A Cyclic 4D-Time Universe Model: Bounce, Expansion, and Turnaround Controlled by Closed Time Geometry

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Abstract

We propose a conceptual cosmological framework in which the fourth dimension—time—is not infinite, but cyclic and bounded. This closed time geometry provides a natural mechanism for both the initiation of cosmic expansion (the bounce) and its termination (the turnaround), removing the need for external triggers. We derive an effective Friedmann equation, inspired by Loop Quantum Cosmology (LQC) [1, 2], that incorporates quantum corrections to avoid singularities, and show how a large-a turnaround can arise through curvature or an effective negative cosmological term. The bounce is interpreted as a single-frame quantum state, linking emergent time concepts [5, 6] with cyclic and conformal cosmological models [3, 4].

1 Introduction

The classical theory of general relativity predicts singularities at the Big Bang and inside black holes, where the equations cease to be valid. Loop Quantum Cosmology (LQC) provides a resolution through quantum corrections that replace singularities with bounces [1, 2]. Other cyclic approaches, such as the ekpyrotic/cyclic scenario [3], posit a sequence of universes but often leave the termination of expansion unspecified. Penrose's Conformal Cyclic Cosmology (CCC) [4] offers an alternative by identifying the remote future of one aeon with the Big Bang of the next through conformal rescaling.

The proposal developed here differs in a key way: time itself is treated as a closed arc, with expansion and contraction bounded by its periodicity. This *cyclic 4D-time* ansatz eliminates the need for ad hoc triggers and provides a unified geometric controller for both the bounce and the turnaround.

2 Framework

2.1 Cyclic Time Ansatz (Derived Periodicity)

We posit periodic cosmic time $\tau \in [0, T)$ such that $a(\tau + T) = a(\tau)$. Turning points occur at $a_{\min}$ (bounce) and $a_{\max}$ (turnaround), where $\dot{a} = 0$. From the effective Friedmann equation

(Sec. 2.2),

$$\dot{a}^2 = a^2 \left[\frac{8\pi G}{3} \rho(a) \left(1 - \frac{\rho(a)}{\rho_c} \right) + \frac{\Lambda}{3} - \frac{k}{a^2} \right] \equiv -V_{\rm eff}(a). \tag{1}$$

The cycle period is then

$$T = 2 \int_{a_{\min}}^{a_{\max}} \frac{da}{\sqrt{-V_{\rm eff}(a)}}, \tag{2}$$

which is finite if both turning points exist. A convenient illustrative ansatz is

$$a(\tau) = a_{\min} + (a_{\max} - a_{\min}) \sin^2\!\left(\frac{\pi\tau}{T}\right). \tag{3}$$

2.2 Effective Friedmann Equation from a Hamiltonian

Following LQC, the effective Hamiltonian constraint is

$$\mathcal{C}_{\rm eff} = -\frac{3}{8\pi G \gamma^2 \lambda^2} a \sin^2(\lambda b) + \rho(a) a^3 = 0, \tag{4}$$

with Barbero–Immirzi parameter γ and area gap $\lambda = \sqrt{\Delta}$. This yields the modified Friedmann equation

$$H^2 = \frac{8\pi G}{3} \rho(a) \left(1 - \frac{\rho(a)}{\rho_c} \right) + \frac{\Lambda}{3} - \frac{k}{a^2}, \quad \rho_c = \frac{3}{8\pi G \gamma^2 \lambda^2}. \tag{5}$$

For $\rho(a) = \rho_{r0} a^{-4} + \rho_{m0} a^{-3} + \rho_\Lambda$:

Bounce condition. At $a = a_{\min}$, $H = 0$ gives $\rho = \rho_c$ and $\ddot{a} > 0$, so the turning point is a stable minimum.

Turnaround condition. At $a = a_{\max}$, $H = 0$ implies

$$\frac{8\pi G}{3} \rho(a_{\max}) \left(1 - \frac{\rho(a_{\max})}{\rho_c} \right) + \frac{\Lambda}{3} - \frac{k}{a_{\max}^2} = 0, \tag{6}$$

linking $a_{\max}$ to observable parameters $(\Omega_{m0}, \Omega_{r0}, \Omega_{\Lambda 0}, \Omega_{k0})$.

3 Results (Toy Examples)

3.1 Cyclic Scale Factor

Figure 1 shows an illustrative periodic $a(\tau)$ with bounce and turnaround.

3.2 Effective $H^2(a)$ with Two Turning Points

Figure 2 shows a toy $H^2(a)$ with both a small-a bounce and a large-a turnaround.

