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UNDERSTANDING THE COMPOSITION OF THE UNIVERSE THROUGH COSMOLOGY AND PARTICLE PHYSICS: A REVIEW FOR HIGH SCHOOL STUDENTS

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Abstract

This study delves into the intricate realm of cosmology, unravelling the elemental composition and evolutionary trajectory of the universe. It meticulously examines the diverse components shaping the cosmic landscape, from the familiar baryonic matter encompassing stars, planets, and galaxies, to the elusive dark matter and dark energy, which collectively dominate a staggering 95% of the universe's energy content. Drawing upon a wealth of observational evidence spanning the large-scale distribution of galaxies to the cosmic microwave background radiation, our understanding of these cosmic constituents is meticulously elucidated. Through meticulous analysis of cosmic phenomena such as galaxy rotation curves and gravitational lensing, the research compellingly unveils the existence and influence of dark matter, challenging established gravitational paradigms. Key discoveries, including the accelerated expansion of the cosmos and the enigmatic nature of dark energy, gleaned from observations of distant supernovae and baryon acoustic oscillations, are underscored. Furthermore, this paper underscores the pivotal role of redshift and Hubble's Law in discerning cosmic expansion rates, paying homage to the seminal contributions of Edwin Hubble. By synthesizing insights from particle physics, theoretical models, and cosmological observations, this work serves as an invaluable resource, shedding light on the universe's composition and evolution while advancing our collective understanding of the cosmos.

Keywords: Astronomy, Cosmology, Universe composition, Dark matter, Hubble Constant, Particle Physics

I. Introduction

Cosmology, the study of the universe's origin, structure, and evolution, has led humanity on an extraordinary journey to understand the universe’s fundamental constituents. This paper embarks on an exploration of cosmology's important concepts, delving into how cosmological methodologies have shaped our understanding of the universe's composition. The paper begins with an introduction to cosmology and an explanation of the concepts essential in cosmology, after which it navigates through the cosmic scale to show the mysterious trio of dark energy, dark matter, and baryonic matter.

Dark energy, a mysterious force driving the accelerated expansion of the universe, acts as a basis of modern cosmology. Through careful analyses of large-scale galaxy distribution, baryon acoustic oscillations, and the cosmic microwave background radiation, its strong influence becomes clear. Similarly, the invisible form of matter known as dark matter affects cosmic events significantly. Galaxy rotation curves and gravitational lensing help us visualise the dark matter presence, guiding our understanding of cosmic structure. Cosmic microwave background radiation (CMBR) and Gravitational lensing are essential tools in cosmological studies, offering unique insights into the early universe, the distribution of matter and the gravitational interactions shaping the evolution of the universe. A very small but most important part of the universe’s composition covers the observable universe, i.e. visible matter also known as Baryonic Matter. Everything that we can observe including the components of life on Earth is all made from this Baryonic matter. Exploring the connection between baryonic matter and possible dark matter candidates like Weakly Interacting Massive Particles (WIMPs), alongside the clarification of the Hubble Constant and Edwin Hubble's influential discoveries, highlights our knowledge of known cosmic elements. Additionally, the paper explores the interesting contrast between matter and antimatter, casting light on their differences and their role in shaping the universe's fundamental properties.

To dig deeper into the clear understanding of the early universe formation, the connection of cosmology with particle physics plays a crucial role. To highlight the segments and evolvement of particle physics, the next section covers the detailing of theories and models that deliver the fundamental knowledge base and modernisation of astrophysics and cosmology, particularly in the domain of subatomic particles. Going through the realm of particle physics, the paper navigates through the categorisation of particles, mass, and the models of theoretical particles. From the ethereal Higgs Boson to the hypothetical graviton, each particle carries

implications for the universe's fabric and the fundamental forces governing it. The comparison between matter and antimatter, along with exploring particles in the standard model of physics, highlights the complex nature of cosmic elements. Many international agencies like NASA, ESA, ISRO, CERN, and LIGO are constantly involved in high-class research and experiments to gain deeper insights into cosmological understanding.
In the last section, this paper scrutinizes the collaborative efforts of international scientific agencies, from the United States, European Union, Japan, Russia, Australia and India in unravelling the universe's mysteries. Spanning timelines from the early 20th century to the present and projecting into the future, these missions herald a new era of discovery and understanding.
In synthesis, this paper not only explains the rich tapestry of cosmology's foundational principles but also clarifies the interplay between theoretical speculation and empirical observation. By bridging the realms of theoretical & particle physics and observational cosmology, it seeks to unravel the universe's composition and evolution, unveiling the profound secrets that govern our cosmic existence.

