UNIVERSITY OF NAIROBI

THE EXPANDING UNIVERSE TROUBLE

BY

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I56/34450/2019

A Thesis Submitted for Examination in Partial Fulfillment of the Requirements for Award of the Degree of Master of Science in Physics of the University of Nairobi

JUNE, 2021

DECLARATION

I declare that this research project is my original work and has not been submitted elsewhere for research. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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LIST OF ABBREVIATIONS

CAMB - Code of Anisotropies in Microwave Background

CMB - Cosmic Microwave Background Radiation

FLRW - Friedman-Lemaitre-Robertson-Walker

H (z) - Hubble parameter

H_0 - Hubble Constant

H0LiCOW - H_0 Lenses in COSMOGRAIL's Wellspring

Mpc - Mega parsecs

SH0ES - Supernovae H_0 of the Equation of State

SNeIa - Type 1a Supernova

TRGB - Tip of the Red Giant Branch

WMAP - Wilkinson Microwave Anisotropy Probe

ΛCDM - Lambda Cold Dark Matter

Ω_0 - Energy Density

ABSTRACT

The Lambda Cold Dark Matter model (ΛCDM) is the current standard model of cosmology, which specifies the evolution of the observable Universe. Since the early 20th Century, astronomers have been aware that the Universe is expanding, but towards the end of this century, cosmologists noted that this expansion is accelerating possibly due to an antigravity force called the dark energy. The nature and the source of dark energy remains a major unsolved problem in modern astronomy that requires resolution. The expansion rate of the Universe or (Hubble constant) gives us the history of our Universe from singularity to the present time and on in the future. There exist different methods of Hubble measurement, with each giving different results for the expansion rate of the Universe. The ongoing research is aimed at gaining insight into the different methods of measuring the Hubble expansion with an objective to settle the raging controversy in different Hubble values. In this research project, the objectives were: to study how cosmological theories, explain the expanding Universe, to understand the idea of nature, history, and the end of the Universe, to explore the historical beginning of the Universe and to evaluate the expansion rate of the Universe. It was found out that measuring the expansion rate, i.e., Hubble constant aids in determining the age of the universe calculated. However, earlier estimates of the expansion by Edwin Hubble's suggested that the Earth and the Sun were older than the universe. Hubble, therefore, concluded that the redshift phenomenon was an unknown property of space and not a measurement of true space velocity. Astronomers later realized that redshift was a consequence of the expansion of space itself, as predicted in Einstein's theory of special relativity. The study proposes that more studies should be conducted to resolve the problem of the nature and the source of dark energy.

CHAPTER 1: INTRODUCTION

1.1 Research Background

The Universe is a whole cosmic system of matter, energy, space, time and their parts including Planets, Stars, and Galaxies, the earliest cosmological model of our Universe were succeeded by Greek and Indian philosophers and were geocentric allocating the Earth at the center. Latter studies upgraded that the Sun is one of the thousands of millions of Stars in the Milk way Galaxy which is one of two trillion Galaxies in the Universe. Since the early 20th Century, astronomers have been aware that the universe is expanding. Towards the final part of the same century, cosmologists end up that this expansion is accelerating. Modern cosmology clarifies the evolution and structure formation of the Universe which is beginning from the singularity up to the current time using the composition and physical laws of the universe. Possibilities of the Universe: flat, open, and closed Universes:

$\Omega_0 < 1$ Defines an open Universe.

Ω_0 is greater than one when the Universe is closed.

Ω_0 is equal to one for the flat case.

The Universe is expanding meaning that, from the history of the early universe the distance between far away Galaxies and us was less than as it is currently; the expansion rate tells us how quickly the Universe is expanding and galaxies are moving away from each other. In 1929 when the present value of the Hubble constant retreated to the Big Bang peculiarity suggested that the Universe be smaller than the age approximated for the Sun and the Earth. The convectional cosmological model named ΛCDM (Lambda Cold Dark Matter) designates a broad scope of aspects including accelerating growth, earliest nucleosynthesis, structure formation, the space-time of flat geometry, variations of Big Bang as well as the initial blend of atoms and baryons. The dark elements that are, dark energy and dark matter accounts for 95 % of our Universe, as reported at Lambda Cold Dark Matter. According to luminosity Supernovae get to 100 million solar luminosities, although this can happen only once in a century to a particular Galaxy.

In the last two decades, the measured Hubble constant H0 value has continuously remained as low as the 70s in which the first-rate value of SH0ES's project was about H0 = 73.5±1.4kms-1Mpc-1 (Riess 2019). The evaluation of independent local of Hubble constant originates from Hubble constant lenses in H0LiCOW (COSMOGRAIL's Wellspring) group, that previous evaluating the time slows down between several images of background quasars to coerce the distinct image direction lengths generated at powerful gravitational lensing coming from foreground galaxy, to yield H_0=73.3±1.8kms-1Mpc-1 (Wong K. C. et al. H0LiCOW XIII. 2019) with a seventh originating from a distinct group (Riess 2019).

Strong-lensing insights into dark energy survey of strong lensing insights STRIDES gives H_0 = 74.2 ± 3.0 kms−1Mpc^{-1} (Riess 2019).

The Red Giant Stars have yielded $H_0 = 69.8 \pm 1.9 kms^{-1}Mpc^{-1}$ and $H_0 = 72.4 \pm 1.9 kms^{-1}Mpc^{-1}$ together with the adjust between ground-based photometry and HST (Riess 2019).

Miras are varying, Red Giant Stars newly pushed into use to evaluate Hubble constant as a scan for two of them TRGB and Cepheids and gets $\mathrm{H_0} = 73.3 \pm 3.9\ \mathrm{kms^{-1}Mpc^{-1}}$ by use of new HST monitoring together with the earlier mentioned discussion about geometric distances. The other two upgrades to the local evaluations of Hubble constant originate from water masers in four Galaxies at pronounced distances $\mathrm{H_0} = 74.8 \pm 3.1\ \mathrm{kms^{-1}Mpc^{-1}}$ together with using a technique referred to as Surface Brightness Fluctuations $\mathrm{H_0} = 76.5 \pm 4.0\ \mathrm{kms^{-1}Mpc^{-1}}$ (Riess 2019).It is informing us that all current and local evaluations run over the early Universe estimation. Hence, the interpretation that the rigidity together with the early time Universe forecast is greatly important and not simply accredited to an error in any group, one technique, or tool. Fresh evaluations from the local Universe by use from the early Universe and gravitational lensing by use of ground-based Cosmic Microwave Background polarization are most predicted to weigh on top of the coming several years and can lay out fresh perceptions.

1.2 Problem Statement

In the early 20th Century, astronomers have been aware that the Universe is continuously expanding, towards the end of this century cosmologists agreed that this expansion is accelerating; dark energy (the force that causes the expansion) is something that scientists do not understand. There are different methods of Hubble measurement those measurements give different results for the expansion rate of the Universe, as researchers have extended to work on these varied methods of measuring Universe expansion, the results were brought have become more and more accurate and they remain incomplete and totally in disagreement with one another. The problem has come to be introduced by researchers as the 'Hubble tension' how can both values be right and yet still not a similar value?

1.3 Research Objectives

1.3.1 Main Objective

The main objective of this research work is to understand more so-called the expanding Universe trouble.

1.3.2 Specific Objectives

The specific objectives of this research work are:

i. To study how cosmological theories, explain the expanding Universe.
ii. To understand the idea of nature, history, and the end of the Universe.
iii. To explore the historical beginning of the Universe
iv. To evaluate the expansion rate of the Universe

1.4 Research Significance and Justification

The Universe is continuously expanding, and that expansion is accelerating but we don't know exactly how quickly. There are two main groups of data that we apply to approximate this key number evaluation of CMB and measurements done locally. The amount at which the Universe is expanding is illustrated by a number named Hubble constant, the expansion of the Universe or expansion rate (Hubble constant) gives us the history of our Universe from singularity to the present time and on in the future.

CHAPTER 2: LITERATURE REVIEW

2.1 Big Bang Theory

The Big Bang model accounts for how the Universe came into existence and how it has been evolving ever since. The theory suggests that the birth of the Universe occurred around 13.7 billion years back. It originated from an extremely dense and hot state a point referred to as singularity. Little is known about this instant, the physics we know breaks down at this point for example there was no space, time, energy or matter. This was followed by an expansion at an incredible rate then matter, energy, space and time came into being.

