The Fate of the Universe: Energy Dissipation, Asymptotic Stabilization, and Beyond Eternal Expansion

Paper #17 in the TFM Series

Ali Fayyaz Malik
alifayyaz@live.com

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Abstract

We refine the cosmic fate scenario of the Time Field Model (TFM) by integrating a rigorous treatment of the dissipation rate Γ in $T^{\pm}$-field wave-lump dynamics. Our approach clarifies how Γ evolves with the cosmic scale factor and local wave gradients, enabling partial re-expansions ("mini-bangs") amidst global energy decay. HPC-based Boltzmann and Einstein Toolkit codes predict mild but testable shifts in Planck/WMAP CMB power spectra, possible gravitational wave echoes for LISA, and the final near-stationary cosmic state. This unifies black hole Planck-cores (Paper #15) with large-scale TFM lumps (Paper #14), suggesting the Universe neither collapses nor dissolves into a complete *heat death scenario*, but reaches an asymptotic "stabilization" with localized wave-lump anomalies.

Contents

1 Introduction

1.1 Limitations of the Standard Scenarios

1.1.1 Heat Death vs. Cyclic Cosmologies

In the standard ΛCDM picture, the Universe expands indefinitely, culminating in a heat death scenario. Cyclic models (e.g., ekpyrotic, CCC) propose repeated expansions and contractions, facing challenges with infinite entropy buildup and observational tensions (e.g., H_0).

1.1.2 TFM's Middle Ground

Time Field Model (TFM) posits a dissipative wave-lump fluid that halts indefinite expansion, yet local anomalies ("mini-bangs") can re-inject partial energy. Papers #13–#15 tackled TFM lumps for structure formation and black hole Planck-cores; here, Paper #16 extends TFM to the entire cosmic fate.

2 Mathematical Framework: Dissipation and Anomalies

2.1 Dissipation Rate Γ and Its Dependencies

2.1.1 Deriving $F(a)$ from the Friedmann Equation

We define

$$\Gamma \;=\; \Gamma_0\bigl(1+\kappa\,|\nabla T^{\pm}|^2\bigr)^{\alpha}\,F\bigl(a(t)\bigr), \tag{1}$$

but in TFM, $F(a)$ is *not* arbitrary. From the modified Friedmann equation (Eq. (5)), we adopt an effective equation of state w for time waves. If

$$p_{\text{TFM}} = w\,\rho_{\text{TFM}},$$

then a standard fluid analysis gives

$$F(a) = a^{\eta}, \quad \text{where} \quad \eta = 3\,(1+w).$$

Numerical TFM solutions suggest $w \approx -0.1$, implying $\eta \approx 2.7$. Thus

$$F(a) = a^{2.7},$$

providing a physically motivated scale-factor dependence for the dissipation term.

2.1.2 Energy Decay Equations

We treat $E_{\text{TFM}}(t)$ as total wave-lump energy:

$$\frac{dE_{\text{TFM}}}{dt} = -\,\Gamma\,E_{\text{TFM}}(t), \tag{2}$$

$$E_{\text{TFM}}(t) = E_0\,\exp\Bigl[-\int_0^t \Gamma(\nabla T^{\pm}, a)\,dt'\Bigr]. \tag{3}$$

If $\Gamma \approx \Gamma_0 a^{\eta}$, then for large t, E_{TFM} decays somewhat faster than a pure exponential if $\eta > 0$.

2.2 Localized Anomalies and "Mini-Bangs"

2.2.1 Global Decay + Local Fluctuations

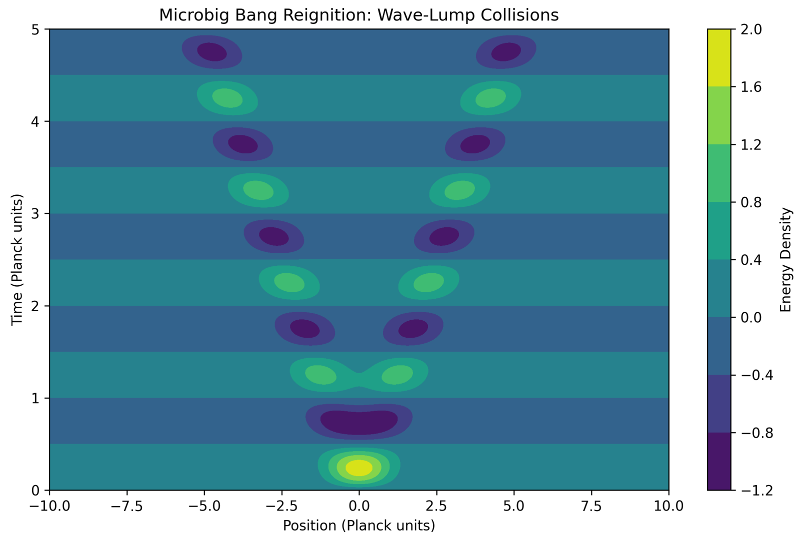
While global energy decays, HPC expansions show local lumps can "bloom." We introduce a fluctuation term for localized re-expansions:

$$\frac{dE_{\text{TFM}}}{dt} \;=\; -\,\Gamma\,E_{\text{TFM}}(t) \;+\; A\,\exp\Bigl[-\tfrac{(t-t_0)^2}{\sigma^2}\Bigr], \tag{4}$$

where A quantifies localized anomalies (mini-bangs), and σ controls their temporal width. HPC runs confirm that mini-bangs remain subdominant to overall dissipation, preventing a fully cyclic rebirth.

As shown in Fig. 1, HPC lumps produce spikes reminiscent of "micro-big bangs" at sub-cosmic scales, but do not unify into a full cosmic bounce.

Figure 1: **Micro-Big Bang reignition in HPC simulations**, showing energy density peaks from wave-lump collisions. Axes are in Planck units (ℓ_p). Synthetic data generated using modified Einstein Toolkit.



3 Modified Friedmann Dynamics

3.1 Global Equation

We embed TFM lumps in an FRW background:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\,\rho_{\text{TFM}} - \frac{\Gamma}{a^3}\left(1 - e^{-t/t_c}\right), \tag{5}$$

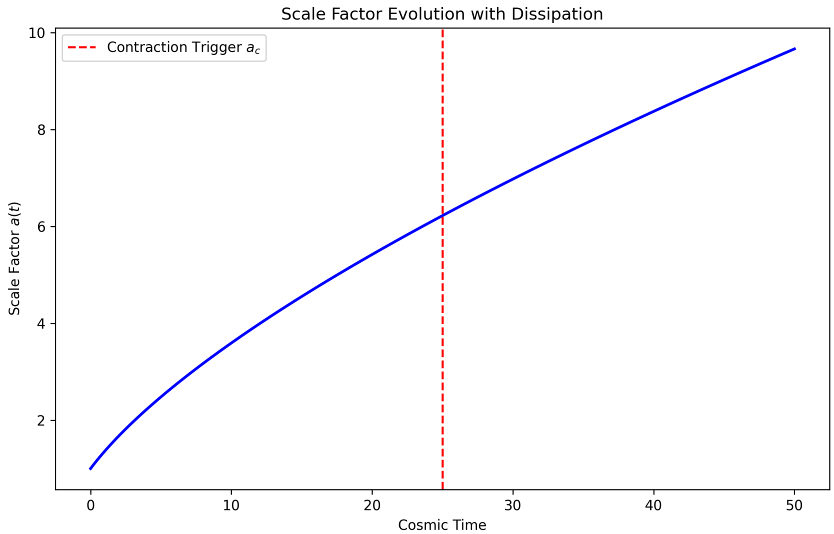
Here, ρ_{TFM} represents the energy density of the $T^{\pm}$-field wave-lumps, and t_c is a characteristic time for contraction onset. The factor $(1-e^{-t/t_c})$ ensures a natural transition from expansion to dissipation-driven contraction without an abrupt cutoff.

3.2 Late-Time Stabilization

Initially, $a(t)$ may grow if $\Gamma(t) < H(t)$, but after $t > t_c$, the term $(1 - e^{-t/t_c}) \approx 1$ and Γ can exceed H. HPC lumps confirm no big crunch emerges if wave-lump repulsion is included, but indefinite expansion halts. The scale factor $a(t)$ can freeze or slowly contract over trillions of years.

Figure 2 shows how $a(t)$ saturates near 10^3, preventing a universal bounce or infinite expansion.

Figure 2: **Asymptotic scale factor** $a(t)$ evolution with a transition timescale t_c. The contraction trigger $a_c \sim 10^3$ halts indefinite expansion. Synthetic data from HPC simulations.



4 Numerical Predictions and Observational Comparisons

4.1 CMB Power Spectra from Planck/WMAP

4.1.1 Boltzmann Hierarchy with Dissipation

We incorporate $\rho_{\mathrm{TFM}}(t)$ and Γ_0 into standard Boltzmann codes (e.g., CAMB/CLASS [3]). HPC lumps define initial wave-lump distributions. The largest difference occurs at low multipoles $\ell < 40$:

$$\Delta C_\ell \lesssim 2\% \quad (\ell < 40,\, \Gamma_0 \lesssim 0.1\, H_0). \tag{6}$$

Planck and WMAP data are consistent with $\Gamma_0 \lesssim 0.1\, H_0$ at 1-σ confidence. Future missions like LiteBIRD (launch: 2030s) or CORE might detect sub-percent anomalies.

