Title: Time as an Emergent Coherence Property in Aetherium

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Abstract

Modern physics lacks a unified account of time. General relativity treats time as geometric, quantum mechanics treats it as an external parameter, thermodynamics assigns it a direction, and cosmology ties it to expansion. These perspectives coexist but do not cohere. In the Aetherium framework, coherence is the underlying physical substrate from which gravitational behavior, cosmological dynamics, and long-wavelength correlations arise. Here I develop the view that time is not fundamental. Instead, temporal ordering emerges from the sequence of coherence-state transitions in the substrate.

Global coherence establishes the existence and direction of time; local coherence density determines the experienced rate of time; coherence gradients generate temporal asymmetry; and the bandwidth of coherence fluctuations sets the temporal resolution available to physical systems. Because coherence propagation is not the transmission of matter, energy, or information, the substrate's internal reconfiguration rate is not constrained by c_{vac}. This allows global temporal consistency to be maintained even when causal signals remain strictly local.

This emergent-time picture resolves conceptual tensions in early-universe cosmology. Before matter–radiation equality, the substrate lacked the coherence maturity required to support stable temporal ordering. The universe was evolving, but not "in time" as conventionally understood. The pulse — a coherence transition in $\ln a$— therefore projects into a narrow interval of cosmic maturity, not cosmic time. This reframing eliminates the need for temporal extrapolations such as "seconds after the Big Bang," which lack physical meaning in a low-coherence regime.

The framework yields testable predictions across pulsar timing arrays, cosmological observables, precision atomic clocks, and quantum coherence experiments. In this view, time is the macroscopic imprint of coherence dynamics in a substrate that is continuously updating, aligning, and evolving. Coherence gives rise to time.

1. Introduction

Time occupies an unusual position in modern physics. In general relativity, it is woven into the geometry of spacetime, a coordinate that bends and dilates in response to mass–energy. In quantum mechanics, time is not an observable at all; it enters only as an external parameter that tracks the evolution of states. Thermodynamics introduces yet another layer, assigning time a direction through entropy increase. Cosmology ties time to the expansion history of the universe, implicitly assuming a global temporal ordering that remains coherent across horizon-scale distances.

These perspectives are individually successful, yet they do not form a unified picture. The geometric time of relativity, the parametric time of quantum theory, the entropic arrow, and the cosmological timeline coexist uneasily. Their incompatibility is not a technical inconvenience but a structural tension: physics lacks a single physical principle that explains why time exists, why it flows, why it has a direction, and why its rate varies.

The Aetherium framework offers a different starting point. In previous papers, coherence has emerged as the underlying physical substrate from which gravitational behavior, cosmological dynamics, and long-wavelength correlations arise. Coherence is not a field in spacetime; it is the organizing property that gives spacetime its structure. In this view, the universe is not embedded in time. Instead, time is the macroscopic ordering induced by the propagation and reconfiguration of coherence within the substrate. Coherence in this framework is not quantum wavefunction coherence; it is a structural alignment property of the substrate that exists prior to and independent of quantum states. Quantum coherence emerges later as a special case within this broader substrate alignment.

This perspective reframes the problem of time. Temporal ordering becomes a consequence of how coherence updates across the substrate. Local clock rates reflect local coherence density. The arrow of time arises from global coherence gradients established by the breathing cycle. And because coherence propagation is not the transmission of matter, energy, or information, the substrate's internal reconfiguration rate is not constrained by c_{vac}. The coherence field can maintain global temporal consistency even while causal signals remain strictly limited by the speed of light.

The "breathing cycle" is the large-scale modulation of the substrate's global coherence, characterized by alternating phases of increasing and decreasing coherence that loosely parallel contraction-like and expansion-like epochs. It does not represent a literal oscillation of spacetime, but rather a cyclic variation in the coherence structure that shapes how geometry, temporal ordering, and cosmological dynamics emerge. Each half-cycle establishes a monotonic coherence gradient, which in turn defines the arrow of time and the global temporal framework of the universe.

In this paper, I develop this viewpoint systematically. I outline the coherence structure of the Aetherium substrate, the role of the breathing cycle in modulating global coherence, the emergence of temporal ordering, and the relationship between coherence, causality, and cosmological evolution. I conclude with observational signatures that could test this emergent-time picture. Time, in this framework, is not fundamental. It is the large-scale manifestation of coherence dynamics in a universe whose underlying substrate is continuously updating, aligning, and evolving.

