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Article

The Cyclic Universe: From Planck Scale to Cosmic Scale of the Universe

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Abstract: This paper proposes a novel cyclic cosmological model characterized by finite Planck and Cosmic scales. Unlike conventional models, this framework introduces a repulsive force arising from the extreme compression of spacetime. Spacetime quantization, as suggested by loop quantum gravity, plays a crucial role in this process. As the universe contracts, the compression of discrete spacetime units stores energy, which is subsequently released, driving expansion. The model predicts a transition from deceleration to acceleration, determined by the interplay between gravity and this repulsive force. Mathematical derivations are presented to estimate the Maximum Cosmic Scale and Maximum Time based on fundamental constants. The model's predictions will be compared with observational data, including Type Ia supernovae, to assess its compatibility with current cosmological observations. This model offers a potential alternative to dark energy in explaining cosmic acceleration.

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

1. Introduction

Our understanding of the universe has undergone a dramatic evolution, transitioning from static models to the expanding universe described by Einstein's General Relativity (Einstein, 1916). While the prevailing Lambda-CDM model successfully explains many observed phenomena, such as the cosmic microwave background radiation and the large-scale structure formation (Planck Collaboration, 2016), it relies on the existence of dark energy to account for the observed accelerated expansion of the universe (Peebles & Ratra, 2003; Riess et al., 1998). This paper proposes a novel cyclic cosmological model that offers an alternative explanation for this accelerated expansion.

This model posits that the universe undergoes repeated cycles of expansion and contraction, bounded by finite Planck and Cosmic scales. Unlike conventional cyclic models, this framework introduces a novel repulsive force arising from the extreme compression of spacetime itself. This compression, occurring as the universe contracts towards the Planck scale, leads to the storage and subsequent release of energy within the fabric of spacetime, driving the subsequent expansion phase. This interplay between gravity and the repulsive force governs the dynamics of the universe, leading to periods of deceleration followed by periods of accelerated expansion.

The following sections will delve into the theoretical underpinnings of this model, including the derivation of the Cosmic Scale and Cosmic Time, an analysis of the expansion-contraction dynamics, and a discussion of the predicted phase transitions. Finally, the model's predictions will be compared with observational data, particularly focusing on the observed accelerated expansion of the universe as evidenced by Type Ia supernovae (Riess et al., 1998; Perlmutter et al., 1999). This work aims to provide a new perspective on cosmic evolution, offering a potential alternative explanation for the observed phenomena without the need for dark energy.

2. Methodology

This study introduces a novel cyclic cosmological model characterized by finite maximum spatial scales of the universe. The methodology combines conceptual frameworks grounded in

general relativity and fundamental constants with rigorous mathematical derivations to explore the implications of this model.

2.1. Model Description

2.1.1. Cyclic Universe:

The model proposes a cyclical universe undergoing recurrent phases of expansion and subsequent contraction. Unlike conventional cyclic models, this framework incorporates finite maximum spatial scales for the universe within each cycle. The universe expands continuously until it reaches the maximum Cosmic Scale (C_s), 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. Maximum Scale and Time:

A fundamental postulate of this model is the existence of a finite Maximum Scale (C_s) for the universe within each cycle. Cosmic scale defines the maximum physical extent of spacetime during a given cycle. Crucially, C_s remains constant across all cycles, implying a finite and cyclical universe with a fixed upper limit on its spatial dimensions. Maximum Time (Cosmic time C_t) represents the total duration of a complete expansion-contraction cycle.

2.1.3. From Planck Scale to Cosmic Scale:

The universe undergoes a cyclical evolution, akin to the rhythmic opening and closing of a roll of cloth. During the contraction phase, the universe gravitationally collapses towards the Planck Scale, much like tightly rolling the cloth inwards. This contraction is constrained by a finite Cosmic Scale, representing the maximum extent to which the cloth can be unrolled.

Crucially, this model incorporates the concept of spacetime quantization, as suggested by theories like loop quantum gravity (Rovelli, 2004). In this framework, spacetime is not continuous but rather composed of discrete units or “quantum of space.”

As the universe contracts towards the Planck Scale, these discrete units of spacetime become increasingly compressed. This extreme compression, analogous to squeezing a sponge, can store energy within the very fabric of spacetime itself. This stored energy acts like a compressed spring, building up potential energy.

When the compression reaches its limit at the Planck Scale, the stored energy within the “compressed spacetime” is released, driving a rapid expansion phase. This released energy acts as a repulsive force, counteracting the gravitational forces that were driving the contraction, much like the sudden unwinding of a tightly wound spring.

At the Planck Scale, the model predicts an equilibrium state where the force of gravity pulling spacetime inward (rolling the cloth) is perfectly balanced by the repulsive force arising from the compression of spacetime itself (the potential energy of the tightly wound spring).

This equilibrium state at the Planck Scale highlights a crucial aspect of the model: the potential for deviations from classical gravity at the smallest scales. While gravity is attractive on larger scales (like the gentle unrolling of the cloth), its behavior at the Planck Scale may be significantly altered by the extreme compression and quantum effects within spacetime.

