# DETERMINATION OF THE SIZE AND GEOMETRY OF THE UNIVERSE

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

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# CERTIFICATION

This is to certify that this project work was carried out by **PAUL-UBAH TREASURE** with Matriculation Number **PSC2008386**, of the Department of Physics, Faculty of Physical Sciences, University of Benin, Benin City, Edo State, Nigeria.

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# DEDICATION

This project is dedicated to the people who have inspired, supported, and guided me throughout this journey.

To my family, for their unwavering love and encouragement. Your belief in me has been my greatest strength.

To my friends, for their endless support and for keeping me grounded.

To my mentor and educators, for their wisdom and guidance. Your insights have been invaluable.

And to every individual who has touched my life in profound ways, this work is a testament to your impact on my journey.

# ACKNOWLEDGEMENT

My sincere efforts have helped me to succeed in the task of completing this project. However, the completion of this project would not have been possible without the kind support and assistance of so many individuals.

I would like to express my heartfelt gratitude to my Project Supervisor, Prof. E.O. Aiyohuyin whose teaching, explanation, patience and encouragement made it possible to write this project through to completion.

I would also like to thank Ufuoma Precious Avworu for her friendship and teamwork during this project.

Besides, my parents, relatives, friends and others for all their unpaid labor and support who in one way or another assisted me morally, financially and physically

Most of all, to God Almighty, the giver of knowledge and wisdom, for his infinite love**.**

# ABSTRACT

On the research of Determining the size and geometry of the universe, we noticed some challenges. It is challenging to estimate the size and shape of the universe. Sheer scale means that light from distant areas has not had time to reach us, truncating observations. Further, the accelerating expansion due to dark energy complicates measurement. Dark matter, which is unseen, affects the universe's gravitational structure in a complex way. It is hard to measure distances due to enormous scales and the need for calibration. Observations rely on visible matter and radiation, so the picture is incomplete and uncertain.

In determining the size and geometry of the universe relies on important methods. Astronomers observe cosmic microwave background (CMB) radiation for data about its structure. They use large-scale structures like the distribution of galaxies to comprehend the universe's shape. Techniques like redshift surveys quantify the expanding universe through light from distant galaxies to determine distances and scale. Gravitational lensing, with deflection of light by massive bodies, indicates where visible and dark matter are. Combining these methods with theoretical models, scientists can develop a coherent picture of the universe's size and shape.

From integrating data from these diverse approaches, we were able to determine the value of the parameters for the scale factor of the universe (a), the curvature of space (k), Hubble's constant (H). I was able to calculate to get the value for the scale factor of the universe (a) to be $9 \times 10^{10}$ light years, and for the value for k which is the curvature of space, to be 1. When k is 1, the universe will be spherical. And also, for the value of the Hubble’s constant to be 69.8km/s/mpc.

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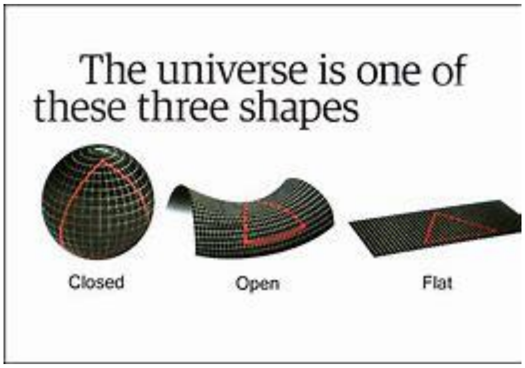
# CHAPTER ONE

# INTRODUCTION

The shape of the universe is quite an interesting topic in cosmology. There are different ways that scientists use to determine the geometry of the universe, which could either be flat, open, or closed. Among the important approaches is that of cosmic microwave background (CMB) radiation observation, which is the afterglow of the Big Bang. Scientists can use temperature fluctuations in CMB as a guide in determining general curvature and shape of the universe. The other way is the study of large-scale structures, like galaxies and galaxy clusters can be used to learn something about the geometry of the universe and how fast it's expanding. There is the critical density too, which describes the shape of the universe. If the actual density and the critical density are equal, then it is flat, if greater than the critical density, it is closed; otherwise, open. In general, the measurement of the shape of the universe includes observational data, theoretical models, and mathematical analysis in order to understand the huge structures that make it.



If the universe is flat, it has some intriguing implications for its structure and fate:

## 1.1 IMPLICATIONS OF A FLAT UNIVERSE

1. Geometry: A flat universe follows the rules of Euclidean geometry. This means parallel lines never meet, the angles of a triangle add up to 180 degrees, and the shortest path between two points is a straight line.

2. Infinite or Finite: While a flat universe could potentially be infinite in extent, it could also be finite if it has a more complex topology, such as a torus (doughnut shape).

3. Critical Density: A flat universe implies that the total density of matter and energy exactly equals the critical density needed to halt its expansion at an infinite time in the future. This delicate balance between expansion and gravity suggests a finely tuned cosmic structure.

4. Expansion: In a flat universe, the expansion rate slows down over time, but it never stops completely. The universe continues to expand forever, albeit at an ever-decreasing rate.

5. Cosmic Microwave Background (CMB): Observations of the CMB, specifically the temperature fluctuations, provide evidence supporting a flat universe. These fluctuations fit well with predictions from the inflationary Big Bang model in a flat universe.

6. Dark Energy: The discovery of dark energy, a mysterious force causing the accelerated expansion of the universe, fits within the flat universe model. Dark energy dominates the universe's energy density, driving its continued expansion.

## 1.2 FATE OF A FLAT UNIVERSE

In a flat universe, the future is shaped by its continuing expansion, influenced by dark energy. The "Big Freeze" scenario is the most likely outcome, where the universe keeps expanding, galaxies drift further apart, stars burn out, and temperatures drop to near absolute zero over incredibly long timescales.

This is a broad overview, and each of these points has fascinating complexities.

In a closed universe, the geometry is curved like a sphere. Here's what happens in a closed universe:

## 1.3 IMPLICATIONS OF A CLOSED UNIVERSE

1. Geometry: A closed universe follows spherical geometry. Parallel lines eventually converge, the angles of a triangle add up to more than 180 degrees, and the shortest distance between two points can curve around the sphere's surface.

