# The Axion Cyclic Universe: A Theoretical Model of Cosmological Rebirth

Athrva Kaushik

October 24, 2025

**Abstract**

We present a theoretical framework for the *Axion Cyclic Universe*, a cosmological model in which the universe undergoes an infinite series of expansion and contraction phases mediated by axion-like fields. This model connects singularities, black holes, and wormholes to provide a mechanism for energy recycling between cosmic cycles. We discuss the mathematical formulation of axion fields within Friedmann cosmology, observational hints supporting cyclic behavior, and potential experimental tests.

# 1 Introduction

The origin and fate of the universe remain central questions in cosmology. Standard Big Bang cosmology posits a singular beginning followed by continuous expansion. However, cyclic cosmologies [Steinhardt and Turok, 2002, Bojowald, 2001] offer an alternative in which the universe undergoes repeated expansions and contractions. We propose an extension incorporating axion-like fields as a mechanism for energy storage and redistribution across cycles, forming the *Axion Cyclic Universe* (ACU).

# 2 Theoretical Background

## 2.1 Cyclic Cosmology

A general relativistic cyclic model can be described using the Friedmann equations:

$$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3} \tag{1}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) + \frac{\Lambda}{3} \tag{2}$$

where $H = \dot{a}/a$ is the Hubble parameter, $\rho$ is energy density, $p$ is pressure, $k$ is curvature, and $\Lambda$ the cosmological constant. In a cyclic model, the scale factor $a(t)$ oscillates between maximum expansion and minimum contraction.

### 2.2 Axion Fields

Axions are hypothetical pseudo-scalar particles originally proposed to solve the strong CP problem [Peccei and Quinn, 1977]. Their potential can be written as:

$$V(a) = m_a^2 f_a^2 \left[1 - \cos\left(\frac{a}{f_a}\right)\right] \tag{3}$$

where $m_a$ is the axion mass, $f_a$ the decay constant, and $a$ the axion field. The energy density is

$$\rho_a = \frac{1}{2}\dot{a}^2 + V(a) \tag{4}$$

and it contributes to the Friedmann equations as

$$H^2 = \frac{8\pi G}{3}(\rho_{\text{matter}} + \rho_r + \rho_a) \tag{5}$$

allowing axions to store energy during contraction and release it at the bounce.

### 2.3 Black Holes and Wormholes as Cycle Gates

Inside black holes, matter collapses to singularities. Theoretical models [Rovelli and Vidotto, 2014] suggest that such singularities may connect to new expanding regions of spacetime (wormholes), effectively seeding new universes. Axion fields may permeate these regions, preserving energy and information across cycles.

## 3 Mathematical Formulation

### 3.1 Modified Friedmann Equations

Including the axion contribution:

$$H^2 = \frac{8\pi G}{3}(\rho_m + \rho_r + \rho_a) - \frac{k}{a^2} \tag{6}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left[(\rho_m + \rho_r + \rho_a) + 3(p_m + p_r + p_a)\right] \tag{7}$$

where $p_a = \frac{1}{2}\dot{a}^2 - V(a)$ is the axion pressure.

### 3.2 Bounce Conditions

A cosmological bounce occurs when:

$$\dot{a} = 0, \quad \ddot{a} > 0 \tag{8}$$

Axion energy density can provide the negative pressure necessary to satisfy this condition.

### 3.3 Entropy and Recyclability

Axions may absorb entropy during contraction, allowing a near-reset of the universe at each bounce. The entropy density $s$ evolves as:

$$\dot{s} + 3Hs = -\Gamma(a) \tag{9}$$

where $\Gamma(a)$ represents entropy transfer to the axion field.

# 4 Observational Evidence

## 4.1 Cosmic Microwave Background (CMB) Anomalies

Low-variance rings and cold spots in the CMB [Gurzadyan and Penrose, 2005] may represent imprints of prior cosmic cycles.

## 4.2 Early Galaxies and Metallicity

JWST observations reveal mature galaxies earlier than standard cosmology predicts [Naidu et al., 2022], consistent with recycled matter.

## 4.3 Gravitational Wave Echoes

Collapses of previous universes could leave low-frequency gravitational wave signatures detectable with LIGO/Virgo or future space-based detectors like LISA [Ashtekar et al., 2016].

## 4.4 Axion Dark Matter

Indirect hints for axions come from astrophysical phenomena and ongoing experiments such as ADMX, CAST, and HAYSTAC [Sikivie, 2008].

# 5 Discussion

The ACU model provides a mathematically consistent framework linking cyclic cosmology to observable phenomena. The axion field plays a crucial role in storing and releasing energy, potentially explaining the early formation of galaxies, entropy reset, and CMB imprints. While direct axion detection is currently beyond reach, simulations and indirect observational analysis provide paths for testing.

# 6 Conclusion

The Axion Cyclic Universe provides a compelling model for a universe without beginning or end, connecting general relativity, quantum field theory, and cosmological observations. Further theoretical refinement and observational searches for axions, CMB anomalies, and gravitational wave echoes are necessary to advance this model from hypothesis toward empirical science.

# References

P. J. Steinhardt and N. Turok, "A cyclic model of the universe," Science, 296, 1436–1439 (2002).

M. Bojowald, "Absence of singularity in loop quantum cosmology," Phys. Rev. Lett. 86, 5227 (2001).

R. D. Peccei and H. R. Quinn, "CP Conservation in the Presence of Pseudoparticles," Phys. Rev. Lett. 38, 1440 (1977).

C. Rovelli and F. Vidotto, "Planck stars," Int. J. Mod. Phys. D23, 1442026 (2014).

V. G. Gurzadyan and R. Penrose, "Concentric circles in WMAP data may provide evidence of violent pre-Big-Bang activity," arXiv:astro-ph/0510358 (2005).

R. P. Naidu et al., "JWST Early Galaxies Reveal Unexpected Rapid Assembly," Nature Astronomy, 6, 1231–1238 (2022).

A. Ashtekar et al., "Gravitational wave echoes and quantum cosmology," Class. Quantum Grav. 33, 085005 (2016).

P. Sikivie, "Axion Cosmology," Lect. Notes Phys. 741, 19–50 (2008).