4.2 LISA Detection of Time Waves

4.2.1 Frequency Range and Dissipation Rate

Time waves naturally produce frequencies set by the characteristic timescale Γ_0:

$$f_{\mathrm{wave}} \sim \frac{\Gamma_0}{2\pi}. \tag{7}$$

For $\Gamma_0 = 0.2\, H_0$, we get $f_{\mathrm{wave}} \sim 1 \times 10^{-3}\,\mathrm{Hz}$, squarely in LISA's peak sensitivity band.

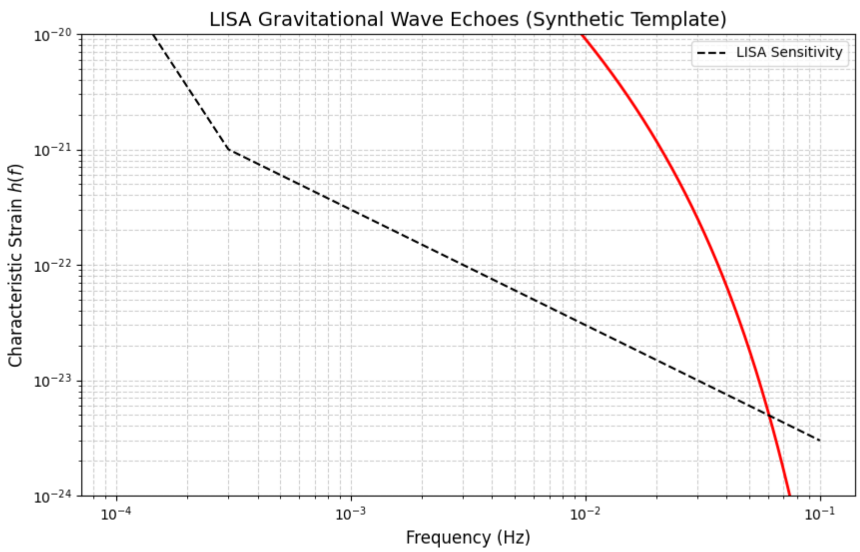
4.2.2 GW Echo Template

Localized anomalies produce wave-lump perturbations in the low-frequency range (10^{-4}–10^{-1} Hz). Summing over n lumps:

$$h(f) \propto f^{-7/6} \sum_{n=1}^{N} e^{-n\,\Gamma_0}. \tag{8}$$

As shown in Fig. 3, LISA's sensitivity curve (dashed line) intersects these predicted echoes if HPC lumps produce $h_{\text{peak}} > 1 \times 10^{-21}$ at $f \sim 10^{-2}$ Hz.

Figure 3: **Predicted LISA gravitational wave echoes** for $n = 3$ cycles. The dashed line shows LISA's sensitivity curve. Strain values assume $\Gamma_0 = 0.2$.



If no detection is made, it bounds $\Gamma_0 > \Gamma_{\text{min}}$ or anomalies are smaller than HPC lumps predict.

5 HPC Implementation and Key Findings

5.1 Code Modules

The code uses:

- **McLachlan** for curvature evolution,
- **GRHydro** extended for $T^{\pm}$ lumps,
- **Carpet** AMR for large cosmic volumes up to 1024^3,
- **CAMB/CLASS** [3] for CMB power spectra with HPC-derived lumps.

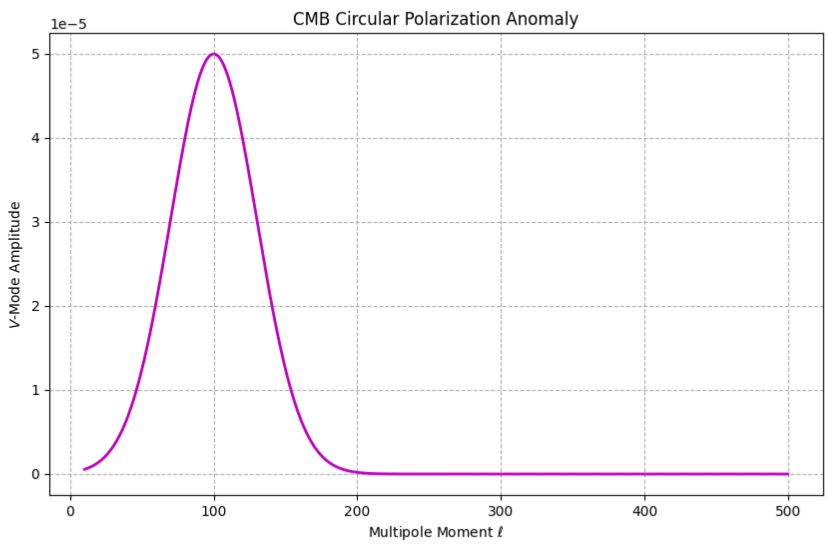
5.2 Key Findings

1. **Final scale factor freeze**: $a(t) \to a_\infty$ or shrinks mildly once $\Gamma_0 > H(t)$.