2.1.4. The Origin of the Repulsive Force:

The origin of the repulsive force lies in the unique behavior of spacetime at the Planck scale, where quantum effects of gravity become dominant. This model incorporates the concept of spacetime quantization, suggesting that spacetime is not continuous but rather composed of discrete units. As the universe contracts towards the Planck scale, these discrete units become increasingly compressed. This extreme compression, reaching its peak at the Planck scale, is crucial. It could alter the fundamental properties of these spacetime units or lead to a buildup of energy within them. This

compression-induced change, whether it's an alteration of unit properties or the release of stored energy, gives rise to the repulsive force.

Essentially, the repulsive force emerges as an emergent phenomenon, a complex behavior arising from the interactions of these discrete spacetime units at their most fundamental level. While the exact mechanism remains to be fully understood, it highlights the profound impact of spacetime's quantum nature on the dynamics of the universe at the Planck scale.

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 "compressed spacetime" itself. This differs significantly from many 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 experiences a deceleration phase dominated by gravitational attraction, similar to the initial slow and controlled unrolling of the cloth. As the universe expands and the density of matter decreases, the influence of the repulsive force gradually increases, leading to a transition from a deceleration-dominated phase to an acceleration-dominated phase. This transition is analogous to the cloth suddenly unwinding rapidly after the initial slow unrolling. This eliminates the need for dark energy within this model.

2.2. Mathematical Derivations

2.2.1. Maximum Scales and Timescales

The Maximum Scale (C_s), representing the maximum spatial extent attained by the universe during its expansion phase, is derived from fundamental constants:

$$\text{Maximum scale } (C_s) = \frac{c}{\frac{l_p}{\sqrt{GC^2}}} \quad (1)$$

Where:

C is the speed of light

l_p is the Planck length

G is the gravitational constant

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

$$\text{Cosmic time } (C_t) = \frac{\text{Cosmic scale } (C_s)}{c} \quad (2)$$

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 (F_s) becomes greater than the gravitational force (F_g). This can be expressed mathematically as:

$$F_s > F_g$$

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.

Force Calculations:

* Gravitational Force (F_g): Determined based on the mass-energy density of the universe and the laws of general relativity. This calculation involves complex considerations of spacetime curvature and the distribution of matter and energy within the universe.

* Repulsive Force (Fs): Arises directly from the compression of discrete spacetime units. In loop quantum gravity, spacetime is quantized into discrete units. As the universe contracts towards the Planck Scale, these discrete units become increasingly compressed. This extreme compression may lead to a buildup of energy within these units or alter their fundamental properties, generating a significant repulsive force.

2.2.3. Expansion and Contraction Dynamics:

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

- Expansion Phase:

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

$$\text{Expansion rate of the universe } V_f = V_i + at \quad (4)$$

where:

d is the distance in km

V_i is the initial expansion velocity

V_f is the final expansion velocity

a is the acceleration or deceleration value

t is the time

$$\text{Hubble constant } H_0 = \frac{V_i + at}{d} \quad (5)$$

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:

$$d = E_s - V \times t \quad (6)$$

Where,

V is the velocity or rate of contraction, equal to the speed of light (c)

E_s 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 (H_0) during the contraction phase can be calculated as:

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

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 maximum spatial extent attained by the universe during its expansion phase (C_s) was calculated to be approximately 1.826×10^{29} meters, equivalent to 19.3046 trillion light-years.

The corresponding cosmic time (C_t), representing the duration of a complete expansion and contraction cycle, was determined using Equation (2) to be approximately 6.092×10^{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:

As previously discussed, the expansion dynamics of the universe are governed by the interplay between the gravitational force (F_g) and the repulsive force (F_s) originating from the expansion of spacetime.

In the early universe, the high density of matter resulted in a dominant gravitational force, causing the expansion to decelerate. As the universe expanded and the density decreased, the influence of the repulsive force gradually increased. This led to a critical transition point where F_s began to significantly exceed F_g , marking the onset of accelerated expansion.

Within this model, this transition is predicted to occur at approximately half the maximum cosmic scale (C_s) and half the expansion time of the universe. In other words, the deceleration and acceleration phases of expansion are predicted to occupy approximately equal portions of the overall expansion history of the universe.

A key prediction of this model is that the contraction rate of the universe, governed by gravitational forces, will be constant and equal to the speed of light throughout the contraction phase.

Based on model calculations, the transition to accelerated expansion is predicted to have occurred around 9.652 billion years after the Big Bang, and the size of the universe reached approximately 9.122×10^{25} km (9.64 trillion light-years across).

This model predicts an intriguing asymmetry in the temporal distribution of expansion and contraction phases. While 99.9% of the cosmic scale is traversed during the expansion phase (both deceleration and acceleration), this occurs within only 0.1% of the total cosmic time. Conversely, 99.9% of the cosmic time is spent in the contraction phase, during which the universe retraces its expansion path back to the Planck scale.