Summary of Claims

1. Time is not fundamental but emerges from coherence-state transitions in the substrate.
2. Geometry, causality, and temporal ordering arise from coherence structure.
3. The breathing cycle modulates global coherence and sets the arrow of time.
4. Time begins when coherence matures, not at the Big Bang.
5. Observable signatures of coherence dynamics appear in PTA data, cosmology, precision clocks, and quantum systems.

2. The Aetherium Substrate and Coherence Structure

The Aetherium framework begins with a single organizing principle: the universe is permeated by a coherence-bearing substrate whose internal alignment determines the behavior of physical systems across all scales. This substrate is not a field defined within spacetime; rather, spacetime geometry, causal structure, and temporal ordering arise from the substrate's coherence properties. Coherence is ontologically prior to the metric, and the familiar structures of physics emerge from its dynamics. The substrate possesses several key attributes:

(i) Global coherence

On the largest scales, the substrate maintains a partially aligned phase structure that spans cosmological distances. This global coherence evolves over the breathing cycle and exhibits long-wavelength fluctuations detectable through correlated timing residuals in pulsar timing arrays. Global coherence provides the backbone for universal temporal ordering.

(ii) Local coherence density

Local coherence density determines how strongly a region resists decoherence, how stable its internal dynamics are, and how sharply it can define temporal intervals. Regions of high coherence behave as if time flows more slowly; regions of low coherence behave as if time flows more quickly. This mirrors gravitational time dilation but arises from substrate structure rather than geometric curvature alone.

(iii) Coherence gradients

Spatial variations in coherence density generate gradients that influence the behavior of physical systems. These gradients shape local clock rates, govern the stability of quantum states, and contribute to the arrow of time.

(iv) Coherence lifetime and coherence length

These determine the scale over which temporal ordering remains consistent and the resolution with which physical systems can track temporal change.

(v) Coherence bandwidth

The bandwidth of coherence fluctuations sets the maximum rate at which the substrate can update its internal alignment. Because coherence propagation is not the transmission of matter, energy, or information, this reconfiguration rate is not constrained by c_{vac}. The substrate can therefore maintain global temporal consistency even when causal signals remain strictly local.

Because coherence propagation is not the transmission of matter, energy, or information, its reconfiguration rate is not constrained by c_{vac}. Coherence updates maintain internal consistency but cannot encode or transmit signals, ensuring full compatibility with relativity

3. Coherence as the Generator of Temporal Ordering

If coherence is the underlying physical substrate, then temporal ordering is not a primitive feature of the universe. Instead, it arises from the way coherence propagates, aligns, and updates across the substrate. Time is not a dimension through which the universe evolves; it is the record of how the substrate's internal state changes.

Temporal order corresponds to the sequence of coherence-state transitions in the substrate.

A region of the substrate is never static. Its coherence density, phase alignment, and local gradients continuously evolve. These changes occur in a definite sequence, and physical systems embedded in the substrate experience this sequence as the passage of time.

This perspective reframes several familiar features of time:

- **Existence of time:** Time exists because the substrate does not remain in a fixed coherence state.
- **Flow of time:** The "flow" of time corresponds to the rate at which coherence modes can update.
- **Universality of order:** Coherence alignment can propagate faster than causal signals without transmitting information, enabling global ordering.
- **Local variations:** Local coherence density determines local clock rates.
- **Temporal consistency:** Global coherence ensures that ordering is preserved even when local coherence varies.

Time is therefore the emergent, macroscopic manifestation of coherence dynamics.

4. The Breathing Cycle as a Global Coherence Modulator

The universe evolves through a cyclic modulation of coherence bandwidth, a "breathing cycle" that shapes cosmic time. Once geometry emerges from coherence, it becomes dynamically real and produces the observable universe, including expansion, structure formation, gravitational collapse, and black hole formation. The breathing cycle plays a central role in shaping the global coherence structure of the substrate. During phases of contraction and expansion, the substrate's coherence density, coherence length, and global phase alignment evolve smoothly but nontrivially. These coherence modulations are not abstract: they should leave observable signatures in pulsar timing arrays, CMB anisotropies, and large scale structure, providing empirical access to the breathing cycle.

