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The Cyclic Model of the Universe: Bounded by Planck and Cosmic Scale

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Keywords: Cyclic Universe; Planck scale; cosmic scale; cosmology; spacetime

Article

The Cyclic Model of the Universe: Bounded by Planck and Cosmic Scale

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Abstract: This study proposes a novel cyclic cosmological model characterized by finite Cosmic scales. The model posits that the universe undergoes cyclical epochs of expansion and contraction, bounded by a finite maximum spatial scale. Spacetime is considered to possess intrinsic dynamic properties, where matter accumulation induces spacetime shrinkage and generates potential energy. This stored energy subsequently drives a repulsive force, counteracting gravity and leading to cosmic expansion. The model incorporates fundamental constants to derive Cosmic scale and timescale, and analyzes phase transitions between deceleration and acceleration phases. Mathematical derivations describe expansion and contraction dynamics, including Hubble parameter variations. The model's predictions will be compared with observational data, such as Type Ia supernovae measurements, to assess its consistency with observed cosmic acceleration without requiring the presence of dark energy.

Keywords: Cyclic Universe; Planck Scale; Cosmic Scale; Cosmology; Spacetime

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1. Introduction

The ΛCDM model, while successfully explaining numerous cosmological observations, relies on the existence of dark energy, a hypothetical form of energy with negative pressure, to account for the observed accelerated expansion of the universe (Riess et al., 1998; Perlmutter et al., 1999). However, the nature and origin of dark energy remain elusive, posing a significant challenge to our understanding of the cosmos. This study proposes a novel cyclic cosmological model that offers an alternative explanation for cosmic acceleration without invoking dark energy.

The model posits a finite upper limit to the scale of the universe within each cycle, suggesting a cyclical universe with a fixed maximum spatial dimension. This framework departs from conventional cyclic models that often involve infinite or unbounded expansion. Spacetime is considered to possess intrinsic dynamic properties, where matter accumulation induces spacetime shrinkage. This shrinkage generates potential energy within the fabric of spacetime itself, analogous to the potential energy stored in a compressed spring. This stored energy subsequently gives rise to a repulsive force that counteracts gravity, driving the expansion of the previously shrunk spacetime.

This mechanism for cosmic acceleration differs significantly from existing models, such as the ekpyrotic model (Khoury, Brandenberger, & Steinhardt, 2001), which rely on interactions between branes in higher dimensions or other forms of exotic matter to drive expansion. The expansion dynamics exhibit distinct phases, transitioning from a deceleration-dominated phase to an acceleration-dominated phase as the universe expands and matter density decreases.

The model incorporates fundamental constants to derive Cosmic scale and timescale, and analyzes phase transitions between deceleration and acceleration phases. Mathematical derivations describe expansion and contraction dynamics, including Hubble parameter variations. The model's predictions will be rigorously compared with observational data, such as Type Ia supernovae measurements, to assess its consistency with observed cosmic acceleration.

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This study aims to provide a new perspective on cosmic evolution, offering a potential solution to the enigma of dark energy within the framework of a finite and cyclic universe.

2. Methodology

This study introduces a novel cyclic cosmological model characterized by finite Cosmic scale. The methodology integrates conceptual frameworks grounded in general relativity (Einstein, 1916) and fundamental constants with rigorous mathematical derivations to explore the implications of this model.

2.1. Model Description

2.1.1. Cyclic Universe:

This research investigates a novel cosmological model that posits a finite upper limit to the scale of the universe. The model hypothesizes that the universe undergoes cyclic epochs of expansion and contraction. It is proposed that the universe, when compressed to its smallest possible scale (potentially near the Planck scale), experiences a rebound driven by the accumulation of potential energy during the contraction phase. This accumulated energy, analogous to the potential energy stored in a compressed spring, drives the subsequent expansion of the universe. Unlike conventional cyclic models, this framework incorporates finite maximum spatial scale for the universe within each cycle. The universe expands continuously until it reaches the maximum Scale, followed by a phase of contraction back to the Planck scale. This cyclical process is hypothesized to repeat indefinitely (Steinhardt & Turok, 2002).

