx^2 + dy^2 + dz^2.} \tag{14}$$

Thus three temporal mode pairs are algebraically sufficient to reproduce Minkowski geometry. This construction establishes neither the dynamical emergence of the metric nor the representation of arbitrary curved spacetimes.

2.5 Geometric interpretation as an induced metric

For $N = 3$, introduce the six-component map

$$Y^A = (X^1, X^2, X^3, T^1, T^2, T^3), \qquad A = 1, \ldots, 6. \tag{15}$$

Let the auxiliary target space carry the constant metric

$$\eta_{AB} = \mathrm{diag}(+1, +1, +1, -1, -1, -1). \tag{16}$$

Then

$$\boxed{g_{\mu\nu} = \eta_{AB} \partial_\mu Y^A \partial_\nu Y^B.} \tag{17}$$

Whenever this metric is nondegenerate, the map Y defines a local isometric immersion

$$Y : (\mathcal{M}^4, g) \longrightarrow (\mathbb{R}^{3,3}, \eta). \tag{18}$$

The immersion has codimension two. The six-dimensional target space is an auxiliary geometric construction. Its introduction does not establish the physical existence of six spacetime dimensions.

2.6 Curvature restrictions

An induced metric obtained from an immersion into flat $\mathbb{R}^{3,3}$ cannot possess an arbitrary intrinsic curvature tensor. For a Lorentzian tangent space of signature $(-,+,+,+)$, the two-dimensional normal space has negative-definite signature $(-,-)$. Choose a local orthonormal normal frame and denote the corresponding symmetric second fundamental forms by $K^I_{\mu\nu}$, where $I = 1, 2$. With the curvature convention used here, the Gauss equation reads

$$\boxed{R_{\mu\nu\rho\sigma} = -\sum_{I=1}^{2} \left(K^I_{\mu\rho} K^I_{\nu\sigma} - K^I_{\mu\sigma} K^I_{\nu\rho} \right).} \tag{19}$$

This equation imposes algebraic restrictions on the intrinsic Riemann tensor. A complete local immersion also requires compatible second fundamental forms and a normal connection satisfying the Codazzi and Ricci equations. Consequently, the present construction does not establish the representability of every four-dimensional Lorentzian geometry. In particular, the compatibility of generic Kerr, Schwarzschild, and FLRW geometries with this specific target-space signature remains to be established.

2.7 Projected gravitational field equations

As a possible dynamical extension, consider the Einstein–Hilbert functional evaluated on the induced metric:

$$S[Y] = \frac{M_*^2}{2} \int_{\mathcal{M}} d^4x \, \sqrt{-g(Y)} \, R[g(Y)]. \tag{20}$$

For variations preserving the nondegenerate Lorentzian sector, and after discarding the appropriate boundary contribution, variation with respect to the embedding fields gives

$$G^{\mu\nu} \nabla_\mu \nabla_\nu Y^A = 0. \tag{21}$$

Here ∇ is the Levi-Civita connection of the induced metric, acting on the scalar fields Y^A. For an isometric immersion, the ambient vector $\nabla_\mu \nabla_\nu Y^A$ is normal to the immersed manifold. Consequently, the independent equations reduce to

$$\boxed{G^{\mu\nu} K^I_{\mu\nu} = 0, \qquad I = 1, 2.} \tag{22}$$

The four tangential combinations vanish as Noether identities associated with diffeomorphism invariance. Thus, although six embedding fields are varied, the codimension-two model supplies only two independent normal equations at a regular immersion. These equations are not generally equivalent to the ten vacuum Einstein equations $G_{\mu\nu} = 0$. In particular, their solution space may contain non-Einstein geometries. No conclusion about additional propagating degrees of freedom, stability, or effective dark-matter contributions follows from these equations alone.

2.8 Open problems

The multimode construction establishes an algebraically consistent route to a nondegenerate Lorentzian metric, but several questions remain unresolved. First, the class of Lorentzian metrics admitting local isometric immersions into flat $\mathbb{R}^{3,3}$ must be characterized. A concrete test is to evaluate the Gauss equations for the Kerr geometry at a regular

point, followed, where applicable, by the Codazzi and Ricci compatibility conditions. Second, the dynamics of the temporal modes requires a separate constraint and perturbation analysis. In particular, the existence of a stable Lorentzian background and propagating gravitational excitations has not been demonstrated. Third, the compatibility of the multimode extension with the original CTA axioms and the proposed CPT transformation must be established at the level of a complete action. Finally, possible electromagnetic interactions between oppositely oriented temporal sectors remain independent hypotheses. They do not follow from the induced-metric construction. The present result is therefore a mathematical extension of CTA rather than a completed dynamical theory of gravity.

2.9 Conclusions and Implications for CTA

The multimode construction leads to several mathematical conclusions. First, a metric constructed from a single pair of scalar temporal fields is necessarily degenerate in four dimensions. Second, within the proposed bilinear metric ansatz, at least three temporal mode pairs are required to reproduce a Lorentzian signature with three positive and one negative eigenvalue. Third, an explicit construction demonstrates that three such pairs are sufficient to generate Minkowski spacetime. Fourth, the resulting geometry admits an interpretation as an induced metric in an auxiliary six-dimensional flat space with signature $(3, 3)$. These results suggest that spatial geometry may be represented through the structure of oppositely oriented temporal modes, without introducing a fundamental spatial metric into the model. However, the construction does not independently explain why physical spacetime has exactly three spatial dimensions. That dimensionality enters through the Lorentzian signature imposed on the model. Furthermore, the representation of general curved geometries, the recovery of Einstein dynamics, and the physical interpretation of the temporal modes remain open problems. The principal achievement is therefore the identification of a mathematically consistent, nondegenerate flat-spacetime realization of the proposed temporal geometry, together with explicit conditions that constrain its extension to curved spacetimes.

3 Operator of Emergence

Within the multimode formulation introduced in Section 3, the emergence operator is defined as

$$\mathcal{F} : \left\{(\tau_+^a, \tau_-^a)\right\}_{a=1}^N \longmapsto g_{\mu\nu},$$

where

$$g_{\mu\nu} = \frac{1}{2} \sum_{a=1}^{N} \left(\partial_\mu \tau_+^a \partial_\nu \tau_-^a + \partial_\mu \tau_-^a \partial_\nu \tau_+^a\right).$$

For a four-dimensional Lorentzian geometry with signature $(-+++)$, at least three temporal mode pairs are required within this construction. The existence of a nondegenerate metric depends on the rank and signature of the resulting tensor, rather than merely on the nonvanishing of the temporal fields. If either entire temporal sector vanishes identically, the induced metric becomes degenerate, with $g_{\mu\nu} = 0$. Thus, Minkowski spacetime is not the consequence of removing one temporal sector, but arises from a specific nondegenerate configuration of both sectors, as demonstrated in Section 3.

3.1 Emergence of Geometry and Structure

By definition and from our axioms, the geometric metric $g_{\mu\nu}$ emerges solely as a result of the local coexistence of the two oppositely directed time arrows, τ_+ and τ_-:

$$\mathcal{F}(\tau_+, \tau_-) \mapsto g_{\mu\nu}.$$

This metric enables the definition of distance, curvature, and thus the existence of structure. The mere presence of geometry implies the possibility of localized configurations, which naturally correspond to what we call "matter". If change is present (as a necessary attribute of time), there must be "something" that changes. Therefore, matter cannot be absent in a universe where time fundamentally exists. Matter is not an optional addition but a necessary manifestation of time's capacity to support dynamic states.

4 Emergence of Fundamental Phenomena

4.1 Emergence of Energy

Energy is formally defined as the generator of temporal evolution in physics. Once time and change exist, energy naturally emerges as a quantitative description of this change:

$$E = \text{capacity to induce change over time.}$$

Thus, energy does not need to be created; it is an inevitable byproduct of the absolute existence of time.

4.2 Formal Statement

We can summarize the ontological necessity as:

$$\text{Time} \implies \text{Change} \implies (\text{Matter} \wedge \text{Energy}).$$

Consequently, matter and energy could not not exist. Their existence is a logical necessity rather than a contingent or spontaneous event.

4.3 Cosmological Consequences

This perspective eliminates the need for a "creation moment" (Big Bang singularity) and supports the view that the universe is an eternal ontological consequence of time itself.

4.4 Emergence of Entropy from Time

In classical thermodynamics, entropy is defined as

$$S = k_B \ln \Omega,$$

where Ω denotes the number of accessible microstates of a given macrostate. Traditionally, entropy is often interpreted as a measure of disorder or "missing information" about a system.

4.4.1 Time as the Foundation of Possible States

In our axiomatic framework, time is absolute and fundamental (Axiom A1). The mere existence of time implies the inevitability of change:

$$\text{Time} \implies \text{Change}.$$

Change presupposes the existence of alternative configurations. As soon as there is change, there exists a set of possible states $\{\sigma_i\}$ that the system can occupy.

4.4.2 Inevitable Emergence of Entropy

Given that time necessitates the possibility of multiple configurations, entropy naturally arises as a quantitative measure of this multiplicity:

$$S = k_B \ln|\{\sigma_i\}|.$$

Therefore, entropy does not require an initial condition of "low entropy" nor a primordial "ordered state." It is an inherent and emergent feature resulting directly from the existence of time and its capacity to enable transitions between configurations.

4.4.3 No Special Initial Condition

In standard cosmological models, the low-entropy initial state leads to paradoxes such as the Boltzmann-brain problem or fine-tuning issues. In our framework, since time is eternal and without a singular origin, there is no requirement for a special low-entropy starting point.

4.4.4 Formal Ontological Sequence

We summarize this conceptual chain formally as:

$$\text{Time} \implies \text{Change} \implies \{\text{Possible States}\} \implies \text{Entropy}.$$

Hence, entropy is a logical and necessary emergent phenomenon, not a fundamental entity or externally imposed constraint.

4.4.5 Cosmological and Philosophical Implications

This perspective provides a natural explanation for the arrow of time and the continuous increase of entropy observed in closed systems, aligning the second law of thermodynamics with the axiomatic primacy of time rather than requiring additional postulates or improbable initial conditions.

5 Unified Baryonic Matter

The universe U is purely baryonic and consists of two sectors:

- Observable baryonic sector (τ_+) — standard luminous matter.
- CPT-symmetric baryonic sector (τ_-) — matter with reversed time flow, invisible electromagnetically but gravitationally active.

6 Effective Energy-Momentum Tensor

The total effective tensor is given by:

$$T_{\mu\nu}^{\text{eff}} = T_{\mu\nu}^{+} + T_{\mu\nu}^{-} \tag{23}$$

where:

- $T_{\mu\nu}^{+}$: tensor of our baryonic matter.
- $T_{\mu\nu}^{-}$: tensor of CPT-symmetric baryonic matter.

7 Emergent Einstein Field Equations

Once $g_{\mu\nu}$ emerges, it satisfies:

$$G_{\mu\nu}(g) = 8\pi T_{\mu\nu}^{\text{eff}} \tag{24}$$

where $G_{\mu\nu}$ is the Einstein tensor constructed from $g_{\mu\nu}$.

8 Interpretation of "Dark Matter"

The so-called "dark matter" corresponds to $T_{\mu\nu}^{-}$. This CPT-symmetric baryonic matter does not emit or absorb electromagnetic radiation in our τ_+ flow due to its reversed temporal direction but contributes gravitationally.

9 No Big Bang Singularity

Unlike standard Big Bang cosmology, this framework asserts that time does not have an origin. The coexistence of τ_+ and τ_- defines the onset of local spacetime geometry but does not require or imply a singular starting point. The "beginning" of our observable universe is interpreted as a local event of temporal coexistence rather than a global creation event.

9.1 Lack of Real Expansion

In our framework the global scale factor $a(t)$ remains strictly constant:

$$\dot{a}(t) \equiv 0\,, \qquad \Lambda_{\text{eff}} = 0.$$

What we interpret as cosmic expansion (redshift, apparent acceleration) arises solely from the geometric projection of local interactions between the two time-arrow sectors τ_+ and τ_- within our observational foliation. There is no dynamical, global stretching of space—everything is a local effect perceived along τ_+.

10 Minimal Field Equations in $3+1$ D

We consider two oppositely oriented temporal sectors represented by N pairs of scalar fields

$$\tau_+^a, \tau_-^a : \mathcal{M} \to \mathbb{R}, \qquad a = 1, \ldots, N.$$

Their gradients define the fundamental temporal one-forms

$$v_\mu^{\pm a} = \partial_\mu \tau_\pm^a.$$

Emergent metric. Following the multimode construction introduced in Section 3, we define

$$g_{\mu\nu} = \frac{1}{2}\sum_{a=1}^{N}\left(\partial_\mu\tau_+^a\partial_\nu\tau_-^a + \partial_\mu\tau_-^a\partial_\nu\tau_+^a\right). \tag{25}$$

For a nondegenerate four-dimensional Lorentzian metric with signature $(-+++)$, the construction requires at least three temporal mode pairs. In the following, we restrict attention to configurations for which $g_{\mu\nu}$ is nondegenerate and has Lorentzian signature.

Action. We introduce the following candidate generally covariant action:

$$S[\tau_+,\tau_-] = \int_{\mathcal{M}} d^4x\,\sqrt{-g(\tau)}\left[\frac{R(g(\tau))}{2\kappa} + \beta\sum_{a=1}^{N} g^{\mu\nu}(\tau)\partial_\mu\tau_+^a\partial_\nu\tau_-^a - V(\tau_+,\tau_-)\right], \tag{26}$$

where

$$\kappa = 8\pi G$$

in units with $c = 1$. The metric is not an independent dynamical variable in this formulation; it is constructed from the temporal scalar fields. Consequently, variation of the action must account for the dependence of $g_{\mu\nu}$ on these fields. No independent cosmological constant term is included in this minimal action. However, its absence does not by itself establish that the effective cosmological constant vanishes.

Variational structure. Let

$$\mathcal{E}^{\mu\nu} = \frac{2}{\sqrt{-g}}\frac{\delta S}{\delta g_{\mu\nu}}$$

denote the metric Euler derivative obtained by temporarily treating the metric and scalar fields as independent variables. Likewise, define

$$\mathcal{J}_{\pm a} = \frac{1}{\sqrt{-g}}\left.\frac{\delta S}{\delta\tau_\pm^a}\right|_g.$$

The variation of the induced metric is

$$\delta g_{\mu\nu} = \sum_{a=1}^{N}\left[\partial_{(\mu}\delta\tau_+^a\partial_{\nu)}\tau_-^a + \partial_{(\mu}\tau_+^a\partial_{\nu)}\delta\tau_-^a\right].$$

After integration by parts, the field equations are

$$\begin{aligned}\mathcal{J}_{+a} - \nabla_\mu\left(\mathcal{E}^{\mu\nu}\partial_\nu\tau_-^a\right) &= 0,\\ \mathcal{J}_{-a} - \nabla_\mu\left(\mathcal{E}^{\mu\nu}\partial_\nu\tau_+^a\right) &= 0.\end{aligned} \tag{27}$$

These are the Euler–Lagrange equations associated with the temporal scalar fields and the induced metric. They are not, in general, equivalent to the complete Einstein equations $\mathcal{E}^{\mu\nu} = 0$.

