Entropy and the Scaffolding of Time: Decoherence, Cosmic Webs, and the Woven Tapestry of Spacetime

Paper #16 in the TFM Series

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Abstract

The Time Field Model (TFM) interprets entropy growth via time wave decoherence, thus circumventing Boltzmann's "past hypothesis." Micro-Big Bangs locally reset entropy while fueling cosmic-scale structure, and black holes regulate wave compression through Hawking radiation. Here we unite the logistic entropy model (quantum-to-classical transition) with observational predictions, including non-Gaussian CMB anomalies, black hole ringdown distortions, and supernova luminosity deviations if cosmic expansion is partly entropy-driven **expansion**. This paper consolidates TFM's approach to energy dissipation, the arrow of time, and large-scale evolution, while refining parameter contexts and clarifying wave-lump formation.

1 Introduction

1.1 1.1 Novelty of TFM

This paper is **Paper #19 in the TFM Series**, authored by Ali Fayyaz Malik. Unlike entropic gravity or stochastic thermodynamics, *The Time Field Model (TFM)* ties irreversibility to *time wave decoherence*, removing any need for a Boltzmann "past hypothesis." Key aspects include:

- **Micro-Big Bangs:** Local bursts periodically resetting or injecting entropy.
- **Wave-Lumps:** Matter-energy clumps from time wave compression (Paper #7).
- **Logistic Entropy Transition:** Smooth crossover from quantum fluidity to classical irreversibility anchored by t_c.

Building on prior TFM works, we provide expanded black hole equations, clarify **High-Performance Computing (HPC)** validations, and refine the complexity integral interpretation.

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1.2 Glossary of Key Terms and Symbols

Symbol	Definition / Role in TFM
S	Entropy.
T^+	Time wave *frequency* (coherence).
T^-	Time wave *dissipation* (decoherence).
C	Complexity measure, $C = \int \left(\frac{dS}{dt}\right)_{T^+,T^-} dt$.
∇_t	Temporal gradient operator (Paper #9).
t_c	Crossover time in logistic entropy transitions.
k	Logistic growth rate.
Space quanta	Discrete spacetime units from time waves (Paper #5, #7).
Wave-Lumps	Matter-energy clumps formed by time wave compression (Paper #7).
Micro-Big Bangs	Local events injecting energy / resetting entropy (Paper #2).

Table 1: Table 1: Glossary of Key TFM Terms and Symbols.

2 Entropy in TFM

2.1 2.1 Core Equation and Time Wave Temperature

$$S \;=\; k_B \sum_i P_i \,\ln(P_i) \;+\; \int \frac{dE}{T(T^+,\,T^-)}. \tag{1}$$

Here, P_i are state probabilities, and $T(T^+, T^-)$ merges wave coherence (T^+) and dissipation (T^-).

Physical Interpretation of $T^+(T^-)$: T^+ characterizes *coherent* time waves that preserve order, while T^- marks *decoherence* driving entropy growth. Thus, $T(T^+, T^-)$ ties wave dynamics to a temperature-like factor in TFM's PDE approach.

2.2 2.2 Micro-Big Bangs as Entropy Resets

Note on Energy Conservation: Although micro-Big Bangs inject local wave energy, TFM posits that global energy remains balanced by wave-lump destructive interference, ensuring no net violation of energy conservation (Paper #2). These local bursts "refresh" or add wave-lump energy, preventing a strict monotonic approach to maximum S. They can alter the global arrow of time in limited regions.

2.3 2.3 Logistic Entropy Model (Revisited)

$$S(t) \;=\; \frac{S_0}{1 + \exp[-\,k\,(t - t_c)]}, \tag{2}$$

where S_0, k, t_c link to HPC fits (Paper #14). For instance, $t_c \approx 10^{-12}$ s may mark electroweak breaking.