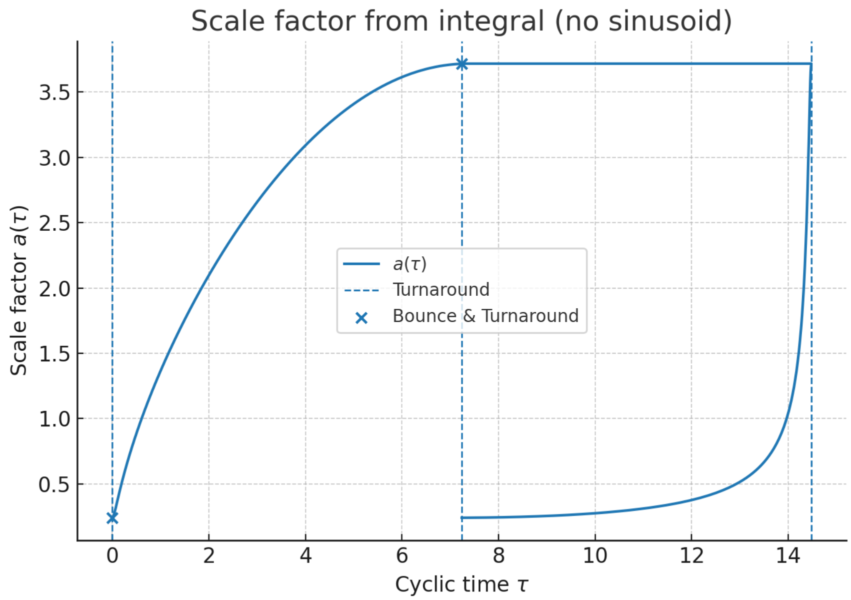

Figure 1: Cyclic time ansatz: $a(\tau)$ with bounce ($\tau = 0$) and turnaround ($\tau = T/2$).

4 Discussion

Compared to standard LQC [1], this model retains the quantum bounce but introduces a built-in turnaround through closed time geometry. Unlike CCC [4], which removes contraction via conformal mapping, this proposal preserves contraction and closes the cycle directly in time itself. The model also resonates with emergent-time perspectives such as the Hartle–Hawking wavefunction [5] and Rovelli's relational view of time [6].

Bounce as a wavefunction. In a Wheeler–DeWitt minisuperspace approximation, the universe wavefunction $\Psi(a)$ near $a_{\min}$ can be modeled as a Gaussian sharply peaked at $a_{\min}$, yielding a single-frame quantum state. Since $H = 0$ at the bounce, extrinsic curvature vanishes and there is no relative time dilation between comoving observers.

5 Conclusions and Next Steps

We have presented a toy model embodying the idea of time as a closed controller loop. This framework unifies bounce and turnaround mechanisms in a geometric ansatz, offering a conceptual alternative to inflationary or purely conformal cyclic models.

Future work should focus on deriving the effective dynamics from a fundamental theory of quantum gravity, and on observational predictions. For instance, perturbations can be evolved with

$$v_k'' + (k^2 - \tfrac{z''}{z})v_k = 0, \qquad \mu_k'' + (k^2 - \tfrac{a''}{a})\mu_k = 0, \tag{7}$$

to yield scalar/tensor spectra with potential signatures in the CMB and primordial gravitational waves. Entropy flow across cycles also warrants further study.

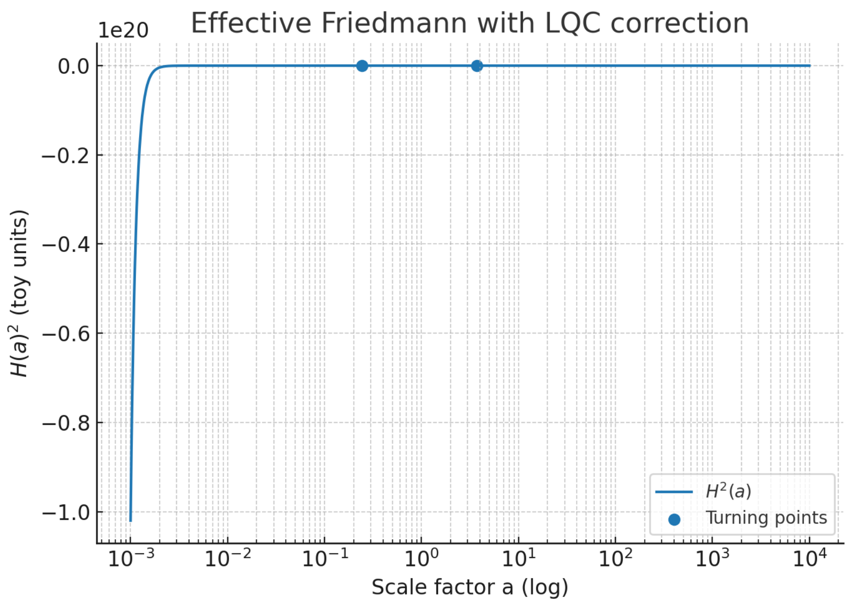

Figure 2: Toy $H^2(a)$ exhibiting a small-a bounce and a large-a turnaround.

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