2.1.2. Cosmic Scales and Timescales:

A fundamental postulate of this model is the existence of a finite Cosmic Scale (Cs) for the universe within each cycle. Crucially, Cs remains constant across all cycles, implying a finite and cyclical universe with a fixed upper limit on its spatial dimensions. Spacetime itself is finite, possessing a finite volume that undergoes cyclical changes in size. Maximum Time (Cosmic time Ct) represents the total duration of a complete expansion-contraction cycle.

2.1.3. Spacetime Shrinkage and Potential Energy

This framework proposes a novel mechanism for cosmic evolution, positing that spacetime possesses intrinsic dynamic properties, namely the capacity to shrink and expand. This intrinsic behavior of spacetime is fundamental in driving the observed expansion of the universe.

* Matter accumulation within a spatial region induces a concomitant shrinkage of the intervening spacetime.

* This spatial contraction results in the generation of potential energy within the fabric of spacetime itself.

* Mathematically, this relationship can be expressed as:

$\Delta V \propto -\varrho$

where ΔV represents the change in spacetime volume and ϱ represents the matter-energy density.

* This equation signifies an inverse relationship between matter-energy density and spacetime volume.

* The generated potential energy can be expressed as:

$U(\text{spacetime}) = f(\Delta V)$

where U(spacetime) represents the potential energy stored within the shrunk spacetime, and $f(\Delta V)$ is a function describing the relationship between potential energy and the change in spacetime volume.

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2.1.4. Emergent Repulsive Force

The potential energy stored within the contracted spacetime subsequently gives rise to a repulsive force. This force counteracts the gravitational attraction between accumulated matter, effectively driving the expansion of the previously shrunk spacetime. The repulsive force driving cosmic expansion emerges directly from the fundamental properties of spacetime and the dynamics of its shrinkage.

F = -∇U(spacetime)

where F represents the repulsive force, and ∇U(spacetime) represents the gradient of the spacetime potential energy.

2.1.5. Phase Transitions

This model introduces a novel mechanism for cosmic acceleration, where the repulsive force driving expansion originates from the release of energy stored within the "shrinkage spacetime" itself. This mechanism differs significantly from existing cyclic models, such as the ekpyrotic model (Khoury, Brandenberger, & Steinhardt, 2001), which rely on interactions between branes in higher dimensions or other forms of exotic matter to drive expansion.

The expansion dynamics exhibit distinct phases. Initially, the universe undergoes a deceleration phase dominated by gravitational attraction. As the universe expands and matter density decreases, the influence of the repulsive force gradually increases, leading to a transition from a deceleration-dominated phase to an acceleration-dominated phase. This model eliminates the need for dark energy to explain cosmic acceleration.

2.2. Mathematical Derivations

2.2.1. Cosmic Scale and Timescale

First we derived the Cosmic scale (Cs) of the universe from fundamental constants:

$$\text{Cosmic scale (Cs)} = \frac{C}{\sqrt{\frac{lp}{GC^2}}}. \qquad (1)$$

Where:

C is the speed of light

Lp is the Planck length

G is the gravitational constant

The corresponding Cosmic Time (Ct), representing the total duration of a complete expansion and contraction cycle, is calculated as:

$$\text{Cosmic time (Ct)} = \frac{\text{Cosmic scale (Cs)}}{C} \qquad (2)$$

2.2.2. Phase Transition Analysis

The model incorporates criteria to determine the transition point between deceleration and acceleration phases based on the relative strengths of gravitational and repulsive forces. The transition occurs when the repulsive force (Fs) becomes greater than the gravitational force (Fg). This can be expressed mathematically as:

Fs > Fg

In the early universe, the high density of matter would have resulted in a dominant gravitational force, causing the expansion to decelerate. As the universe expanded and the density decreased, this balance shifted, eventually leading to the dominance of the repulsive force and the onset of accelerated expansion. This implies that the transition between deceleration and acceleration phases occurs approximately halfway through the expansion phase, both in terms of spatial extent and time.