2. Finite Space: A closed universe is finite in size but unbounded, meaning you could travel in a straight line and eventually end up back where you started, like traveling around the surface of the Earth.

3. Critical Density: The total density of matter and energy exceeds the critical density, causing the universe's expansion to eventually halt and reverse.

## 1.4 FATE OF A CLOSED UNIVERSE

1. Big Crunch: In a closed universe, gravity will eventually slow the expansion and cause the universe to contract. This leads to the "Big Crunch," where the universe collapses back into a hot, dense state similar to its initial conditions in the Big Bang.

2. Cyclic Models: Some theories suggest that the universe could undergo cycles of Big Bangs and Big Crunches, leading to an eternally repeating universe. This scenario contrasts with the current understanding, which suggests our universe is flat and dominated by dark energy, leading to continuous expansion.

In an open universe, the geometry is hyperbolic, and it has some distinct characteristics and implications:

## 1.5 IMPLICATIONS OF AN OPEN UNIVERSE

1. Geometry: An open universe follows hyperbolic geometry. Parallel lines diverge, the angles of a triangle add up to less than 180 degrees, and the surface has a saddle-shaped curvature.

2. Infinite Space: An open universe is infinite in extent. It has no bounds and continues to expand forever without looping back on itself.

3. Critical Density: The total density of matter and energy is less than the critical density, which means gravity is not strong enough to halt the universe's expansion.

## 1.6 FATE OF AN OPEN UNIVERSE

1. Eternal Expansion**:** In an open universe, the expansion will continue forever. The galaxies will drift farther apart, and the universe will grow colder and darker as stars burn out and new ones stop forming.

2. Big Freeze: Eventually, the universe could reach a state known as the "Big Freeze" or "Heat Death." In this scenario, all thermodynamic energy exchanges cease, leading to a universe that is uniformly cold and lifeless.

3. Dark Energy: If dark energy continues to influence the universe's expansion, it could lead to an accelerated rate of expansion, further ensuring that the universe becomes increasingly sparse and cold over time. While current evidence suggests that the universe is flat, these scenarios provide intriguing possibilities based on different curvatures.

## 1.7 ORIGIN OF THE UNIVERSE

One of the most important topics in science and philosophy is related to the origin of the universe. Here is an intensive discussion on this very interesting subject:

The Big Bang Theory

The Big Bang theory is the more acceptable hypothesis among scientists and researchers toward the origin of the universe. The proposition of this theory is that the universe came from an extremely hot and dense state around 13.8 billion years ago, and since that pivotal moment, it has been undergoing a continuous process of expansion, stretching outwards into the vastness of space.

Critical Evidence Probing the Big Bang Theory

1. Cosmic Microwave Background (CMB) Radiation

The Cosmic Microwave Background, abbreviated as the CMB, is a very faint but significant glow of radiation that is the residual heat leftover from the Big Bang event, which was a monumental occurrence in our universe's history, and this was discovered in the year 1965. This omnipresent radiation fills the vast expanse of the universe and is a valuable snapshot or glimpse into the early universe, specifically occurring roughly 380,000 years following the Big Bang event, at a time when the first atoms began to form and the universe changed into a state where it became transparent to different forms of radiation. The uniformity and slight fluctuations in the CMB give clues about the universe's initial conditions and its subsequent evolution.

2. Concept of Hubble's Law and the Phenomenon of Redshift

Great astronomer Edwin Hubble proved the observation that indeed the galaxies are moving away from our place in the universe, and their velocity is directly proportional to the distance that separates us from them. This situation is referred to as the redshift of light emanating from distant galaxies, and it is strong evidence for the expansion of the universe in reality. This important find comes as a strong support to the dominating concept where the universe, in its very early age, was much smaller in size, much hotter in temperature, and much denser in composition.

3. Abundance of Light Elements

Big Bang nucleosynthesis theory explains the distribution of light elements, like hydrogen, helium, and lithium, which were created within the first couple of minutes of the universe. The observations made about the cosmic abundances of these particular elements entirely agree with the established predictions beforehand, and therefore such provides a very significant and even strong confirmation of the very much widely accepted Big Bang theory.

## 1.8 ERAS OF THE EARLY UNIVERSE

1. Planck Epoch

At very early times, the universe was in a state in which it was characterized by an extremely high temperature and a density so high that it could hardly be compared to anything. All the four forces of nature- gravity, electromagnetic force, the strong nuclear force and the weak nuclear force- all were tightly bound together as one

2. Era of great unification

Gravity became distinct and separated from the other fundamental forces governing the universe. As this separation occurred, the universe expanded outward and at the same time cooled down.

3. Inflationary Epoch

Such a dramatic and very brief epoch of very rapid expansion of the universe was known as cosmic inflation. The extraordinary episode led to the smoothing out of the beginning inhomogeneities and continued to form the large-scale structure which we observe at present in our universe.

4. Quark Epoch

It had cooled to a point at which quarks and gluons are able to condense; it was these elementary particles that would eventually decay into protons and neutrons.

5**.** Hadron and Lepton Epochs

Nuclei were formed by protons and neutrons. The electrons were liberated, and a very hot and dense plasma was the result.

6. Photon Epoch

The universe continued to expand and cool when atoms were formed. The universe became transparent to radiation. That is when the CMB radiation was emitted.

Establishing and building structures:

1. Dark Ages

The universe went into the Dark Ages, as it is commonly known, after the emergence of the Cosmic Microwave Background referred to by many as the CMB. The most conspicuous characteristic of this period was the lack of stars or galaxies, as they had yet to make their appearance.

2. Reionization:

The first stars and galaxies started to form in the universe, sending brilliant radiation out through space to light and ionize the hydrogen gas that surrounded them. It was the end of the Dark Ages prior to their formation.

3. Galaxy formation process and evolution in time: Over billions of years, the force of gravity as one of the fundamental forces allowed clumping to emanate across matter. It then grew into stars, intricate galaxies, and more prominent objects that include groups called galaxy clusters and even bigger structures called superclusters.

