Draft version August 2, 2024
Typeset using LaTeX twocolumn style in AASTeX631

Cosmic Cloning: Examining the Multiverse Theory

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Abstract

The Marvel Cinematic Universe has continued to grow and expand over the years. In Phase 4, the multiverse was seriously addressed in *Spiderman: No Way Home* and was further expanded on in *Doctor Strange: Multiverse of Madness*, but is there actual science behind this SciFi idea? In their seminal paper, "A Smooth Exit from Eternal Inflation?" (Hawking & Hertog 2018), the late Dr. Stephen Hawking and Dr. Thomas Hertog propose that the exit from an eternally inflating universe is finite and smooth, challenging the traditional concept of an infinite multiverse. By leveraging a dual Conformal Field Theory (CFT) approach, they examine the boundaries between regions of eternal expansion and those that do not. This paper delves into both supportive and critical perspectives on the multiverse theory, highlighting the mathematical foundations laid by experts like Alan Guth (Guth 2007) and addressing skepticism regarding the predictability and observational evidence of such models. While the theory remains speculative with no direct observational validation, it presents a compelling framework for exploring the origins and structure of our universe. This research aims to elucidate the ongoing debate, providing a comprehensive analysis of the theoretical underpinnings and implications of the multiverse hypothesis. I find that it is not unreasonable to defend and advance scientific analyses of it, despite no evidence to confirm or deny the theory.

1. INTRODUCTION

The multiverse Theory has emerged as a pivotal concept in theoretical physics and cosmology, proposing that our universe is just one of many that exist simultaneously. This idea, while initially speculative, has gained significant traction due to advancements in quantum mechanics, cosmic inflation theory, and string theory. The notion of a multiverse challenges our understanding of the cosmos and offers profound implications for the nature of reality, the origin of the universe, and the fundamental laws of physics.

A seminal contribution to this field is the work of the late Dr. Stephen Hawking and Dr. Thomas Hertog, who in their paper "A Smooth Exit from Eternal Inflation?", proposed that the transition from an eternally inflating universe is finite and smooth. This challenges the traditional concept of an infinite multiverse composed of isolated bubble universes. Their approach, which uses a dual Conformal Field Theory (CFT), provides a new perspective on the boundaries between regions of eternal expansion and those that do not (Hawking & Hertog 2018).

To understand their approach, it is important to define some key terms. A **dual** in scientific terms refers to a mathematical relationship between two theories that can describe the same phenomena from different perspectives (Atiyah 2007). In this case, a Conformal Field Theory (CFT) that is dual (mathematically equivalent) to an eternally inflating spacetime is used to describe the physics at the boundaries between an eternally inflating universe and regions where it is not.

Eternal Inflation refers to an aspect of the multiverse theory proposed by Guth (Guth 2007) and others that suggests that once a region of spacetime starts inflating, it rapidly out-expands the rest of the universe and continues to do so indefinitely in most areas. This exponentially increases the distance between pockets of no inflation, allowing for individual hot big bangs with no causal link between pockets (Siegel 2018).

Conformal Field Theory (CFT) is a type of quantum field theory that is invariant under conformal transformations, which are changes in the metric that preserve angles but not necessarily distances (Ginsparg 1988). This allows physicists to model complex systems and their boundaries in a highly symmetric way.

Cosmic Inflation is the theory that the universe underwent an exponential expansion in its earliest moments, solving several key problems in cosmology (HtUW 2014; deGrasse Tyson & Goldsmith 2004). Proposed by Alan Guth in the early 1980s, this theory addresses the horizon problem, the flatness problem, and the magnetic monopole problem. The horizon problem questions why different regions of the universe have the same temperature despite being causally disconnected. The flatness problem deals with why the universe appears geometrically flat, requiring precise initial conditions. The magnetic monopole problem involves the non-observation of predicted magnetic monopoles. Cosmic inflation garnered support by predicting observational characteristics, such as the nearly uniform Cosmic Microwave Background (CMB) Radiation (Partridge 2019) with slight anisotropies (i.e. variations across different directions), which are the seeds of all current structures in the universe. Measurements from satellites like COBE, WMAP, and Planck provided detailed maps of the CMB, revealing the general isoptropy as well as the predicted anisotropies (Torbet et al. 1999; Melchiorri et al. 2000; Hanany et al. 2000) and supporting the inflationary model. This framework explains the initial density perturbations that led to the formation of galaxies and cosmic structures, becoming a cornerstone of modern cosmology.

