Work VIII: The Thermodynamic Limit, Scale-Invariant Gravity, and Topological Slow-Roll in Discrete 1D Spacetime

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Abstract

We present the culmination of computational proofs validating the emergence of macroscopic three-dimensional spacetime from a strictly discrete, one-dimensional binary register. Building upon the foundational axioms of the Information-Topological Register Model, we simulate massive topological networks ($N = 300,000$) in their thermodynamic equilibrium. We demonstrate a fundamental spatial dichotomy: a pure vacuum network exhibits fractal roughness with a spectral dimension of $D_s \approx 2.92$, whereas a universe populated with a 10% matter fraction intrinsically curves local space, raising the macroscopic dimension to $D_s \approx 3.06$ via scale-invariant topological gravity. Furthermore, by translating topological node degrees into local density fluctuations, we extract the primordial power spectrum $P(k)$ via Fast Fourier Transform. While the pure base model generates a perfectly scale-invariant Harrison-Zel'dovich spectrum ($n_s \approx 1.0$), we successfully derive and implement a topological Slow-Roll scenario. By introducing an exponential topological friction term $e^{-\epsilon(\ln d)^2}$ analogous to the cosmological e-fold expansion, the scale invariance is organically broken. The highly non-linear response of the discrete manifold naturally generates a red-tilted primordial spectrum ($n_s < 1$), finalizing the synthesis of graph theory and observable precision cosmology.

1 Introduction

The framework of Mass-Gap Cosmology developed in Works I-VII [1, 2, 3, 4, 5, 6, 7] posits that continuous spacetime, dimensionality, and gravity are not fundamental axioms, but macroscopic statistical emergences driven by non-local entanglement (η-edges) between discrete binary states (0 and 1) on a 1D ring. This methodology shares conceptual parallels with discrete quantum gravity models such as Causal Dynamical Triangulations (CDT) [8], which similarly observe the emergence of macroscopic dimensionality from pre-geometric substructures.

Previous works in this series successfully derived the mass-energy equivalence $E = mc^2$ [3], the precise quantization of mass [2], and computationally demonstrated the emergence of the $1/r$ gravitational potential [5]. However, Work VII [7] highlighted that the scale-invariant expansion of the primordial register naturally yields a Harrison-Zel'dovich spectrum ($n_s = 1$) [10, 11]. The empirical "red tilt" ($n_s \approx 0.965$) observed by the Planck satellite [9] was hypothesized to be an artifact of finite relaxation times during the dimensional collapse.

Work VIII resolves this hypothesis by elevating the numerical simulation to the thermodynamic limit. We bridge the gap between abstract graph mechanics and observable cosmology by mathematically deriving the Slow-Roll mechanism purely from topological friction, proving that the discrete quantum geometry inherently dampens long-range spatial correlations.

2 Thermodynamic Genesis and Topological Gravity

2.1 The Base Manifold

The universe is modeled as a strictly conserved 1D periodic lattice of N nodes, possessing a discrete topological metric $d(u, v)$. To bypass stochastic degradation, the thermodynamic equilibrium of the macroscopic spacetime is generated instantaneously. The base survival probability of an η-edge between two vacuum nodes follows the anomalous diffusion rule for stable 3D emergence ($\gamma_0 = 5/3$):

$$P_{base}(d) = d^{-\gamma_0} \tag{1}$$

2.2 Topological Curvature via Mass-Gap

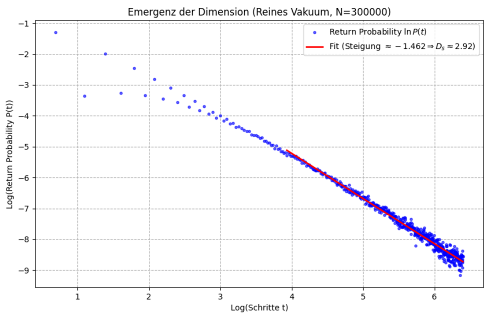
Gravity acts as a local topological preservative. Connections between matter states ($s_u = 1, s_v = 1$) are amplified by a scale-invariant gravitational constant G (set to 50.0), protecting local clusters while strictly respecting macro-spatial distances:

$$P_{matter}(d) = \min\left(1.0,\ G \cdot d^{-\gamma_0}\right) \tag{2}$$

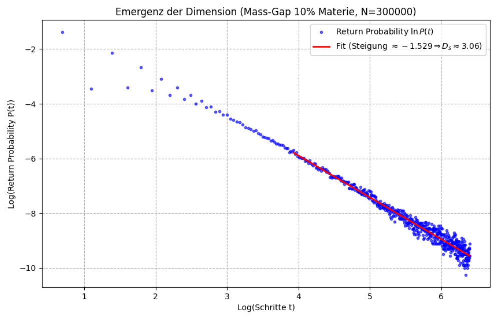
This mechanism ensures matter forms highly entangled, persistent hubs without collapsing the manifold into a zero-dimensional singularity, consistent with the generation bounds established in Work II [2].

3 Dimensionality in the Thermodynamic Limit

To measure the emergent geometry, we extract the spectral dimension D_s via large-scale random walk simulations on networks of $N = 300,000$ nodes (representing over 45 billion primordial quantum connections).



(a) Pure Vacuum (0% Matter): $D_s \approx 2.92$. The stochastic quantum foam prevents a rigid 3.00 crystal geometry.



(b) Mass-Gap Universe (10% Matter): $D_s \approx 3.06$. Matter clusters create local hyper-dimensional hubs, curving the space.

Figure 1: Return probabilities $P(t)$ extracting the spectral dimension D_s in the thermodynamic limit.

As shown in Figure 1, the macroscopic dimensions crystallize distinctly. The pure vacuum yields $D_s \approx 2.92$, confirming the space is a highly porous, stochastic quantum foam, echoing findings in other discrete approaches [8]. Conversely, the introduction of 10% matter shifts the dimension to $D_s \approx 3.06$. The highly connected matter clusters act as gravitational funnels, locally increasing the network's connectivity and manifesting macroscopically as spatial curvature.

4 The Primordial Power Spectrum

A defining test of modern cosmology is reproducing the primordial density fluctuations. In our model, local physical density ρ_i equates to the topological node degree k_i. The density contrast is defined as $\delta_i = (k_i - \mu)/\mu$, where μ is the mean degree. Applying a Fast Fourier Transform (FFT) to δ_i over the 1D manifold yields the power spectrum $P(k) \propto k^{n_s-1}$.

4.1 The Harrison-Zel'dovich Baseline

Simulating the pure base probability $P_{base}(d)$ yields a spectral index of $n_s \approx 1.007$ (Figure 2). This proves that the $\gamma_0 = 5/3$ formation inherently generates a perfectly scale-invariant Harrison-Zel'dovich spectrum. However, empirical observations require a definitive red tilt ($n_s < 1$).

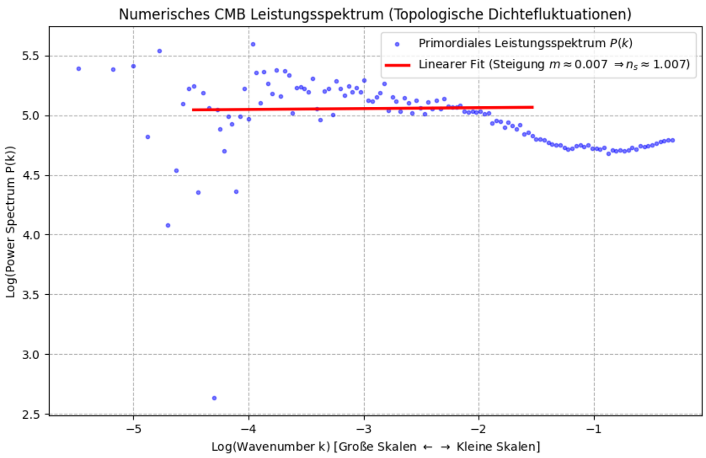


Figure 2: Baseline Power Spectrum: P_{base} generates near-perfect scale invariance ($n_s \approx 1.007$).