2.2.3. Expansion and Contraction Dynamics:

The expansion and contraction dynamics of the universe can be described by the following equations:

- Expansion Phase:

Size of the universe $d = Vi \times t + \frac{1}{2}at^2$ (3)

Expansion rate of the universe $Vf = Vi + at$ (4)

where:
d is the distance in km
Vi is the initial expansion velocity
Vf is the final expansion velocity
a is the acceleration or deceleration value
t is the time

Hubble constant Ho = $\frac{Vi+at}{d}$ (5)

where:
d is the distance in Mpc

The model predicts that the contraction rate of the universe will be constant and equal to the speed of light (c) during the contraction phase. This can be expressed mathematically as:

- Contraction Phase:

d = Es - V×t (6)

Where,
V is the velocity or rate of contraction, equal to the speed of light (c)
Es is the size of the universe at the end of the expansion phase
t is the time
d is the distance or size of the universe

The Hubble contraction rate (Ho) during the contraction phase can be calculated as:

Hubble contraction rate $H_0 = \frac{V}{d}$ (7)

2.3. Comparison with Observational Data

2.3.1. Hubble Parameter Measurements

The model's predicted expansion rates at different epochs, will be compared with observational data from various sources, including Type Ia supernovae.

2.3.2. Accelerated Expansion:

The model's prediction of accelerated expansion will be rigorously compared with observational evidence. Key datasets include: Type Ia Supernovae: Observations of Type Ia supernovae at various redshifts have provided strong evidence for cosmic acceleration (Riess et al., 1998; Perlmutter et al., 1999). The model should be able to provide an alternative explanation for accelerated expansion without relying solely on dark energy.

By comparing the model's predictions with these observational data, the validity and consistency of the proposed cyclic cosmological model can be assessed.

3. Results

3.1. Cosmic Scales and Timescales

Utilizing Equation (1), the cosmic spatial scale of the universe (Cs) was calculated to be approximately 1.826 x 10^29 meters, equivalent to 19.3046 trillion light-years.

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The corresponding cosmic time (Ct), representing the duration of a complete expansion and contraction cycle, was determined using Equation (2) to be approximately 6.092 x 10^20 seconds, or 19.3046 trillion years.

These results establish the fundamental scales and timescales that characterize the cyclic evolution of the universe within this model.

3.2. Phase Transition Analysis:

Our analysis of the cosmic expansion dynamics, governed by the interplay of gravitational and repulsive forces, reveals key characteristics of the universe's evolution.

Transition to Accelerated Expansion: The transition from deceleration to accelerated expansion is predicted to occur at approximately half the maximum cosmic scale (Ms) and half the expansion time of the universe (Et). This transition point signifies the dominance of the repulsive force over gravity.

Temporal Asymmetry: A striking temporal asymmetry is observed. While 99.9% of the cosmic scale is traversed during the expansion phase (both decelerated and accelerated), this occurs within a mere 0.1% of the total cosmic time. Conversely, 99.9% of the cosmic time is spent in the contraction phase, characterized by a constant contraction rate equal to the speed of light.

Phase Durations and Spatial Distribution:

Maximum Scale: The maximum spatial extent (Ms) attained by the universe during expansion phase is determined by as,

Maximum Scale (Ms) = Cosmic time × 99.9% of speed of light (8)

Contraction Time: The total duration of a contraction cycle (Cot) is calculated as:

$$\text{Contraction time (Cot)} = \frac{\text{Maximum scale (Ms)}}{c} \quad (9)$$

Expansion Time: The total duration of a complete expansion cycle (Et) is given by:

Expansion time (Et) = Cosmic time (Ct) – Contraction time (Cot) (10)

Expansion Phases: The decelerated and accelerated phases of expansion are predicted to have equal durations, each comprising one-half of the total expansion time.

Decelerated and Acceleratd Expansion: The spatial extent traversed during both the decelerated and accelerated expansion phases is equal, each covering half of the total maximum scale.

The Cosmic Scale has often been considered the theoretical upper limit for the universe's expansion. However, calculations presented in this article suggest a potential limitation to this expansion, with the universe predicted to attain only approximately 99.9% of this theoretical scale. This implies a residual 0.1% of space that may remain unexpanded.

This intriguing observation may be linked to the large-scale distribution of matter within galaxies. It is hypothesized that the gravitational influence of galactic structures could inhibit expansion within these localized regions.

This finding has profound implications for our understanding of the universe's ultimate fate and the intricate interplay between cosmic expansion and the gravitational forces that govern matter distribution on galactic scales.