As the expansion proceeded, matter began to interact gravitationally forming gas clouds and this led to the birth of Stars and Planets. Scientists argue that this expansion is finite and will come to a halt one day. It is hypothesized that the Universe will then collapse into a Big Crunch. The Universe then cooled adequately permitting the formation of subatomic particles, such as photons, electrons, protons and neutrons**.** Within the first three minutes, simple atomic nuclei had formed however electrically neutral atoms formed thousands of years later. Atoms of lighter elements then formed mainly hydrogen, along with helium and traces of lithium.

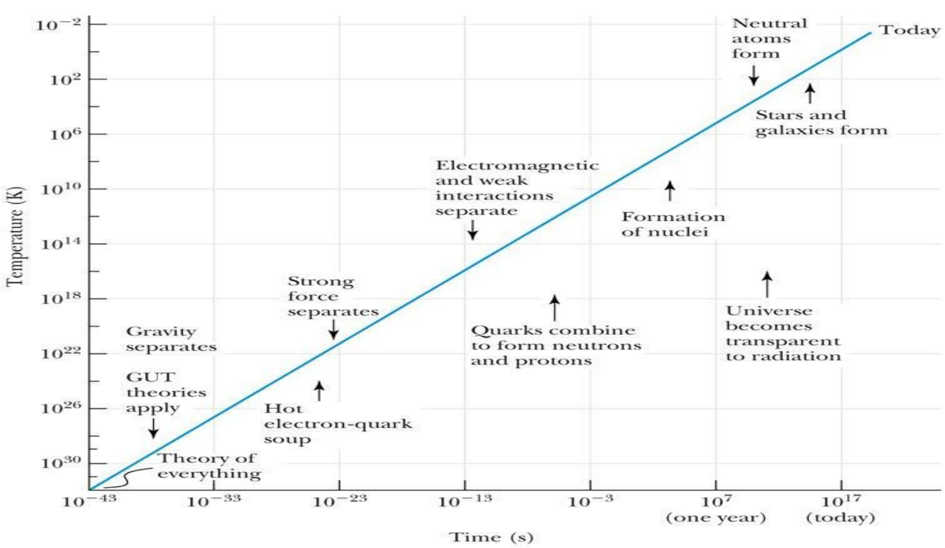

Figure 2. 1 The History of the Universe

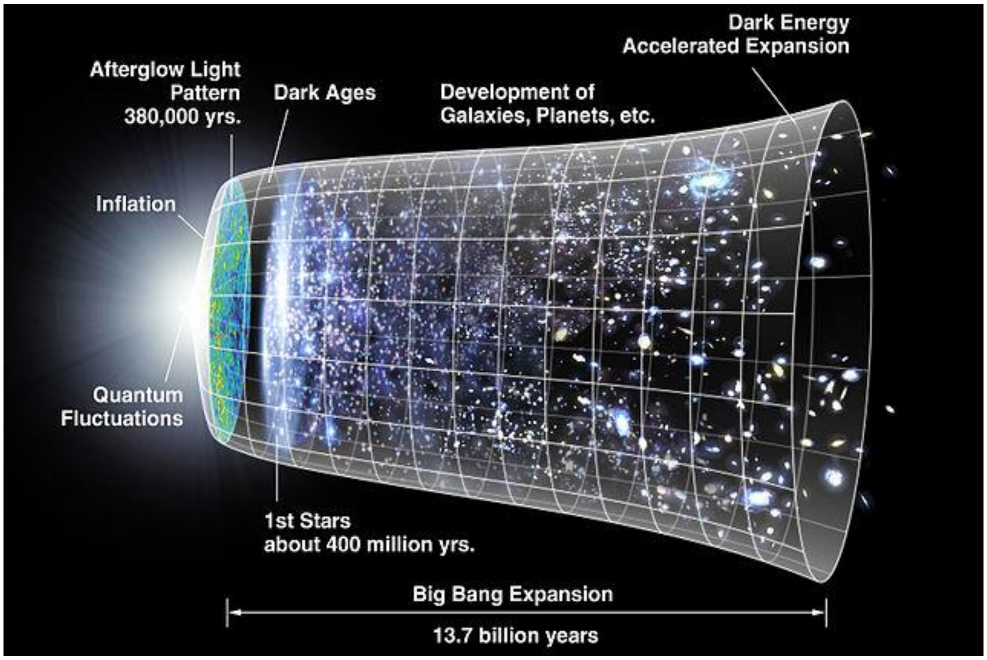

Figure 2.2: The Age of the Universe

Studies done on Supernovae reveal that the expansion of the Universe is accelerating which is contrary to what is expected. According to Newtonian Physics the presence of matter in the Universe should slow down the rate of expansion since it creates gravity. Gravity should therefore slow down the expansion since matter is expected to attract instead of repelling**.** It has been postulated that a peculiar form of energy is not well understood it is pushing the Galaxies apart. This mysterious energy has been dubbed dark energy.

2.1.1 Proofs of the Big Bang

a) The Expanding Universe

In the year 1929 Hubble using his telescope observed that distant Galaxies were all moving away from us. This recession was detected to occur at a speed that was proportional the distance that Galaxies were away from us.

$$V = H_o D$$

Where, V is the velocity H_o is the Hubble's constant and D is the distance of separation.

The further an object is the faster the rate of recession. This has the implication that there was a moment in time when the entire Universe was a single point in space.

b) Cosmic Microwave Background radiation

The CMB is a faint glow of light that is detected on Earth from every direction. It fills the Universe and is characterized by nearly uniform intensity. It is the heat that remained after creation he photosphere of the big bang which has been travelling through space for the last 13 billion years. The observable Universe that is visible to us today is a sphere which is approximately 15 billion light-years in radius. Since light travels at a fixed speed as a consequence of this is that looking at distant objects is the same as looking back in time. For example, the light we receive from Jupiter is emitted about an hour back in time, whereas the light from the Sun arrives about eight minutes after being emitted.

Similarly, light received from distant Galaxies today was emitted millions of years ago. The Cosmic Microwave Background radiation is the most ancient light that can be seen in time and space. This radiation has been traversing the Universe for more than 13 billion years ago, even long before the Milky Way Galaxy existed. It is a residue of the Universe's infancy, when it was not as cold and dark as it is now, but a firestorm of radiation and elementary particles instead. Objects such as Planets, Stars, and Galaxies that surround us today formed from these particles through gravitational interactions as the Universe expanded and cooled. This residual radiation is important in cosmology since it bears the fossil imprint of primordial particles and conditions of our Universe. It consists of a pattern of minute intensity variations which scientists use to decipher the vital statistics of the Universe.

When the CMB light was released, it was as hot and bright as the surface of a Star. Since then space was stretched by a factor of a thousand due to the expansion of the Universe. This led to the cooling of the CMB now detected by radio telescopes which register a temperature of about 2.73 degrees above absolute zero. The wavelength of this cosmic background light was stretched into the microwave part of the electromagnetic spectrum this is known as red shifting.

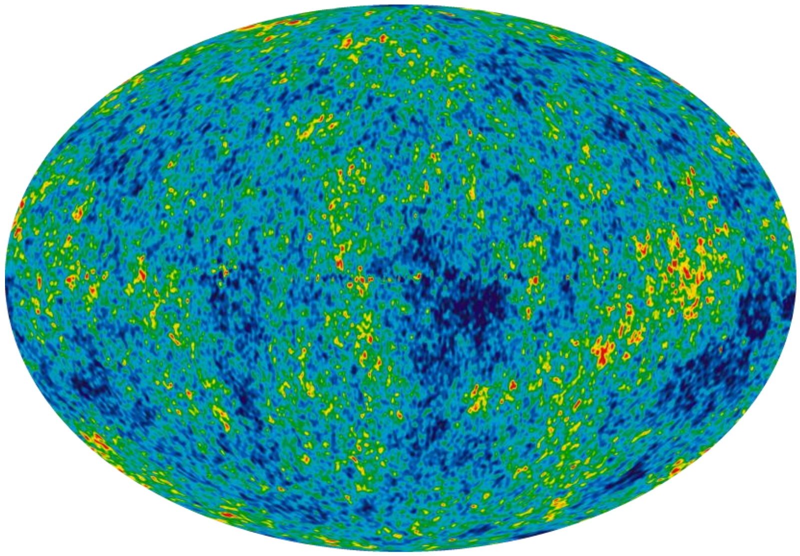

Figure 2.3: All-sky mollified map of the CMB

2.2 Heinrich Wilhelm Olbers theory for the expansion of the universe (Olbers' paradox)

Heinrich Wilhelm Olbers a German astronomer in his calculations showed that the night sky should be white instead of being dark since the Universe is filled with countless Stars and Galaxies which emit light. This is known as Olbers' Paradox. He argued that for an infinitely old Universe the light emitted from stars should have enough time to reach the Earth. The discovery that the Universe began with The Big Bang, has profound implications for the Olber's paradox. The light produced by distant sources such as Stars and Galaxies, is stretched beyond the red region of visible light into a spectrum that can't be detected by the naked eye.