## 1.9 ALTERNATIVE THEORIES ON THE ORIGIN OF THE UNIVERSE

Other theories have been proposed, although the Big Bang theory remains the dominant model

## 1.10 STEADY STATE THEORY

This is in contrast to the previous view of the universe, having no such definitive beginning or end but rather holding that the universe maintains some sort of mean average density as it continues to expand over time. However, this theory is largely discredited based upon various observations and empirical evidence gathered in the field of cosmology.

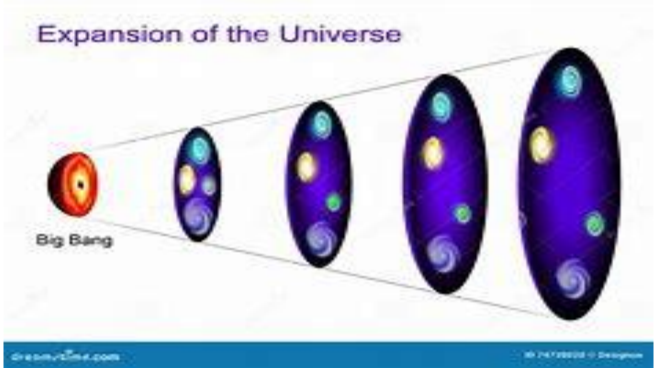
## 1.11 CYCLIC MODELS

These postulate that the universe undergoes some sort of cycle of periods of Big Bangs succeeded by Big Crunches.

Contemporary Knowledge and Directions for Future Research Modern cosmology is deeply involved in the quest to understand the origin and evolution of the universe, with a series of advanced technologies that help to execute this search. Among them are the Hubble Space Telescope and the James Webb Space Telescope, respectively capable of making access to the cosmic environment unprecedentedly deeper. Particle accelerators, such as the Large Hadron Collider, also play their part in understanding the primary constituents of matter and energy. Through these combined endeavors, scientists search for a better understanding of principles and concepts such as the appearance of the early universe, dark matter, dark energy, and the laws that govern its broad field.

## 1.12 PROPERTIES OF THE UNIVERSE

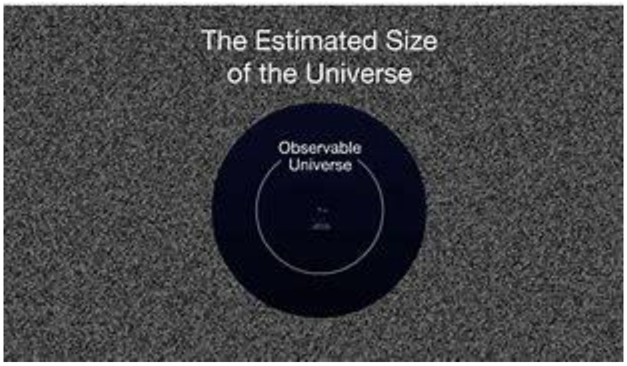
Here are a few basic facts about the universe:



## 1.13 EXPANSION

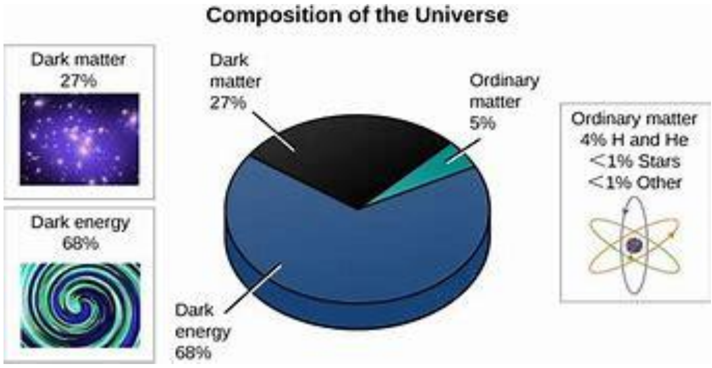
The universe is expanding. Galaxies are moving away from each other, and this expansion is noted by the redshift of light from distant galaxies. This expansion began with the Big Bang some 13.8 billion years ago.

## 1.14 AGE AND SIZE



The age of the universe is approximately 13.8 billion years. The radius of the observable universe is about 46 billion light-years, but the whole universe might be much bigger or possibly even infinite.

## 1.15 COMPOSITION



The whole, complex universe comprises a lot of diverse forms of matter and several kinds of energy.

1. Dark Energy: This makes up a large portion, about 68% of the entire universe, and is what dark energy is responsible for in terms of driving the accelerated expansion of the universe itself.

2. Dark Matter: Dark matter constitutes approximately 27% of the universe and responds to gravity but not electromagnetic radiation, making it invisible and only detectable through its gravitational effects3. Ordinary Matter: It has been calculated that a mere 5% of the whole universe consists of what we call ordinary matter, including, but not limited to, stars and planets. Everything which we can see and with which we interact and come into physical contact in our everyday lives.

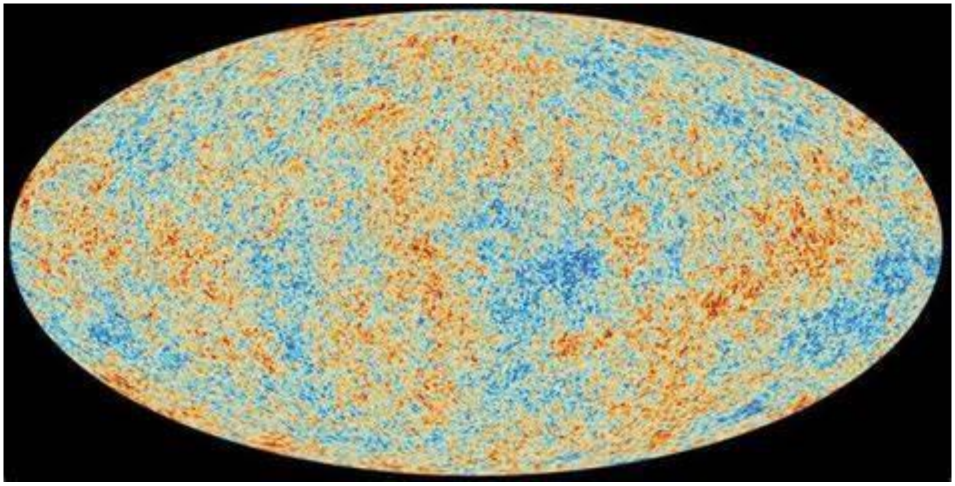
## 1.16 STRUCTURE

The universe features a big and intricate large-scale structure, which the following properties can describe:

1. Galaxies: Groups of stars, dust, and gas that are held together by gravity.
2. Galaxy Clusters: Groups of galaxies held together by gravity.
3. Superclusters: Enormous gatherings of galaxy clusters.
4. Cosmic Web: The large-scale organization of matter in the universe, which takes the

form of a web with filaments of galaxies and voids.