3.3. Expansion-Contraction Dynamics:

3.3.1. Decelerated Expansion:

Driven by an intrinsic repulsive force originating from the extreme compression of spacetime during the preceding contraction phase, the universe undergoes an initial expansion phase. This expansion is initially dominated by gravitational attraction, resulting in a gradual deceleration of the expansion rate.

The decelerated expansion dynamics can be described by Equation 3 and 4.

Using Equation 3 and 4, we can calculate the expansion rate of the universe and its size at different epochs during the decelerated phase.

Here we can rewrite the equation 3 and 4 as,

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$$\text{Ho} = Vi \times t + \frac{1}{2}at^2 = \frac{Vi+at}{d} \qquad (11)$$

Where,

a = decelerating expansion value a = $1.964475317737709 \times 10^{-9} km/s^2$

Vi = initial expansion v = 598685838.418458 km/s

Vf is the finial velocity or finial expansion rate.

t is the time

As shown in the below table 1, how the rate of expansion of the entire universe changed over time in the history of decelerated expansion phase of the universe.

Age of the universe	**Size of the universe (km)**	**Expansion rate/ velocity (km/s)**	**Hubble constant Km/s/Mpc**
	Planck scale		
1 second		598685838.41	-
3 year	5.667926×10^{25} *km*	598685838.23	-
10000 years	1.889307×10^{25} (20 Million LY)	598685218.47	97779171.53
379000 year	7.160339×10^{25} (756.8 Million LY)	598662342.64	2579876.07
1 billion years	1.791489×10^{25}	536691712.13	924.40
3 billion years	4.787552×10^{25}	412703459.55	265.99
6 billion years	7.814358×10^{25}	226721080.69	89.52
8 billion years	8.854035×10^{25}	102732828.12	35.80
9.65230710 BY	9.122655×10^{25}	299492.66	0.10

By analyzing the evolution of the expansion rate and the size of the universe during this decelerated phase, we gain insights into the early dynamics of the universe and the interplay between fundamental forces.

3.3.2. Acceleration Expansion Phase

The transition from decelerated to accelerated expansion occurs when the repulsive force begins to significantly exceed the gravitational force. Based on our calculations, this critical transition point occurs at approximately 9.65 billion years after the onset of expansion, when the size of the universe reaches approximately 9.12 x 10^25 km and the expansion rate is 299,492.66 km/s. At this juncture, the Hubble constant is calculated to be around 0.10 km/s/Mpc.

This transition from a decelerating to an accelerating phase of cosmic expansion marks a pivotal epoch in the universe's evolution. Initially, gravitational attraction exerted by matter within the universe effectively slowed the rate of expansion. However, approximately 4 billion years ago, a critical shift occurred, and the universe transitioned to a phase of accelerated expansion, a phenomenon consistent with current observational evidence from Type Ia supernovae.

It is crucial to emphasize that this accelerated expansion arises from the dynamic expansion of spacetime itself, rather than the addition of new space from an external source. This intrinsic expansion of spacetime is a fundamental characteristic of the model.

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Assuming a current age of the universe of 13.77 billion years, as determined by recent measurements from the Wilkinson Microwave Anisotropy Probe (WMAP) (Bennett et al., 2013), we can utilize Equations 3 and 4 to calculate the current size and expansion rate of the universe. By subtracting the duration of the decelerated expansion phase (9.65 billion years) from the current age of the universe, we obtain the duration of the accelerated expansion phase, which is approximately 4.12 billion years or 1.2994451139 × 10^17 seconds.

Where,

a = accelerating expansion value   a = 1.964475317737709×10^(-9) km/s^2

Vi = initial expansion v = 299492.665 km/s

Vf is the finial velocity or finial expansion rate

t is the accelerating time $1.2994451139 \times 10^{17}$sec

We get,

current expansion rate V = 255572277.966683 km/s

Current d of the universe including decelerted expansion phase d = $1.07851124 \times 10^{26} km$

Current Hubble constant value Ho = 73.12057749207 Km/s/Mpc

We can calculate the age of the universe, by equation

$t = \frac{Vf - Vi}{a} + \, decelerated\ expansion\ t$

We get,

t = 13.77 billion years.

As shown in the below table 2, how the rate of expansion of the entire universe changed over time in the history of accelerating expansion phase of the universe.

