

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),

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

The cycle period is then

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

which is finite if both turning points exist. For illustration, we may approximate with

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

2.2 Effective Friedmann Equation from a Hamiltonian

Following LQC, the effective Hamiltonian constraint is

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

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

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

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

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

linking a_{\max} to observable parameters $(\Omega_{m0}, \Omega_{r0}, \Omega_{\Lambda0}, \Omega_{k0})$.

3 Results (Equation-Driven Figures)

3.1 Cyclic Scale Factor from Integral Solution

Figure 1 shows $a(\tau)$ constructed from the integral solution $d\tau/da = [a\sqrt{H^2(a)}]^{-1}$ using Eq. (5). Turning points at a_{\min} and a_{\max} are marked.

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

Figure 2 shows the effective $H^2(a)$ with bounce and turnaround points found by solving $H^2 = 0$.

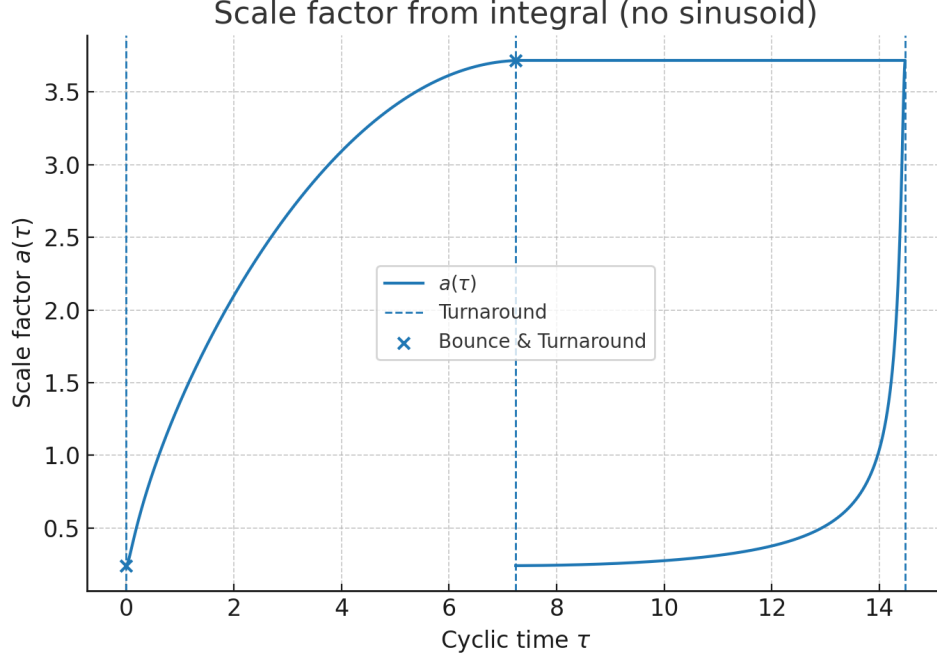


Figure 1: **Scale factor from the integral solution.** $a(\tau)$ reconstructed from $d\tau/da = [a\sqrt{H^2(a)}]^{-1}$. Bounce (a_{\min}) and turnaround (a_{\max}) are indicated. Parameters are listed in Table 1.

Reproducibility. All figures are generated by `make_figs.py`, which computes a_{\min} , a_{\max} , evaluates T , and produces both plots. A file `turning_points.txt` records the numerical values used.

Toy Parameters Used for Figures

For reproducibility, the following dimensionless toy parameters were used in the script `make_figs.py` to generate Figs. 1 and 2:

Parameter	Value	Description
ρ_{m0}	1.0	Matter-like density coefficient ($\propto a^{-3}$)
ρ_{r0}	0.1	Radiation-like density coefficient ($\propto a^{-4}$)
ρ_{Λ}	-0.02	Effective negative cosmological term (drives turnaround)
ρ_c	100.0	Critical LQC density (bounce condition)
k	0	Spatial curvature (set to flat in this run)
Λ	0	Additional cosmological constant term (set to zero)

Table 1: Toy parameter values used in the numerical generation of figures. Changing ρ_{Λ} or k modifies the turnaround scale a_{\max} , while ρ_c sets the bounce scale a_{\min} .