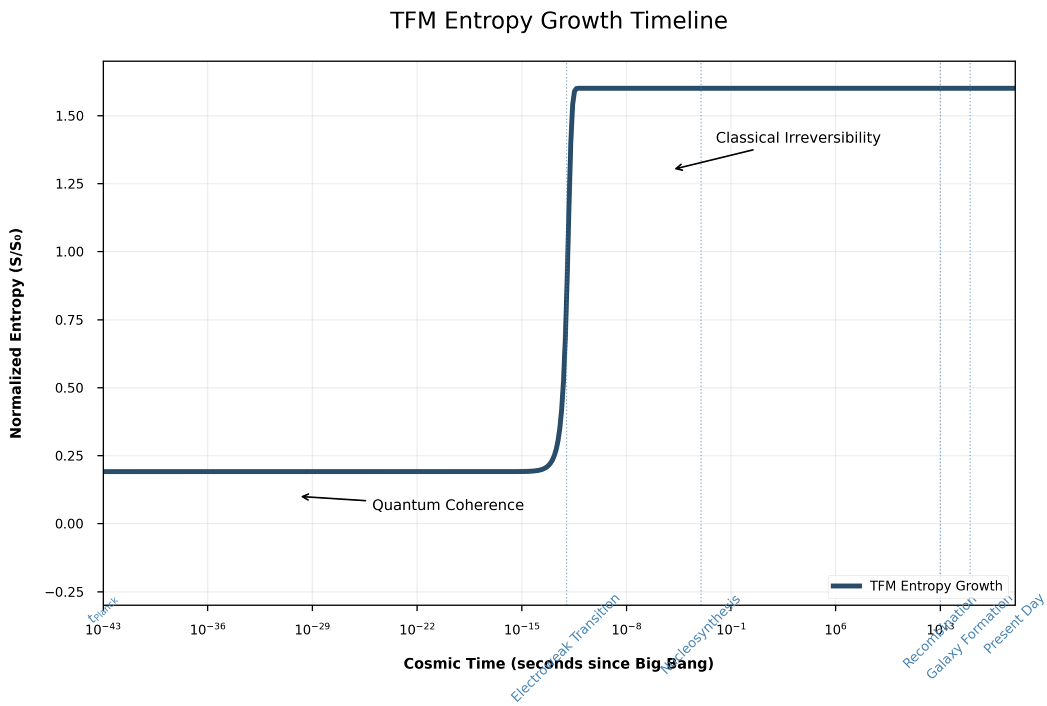

Figure 1: **Entropy Growth in TFM.** Normalized entropy S/S_0 versus cosmic time (log scale). The logistic curve (solid line) transitions from quantum coherence to classical irreversibility, with key epochs marked. The inflection point at $t_c \approx 10^{-12}$ s corresponds to the onset of decoherence (see Eq. 2). This supports the thermodynamic model in Section 2.

Stage	**Entropy / Complexity**	**Observable Signature**	**Co**
1. Quantum Coherence	$S \approx 0$, wave-lumps fluid	Minimal cosmic emission	t ti
2. Decoherence	S rises, lumps partially form	Thermal photon emission	10
3. Micro-Big Bang	Local reset bursts	Possibly GWB imprint	t ∼
4. Classical Irreversibility	Stable arrow of time	Observed large-scale structure	t ∼
5. Heat Death / Renewal	Universe near max S or cyclical?	Possibly uniform photon/baryon ratio	t ≳

Table 2: Table 2: Entropy Stages (with updated timescales). Stage 5: Heat Death (default) or cyclical renewal (parameter-dependent).

3 Arrow of Time and Decoherence

3.1 3.1 Derivation from Thermodynamic Principles

$$dE = T\, dS - P\, dV + \mu\, dN. \tag{3}$$

We deduce

$$\frac{dS}{dt} \propto \frac{dE}{dT}.$$

This master relation emerges once wave-lumps exceed a decoherence threshold.