## 1.17 COSMIC MICROWAVE BACKGROUND (CMB)



The Cosmic Microwave Background, or simply CMB, is the thermal radiation left over from the Big Bang. It is a very faint, omnipresent radiation that fills the universe. This phenomenon is a wonderful snapshot, giving us a view of the universe when it was just 380,000 years old, while at the same time carrying very important data about its earliest state and overall constitution.

## 1.18 THE INTERACTION FORCES OF NATURE

The universe is governed by four fundamental forces:

1. Gravity: The force of attraction between masses.

2. Electromagnetic Force: This is the force that exists between two electrically charged particles.

3. Strong Nuclear Force: The force that holds atomic nuclei together.

4. Weak Nuclear Force: This force is primarily responsible for the radioactive decay that occurs in unstable atomic nuclei.

## 1.19 CURVATURE AND TOPOLOGY

Recent observations indicate that, on large scales, the universe appears to be flat in shape, suggesting that it obeys the laws of Euclidean geometry. However, the ultimate nature of its global topology—be it finite with a boundary or infinite, extending forever—remains an open question and a subject of utmost uncertainty and mystery.

## 1.20 LAWS OF PHYSICS

The whole universe is governed by a set of physical laws that are consistently uniform. They include the laws of conservation of energy and momentum, principles of relativity, and quantum mechanics. Cosmic Evolution; The universe is an evolving entity, and it has evolved to what it is today from a very hot and dense state over a course of billions of years. This complex process of evolution encompasses within its framework the formation of basic building blocks like atoms, the birth and growth of stars, galaxies, and even bigger cosmic structures. Moreover, the framework contains the life cycle of the stars with all the processes connected with their birth and death.

## 1.21 THE SIZE OF THE UNIVERSE

The vastness of the universe is surely among those concepts that are hardly believable and, at the same time, utterly astonishing in the field of cosmology. To understand this fantastic concept more thoroughly, let us work through it and break it down piece by piece.

## 1.22 OBSERVABLE UNIVERSE

Definition: The visible universe is all the matter and the energy we are able to see or detect from our home planet, Earth, aided by technology available to us at this current point in time.

Radius and Diameter:

Radius: The radius is estimated to be about 46 billion light-years.

Diameter: Estimated to be about 92 billion light-years. This huge distance includes all of the galaxies, billions of stars, and other forms of matter that we can observe from our vantage point in the universe.

Limitations:

Light speed: Since light travels at a finite speed, there is an absolute maximum to the distance we can see. The consequence of this is that when we view distant celestial objects or features of the universe, we do not view them as they are in the present moment but as they were sometime in the past.

Cosmic Horizon: The observable universe is bounded by the "cosmic horizon," outside which light hasn't had enough time to reach us since the Big Bang.

Beyond the Observable Universe

Total Universe:

This observable universe could be just an insignificant fraction of the whole universe.

Some postulates state that it can, indeed be infinite and unbounded in its dimensions.

Cosmic Inflation:

In the very early stages of the universe, immediately after the Big Bang itself, the universe expanded violently in an epoch known as inflation.

This rapid and rapidly accelerating expansion caused many different parts of the universe to shift themselves far past our observable horizon, outside our observing power

Implications Related to Shape and Size

Flat Universe:

The universe thus portrays itself with a geometry that is flat, as current measurements made imply that at large distances the universe obeys the theory of Euclidean geometry.

A flat universe is either unbounded in every direction as without boundary or may have a much more complex and sophisticated topology defining its geometry and architecture.

Curvature:

Positive Curvature: If the universe holds positive curvature, then it can be regarded as closed and at the same time finite in nature. This, in turn, can be visualized in a kind of three-dimensional illustration, as is the concept of the surface of a sphere.

It is an open universe, infinite in extent that looks like a saddle in shape, and curves away from each other.

Expansion and Future Size

Hubble's Law:

Galaxies have been receding from Earth, and this fact suggests that the speed they are moving with is directly proportional to the distance at which such galaxies happen to be from earth.

This observation strongly indicates that the universe is expanding uniformly throughout its vast expanse.

Rapid Growth

Observational evidence shows that the expansion of the universe is accelerating, because of dark energy.

Thus, what this suggests is that the edges or boundaries of the observable universe are to be extended to keep on spreading with time.