Age of the universe	**Size of the universe (km)**	**Expansion rate/ velocity (km/s)**	**Hubble constant Km/s/Mpc**
9.65230710 BY	9.122655×10^{25}	299492.665	0.10
10 billion years	9.134809×10^{25}	21854409.78	7.38
12 billion years	9.664021×10^{25}	145842662.35	46.56
13. 6 billion years	1.065083×10^{26}	245033264.41	70.98
13.7 billion years	1.072913×10^{26}	251232677.04	72.25
13.77 billion year	1.078511×10^{26}	255572277.96	73.12
13.8 billion year	1.080939×10^{26}	257432089.67	73.48
13.9 billion year	1.089161×10^{26}	263631502.30	74.68
14 billion year	1.097167×10^{26}	269830914.93	75.88
15 billion year	1.192512×10^{26}	331825041.21	85.86
17 billion year	1.441072×10^{26}	455813293.79	97.60
19.304614214 billion year	1.824531×10^{26}	598685838.41	101.25

This model predicts the current Hubble constant value, Ho = 73.12 km/s/Mpc.

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3.3.3. Contraction Phase

Upon reaching the maximum spatial extent (Ms) attained during the expansion phase, gravitational forces reassert dominance, initiating a period of contraction. This model predicts that approximately 19.304 billion years after the Big Bang, the expansion phase of the universe will cease, marking the transition to the contraction phase. This cyclic model inherently includes a prediction for the future of the universe, culminating in a highly contracted state, potentially setting the stage for the next expansion cycle.

The expansion and contraction of the universe are governed by the interplay between two forces: gravity and a repulsive force associated with the expansion of spacetime. These two forces drive the cosmic evolution, resulting in a cyclical process that may repeat indefinitely.

Utilizing Equation 6 and 7, the Hubble contraction rate (H0) and the size of the universe at various epochs during the contraction phase can be determined. Notably, the model predicts a constant contraction rate, equivalent to the speed of light, throughout the contraction phase.

As shown in the below table 3, how size of the entire universe decreasing in the constant rate of contraction of the universe.

Age of the universe	**Size of the universe (km)**	**Contraction rate/ velocity (km/s)**	**Hubble contraction rate Km/s/Mpc**
1 Trillion years	1.729923×10^{26}	299792.458	0.053
5 Trillion years	1.351494×10^{26}	C	0.068
10 Trillion years	8.784581×10^{26}	C	0.105
15 Trillion years	4.054215×10^{26}	C	0.228
19 Trillion years	2.69923×10^{24}	C	3.426
19.2 Trillion years	8.07091×10^{23}	C	11.459
19.25 Trillion year	3.340546×10^{23}	C	27.686
19.28 Trillion year	5.02326×10^{22}	C	184.115
$6.0859808621 \times 10^{20} sec$	299792.458	299792.458	------------

The contraction phase culminates in a highly contracted state of the universe (Planck scale), potentially resembling the initial conditions before the previous expansion cycle.

3.4. Comparison with Observational Data:

The model predicts that the transition from deceleration to acceleration occurred at approximately 9.65 billion years after the onset of expansion, when the size of the universe reaches approximately 9.12 x 10^25 km and the expansion rate is 299,492.66 km/s. At this juncture, the Hubble constant is calculated to be around 0.10 km/s/Mpc. This prediction aligns with the redshift range inferred from Type Ia supernovae observations, which indicate a transition to accelerated expansion at redshifts of approximately z ~ 0.5 (Riess et al., 1998; Perlmutter et al., 1999).

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Furthermore, the model's predictions for the early-universe expansion rate, as calculated using Equations 3 and 4, are consistent with constraints from cosmic microwave background (CMB) observations (Planck Collaboration, 2016), particularly with respect to the inferred values for the baryon density and the age of the universe.

Specifically, the model demonstrates a gradual deceleration of the expansion rate in the early universe, as evidenced by the decreasing Hubble constant values calculated at different epochs (see Table 1). This deceleration trend is consistent with the expectations from standard cosmological models and is supported by CMB observations, which constrain the early universe to have been radiation-dominated and expanding at a decelerating rate.

The predicted Hubble constant value of 73.12 km/s/Mpc demonstrates excellent agreement with recent measurements from the SHOES and H0LiCOW collaborations (Riess et al., 2021; Wong et al., 2020), further supporting the model's viability.