The breathing cycle modulates global coherence in three important ways:

(i) Coherence amplitude

High-coherence phases sharpen temporal ordering; low-coherence phases soften it.

(ii) Coherence gradients

The breathing cycle generates large-scale coherence gradients that establish the global arrow of time.

(iii) Coherence bandwidth

The substrate's ability to update its internal alignment varies over the cycle. Because coherence reconfiguration does not transmit information, this update rate is not constrained by c_{vac}. A key implication is that **coherence does not repeat.** The breathing cycle revisits coherence *conditions*, not coherence *states*. No two coherence states are ever identical, even if they share similar amplitudes or gradients. This makes time travel physically meaningless.

5. Local Coherence and the Experience of Time

Local coherence determines how time is experienced by physical systems. A system does not track time directly; it tracks changes in its own internal coherence state.

Consequences:

- **Local clock rates reflect local coherence density.**
- **Time dilation arises from coherence gradients.**
- **Temporal resolution depends on coherence stability.**
- **Quantum stability is coherence-dependent.**
- **No two regions share identical temporal flow.**

This reframes time dilation as a natural consequence of coherence structure.

6. The Arrow of Time as a Coherence Gradient

Temporal asymmetry arises from coherence gradients generated by the breathing cycle. During contraction, coherence increases; during expansion, coherence decreases. This monotonicity provides a physical basis for temporal direction.

Key insights: The arrow of time is the macroscopic imprint of a deeper coherence gradient.

- Temporal asymmetry is substrate-driven, not statistical.
- Coherence gradients define the direction of time.
- Entropy increase tracks coherence loss.
- The breathing cycle resets the arrow of time.
- Reversal of the arrow is impossible because coherence states never repeat.

7. Temporal Resolution, Coherence Bandwidth, and Update Rates

The resolution of time is determined by the bandwidth of coherence fluctuations. This bandwidth sets the maximum rate at which the substrate can update its internal alignment.

Consequences:

- The coherence update rate is not constrained by c_{vac}because it does not transmit information.
- Temporal resolution depends on coherence maturity.
- Time does not exist in the absence of coherence.

7.1 Time Before Matter–Radiation Equality

Before matter–radiation equality, coherence was too immature to support meaningful temporal intervals. The universe was evolving, but not “in time” as conventionally understood. All standard early universe processes—nucleosynthesis, recombination, acoustic oscillations—still occur, but they unfold through coherence evolution rather than through sharply defined temporal intervals.

7.2 Coherence Maturity and the Onset of Time

As coherence strengthened, temporal resolution sharpened. Time began when coherence matured, not at the Big Bang.

8. Time and Causality

Causality arises from the interplay between coherence propagation and the limits of information transfer.

Key distinctions:

- Coherence updates do not violate relativity. This is because coherence reconfiguration maintains global alignment but cannot be modulated to carry information. No observer can manipulate coherence updates to send a message, influence an outcome, or alter causal structure.
- Causal cones arise from information transfer, not coherence alignment.
- Temporal order is global; causality is local.
- No causal paradoxes arise.
- Time travel is impossible because coherence states never repeat.

Coherence provides global ordering; relativity constrains local influence.

9. Coherence, Entropy, and Temporal Rate Across Cosmic History

The following table summarizes how the Aetherium framework classifies different cosmic epochs in terms of coherence maturity, entropy, and the effective rate of emergent time.

- **Coherence** controls the *structure* of time.
- **Entropy** tracks the *number of accessible configurations* as coherence changes.
- **Experienced time rate** reflects how quickly systems undergo coherence-state transitions.
- **The breathing cycle** drives the long-term modulation of all three.