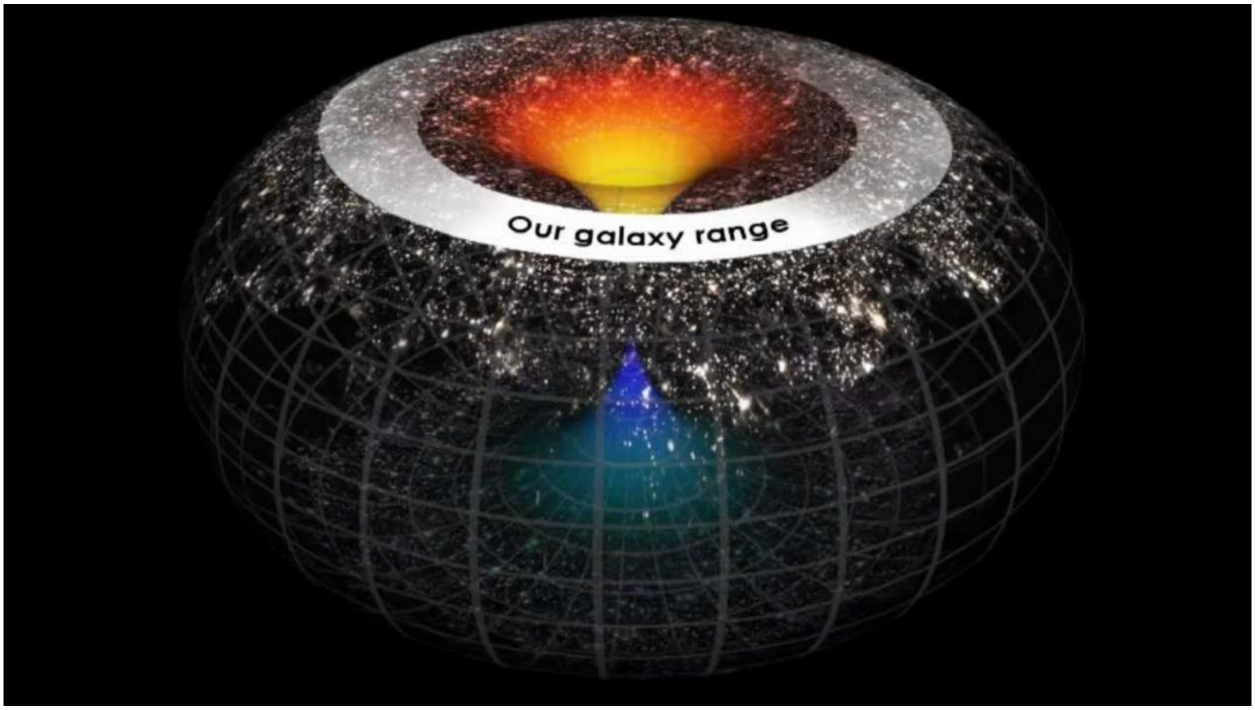
## 1.23 THEORETICAL PERSPECTIVES IN DEPTH

Multiverse Theory:

Various theories have advanced the rather intriguing possibility that our universe is but one in a set of universes often called a "multiverse". In this multiverse, each universe has the distinct characteristics and laws of physics that are substantially different from each other. Quantum Mechanics and Cosmology The principles of quantum mechanics, along with the all-encompassing framework provided by the theory of relativity, are necessary for a better perception of such an immense and complex universe.

Cosmic Models of Inflation: There are so many and varied models of cosmic inflation that indicate a pretty wide range of both size and shape that the universe can take; even models which predict infinite universes or even cyclic models that suggest a repeating cycle of cosmic events. Text Summary The visible universe, with a diameter of approximately 92 billion light-years, is only a small fraction of the whole universe, which may be much greater or even infinite in size. The universe expansion by dark energy maintains that our visible limits are steadily expanding and, therefore, growing with time to bring more of the vast cosmos into our view. The scale and magnitude of the universe are also big and ongoing topics of immense research and pioneering breakthroughs in the field of cosmology, always pushing the frontiers of both our knowledge and imagination further and further.

## 1.24 SHAPE OF THE UNIVERSE



The shape of the universe is one of the most intriguing questions in cosmology, with regards to understanding its curvature and topology.

Curvature of the Universe

1.POSITIVE CURVATURE (CLOSED UNIVERSE) SHAPE

It is said to be round in shape, like that of a perfectly smooth and continuous sphere.

Geometry: Parallel lines do eventually meet, and the sum of the angles of a triangle is greater than 180 degrees in this world.

Infinitely Small but Never Bounded: The universe is small in size, but it does not contain edges or borders. This interesting feature is such that if one could travel through the universe, then one would never reach a final boundary or limit of the universe.

### 1.NEGATIVE CURVATURE (OPEN UNIVERSE):

Shape: The shape is hyperbolic in nature, like that of a saddle.

Geometry: Parallel lines, in this universe, diverge and the angles of a triangle are added to be less than 180 degrees.

Infinite: The universe is of an infinite extent, and it will continue to expand without bounds for all time.

### 2. ZERO CURVATURE (FLAT UNIVERSE):

Form: Planar, that is Euclidean.

Geometry: Parallel lines are parallel and the sum of angles in a triangle is precisely 180 degrees.

Potentially Infinite: It is possible that a flat universe is infinite, or it could be finite but not in the manner expected, such as the topology could make it "bounded but infinite".

## EVIDENCE AND OBSERVATIONS

### 1. Cosmic Microwave Background (CMB):

Observations of the CMB tell us a lot about the curvature of the universe. Small-scale anisotropies, measured in extreme detail for the temperature fluctuations of CMB, indicates that the universe is very close to being flat.

### 2. Supernovae Observations:

Observations of the explosions that happen in distant supernovae are significant observations that will provide scientists and researchers with the rate at which the universe continues to accelerate with time. Observations also tend to provide support toward the predominant idea that the universe is flat-geometry.

3. Large-scale structures: The distribution patterns of galaxies together with the groups of galaxies comprise significant assistance for cosmologists in an attempt to

understand the universe in its entirety in terms of their curvature. In fact, at the large scale, there is an impression that these structures are compatible with the properties of a flat universe. This includes structure and arrangement of the topology of the universe.

## THE GLOBAL FRAMEWORK AND GEOGRAPHICAL SHAPE OF THE PLANET

Finite or Infinite: The curvature of the universe may provide very important information regarding the global shape as well as the global configuration, but it is the topology, which explains more about the general structure and arrangement of the universe. As a fascinating fact, even a space that may appear flat can have a rich, multi-layered topology-a simplicity within complexity.

Multiple Connectedness: A flat universe would have a topology that might be such that you went one way and you came out to where you started again. A lot like a video game map, you go right and then turn right again, instead finishing on the left.

Possible Models: Torus: in the case of a flat universe with toroidal topology, it would imply that if one went in a straight line, then sooner or later this path would bring that person back to where the person started that journey.