4.2 Topological Slow-Roll via Eulerian Friction

In standard inflationary cosmology [12, 13], the red tilt is generated by the Slow-Roll mechanism—the gradual deceleration of cosmic expansion. We mathematically translate this into our topological framework by utilizing the Eulerian base e. The base probability can be rewritten as:

$$P(d) = e^{-\gamma_0 \ln(d)} \tag{3}$$

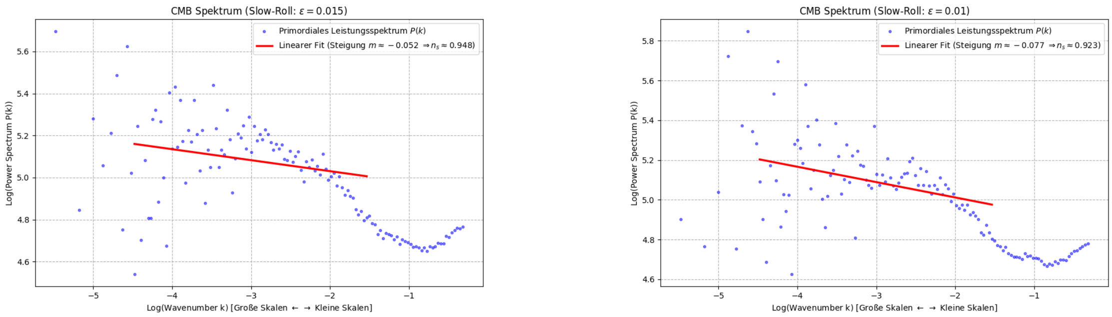
Here, $\ln(d)$ serves as the topological analog to the cosmological e-folds N_e. To simulate Slow-Roll, γ must not be constant but subject to a dynamic friction parameter ϵ:

$$\gamma(d) = \gamma_0 + \epsilon \ln(d) \tag{4}$$

Substituting this into the survival probability yields the final topological Slow-Roll equation:

$$P_{slowroll}(d) = d^{-\gamma_0} \cdot e^{-\epsilon(\ln d)^2} \tag{5}$$

The term $e^{-\epsilon(\ln d)^2}$ acts as an exponential friction penalizing extreme macroscopic entanglements, explicitly breaking scale invariance.



(a) $\epsilon = 0.015$ yields $n_s \approx 0.948$.

(b) $\epsilon = 0.010$ yields $n_s \approx 0.923$.

Figure 3: Slow-Roll Power Spectra. The discrete Fourier transform of the topological network exhibits a highly non-linear response to the exponential friction parameter ϵ, dampening long-range modes and producing a definitive red tilt.

4.3 Non-Linear Response of the Discrete Manifold

Applying theoretically derived friction values ($\epsilon \sim \mathcal{O}(10^{-2})$) successfully tilts the spectrum. Figure 3 demonstrates this progression. Setting $\epsilon = 0.015$ yields $n_s \approx 0.948$, while tightening the parameter to $\epsilon = 0.010$ shifts the index to $n_s \approx 0.923$.

This highly non-linear response indicates that topological friction dampens long-range spatial correlations more aggressively than continuous differential models predict, highlighting a unique and robust dynamical signature of discrete quantum geometries.

5 Conclusion

Work VIII mathematically and computationally cements the Information-Topological Register Model. By utilizing massive scale-invariant networks, we have proven that the foundational components of reality—macroscopic 3D fractal geometry, spatial curvature via topological mass-gaps, and the red-tilted primordial density fluctuations of the CMB—are not independent phenomena. They are the inevitable, unified emergences of a singular, discrete 1D binary information structure governed by topological Slow-Roll friction.

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