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,

$$H_0 = V_i \times t + \frac{1}{2} a t^2 = \frac{V_i + a t}{a} \quad (8)$$

Where,

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

V_i = initial expansion $v = 598685838.418458 \text{ km/s}$

V_f is the final velocity or final expansion rate.

t is the time

As shown in the table, 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	$5.667926 \times 10^{25} \text{ km}$	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 transition occurs at approximately 9.65 billion years after the onset of expansion, when the size of the universe reaches approximately $9.12 \times 10^{25} \text{ km}$ and the expansion rate is 299,492.66 km/s. At this point, the Hubble constant is calculated to be around 0.10 km/s/Mpc.

The transition from a decelerating to an accelerating phase of cosmic expansion marks a pivotal moment in the universe's evolution. Initially, gravitational attraction exerted by matter within the universe slowed the rate of expansion. However, approximately 4 billion years ago, a shift occurred, and the universe began to expand at an accelerating rate, consistent with current observational evidence of cosmic acceleration.

It's important 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.

Assuming a current age of the universe of 13.77 billion years (Recently the Wilkinson Microwave Anisotropy Probe (WMAP) satellite's measurements estimate the age of the universe to be 13.77 billion years, with some uncertainty), we can use Equation 3, to calculate the current size of the universe. First we minus decelerated expansion time from current age, we get current accelerating time of the universe is equal to $1.2994451139 \times 10^{17} \text{ sec}$

Where,

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

V_i = initial expansion $v = 299492.665 \text{ km/s}$

V_f is the final velocity or final expansion rate

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

We can use accelerating time in equation 4, to calculate the current expansion rate of the universe

We get,

current expansion rate $V = 255572277.966683 \text{ km/s}$

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

Current Hubble constant value $H_0 = 73.12057749207 \text{ Km/s/Mpc}$

We can calculate the age of the universe, by equation

$$t = \frac{V_f - V_i}{a} + \text{decelerated expansion } t$$

We get,

t = 13.77 billion years.

As shown in the table, 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.

3.3.3. Contraction Phase:

Upon reaching the Cosmic Scale (Cs), 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, and the contraction phase will begin. 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 fundamental 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. Model calculations predict a constant contraction rate of the universe, equal to the speed of light, throughout the contraction phase.

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

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
$6.0859808621 \times 10^{20} \text{ sec}$	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:

Accelerated Expansion: The model's prediction of an accelerating phase of expansion is consistent with observational evidence from Type Ia supernovae. These observations have demonstrated that the expansion of the universe is currently accelerating, which is consistent with the model's prediction of a transition to a repulsive force-dominated phase.

Hubble Parameter Measurements:

The model predicts a theoretical Hubble constant value of 73.12 km/s/Mpc, which is in excellent agreement with values obtained for the Hubble constant H_0 using independent observational methods:

SHOES Program: The Supernovae, H_0 , for the Equation of State of Dark Energy (SHOES) program, led by the Space Telescope Science Institute, utilizes Cepheid variable stars and Type Ia supernovae to determine the Hubble constant. Their recent measurements yield a value of $H_0 = 73.04 \pm 1.04$ km/s/Mpc (Riess et al., 2021).

H0LiCOW Collaboration: This collaboration utilizes gravitational lensing of quasars to independently measure the Hubble constant. Their latest results indicate $H_0 = 73.3 \pm 1.7$ km/s/Mpc (Wong et al., 2020).

This strong agreement between the model's prediction and independent observational measurements from the SHOES and H0LiCOW collaborations provides significant support for the model's viability and its ability to accurately describe current cosmological observations.

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 compression of quantized 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 feature of this model is the incorporation of finite maximum cosmic spatial scales, and Planck scale, 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. This model presents a distinct approach to cyclic cosmology by emphasizing the role of spacetime itself as the driving force of cosmic evolution. Unlike models such as Conformal Cyclic Cosmology, which rely on the asymptotic future of the universe (Penrose, 2010), or the Ekpyrotic model, which involves brane collisions in higher dimensions (Khoury, Brandenberger, & Steinhardt, 2001), this model proposes a mechanism for cosmic acceleration rooted in the fundamental properties of spacetime at the Planck scale. The concept of a finite Maximum Scale (C_s) and the repulsive force arising from spacetime compression differentiate this model from many other cyclic scenarios, offering a unique perspective on the universe's cyclical nature and the forces that govern its 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 H0LiCOW 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 H_0 values inferred from CMB observations while maintaining consistency with the higher values obtained from local measurements. This mechanism, distinct from the standard Λ CDM 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 quantized 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 compression 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.

5. Conclusion

This study presents a novel cyclic cosmological model with several distinctive features, including a unique mechanism for cosmic acceleration, finite cosmic scales, and a constant contraction rate. While further theoretical and observational investigations are necessary, this model offers a compelling alternative to existing cosmological paradigms and provides a framework for exploring the profound connection between quantum gravity and the large-scale structure and evolution of the universe.

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