Scientists have been able to successfully quantify the speed of light; Danish astronomer Olaus Roemer was able to do this. In 1676 he concluded that it was a constant about 3.00×10^8 meters per second. He achieved this by studying and recording the position of Jupiter's moons in their orbit at various times.

Considering the finite speed of light and the enormous separation between us and the stars implies that it is unlikely to receive that same intensity of light which is produced by stars, assuming it reaches the Earth at all. In the present-day cosmologists understand that the Universe is constantly expanding at various speeds and the further the objects are away from us the higher the rate of recession. This has the effect that this recession occasionally exceeds the speed of light especially for very distant objects. If a source is shifted by this recession in the space-time metric at a such considerable rate, then radiation from such a source will never reach the Earth. This phenomenon was extensively explored by Edwin Hubble which laid the foundation of the Big Bang theory.

Red shifting has the effect that the wavelength of light emitted from a star will be stretched to a longer wavelength. The higher the speed of recession the greater the red shift will be. The continuous expansion of the universe has led to the Electromagnetic waves emitted from distant stars to be stretched to an extent that the wavelength exceeds that of visible light. The eye can detect wavelengths ranging from 390 to 750nm (nanometer: $1x10^{-9}$) . The stretching of wavelength causes the EM radiation to have a lower frequency, light is then shifted from the visible region into the infrared region of the EM spectrum. Light in this region can no longer be detected by our naked eyes hence the reason why the night sky appears dark. This supports Heinrich Olbers argument. The expansion of the Universe had not been discovered until 1929 therefore he was not aware of the red shifting effect.

Infrared telescopes and cameras such as the Spitzer Space Telescope (launched in 2003) have successfully detected infrared light in our atmosphere which is nearly uniform in all directions. This Cosmic Microwave Background Radiation (CMBR) provides evidence for the constantly expanding Universe. The Big Bang hypothesis hints that there is an instant in time billions of years back when our Universe was considerably smaller and objects such as stars were closer together. Light emitted from the relatively closer sources at this time would still be easily visible. Which has the implication that our neighborhood in the primordial Universe would be well lit instead of being dark. The nearly uniform radiation detected as the CMB is the remnant of Big Bang explosion. This was the birth of the Universe predicted to have taken place13.8 billion years back in time. At this point was all matter and energy content in the Universe was contained in a single tiny point. The Universe at this distinct point then underwent extremely rigorous explosion of intense heat and continuous expansion before the explosion structures such as stars were not present.

2.3 Historical Beginning of the Universe

It is believed that at the earliest ages after the big bang atoms could not form because our Universe was not only hotter but also denser. Afterward, as the Universe expanded, cooling occurred and nuclear reactions between protons and neutrons took place resulting in the synthesis of lighter elements called nuclei by a process known as nucleosynthesis. The abundance of these elements today is in agreement with what is observed and the photons that were leftover formed a remaining CMB which also agrees with other observations (B. R. Vogeley 2008). An explanation for this is that the observed CMB light has been traveling through the Universe and since the universe is expanding, the wavelengths of these CMB radiations that we observe now must have had a higher temperature when the Universe was younger meaning it was hotter, and since the temperature has red-shifted as per Wien's law. According to Lemaıtre, the rest of known physics must be accounted for in the general relativistic cosmological models (B. R. Vogeley 2008).

In 1929, Edwin Hubble an astronomer in his report concluded that, from his observations, Galaxies in the Sky were moving away from us and each other. He added that those Galaxies that are near to us move away relatively slow while those far away move faster away from us. This observation by Hubble has contributed greatly to cosmology and now the question asked is whether our Galaxy is different from all other Galaxies in terms of moving away from others. The answer to this question is that the whole Universe is expanding and yes our galaxy is no exceptional meaning that if the observation was made from a different galaxy the same results could be obtained. Therefore, for the uniform expanding Universe, every observer is in the center and everything moves outwards from him or her.

It is these observations that lay a foundation for history and the structure formation theories of the Universe. We define cosmology as the study of the general structure and formation of the Universe, some theories try to explain cosmology since Hubble's observations but the main one and the most general is called the big bang model. The intriguing topic of discussion is that if the Universe is finite or infinite. According to Albert Einstein, through his theory of general relativity, the answer to this question can only be predicted by the density of the matter of the Universe since a finite Universe has a larger matter density as opposed to an infinite Universe. One of the goals of cosmology is to give an explanation about the origin, evolution, structure formation, and composition of the whole Universe and be able to understand the laws of physics and the physical processes governing it.

The fact that the Universe is expanding making the galaxies are receding insinuated that the average density of matter is decreasing and by this, it was concluded that, in about 10-15 billion years ago the density was almost infinite. Here now, we have two possibilities. One is that the Universe will constantly expand forever and another one is that the Universe will slow down in its expansion and the electuary start to contract according to Relativity. Therefore, what will happen to the Universe according to this theory is depended on whether or not the average density of the universe surpasses a definite value which determines whether the Universe is infinite or finite.

2.4 The Expanding Universe

About four hundred years ago, many physicists especially astronomers, struggled to answer questions concerning the size and age of the Universe and whether it could go on forever, or it will stop at some point. Another question of concern was whether the Universe always existed or had a beginning where it came to existence. The expansion of the Universe discovery by Edwin Hubble, an astronomer who was based at Carnegie Observatories, in 1929, was so critical that led to scientific answers for these questions. The Greeks had ventured into probing the Universe in ancient times and they could not affirm whether the universe was finite or infinite. This problem became a paradox to them, and they resolved that the Universe is either finite or infinite and both alternatives presented problems.

Originally, the Earth was believed to be at rest and that the celestial bodies were rotating around it but as time went by it was discovered that the Earth was a planet rotating around the Sun which made up the Solar System which is found in the milk way, a rotating galaxy which moves at a speed of hundreds of kilometers per second to an unknown destination within the Universe which contains billions of such galaxies. When modern astronomy arose, another paradox puzzle presented itself to astronomers. A German astronomer called Heinrich Olbers, in the early 1800s, disputed that the universe is finite. In his remarks, he acknowledged that the known dark regions in the sky can only be explained by the finite universe. And the reason why this was a paradox is that Isaac Newton in his law of gravity, he found that gravity is always attractive.

This means that all objects in the Universe attract each and therefore if the Universe was truly finite, then this gravity would make the Universe contract and collapse to itself since all objects in it are attracted to each other, but this did not happen instead they are moving away from each other. The same problem occurred to Albert Einstein after he discovered his theory of gravity in the General Theory of Relativity. Even though he had assumed the Universe to be static, in his equations, the Universe should be either collapsing or expanding. The initial solution of these equations contained a fixed term referred to as a cosmological constant, which meant to cancel the influence of gravity on large scales, and it is this constant that caused a static Universe. Later, Hubble observed that the Universe to be expanding; this made Einstein to conclude that the constant he invoked in his equations was the worst mistake he had made. Cosmological constant was his "greatest blunder."

Astronomers have obtained new data which they used in attempting to know the plethora of faint and nebulous objects they were observing. From the year 1912 to 1922, Vesto Slipher, an astronomer based at Lowell Observatory in Arizona was able to observe from many objects that the spectrum of light was systematically shifted to longer wavelengths what if known as red-shifted and later it was discovered that these objects were distant galaxies.

One of the characteristics of the Big Bang cosmological model is the expanding Universe. That is, it started from an extremely hot and dense point, and that the elements we have now in our Universe first suffered a cataclysmic case, and with time a constant expansion followed in which cooling and thinning out of these parts occurred. This idea of the expanding Universe has its implications in the field of Physics. One is that it unifies the very small and the very large (Villanueva 2009).

The inventions about the microscopic particles and their interactions could sometimes excite scientists, however, they were aware of the fact that nature was biased towards simplicity and the diversity of the forces deviation was due to this fact and that for these forces to unite simplicity must prevail. From their calculations, they concluded that this could be only possible in the existence of exceedingly high energies. But these energies were not available anywhere in the Universe; therefore, this possibility was not helpful. In these situations, the energies would have been tremendously high.

