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Tracing the Early Universe Without Initial Assumptions: A History-Dependent Reconstruction from the Infinite Transformation Principle (ITP)

Stephen Atalebe

Masaryk University, Brno, Czech Republic; 478944@muni.cz

Abstract

This paper investigates whether the present large-scale structure of the universe contains sufficient fossil information to reconstruct a consistent early state without imposing any initial conditions such as a singularity, inflation, or Gaussianity. Using the Infinite Transformation Principle (ITP), we treat cosmic evolution as a history-dependent, non-Markovian process that retains weak memory on long-wavelength modes. We formulate the inverse cosmological problem as a stability analysis of the backward flow operator T^{-1}. The ITP introduces a memory functional $M(z)$, creating a correction $\Delta J(z)$ to the forward Jacobian. We show that $\Delta J(z) \approx -D\, P_{\text{long}}$ acts as a dissipative, contractive filter on superhorizon modes. Using low-ℓ CMB structure, supervoid topology, and curvature drift $\Omega_k(z)$ as preserved sufficient statistics, we reconstruct the early-state manifold $\mathcal{E}$. A supporting mathematical appendix demonstrates backward stability on the relevant subspace. The reconstruction yields finite-density, phase-coherent, geometrically regulated early states without requiring a classical singularity or inflationary smoothing. Long-wavelength modes remain contractive under backward evolution due to the thermodynamic role of the memory field. The three large-scale observables enforce a unique, self-consistent solution for the memory kernel $K(z, z')$, eliminating the degeneracy inherent in the standard Markovian ΛCDM framework. Within its domain of validity, the ITP reconstruction converts the early universe from an assumed beginning into a mathematically recoverable state. The framework makes four falsifiable predictions: persistent low-ℓ CMB coherence, CMB–void alignment, slow curvature drift ($|\mathrm{d}\Omega_k/\mathrm{d}z| \sim 10^{-4}$), and a non-zero equilateral/orthogonal non-Gaussianity. Failure of any single prediction falsifies the entire approach.

Keywords: cosmology; cosmic microwave background; non-Markovian dynamics; structural memory; inverse problem; Infinite Transformation Principle; early universe

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1. Introduction

Standard ΛCDM cosmology reconstructs the early universe by assuming an initial condition—hot, dense, and singular—and evolving it forward under Markovian dynamics [1]. Within this framework, the present carries too little information for the inverse problem to be solvable: many different pasts can generate the same present-day structure [2,3]. The early universe is effectively postulated rather than reconstructed.

This work takes a reconstruction-based approach. The central idea is that cosmic evolution retains structural memory encoded in nonlocal, long-wavelength correlations [4–6]. Once memory is included, the inverse problem becomes stable within the subspace of memory-preserving observables.

This paper:

- introduces the Infinite Transformation Principle (ITP) as a history-dependent dynamical law;
- identifies three fossil observables that retain primitive structural information [1,9,10];
- constructs a stable backward evolution through a memory-corrected Jacobian;
- derives a narrow, finite, non-singular early-state manifold [11,12];

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- provides four independent, parameter-free predictions [14].

The resulting structure does not require a singular beginning once memory is accounted for.

2. Methods: The Infinite Transformation Principle

2.1. History-Dependent Evolution

We describe cosmic evolution as a history-dependent mapping on a configuration space $S(z)$:

$$S(z+\Delta z) = T\big(S(z), M(z)\big), \quad (1)$$

where z is redshift and $M(z)$ is a nonlocal memory functional. Inspired by nonlocal gravity and vacuum-polarisation effects [7], we represent memory as

$$M(z) = \int_z^\infty K(z,z')\, S(z')\, dz', \quad (2)$$

with kernel $K(z,z')$. We decompose the evolution operator as $T = T_0 + \delta T[M]$, where T_0 is the standard GR-based forward evolution and δT is a weak, nonlocal correction affecting long-wavelength modes.

2.2. Physical Origin of Memory

The memory functional $M(z)$ can arise from nonlocal gravitational feedback from long-wavelength tidal fields [4,8] or from coarse-grained effective field theories where integrating out short scales induces nonlocal kernels [6]. We work with a phenomenological kernel whose large-scale effects can be constrained.

2.3. Sufficient Statistics

We identify three fossil observables that retain long-wavelength structural memory:

1. low-ℓ CMB structure $C_{\ell<10}$, including anisotropy anomalies [1,17];
2. supervoid topology V_{void} and cosmic web morphology [9,19];
3. curvature–redshift evolution $\Omega_k(z)$ [10].

These act as sufficient statistics for the inverse problem at long wavelengths.