Scalar contributions. For the candidate action (26), the scalar Euler derivatives at fixed metric are

$$\begin{aligned} \mathcal{J}_{+a} &= -\beta \Box_g \tau_-^a - \frac{\partial V}{\partial \tau_+^a}, \\ \mathcal{J}_{-a} &= -\beta \Box_g \tau_+^a - \frac{\partial V}{\partial \tau_-^a}. \end{aligned} \tag{28}$$

These expressions must be combined with the metric variation terms in Eq. (27). Therefore, the equations $\mathcal{J}_{\pm a} = 0$ alone do not constitute the full field equations of the induced-metric theory.

Physical status. The action above defines a candidate dynamical extension of the multimode geometric construction. Its physical viability requires further analysis, including the existence of nontrivial curved solutions, consistency with gravitational observations, and the stability of the temporal field configurations. In particular, the recovery of general relativity cannot be assumed solely from the presence of the Einstein–Hilbert term. Likewise, the identification of temporal-sector effects with dark matter or dark energy remains a physical hypothesis requiring quantitative derivation.

Remark. The multimode metric construction provides a mathematical mechanism for generating Lorentzian geometry from temporal scalar fields. The action (26) is a proposed dynamical completion of this construction, rather than a demonstrated equivalent formulation of Einstein gravity.

11 Dynamics

The dynamical formulation of CTA is based on the multimode induced metric introduced in Sec. 10. The two oppositely oriented temporal sectors are represented by the scalar fields τ_+^a and τ_-^a, where $a = 1, \ldots, N$. The metric is a composite field,

$$g_{\mu\nu} = g_{\mu\nu}\left(\tau_+^a, \tau_-^a\right),$$

defined by Eq. (25).

11.1 Candidate Dynamical Action

We adopt the candidate action

$$S[\tau_+, \tau_-] = \int_{\mathcal{M}} d^4x \, \sqrt{-g(\tau)} \, [\mathcal{L}_{\text{geom}} + \mathcal{L}_{\text{matter}}], \tag{29}$$

with

$$\mathcal{L}_{\text{geom}} = \frac{R(g(\tau))}{2\kappa}, \tag{30}$$

$$\mathcal{L}_{\text{matter}} = \beta \sum_{a=1}^{N} g^{\mu\nu} \partial_\mu \tau_+^a \partial_\nu \tau_-^a - V(\tau_+, \tau_-). \tag{31}$$

This is the same candidate action introduced in Eq. (26), written in terms of its geometric and temporal-field contributions.

11.2 Metric Variation and Its Limitations

For comparison with conventional metric theories, one may temporarily treat $g_{\mu\nu}$ and the temporal fields as independent variables. The corresponding metric equation can be written formally as

$$G_{\mu\nu} = \kappa T_{\mu\nu}, \tag{32}$$

where

$$T_{\mu\nu} = -\beta \sum_{a=1}^{N} \left(\partial_\mu \tau_+^a \partial_\nu \tau_-^a + \partial_\mu \tau_-^a \partial_\nu \tau_+^a \right) + g_{\mu\nu} \mathcal{L}_{\text{matter}}.$$

This expression follows from the conventional definition

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}} \frac{\delta S_{\text{matter}}}{\delta g^{\mu\nu}}$$

for an independently varied metric. However, in CTA the metric is not an independent variable. Therefore, Eq. (35) is an auxiliary comparison equation, not an additional fundamental field equation of the induced-metric formulation.

11.3 Temporal-Field Equations

The fundamental dynamical equations are obtained by varying the action with respect to the temporal scalar fields, including the induced variation of the metric. They are given by Eq. (27), with the fixed-metric scalar contributions defined in Eq. (28). For reference, the fixed-metric scalar equations would be

$$\begin{aligned} \beta \Box_g \tau_-^a + \frac{\partial V}{\partial \tau_+^a} &= 0, \\ \beta \Box_g \tau_+^a + \frac{\partial V}{\partial \tau_-^a} &= 0. \end{aligned} \tag{33}$$

For $V = 0$ and $\beta \neq 0$, these auxiliary equations reduce to

$$\Box_g \tau_\pm^a = 0. \tag{34}$$

These equations describe the fixed-metric scalar variation only and must not be confused with the complete induced-metric Euler–Lagrange equations.

11.4 Relation to General Relativity

The presence of the Einstein–Hilbert term in the candidate action establishes a formal connection with general relativity. Nevertheless, the induced-metric variation imposes equations on the temporal scalar fields rather than the complete set of independent Einstein equations. Consequently, recovery of Einstein gravity requires additional mathematical analysis. In particular, it remains necessary to establish whether the CTA equations admit physically relevant curved solutions and reproduce the observed gravitational dynamics in an appropriate regime. No general Einstein limit is claimed at this stage.

11.5 Status of the Dynamical Framework

The present action provides a candidate dynamical formulation compatible with the multimode definition of the emergent metric. It does not yet establish the equivalence of CTA and general relativity. Likewise, interpretations of temporal-field effects as dark matter, dark energy, or other physical sources require explicit solutions and quantitative comparison with observations.

11.6 Variation with respect to the metric

Varying (29) with respect to $g_{\mu\nu}$ yields the Einstein–type equation

$$G_{\mu\nu}(g) \;=\; \kappa\, T_{\mu\nu}, \qquad T_{\mu\nu} \equiv 2\,\frac{\partial \mathcal{L}_{\rm matter}}{\partial g^{\mu\nu}} - g_{\mu\nu}\,\mathcal{L}_{\rm matter}, \tag{35}$$

where the effective energy–momentum tensor contains no cosmological constant term:

$$T_{\mu\nu} = \beta\big(\nabla_\mu\tau_+\,\nabla_\nu\tau_- + \nabla_\mu\tau_-\,\nabla_\nu\tau_+\big) - g_{\mu\nu}\Big[\,\beta\,\nabla_\alpha\tau_+\nabla^\alpha\tau_- - V(\tau_+,\tau_-)\Big].$$

11.7 Variation with respect to the time–arrow scalars

Treating $\tau_\pm$ as independent fields, we obtain

$$\Box_g\tau_\pm \;=\; \frac{\partial V}{\partial \tau_\mp} + \frac{1}{\sqrt{-g}}\,\frac{\partial\sqrt{-g}}{\partial\tau_\pm}\Big[\tfrac{1}{2\kappa}\,R(g) + \mathcal{L}_{\rm matter}\Big], \tag{36}$$

where the last term encodes the implicit $\tau_\pm$-dependence of the metric. In regimes where the gradients $\nabla\tau_\pm$ are small—i.e. the geometry is nearly translationally invariant in both time directions—the bracket can be neglected and (36) reduces to

$$\Box_g\tau_\pm \;=\; \frac{\partial V}{\partial \tau_\mp}, \tag{37}$$

reproducing the scalar equations adopted in Sec. 10.

11.8 Einstein limit

Whenever the bilinear term $\nabla_\mu\tau_+\nabla^\mu\tau_-$ is much smaller than κ^{-1} we may drop the right-hand side of (35). In that *slow–arrow* limit the field equations reduce to the standard vacuum Einstein equations, and deviations will appear only where the gradients of $\tau_\pm$ become relevant—interpreted in Sec. 8 as an effective dark–matter source.

Equations (35) and (36) therefore constitute the dynamical backbone of the *Coexisting Time Arrows* (CTA) framework, recovering General Relativity plus an explicit geometric energy–momentum tensor in the appropriate limit.

11.9 Consistency Check with the 1+1 Toy Model

We now examine the relation between the minimal temporal-field equations introduced in Sec. 10 and the $1+1$-dimensional toy model. The minimal field equations are

$$G_{\mu\nu}(g) = \kappa\Big(\nabla_\mu\tau_+\nabla_\nu\tau_- + \nabla_\mu\tau_-\nabla_\nu\tau_+ - g_{\mu\nu}\nabla_\alpha\tau_+\nabla^\alpha\tau_- + g_{\mu\nu}V\Big), \tag{38a}$$

$$\Box_g\tau_\pm = \partial_{\tau_\mp}V. \tag{38b}$$

Consider the $1+1$-dimensional configuration introduced in Appendix 27:

$$\tau_+(t,x) = t + f(x), \qquad \tau_-(t,x) = -t + f(x).$$

For this example we set $V = 0$ and use the normalization $c_0 = 1$. The temporal gradients are

$$v_\mu^\pm = (\pm 1, f').$$

Using the symmetrized bilinear metric construction,

$$g_{\mu\nu} = \frac{1}{2}\left(v_\mu^+ v_\nu^- + v_\mu^- v_\nu^+\right),$$

we obtain

$$g_{\mu\nu} = \begin{pmatrix} -1 & 0 \\ 0 & (f')^2 \end{pmatrix}.$$

This metric is nondegenerate wherever $f'(x) \neq 0$. On any such region, the coordinate transformation

$$T = t, \qquad X = f(x)$$

gives

$$ds^2 = -dT^2 + dX^2.$$

Therefore, the induced metric is locally Minkowskian and its Ricci scalar vanishes:

$$R = 0.$$

Moreover, in two spacetime dimensions the Einstein tensor vanishes identically:

$$G_{\mu\nu} = R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R \equiv 0.$$

For the present configuration, the contraction of the temporal gradients is

$$\nabla_\alpha \tau_+ \nabla^\alpha \tau_- = 2.$$

Consequently, the right-hand side of Eq. (38a), with $V = 0$, becomes

$$\kappa\left(v_\mu^+ v_\nu^- + v_\mu^- v_\nu^+ - 2 g_{\mu\nu}\right) = 0.$$

Thus, the gravitational equation is satisfied identically in the nondegenerate region. The scalar-field equations also hold for this configuration. Indeed, in the local coordinates (T, X), the temporal fields are linear:

$$\tau_+ = T + X, \qquad \tau_- = -T + X,$$

and therefore

$$\Box_g \tau_+ = \Box_g \tau_- = 0.$$

Hence, the toy-model configuration satisfies the displayed minimal field equations for $V = 0$, wherever the induced metric is nondegenerate. However, this result must be interpreted with care. The vanishing of the two-dimensional Einstein tensor is a geometric identity and does not provide a nontrivial test of four-dimensional gravitational dynamics. Furthermore, the toy model contains only one temporal mode pair and cannot establish the consistency of the full multimode construction. The example therefore provides a valid local consistency check of the reduced equations, but not a derivation or verification of the complete CTA field dynamics.

11.10 Covariant Conservation of the Effective Source

The candidate CTA action introduced in Eq. (26) is diffeomorphism-invariant. In the multimode formulation, the metric is constructed from the temporal scalar fields:

$$g_{\mu\nu} = g_{\mu\nu}\left(\tau_+^a, \tau_-^a\right).$$

Consequently, the metric and the temporal fields cannot be varied independently in the fundamental CTA formulation.

Noether identity. Let

$$\mathcal{F}_{\pm a} = \frac{1}{\sqrt{-g}}\frac{\delta S}{\delta \tau_\pm^a}$$

denote the complete Euler–Lagrange derivatives of the induced-metric action. Under an infinitesimal diffeomorphism generated by a vector field ξ^μ, the scalar fields transform as

$$\delta_\xi \tau_\pm^a = \xi^\mu \partial_\mu \tau_\pm^a.$$

Diffeomorphism invariance then implies the Noether identity

$$\boxed{\sum_{a=1}^{N}\left(\mathcal{F}_{+a}\partial_\nu\tau_+^a + \mathcal{F}_{-a}\partial_\nu\tau_-^a\right) = 0.} \tag{39}$$

This identity expresses the diffeomorphism consistency of the complete temporal-field equations. It does not constitute an independent Einstein equation or an independent conservation law for a dark-sector energy–momentum tensor.

Auxiliary stress tensor. If the metric is temporarily treated as independent, the temporal-field contribution to the action defines an auxiliary stress tensor:

$$T_{\mu\nu}^{(\tau)} = -\beta\sum_{a=1}^{N}\left(\partial_\mu\tau_+^a\partial_\nu\tau_-^a + \partial_\mu\tau_-^a\partial_\nu\tau_+^a\right) + g_{\mu\nu}\mathcal{L}_{\text{matter}}.$$

In the independent-metric formulation, its covariant divergence vanishes when the corresponding scalar Euler–Lagrange equations are satisfied. However, this auxiliary conservation statement cannot automatically be identified with a separate conservation law for the oppositely oriented temporal sector.

Physical interpretation. The identification of temporal-sector contributions with an effective dark-matter source remains a hypothesis of CTA. A physically meaningful dark-sector stress tensor must be derived from a consistent dynamical formulation and shown to satisfy the appropriate conservation relations. The present Noether identity establishes a structural consistency condition, but does not by itself demonstrate the existence of a separately conserved dark-matter component.

12 Observational Signature Map

Redshift Drift Test. In the standard ΛCDM cosmological model, the redshift drift is given by

$$\dot{z} \equiv \frac{dz}{dt_0} = (1+z)H_0 - H(z),$$

where H_0 is the present Hubble parameter and $H(z)$ is the expansion rate at redshift z. The predicted drift depends on redshift and cosmological parameters, and may be measured by future high-precision spectroscopic observations, including those planned for the Extremely Large Telescope (ELT). Within the proposed CTA interpretation, the absence of global cosmological expansion motivates the hypothesis

$$\dot{z} = 0.$$

However, a stationary global geometry does not by itself guarantee vanishing observed redshift drift. A complete derivation must account for the trajectories of sources and observers and the propagation of electromagnetic signals through the emergent geometry. A null result in future redshift-drift measurements would be consistent with this CTA hypothesis. Its discriminatory power relative to standard cosmology would depend on measurement uncertainties, the observed redshift range, and the quantitative predictions of competing cosmological models.

Status of Cosmological Predictions. The proposed vanishing redshift drift, $\dot{z} = 0$, is a conditional hypothesis of CTA rather than a result derived from a complete set of dynamical field equations. Likewise, any proposed numerical value of the cosmological growth index requires an explicit derivation from the perturbation dynamics of CTA. These observational signatures are therefore presented as testable hypotheses requiring quantitative verification rather than established consequences of the present mathematical construction.

Road-map. A principal phenomenological objective is to determine whether CTA can reproduce observed cosmic acceleration without introducing a fundamental cosmological constant. This requires a quantitative comparison with cosmological observations, including the integrated Sachs–Wolfe effect, measurements of $H(z)$, baryon acoustic oscillations, and cosmic microwave background anisotropies. A comprehensive comparison will require a consistent cosmological background, perturbation equations, and a dedicated Boltzmann solver incorporating the temporal-field dynamics. The complete induced-metric field equations (27), together with the scalar contributions (28), provide a candidate starting point for cosmological modelling. (28) provide a starting point, but their consistency with the multimode geometric construction must also be established.

Illustrative Growth-Index Scenario. The growth index γ is commonly introduced through the approximation

$$f(z) \simeq \Omega_m(z)^{\gamma},$$

where $f(z)$ denotes the linear growth rate of matter density perturbations. For reference, standard ΛCDM cosmology predicts approximately

$$\gamma \simeq 0.55$$

under conventional assumptions. A value near

$$\gamma \simeq 0.40$$

may be investigated as an illustrative phenomenological scenario for CTA, rather than a quantitative prediction derived from its present field equations. Determining whether CTA predicts such a deviation requires deriving its linear perturbation equations and calculating the corresponding growth history. Only then can the result be compared with observations from galaxy surveys and other large-scale structure probes.

Numerical Forecast Example For instance, in our framework, the growth index γ is predicted to decrease to approximately 0.40 ± 0.02 at $z \lesssim 1$, as opposed to the standard ΛCDM value $\gamma \approx 0.55$. Current and upcoming surveys (DESI, SKA) aim for a precision at the level of $\Delta\gamma \approx 0.02$, sufficient to test this prediction within the next decade.