Over time, observation has proofed that the Universe experienced a cataclysmic event (Big Bang), and it has indicated that it is expanding even now. Observation of the CMB radiation is one of the proofs which exhibit a thermal black body spectrum of about 3 K.

Another proof-based observation for galaxies where there is an indication of collection of redshifts and points out that the further galaxies are greatly red-shifted, and this means that the outermost galaxies are accelerating away faster than the innermost ones. These two proofs alone are key in understanding the Big Bang theory (Villanueva 2009).

CHAPTER 3: THEORETICAL FRAMEWORK

3.1 Scale Factor

To describe the effect of expansion we introduce a scale factor, which its' current value is set to be one. Initially, a (scale factor) was less than as it is currently. In Figure 3.1, space consistently expands as time moves. Points on the grid become at the coordinates, the commoving distance within two points that are used to calculate the difference of the coordinates becomes constant. Albeit the physical distance correlates to the scale factor and it evolves with time.

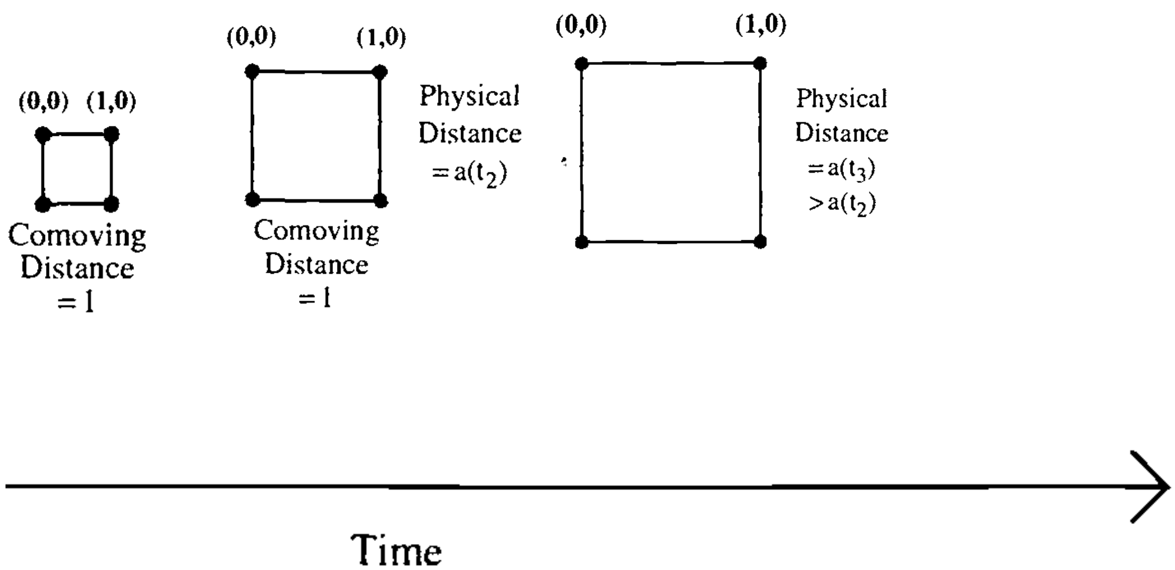

Figure 3.1: Universal Expansion

The commoving distance within points on a grid becomes fixed as the Universe continues to expand. The physical length is comparative to the commoving distance multiplied by the scale factor, so it expands while time moves. Furthermore, the scale factor coupled with its measurement, the smooth Universe is distinguished by another factor, its physical geometry. There exist three possibilities: open, flat, and closed Universe. The Universe is Euclidean means that the Universe is flat, the molecules maintain parallel provided they move without restrain. General relativity makes proportional energy to geometry. Accordingly, in the flat Universe, the energy density is equal to a critical density, which is estimated as 10^{-29}g cm^{-3} , if the density is greater than the critical density, it follows that it's a closed Universe. The correlation of a closed Universe to that of a surface of a sphere goes vaster, they are said to be a positive curvature.

Finally, if the density is lower than the critical density the Universe seems to be open, such that the originally parallel paths diverge. To know more about the past information of the Universe, we should find out the growth of scale factor a with cosmic time t. Also, GR predicts the relation of this evolution to the energy in the universe, the scale factor becomes higher as the universe ages. At initial times $a \propto t^{1/2}$ whereas later the dependence changes to $t^{2/3}$ how the scale factor differs with time is decided by the energy density of the Universe.

3.2 Einstein Field Equations (EFE)

These equations outline the fundamental interplay of gravitation due to space-time warping by energy and matter. EFE is a tensor equation associating a set of symmetric 4×4 tensors. Every tensor contains 10 independent elements.

The EFE are expressed in the form;

$$R_{\mu v} - \frac{1}{2} g_{\mu v} R + g_{\mu v} \Lambda = \frac{8\pi G}{c^4} T_{\mu v} \tag{1}$$

Where $R_{\mu v}$ Ricci tensor

$g_{\mu v}$ - Metric tensor

Λ - Cosmological constant

G - Gravitational constant

c - light velocity in space

R - Scalar curvature

$T_{\mu v}$ - Represents stress–energy tensor

And $\mu, v = 0, 1, 2, 3$

The equations in factors outside of GR are identical to the EFE. Vacuum field equations attained when T corresponds to zero defines Einstein manifolds.

$$G_{\mu v} = \frac{1}{2} g_{\mu v} R \tag{2}$$

The Einstein field equations can be expressed in a compact form as

$$G_{\mu v} + g_{\mu v} = \frac{8\pi G}{c^4} T_{\mu v} \tag{3}$$

By use of geometrized units, in which G = c = 1 equation (3) can be expressed as

$$G_{\mu v} + g_{\mu v} = 8\pi T_{\mu v} \tag{4}$$

The left-hand side expresses the curvature of space-time as indicated by metric c while the right-hand side expresses the matter or energy content of space-time and hence the Einstein field equations can therefore be explained to be a set of equations determining how matter or energy indicates curvature of space-time.

3.3 Cosmic Microwave Background Radiation (CMB)

Observed CMB radiation gives good evidence for the hot Big Bang (Scott 2001). The standard model of cosmology explains partially in an acceptable way of the main stages of evolution of the observable universe, over time. The CMB is the oldest cosmological signal we can currently observe. Mapping its fluctuations gives a wealth of accurate information on processes before, during, and after the recombination. The recent WMAP and Planck satellites have measured several parameters to percent accuracy by comparing the temperature and polarization anisotropies to predictions.

In the 1950's scientists started taking into serious consideration the effects of a hot big bang as implied by the discovery of the cosmic expansion by Hubble. Alpher, Herman, Gamow, and others realized that the photons that initially dominated the energy density should have been still around after they last scattered when neutral atoms first formed at a temperature of a few thousand degrees and an epoch roughly 350,000 years after the big bang. They predicted then that an isotropic black-body bath of radiation at around 5K could be detected. This indeed occurred in 1965 when Penzias and Wilson discovered by chance an unexplained isotropic 3K radiation, correctly interpreted by Dicke, Peebles, and collaborators as the sought-for big bang remnant.

After the full relativistic treatment of linear perturbations developed by Lifshitz and Khalatnikov and Sakharov in the early 60s, Sachs and Wolfe (1966) showed then that the existence of today's inhomogeneity should imply some level of in homogeneities also on the CMB due to the gravitational red- or blue shift induced by matter perturbations of CMB photons. In subsequent years, Silk, Peebles, Yu, and others found out how the interactions between photon and baryons before and during the recombination process could have imprinted small angular scale perturbations due to the propagation of sound waves in the coupled plasma. In the early 80s, these calculations were extended to consider dark matter.

3.4 The Hubble rate

Before the Hubble space telescope was launched, there was a huge uncertainty over the rate at which objects in the universe were receding from each other. This value is needed to calculate the age of the universe, estimate its evolution over billions of years, and understand the forces driving it. At first, astronomers were delighted to narrow the expansion estimate to 10 percent accuracy. Now, with a lot of perseverance and precise observations, they are approaching one percent accuracy. Using the largest telescope of the time, Edwin Hubble in 1929 discovered that the more distant a galaxy is from us, the faster it appears to be receding into space. This means that the universe is expanding uniformly in all directions. Hubble noted that light from faraway galaxies appeared to be stretched to longer wavelengths, or reddened, a phenomenon called redshift.