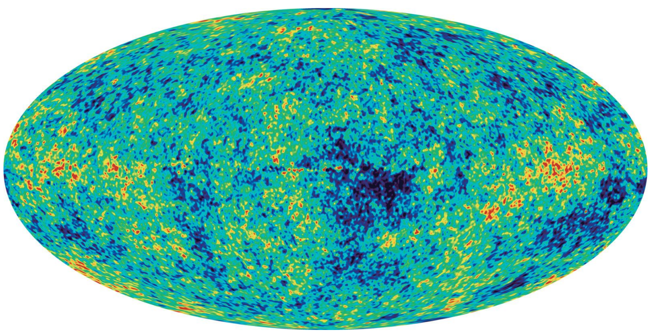

Figure 1. The Cosmic Microwave Background Radiation is the glow of the universe from the first translucent seconds of the universe.

Despite these advancements, the multiverse theory remains contentious. Key figures such as Alan Guth have provided strong mathematical foundations for the theory of eternal inflation from the theory of cosmic inflation, suggesting the existence of multiple universes as a natural consequence (Guth 2007). However, critics argue that the theory lacks predictability and observational evidence, raising questions about its scientific validity (Frank 2022). Skepticism also surrounds the reliance on unproven mathematical models and assumptions (Ellis 2011).

This paper aims to delve into the ongoing debate surrounding the multiverse hypothesis, providing a comprehensive analysis of both supportive and critical perspectives. We will examine the theoretical underpinnings laid by Hawking, Hertog, Guth, and others, while addressing the major criticisms and unresolved questions. By exploring these perspectives, this study seeks to elucidate the complexities of the multiverse theory and its implications for our understanding of the universe.

The paper is structured as follows: Section 2 provides a detailed background and theoretical framework, including an overview of cosmic inflation and CFT. Section 3 discusses these findings in the context of current research. Finally, Section 4 concludes with a summary of the key points

2. BACKGROUND AND THEORY

The concept of the multiverse has evolved significantly over the past few decades, becoming a central topic in theoretical physics and cosmology. The idea that our universe is just one of many has its roots in quantum mechanics, cosmic inflation, and string theory. This section provides a comprehensive overview of the theoretical background and key concepts that form the foundation of this study.

2.1. *Historical Development*

The notion of multiple universes can be traced back to the early 20th century with the development of quantum mechanics. The many-worlds interpretation was proposed by Hugh Everett in his PhD Thesis "Relative State Formulation of Quantum Mechanics" in 1957 (Everett 1957), and a detailed explanation was given in the 1973 book "The Theory of the Universal Wave Function", with contributions from Everett (Everett et al. 1973). This interpretation suggests that every quantum event branches into multiple, non-communicating parallel worlds. This idea laid the groundwork for later multiverse theories.

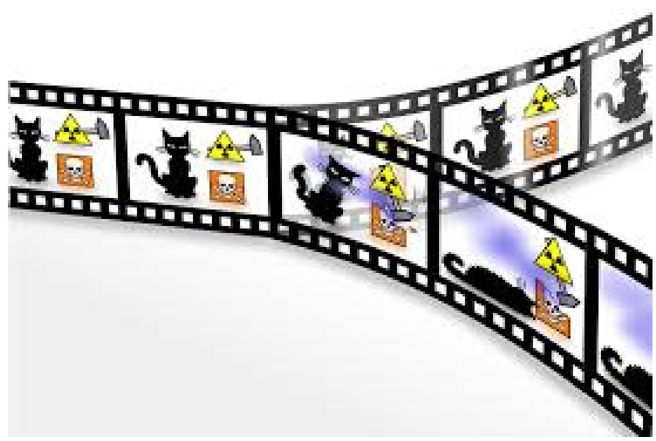

Figure 2. The Many Worlds Interpretation illustrates how a quantum event with multiple possible outcomes results in a branching of the universe, with each branch representing a different outcome.

In the 1980s, Alan Guth's theory of cosmic inflation revolutionized our understanding of the early universe. Guth proposed that the universe underwent a rapid exponential expansion shortly after the Big Bang, solving several key problems in cosmology, such as the horizon and flatness problems (Guth 1981). One implication of this theory is eternal inflation, where different regions of space inflate at different rates, creating multiple, causally disconnected bubble universes.

2.2. *Theoretical Framework*

A critical development in multiverse theory came with the work of Stephen Hawking and Thomas Hertog. In their paper, "A Smooth Exit from Eternal Inflation?" (Hawking & Hertog 2018), they proposed a new approach to understanding the boundaries of eternally inflating regions. By applying a dual CFT, they modeled these boundaries more accurately, suggesting that the transition from an eternally inflating universe could be finite and smooth, rather than resulting in isolated bubble universes.