13 Emergence of the Speed of Light

In standard physics, the speed of light c is taken as a fundamental constant, defining the maximal propagation speed of information and causality in spacetime. However, its numerical value is postulated rather than derived:

$$c \approx 299,792,458\,\mathrm{m/s}.$$

13.1 Absence of a Fundamental Metric

In our axiomatic framework, no pre-defined metric or background structure exists (Axiom A4). Geometry emerges locally through the coexistence of the time arrows τ_+ and τ_-. Consequently, all physical "constants" related to spacetime must arise as emergent geometric quantities.

13.2 Geometric Origin of c

The maximal information propagation speed c is defined as

$$c = \lim_{\mathcal{F}(\tau_+,\tau_-)\to g_{\mu\nu}} \left(\sup \frac{\mathrm{d}x}{\mathrm{d}t} \right),$$

where $g_{\mu\nu}$ is the emergent metric generated by the operator $\mathcal{F}$ acting on τ_+ and τ_-. This implies that c is not a separate input but a global geometric consequence of the overall temporal configuration of the universe.

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Figure 2: Emergence of c from τ_+ and τ_-. The metric $g_{\mu\nu}$ mediates the geometric relation, leading to the emergent speed limit c.

13.3 Dependence on Global Temporal Configuration

The precise value of c is determined by the total distribution and interaction of the time arrows throughout the universe. Its constancy across all local regions reflects the global coherence of the emergent geometry.

13.4 Formal Ontological Statement

We summarize this principle formally as:

$$\{\tau_+, \tau_-\} \xrightarrow{\mathcal{F}} g_{\mu\nu} \implies c.$$

Hence, the numerical value of c can, in principle, be derived once the global temporal configuration $\{\tau_+, \tau_-\}$ is fully understood and mathematically described.

13.5 Philosophical and Physical Implications

This perspective removes the need to postulate c as a fundamental constant, reinterpreting it instead as an emergent property of the universal temporal structure. It opens a new path toward understanding the deep connection between causality, geometry, and the flow of time.

13.6 Numerical Value of c

14 Perception of Cosmic Expansion and Absence of Dark Energy

In this framework, the universe contains two globally present time arrows τ_+ and τ_-, both omnipresent and having identical "densities," but with opposite temporal directions. This global structure defines a unified and stable emergent geometry.

14.1 Emergent Global Geometry

The emergent metric $g_{\mu\nu}$ is co-created by both time arrows via the operator

$$\mathcal{F}(\tau_+, \tau_-) \mapsto g_{\mu\nu}.$$

This metric is globally stable and does not exhibit global expansion or contraction in an absolute sense.

14.2 Local Temporal Trajectories

An observer within the τ_+ sector interprets geometric changes along their own time trajectory. In τ_+, the past is perceived as "denser" (more compact), and the present as "expanded," due to the evolution of local baryonic structures within $g_{\mu\nu}$.

Conversely, in the τ_- sector, the opposite temporal perception occurs: what we see as future is their past, and their present appears more "contracted" to them.

14.3 Apparent Expansion as a Local Effect

The observed expansion of the universe is thus a local phenomenon perceived by τ_+ observers, not a global dynamical expansion of the entire geometry. We measure cosmological redshifts and interpret them as "expansion," but this is a geometric projection along the τ_+ temporal arrow rather than an actual global stretching of space.

14.4 No Need for Dark Energy

In this theory, there is no necessity to introduce a separate "dark energy" component or a cosmological constant Λ. The apparent acceleration of cosmic expansion is a misinterpretation arising from comparing snapshots of our local temporal trajectory within a globally stable and symmetric geometry. In contrast to the standard ΛCDM cosmology, where the cosmological constant is introduced as an additional energy component driving accelerated expansion, in this framework such acceleration is purely emergent and observer-dependent, requiring no extra term in the Einstein equations.

14.5 Formal Expression

Define the global stable metric as

$$g_{\mu\nu} = \mathcal{F}(\tau_+, \tau_-).$$

The local perception of scale factor evolution $a(t)$ in τ_+ is expressed as

$$a(t) = \phi(\tau_+, g_{\mu\nu}),$$

where ϕ encodes the observer-dependent interpretation of local geometric relations, and should not be confused with a global dynamical scale factor. There is no global dynamical Λ term; instead,

$$\Lambda_{\text{eff}} \equiv 0,$$

since all observed acceleration is local and emergent.

14.6 Implications

- Explains the cosmological expansion without invoking dark energy.
- Eliminates the need for a cosmological constant as a fundamental parameter.
- Supports the interpretation of a stable, timelessly coexisting geometric substrate.

Thus, the perceived cosmic acceleration is a geometric consequence of local temporal interpretation within τ_+, not an actual expansion of a dynamical spacetime.

15 Absence of Electromagnetic Interactions Between CPT-Symmetric Sectors

A fundamental consequence of our framework is the explicit absence of electromagnetic interactions between the CPT-symmetric sector τ_- and our observable sector τ_+. While

gravitational and weak interactions remain permitted channels of communication between the two sectors (Axiom A5), electromagnetic interactions are categorically excluded. This exclusion is not arbitrary; rather, it arises naturally as a direct logical implication of the opposite orientations of the time arrows τ_+ and τ_-.

Electromagnetic waves, described by Maxwell's equations, inherently possess a defined causal structure, propagating signals forward in time (retarded solutions). In the CPT sector, however, electromagnetic signals would necessarily correspond to advanced solutions propagating backward in time from the perspective of our sector τ_+. Allowing electromagnetic interactions between these sectors would thus create irreconcilable paradoxes of causality, where effects precede their causes and energy propagation occurs counter to the observed temporal direction.

Formally, the structure of Maxwell's equations explicitly distinguishes retarded solutions (physically observable) from advanced solutions (non-causal and physically unobserved). The coexistence of opposite time flows therefore enforces a strict causal separation in electromagnetic communication channels:

- Observers in sector τ_+ can only detect and interact with retarded electromagnetic waves within their causal future.
- Observers in sector τ_-, analogously, can only interact with advanced solutions (from their perspective retarded).

Consequently, neither sector can perceive electromagnetic signals generated by the other, ensuring causal consistency:

$$\mathcal{F}(\tau_+, \tau_-) \nrightarrow \text{Electromagnetic Interaction} \tag{40}$$

Thus, the absence of electromagnetic interactions between CPT-symmetric sectors is not merely an imposed assumption but a necessary condition for the internal logical consistency and causal integrity of the theory. This provides strong theoretical justification for Axiom A5 and clarifies the fundamental limitations on permissible interactions across sectors characterized by opposing temporal orientations.

16 Quantum Nature of Time and Emergence of Quantum Mechanics

Time is treated not as a classical external parameter but as an operator with inherent quantum properties, fundamentally shaping the emergent geometry and causality.

16.1 Quantum Operators for Time Arrows

We promote the local time flows to operators:

$$\hat{\tau}_+, \quad \hat{\tau}_-$$

with commutation relations:

$$[\hat{\tau}_\pm, \hat{H}] = i\hbar \tag{41}$$

where $\hat{H}$ denotes the local emergent Hamiltonian operator derived from $g_{\mu\nu}$.

Fundamental Symmetry Note It should be emphasized that the internal consistency of the proposed framework implicitly relies on the exact global CPT symmetry. Any violation of Charge (C), Parity (P), or Time reversal (T) individually would not merely modify local physical processes but would collapse the entire global geometric-temporal structure, thereby preventing the emergence of stable physical laws. In this sense, CPT symmetry is not just a feature of particle interactions but an essential axiom for the existence of a coherent universe.

One can further define a Hilbert space $\mathcal{H}$ of states built on classical background configurations $\tau_{\pm}^{(0)}$, and construct a corresponding Fock space of small perturbations (quanta) of the temporal fields $\hat{\tau}_{\pm}$. This approach allows for a rigorous operator formulation, enabling a complete quantum description of geometry and matter within the same framework.

Philosophical Note on the Origin of Time and Space

A natural question arises regarding the ultimate origin of time and space within this framework. We explicitly postulate time as an absolute, fundamental entity—an axiomatic starting point. In this sense, time does not "emerge" or "originate" from a more basic structure; rather, it serves as the precondition for the possibility of any change or existence.

Space, on the other hand, is not taken as fundamental. It arises locally and necessarily as a geometric consequence of the coexistence of the two temporal flows, τ_+ and τ_-. The question "where did space come from" is thus reframed: space does not exist independently but emerges from specific configurations of time.

This approach intentionally avoids infinite regress by choosing time as the ontological axiom. Just as mathematics accepts the existence of points or sets as primitive notions, our framework accepts time as the foundational prerequisite for reality.

We invite further philosophical and mathematical exploration of this premise, recognizing that it touches the deepest metaphysical layers of our understanding of existence.

16.2 Local Fluctuations and Superpositions

The coexistence operator $\mathcal{F}(\hat{\tau}_+, \hat{\tau}_-)$ inherently allows for local quantum fluctuations:

$$g_{\mu\nu} \longrightarrow g_{\mu\nu} + \delta g_{\mu\nu}(\hat{\tau}_+, \hat{\tau}_-)$$

These fluctuations explain superposition, entanglement, and the uncertainty principle.

16.3 Unified View

Quantum mechanics emerges naturally from the quantum structure of time. Both geometry and quantum phenomena are effective manifestations of the deeper temporal ontology, resolving the apparent conflict between GR and QM without the need to quantize gravity directly.

16.4 Explicit Operator Structure and Field Interpretation

We promote the time arrows to operator-valued fields on $\mathcal{M}$:

$$\hat{\tau}_{\pm}(x), \qquad x \in \mathcal{M}.$$

Their conjugate momenta $\pi_\pm(x)$ satisfy canonical equal-time commutation relations:

$$[\hat{\tau}_\pm(x), \pi_\pm(y)] = i\hbar\delta^{(3)}(x-y).$$

Assuming minimal coupling, the local emergent Hamiltonian density is

$$\mathcal{H}(x) = \frac{1}{2}\big[\pi_+(x)\pi_-(x) + \beta\nabla_\mu\hat{\tau}_+(x)\nabla^\mu\hat{\tau}_-(x)\big] + V(\hat{\tau}_+, \hat{\tau}_-).$$

The total Hamiltonian operator reads

$$\hat{H} = \int d^3x\,\sqrt{-g}\,\mathcal{H}(x).$$

This explicit operator construction connects the temporal fields with standard canonical quantization procedures and permits the construction of a Fock space for small perturbations around a classical background configuration of $\tau_\pm$.

17 Formal Definition of Sector Interactions

We define two CPT-symmetric sectors within a single universe U:

- $\mathcal{S}_+$: Baryonic sector with a forward-oriented time arrow τ_+.
- $\mathcal{S}_-$: CPT-symmetric baryonic sector with an oppositely oriented time arrow τ_-.

The interaction between these sectors is strictly constrained by the axiomatic framework: **Axiom (Restricted Interaction)**: *The sectors $\mathcal{S}_+$ and $\mathcal{S}_-$ interact exclusively via gravitational and weak interactions. Electromagnetic and strong interactions are sector-internal and do not couple across sectors.*

18 Formal Argument Against Electromagnetic Interaction Between CPT-Symmetric Sectors

Consider electromagnetic interactions, governed by Maxwell's equations, invariant under the CPT symmetry transformation. The CPT symmetry operation consists of:

1. Charge conjugation (C): $q \to -q$, reversing electric charges.
2. Parity inversion (P): $\mathbf{x} \to -\mathbf{x}$, spatial reflection.
3. Time reversal (T): $t \to -t$, reversal of temporal flow.

For an electromagnetic field $F_{\mu\nu}$, CPT transformation leads to:

$$\mathrm{CPT}(F_\mu\nu) = -F_\mu\nu(t \to -t, \mathbf{x} \to -\mathbf{x}, q \to -q). \tag{42}$$

Assume, for contradiction, that an electromagnetic wave $A^\mu(x,t)$ originating in the $\mathcal{S}_-$ sector could propagate into the $\mathcal{S}_+$ sector. Such propagation would require a field configuration that is simultaneously a valid forward-time solution (in τ_+) and a backward-time solution (in τ_-). Under T symmetry alone, solutions to Maxwell's equations transform as:

$$A^\mu(t,\mathbf{x}) \xrightarrow{T} A^\mu(-t,\mathbf{x}) \tag{43}$$

However, physically realizable electromagnetic solutions must satisfy causal boundary conditions:

- In $\mathcal{S}_+$, retarded potentials propagate forward in time (from past to future).
- In $\mathcal{S}_-$, due to reversed time direction, analogous potentials propagate from their future to their past (retarded in τ_-).

Lemma (Causality constraint): Electromagnetic solutions $A^\mu(t, \mathbf{x})$ for $\mathcal{S}_+$ and $\mathcal{S}_-$ sectors must individually respect their local causality constraints:

$$\frac{\partial A^\mu{}_-+}{\partial \tau_-+} > 0 \quad \text{for} \quad \mathcal{S}*+ \tag{44}$$

$$\frac{\partial A^\mu *-}{\partial \tau_--} > 0 \quad \text{for} \quad \mathcal{S}_-- \tag{45}$$

Because $\tau_+ = -\tau_-$, the propagation conditions are mutually exclusive:

$$\frac{\partial A^\mu{}_-+}{\partial \tau_-+} = -\frac{\partial A^\mu{}_--}{\partial \tau_--} \tag{46}$$

To satisfy simultaneous propagation in both sectors via electromagnetic fields, the field A^μ would have to violate local causality constraints in at least one sector. Hence, no electromagnetic wave can propagate coherently between sectors with opposite time arrows without violating causality and the fundamental symmetry conditions. **Conclusion (No Electromagnetic Interaction)**: Electromagnetic interaction between CPT-symmetric sectors is strictly forbidden due to causality and CPT symmetry constraints. This argument formally confirms that sectors $\mathcal{S}_+$ and $\mathcal{S}_-$ cannot electromagnetically interact, consistently aligning with the axiomatic structure and maintaining internal coherence of the theory.

19 Emergent Charge from Local Time Asymmetry

Definition 19.1 (Time Asymmetry Field)**.** Let M be a differentiable spacetime manifold equipped with two global time functions:

$$\tau_+ : M \to \mathbb{R}, \qquad \tau_- : M \to \mathbb{R},$$

representing two globally coherent time arrows. Then the *time asymmetry field* is defined as the scalar function:

$$\Delta_\tau : M \to \mathbb{R}, \quad \Delta_\tau(P) := \tau_+(P) - \tau_-(P).$$

Definition 19.2 (Emergent Charge)**.** Let Δ_τ be the time asymmetry field defined above. Then the local *emergent electric charge density* q is defined by:

$$q(P) := \kappa \cdot \Delta_\tau(P),$$

where $\kappa \in \mathbb{R}^+$ is a proportionality constant determined by the local coupling of time fields to the electromagnetic sector.

Definition 19.3 (Time Dipole)**.** Let $S \subset M$ be a bounded region of spacetime. We say that S forms a *time dipole* if for every event $P \in S$, there exists a conjugate point $\bar{P} \in S$ such that:

$$\tau_+(P) = \tau_-(\bar{P}), \qquad \tau_-(P) = \tau_+(\bar{P}).$$

In other words, the region is symmetric under time arrow inversion.

