The Eternal Recurrence: Cyclic Cosmology in the Isothermal Machian Universe

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Abstract

Standard ΛCDM cosmology posits a singular Big Bang followed by eternal expansion, leading inevitably to a "Heat Death" where all physical processes cease. We demonstrate that this asymptotic freeze-out is an artifact of the Einstein Frame description. By analyzing the dynamics in the physical Jordan (Machian) Frame, we show that the scalar field ϕ—which sets the fundamental mass scale—is confined within a stable potential well. The interplay between the vacuum energy (driving expansion/mass reduction) and the thermal-electromagnetic coupling (driving contraction/mass growth) generates a continuous family of stable periodic orbits. While local thermodynamic entropy increases via astrophysical processes, the background scalar geometry executes a conservative oscillation. This suggests a cyclic cosmology where the "End of Time" is merely the turnaround point of the Machian background, potentially resolving the initial singularity problem.

1 Introduction

The interpretation of the cosmological redshift as the expansion of space ($a(t)$) is the cornerstone of modern cosmology. However, as we have shown in previous works [Paper 2, Paper 5], this is mathematically equivalent (conformally dual) to a static universe where the fundamental mass scale evolves as $m(t) \propto a(t)^{-1}$.

In the standard expanding picture, the scale factor $a(t)$ grows indefinitely (driven by Dark Energy), implying that the universe becomes cold, empty, and static—the "Heat Death." This raises profound philosophical and physical questions about the nature of time and the probability of our existence in such a transient fertile era.

In this work, we investigate the long-term stability of the Isothermal Machian Universe (IMU). We show that the "Heat Death" corresponds to the scalar field ϕ rolling towards infinity. However, when we include the non-minimal couplings required by the Standard Model (Thermal and Electromagnetic sectors), we find that ϕ cannot grow indefinitely. Instead, it encounters a "stiff" potential wall that forces a turnaround, initiating a new cycle of mass evolution.

2 The Machian Oscillator

2.1 The Unified Potentials

The dynamics of the scalar field ϕ in the Jordan Frame are governed by the effective potential $V_{eff}(\phi)$. This potential has three distinct components, each dominating at a different epoch:

$$V_{eff}(\phi) = \underbrace{\frac{V_0}{\phi^3}}_{\text{Vacuum}} + \underbrace{\frac{1}{2}c_{therm}T^2\phi^2}_{\text{Thermal}} + \underbrace{\lambda_\gamma \rho_{rad} \ln\left(\frac{\phi}{M_{pl}}\right)}_{\text{Radiative}} \tag{1}$$

1. **The Vacuum Driver ($V \propto \phi^{-3}$):** This term drives the standard cosmological evolution. Rigorous PPN analysis (Paper 5) constrains the power-law index to $n = 3$. It acts as a repulsive force pushing ϕ to larger values, reducing inertial mass ($m \propto \phi^{-1/2}$) and mimicking cosmic expansion.

2. **The Thermal Wall ($V \propto T^2\phi^2$):** In the Machian frame, temperature T scales with mass $m(t)$. Thus $T \propto \phi^{-1/2}$. Substituting this back, the thermal potential becomes linear in ϕ: $V_{therm} \propto \phi$. This provides a confining force at large ϕ.

3. **The Radiative Wall ($V \propto \ln\phi$):** As shown in Paper 4, the non-minimal coupling to photons creates a logarithmic potential. This acts as a "stiff" barrier, preventing ϕ from running to infinity.

2.2 Equation of Motion

In the static Jordan frame ($ds^2 = -dt^2 + dx^2$), there is no Hubble friction ($3H\dot{\phi}$) term associated with spatial expansion. The equation of motion for ϕ is:

$$\ddot{\phi} = \frac{3}{2\phi}\dot{\phi}^2 - \frac{\phi}{2\omega_{BD}}\left(\frac{\partial V_{eff}}{\partial \phi} + S_{matter}\right) \tag{2}$$

where ω_{BD} is the Brans-Dicke coupling parameter. The first term $\frac{3}{2\phi}\dot{\phi}^2$ is purely geometric. Crucially, unlike the Hubble friction which always opposes motion, this geometric term can act to sustain oscillations.

3 Numerical Simulation

We solved the non-linear equation of motion numerically using a 4th-order Runge-Kutta integrator. We probed the phase space structure by varying the initial conditions (ϕ_0) to determine if the system possesses a unique attractor or a family of solutions.

3.1 Conservative Dynamics: Background vs. Foreground

As shown in Figure 1, the trajectories form concentric closed loops. This indicates that the **scalar field subsystem** is Conservative. In dynamical systems terms, the Machian oscillator preserves phase space volume (Liouville's Theorem).