The metric for an inflating universe can be described by the de Sitter metric (de Sitter 1917):

$$ds^2 = -dt^2 + e^{2Ht}(dx^2 + dy^2 + dz^2)$$

where H is the Hubble constant during inflation, describing the rate of expansion. The concept of duality implies that the behavior of this spacetime can be equivalently described by a lower-dimensional CFT. In this duality, the 4-dimensional de Sitter space, which describes an inflating universe, can be related to a 3-dimensional Conformal Field Theory. This means that the complex dynamics of an inflating universe can be translated into a CFT on a lower-dimensional boundary, making calculations more tractable. CFTs possess a high degree of symmetry, known as conformal symmetry, which preserves angles but not distances, allowing physicists to model these boundaries with greater precision.

Alan Guth's metric for cosmic inflation is similar to the de Sitter metric (Guth 1981):

$$ds^2 = -dt^2 + a(t)^2(dx^2 + dy^2 + dz^2)$$

where a(t) is the scale factor that describes how distances in the universe expand over time. During inflation, a(t) increases exponentially.

Hawking and Hertog used principles inspired by the AdS/CFT correspondence to relate the physics of 4-dimensional de Sitter space to a 3-dimensional CFT. They constructed a dual CFT to describe the boundaries of inflating regions, simplifying the complex dynamics of the universe's expansion. This dual CFT provided a framework to analyze the geometric and physical properties of these boundaries, using the stress-energy tensor to understand transitions. Their approach led to the prediction that the transition from an eternally inflating universe is smooth and finite, rather than abrupt and resulting in isolated bubble universes. This novel perspective suggests that the boundaries between inflating and non-inflating regions are more interconnected than previously thought.

2.3. *Literature Review*

Numerous studies have explored the implications of cosmic inflation and the multiverse hypothesis. For instance, Rüediger Vaas has provided a comprehensive review of multiverse scenarios, discussing their classification, causes, and the controversies surrounding them (Vaas 2010). Despite the robust theoretical framework, the multiverse hypothesis remains contentious.

The current understanding of the multiverse is primarily informed by quantum mechanics, cosmic inflation, and the work of key physicists like Stephen Hawking and Alan Guth. Recent advancements in these fields have provided new insights into the possible existence of multiple universes, with significant contributions from the study of eternal inflation and conformal field theory.

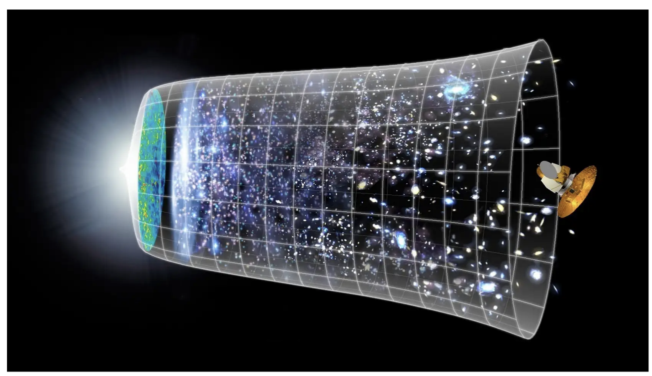

Figure 3. Alan Guth's Theory of Cosmic Inflation shaped much of the Multiverse Theory and the development of Cosmology

2.4. *Quantum Mechanics and the Multiverse*

Quantum mechanics also plays a crucial role in multiverse theories, particularly through the many-worlds interpretation. This idea laid the groundwork for later theories proposing the existence of a multiverse, where every possible outcome of a quantum event actually occurs in some universe.

3. DISCUSSION

The multiverse hypothesis remains one of the most intriguing and contentious topics in modern cosmology. Theoretical advancements have provided a robust framework for understanding the potential existence of multiple universes, yet empirical validation remains elusive.

Stephen Hawking and Thomas Hertog's work represents a significant theoretical advancement. However, it is important to note that this remains a mathematical model, with predictions that are yet to be empirically validated.

Similarly, Alan Guth's theory of cosmic inflation has laid the groundwork for the concept of eternal inflation, suggesting that our universe could be one of many that have arisen from an inflationary process. The mathematical foundations of this theory are robust, and it has successfully predicted several key features of our universe, such as the nearly uniform CMB radiation. Nonetheless, the leap from cosmic inflation to a multiverse is speculative and requires further theoretical and observational support.

Rüediger Vaas (Vaas 2010) provides a balanced perspective, noting that while the multiverse hypothesis is currently an open issue, it is not unreasonable to defend and advance scientific analyses of it. He suggests that, in principle, there are possibilities for both verifying the existence of other universes and theoretically embedding these claims within a broader scientific framework.