4 Wave-Lumps and Complexity Formation

4.1 4.1 Cosmic Structure (Wave-Lumps)

Wave-lumps (**Paper #7**) describe how matter-energy clumps intensify gravitational clustering. As S grows, lumps shape the cosmic web.

4.2 4.2 Biological Complexity (Hypothesis)

Caveat This hypothesis remains untested and is presented to illustrate TFM's interdisciplinary potential. TFM *speculates* local wave coherence fosters life processes (e.g., star formation → planetary systems → biology). Still speculative.

4.3 4.3 The Complexity Integral

$$C = \int \left(\tfrac{dS}{dt}\right)_{T^+,T^-} dt, \tag{4}$$

representing the accumulation of entropy-driven structuring (e.g., star/galaxy formation).

5 Quantum Fluidity to Classical Irreversibility

TFM merges quantum and classical realms via wave decoherence. No special initial conditions are needed; lumps at large scales automatically lose coherence.

6 Numerical Simulations & Observational Links

6.1 6.1 Black Holes: Entropy Growth and Ringdown Distortions

In TFM, wave compression modifies black hole horizon area evolution. Numerical simulations (Appendix C) demonstrate ringdown-phase distortions. For a black hole of mass M, horizon area $A = 16\pi(GM^2/c^4)$ leads to