Measuring the expansion rate, i.e., Hubble constant aids in determining the age of the universe calculated. However, earlier estimates of the expansion by Edwin Hubble's suggested that the Earth and the Sun were older than the universe. Hubble, therefore, concluded that the redshift phenomenon was an unknown property of space and not a measurement of true space velocity. Astronomers later realized that redshift was a consequence of the expansion of space itself, as predicted in Einstein's theory of special relativity. However, the age estimate is only as reliable as the accuracy of the distance measurements.

A precise value for the Hubble constant is a critical anchor point for calibrating other fundamental cosmological parameters for the universe.

By the late 1990s, the refined value of the Hubble constant was reduced to an error of only about 10 percent. Another team of astronomers continues to streamline and strengthen this by calibrating more Cepheids ever more distant than the local universe. These data were cross correlated with even farther milepost measurements of exploding stars, supernovas, to build a cosmic "distance ladder." A variety of other observing strategies have been applied to look at other milepost markers such as red giant stars. The present rate of the universe's expansion is derived from various cosmological models and from data encoded in the CMB. The CMB is a snapshot of the early cosmos as made by the Planck space observatory. The value from the Planck data disagrees with more direct measurements of the nearby Universe made with Hubble and other observatories.

According to standard cosmological models, the values from the early and local universe should be the same. Because they are not, it presents a major challenge to theorists by implying that there is an incomplete understanding of the physical underpinnings of the universe. A century after the discovery of the expanding universe, the Hubble Space Telescope has allowed astronomers to enter the realm of precision astronomy, nailing down the expansion rate to extraordinary precision through several complementary observing strategies. Future Hubble telescope observations may help settle the discrepancy between two independent approaches that measure the early universe versus the late universe's expansion. This may open up a whole new frontier in our understanding of the evolving universe.

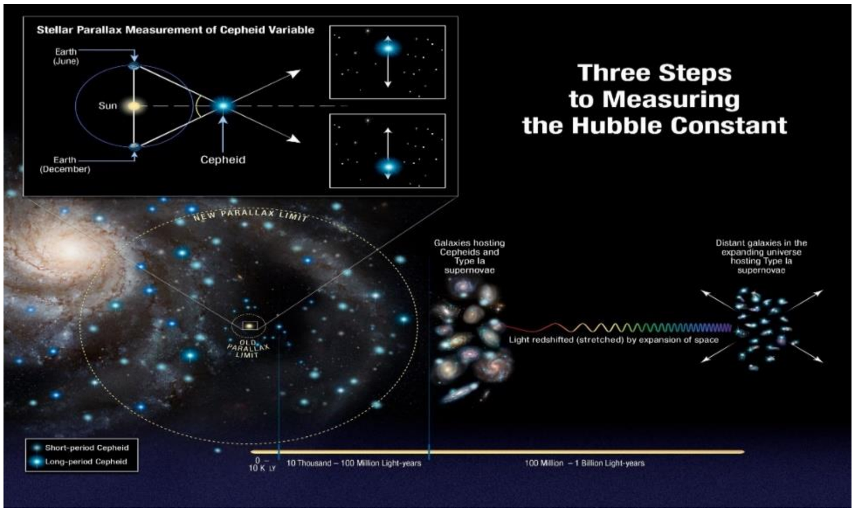

Figure 3.2: Steps of Measuring Hubble Constant

3.5 Hubble Constant

This is a unit that gives details from a specific point in space of how quickly at different distances the universe is expanding. It is among the foundations of the mastery of our universe's evaluation together with physicists are entangled in a discussion above its actual value. In the 1920s an American astronomer called Edwin Hubble first evaluated the H_0. Its inverse has dimensions of time (Madore 2010). Hubble observed that all the galaxies in the universe look like they are receding from our planet. Moreover, the further the galaxy the higher the speed. This became the foundation for Hubble law, which attests there exists a correlation between the distance object is from us in the cosmos and its receding speed. Hubble tried to approximate the constant which carries his name and arrived at a value of about 501 km/s/Mpc in cosmologists' units.

There is no exact value of the Hubble constant, and this is still a challenge to many astronomers as they are trying to find the range within which its value falls. In the 1990s, astronomers found out that those dimmer supernovae were faraway than they had suspected. This led to a suggestion that our universe was expanding and this expansion was accelerating and from this, they drew a conclusion that there must be some unseen energy pushing this matter away from each other and they called this energy dark energy in which according to them had to be included in the models of the universe.

This was particularly important information that now led to researchers that started to find out at what rate the Universe was accelerating and how the Universe started to evolve and what could be its fate.

In 2016 the value of the Hubble constant calculated using Cepheid variables data was 73.4 km/s/Mpc. Also, in the year 2018, by using Planck's data that was obtained from cosmic microwave background by the Planck satellite, the European Space Agency's found an alternate value of Hubble constant which was 67.4 km/s/Mpc (46,200 mph per million light-years) Also, another group of astronomers, in July 2019, used a different technique to obtain another new Hubble constant value of 69.8 km/s/Mpc. In this technique, researchers considered the radiation from red giant stars, which all come to the same peak brightness at the final point in their evolution, and astronomers by observing dim red giant stars as they take apart to appear from Earth, they could approximate their distance.

CHAPTER 4: RESEARCH METHODOLOGY

This research work began by studying the current standard cosmological model, that is, the FLRW model the necessary and sufficient conditions for space-time to be FLRW considered. This was followed by exploring the Hubble constant which expresses that there is a directly proportional between the distance of the galaxy and the speed at which it is receding from us.

4.1 Source of Data

I explored that the expansion history of the Universe in power-law cosmology is crucial relies on two important parameters namely H_0 (Hubble constant) and q (deceleration parameter). I discovered that the limitations on these parameters from the current H(z) (Hubble parameter) and SNeIa (Type 1a supernova) data.

4.1.1 Deceleration parameter q

In the FLRW (Friedmann–Lemaître–Robertson–Walker) model the deceleration parameter q is dimensionless, and it dictates the acceleration of the expansion of space.

$$q = -\frac{\ddot{a}}{aH^2} = -\left(1 + \frac{\dot{H}}{H^2}\right) \tag{5}$$

$$\dot{H} = \frac{dH}{dt} = aH\frac{dH}{dt} \tag{6}$$

4.1.2 Analytical Code for CMB Anisotropies

The CAMB is a Fortran 90 application that works out the power spectra of CMB after identifying an assemblage cosmological parameters. The package was written by Antony Lewis and Anthony Challinor. The LAMBDA has evolved a web-based server-side interface to cosmic microwave background that admits users to enter parameters in a web mode and run the program. The results are displayed graphically, and the spectrum files are formed accessible for downloading.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 The History of the Universe

The study found that during the first 10^{-43} seconds after the Big Bang there is little information about our Universe and the physics of that time is extremely different from what is known today. The Universe originated from an extremely hot and dense state. The study further found that by the time 10^{-43} the Universe had a size of less than 10^{-52} meters. Based on the findings, the four fundamental forces of strong, electromagnetic, weak, and gravity were all unified into one force. The temperature was probably 1030 K.

According to the assertions by Linde, Linde and Mezhlumian (1994), the Universe then cooled adequately permitting the formation of subatomic particles. Within the first three minutes simple atomic nuclei had formed however electrically neutral **a**toms formed thousands of years later. Atoms of lighter elements then formed mainly hydrogen, along with helium and traces of lithium.

The findings were broken down into various events that took place at each time intervals as shown below:

5.1.1 Gravity Separates

The findings revealed that during the time 10^{-43}s to 10^{-35}s, there was an expansion of space to the size of ten to thirty meters, while the temperature was 1028 K and the event that took place was that gravity separated as the first distinct force.

5.1.2 Dense plasma (Quark-Electron Soup)

According to the study between the time 10^{-35} s to 10^{-13}s the Universe was in plasma form i.e., a hot soup of electrons and quarks with a temperature of 1016 K and the size of 10^{-1} m. Elementary particles such as quarks and leptons are believed to have formed at this stage.

5.1.3 Neutrons and Protons Form

The third event was the formation of Neutrons and Protons which occurred between 10^{-13} s to 10^{-3}s when the universe was at a temperature of about 1015 K. Quarks which had formed earlier bound together to form neutrons and protons, electromagnetic and weak forces separated at this duration.