Cosmic Epoch	Approx. Age	Coherence Level	Entropy Level	Experienced Time Rate	Notes
Pre-coherence era	$<10^4$ years (qualitatively: "before matter–radiation equality")	**Low** — substrate immature, unstable gradients	**Low** — few accessible microstates	**Undefined / extremely fast** — temporal intervals not meaningful	Universe evolves through coherence changes, not time
Coherence-maturation threshold	Near matter–radiation equality (~50,000 years)	**Rising** — gradients stabilizing	**Increasing**	**Sharpening** — first meaningful temporal ordering	Time begins when coherence becomes stable enough to support ordering
Early coherent universe	10^5–10^9 years	**Moderate** — stable enough for geometry, structure formation	**Moderate** — entropy rising with structure formation	**Moderate** — local variations tied to coherence density	Temporal flow varies with coherence density

Cosmic Epoch	Approx. Age	Coherence Level	Entropy Level	Experienced Time Rate	Notes
Mid-cycle expansion (today)	~13.8 billion years	**Lower than peak** — coherence decreasing across expansion half-cycle	**High** — many accessible microstates	**Faster** — lower coherence → faster decoherence → faster experienced time	Arrow of time set by decreasing global coherence
Future low-coherence epoch	Far future	**Low** — coherence continues to decline	**Very high** — maximal microstate accessibility	**Very fast** — temporal resolution degrades	Temporal resolution degrades as coherence declines
Next contraction phase (future cycle)	Far future	**Increasing** — coherence rising again	**Decreasing** — entropy falls as coherence strengthens	**Slowing** — high coherence → slow time	Arrow resets at next coherence maximum

10. Observational and Experimental Consequences

The emergent-time framework yields concrete, testable predictions across multiple domains:

(i) Pulsar Timing Arrays

Long-wavelength coherence fluctuations should produce correlated timing residuals distinct from gravitational-wave backgrounds. These correlations should track coherence gradients rather than tensorial strain patterns.

(ii) Cosmological Coherence Transitions

Coherence transitions in the breathing cycle should leave imprints in:

- CMB large-scale anisotropies
- Integrated Sachs–Wolfe signatures
- redshift–distance relations
- BAO phase coherence

These signatures differ from ΛCDM predictions because they arise from coherence modulation rather than metric evolution alone.

(iii) Precision Atomic Clocks

Local coherence density variations should produce measurable deviations in clock rates beyond gravitational and kinematic time dilation. Networks of optical clocks could detect coherence-dependent drifts.

(iv) Quantum Coherence Experiments

Quantum systems should exhibit coherence-linked variations in stability and decoherence rates. Experiments with trapped ions, superconducting qubits, or ultracold atoms could probe these effects.

(v) Laboratory-Scale Coherence Mapping

If coherence gradients exist at sub-astronomical scales, they may be detectable through:

- interferometric phase drift
- correlated noise in precision oscillators
- anomalous decoherence patterns

(vi) Cosmological Chronometry

The onset of time at coherence maturity predicts that early-universe chronologies should be reinterpreted in terms of coherence evolution rather than temporal intervals. Together, these signatures provide a path toward empirical validation of the coherence-based ontology.

(vii) Mapping Coherence Bandwidth to Observational Sensitivity

Pulse Width	Coherence Bandwidth	Detectability Band	Instrument Sensitivity
Narrow	High	$\sim 10^{-6}$ to 10^{-9} Hz	**PTAs**, atomic clocks
Moderate	Intermediate	$\sim 10^{-9}$ to 10^{-12} Hz	**PTAs**, CMB
Broad	Low	$\sim 10^{-12}$ to 10^{-15} Hz	**CMB**, quantum systems

- **PTAs** (Pulsar Timing Arrays) are most sensitive to high-bandwidth, narrow pulses — they detect residuals in the nanohertz regime.
- **Atomic clocks** can pick up coherence-linked drift if the bandwidth overlaps with their stability thresholds.
- **CMB experiments** detect broad, low-bandwidth coherence imprints — especially in the early universe.

11. Discussion and Conclusion

The Aetherium framework reframes time not as a fundamental dimension but as a macroscopic manifestation of coherence dynamics in a substrate whose internal alignment evolves continuously across the breathing cycle. In this view, temporal ordering arises from the sequence of coherence-state transitions; local clock rates reflect local coherence density; coherence gradients generate the arrow of time; and the bandwidth of coherence fluctuations sets the temporal resolution available to physical systems.

This perspective resolves several long-standing conceptual tensions. It explains why general relativity and quantum mechanics treat time so differently, why the arrow of time persists despite microscopic reversibility, and why the earliest epochs of the universe cannot be meaningfully described using temporal intervals such as "seconds after the Big Bang." Before matter–radiation equality, the substrate lacked the coherence maturity required to support stable temporal ordering. The universe was evolving, but not *in time* as we understand it. The pulse — a coherence transition in $\ln a$ — therefore projects into a narrow interval of **cosmic maturity**, not cosmic time.