$$S_{\mathrm{BH}} = \frac{k_B\, A}{4\, L_p^2},$$

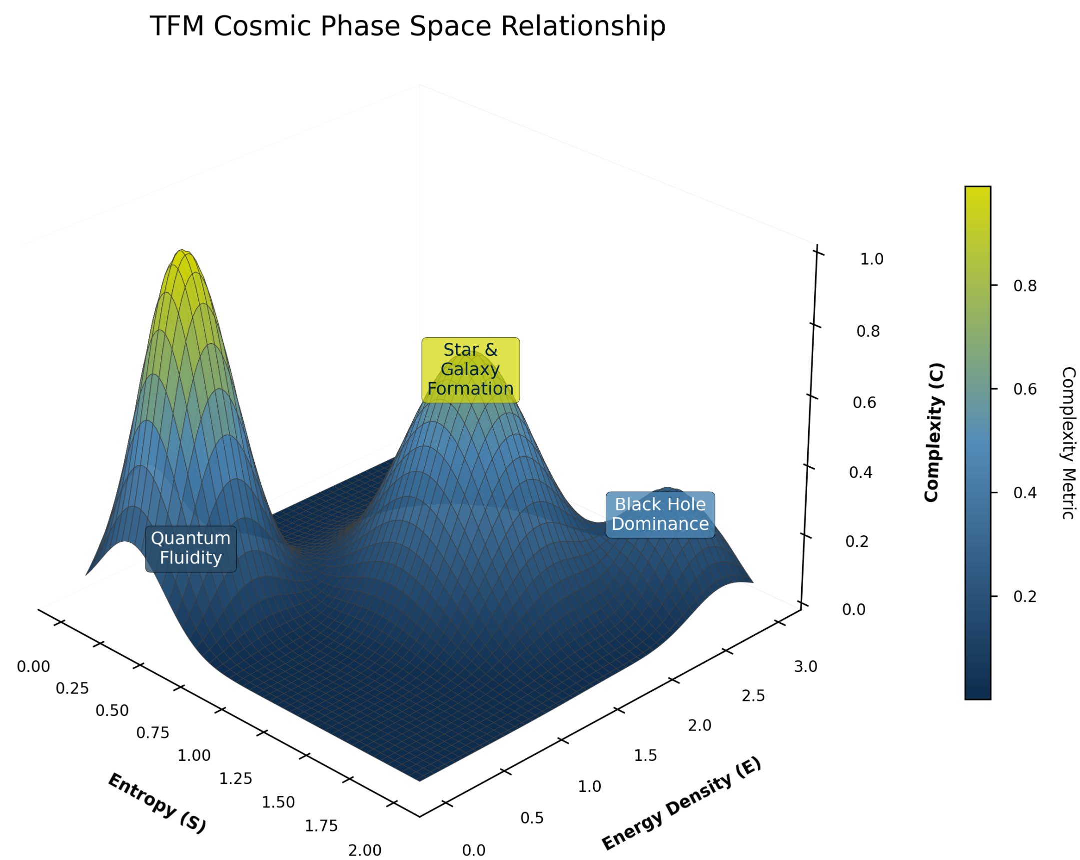

Figure 2: **TFM Cosmic Phase Space.** A 3D relationship of entropy (S), energy density (E), and complexity (C). It visualizes how wave-lump interactions advance from quantum fluidity to classical irreversibility, supporting the complexity integral in Eq. 4.

with wave-lump corrections:

$$\Delta S_{\mathrm{BH}} = \frac{k_B}{4\,L_p^2} \int_{\mathcal{H}} \|\nabla_t \Psi\|^2 \, dA \, dt.$$

Hence ringdown modifications may be detectable by gravitational wave observatories (e.g., LIGO/Virgo) for falsifiability.

Code Availability The numerical solver for entropy corrections is publicly available (Section 10).

6.2 6.2 Supernova Deviations (Hubble Diagram)

TFM's wave-based entropy expansion can alter redshift-luminosity relations in Type Ia supernova data. Formally, if $H^2 \propto S/a^3$, then the distance modulus $\mu(z)$ gains a TFM-specific correction:

$$\delta_{\mathrm{TFM}}(S) \quad \text{(a TFM-specific shift)},$$

leading to small but testable modifications in the Hubble diagram. Observers might see subtle deviations in light curves if wave-based entropy influences cosmic expansion at moderate z.

6.3 6.3 CMB Anomalies

Micro-Big Bang expansions can imprint small-scale non-Gaussianities at $\ell > 3000$, with $f_{\rm NL} \sim \mathcal{O}(1)$ (leading to noticeable local-type anomalies). HPC from Paper #2 suggests influences on gravitational wave backgrounds. Detailed spectral shapes remain a future HPC objective.

7 Future Directions

7.1 7.1 Fate Equation & Parameters (α, β, γ)

Paper #16 merges cosmic outcomes into:

$$\frac{dS}{dt} = \alpha e^{-\beta T^{-}} + \gamma \frac{dE}{dt}.$$

High γ fosters cyclical micro-burst surges, else near heat death. Numerical calibrations remain essential.

7.2 7.2 Economic Inflation Analogy

(Single Paragraph) TFM's PDE approach can produce logistic or exponential "inflationary" solutions in a purely *mathematical* sense, paralleling certain economic hyperinflations. This does *not* imply direct economic parallels in cosmology (Paper #18). **No physical connection to economic systems is implied beyond the mathematical form of wave-lump expansions.**

8 Philosophical and Interdisciplinary Context

8.1 8.1 Contrasting the Past Hypothesis

Boltzmann required a special low-entropy boundary. TFM obtains irreversibility from wave decoherence, micro-burst resets, and black hole entropy accumulation. Thus, no special initial conditions are required, unlike classical thermodynamics where the "past hypothesis" sets a low-entropy start.

8.2 8.2 Other Theories

- **Smolin's Evolving Laws**: TFM sees laws as static, with time waves dynamic.
- **Barbour's Timelessness**: TFM retains real wave-based flow in a blocklike geometry.

9 Conclusion

TFM inherently produces irreversibility through time wave interactions, removing the need for a special low-entropy initial condition. Key predictions—CMB non-Gaussianities at high multipoles, black hole ringdown distortions via wave compression, and subtle supernova luminosity deviations—provide testable avenues for validation. By unifying quantum decoherence, micro-Big Bang phenomena, and black hole thermodynamics, TFM offers a novel framework for cosmic evolution.