More general, less symmetrical shapes: the universe may well have a whole range of more complicated topologies than are dreamt of in our philosophy, which we, as mortals, have never seen or can't hope to fully appreciate. Modern Knowledge From all the current observations that have been collected and tabulated, the universe would seem to have flat geometry; with this estimate in place, however, one should recognize the error margins. The implications give off the look that while moving to the biggest scales, on the whole, it follows Euclidean geometry because of its outline of known shapes and relations, but the real topography whether the universe is infinitely extended in all directions or has finite-scale yet unbounded, the physics of the universe is still only part of active study and research at the hands of scientists in the field. To go deeper and analyze these really very complex thoughts and ideas, employing highly refined measurements and such advanced theories is necessary, but the effort results in a much more thorough and detailed image of the immense and vast cosmos we live in.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

The aim of this literature survey is to holistically synthesize all important research findings coupled with various theories associated with the origin of the universe. It encompasses seminal works that have initially defined and shaped the current level of understanding, recent developments of the field concerned, and also points out debates that are still continued within the domain of cosmology.

1. The Big Bang Theory Simon Singh, "The Big Bang" (2004): Provides a broad and detailed chronicle with a deep explanation of the Big Bang theory, its origins, and what it meant to the interpretation of the universe. Presents in some detail the contributions and significant roles of key scientists who were directly influential in the development and formulation of this important scientific theory. Stephen Hawking, "A Brief History of Time" (1988): Explores and discusses a number of very fundamental and profound questions that arise concerning the universe and its creation, evolution, and general structure. Introduces and discusses interesting ideas like black holes and time itself having a rather complex nature.

2. Cosmic Microwave Background Radiation (CMB) Penzias and Wilson, "A Measurement of Excess Antenna Temperature at 4080 Mc/s"(1965): A discovery of the Cosmic Microwave Background Radiation, which constitutes very strong evidence supporting the Big Bang theory. Planck Collaboration, "Planck 2018 Results"(2018): A set of thorough and precise measurements testing the fluctuations in the temperature of the Cosmic Microwave Background Radiation. These data are in significant agreement with the inflationary Big Bang model and provide great insight into the nature and composition of the universe at large.

3. Cosmic Inflation Alan Guth, "Inflationary Universe" (1981): This paper represents the beginning of the inflation revolution, hypothesized to explain the homogeneous nature of the universe over long distances. Liddle and Lyth, "Cosmological Inflation and Large-Scale Structure" (2000): The paper published a thorough and intricate overview of several models of inflation and went on to make far-reaching implications for the structure of the universe.

4. Dark Matter and Dark Energy Fritz Zwicky, "Die Rotverschiebung von Extragalaktischen Nebeln" (1933): The first observations and initial evidence that indicated that there had to be dark matter were based on in-depth galaxy cluster

observations that he did. Riess et al. "Observational Evidence from Supernovae for an Accelerating Universe and a Cosmological Constant" (1998): Their groundbreaking finding shed light on the phenomenon of accelerated expansion of the universe which showed the presence of dark energy as the main contributor to cosmic dynamics with very strong evidence.

5. Alternative Theories Fred Hoyle, "The Steady State Theory" (1948): In this theory, it is portrayed that matter is always continuously created. These processes lead to a given, fixed density of the universe over time, as it expands. Paul Steinhardt and Neil Turok, "Endless Universe" (2007): This was a detailed exposition on the cyclic models of the universe which purported that there are repetitive phases of expansion and contraction at periodic intervals. Conclusion Yet, as has been gathered from the literature review, the current level of understanding with regard to many of the most prevalent theories and a great deal of evidence that exists with regards to the beginning of the universe itself has been thoroughly and complexly described. Although it is true that the Big Bang theory continues to enjoy the distinction of being the most widely accepted model in the field, the constant and unrelenting research aimed at dark matter, dark energy, and a host of alternative theories continues to try to further delineate and improve our knowledge about the great and complicated universe.

## 2.1 AIM AND OBJECTIVES

### AIM

The aim of this work is to find out the size and geometry of the universe whether it’s flat, open or closed.

### OBJECTIVES

The main objectives of this work, is to;

1. To determine the value of H (Hubble's constant).
2. To determine the value for mass density.
3. To determine the value of energy density.
4. To determine the curvature of space (K).
5. To determine the value of the scale factor (a) of the universe.
6. To determine the radiation energy density.

# CHAPTER THREE

## 3.0 METHODOLOGY

Introduction to the Methodology for Measuring the Universe.

The enormity and complexity of the universe require that a vast multidisciplinary approach be employed in the quest to understand its extent, form, constitution, and temporal evolution. The method that has been developed for measuring the universe is an effective combination of various techniques of observation, well-established models of theory, empirical data from experiments, and intelligent analysis with the help of appropriate tools. Here follows a critical look at the key methodologies that have been involved in this area of study. By incorporating approaches in a well-thought manner, such as observational, theoretical, experimental, and analytical methodologies, it would, therefore, be possible for any scientist to build a complete, elaborate, and exact picture of the enormous universe. These different methods have enabled the uncovering of some fundamental secrets of the cosmos about its origin, structure, and the ultimate fate and future of the universe. We'll be working more with Big Bang Cosmology because, it provides a spectacularly successful description of our universe which is supported by three main observational pillars, which are;

1. The uniform expansion of the universe,

2. The abundances of the light elements,

3. The highly uniform background of microwave radiation. A simple explanation for this observation is that the space between the galaxies is expanding isotropically. Such a homogeneous and isotropic expansion can be characterized by an overall scale factor a(t) that depends only on time.

As the universe expands, the wavelength λ of freely propagating light is stretched so that

$$\lambda(t_0) = \lambda(t)\frac{a(t_0)}{a(t)} \text{ .............. } (1)$$

Where $t_0$ denotes the present time and t denotes the time when the light was emitted.

From equation (1), we can relate the redshift to the size of the universe

$$z = \frac{\lambda(t_0) - \lambda(t)}{\lambda(t)} \text{ .............. (2)}$$

Since we expect atoms to behave the same way in the past, we can use atomic spectra measured on Earth to fix $\lambda(t)$. From equation (1), we can relate the redshift to the size of the universe

$$a = \frac{a_0}{(1+z)} \text{ .............. (3)}$$

We adopted a standard shorthand;

$$a_0 = a_0(t_0), a = a(t), \lambda_0 = \lambda(t_0), \lambda = \lambda(t).$$

By measuring the redshift, we can deduce the size of the universe when Light was given out. The relative size of the universe provides us with a natural time in Cosmology: astronomers use redshift z as Units of time: z = 0 today, z = ∞ at the big bang cosmology because the redshift is a measurable quantity, unlike time t. A photon's energy E varies inversely with its wavelength λ. A photon gas at temperature T contains photons of energies within a narrow band centered at an energy E proportional to the temperature.