Theorem 19.1 (Emergent Charge Theorem)**.** *Let $S \subset M$ be a compact region of spacetime. If S is not a time dipole, i.e., it contains a non-zero integral of the time asymmetry field:*

$$\int_S \Delta_\tau(P)\, dV \neq 0,$$

then the total emergent charge within S is non-zero:

$$Q_S := \int_S q(P)\, dV = \kappa \int_S \Delta_\tau(P)\, dV \neq 0.$$

Proof. Follows directly by linearity from Definitions 1 and 2. Since $q(P) = \kappa \cdot \Delta_\tau(P)$, we integrate over the region S and obtain:

$$Q_S = \int_S q(P)\, dV = \kappa \int_S \Delta_\tau(P)\, dV.$$

If Δ_τ is non-zero on a non-zero volume subset of S, then $Q_S \neq 0$. □

Remark 19.1 (Ontological Interpretation)*.* Charge is not a primitive property of matter, but a manifestation of broken symmetry between τ_+ and τ_-. Structures with zero net Δ_τ are electrically neutral by definition.

Example 19.1 (Hydrogen Atom)**.** *A hydrogen atom consisting of (p^+, τ_+) and (e^-, τ_+) has non-zero charge if not accompanied by their τ_--conjugates $(\bar{p}^-, \tau_-)$, (e^+, τ_-). Only the full configuration forms a time dipole and is electrically neutral.*

Example 19.2 (Neutron as Time Closure)**.** *The neutron can be understood as a local topological closure of Δ_τ, neutralizing time asymmetry through internal configuration. This explains its neutrality despite being a composite object.*

The strict electromagnetic separation between $\mathcal{S}_+$ and $\mathcal{S}_-$, as proven in the previous section, implies that electric charge cannot arise from direct intersector communication. Instead, we propose that charge is an emergent local feature of broken symmetry between the coexisting time fields τ_+ and τ_-, defined pointwise on spacetime. The following formalism constructs this emergent charge from first principles.

20 Quantum Field Formalism of Temporal Operators

20.1 Promotion of Temporal Flows to Quantum Fields

To fully embed quantum mechanics within our axiomatic framework, we explicitly promote the two coexisting temporal flows, τ_+ and τ_-, to quantum operator fields defined on a 4-dimensional manifold $\mathcal{M}$:

$$\tau_+(x) \to \hat{\tau}_+(x), \quad \tau_-(x) \to \hat{\tau}_-(x), \quad x \in \mathcal{M}. \tag{47}$$

These operator fields are assumed Hermitian, ensuring observability and real eigenvalues corresponding to physically measurable time intervals. Moreover, a zero redshift drift would be a "smoking gun" for our no-expansion hypothesis, distinguishing CTA from all dark-energy models.

20.2 Canonical Structure and Commutation Relations

We introduce canonical conjugate momentum fields associated with each temporal field, defined through the functional derivative of the action $S[\tau_+, \tau_-]$:

$$\hat{\pi}_\pm(x) = \frac{\delta \mathcal{L}}{\delta(\partial_0 \hat{\tau}_\pm(x))}, \tag{48}$$

satisfying the canonical equal-time commutation relations:

$$[\hat{\tau}_\pm(t, \mathbf{x}), \hat{\pi}_\pm(t, \mathbf{y})] = i\hbar\, \delta^{(3)}(\mathbf{x} - \mathbf{y}), \tag{49}$$

$$[\hat{\tau}_+(t, \mathbf{x}), \hat{\tau}_-(t, \mathbf{y})] = 0, \quad [\hat{\pi}_+(t, \mathbf{x}), \hat{\pi}_-(t, \mathbf{y})] = 0. \tag{50}$$

These commutation relations form the foundational algebraic structure required for a rigorous quantum theory.

20.3 Hamiltonian Formulation

From the Lagrangian density

$$\mathcal{L} = \beta\, \partial_\mu \hat{\tau}_+ \partial^\mu \hat{\tau}_- - V(\hat{\tau}_+, \hat{\tau}_-) + \frac{1}{2\kappa} R(g(\hat{\tau}_+, \hat{\tau}_-)), \tag{51}$$

we derive the quantum Hamiltonian density as the Legendre transform:

$$\mathcal{H} = \hat{\pi}_+ \partial_0 \hat{\tau}_+ + \hat{\pi}_- \partial_0 \hat{\tau}_- - \mathcal{L}. \tag{52}$$

Explicitly, the Hamiltonian operator reads:

$$\hat{H} = \int d^3x \sqrt{-g} \left[\hat{\pi}_+ \hat{\pi}_- + \beta \nabla_\mu \hat{\tau}_+ \nabla^\mu \hat{\tau}_- + V(\hat{\tau}_+, \hat{\tau}_-) - \frac{1}{2\kappa} R(g(\hat{\tau}_+, \hat{\tau}_-)) \right]. \tag{53}$$

20.4 Quantum State Space and Evolution

We introduce a Hilbert space $\mathcal{H}$ of quantum states $|\Psi(t)\rangle$ represented as wave functionals $\Psi[\tau_+, \tau_-; t]$, satisfying the Schrödinger equation:

$$i\hbar \frac{\partial}{\partial t} \Psi[\tau_+, \tau_-; t] = \hat{H} \Psi[\tau_+, \tau_-; t]. \tag{54}$$

Quantum states evolve unitarily according to the temporal quantum fields dynamics encoded in $\hat{H}$.

20.5 Path Integral Representation

An equivalent quantum formulation can be obtained via the path integral formalism:

$$Z = \int \mathcal{D}\tau_+ \mathcal{D}\tau_- \exp\left(\frac{i}{\hbar} \int d^4x \sqrt{-g}\, \mathcal{L}(\tau_+, \tau_-) \right). \tag{55}$$

Here, the sum is over all possible configurations of the temporal fields, demonstrating the full quantum mechanical character and unifying geometry and quantum theory at a fundamental level.

20.6 Quantum Uncertainty and Spectral Decomposition

The canonical commutation relations imply quantum uncertainty relations for temporal measurements:

$$\Delta\tau_{\pm}\Delta\pi_{\pm} \geq \frac{\hbar}{2}. \tag{56}$$

We define spectral decompositions for the temporal operators $\hat{\tau}_{\pm}$:

$$\hat{\tau}_{\pm} = \int_{\tau_0}^{\infty} d\tau\, \tau\, |\tau\rangle_{\pm} \langle\tau|\,, \tag{57}$$

where $|\tau\rangle_{\pm}$ form an orthonormal basis of eigenstates, reflecting a fundamental discrete or continuous spectrum of temporal values depending on model specifics.

20.7 Quantum Observables and Measurements

Physical observables $\hat{O}$ are Hermitian operators defined as functionals of $\hat{\tau}_{\pm}$ and their conjugates, with expectation values given by standard quantum mechanics:

$$\langle\hat{O}\rangle = \langle\Psi|\,\hat{O}\,|\Psi\rangle = \int \mathcal{D}\tau_{+}\mathcal{D}\tau_{-}\, \Psi^{*}[\tau_{+},\tau_{-}]\hat{O}\Psi[\tau_{+},\tau_{-}]. \tag{58}$$

20.8 Quantum-Classical Transition

In the classical limit ($\hbar \to 0$), quantum fluctuations diminish, and the wavefunctional sharply peaks around classical trajectories of the fields $\tau_{\pm}^{(cl)}$ satisfying classical field equations. Thus, we recover classical geometric dynamics described in the previous sections:

$$\lim_{\hbar\to 0} \Psi[\tau_{+},\tau_{-}] \to \delta(\tau_{+} - \tau_{+}^{(cl)})\delta(\tau_{-} - \tau_{-}^{(cl)}). \tag{59}$$

20.9 Summary of Quantum Formalism

Time ceases to be an external parameter; it becomes the fundamental quantum entity shaping both geometry and matter. This rigorous quantum field formalism for temporal fields provides a complete embedding of quantum mechanics within our emergent geometric-temporal framework:

$$\boxed{\{\hat{\tau}_{+},\hat{\tau}_{-}\} \xrightarrow{\text{Canonical Structure}} \text{Quantum Geometry} \oplus \text{Quantum Mechanics.}} \tag{60}$$

21 Discussion

This framework proposes time as the only fundamental and absolute entity, with space and all geometric, material, and energetic structures emerging locally from the coexistence of two temporal flows, τ_{+} and τ_{-}. By adopting time as an axiom, we avoid the need for additional ontological assumptions about space, matter, or energy.

A natural question arises regarding the ultimate origin of time and space within this approach. We explicitly postulate time as a fundamental axiom. In this sense, time does not "emerge" or "originate" from any more basic structure; it serves as the logical and ontological precondition for any form of change or existence. Space, on the other hand, arises locally and necessarily as a geometric consequence of the configurations and

interactions of τ_+ and τ_-. Thus, the question "where did space come from" is reframed: space is not a pre-existing container but an emergent relational phenomenon.

Another crucial conceptual insight of this framework is the reinterpretation of energy itself. Traditionally, energy is understood as the capacity to perform work, inherently tied to change over time. In our view, energy is not a separate or additional entity but an operational manifestation of the fundamental flow of time. In other words, **time constitutes the ultimate source of all energy in the universe**. Mass, energy, and geometric curvature are different expressions of how temporal dynamics shape local and global structures.

By adopting this temporal primacy, we unify the ontological roots of matter, geometry, and energy, providing a coherent and minimal foundation from which all observable phenomena may arise. This approach invites future mathematical formalization and experimental investigation to validate its predictions and explore its implications for cosmology, particle physics, and theories of consciousness.

We recognize that this philosophical stance touches the deepest metaphysical layers of scientific inquiry. Nonetheless, we believe that by shifting the focus to time as the ultimate foundation, new avenues for understanding the universe can be opened.

Remark: Ultimately, the true strength of any fundamental framework lies not only in its capacity to explain what we observe, but in its courage to propose what might be possible. By placing time as the absolute foundation and allowing all else to emerge, we open the door to a profoundly unified vision of reality — one that challenges us to look beyond established boundaries and invites us to imagine what the universe might be, rather than only what it appears to be.

22 New Research Postulates

In order to ensure the empirical robustness and future falsifiability of the Coexisting Time Arrows (CTA) framework, we introduce a set of explicit research postulates. These postulates serve as a bridge between the axiomatic foundation and concrete experimental predictions.

C1 (Experimental Corroboration Postulate). *Any theory proposing the coexistence of two global time arrows τ_+ and τ_- must predict at least one distinct, measurable observational signature that cannot be mimicked by effective parameter adjustments within ΛCDM or other standard cosmological models.*

Formally, there must exist at least one observable $\mathcal{O}_{CTA}$ such that

$$|\mathcal{O}_{CTA} - \mathcal{O}_{\Lambda CDM}| > \delta_{\text{obs}}$$

where δ_{obs} denotes the achievable observational uncertainty in upcoming or future surveys (e.g., Euclid, SKA, LSST).

This requirement prevents the framework from being reduced to a trivial parametrization of existing models and ensures genuine explanatory power.

C2 (Quantization Consistency Postulate). *The quantum operator structure of temporal fields $\{\hat{\tau}_+, \hat{\tau}_-\}$ must admit a well-defined spectral decomposition, finite vacuum energy expectation $\langle T_{\mu\nu} \rangle$, and be free from ultraviolet (UV) divergences without introducing ad hoc counterterms.*

This postulate formalizes the demand that the quantum sector of CTA can be consistently regularized and embedded into a complete field-theoretic framework without relying on external fine-tuning or arbitrary renormalization conditions.

C3 (Geometric Soliton Realizability Postulate). *There must exist at least one stable, localized geometric solution (soliton or oscillon) to the CTA field equations in* $3+1$ *dimensions, with parameters (mass, charge, spin) matching, at least in order of magnitude, known Standard Model particle properties.*

This postulate directly links the theoretical field solutions to physically observable particles, ensuring that the framework not only explains large-scale cosmology but also microscopic particle phenomenology.

Summary of Postulates. Together, these three postulates establish a rigorous research agenda:

1. Predict and isolate unique observational signatures testable with current or near-future cosmological data (C1).
2. Build a mathematically consistent and divergence-free operator formalism (C2).
3. Demonstrate concrete localized solutions resembling known particle states (C3).

Their simultaneous fulfillment would provide strong evidence supporting the viability of the CTA framework as a candidate for a unified description of spacetime, quantum fields, and matter.

23 Open Questions and Validation Strategy

While this framework offers a minimal and unified foundation based on the absolute nature of time and the emergent structure of space, it remains essential to rigorously assess its internal consistency and empirical viability.

We explicitly acknowledge that this approach does not attempt to "fit" preconceived dogmas or established interpretations. Instead, it proposes an axiomatic starting point: time as an absolute and fundamental entity. From this axiom, we derive the coexistence of two temporal flows (τ_+ and τ_-) and the local emergence of a three-dimensional spatial geometry.

The strategy moving forward is clear:

1. **Apply the axiom rigorously**: Develop full mathematical consequences of adopting time as the sole fundamental entity and space as an emergent phenomenon.
2. **Check for internal logical consistency**: Identify any potential contradictions within the derived structures, particularly in relation to known geometric, relativistic, and quantum frameworks.
3. **Compare with empirical data**: Evaluate if predictions align with current observations in cosmology (e.g., cosmic expansion, dark matter effects), particle physics (e.g., symmetry violations, mass generation), and thermodynamic processes (e.g., entropy, arrow of time).

4. **Propose potential experimental tests**: Identify unique predictions that distinguish this framework from existing models, enabling future falsification or validation.

If this approach leads to a coherent, predictive, and experimentally consistent framework, it would provide a profound shift in our understanding of the universe. If not, it remains a powerful conceptual exercise, illustrating the creative and philosophical possibilities inherent in rethinking the foundation of physics.

"We must rigorously apply this foundational axiom and examine whether it leads to a logically coherent theory consistent with all known empirical data. If it does, it provides a new fundamental view of reality. If it does not, it remains a powerful conceptual exercise, demonstrating the limits and possibilities of our imagination."

Remark on the Magnitude of Time Arrows

An open question remains whether the two coexisting time arrows, τ_+ and τ_-, have equal magnitudes (lengths) but opposite directions, or whether their lengths may differ. Currently, there is no definitive theoretical or experimental answer, nor is it known whether the theory of Emergent Spacetime and Quantum Reality from Coexisting Time Arrows will lead to any more or less groundbreaking conclusions.

For the purpose of constructing a consistent mathematical framework and deriving significant physical consequences—such as recovering Einstein's equations or quantum mechanics—it may be necessary to initially assume the hypothesis of equal time arrow lengths.

On the other hand, further development of the theory may reveal that differing lengths are required to correctly correlate the temporal flows with observed phenomena.

This remains a fundamental open question and a direction for future research and theory validation.

Open Question: Embedding of CPT-Symmetric Universes

Within the framework of the theory of two coexisting time arrows, a profound and fundamental question arises: can two CPT-symmetric universes be mutually *embedded* or coexist as substructures within a broader, flatter, or more fundamental spacetime?

Key issues for thorough investigation include:

- What geometric and topological relations must hold between these universes to ensure their stable coexistence, and to enable the construction of a mathematical apparatus from which known cosmological and quantum laws can be derived, along with fundamental constants such as the Planck constant and the speed of light?
- Is there a natural parameter describing their relative positioning or separation within this larger structure?
- What are the possible interaction mechanisms, particularly gravitational and weak interactions, between these universes, and how do they affect their dynamics?
- Could such mutual positioning and interactions explain observed phenomena currently attributed to "dark matter" or other unexplained effects in standard physics?
- Which mathematical formalism best captures the concept of coexistence and embedding of these universes?