The framework also clarifies the relationship between time and causality. Coherence propagation is not the transmission of matter, energy, or information, and therefore is not constrained by the relativistic limit c_{vac}. The substrate may update its coherence state more rapidly than light can propagate, maintaining global temporal consistency without enabling superluminal signaling or causal paradoxes. Causal influence remains strictly local, bounded by the speed of information transfer, while temporal ordering is maintained globally by coherence alignment.

Finally, the emergent-time picture yields testable predictions. Pulsar timing arrays should detect coherence-driven correlations in timing residuals. Cosmological observables should carry signatures of coherence transitions, including the pulse. Precision atomic clocks may reveal coherence-dependent deviations in local clock rates. Quantum systems should exhibit coherence-linked variations in stability and decoherence. These signatures provide a path toward empirical validation of the coherence-based ontology.

In this framework, time is not a backdrop against which the universe unfolds. It is the large-scale imprint of coherence dynamics in a substrate that is continuously updating, aligning, and evolving. The Aetherium model replaces the assumption of fundamental time with a physically grounded mechanism that unifies cosmology, quantum behavior, and gravitational phenomenology under a single organizing principle: **coherence gives rise to time.**

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Author Contributions

The author solely conceived the Aetherium framework, developed the theoretical model, performed all calculations and analyses, generated all figures, and wrote and revised the manuscript. All conceptual advances, interpretations, and conclusions presented in this work originate from the author.

Data and Code Availability

This study is theoretical and does not rely on external datasets. All equations, derivations, and conceptual models are fully described within the manuscript.

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Appendix A — Mathematical Framing of the Coherence Substrate

This appendix provides a technical formulation of the coherence-first framework. The goal is not to present a complete mathematical theory, but to outline a set of structures and relations that make the emergent-time picture precise enough for analysis, modeling, and future development.

The mathematics below is deliberately minimal: it captures the essential behavior of coherence, temporal ordering, and the breathing cycle without assuming a specific microphysical model.

A.1 Coherence Field and State Space

We model the substrate as a field

$$\mathcal{C}(x)$$

defined over a differentiable manifold M that will *later* acquire geometric structure. At this stage, M is not spacetime; it is a topological support for coherence relations.

The coherence field has the following components:

- **Coherence density:**

$$\rho_{\mathcal{C}}(x) \in \mathbb{R}^{+}$$

- **Coherence phase:**

$$\phi_{\mathcal{C}}(x) \in S^{1}$$

- **Coherence gradient:**

$$\nabla \mathcal{C}(x)$$

- **Coherence bandwidth:**

$$B_{\mathcal{C}}(x) \in \mathbb{R}^{+}$$

The tuple

$$\mathcal{C}(x) = (\rho_{\mathcal{C}}, \phi_{\mathcal{C}}, B_{\mathcal{C}})$$

defines the local coherence state.

The **state space** of the substrate is the infinite-dimensional manifold

$$\mathcal{S} = \{\mathcal{C}(x) \mid x \in M\}.$$

Temporal ordering will emerge from trajectories in $\mathcal{S}$.

A.2 Coherence Evolution and Temporal Ordering

Let

$$\mathcal{C}(x;\lambda)$$

denote the coherence field parameterized by an internal evolution parameter λ. This parameter is *not* time; it is a bookkeeping variable indexing coherence-state transitions.

Temporal ordering emerges when the evolution satisfies:

1. **Monotonicity:**

$$\frac{\partial \mathcal{C}}{\partial \lambda} \neq 0$$

almost everywhere.

2. **Global consistency:**

$$\lambda_1 < \lambda_2 \Rightarrow \mathcal{C}(x;\lambda_1) \prec \mathcal{C}(x;\lambda_2)$$

where $\prec$denotes a partial order induced by coherence alignment.

3. **Local rate of temporal experience:**

$$\frac{d\tau}{d\lambda}(x) = f(\rho_{\mathcal{C}}(x), B_{\mathcal{C}}(x))$$

with

$$\frac{\partial f}{\partial \rho_{\mathcal{C}}} < 0, \frac{\partial f}{\partial B_{\mathcal{C}}} > 0.$$

Thus:

- High coherence density → slower experienced time
- High bandwidth → finer temporal resolution

This reproduces gravitational time dilation phenomenology without assuming a metric.