II. Cosmology: Scale of the Universe

Cosmology, a branch of astronomy, delves into the universe's origin and evolution, spanning from the Big Bang to the present day.[1] Its objective is to unravel the cosmos' nature, encompassing its physical laws and overarching properties governing its behaviour. Cosmologists, dedicated scientists in this field, employ a blend of theoretical frameworks, observations, and computational models to decipher the universe's history and composition.

Fig. 1. The illustration depicts the observable universe on a logarithmic scale, with increasing distance from the Sun radiating outward. (Left), and The Hubble eXtreme Deep Field (XDF), finalized in September 2012, captures the most distant galaxies ever photographed at the time. Apart from a handful of prominent foreground stars distinguished by their diffraction spikes, each pinpoint of light in the image represents an individual galaxy. (Right) [2]

The Constraints of Cosmology: Navigating the constraints of cosmology proves challenging, primarily due to limited direct observations caused by vast celestial distances and timescales. Thus, cosmologists rely on indirect evidence such as the cosmic microwave background radiation and the distribution of galaxies to interpret cosmic history and composition. Tackling the enigmatic dark matter and dark energy, constituting a staggering 95% of the universe's energy, remains a significant hurdle given their elusiveness.[3] Despite these challenges, cosmology has made remarkable progress, offering insights into the universe's evolution. Ongoing advancements in theoretical methodologies and observational technologies promise to unravel more cosmic mysteries and shed light on the universe's ultimate destiny.
How Cosmology Has Decided the Composition of the Universe: Through a combination of observational data, advanced technologies, and theoretical models, cosmologists have been able to understand the division of the universe's 3 main components: Dark Energy, Dark Matter, and Baryonic Matter.[2] Furthermore, developments in observational technologies—such as high-resolution imaging and spectroscopy—have made it possible to characterise ordinary stuff, which is primarily made up of baryons like protons and neutrons. The integration of theoretical models and empirical data in cosmology has not only made the universe's complex structure visible. Still, it has also influenced our understanding of its fundamental dynamics and principles. Cosmologists have deciphered the universe's composition through a synthesis of observational data, technological advancements, and theoretical constructs. Breakthroughs in observational tools, including high-resolution imaging and spectroscopy, have facilitated the characterization of ordinary matter, primarily composed of baryons like protons and neutrons. The fusion of theoretical models with empirical evidence not only unveils the universe's intricate structure but also deepens our understanding of its underlying dynamics and principles.

III. Composition of Universe

The composition of the universe encompasses dark energy, dark matter, and baryonic matter, each playing a crucial role in shaping cosmic structures and phenomena.[4] Cosmological observations suggest the Universe's composition is dominated by unseen components. Ordinary matter, the kind that forms stars, planets, and us, comprises a mere 4.9% of the total mass-energy budget. Roughly 26.8% is attributed to dark matter, a mysterious substance with gravitational effects but undetectable through electromagnetic interactions. The largest constituent, however, is dark energy, accounting for 68.3%. Dark energy exhibits a repulsive force, causing the Universe's expansion to accelerate. The true nature of dark matter and dark energy remains an active area of research in cosmology. In this section, dark energy, dark matter, and Baryonic matter are discussed in detail.