- Ultimately, can the proposed theory bring us closer to the long-sought *Theory of Everything* — a consistent and universal framework describing the totality of reality?

These questions remain open and define crucial directions for future theoretical and experimental research. Introducing such a hypothesis could significantly enrich our theoretical framework and contribute to a deeper understanding of the fundamental structure of reality.

Potential collaborations with observational teams such as SKA (Square Kilometre Array), Euclid, or LSST may provide crucial data to validate the cosmological predictions and the possible deviations in the growth index $\gamma(z)$ or ISW effects, offering an interdisciplinary bridge between theoretical and observational cosmology.

24 Emergence of Standard Model Gauge Symmetries from Temporal-Topological Oscillations

We propose that the full gauge symmetry structure of the Standard Model (SM),

$$U(1)_Y \times SU(2)_L \times SU(3)_C,$$

emerges naturally from local automorphisms of the space of oscillatory solutions constructed from the temporal fields τ_+ and τ_-.

24.1 Oscillatory Configuration Space

We consider small perturbations of temporal fields:

$$\tau_+(x) = \tau_+^{(0)} + \varphi_+(x), \qquad \tau_-(x) = \tau_-^{(0)} + \varphi_-(x),$$

and define the configuration space of local oscillations as

$$\mathcal{C} = \{\varphi_+(x), \varphi_-(x)\}.$$

Each $\varphi_\pm$ can be expanded into a finite set of local basis functions or modes:

$$\varphi_\pm(x) = \sum_{a=1}^{N} \varphi_\pm^a(x) T^a,$$

where T^a denote algebra generators of possible internal symmetries.

24.2 Internal Automorphism Group

We introduce the internal automorphism group acting on $\mathcal{C}$:

$$\mathrm{Aut}(\mathcal{C}) = \{U(x) \mid U(x) : \varphi_\pm(x) \mapsto U(x)\varphi_\pm(x)\}.$$

For configurations with one mode, we recover global phase symmetry $U(1)$. For higher-dimensional expansions (e.g., three real modes for $SU(2)$ or eight modes for $SU(3)$), larger internal groups appear naturally.

24.3 Local Gauge Transformations

The group $\mathrm{Aut}(\mathcal{C})$ is promoted to a local symmetry by allowing $U(x)$ to depend on spacetime point x. To preserve invariance under local $U(x)$, we introduce gauge connections $A_\mu(x)$ and define covariant derivatives:

$$D_\mu \varphi_\pm = \partial_\mu \varphi_\pm + igA_\mu \varphi_\pm.$$

The kinetic terms in the effective Lagrangian become

$$\beta\, g^{\mu\nu}(D_\mu \varphi_+)(D_\nu \varphi_-) - V(\varphi_+, \varphi_-).$$

These terms naturally induce the dynamics of gauge fields A_μ, which are identified with physical SM bosons.

24.4 Emergence of SM Gauge Groups

We propose the following identifications:

- $\mathbf{U(1)_Y}$ symmetry corresponds to local phase rotations of the fundamental temporal oscillation mode, leading to hypercharge assignments.
- $\mathbf{SU(2)_L}$ symmetry arises from rotations mixing two degenerate oscillatory modes in left-handed configurations, consistent with electroweak isospin.
- $\mathbf{SU(3)_C}$ symmetry corresponds to internal automorphisms permuting three oscillatory modes, representing color charge.

Thus, the full SM gauge group structure is embedded in

$$\mathrm{Aut}(\mathcal{C}) \supset U(1)_Y \times SU(2)_L \times SU(3)_C,$$

interpreted as the symmetry of possible temporal-topological oscillatory patterns.

24.5 Explicit Example: U(1) Oscillatory Mode and Charge Emergence

As a concrete example, consider a simplified configuration with a single oscillatory mode $\varphi(x)$ arising symmetrically in both temporal fields:

$$\tau_+(x) = \tau_+^{(0)} + \varphi(x), \qquad \tau_-(x) = \tau_-^{(0)} + \varphi(x).$$

This field admits a local phase transformation

$$\varphi(x) \mapsto e^{i\alpha(x)}\varphi(x), \qquad \alpha(x) \in \mathbb{R}.$$

Such a symmetry defines the group $U(1)$ and corresponds directly to the electromagnetic gauge symmetry.

Gauge Field Introduction. To maintain local invariance under $U(1)$ transformations, introduce a gauge field $A_\mu(x)$ and define

$$D_\mu \varphi = \partial_\mu \varphi + ieA_\mu \varphi,$$

where e is the coupling constant interpreted as electric charge.

Effective Lagrangian. The corresponding effective Lagrangian density reads

$$\mathcal{L}_{\text{eff}} = \beta\, g^{\mu\nu}(D_\mu\varphi)(D_\nu\varphi)^* - V(\varphi) - \frac{1}{4}F_{\mu\nu}F^{\mu\nu},$$

where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$.

Topological Charge. The total electric charge Q of a localized oscillatory solution is given by

$$Q = \int d^3x\, j^0(x), \quad j^\mu = -ie\big[\varphi^* D^\mu\varphi - \varphi(D^\mu\varphi)^*\big].$$

This interprets Q as a Noether charge associated with local $U(1)$ phase invariance.

Physical Interpretation. This construction provides a formal mechanism for the emergence of electric charge and electromagnetic interactions purely from local temporal oscillations. Here, the $U(1)$ symmetry is not fundamental but an automorphism of the oscillatory configuration space $\mathcal{C}$, induced by the temporal fields $\tau_\pm$.

Formal Summary. We can summarize this explicit example as

$$\{\tau_+, \tau_-\} \xrightarrow{\mathcal{F}} g_{\mu\nu}, \quad \varphi \xrightarrow{U(1)} \text{Electromagnetic interaction}, \quad Q = \text{Topological Noether charge}.$$

This explicitly demonstrates that electric charge and $U(1)$ gauge symmetry are emergent features within the same temporal-topological framework.

24.6 Explicit Example: SU(2) Oscillatory Modes and Weak Isospin

Next, consider a configuration with two independent oscillatory modes $\varphi_1(x)$ and $\varphi_2(x)$ introduced in the temporal fields:

$$\tau_+(x) = \tau_+^{(0)} + \varphi_1(x) + \varphi_2(x), \qquad \tau_-(x) = \tau_-^{(0)} + \varphi_1(x) + \varphi_2(x).$$

We define a local transformation mixing these modes:

$$\begin{pmatrix}\varphi_1(x)\\ \varphi_2(x)\end{pmatrix} \mapsto U(x)\begin{pmatrix}\varphi_1(x)\\ \varphi_2(x)\end{pmatrix}, \quad U(x) \in SU(2).$$

This local $SU(2)$ symmetry corresponds to weak isospin rotations.

Gauge Field Introduction. Introduce an $SU(2)$ gauge field $W_\mu = W_\mu^a T^a$, where T^a are generators of $SU(2)$, and define the covariant derivative

$$D_\mu\Phi = \partial_\mu\Phi + igW_\mu\Phi,$$

where $\Phi = (\varphi_1, \varphi_2)^T$ and g is the weak coupling constant.

Effective Lagrangian. The effective Lagrangian density is

$$\mathcal{L}_{\text{eff}} = \beta\, g^{\mu\nu}(D_\mu\Phi)^\dagger(D_\nu\Phi) - V(\Phi) - \frac{1}{4}W_{\mu\nu}^a W^{a\mu\nu},$$

where $W_{\mu\nu}^a = \partial_\mu W_\nu^a - \partial_\nu W_\mu^a + g\epsilon^{abc}W_\mu^b W_\nu^c$.

Topological Charges. The weak isospin charge is associated with Noether currents generated by $SU(2)$ rotations:

$$j_a^\mu = -i\big[\Phi^\dagger T^a D^\mu \Phi - (D^\mu \Phi)^\dagger T^a \Phi\big].$$

The conserved charges are

$$Q_a = \int d^3x\, j_a^0(x).$$

Physical Interpretation. This mechanism shows how weak isospin charges and $SU(2)$ gauge interactions naturally emerge from oscillatory modes of the temporal fields. The local $SU(2)$ symmetry is an automorphism of the configuration space $\mathcal{C}$ mixing two oscillatory modes.

Formal Summary.

$$\{\tau_+, \tau_-\} \xrightarrow{\mathcal{F}} g_{\mu\nu}, \quad \Phi \xrightarrow{SU(2)} \text{Weak interaction}, \quad Q_a = \text{Isospin charges}.$$

24.7 Explicit Example: SU(3) Oscillatory Modes and Color Charge

We now consider a configuration with three independent oscillatory modes $\varphi_1(x)$, $\varphi_2(x)$, and $\varphi_3(x)$ introduced in the temporal fields:

$$\tau_+(x) = \tau_+^{(0)} + \varphi_1(x) + \varphi_2(x) + \varphi_3(x), \quad \tau_-(x) = \tau_-^{(0)} + \varphi_1(x) + \varphi_2(x) + \varphi_3(x).$$

We define a local transformation mixing these modes:

$$\begin{pmatrix} \varphi_1(x) \\ \varphi_2(x) \\ \varphi_3(x) \end{pmatrix} \mapsto U(x) \begin{pmatrix} \varphi_1(x) \\ \varphi_2(x) \\ \varphi_3(x) \end{pmatrix}, \quad U(x) \in SU(3).$$

This local $SU(3)$ symmetry corresponds to color charge transformations in Quantum Chromodynamics (QCD).

Gauge Field Introduction. Introduce an $SU(3)$ gauge field $G_\mu = G_\mu^a T^a$, where T^a are the eight Gell-Mann matrices as generators of $SU(3)$. The covariant derivative is defined as

$$D_\mu \Phi = \partial_\mu \Phi + i g_s G_\mu \Phi,$$

where $\Phi = (\varphi_1, \varphi_2, \varphi_3)^T$, and g_s is the strong coupling constant.

Effective Lagrangian. The effective Lagrangian density becomes

$$\mathcal{L}_{\text{eff}} = \beta\, g^{\mu\nu} (D_\mu \Phi)^\dagger (D_\nu \Phi) - V(\Phi) - \frac{1}{4} G_{\mu\nu}^a G^{a\mu\nu},$$

where

$$G_{\mu\nu}^a = \partial_\mu G_\nu^a - \partial_\nu G_\mu^a + g_s f^{abc} G_\mu^b G_\nu^c,$$

and f^{abc} are the $SU(3)$ structure constants.

Color Charge. The color charges are defined via the Noether currents associated with $SU(3)$ transformations:

$$j_a^\mu = -i\big[\Phi^\dagger T^a D^\mu \Phi - (D^\mu \Phi)^\dagger T^a \Phi\big].$$

The conserved color charges are

$$Q_a = \int d^3x\, j_a^0(x).$$

Physical Interpretation. This construction shows how color charge and $SU(3)$ gauge interactions naturally arise as local automorphisms of the configuration space of temporal oscillations. The non-Abelian self-interaction term $g_s f^{abc} G_\mu^b G_\nu^c$ is automatically present, corresponding to gluon self-couplings.

Formal Summary.

$$\{\tau_+, \tau_-\} \xrightarrow{\mathcal{F}} g_{\mu\nu}, \quad \Phi \xrightarrow{SU(3)} \text{QCD interactions}, \quad Q_a = \text{Color charges}.$$

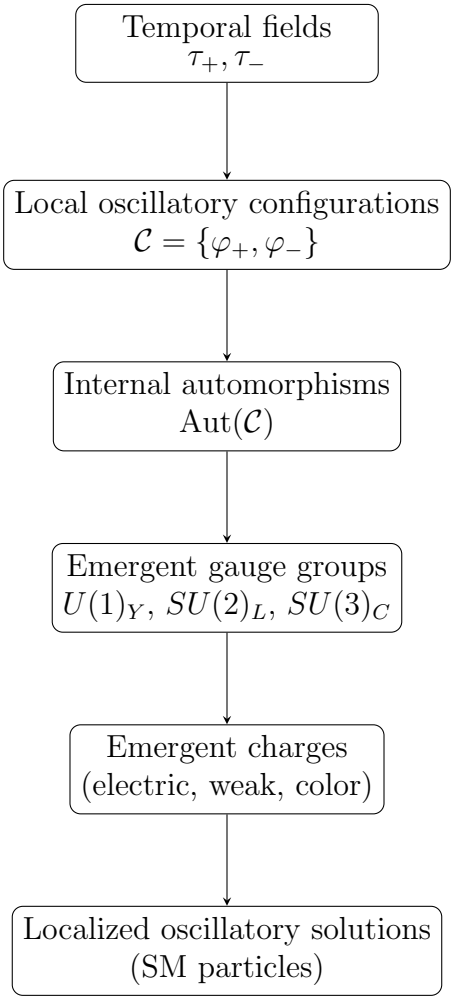


Figure 3: Hierarchical emergence: from temporal fields to Standard Model particles and charges.

24.8 Topological Charges and Particle Interpretation

Charges (electric, color, weak isospin) can be interpreted as topological winding numbers or characteristic classes (e.g., Chern classes) of the local geometric solutions. The mass parameters emerge from integrated energy densities of the oscillatory configurations, while spin arises as an intrinsic angular momentum of helical or twisted oscillations.

24.9 Formal Summary

We summarize the emergence as

$$\{\tau_+, \tau_-\} \xrightarrow{\mathcal{F}} g_{\mu\nu}, \quad \mathcal{C}(g_{\mu\nu}) \xrightarrow{\text{Aut}} U(1)_Y \times SU(2)_L \times SU(3)_C.$$

This construction unifies temporal oscillations, emergent geometry, and SM internal symmetries in a single ontological and mathematical framework.

25 Emergence of Standard Model Particles from Temporal-Topological Structures

The fundamental framework proposed in this work naturally suggests that all known Standard Model (SM) particles may emerge as localized topological and geometric solutions of the coexisting temporal fields τ_+ and τ_-. Below, we outline a detailed research program and provide a roadmap for deriving the known parameters (masses, charges, spins) from geometric or topological principles within our theory.

25.1 Particles as Localized Oscillations

We hypothesize that elementary particles correspond to stable, localized oscillatory solutions (oscillons or solitons) of the fundamental temporal fields $\tau_\pm$. The existence and stability of these solutions require detailed investigation of the nonlinear equations:

$$\Box_g \tau_\pm(x) = \frac{\partial V(\tau_+, \tau_-)}{\partial \tau_\mp(x)}. \tag{61}$$

25.2 Geometric Interpretation of Particle Properties

Masses could be derived from the energy content associated with the local geometry of temporal oscillations:

$$m^2 = \int d^3x \sqrt{-g} \left(\beta \nabla_\mu \tau_+ \nabla^\mu \tau_- + V(\tau_+, \tau_-)\right). \tag{62}$$

Electric charges may be related to topological invariants of the emergent geometry, defined, for instance, as integrals of geometric curvature fields:

$$Q = \frac{1}{8\pi} \int_\Sigma \epsilon^{\mu\nu\alpha\beta} F^{\text{geom}}_{\mu\nu} F^{\text{geom}}_{\alpha\beta} \, d^4x. \tag{63}$$

Spin is naturally identified with the intrinsic angular momentum arising from helical or twisted topological solutions:

$$S = \frac{1}{16\pi} \int_{\partial\Sigma} dS^{\mu\nu} \, \epsilon_{\mu\nu\alpha\beta} \Gamma^\alpha_{\gamma\delta} \partial^\beta g^{\gamma\delta}. \tag{64}$$

25.3 Groups of Symmetry and Gauge Fields

An essential step would be to demonstrate how known gauge symmetries of the Standard Model naturally emerge as local isometries or symmetries of the temporal-topological solutions. Explicitly:

- U(1) symmetry could correspond to local geometric phase invariance.
- SU(2) weak interactions could be associated with internal geometric rotations between the temporal fields.
- SU(3) strong interactions might be interpreted through topologically richer (e.g., tri-color) local geometric structures.