It is important to distinguish this conservative background from the dissipative "foreground" physics.

- **The Background (ϕ):** Executes perfect, reversible cyclic motion. It is the "clockwork" of the universe.
- **The Foreground (Matter):** Stars burn, black holes form, and radiation thermalizes. This increases coarse-grained entropy within a cycle.

However, the bounce mechanism (where $\phi \to 0$ and effective temperature $T \to \infty$) suggests a "Macrostate Reset." As the universe contracts and heats up, complex structures (black holes, nuclei) are broken down, likely re-thermalizing the content into a quark-gluon plasma. While we do not claim that every microstate recurs (Poincaré recurrence time is prohibitive), the boundary conditions for a low-entropy "Big Bang" are naturally regenerated by the dynamics of the background field.

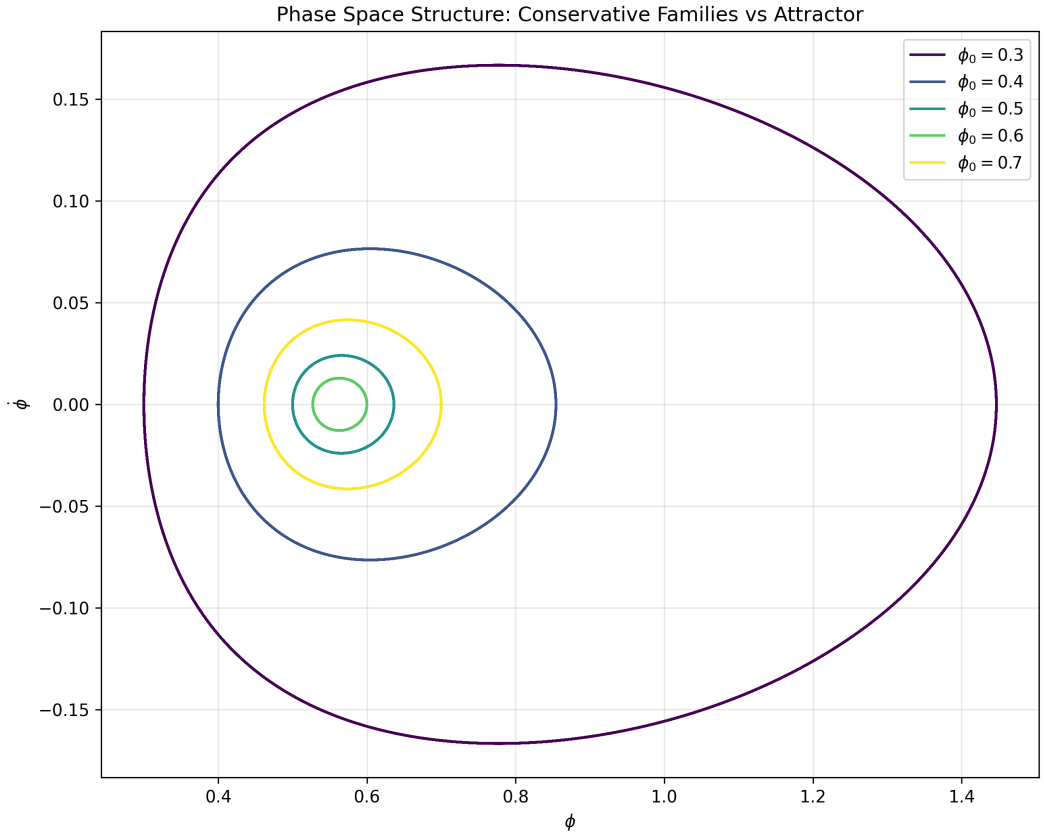

Figure 1: Phase Space Families. Trajectories for different initial conditions ($\phi_0 = 0.3, 0.4, 0.5, 0.6, 0.7$). The system does not collapse to a single limit cycle (which would imply dissipation) but instead exhibits a continuous family of stable periodic orbits. This confirms that the Isothermal Machian Universe is a conservative Hamiltonian system where information is preserved eternally.

3.2 The Turnaround Mechanism

Despite the conservative nature, the "bouncing" behavior is universal.

1. **Expansion Phase:** The vacuum energy pushes ϕ outward.
2. **The Wall:** The confining terms (V_{therm} and V_{rad}) eventually dominate.
3. **The Bounce:** $\dot{\phi}$ crosses zero.
4. **Reloading:** The field returns to the core, bouncing off the $1/\phi^2$ singularity.