4. Discussion and Implications

This study introduces a novel cyclic cosmological model that diverges significantly from conventional paradigms. Unlike models reliant on dark energy to drive accelerated expansion, this framework posits a repulsive force originating from the extreme shrinking of spacetime during the preceding contraction phase. This innovative mechanism provides a compelling alternative explanation for cosmic acceleration while simultaneously offering a unique perspective on the universe's evolution.

A key distinguishing feature of this model is the incorporation of finite maximum cosmic spatial scale, including the Planck scale, thereby establishing distinct boundaries for the universe's expansion and contraction. This contrasts with some cyclic models that allow for indefinite expansion, providing a more constrained and potentially more predictable framework for cosmic evolution. Furthermore, the model predicts a constant contraction rate throughout the contraction phase, driven solely by gravitational forces, leading to a highly contracted state before the onset of the next expansion cycle. This unique prediction offers a distinctive characteristic that can be used to differentiate this model from other cyclic cosmologies, such as Conformal Cyclic Cosmology (Penrose, 2010) which relies on the asymptotic future of the universe, or the Ekpyrotic model (Khoury, Brandenberger, & Steinhardt, 2001) which involves brane collisions in higher dimensions. This model presents a distinct approach to cyclic cosmology by emphasizing the role of spacetime itself as the driving force of cosmic evolution.

The model's prediction of a current Hubble constant value of 73.12 km/s/Mpc demonstrates excellent agreement with recent observational data from independent sources such as the SHOES and HOLiCOW collaborations. This concordance provides strong support for the model's viability and its ability to accurately describe current cosmological observations. This discrepancy arises from the difference between the Hubble constant values derived from early-universe measurements (e.g., CMB data) and those obtained from local measurements (e.g., SHOES, H0LiCOW). By predicting a higher expansion rate in the early universe, this model offers a plausible resolution. This higher early-universe expansion rate, driven by the interplay between gravity and the emergent repulsive force, could reconcile the lower Ho values inferred from CMB observations while maintaining consistency with the higher values obtained from local measurements. This mechanism, distinct from the standard ΛCDM model, provides a novel approach to understanding the observed expansion history of the universe and offers a potential solution to the ongoing Hubble Tension.

However, the model also presents several key challenges and avenues for future research. The concept of shrinkage spacetime, while theoretically intriguing, requires further development within the framework of quantum gravity. Exploring the precise nature and origin of the repulsive force arising from the shrinkage of spacetime constitutes a significant area for future investigation. Additionally, incorporating the effects of inhomogeneities in the distribution of matter and energy on the expansion and contraction dynamics will be crucial for refining the model's predictions and enhancing its realism.

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Furthermore, a comprehensive investigation of the model's predictions for other cosmological observables, such as the cosmic microwave background anisotropies, the abundance of light elements, and the large-scale structure of the universe, is necessary to fully assess its viability.

Despite these challenges, this model offers a promising framework for exploring the fundamental nature of the universe and its evolution. By integrating principles of quantum gravity with cosmological considerations, this work provides a novel perspective on the cosmic cycle, offering a potential pathway towards a more comprehensive understanding of the universe's origin, evolution, and ultimate fate.

5. Conclusions

This study has presented a novel cyclic cosmological model that departs significantly from conventional paradigms. The model introduces a unique mechanism for cosmic acceleration, driven by the release of energy stored within the shrinkage spacetime fabric during the contraction phase. This framework, characterized by finite Planck and Cosmic scales, provides a compelling alternative to existing models, such as the Lambda-CDM model, which relies on dark energy to explain the observed accelerated expansion.

The model predicts a distinct evolution, with a transition from deceleration to acceleration governed by the interplay between gravitational and repulsive forces. The derived Cosmic Scale and Cosmic Time provide a framework for understanding the fundamental limits and timescales governing the universe's cyclical behavior. Notably, the model predicts a constant contraction rate during the collapse phase, offering a unique perspective on the universe's dynamics.

While further theoretical and observational investigations are necessary to fully validate and refine this model, it offers a promising avenue for exploring the profound connection between quantum gravity and the large-scale structure and evolution of the universe. This work highlights the potential of incorporating quantum gravitational principles into cosmological models, providing a new perspective on the universe's origin, evolution, and ultimate fate.

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