2.4. Independent Structural-Memory Diagnostics

To test whether early-universe structure requires an imposed "initial condition" or can emerge from a non-Markovian memory kernel, we applied four inverse-direction diagnostics:

(1) CMB Phase-Coherence Inverse Kernel Test

Using the low-ℓ Planck PR4 Commander map ($\ell \in [2,5]$) [1], we reconstructed the minimal kernel $M(t)$ capable of reproducing the observed bipolar power spectrum (BiPoSH). The method compares the observed $\kappa_{\ell\ell'}(L)$ with 10,000 ΛCDM Gaussian simulations to derive a null envelope.

(2) Metallicity $Z(z)$ Structural-Memory Kernel Test (SMKT)

We applied inverse-model logic to the metallicity history $Z(z)$ from multi-survey compilations. The statistic $T_{\max}$ measures the maximal deviation from a memory-less baseline [19].

(3) Gaussian Heartbeat Detection

Using flexible versus smooth GP kernels, we tested for a coherent periodic component in expansion-history residuals [24]. A significant periodic component under the flexible GP but not under the constrained smooth GP indicates latent structure.

(4) Injection–Recovery Stability Tests

We injected sinusoidal memory terms of amplitude $\mu \in [0, 0.40]$ and evaluated detection probability under the SMKT framework [25].

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3. Results: Mathematical Reconstruction

3.1. Linear Stability and Jacobian Structure

Under ITP, the Jacobian becomes $J(z) = J_0(z) + \Delta J(z)$, with $\Delta J(z) \approx -D\, P_{\mathrm{long}}$. The negative sign reflects a thermodynamic necessity: the memory field acts to suppress structural divergence relative to the minimal-entropy trajectory encoded by Ψ_{min}. Backward evolution inherits this as a contractive damping term, ensuring $|\lambda_{n,\mathrm{back}}| < 1$.

3.2. Convergent Evidence

All three diagnostics independently detect structure incompatible with a memory-less early universe:

1. **CMB Phase-Coherence:** The observed bipolar coefficient pattern exceeded the 99.1% null envelope. Posterior maps favoured a minimal non-zero kernel $M(t) > 0$.
2. **Metallicity $Z(z)$:** We obtained $T_{\mathrm{max}} = 0.9243$ and a global p-value $p = 0.0010$, rejecting the smooth, memory-less null at $> 3\sigma$.
3. **Gaussian Heartbeat:** The flexible GP recovered a coherent 1.66–1.73 Gyr periodic component with p-value ~ 0.000, while the smooth baseline yielded $p \approx 0.030$.

3.3. Cross-Consistency

The key result is that three statistically independent tests—CMB phase structure, $Z(z)$ memory, and expansion-residual periodicity—all converge on the same conclusion: A non-zero structural-memory kernel is preferred over a memory-less (Markovian) early universe.

4. Discussion

4.1. Coherence and Non-Randomness

Memory enforces phase coherence on large scales. The fossil constraints exclude random initial states. Large-angle CMB anomalies strongly constrain random initial states [17].

4.2. Unified Constraint from Fossils

CMB low-ℓ modes and curvature drift both require the same memory kernel $K(z, z')$, producing an internally consistent inversion.

4.3. No Singular Beginning Required

All reconstructed early states are finite within the semiclassical domain. A singular origin is not mathematically required [11,13].

4.4. Falsifiable Predictions

The framework survives only if all four predictions hold:

1. Persistent CMB low-ℓ coherence ($> 3\sigma$).
2. Void–CMB alignment ($< 25^\circ$).
3. Slow curvature drift ($|d\Omega_k/dz| \sim 10^{-4}$).
4. Equilateral/orthogonal primordial non-Gaussianity at large scales.

5. Conclusions

Allowing the universe to retain structural memory transforms cosmology from forward simulation to reconstruction. The convergence of multiple independent inverse-tests indicates that early-universe evolution carries a non-zero hereditary component. This result does not break ΛCDM; it reframes it as the present-cycle attractor of a deeper, history-dependent process.

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Appendix A. Stability of the Memory-Corrected Backward Flow

We expand $S(z)$ in a basis $\{\psi_n\}$. For a toy memory kernel $K(z, z') = \alpha e^{-\beta(z'-z)} P_{\text{long}}$, the correction behaves as $\delta a_n(z) \approx -\gamma_n a_n(z)$. The backward eigenvalues are $\lambda_{n,\text{back}} = 1/(\lambda_n^{(0)} - \gamma_n) - q_n$. For realistic values, $|\lambda_{n,\text{back}}| < 1$, ensuring stability.

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