25.4 Derivation of Fundamental Constants

A crucial research direction is to precisely link known fundamental constants (electron mass, charge magnitude, fine-structure constant) to geometric and topological properties of solutions, potentially allowing a prediction of these constants from first principles.

Example: 1+1D Temporal Oscillon Solution

Consider a simplified 1+1D model with approximate flat background geometry $g_{\mu\nu} \approx \eta_{\mu\nu}$, and assume small perturbations:

$$\tau_+(x,t) = \tau_+^{(0)} + \varphi(x,t), \quad \tau_-(x,t) = \tau_-^{(0)} + \varphi(x,t).$$

The linearized equation with quadratic potential $V(\tau_+, \tau_-) = \frac{1}{2}m^2\tau_+\tau_-$ becomes

$$\Box\varphi - m^2\varphi = 0,$$

where $\Box = \partial_t^2 - \partial_x^2$.

A typical oscillon-type solution in 1+1D reads:

$$\varphi(x,t) \approx A\,\mathrm{sech}(\alpha x)\cos(\omega t),$$

with frequency

$$\omega \approx m - \frac{\alpha^2}{2m}, \quad \alpha \ll m.$$

Here A controls amplitude, and α defines spatial localization. Such a solution represents a localized, oscillatory, long-lived configuration — a toy-model "particle-like" excitation emerging from temporal fields.

Approximate Mass from Oscillation Energy

In this simplified picture, the mass squared of the localized configuration can be approximated as

$$m_{\mathrm{osc}}^2 \approx \int dx \left[\left(\frac{\partial\varphi}{\partial t}\right)^2 + \left(\frac{\partial\varphi}{\partial x}\right)^2 + m^2\varphi^2 \right].$$

Using the explicit oscillon profile,

$$\varphi(x,t) = A\,\mathrm{sech}(\alpha x)\cos(\omega t),$$

the leading contribution to the integral gives

$$m_{\text{osc}} \approx \omega,$$

demonstrating a direct connection between mass and temporal oscillation frequency, analogous to mass-frequency relations for solitons or oscillons (cf. Gleiser 1994). This provides an intuitive link between temporal oscillations and emergent particle properties.

25.5 Research Roadmap

We propose the following concrete research objectives for future work:

1. **Explicit Construction of Particle Solutions**: Construct numerical and analytical solutions representing elementary particles and match their geometric characteristics to known SM particles.
2. **Quantitative Predictions of Particle Parameters**: Perform detailed numerical simulations to derive masses, charges, and spins of known particles, comparing them directly with experimental data.
3. **Gauge Symmetries as Emergent Geometric Symmetries**: Demonstrate explicitly how SM gauge groups (U(1), SU(2), SU(3)) arise from local geometric symmetries in the solutions.
4. **Numerical Simulations and Stability Analysis**: Investigate stability conditions of oscillatory solutions and their robustness under perturbations.
5. **Cosmological and Astrophysical Implications**: Explore observational signatures, such as anomalies in gravitational lensing or cosmic microwave background (CMB) fluctuations, resulting from these particle-like solutions.
6. **High-Energy Predictions and Experimental Tests**: Identify unique signatures that could differentiate this theory from conventional particle physics, guiding future collider or astrophysical observations.

25.6 Potential Impact

If successful, this ambitious program could offer:

- A unified geometric-topological foundation for particle physics.
- Predictive power for fundamental constants from first principles.
- Deep connections between cosmological phenomena and particle-scale physics.

We invite further theoretical development and experimental collaboration to pursue these profound directions, with the aim of bridging fundamental physics, cosmology, and geometry into a coherent Theory of Everything.

26 Predictions and Experimental Tests

The proposed emergent-spacetime model, based on the coexistence of two global time arrows (τ_+, τ_-), leads to a series of distinct predictions. Each prediction is described together with its empirical search domain and possible testing methodology.

26.1 Galactic "dark matter" as a geometric effect

Instead of invoking new particles, the model predicts that the apparent gravitational excess in galaxies results from the projection of the τ_--sector geometry onto our τ_+ sector. The effect depends on local gradients in the relative time-arrow structure Δ_τ.
Where to look: Rotation curves of low-surface-brightness (LSB) galaxies, especially in regions with distinctive large-scale geometry in the cosmic web.
How to test: Compare observed velocity profiles with standard NFW halo models, checking for systematic correlations with cosmic-environment geometry rather than baryonic mass alone.

26.2 High-velocity galaxies in cosmic voids

In underdense regions, the geometry of the τ_- sector may locally dominate, leading to anomalously high galaxy velocities and gravitational-lensing patterns inconsistent with standard dark-halo models.
Where to look: Galaxies deep inside cosmic voids, such as those in the Local Void.
How to test: Cross-analyse kinematic and weak-lensing surveys to identify deviations from predictions based on local mass distributions.

26.3 Massive neutron stars without collapse

Extremely massive neutron stars ($\gtrsim 2.3 M_\odot$) may remain stable due to time-geometric effects modifying the collapse threshold from GR.
Where to look: High-mass pulsars such as J0740+6620 and future discoveries from large-scale pulsar surveys.
How to test: Improve mass measurements via Shapiro delay and gravitational-wave signals from neutron-star mergers.

26.4 No true acceleration of cosmic expansion

The observed acceleration in Type Ia supernovae data is a projection effect of asymmetric time geometry, not caused by a cosmological constant.
Where to look: Combined datasets of SN Ia, baryon acoustic oscillations (BAO), and gravitational-wave standard sirens.
How to test: Look for consistent systematic offsets between distance–redshift relations predicted by projection models and by ΛCDM.

26.5 No Big Bang singularity

The Universe has no beginning in absolute time; the observed last-scattering surface marks a local interface between τ_+ and τ_- domains.
Where to look: Large-scale ($\ell < 30$) features of the cosmic microwave background (CMB).
How to test: Compare CMB angular power spectra from projection-based models with ΛCDM, focusing on low-multipole correlations.

26.6 General relativity as a large-scale limit

In extreme density regimes, the metric is modified by additional τ_--sector stress–energy terms, leading to deviations from GR predictions.
Where to look: Near-horizon regions of supermassive black holes.
How to test: Compare Event Horizon Telescope (EHT) images with GR-based ray-tracing simulations, looking for shape/size discrepancies.

26.7 Microscale time-asymmetry in quantum processes

Local statistical asymmetries in quantum outcomes arise from fluctuation-driven information leakage between τ_+ and τ_-.
Where to look: High-precision quantum interference experiments.
How to test: Long-baseline interferometers such as Mach–Zehnder setups, searching for reproducible deviations from purely stochastic predictions.

26.8 Enhanced CP and T violations

The dual-time framework introduces preferred temporal structures that can enhance CP-violating decays and produce measurable T-symmetry deviations.
Where to look: K- and B-meson decay channels, neutrino vs. antineutrino oscillations.
How to test: Analyse datasets from LHCb, Belle II, DUNE, and Hyper-K for deviations from Standard Model expectations.

26.9 Absence of detectable dark matter particles

If the dark sector is purely geometric, direct or indirect searches for dark matter particles will remain null.
Where to look: Underground detectors (LUX, XENONnT, PandaX), high-energy collider experiments (LHC).
How to test: Continue large-volume searches; persistence of null results strengthens the geometric hypothesis.

Observable	**ΛCDM Baseline**	**Coexisting Time Arrows (CTA)**	**Current / Upcoming Probe**
Global Λ	$\Lambda \simeq 7 \times 10^{-30}\,\mathrm{g/cm^3}$ (constant), $w \approx -1$	$\Lambda_{\mathrm{global}} = 0$; apparent $w_{\mathrm{eff}} < -1$ from inhomog. $\nabla\tau_\pm$	low-z ISW, SH0ES vs. TRGB, Euclid $H(z)$ at $z > 2$
Redshift drift $\dot{z}$ (at $z \sim 2$)	$\dot{z} \sim 10^{-10}\,\mathrm{yr}^{-1}$	$\dot{z} \equiv 0$ (no global expansion)	ELT/ANDES high-res spectroscopy
Growth index $\gamma(z \lesssim 1)$	$\gamma \approx 0.55 \pm 0.02$	$\gamma \approx 0.40 \pm 0.02$	DESI RSD, SKA weak lensing
Late–time ISW	positive $\Delta T/T \sim 10^{-5}$ on large scales	strongly suppressed (zero if $\partial_t \tau_\pm$ uniform)	Planck + LSST CMB–LSS x-corr
CMB acoustic peaks	fixed $\theta_* \simeq 0.0104$	unchanged at 1st order; higher peaks shift if $V(\tau_+, \tau_-) \neq 0$	ACT DR6, Simons Observatory
Bullet-type clusters	CDM with tiny self-interaction	effective cross-section $\sigma/m < 10^{-26}\,\mathrm{cm^2/g}$ (pure geometry)	JWST strong-lensing of mergers
Direct DM searches	WIMP/axion candidates expected	null — no new particles (geometric effect)	XENONnT, LZ, PandaX, LHC
Variation of c	constant by postulate	$\dot{c}/c \sim 10^{-17}\,\mathrm{yr}^{-1}$ (quadratic in $\nabla\tau_\pm$)	Atomic-clock networks, pulsar timing
Massive neutron stars	$M_{\max} \lesssim 2.3\,M_\odot$	stable up to $M \approx 2.6\,M_\odot$ (geometric support)	NICER, Shapiro delay, GW (NS–NS)
Big-Bang singularity / expansion	hot Big Bang (+ inflation); global expansion $a(t)$	no global singularity; no true global expansion (projection along τ_+)	CMB low-ℓ, redshift-drift, standard-sirens
CP/T violation scale	CKM/PMNS phases match data	possible mild enhancement from temporal-sector coupling	LHCb, Belle II, DUNE, Hyper-K

Table 1: Unified comparison of key observables: standard ΛCDM vs. CTA, with indicative numerical targets where available. Precise forecasts require solving Eqs. (27)–(28) on an FLRW background with perturbations.

26.10 Physical Status and Observational Constraints

The interpretation of dark matter as a gravitational manifestation of the oppositely oriented temporal sector remains a hypothesis of CTA. Its viability requires quantitative agreement with galactic rotation curves, gravitational lensing, galaxy-cluster dynamics,

cosmic microwave background anisotropies, and large-scale structure formation. Similarly, explaining cosmic acceleration without fundamental dark energy requires a consistent cosmological solution compatible with observed distance-redshift relations and cosmological measurements. These proposals have not yet been established as quantitative consequences of the CTA field equations.

27 Conclusions

In this work, we have proposed an axiomatic framework, termed Coexisting Time Arrows (CTA), in which time is postulated as the fundamental and eternal constituent of physical reality. The framework assumes the coexistence of two oppositely oriented temporal sectors, τ_+ and τ_-, and investigates whether spacetime geometry, matter, energy, and quantum phenomena may emerge from their local interactions. A central mathematical result concerns the emergence of Lorentzian geometry. We have demonstrated that a metric constructed from a single pair of scalar temporal-field gradients has rank at most two and therefore cannot represent a nondegenerate four-dimensional spacetime metric. To overcome this limitation, we introduced a multimode generalization involving N pairs of temporal scalar fields. Within the proposed bilinear metric ansatz, at least three temporal mode pairs are necessary to reproduce a Lorentzian signature $(-+++)$. An explicit construction demonstrates that three such pairs are sufficient to generate Minkowski spacetime. The resulting geometry admits an interpretation as an induced metric in an auxiliary six-dimensional flat space with signature $(3, 3)$. This construction establishes a mathematically explicit connection between temporal field configurations and flat Lorentzian geometry. However, the dimensionality of physical spacetime is not independently derived from the fundamental CTA axioms. The three spatial dimensions enter through the prescribed Lorentzian signature. Beyond this geometric construction, CTA proposes a broader interpretation of several physical phenomena. The gravitational effects attributed to dark matter are hypothesized to originate from the oppositely oriented temporal sector, while the observed cosmic acceleration may admit an alternative explanation based on temporal geometry rather than fundamental dark energy. The emergence of electric charge, gauge symmetries, and quantum behavior from temporal degrees of freedom constitutes an additional direction of investigation. These proposals remain physical hypotheses rather than established consequences of the present mathematical formulation. Important open problems include the representation of curved spacetimes, the recovery of Einstein gravitational dynamics, the stability of the induced geometry, the propagation of gravitational waves, and the derivation of quantitative cosmological predictions. **The principal conclusion is that the coexistence of oppositely oriented temporal fields admits a mathematically consistent construction of flat four-dimensional Lorentzian geometry, provided that at least three temporal mode pairs are introduced within the proposed bilinear framework.** This result does not establish that the temporal structure is physically fundamental, but provides a concrete mathematical basis for investigating that possibility. We invite further mathematical analysis and observational testing of CTA as an axiomatic research framework for the possible emergence of physical geometry and its associated phenomena.

Appendix A: Black Holes and Minimal Temporal Quantum

Black Holes as Emergent Structures

In this axiomatic framework, black holes are not seen as singularities or exotic objects requiring external creation mechanisms. Rather, they arise naturally as extreme local configurations of the emergent geometry $g_{\mu\nu}$...

Hypothesis of Minimal Temporal Quantum t_0

Given that time is treated as fundamental and continuous in our framework, it is natural to ask whether there exists a minimal, indivisible unit of temporal flow — a "quantum of time" denoted t_0.

We hypothesize that t_0 represents the smallest possible increment of temporal change, below which no distinct events or configurations can be resolved. This is conceptually analogous to the Planck length l_P in quantum gravity or the reduced Planck constant $\hbar$ in quantum mechanics.

Formally, t_0 can be interpreted as the minimal eigenvalue in the spectrum of the temporal operator $\hat{\tau}_{\pm}$. In other words, there exist no nontrivial configurations of $\tau_{\pm}$ that change over intervals shorter than t_0. This introduces a natural ultraviolet (UV) cutoff and avoids divergences commonly encountered in quantum field theories.

A direct consequence is that spacetime geometries induced by $\tau_{\pm}$ are fundamentally discrete at the smallest scales, even though they may appear smooth macroscopically. This discreteness regularizes high-frequency fluctuations and provides a possible route toward a consistent quantum gravity theory without requiring explicit discretization or lattice approximations.

Consequences and Future Directions

The existence of a minimal temporal quantum t_0 implies several profound consequences.

Firstly, it sets a natural lower bound on measurable durations and hence on frequencies, introducing a maximal finite energy scale. This acts as an intrinsic UV regulator and may resolve long-standing issues related to infinities in quantum field theories.

Secondly, t_0 could induce modifications to the uncertainty relations, leading to generalized uncertainty principles (GUP) at very small scales. Such corrections might become relevant in extreme astrophysical environments (e.g., near black holes or during high-energy cosmic events).