5.1.4 Formation of Deuterons

The Universe then cooled to approximately 109 K between 10^{-3}s and 3 minutes and the formation of deuterons occurred, which marked the onset of nucleosynthesis. The size of the Universe was around 1010 meters at this point.

5.1.5 Formation of Light Nuclei

Nucleosynthesis led to the formation of light atomic nuclei such as helium between the duration of three minutes to years. The Universe had experienced an expansion to the size of about 1021 meters making the temperature to drop up to 104K.

5.1.6 Matter–Dominated Universe

This final event to have occurred was found to be domination of the Universe by matter. The study found that between three hundred thousand years to the present time, temperatures in the Universe had dropped enough allowing electromagnetic radiation to decouple from matter. Photons produced at this time at a temperature of about 3000K have been detected uniformly in all directions as the CMB. They have been recorded at a redshifted temperature of about 2.7K. These findings were found to be consistent with the explanation by Weitekamp (2017) on The Big Bang Theory which described the Big Bang Theory as a model that explains how the Universe came into existence and how it has been evolving ever since. According to previous researchers, the theory suggests that the birth of the Universe occurred 13.7 billion years ago. Originating from an extremely dense and hot state a point referred to as singularity. Little is known about this instant, the physics we know breaks down at this point for example there was no space, time, energy or matter. This was followed by an expansion at an incredible rate then matter, energy, space and time came into being. As the expansion proceeded, matter began to interact gravitationally forming gas clouds and this led to the birth of stars and planets. Scientists argue that this expansion is finite and will come to a halt one day. It is hypothesized that the Universe will then collapse into a Big Crunch.

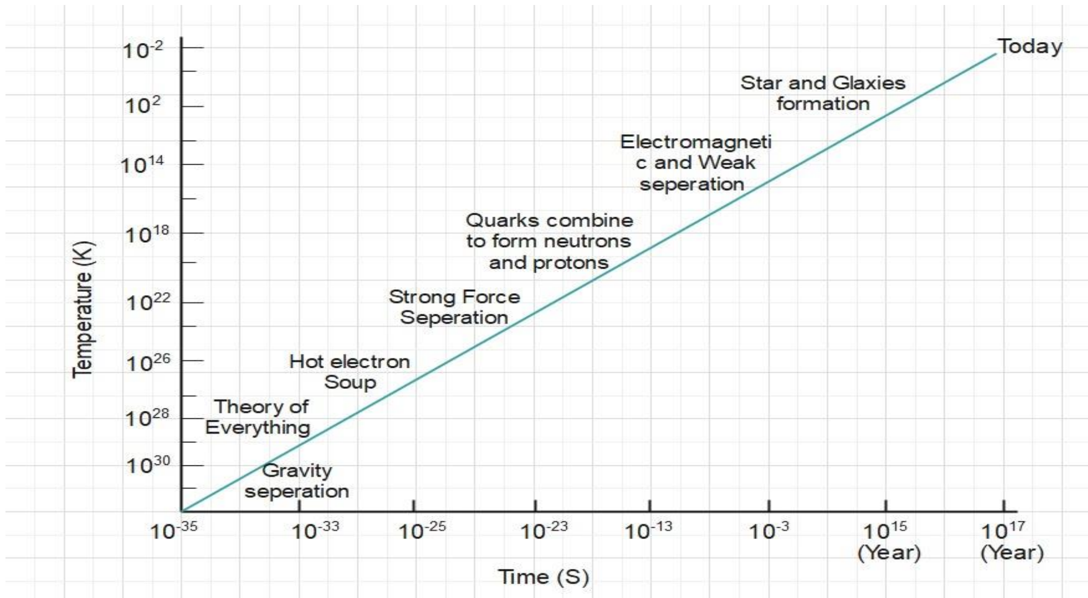

Figure 5.1: Graphical Representation of Big Bang Theory

Further, studies on supernovae reveal that the rate at which the Universe is expanding is accelerating contrary to what is expected. According to Newtonian physics the presence of matter in the Universe should slow down the rate of expansion since it creates gravity. Gravity should therefore slow down the expansion since matter is expected to attract instead of repelling**.** It has been postulated that a peculiar form of energy is not well understood it is pushing the galaxies apart. This mysterious energy has been dubbed dark energy.

5.2 Proofs of the Big Bang

5.2.1 The Expanding Universe

In the year 1929 Hubble using his telescope observed that distant galaxies are fling away from us.

$$V = H_o D$$

Where, V is the velocity H_o is the Hubble's constant and D is the distance of separation. The further an object is the faster the rate of recession. This has the implication that there was a moment in time when the Universe was a single point in space.

5.2.2 Cosmic Microwave Background Radiation

The Cosmic Microwave Background radiation (CMBR) is a faint glow of light that is detected on Earth from every direction. It fills the universe and is characterized by nearly uniform intensity. The radiation remained after creation he photosphere of the big bang which has been travelling through space for the last 13 billion years. The observable Universe that is visible to us today is a sphere which is approximately 15 billion light-years in radius. Since light travels at a fixed speed, this implies that looking at distant objects is the same as looking back in time. For example, the light we receive from Jupiter is emitted about an hour back in time, whereas the light from the sun arrives about eight minutes after being emitted. Similarly, light received from distant galaxies today was emitted millions of years ago.

The CMB is the most ancient light that can be seen in time and space. This radiation has been traversing the universe for billions of years long before our home galaxy the Milky Way galaxy existed. This is important in cosmology since it bears the fossil imprint of primordial particles and conditions of our universe. It consists of a pattern of minute intensity variations which harbor useful information about the universe. When the CMB light was released, it was as hot and bright as the surface of a star. Since then, space was stretched by a factor of a thousand due to the expansion of the universe. This led to the cooling of the CMB now detected by radio telescopes which register a temperature of about 2.73 K. The wavelength of this cosmic background light was stretched into the microwave region of the EM spectrum this is known as red shifting.

The second variable analyzed Hubble’s law and the findings were as shown in Figure 5.2.

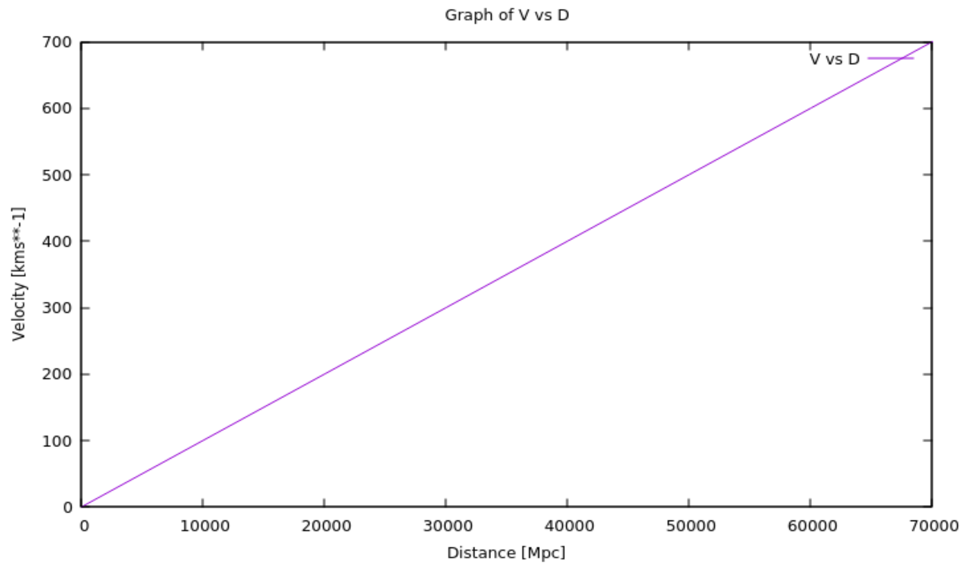

Figure 5.2: The Hubble Diagram

Hubble's Law is defined by:

$$V = H_o D$$

Where, V is the velocity H_o is the Hubble's constant and D is the distance of separation.

The further an object is the faster the rate of recession. The gradient represents the Hubble constant (H_o), this can be directly related to the age of the Universe: Hubble time, t_o is given by

$$t_o = \frac{1}{H_o}$$

H_0 has been discovered to vary with time hence contradicting the constant name which it has. It is therefore referred to as the Hubble parameter considering its change in time. It can be denoted by

$$H_0 = \frac{a(\dot{t})}{a(t)}$$

Where *a (t)* is the time-dependent scale factor of the universe, and $a(t)$ is the rate of change of the scale factor. The scale factor describes the expansion of the fabric of space.