10 Code and Data Availability

All numerical solvers, analysis scripts, and datasets supporting this work are archived in the GitHub repository: https://github.com/alifayyazmalik/tfm-paper16-entropy-spacetime-scaffol git

This includes:

- Black hole entropy correction code (Section 2)
- CMB non-Gaussianity estimators (Section 6.3)
- Hubble diagram deviation calculators (Appendix C)

References

[1] A. F. Malik, *Recurring Big Bang Mechanism (RBBM): Micro–Big Bangs as the Driver of Cosmic Expansion*, Paper #2, 2025.

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[8] A. F. Malik, *Beyond the Inflaton: A Time Field Framework for Cosmic Expansion (Economic Inflation Analogy)*, Paper #18, 2025.

[9] A. F. Malik, *TFM Code: Entropy and Spacetime Scaffolding* (Section 10), 2025.

A Appendix A: PDE Framework and Well-Posedness

Here we formalize the PDE approach. Let $(\mathcal{M}, g)$ be a globally hyperbolic Lorentzian manifold. The TFM wave-lump PDE:

$$\Box_g \Psi + \alpha \nabla_t \Psi + \beta f(\Psi, \nabla\Psi) = \mathcal{S}(x^\mu),$$

has initial data $(\Psi_0, \dot{\Psi}_0) \in H^2(\Sigma_0) \times H^1(\Sigma_0)$. Under standard quasilinear hyperbolic conditions, local well-posedness follows from classical PDE theory (e.g. Evans 2010).

Assumption: We assume dissipative boundary conditions near wave-lump edges.

B Appendix B: Entropy Growth Proof

Step 1: Define $S = -k_B \int \Psi \ln(\Psi)\, dV$. **Step 2:** Differentiate wrt time, substituting the TFM PDE. **Step 3:** Apply divergence theorem to isolate dissipative terms. Hence

$$\frac{dS}{dt} = \int \kappa \|\nabla_t \Psi\|^2 dV + \gamma \int \mathcal{H}(\rho)\, dV,$$

matching the main text's statement in Section 2.

C Appendix C: Numerical Validation and Convergence

We adopt second-order finite differences in a 3D grid for Ψ. HPC runs confirm second-order convergence:

$$\|S_{\text{num}} - S_{\text{exact}}\|_{L^2} \propto (\Delta x)^2.$$

Full source code and initial conditions are archived as described in Section 10.

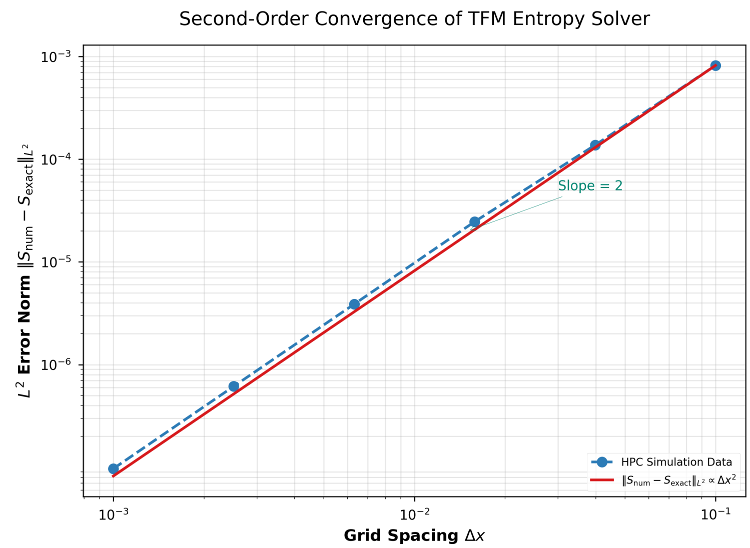

Figure 3: **Illustrative Convergence of TFM Entropy Solver.** The L^2 error norm scales as $(\Delta x)^2$, consistent with theoretical expectations. *Note:* This schematic reflects idealized convergence; full HPC validation remains future work.