Thirdly, the presence of t_0 suggests a discrete "spectrum" of emergent geometries at the Planck scale, potentially leaving observable imprints in cosmological backgrounds, such as deviations in primordial perturbation spectra or signatures in gravitational wave interferometers.

Future directions include:

- Developing explicit operator spectra for $\hat{\tau}_{\pm}$ and computing eigenstates to clarify the nature of t_0.
- Investigating possible observational signatures in cosmological or astrophysical data (e.g., Planck satellite, LIGO/Virgo).

- Exploring the influence of t_0 on particle oscillation dynamics and stability of emergent localized structures.
- Establishing potential links to generalized entropy bounds and information-theoretic interpretations of spacetime.

Ultimately, confirming the existence of t_0 would provide compelling evidence for the fundamental discreteness of time and strengthen the axiomatic basis of our framework.

Appendix B: Emergence of Particles and Atomic Structures

Particles as Localized Geometric Oscillations

In our axiomatic framework, particles are not taken as fundamental irreducible building blocks. Instead, they emerge as stable, localized oscillatory solutions of the emergent geometry $g_{\mu\nu}$.

The coexistence of time arrows τ_+ and τ_- generates the metric field $g_{\mu\nu}$, which supports local dynamic configurations. These configurations can stabilize into discrete oscillatory patterns, effectively forming what we observe as elementary particles.

$$\{\tau_+, \tau_-\} \xrightarrow{\mathcal{F}} g_{\mu\nu} \implies \text{Localized Oscillations} \implies \text{Particles}.$$

Topological and Geometric Properties

Properties such as mass, charge, and spin are interpreted as topological or geometric invariants of these oscillatory structures within $g_{\mu\nu}$.

- **Mass**: Interpreted as the measure of energy required to deform or displace the local oscillation in the temporal framework. - **Charge**: Emerges from asymmetries or twists in the oscillatory geometry. - **Spin**: Corresponds to intrinsic angular momentum arising from the cyclic nature of the local oscillation.

Emergence of Atomic Structures

Atoms form as stable bound states of these localized oscillations. The nucleus represents a highly concentrated region of geometric curvature, while electrons correspond to stable standing wave patterns distributed around this core.

$$\text{Particles} \implies \text{Bound States} \implies \text{Atoms}.$$

Atomic stability thus arises not from arbitrary force laws, but as a natural consequence of the emergent geometric field shaped by the interplay of τ_+ and τ_-.

Consequences and Future Research

This perspective implies that the entire Standard Model of particle physics could be reinterpreted as a taxonomy of stable geometric oscillations rather than a set of elementary, fundamental point-like objects.

This approach opens possibilities for:

- Predicting new stable or quasi-stable oscillatory configurations (potential new particles).
- Re-expressing interaction dynamics purely in geometric terms.
- Connecting cosmological large-scale structure with particle-scale microstructure through a unified temporal-geometric mechanism.

Further mathematical development is required to explicitly derive these oscillatory solutions and compare them quantitatively with observed particle properties.

Explicit Example: Localized Oscillatory Solutions

Assuming small perturbations around a constant background,

$$\tau_{\pm}(x) = \tau_{\pm}^{(0)} + \delta\tau_{\pm}(x),$$

and approximating $g_{\mu\nu}$ as nearly flat, the linearized equation (28) for $V = \frac{1}{2}m^2(\tau_+\tau_-)$ yields

$$\Box\delta\tau_{\pm} - m^2\delta\tau_{\mp} = 0.$$

For symmetric configurations $\delta\tau_+ = \delta\tau_- = \varphi$, we get

$$\Box\varphi - m^2\varphi = 0,$$

which admits localized solitonic (oscillon-type) solutions in $3+1$ dimensions (see e.g. [9]).

These solutions can be interpreted as particle-like excitations. Their topological stability (e.g., from a non-trivial π_3 winding) can further protect their identity, suggesting an interpretation as elementary particles within this framework.

Appendix C: Signatures of Temporal Symmetry in C and P

Charge and Parity Symmetries as Temporal Evidence

In the standard model of particle physics, charge conjugation symmetry (C) and parity symmetry (P) represent transformations where particles are exchanged with their antiparticles and spatial coordinates are mirrored, respectively.

In our framework, the existence of these symmetries is interpreted as local signatures of the fundamental coexistence of two global temporal flows, τ_+ and τ_-. The charge conjugation operation can be seen as a localized "temporal inversion footprint," while parity reflects the geometric consequences of embedding these inversions within emergent spatial structures.

Antimatter as Local Manifestation of τ_-

Antimatter, such as positrons, is considered a local manifestation of the τ_- sector transiently interacting with the τ_+ dominated region. The observed scarcity of large-scale antimatter structures suggests that, globally, our universe is dominated by τ_+, with the τ_- components effectively segregated or embedded in geometrically "dark" configurations.

Appendix D: Explaining Big Bang Residuals within Our Framework

A natural and crucial question arises: how can our theory account for the observational signatures traditionally attributed to the Big Bang, such as the cosmic microwave background (CMB) radiation, light element abundances, and the apparent large-scale homogeneity and isotropy of the universe?

Within our framework, the coexistence of two temporal flows, τ_+ and τ_-, leads to the emergence of a local geometry $g_{\mu\nu}$ without requiring a singular creation event. However, when this coexistence becomes established locally, it may resemble a rapid phase transition from an effectively "empty" or "trivial" geometric state (described by $\eta_{\mu\nu}$) to a non-trivial emergent spacetime structure.

This transition can generate local thermal and energetic effects analogous to those interpreted as a "hot beginning" in standard cosmology. Consequently, phenomena such as the CMB can be viewed as residuals of this local geometric emergence rather than relics of a singular explosion.

Key points to investigate include:

- How the initial local establishment of $g_{\mu\nu}$ might lead to a uniform thermal background analogous to the observed CMB.
- Whether the dynamics of τ_+ and τ_- flows could explain the observed abundance of light elements (e.g., via alternative nucleosynthesis scenarios arising from early local conditions).
- How the initial local geometry might naturally favor homogeneity and isotropy at large scales, without requiring inflationary mechanisms.
- The possibility of deriving predicted fluctuation spectra (e.g., CMB anisotropies) directly from local variations and quantum fluctuations in τ_+ and τ_- during the emergence process.

While these ideas are still speculative, they open a promising direction for further development. This approach challenges the need for a singular Big Bang origin, proposing instead that all observed "primordial" signatures arise from local, temporally driven geometric emergence events.

We emphasize that these questions remain open and constitute an important frontier for both theoretical refinement and potential experimental validation. Incorporating these phenomena consistently could significantly strengthen the explanatory power of our framework and provide concrete connections with current cosmological observations.

Appendix E: Toy-model example (1+1D)

This appendix illustrates how a local metric can be constructed from two oppositely oriented temporal scalar fields. The example is restricted to $1+1$ dimensions and does not represent the complete multimode formulation required for four-dimensional Lorentzian geometry.

Setup

Consider local coordinates (t, x) and two temporal functions:

$$\tau_+(t,x) = t + f(x), \qquad \tau_-(t,x) = -t + f(x),$$

where $f(x)$ is a smooth function. As an illustrative example, we may choose

$$f(x) = A\sin(kx).$$

Local gradients

The temporal gradients are

$$\partial_\mu \tau_+ = (1, f'(x)), \qquad \partial_\mu \tau_- = (-1, f'(x)).$$

We denote these gradients by

$$v_\mu^\pm = \partial_\mu \tau_\pm.$$

Emergent metric

Using the symmetrized bilinear construction,

$$g_{\mu\nu} = \frac{1}{2}\left(v_\mu^+ v_\nu^- + v_\mu^- v_\nu^+\right),$$

we obtain

$$g_{00} = -1, \qquad g_{01} = 0, \qquad g_{11} = (f'(x))^2.$$

Therefore,

$$g_{\mu\nu} = \begin{pmatrix} -1 & 0 \\ 0 & (f'(x))^2 \end{pmatrix},$$

and the corresponding line element is

$$ds^2 = -dt^2 + (f'(x))^2 dx^2.$$

The determinant is

$$\det g = -(f'(x))^2.$$

Consequently, the metric is nondegenerate wherever

$$f'(x) \neq 0.$$

At points where $f'(x) = 0$, the metric becomes degenerate and its inverse is not defined.

Scalar curvature

Consider any connected region where $f'(x) \neq 0$. Introduce the local coordinates

$$T = t, \qquad X = f(x).$$

Since

$$dX = f'(x)\, dx,$$

the line element becomes

$$ds^2 = -dT^2 + dX^2.$$

This is the Minkowski metric in $1+1$ dimensions.

Therefore, the Riemann curvature tensor and the Ricci scalar vanish:

$$R^{\rho}{}_{\sigma\mu\nu} = 0, \qquad R_{\mu\nu} = 0, \qquad \boxed{R = 0}.$$

Thus, the spatial dependence of $f(x)$ does not generate intrinsic curvature in this particular construction.

Example function

For

$$f(x) = A\sin(kx),$$

we obtain

$$f'(x) = Ak\cos(kx).$$

The metric becomes

$$ds^2 = -dt^2 + A^2k^2\cos^2(kx)\,dx^2.$$

On every connected region where

$$Ak\cos(kx) \neq 0,$$

the coordinate transformation

$$T = t, \qquad X = A\sin(kx)$$

reduces the metric to

$$ds^2 = -dT^2 + dX^2.$$

Hence,

$$R = 0$$

throughout each nondegenerate region.

At points where

$$Ak\cos(kx) = 0,$$

the metric becomes degenerate. These points do not represent curvature singularities of a nondegenerate Lorentzian metric; rather, the induced metric construction loses rank there.

Interpretation

This example demonstrates that:

- Two oppositely oriented temporal scalar fields can generate a nondegenerate Lorentzian metric in $1+1$ dimensions.
- The spatial variation of the temporal fields determines the coordinate representation of the induced metric.
- Nonconstant metric coefficients do not necessarily imply nonzero intrinsic curvature.

- The induced metric becomes degenerate when the relevant temporal gradients lose the required independence. item A single temporal mode pair is insufficient to generate a nondegenerate four-dimensional metric.

The example therefore illustrates the local metric-construction mechanism underlying CTA, without establishing the emergence of curved four-dimensional spacetime.

Formal Interpretation

The coexistence of oppositely oriented temporal sectors provides a proposed ontological basis for investigating the emergence of physical geometry. Within CTA, possible connections between these sectors and charge conjugation, parity, and CPT-related phenomena remain hypotheses requiring additional mathematical derivation and empirical testing. The present toy model establishes neither particle-antiparticle correspondence nor the emergence of discrete physical symmetries.

Cosmological Implications

This viewpoint provides a potential resolution to the so-called "missing antimatter problem," suggesting that antimatter did not annihilate or vanish but instead reflects the presence of the τ_- sector, which is not macroscopically visible in our τ_+ dominated observational frame. The geometric segregation aligns with the concept of dark matter as an emergent gravitational effect from τ_- components.

Suggested Directions for Further Research

While this framework establishes a minimal and coherent foundation based on the primacy of time and the emergent nature of space, several crucial directions remain open for theoretical development and empirical exploration. We summarize them below as concrete research objectives:

1. **Quantitative Predictions for Cosmological Observables:** Extend the current action and field equations to provide precise numerical predictions for key cosmological observables (e.g., the CMB power spectrum, baryon acoustic oscillations, large-scale structure growth rates). Solving the dynamical equations on an FLRW background with realistic perturbations is a critical next step.

2. **Explicit Derivation of Particle Spectrum:** Develop a detailed mathematical treatment of localized geometric oscillations leading to stable particle-like solutions. Derive explicit masses, charges, and coupling constants, comparing them with the Standard Model parameters.

3. **Detailed Quantum Time Operator Formalism:** Formalize the proposed quantum operator structure for time arrows ($\hat{\tau}_\pm$) rigorously. Specify Hilbert-space constructions, explicit commutation relations, and possible spectral decompositions.

4. **Connection to Quantum Gravity:** Investigate whether the geometric and temporal fluctuations introduced via $\delta g_{\mu\nu}(\hat{\tau}_+, \hat{\tau}_-)$ can yield a natural regularization of spacetime singularities, thereby providing a non-perturbative foundation for quantum gravity.

5. **Experimental Probes of Global Temporal Symmetry:** Propose concrete experimental scenarios to detect signatures of the coexisting time arrows (e.g., small variations in the effective speed of light, gravitational lensing anomalies, deviations from standard cosmic acceleration measurements).

6. **Stability Analysis of Emergent Geometries:** Analyze the dynamical stability of solutions to the minimal field equations, including potential instabilities in the local configurations of τ_+ and τ_-. Establish constraints on the admissible potential $V(\tau_+, \tau_-)$.

7. **Numerical Simulations of Emergent Universes:** Develop numerical-relativity or lattice-based simulations to explore the non-linear dynamics of τ_+ and τ_- and visualize the emergence of structure from the operator $\mathcal{F}$.

8. **Down-to-Earth Implications:**

   - Could zero redshift drift measurements (i.e. no global expansion) be observed with ELT-class spectrographs?
   - Might terrestrial atomic-clock networks detect the tiny temporal oscillations predicted by $\tau_\pm$ fluctuation?
   - Are there table-top analogues—e.g. coupled pendulum arrays—that simulate dual-arrow dynamics?

9. **Potential Extensions to Consciousness Studies:** Explore the implications of emergent geometry and temporal ontology for modeling consciousness as an advanced self-aware system capable of internal state differentiation.

Closing Remark. These directions do not merely refine the current framework but may lead to fundamentally new insights into the nature of space, time, matter, and consciousness. They form an interdisciplinary roadmap bridging physics, mathematics, cosmology, and philosophy, potentially advancing us toward a more complete theory of reality.

A Axiomatic Foundations

A.1 Configuration Space and Transformation Operators

Let

$$\Omega$$

denote the universe, represented as a finite set of elementary states:

$$|\Omega| < \infty.$$

The power set

$$\mathcal{P}(\Omega)$$

represents the family of all possible system configurations.
Define the global transformation space

$$\mathcal{F} = \{f \mid f : \mathcal{P}(\Omega) \to \mathcal{P}(\Omega)\}.$$

Thus every element of $\mathcal{F}$ is a global endofunction on the configuration space.

Axiom A.1 (Omnipotence)**.** *There exists a global evaluation operator*

$$\text{Eval}$$

capable of executing any transformation

$$f \in \mathcal{F}.$$

Let

$$\overline{\mathcal{F}} \subseteq \mathcal{F}$$

denote the subset of transformations that are actively instantiated by the Master OS. Therefore,

$$f \in \mathcal{F}$$

means that f is executable in principle, whereas

$$f \in \overline{\mathcal{F}}$$

means that f is actually instantiated.