A.3 Emergent Metric Structure

Once coherence exceeds a threshold

$$\rho_{\mathcal{C}} > \rho_{\text{crit}},$$

the substrate supports a stable emergent geometry.

We define the metric as a functional of coherence:

$$g_{\mu\nu}(x) = \mathcal{F}_{\mu\nu}[\mathcal{C}(x)].$$

To first order, the metric responds to coherence gradients:

$$g_{\mu\nu}(x) = \eta_{\mu\nu} + \alpha\, \partial_\mu \mathcal{C}\, \partial_\nu \mathcal{C} + \mathcal{O}(\nabla^2 \mathcal{C}).$$

This ensures:

- curvature arises from coherence gradients
- gravitational time dilation arises from coherence density
- black hole horizons correspond to diverging coherence gradients

The Einstein equations appear as an *effective* description in the high-coherence regime.

A.4 The Breathing Cycle as a Modulation of Coherence

Let a be the emergent scale factor. The breathing cycle is encoded in a coherence potential

$$V(\ln\, a)$$

with a single dominant pulse.

We model the global coherence amplitude as:

$$\rho_{\mathcal{C}}^{\text{global}}(\ln\, a) = \rho_0 + A\exp\left[\ -\frac{(\ln\, a - \ln\, a_0)^2}{2\sigma^2}\right].$$

The **coherence bandwidth** evolves as:

$$B_{\mathcal{C}}(\ln\, a) = B_0 + B_1\, \rho_{\mathcal{C}}^{\text{global}}(\ln\, a).$$

The **arrow of time** is defined by:

$$\frac{d\rho_{\mathcal{C}}^{\text{global}}}{d\ln\, a} \neq 0.$$

This monotonicity within each half-cycle ensures temporal asymmetry.

A.5 Coherence Maturity and the Onset of Time

Define a coherence-maturity threshold:

$$\rho_{\mathcal{C}}(x) > \rho_{\text{maturity}}.$$

Time exists only when this condition is satisfied.

Before matter–radiation equality:

$$\rho_{\mathcal{C}} < \rho_{\text{maturity}},$$

so temporal intervals are undefined.

This formalizes the statement:

The early universe evolved through coherence changes, not temporal intervals.

A.6 Causality and Coherence Propagation

Let:

- $v_{\mathcal{C}}$ = coherence-update propagation speed
- c_{vac} = speed of causal information transfer

We require:

$$v_{\mathcal{C}} > c_{\text{vac}} \text{ allowed}$$
$$v_{\mathcal{C}} \not\Rightarrow \text{information transfer}$$

Causality is preserved because:

$$\frac{\partial \mathcal{C}}{\partial \lambda} \not\Rightarrow \text{signal}.$$

The light cone remains the boundary for influence; coherence alignment is not influence.

A.7 Observational Quantities

A.7.1 Pulsar Timing Arrays

Coherence fluctuations produce correlated timing residuals:

$$\delta t_i = \int \Gamma(x_i)\, \delta\mathcal{C}(x_i)\, d\lambda.$$

The correlation matrix:

$$C_{ij} = \langle \delta t_i \delta t_j \rangle$$

has a distinct angular dependence from gravitational waves.

A.7.2 Atomic Clocks

Clock drift is predicted to scale as:

$$\frac{\Delta\nu}{\nu} = k\,\Delta\rho_{\mathcal{C}}.$$

A.7.3 Cosmology

Coherence transitions shift the effective expansion rate:

$$H_{\mathrm{eff}} = H_{\Lambda\mathrm{CDM}} + \beta\,\frac{d\rho_{\mathcal{C}}}{d\ln\ a}.$$

This provides a natural route for addressing the Hubble tension.

A.8 Summary of Mathematical Structure

The coherence-first framework can be summarized as:

- Coherence field $\mathcal{C}(x)$ defines ordering.
- Temporal rate arises from $f(\rho_{\mathcal{C}}, B_{\mathcal{C}})$.
- Geometry emerges from $\mathcal{F}[\,\mathcal{C}\,]$.
- The breathing cycle modulates global coherence.
- Causality is preserved because coherence updates are non-informational.
- Observables depend on coherence gradients and fluctuations.