According to previous scholars, Hubble constant is a unit that gives details from a specific point in space of how quickly at different distances the universe is expanding. It is among the foundations of the mastery of our universes evaluation together with physicists are entangled in a discussion above its actual value. In the 1920s an American astronomer called Edwin Hubble first evaluated the H_0. The Hubble constant has units of kilometers per second per megaparsec. Its inverse has dimensions of time (Madore 2010). Hubble observed that all the galaxies in the Universe look like they are receding from our planet. Moreover, the further the galaxy the higher the speed.

This became the foundation for Hubble law, which attests there exists a correlation between the distance object is from us in the cosmos and its receding speed. Hubble tried to approximate the constant which carries his name and came up with a rate of about 342,000 mph million light-years or 501 km/s/Mpc in cosmologists' units. There is no exact value of the Hubble constant, and this is still a challenge to many astronomers as they are trying to find the range within which its value falls. In the 1990s, astronomers found out that those dimmer supernovae were faraway than they had suspected. This led to a suggestion that our universe was expanding and also this expansion was accelerating and from this, they drew a conclusion that there must be some unseen energy pushing this matter away from each other and they called this energy dark energy in which according to them had to be included in the models of the universe. Presented in Figure 4 are the results on Hubble observations.

5.2.3 Hubble Observations

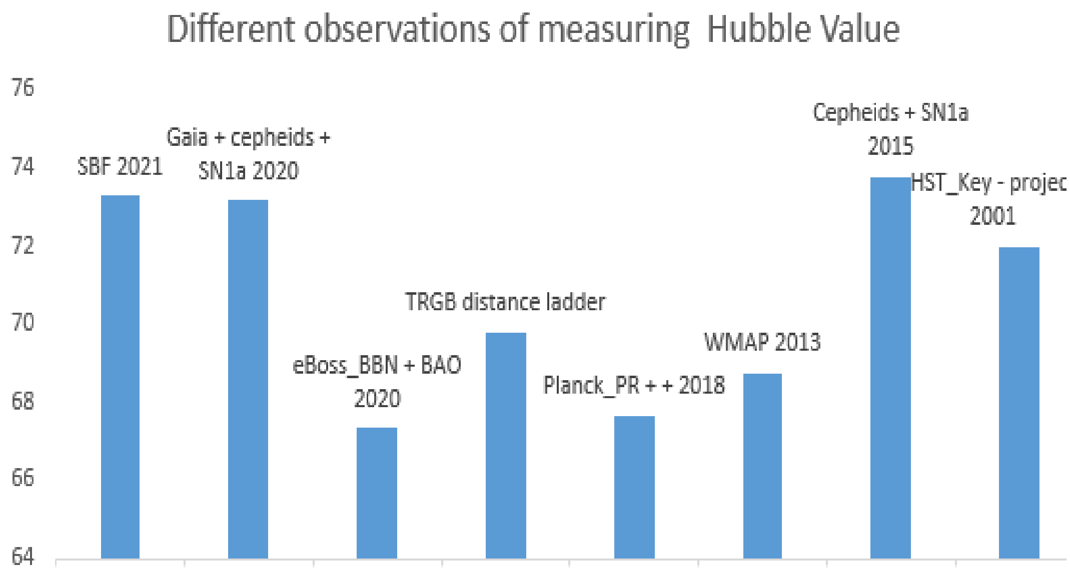

Figure 5.3: Hubble Observations

Figure (5.3) represents values of the Hubble constant that have been measured and recorded from various experiments so far. This study summarized different methods and results, tabulated from a wide range of sources such as Cepheids in the galaxy NGC 4258 and many other additional galaxies the values are in the units of kilometers per second per megaparsec (km s^{-1} Mpc^{-1}) (SBF-distances 2020),

H_0 = 73.2 (Gaia + cepheids + SN1a 2020),

H_0 = 67.35 (eBOSS_BBN +BAO 2020),

H_0 = 769.8(TRGB distance ladder 2019),

H_0 = 67.66 (Planck PR + 2018),

H_0 = 73.8 (Cepheids + SN1a 2015,

H_0 = 68.76 (WMAP 2013)

H_0 = 72 (HST-Key-project 2001).

The value of the Hubble parameter can be obtained by determining the velocity of recession of an object and the distance of such an object from the Earth. It is difficult to determine the velocity of recession directly hence this is determined by quantifying the redshift **z** of such an object. This is the stretching of the wavelength at which the radiation from a given source is emitted a phenomenon well known as the Doppler shifting.

$$Z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$$

In this case λ_{rest} is the rest wavelength or rather the initial wavelength and $\lambda_{observed}$ is the wavelength at which an object is observed or detected. Scientists are able to determine the redshift since particular elements have spectral lines which are emitted at characteristic wavelengths. Therefore, the wavelength λ_{rest} can be easily quantified.

The velocity *v* at which a source recedes is given by the relation.

$$v \approx z \times c$$

Where c is the speed of light.

Table 5.3: Hubble Parameter versus Redshift Data

Red shift (Z)	Hubble Constant (H_0)
0.07	69 ± 19.6
0.09	69 ± 12
0.12	68.6 ± 26.2
0.179	75 ± 4
0.199	75 ± 5
0.2	72.9 ± 29.6
0.4	95 ± 17
0.47	89 ± 50
0.9	117 ± 23
2.34	223 ± 7
2.36	227 ± 8

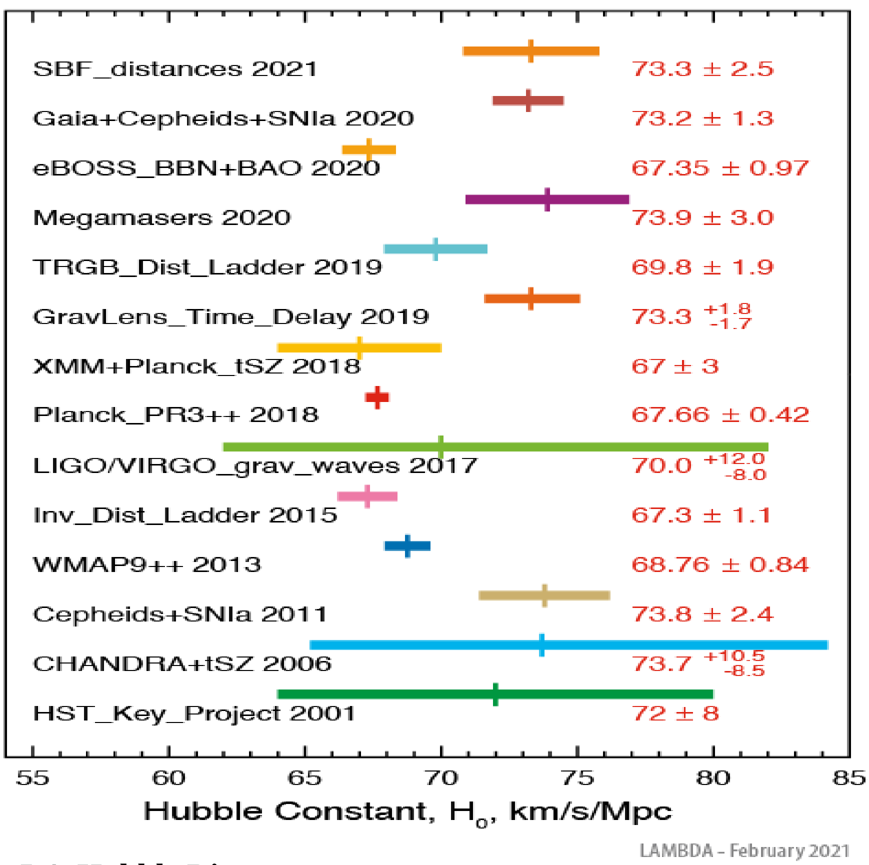

Figure 5.4: Hubble Diagram

The Hubble Constant H_0 defines the values of the expansion rate today. This is measured by applying different approaches such as distance ladder method, theoretical model predictions and data from experiments such as;

- Hubble Space Telescope (HST)
- Planck Satellite
- Wilkinson Microwave Anisotropy Probe (WMAP)
- Supernovae such as SNIa
- Cepheids
- TRGB Dist Ladder
- Baryon Acoustic Oscillations (BAO)
- Big Bang Nucleosynthesis (BBN)

There is no exact value of the Hubble constant and this is still a challenge to many astronomers as they are trying to find the range within which its value. The researcher observed the relationship between Hubble value and time in years and the results were as presented in Figure 5.5.