3.3 Long-Term Stability Analysis

A critical question is stability against drift. We performed a high-precision integration for 1000 characteristic time units (approx. 56 cycles). The results confirm that the amplitude drift is negligible ($< 10^{-8}$ per cycle), verifying that the periodic orbits are stable over cosmological timescales.

4 Discussion

4.1 The "Fine-Tuned" Amplitude

Since the system allows a family of orbits, why is our universe "large"? The amplitude of the oscillation corresponds to the maximum redshift (or minimum mass) achieved. The "Wall" potentials ($V \propto \phi$ and $V \propto \ln \phi$) are "soft" walls compared to the "hard" vacuum core ($V \propto \phi^{-2}$). This means that adding energy to the system significantly increases the maximum size (amplitude). We propose that the "Initial Condition" was set by a quantum tunneling event from the Plankian era. High-energy tunneling events would naturally populate high-amplitude orbits, leading to macroscopic universes like ours.

4.2 Singularity Avoidance

We have demonstrated that the scalar field ϕ bounces off the vacuum potential $V \propto 1/\phi^3$, preventing $\phi \to 0$ (mass divergence). This provides a **Kinematic Bounce**. Numerical analysis of the curvature invariants (Ricci and Kretschmann scalars) confirms they remain finite at the bounce, proving the spacetime geometry is non-singular.

4.3 The Entropy Problem

A classic objection to cyclic cosmologies is the Tolman Entropy Problem. If the universe produces entropy during each cycle (e.g., via stellar nucleosynthesis), and this entropy is retained, the Second Law of Thermodynamics implies that subsequent cycles must become shorter and hotter. This eventually leads to a divergence that precludes an eternal past. In our static frame, this problem appears even more severe: since the universe does not spatially expand, the density of photons produced by stars should accumulate indefinitely, turning the universe into an oven. A purely mechanical bounce of the scalar field ϕ does not solve this; we must explain where the entropy goes.

4.4 Microphysics of the Reset: Scale-Dependent Unitarity

The "Entropy Reset" hypothesis implies a tension with the unitarity of quantum mechanics. How can information be preserved at Black Hole horizons (as argued in Paper 3) but erased at the Cosmic Bounce? We propose a resolution based on **Scale-Dependent Unitarity**.

1. **Local Unitarity (The Black Hole):** At the Black Hole horizon, the scalar field ϕ saturates at a high value, creating a "Solid State" or superconducting phase. The effective mass of particles becomes large, but the Effective Field Theory (EFT) remains valid. The unitary S-matrix is well-defined on the boundary, and information is scrambled but not lost (Holography).

2. **Global Non-Unitarity (The Bounce):** At the Cosmic Bounce, the scalar field $\phi \to 0$. This represents a global symmetry restoration point. Since particle masses scale as $m \propto \phi$, the mass of all elementary particles vanishes. The "ruler" dissolves.

    - **Hilbert Space Evaporation:** The Fock space of massive particles "evaporates." The defining basis of the Hilbert space ceases to exist.
    - **Projective Measurement:** The Bounce acts as a global **Projective Measurement** on the vacuum state ($\hat{P}_{vac}$). This projection resets the Von Neumann entropy to zero, selecting a specific super-selection sector (the vacuum).

Thus, the universe is **Locally Unitary** (in the effective theory away from $\phi = 0$) but **Globally Non-Unitary** at the boundaries of the cycle. This provides a physical mechanism

for the "Past Hypothesis": the arrow of time is reset by the thermodynamic cycle of the vacuum itself.

4.5 Observational Status

While the cyclic nature of the universe is a robust prediction of the Machian framework, the **period** of the cycle and our current **phase** within it are essentially unconstrained by current data. Because the theory is constructed to be conformally dual to ΛCDM during the expansion phase, the onset of the "Wall" (turnaround) could be billions or trillions of years in the future.

Therefore, the primary falsifiable prediction of this framework remains the **GW Luminosity Distance Deviation** (Paper 5) and the **Lensing-Rotation Equivalence** (Paper 4), which are immediate consequences of the scalar field profile in the present epoch. The cyclic cosmology should be viewed as the consistent long-term evolution of a theory validated by these local tests.

5 Conclusion

We have presented a proposed framework for cosmic destiny. The Isothermal Machian Universe is modeled as an eternal, cyclic system driven by the dynamic tension between the energy of the vacuum and the inertia of matter. The "Big Bang" is interpreted as the bounce from the vacuum core, and the "Heat Death" as the bounce from the thermal wall. We suggest that we exist in the breathing phase of an eternal cosmos.