Given the current state of knowledge, it is essential to maintain a cautious yet open-minded approach to the multiverse hypothesis. Continued theoretical work, combined with advances in observational technology, may eventually provide more definitive answers. For now, the multiverse remains a compelling, albeit speculative, framework for exploring the nature of our universe and its origins.

4. CONCLUSIONS

The multiverse hypothesis offers a profound and challenging framework for understanding the nature of reality. Theoretical models, such as those proposed by Hawking and Hertog, and the foundations laid by Alan Guth, provide compelling mathematical frameworks for considering the existence of multiple universes. These models challenge traditional notions and push the boundaries of our understanding.

However, the multiverse hypothesis remains speculative, with no direct observational evidence to support its claims. Critics highlight the challenges in predictability and falsifiability, emphasizing the need for empirical validation.

As noted by Vaas, the multiverse hypothesis is an open issue, warranting further scientific analysis and exploration. Theoretical and observational advancements may eventually shed more light on this intriguing concept. For now, the multiverse remains a fascinating topic that stimulates both scientific and philosophical discussions, encouraging us to expand our horizons and question the nature of reality itself.

This paper has aimed to provide a balanced overview of the multiverse hypothesis, examining both supportive and critical perspectives. By exploring the theoretical underpinnings and ongoing debates, we hope to contribute to a deeper understanding of this complex and captivating topic. Future research, driven by both theoretical innovation and observational breakthroughs, will be crucial in advancing our knowledge and potentially validating the existence of a multiverse.

5. ACKNOWLEDGMENTS

I would like to thank Dr. Allison Kirkpatrick for her invaluable feedback on the format and content of this paper. Her insights and suggestions were instrumental in refining the structure and clarity of this research.

REFERENCES

Atiyah, M. 2007. https://fme.upc.edu/ca/arxius/butlleti-digital/riemann/071218_conferencia_atiyah-d_article.pdf

de Sitter, W. 1917, Proc. Kon. Ned. Acad. Wet., 20, 229. https://www.dwc.knaw.nl/DL/publications/PU00018547.pdf

deGrasse Tyson, N., & Goldsmith, D. 2004, Origins: Fourteen Billion Years of Cosmic Evolution (W. W. Norton & Co.), 84–85

Ellis, G. 2011, Scientific American, 305, 38, doi: 10.1038/scientificamerican0811-38

Everett, H. 1957, Reviews of Modern Physics, 29, 454, doi: 10.1103/RevModPhys.29.454

Everett, H., Wheeler, J. A., DeWitt, B. S., et al. 1973, The Many-Worlds Interpretation of Quantum Mechanics, ed. B. DeWitt & R. N. Graham, Princeton Series in Physics (Princeton, New Jersey: Princeton University Press)

Frank, A. 2022, Big Think. https://bigthink.com/13-8/multiverse-no-evidence/

Ginsparg, P. 1988, Applied Conformal Field Theory. https://arxiv.org/abs/hep-th/9108028

Guth, A. H. 1981, Phys. Rev. D, 23, 347, doi: 10.1103/PhysRevD.23.347

—. 2007, Journal of Physics A: Mathematical and Theoretical, 40, 6811–6826, doi: 10.1088/1751-8113/40/25/s25

Hanany, S., Ade, P., Balbi, A., et al. 2000, The Astrophysical Journal, 545, L5–L9, doi: 10.1086/317322

Hawking, S. W., & Hertog, T. 2018, Journal of High Energy Physics, 2018, doi: 10.1007/jhep04(2018)147

HtUW. 2014, How The Universe Works: First Second of the Big Bang, Discovery Science

Melchiorri, A., Ade, P. A. R., de Bernardis, P., et al. 2000, The Astrophysical Journal, 536, L63–L66, doi: 10.1086/312744

Partridge, R. B. 2019, in The Oxford Handbook of the History of Modern Cosmology, ed. H. Kragh & M. S. Longair (Oxford University Press), 292–345, doi: 10.1093/oxfordhb/9780198817666.013.8

Siegel, E. 2018, Big Think. https://bigthink.com/starts-with-a-bang/ i-am-an-astrophysicist-heres-what-stephen-hawkings-final-paper-was-

Torbet, E., Devlin, M. J., Dorwart, W. B., et al. 1999, The Astrophysical Journal, 521, L79–L82, doi: 10.1086/312197

Vaas, R. 2010, Multiverse Scenarios in Cosmology: Classification, Cause, Challenge, Controversy, and Criticism. https://arxiv.org/abs/1001.0726