Thus, $T \sim E \sim \lambda^{-1}$,

Mathematically,

$T \propto E \propto \lambda^{-1}$

The temperature of the photon gas now evolves as;

$$\frac{T}{T_0} = \frac{E}{E_0} = \frac{\lambda_0}{\lambda} = \frac{a_0}{a} = 1 + z \text{ .............. (4)}$$

This equation tells us that the universe should have been much hotter in the past than it is today. If no particles are created or destroyed, the density of ordinary matter is inversely proportional to the occupied volume, so it scales as $\rho m \sim \alpha^{-}3$. If no photons are created or destroyed, the number of photons per unit volume also scales as α . However, the energy of each photon is decreasing in −3 accordance with equation (4), so that the energy density of the photon gas scales as ργ ~α . As the universe expands, the temperature drops. Within the first −4 minute the temperature drops to

109 ◦K, and the neutrons and protons begin to fuse together to produce the nuclei of the light element's deuterium, helium, and lithium. In order to produce the abundances seen today, the nucleon density must have been roughly 10 . Today we observe a nucleon density of $\sim$ 18 $cm$ −3 10 −6 $cm$ −3 which tells us the universe has expanded by a factor of roughly (10 / ) 1/3 = 18 10 −6 10 .Using equation (4), we therefore expect the photon gas today to be at a temperature of roughly 10◦K. George Gamow made this back-of-the-envelope prediction in 1946. In 1965 Penzias and Wilson discovered a highly uniform background of cosmic microwave radiation at a temperature of $\sim$ 3◦ K. This cosmic microwave background (CMB) is quite literally the afterglow of the big bang. More refined nucleosynthesis calculations predict a photon temperature of $\sim$ 3◦K, and more refined measurements of the CMB reveal it to have a black body spectrum at a temperature of $T_0 = 2.728 \pm 0.010$ ◦K. Typical cosmic microwave photons have wavelengths roughly equal to the size of the letters on this page. The metric on the spacelike slice Σ(t) at time t is given by the scale factor a(t) times the standard metric of constant curvature k = +1, 0, −1. The sectional curvature is k/a($t$) , so when |k| = 1, the scale factor a(t) is the curvature radius; 2 when k = 0, the scale factor remains arbitrary. The function a(t) describes the evolution of the universe.

$$(\frac{\dot{a}}{a})^2 = \frac{k}{a^2} = \frac{8\pi G}{3}\rho \text{ .............. (5)}$$

Here G is Newton's gravitational constant, ρ is the mass-energy density, α= da/dt; and we have chosen units that make the speed of light c = 1. The first term in equation (5) is the Hubble parameter $H = \frac{\dot{a}}{a}$ which tells how fast the universe is expanding or contracting. More precisely, it tells the fractional rate of change of cosmic distances. Its current value $H$ , called the Hubble constant, is about 73.8 0 km/sec/Mpc, with an uncertainty of about 2.4 km/sec/Mpc. Different methods of measurement have yielded slightly varying values, but this is one of the most precise measurements available. Thus, for example, the distance to a galaxy 100 Mpc away would be increasing at about 6,500 km/sec, while the distance to a galaxy 200 Mpc away would be increasing at about 13,000 km/sec. Substituting $H = \frac{\dot{a}}{a}$ into equation (5) shows that when k = 0, the mass-energy density ρ must be exactly 3H2/8πG. Similarly, when k = +1 (resp. k = −1), the mass-energy density ρ must be greater than (resp. less than) 3$H$ /8πG. Thus, if we can measure the current density and $\rho_0$ the Hubble constant $H$ with sufficient precision, we can deduce the sign k of the curvature. Indeed, if k = 0, we can solve for the curvature radius.

k = $H^2a^2(\Omega - 1)$ …………… (6)

From equation (6) we derive $a$ to be;

$$a^2 = \frac{k}{H^2(\Omega - 1)}$$

$a = \frac{1}{H}\sqrt{\frac{k}{(\Omega - 1)}}$ if k ≠ 0 …………… (7)

where the density parameter $\Omega$ is the dimensionless ratio of the actual density ρ to the critical density ρ = 3 /8πG. The universe contains different forms of mass energy, each of which contributes to the total density:

$\Omega = \frac{\rho}{\rho_c} = \frac{\rho_\gamma + \rho_m + \rho_\Lambda}{\rho_c} = \Omega_\gamma + \Omega_m + \Omega_\Lambda$ …………… (8)

$\rho_\gamma$ is the energy density in radiation

$\rho_m$ is the energy density in matter

$\rho_\Lambda$ is a possible vacuum energy

The red shifts of galaxies measure that in every direction, these galaxies are proceeding away from Earth. The expansion becomes understandable with Hubble's law. Hubble constant is a constant of proportionality in the relation between the velocities of remote galaxies and their distances. It expresses the rate at which the universe is expanding. It is denoted by the symbol H. The first value for $H$ estimated by Hubble was 500 km (3110 miles) per second per megaparsec (one megaparsec equals 3,260,000 light-years). Modern estimates, based on the distance to the cosmic microwave background radiation left over from the big bang place the value of H at about 69.8km/second/megaparsec. The density parameter Ω is defined as the ratio between the actual (or observed) density ρ and the critical density ρ of the universe. The relation between the actual $c$ density and the critical density determines the overall geometry of the universe; when they are equal, the geometry of the universe is flat-that is, Euclidean. In the previous models, without a term for a cosmological constant, critical density was understood to be the watershed point between an expanding and a contracting Universe. Amazingly, studies of the rate of expansion have determined that the universe's density is amazingly close to the critical density that would allow it to expand indefinitely. $\Omega m$ is the mass density. The WMAP (Wilkinson Microwave Anisotropy Probe, a space mission, launched by NASA in the year 2001 for measuring the temperature fluctuation across the sky in CMB radiation) estimated the mass density at the present time as $\Omega m= 0.27 \pm 0.04$. However, the estimate of ordinary or baryonic matter was only 0.044 ± 0.004 and hence baryonic matter accounts for only 17% of matter of the universe, the rest being labeled as “dark matter”. WMAP estimates this equivalent mass density of the relativistic particles, consisting of electromagnetic energy and neutrinos, as given by $\Omega\gamma$= 8.24 x10 . −5 The consequence of this is that, as far as the balance with mass is concerned, mass strongly dominates over radiation in the present epoch. In the early universe, radiation was dominant over both matter and dark energy. $\Omega\Lambda$ is the fraction of the effective mass of the universe that is attributed to "dark energy" or the cosmological constant, is equal to 0.73 ± 0.04. For the fact that this form of dark energy now dominates 73% of the influence on the expansion of the universe at this stage, it is considered to be the leading influence of such expansion. This past history of the big bang is perceived to be at first radiation dominated, then matter dominated, and now having passed into the era where dark energy is the dominant influence.