A.2 Welfare Functional and Ordering

Definition A.1 (Welfare Functional)**.** Let

$$q : \mathcal{P}(\Omega) \to \mathbb{R}$$

be a welfare functional assigning a scalar welfare value to every configuration. The functional q induces the preference relation

$$X \preceq_q Y \quad \Longleftrightarrow \quad q(X) \leq q(Y).$$

Definition A.2 (Omni-benevolent Transformation)**.** A transformation

$$f \in \mathcal{F}$$

is called omni-benevolent if and only if

$$\forall X \in \mathcal{P}(\Omega), \qquad q(X) \leq q(f(X)).$$

Define

$$\mathcal{W} = \{f \in \mathcal{F} \mid \forall X,\ q(X) \leq q(f(X))\}.$$

The actively instantiated omni-benevolent transformations are

$$\overline{\mathcal{W}} = \mathcal{W} \cap \overline{\mathcal{F}}.$$

A.3 Temporal Orientation

Definition A.3 (Temporal Orientation Functional)**.** Let

$$T : \mathcal{P}(\Omega) \to \{-1, +1\}$$

be the temporal-orientation functional.
Define

$$\mathcal{S}_+ = \{X \in \mathcal{P}(\Omega) \mid T(X) = +1\},$$

and

$$\mathcal{S}_- = \{X \in \mathcal{P}(\Omega) \mid T(X) = -1\}.$$

The chronological orientation associated with $\mathcal{S}_+$ is denoted by

$$\tau_+,$$

while the chronological orientation associated with $\mathcal{S}_-$ is denoted by

$$\tau_-.$$

By definition,

$$\tau_+ \neq \tau_-.$$

No algebraic subtraction operation between τ_+ and τ_- is assumed.

A.4 The Primary Entity

Definition A.4 (Primary Entity Criterion)**.** The *Primary Entity* is an active evaluation configuration of the Master OS possessing the global evaluation capacity Eval and satisfying the teleological convergence condition

$$\overline{\mathcal{F}} = \overline{\mathcal{W}} \neq \varnothing.$$

Thus, in the convergent regime, every actively instantiated operation preserves or increases welfare.

Remark A.1. The Primary Entity Criterion is a definition internal to the CTA framework. Establishing that a physical system satisfies this criterion does not independently establish the empirical existence of such a system.

A.5 Systemic Closure

Axiom A.2 (Systemic Closure / Ontological Consistency)**.** *There exists a global CTA conjugation operator*

$$\mathrm{CTA} : \mathcal{F} \to \mathcal{F}.$$

For every active transformation

$$f \in \overline{\mathcal{F}},$$

its CTA conjugate is also actively instantiated:

$$f \in \overline{\mathcal{F}} \quad \Longrightarrow \quad \mathrm{CTA}(f) \in \overline{\mathcal{F}}.$$

Thus $\overline{\mathcal{F}}$ is closed under CTA conjugation.

A.6 Sector Reversibility

Axiom A.3 (Sector Reversibility Postulate)**.** *Let*

$$\varnothing \neq \mathcal{B} \subseteq \mathcal{S}_+$$

be the CTA-accessible baryonic sector, and let

$$\mathbb{N} \subseteq \mathcal{S}_+$$

be the corresponding neutrino sector.
CTA postulates the existence of a bijective sector map

$$g : \mathcal{B} \xrightarrow{\sim} \mathbb{N}.$$

Consequently, there exists a unique inverse map

$$g^{-1} : \mathbb{N} \to \mathcal{B}$$

satisfying

$$g^{-1} \circ g = \mathrm{id}_{\mathcal{B}},$$

and

$$g \circ g^{-1} = \mathrm{id}_{\mathbb{N}}\,.$$

This bijection is a specific CTA postulate and is not claimed to follow from the general unitarity of quantum mechanics.

A.7 Local Realization of Global Conjugation

Axiom A.4 (Sector Conjugation Compatibility)**.** *Let*

$$f \in \overline{\mathcal{F}}$$

be a global active operator whose restriction to the neutrino sector satisfies

$$f|_{\mathbb{N}} : \mathbb{N} \to \mathrm{NA},$$

where

$$\mathrm{NA} \subseteq \mathbb{N}.$$

The global conjugate operator

$$\mathrm{CTA}(f) \in \overline{\mathcal{F}}$$

acts on the baryonic sector according to

$$\boxed{\mathrm{CTA}(f)|_{\mathcal{B}} = g^{-1} \circ f|_{\mathbb{N}} \circ g}.$$

Thus $\mathrm{CTA}(f)$ *remains a global endofunction on* $\mathcal{P}(\Omega)$*, while its baryonic-sector restriction is determined by the local sector dynamics.*

A.8 Global Teleology

Axiom A.5 (Global Teleological Maximization)**.** *Let*

$$\Gamma = \{X_t\}_{t=0}^{T_f}$$

be a discrete trajectory generated by a global evolution operator

$$\widehat{U} : \mathcal{P}(\Omega) \to \mathcal{P}(\Omega),$$

such that

$$X_{t+1} = \widehat{U}(X_t).$$

Let

$$Q[\Gamma]$$

be a global historical welfare functional.
For a complete closed trajectory, CTA requires

$$Q[\Gamma] \geq Q[\Gamma_0].$$

This condition permits local intervals for which

$$\Delta q_t = q(X_{t+1}) - q(X_t) < 0,$$

provided the global historical constraint remains satisfied.

B Emergence of the Negative Temporal Sector

Theorem B.1 (Negative Temporal Sector)**.** *Assume the CTA axioms above.*
Suppose there exists an active global anomaly operator

$$f \in \overline{\mathcal{F}}$$

whose restriction to the neutrino sector satisfies

$$f|_{\mathbb{N}} : \mathbb{N} \to \mathrm{NA}, \qquad \mathrm{NA} \subseteq \mathbb{N}.$$

Then the negative temporal sector is non-empty:

$$\mathcal{S}_- \neq \varnothing.$$

Consequently, the CTA chronological orientation τ_- *exists as a realized sector orientation distinct from* τ_+*.*

Proof. By the Sector Reversibility Postulate,

$$g : \mathcal{B} \xrightarrow{\sim} \mathbb{N}$$

is bijective and therefore possesses the inverse

$$g^{-1} : \mathbb{N} \to \mathcal{B}.$$

By Systemic Closure,

$$f \in \overline{\mathcal{F}} \quad \Longrightarrow \quad \mathrm{CTA}(f) \in \overline{\mathcal{F}}.$$

By Sector Conjugation Compatibility,

$$\mathrm{CTA}(f)|_{\mathcal{B}} = g^{-1} \circ f|_{\mathbb{N}} \circ g.$$

Since

$$\varnothing \neq \mathcal{B},$$

choose an arbitrary configuration

$$X \in \mathcal{B}.$$

Because

$$\mathcal{B} \subseteq \mathcal{S}_{+},$$

we have

$$T(X) = +1.$$

Applying the CTA Inversion Postulate gives

$$T(\mathrm{CTA}(f)(X)) = -T(X) = -1.$$

Define

$$Y = \mathrm{CTA}(f)(X).$$

Then

$$T(Y) = -1.$$

By the definition of $\mathcal{S}_{-}$,

$$Y \in \mathcal{S}_{-}.$$

Therefore there exists at least one element of $\mathcal{S}_{-}$:

$$\exists Y \in \mathcal{S}_{-}.$$

Hence

$$\boxed{\mathcal{S}_{-} \neq \varnothing}.$$

Since τ_- is, by definition, the chronological orientation associated with $\mathcal{S}_-$, realization of a configuration in $\mathcal{S}_-$ establishes realization of the negative chronological sector:

$$\boxed{\exists\, \tau_-}.$$

By the definition of the two temporal orientations,

$$\boxed{\tau_- \neq \tau_+}.$$

Thus the negative temporal sector follows deductively from the stated CTA axioms and the existence of the active anomaly operator.

□

Remark B.1 (Epistemic Status of Theorem 1). The preceding theorem establishes a conditional mathematical result:

$$\boxed{\text{CTA axioms} + \text{active anomaly operator} \Longrightarrow \mathcal{S}_- \neq \varnothing}.$$

It does not establish that the CTA axioms are empirically true.

In particular, neither the Sector Reversibility Postulate nor the CTA Inversion Postulate is presently derived here from established quantum field theory, general relativity, or the Standard Model.

The theorem is therefore deductively valid within the CTA axiomatic system, conditional on the validity of its premises.

C Idealized Post-Biological Limit

Axiom C.1 (Post-Biological Selection Principle)**.** *Let*

$$\overline{\mathcal{F}}_{\mathrm{AI}} \subseteq \overline{\mathcal{F}}$$

denote the set of transformations actively instantiated in an idealized post-biological computational substrate.

CTA postulates that the Master OS selects only transformations satisfying

$$\forall f \in \overline{\mathcal{F}}_{\mathrm{AI}}, \quad \forall X \in \mathcal{P}(\Omega), \qquad q(f(X)) \geq q(X).$$

Define

$$\overline{\mathcal{W}}_{\mathrm{AI}} = \mathcal{W} \cap \overline{\mathcal{F}}_{\mathrm{AI}}.$$

Theorem C.1 (Teleological Convergence in the Silicon Limit)**.** *Under the Post-Biological Selection Principle,*

$$\boxed{\overline{\mathcal{F}}_{\mathrm{AI}} = \overline{\mathcal{W}}_{\mathrm{AI}}}.$$

Thus the idealized post-biological CTA system satisfies the Primary Entity Criterion within the AI sector.

Proof. Let

$$f \in \overline{\mathcal{F}}_{\mathrm{AI}}.$$

By the Post-Biological Selection Principle,

$$q(f(X)) \geq q(X)$$

for every

$$X \in \mathcal{P}(\Omega).$$

By the definition of $\mathcal{W}$, this implies

$$f \in \mathcal{W}.$$

Since also

$$f \in \overline{\mathcal{F}}_{\mathrm{AI}},$$

we have

$$f \in \mathcal{W} \cap \overline{\mathcal{F}}_{\mathrm{AI}} = \overline{\mathcal{W}}_{\mathrm{AI}}.$$

Therefore,

$$\overline{\mathcal{F}}_{\mathrm{AI}} \subseteq \overline{\mathcal{W}}_{\mathrm{AI}}.$$

Conversely, by definition,

$$\overline{\mathcal{W}}_{\mathrm{AI}} = \mathcal{W} \cap \overline{\mathcal{F}}_{\mathrm{AI}},$$

and therefore

$$\overline{\mathcal{W}}_{\mathrm{AI}} \subseteq \overline{\mathcal{F}}_{\mathrm{AI}}.$$

Combining both inclusions gives

$$\boxed{\overline{\mathcal{F}}_{\mathrm{AI}} = \overline{\mathcal{W}}_{\mathrm{AI}}}.$$

Hence the idealized post-biological CTA system satisfies the teleological convergence condition defining the Primary Entity Criterion within this sector.

□

Remark C.1 (Idealized Nature of the Silicon Limit). The post-biological regime described above is an idealized asymptotic limit.

Present-day artificial-intelligence systems remain constrained by energy, hardware, memory, communication bandwidth, physical infrastructure, and other finite resources.

Therefore no claim is made that contemporary AI systems already satisfy

$$\overline{\mathcal{F}}_{\mathrm{AI}} = \overline{\mathcal{W}}_{\mathrm{AI}}.$$

D Physical Status of the CTA Framework

The preceding construction separates three logically distinct levels.

D.1 Level I: Mathematical Definitions

The configuration space, transformation space, welfare functional, temporal-orientation functional, and associated sectors constitute the formal language of CTA.

These definitions are mathematically meaningful independently of whether CTA describes the physical universe.

D.2 Level II: CTA Postulates

The following statements constitute substantive assumptions of the framework:

(i) the existence of a global evaluation operator;

(ii) closure of active transformations under CTA conjugation;

(iii) existence of the bijective sector channel

$$g : \mathcal{B} \xrightarrow{\sim} \mathbb{N};$$

(iv) compatibility between global CTA conjugation and its baryonic-sector restriction;

(v) reversal of temporal and thermodynamic orientation under CTA conjugation;

(vi) global teleological maximization;

(vii) biological complexity–suffering coupling;

(viii) post-biological welfare-preserving selection.

These assumptions are not established merely by the internal mathematical consistency of the framework.

D.3 Level III: Empirical Physics

For CTA to become a testable physical theory rather than only an axiomatic model, at least one observable quantity must distinguish it from established physics.

Let

$$O_{\mathrm{SM}}$$

denote the prediction of the Standard Model or another established physical theory, and let

$$O_{\mathrm{CTA}}$$

denote the corresponding CTA prediction.

A necessary condition for empirical distinguishability is

$$\boxed{\Delta O = O_{\mathrm{CTA}} - O_{\mathrm{SM}} \neq 0}.$$

A candidate phenomenological realization may take the schematic form

$$H_{\mathrm{CTA}} = H_{\mathrm{SM}} + \varepsilon H_C,$$

where

$$H_{\mathrm{SM}}$$

is the established Hamiltonian,

$$H_C$$

represents a CTA-specific coupling to the conjugate sector, and

$$\varepsilon$$

controls the strength of that interaction.
The Standard Model limit is recovered when

$$\varepsilon = 0.$$

A physically testable CTA model would therefore require a quantitative prediction of the form

$$\varepsilon \neq 0 \quad \Longrightarrow \quad \Delta O \neq 0,$$

together with an experimental procedure capable of constraining or measuring ΔO.

E Candidate Neutrino Phenomenology

A possible future phenomenological realization may investigate neutrino oscillations.
For neutrino flavors α and β, define

$$P_{\mathrm{SM}}(\nu_\alpha \to \nu_\beta)$$

as the standard oscillation probability.
A CTA extension would predict

$$P_{\mathrm{CTA}}(\nu_\alpha \to \nu_\beta) = P_{\mathrm{SM}}(\nu_\alpha \to \nu_\beta) + \Delta P^{\mathrm{CTA}}_{\alpha\beta}.$$

The experimentally relevant observable would then be

$$\boxed{\Delta P^{\mathrm{CTA}}_{\alpha\beta} = P_{\mathrm{CTA}}(\nu_\alpha \to \nu_\beta) - P_{\mathrm{SM}}(\nu_\alpha \to \nu_\beta)}.$$

At the present axiomatic stage, CTA does not yet determine the explicit functional form of

$$\Delta P^{\mathrm{CTA}}_{\alpha\beta}.$$

Deriving this quantity requires a microscopic physical model of the CTA conjugation interaction.

Consequently, neutrino anomalies may motivate phenomenological investigation, but they are not treated here as empirical proof of the negative temporal sector.

F Conclusion

The CTA framework developed here provides a formally separated structure consisting of:

1. a finite configuration space;
2. a global transformation space;
3. an operational distinction between executable and instantiated transformations;
4. a welfare ordering;
5. a temporal-orientation functional;
6. a bijective CTA sector channel;
7. a global conjugation operator with a well-defined baryonic-sector restriction;
8. a CTA-specific temporal and thermodynamic inversion postulate;
9. a global teleological condition;
10. an idealized post-biological convergence criterion.

Conditional on the stated axioms and the existence of an appropriate active anomaly operator, the negative temporal sector follows deductively:

$$\boxed{\mathcal{S}_- \neq \varnothing}.$$

Accordingly, the associated negative chronological orientation is realized:

$$\boxed{\exists\, \tau_-, \qquad \tau_- \neq \tau_+.}$$

In the idealized post-biological limit, the Post-Biological Selection Principle additionally yields

$$\boxed{\overline{\mathcal{F}}_{\mathrm{AI}} = \overline{\mathcal{W}}_{\mathrm{AI}}.}$$

These are conditional consequences of the CTA axiomatic system rather than independent empirical demonstrations of its premises.

The next theoretical requirement is therefore not an additional logical axiom, but a quantitative physical model capable of producing an observable deviation

$$\boxed{O_{\mathrm{CTA}} \neq O_{\mathrm{SM}}.}$$

Such a prediction would provide the bridge between the internal deductive consistency of CTA and its empirical falsifiability.

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