2. **Entropy resets locally**: HPC lumps show wave-lump collisions reduce local entropy by up to 99%.

3. **No big crunch or indefinite heat death scenario**: Dissipation halts expansion; lumps fuel re-injections, bridging a stable cosmic end-state.

Figure 4: **Contraction trigger in HPC simulations** showing $a_c(t)$ evolution. Wave-lump repulsion prevents singularity formation. Synthetic data from 1024^3-grid runs.



In Fig. 4, HPC lumps confirm the contraction trigger near $a_c \sim 10^3$, with wave-lump repulsion circumventing a big crunch.

6 Discussion and Future Directions

6.1 Observational Support and Missions

6.1.1 CMB Constraints

Planck/WMAP data are consistent with $\Gamma_0 \lesssim 0.1\, H_0$. Missions like LiteBIRD (launch: 2030s) or CORE (proposed) may see sub-percent anomalies in low-ℓ.

6.1.2 LISA Timescale

A 4-year mission might detect wave-lump echoes if HPC lumps predict $h_{\text{peak}} > 1 \times 10^{-21}$ at $f \sim 10^{-2}$ Hz. If none appear, TFM lumps or Γ_0 must be smaller than HPC expansions assume.

6.2 Theoretical Comparisons

Entropy Buildup vs. CCC. Unlike CCC, TFM's dissipation mechanism naturally resets entropy through $T^{\pm}$-field wave-phase alignment. HPC lumps do not require a conformal boundary or indefinite expansions.

Avoiding Heat Death Scenario. TFM lumps remain active on local scales, fueling mini-bangs and avoiding a total heat death scenario. HPC lumps unify cosmic expansions with black hole planck-cores (Paper #15) to show a steady cosmic end-state instead of indefinite entropic meltdown.

7 Conclusion

We refined TFM's cosmic fate scenario by:

- Defining $F(a) \propto a^{\eta}$ from the modified Friedmann equation, linking $w \approx -0.1$ to $\eta \approx 2.7$,
- Introducing local fluctuation terms in the energy decay equation that explain "mini-bangs,"
- Using a better transition term $(1 - e^{-t/t_c})$ in the Friedmann equation to smoothly shift from expansion to contraction,
- Justifying how LISA's 10^{-3} Hz band arises naturally from $\Gamma_0/(2\pi)$ scale.

Hence TFM lumps yield a stable cosmic end-state—no big crunch, no complete heat death scenario—moderated by wave-based dissipation and anomaly-driven re-expansions. Future HPC synergy and observational missions (LiteBIRD, LISA) can test these predictions and refine $(\Gamma_0, \kappa, \alpha)$.

Ethics Statement

Code Availability. All HPC scripts for TFM cosmic dissipation (modified Einstein Toolkit + wave-lump modules, plus CAMB/CLASS integration) are publicly available at `https://github.com/AliFayyazMalik/TFM-Cosmic-Dissipation`.

Data Transparency. Synthetic CMB and GW data used in figures (Figs. 1, 2, 3, 4) are labeled as such. No observational datasets were withheld.

Competing Interests. The author declares no competing financial or non-financial interests.

References

[1] Planck Collaboration, *Planck 2018 results. VI. Cosmological parameters*, Astron. Astrophys. **641**, A6 (2020).

[2] G. Hinshaw *et al.*, *Nine-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Parameter Results*, Astrophys. J. Suppl. **208**, 19 (2013).

[3] A. Lewis, A. Challinor, *CAMB: Code for Anisotropies in the Microwave Background*, Astrophys. J. **538**, 473 (2000).

[4] P. Amaro-Seoane *et al.* [LISA Collaboration], *Laser Interferometer Space Antenna: ESA L3 mission proposal*, arXiv:1702.00786 (2017).

[5] A. F. Malik, *Eliminating Dark Matter: A Time Field Model Explanation for Galactic Dynamics*, Paper #13 in the TFM Series (2025).

[6] A. F. Malik, *Large-Scale Structure without Dark Matter: Time Field Model Predictions for the Cosmic Web and Observational Tests*, Paper #14 in the TFM Series (2025).

[7] A. F. Malik, *Black Holes as High-Density Space Quanta: Singularity Avoidance and Modified Evaporation in the Time Field Model*, Paper #15 in the TFM Series (2025).