# CHAPTER FOUR

## 4.0 CALCULATIONS, RESULTS AND DISCUSSION

The Hubble constant (H) = 69.8 km/s/mpc

The Wilkinson Microwave Anisotropy Probe (WMAP) estimated the mass density $\Omega_m$, mass density of the relativistic particles $\Omega_\gamma$, mass of the universe that is attributed to dark energy $\Omega_\Lambda$ as:

$\Omega_m = 0.27 \pm 0.04$

$\Omega_\gamma = 8.24 \text{x} 10^{-5}$

$\Omega_\Lambda = 0.73 \pm 0.04$

The Density Parameters ($\Omega$) = $\Omega_\gamma + \Omega_m + \Omega_\Lambda$

($\Omega$) = 1.02 ± 0.02{Carroll and Ostile (2007)}

Indicating that the universe is very close to critical density or $\Omega = 1$.

Calculating for $a$ when k = 1 and when k = -1

Case 1a: when k = 1, and $\Omega = 1.02$

$$a = \frac{1}{H}\sqrt{\frac{k}{(\Omega - 1)}}$$

$$a = \frac{1}{69.8}\sqrt{\frac{1}{(1.02 - 1)}}$$

$a = 0.101305 \text{ (km/s/mpc)}$

Converting the unit to light years

$0.101305(\mathrm{km/s/mpc})^{-1}$

$0.101305\ ((\frac{km}{sec} \times \frac{1}{mpc})^{-1}$

1mpc = $30.86 \times 10^{18}$km

$$\frac{0.101305\,\mathrm{sec} \times mpc}{km}$$

$$\frac{0.101305\ \ \mathrm{sec}\times 30.86\ \times\ 10^{18} km}{km}$$

= $3.126\times 10^{18} secs$

But,

31557600 secs = 1 light year

Therefore,

$a = 9\times 10^{10}$ light years.

Case 2a: when k = -1, and Ω = 1.02

$$a = \frac{1}{69.8}\sqrt{\frac{-1}{(1.02-1)}}$$

$$a = \frac{1}{69.8}\sqrt{\frac{-1}{(1.02-1)}}$$

$a = 0.101305i$ km/s/mpc

The value for a when k is -1 is a complex number hence the value is not physical.

In summary, the scale factor ($a$) represents how the size of the universe changes over time. It increases as the universe expands, and is normalized to 1 at the present time. It plays a fundamental role in cosmological models, providing a measure of the expansion history of the universe.

Also, in cosmology and general relativity, the symbol $k$ represents the curvature of space in the context of the geometry of the universe. It is a parameter that tells us whether the universe is flat, positively curved (spherical), or negatively curved (hyperbolic), based on how the space behaves on large scales. The value of $k$ is one of the parameters that appears in the Friedmann–Lemaitre–Robertson–Walker (FLRW) metric, which can take three possible values $k=0$: Flat universe – The geometry of space is flat.

$k=+1$: Positively curved (spherical) universe.

$k=-1$: Negatively curved (hyperbolic) universe.

## CHAPTER FIVE

## FINDINGS, CONTRIBUTION TO KNOWLEDGE, SUGGESTION FOR FURTHER STUDIES

### 5.0 FINDINGS

The following are the findings of this work

1.The scale factor of the universe, $a$ has value $a = 9 \times 10^{10}$ light years.

2.The curvature of space, k having universal values of +1, 0 and -1, indicating a spherical, flat and hyperbolic universe respectively.

3.The value of the Hubble's constant (H) = 69.8 km/s/mpc, implies that for every 1 megaparsec of distance, galaxies are moving away from us (due to the expansion of the universe) at a velocity of 69.8 km/s.

4.According to Friedmann equations, when $\Omega=1$, the universe is said to be flat. From my research the total energy density of the universe is found to be $1.02\pm0.02$, which suggests that the total universe's energy density is slightly above the critical density by about 2%. And since the value is very close to 1, indicating that the universe is nearly flat. The small deviation (0.02) is within the error margin, suggesting that the universe's geometry is effectively flat. The vacuum energy density is $0.73 \pm 0.04$ . The radiation energy density is $8.24\text{x}10^{-5}$. The mass energy density is $0.27 \pm 0.04$

### 5.1 CONTRIBUTION TO KNOWLEDGE

The scale factor which is from our calculation, is a fundamental concept that has significantly advanced our understanding of the universe's expansion and its history. By studying the scale factor, scientists can gain insights into the composition, dynamics, and ultimate fate of the universe. It is a dimensionless parameter that describes how the size of the universe changes with time. The scale factor is often denoted by a(t), where t represents time.

## 5.2 CONCLUSION

Research on the measurement of the universe has significantly advanced our understanding of its structure, size, and evolution. The project, therefore, concluded from its calculation that the universe is spherical and its curvature of radius is ninety-nine billion light years. Measuring the universe-whether it is flat, spherical, or hyperbola-is very critical in understanding its overall shape, evolution, and fate.

## 5.3 SUGGESTION FOR FURTHER STUDIES

A potential direction for further study would be to devise a more accurate method for computing the Energy density. To improve the accuracy of measuring the energy density, and achieve a greater precision.

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