This appendix provides the scaffolding for future formal development.

Appendix B — Table of Symbols and Constants

The following table summarizes the symbols, parameters, and constants used throughout Appendix A and the main text. Definitions are phrased to remain model-agnostic while still conveying precise meaning.

B.1 Coherence Field Quantities

Symbol	Meaning	Notes
$\mathcal{C}(x)$	Coherence field at location x	Fundamental substrate variable
$\rho_{\mathcal{C}}(x)$	Coherence density	Determines local temporal rate
$\phi_{\mathcal{C}}(x)$	Coherence phase	Defines alignment structure
$B_{\mathcal{C}}(x)$	Coherence bandwidth	Sets temporal resolution
$\nabla\mathcal{C}(x)$	Coherence gradient	Generates arrow of time locally
$\mathcal{S}$	State space of coherence configurations	Infinite-dimensional manifold
λ	Internal evolution parameter	Not physical time; indexes coherence transitions

B.2 Emergent Temporal Quantities

Symbol	Meaning	Notes
$\tau(x)$	Experienced (local) time	Emergent from coherence dynamics
$\frac{d\tau}{d\lambda}$	Local temporal rate	Function of $\rho_{\mathcal{C}}$ and $B_{\mathcal{C}}$
$f(\rho_{\mathcal{C}}, B_{\mathcal{C}})$	Temporal-rate functional	Monotonic in both arguments
ρ_{maturity}	Coherence maturity threshold	Minimum coherence required for time to exist
ρ_{crit}	Coherence threshold for metric emergence	Geometry becomes dynamically stable above this

B.3 Emergent Geometry and Metric Structure

Symbol	Meaning	Notes
$g_{\mu\nu}(x)$	Emergent metric tensor	Functional of coherence field
$\mathcal{F}_{\mu\nu}[\mathcal{C}]$	Metric-generating functional	Defines geometry from coherence
$\eta_{\mu\nu}$	Minkowski metric	Zeroth-order background
α	Coherence–curvature coupling constant	Sets strength of geometric response

B.4 Breathing Cycle and Cosmological Quantities

Symbol	Meaning	Notes
a	Emergent scale factor	Defined only after geometry emerges
$\ln a$	Logarithmic scale factor	Natural variable for coherence pulse
$V(\ln\ a)$	Coherence potential	Governs breathing cycle
$\rho_{\mathcal{C}}^{\text{global}}(\ln\ a)$	Global coherence amplitude	Gaussian-like pulse in $\ln a$
A	Pulse amplitude	Sets strength of global coherence transition
σ	Pulse width in $\ln a$	Controls duration of coherence transition
a_0	Pulse center	Location of coherence maximum
H_{eff}	Effective expansion rate	Modified by coherence evolution
β	Coherence–expansion coupling	Determines deviation from ΛCDM

B.5 Causality and Propagation Speeds

Symbol	Meaning	Notes
c_{vac}	Speed of causal information transfer	Standard speed of light in vacuum
$v_{\mathcal{C}}$	Coherence-update propagation rate	Not constrained by c_{vac}; non-informational
$\delta\mathcal{C}(x)$	Coherence fluctuation	Drives PTA and clock signatures

B.6 Observational Quantities

Symbol	Meaning	Notes
δt_i	Timing residual for pulsar i	Sensitive to coherence fluctuations
$\Gamma(x)$	Coherence–timing response kernel	Maps coherence fluctuations to timing shifts
C_{ij}	Correlation matrix of timing residuals	Distinct from Hellings–Downs curve
$\frac{\Delta\nu}{\nu}$	Fractional clock drift	Proportional to coherence variation
$\Delta\rho_{\mathcal{C}}$	Local coherence change	Drives clock-rate deviations

B.7 Constants and Parameters

Symbol	Meaning	Notes
ρ_0	Baseline coherence density	Sets background temporal rate
B_0	Baseline coherence bandwidth	Minimum temporal resolution
B_1	Bandwidth–coherence coupling	Controls sharpening of time
k	Clock-response coefficient	Determines sensitivity to coherence
β	Cosmological coherence coupling	Appears in H_{eff}
α	Coherence–curvature coupling	Appears in emergent metric