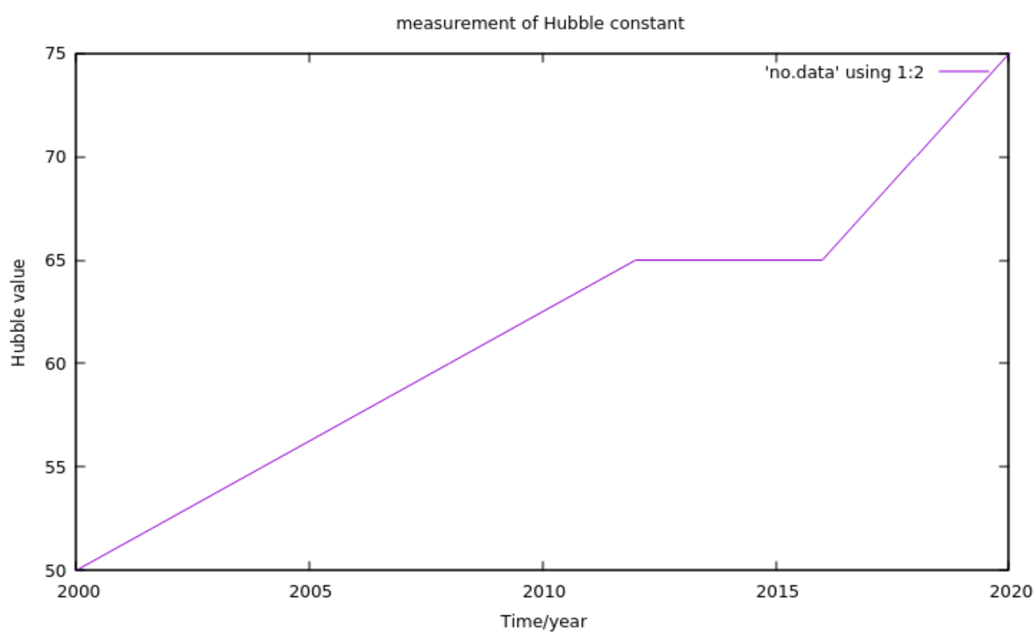

Figure 5.5: The Hubble Value against Time

According to Kolb, Matarrese, Notari and Riotto (2005), Before the Hubble telescope was launched, there was a huge uncertainty in determining the Hubble rate. This value is needed to calculate the age of the universe, estimate its evolution over billions of years, and understand the forces driving it. At first, astronomers were delighted to narrow the expansion estimate to 10 percent accuracy. Now, with a lot of perseverance and precise observations, they are approaching one percent accuracy. In 1929, Edwin Hubble provided the first observational evidence for the universe having a finite age. Edwin Hubble used the largest telescope of the time, to discover that the universe was expanding. In his endeavor he found out that the universe is expanding uniformly in all directions. Hubble noted that light from faraway galaxies appeared to be stretched to longer wavelengths, or reddened, a phenomenon called redshift.

Hubble, therefore, concluded that the redshift phenomenon was an unknown property of space and not a measurement of true space velocity. Astronomers later realized that redshift was a consequence of the expansion of space itself, as predicted in Einstein's theory of special relativity. However, the age estimate is only as reliable as the accuracy of the distance measurements. A precise value for the Hubble constant is a critical anchor point for calibrating other fundamental cosmological parameters for the universe. The initial rate of expansion which was calculated by Hubble was off by a factor of two. In 1994, astronomers began refining the Hubble constant by making precise distance measurements out to the Virgo cluster of galaxies, located 56 million light-years away. These enabled astronomers to refine the value of the Hubble constant with better and higher precision. They achieved this by making observations of a class of star called Cepheid Variables. They are useful since they are pulsating stars with known intrinsic brightness.

By the late 1990s, the refined value of the Hubble constant was reduced to an error of only about 10 percent. Another team of astronomers continues to streamline and strengthen this by calibrating more Cepheids ever more distant than the local universe. These data were cross correlated with even farther milepost measurements of exploding stars, supernovas, to build a cosmic “distance ladder.” The measurement of the Hubble constant improved from 10 percent uncertainty at the start of the 2000s to less than 2 percent by 2019. A variety of other observing strategies have been applied to look at other milepost markers such as red giant star. A novel technique uses Hubble to look at where the gravity of a foreground galaxy acts like a giant magnifying lens, amplifying and distorting light from background objects such as quasars. Astronomers next reliably deduce the distances from the galaxy to the quasar, and from Earth to the galaxy and to the background quasar. By comparing these distance values, the researchers measured the universe's expansion rate that is completely independent of the “distance ladder” techniques.

However, there is a troubling disagreement between the collective programs arriving at values for the Hubble constant in the nearby universe as compared with those of the early universe. The present rate of the universe’s expansion can be predicted from the cosmological model using measurements of the early universe, as encoded in the Cosmic Microwave Background (CMB). The CMB is a snapshot of the cosmos as it looked earlier in time as made by the Planck space observatory. The value from the Planck data disagrees with more direct measurements of the nearby universe made with Hubble and other observatories.

According to standard cosmological models, the values from the early and local universe should be the same. Because they are not, it presents a major challenge to theorists by implying that there is an incomplete understanding of the physical underpinnings of the universe. A century after the discovery of the expanding universe, the Hubble Space Telescope has allowed astronomers to enter the realm of precision astronomy, nailing down the expansion rate to extraordinary precision through several complementary observing strategies. Future Hubble telescope observations may help settle the discrepancy between two independent approaches that measure the early universe versus the late universe’s expansion. This may open up a whole new frontier in our understanding of the evolving universe.

According to Freedman and Madore (2010), Hubble constant is a unit that gives details from a specific point in space of how quickly at different distances the universe is expanding. It is among the foundations of the mastery of our universes evaluation together with physicists are entangled in a discussion above its actual value. In the 1920s an American astronomer called Edwin Hubble first evaluated the H_0. Its inverse has dimensions of time (Madore 2010). Hubble observed that all of the galaxies in the universe look like they are receding from our planet. Moreover, the further the galaxy the higher the speed. This became the foundation for Hubble law, which attests there exists a correlation between the distance object is from us in the cosmos and its receding speed. Hubble tried to approximate the constant which carries his name and came up with a rate of about 342,000 mph million light-years or 501 km/s/Mpc in cosmologists' units.

CHAPTER 6: CONCULUSION

Cosmology is a field that is undergoing rapid development, both theoretically and empirically, and it is riddled with enigmas. What caused the Big Bang? What drove inflationary expansion, and how did inflation end? What is dark matter, the dominant gravitational matter, and how is dark energy fueling the current accelerated expansion? Will it come to a halt or dilute the Universe? Why are today's dark matter and dark energy of the same magnitude? Is our space-time a brane in a higher-dimensional bulk universe, or do we exist in a four-dimensional space-time described by General Relativity? Cosmology is without a doubt one of our time's most difficult intellectual challenges.

The value of the Hubble Parameter derived from cepheid variables, following the linear trend of closer galaxies, is $H_0 = 62.5\ kms^{-1}Mpc^{-1}$, whereas averaging the maximum and minimum values gives $H_0 = 72.6\ \pm 40.5\ kms^{-1}Mpc^{-1}$.

This is like Riess et al. results utilizing Cepheid Variables, but has a higher level of uncertainty. The difference in uncertainty is due to Riess et al classification of two types of cepheid variables and their calibrations of cepheids using various distance measurement methods, which enhances the accuracy of the cepheids.

To look at trends at larger distances, data of Type Ia Supernovae were used, giving $H_0 = 53.6\ kms^{-1}Mpc^{-1}$, This is within the published value range. At longer distances, the data of Type Ia Supernovae show a non-linear pattern, with the gradient decreasing with distance, indicating a possible acceleration of the expansion.

The range of uncertainty in the expansion rate suggests that we will not be able to come up with an exact model of the universe based on this data alone, and that multiple models of the universe's fate are feasible. However, the acceleration in the expansion suggests the presence of dark energy, indicating that we are most certainly in a dark energy-dominated expansion age.

Due to the measured matter density in the universe, it is highly likely that our universe will continue to expand indefinitely and will not terminate in a "Big Crunch," as the gravitational impact of regular matter is insufficient to stop the expansion.

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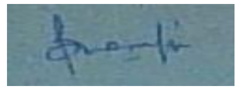
Verified copy of similarity index  12/07/2021

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