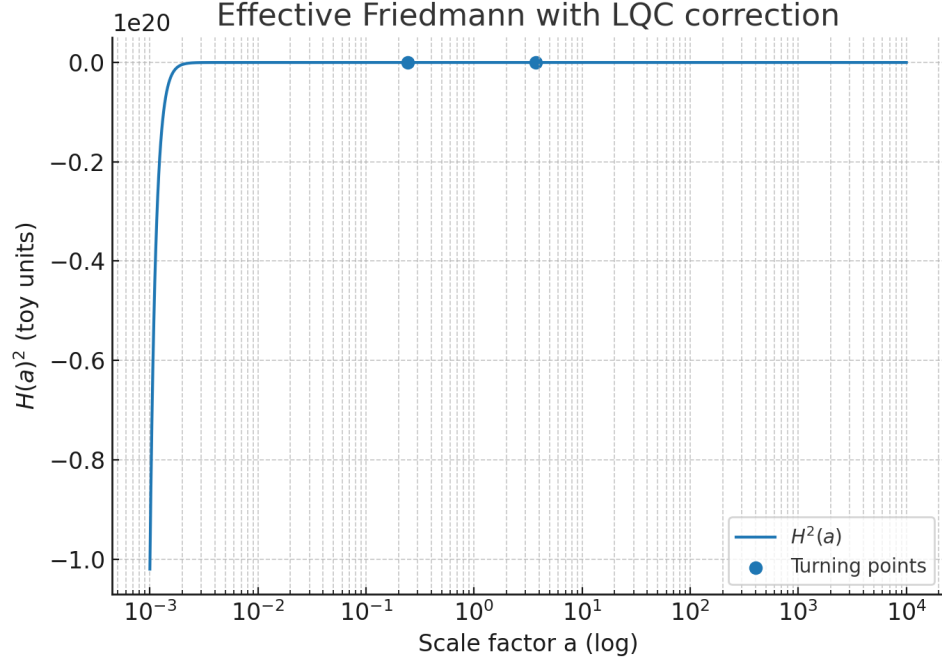


Figure 2: **Effective** $H^2(a)$. Derived from Eq. (5) with toy parameters $(\rho_{m0}, \rho_{r0}, \rho_{\Lambda}, \rho_c)$. Zeros mark the bounce and turnaround. Parameters are listed in Table 1.

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

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

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

Open science. All figures and parameter values are fully reproducible from the public GitHub repository accompanying this work.

Acknowledgments

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References

- [1] A. Ashtekar, T. Pawłowski, and P. Singh, “Quantum nature of the big bang: Improved dynamics,” *Phys. Rev. D*, vol. 74, p. 084003, 2006. doi:10.1103/PhysRevD.74.084003
- [2] M. Bojowald, “Absence of singularity in loop quantum cosmology,” *Phys. Rev. Lett.*, vol. 86, p. 5227, 2001. doi:10.1103/PhysRevLett.86.5227
- [3] P. J. Steinhardt and N. Turok, “A cyclic model of the universe,” *Science*, vol. 296, pp. 1436–1439, 2002. doi:10.1126/science.1070462
- [4] R. Penrose, *Cycles of Time: An Extraordinary New View of the Universe*. London: Bodley Head, 2010. ISBN: 978-0224080361
- [5] J. B. Hartle and S. W. Hawking, “Wave function of the Universe,” *Phys. Rev. D*, vol. 28, pp. 2960–2975, 1983. doi:10.1103/PhysRevD.28.2960
- [6] C. Rovelli, *Reality Is Not What It Seems: The Journey to Quantum Gravity*. Penguin Books, 2017. ISBN: 978-0735213920