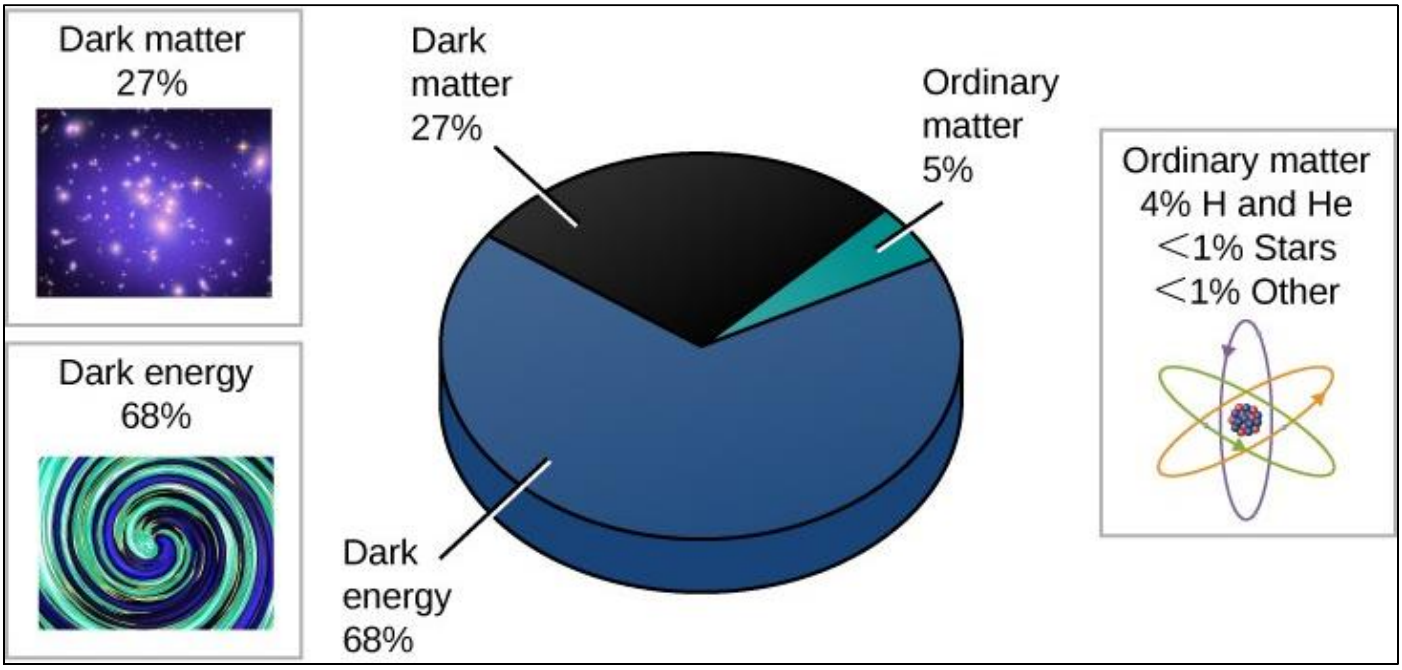

Fig. 2. Present-day composition of the universe, with the highest presence of Dark Energy at 68.3%, and matter composing 26.8% Dark Matter and 4.9% Baryonic Matter.

Dark Energy

Dark energy is a mysterious force that scientists believe is causing the universe to expand at an accelerating rate.[6] It's important to note that dark energy isn't fully understood, but it's thought to be a type of energy that fills all of space and pushes things apart. The evidence of dark energy primarily comes from cosmologist's observations of distant supernovae. Before 1998, scientists believed that the universe's expansion was decelerating due to the mutual gravitational attraction of all matter. However, in 1998, two independent teams studying distant Type Ia Supernovae found that these supernovae were fainter than expected, suggesting that the expansion of the universe was accelerating.[7] The reason for this was that all Type Ia supernovae are "standard candles" in cosmology as they have intrinsic brightness, meaning that all Type Ia supernovae wherever they are in the universe, of the same intrinsic brightness should have the same apparent brightness. So, when the two independent teams studied the Type Ia supernovae, they observed that these objects were fainter than expected for their redshifts. As the universe expands, the wavelengths of light emitted by far-off objects also stretch out, causing a shift of the light towards longer wavelengths, a phenomenon known as redshift.

- Redshift [8]
  When the light from an object, such as a star, galaxy, or other celestial body, is moved toward longer wavelengths as it travels through space, the process is known as redshift in astronomy. This change in direction toward the red end of the electromagnetic spectrum is seen as a displacement of spectral lines or a change in the hue of the light.
  The formula for redshift is as follows:

$$z = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} \quad \text{--- Equation 1.}$$

where,

z = Redshift

$\lambda_{observed}$ = Observed Wavelength of Light

$\lambda_{emitted}$ = Wavelength of Light Emitted by the Source

Thus, the higher the redshift, the larger the stretching of the light, and the farther away the object is from Earth. Thus scientists determined that the explanation for the dimmer Type Ia supernovae was that the expansion of the universe was accelerating.[9] But this implied the presence of a mysterious force that was acting against gravity, pushing galaxies apart with increasing strength over cosmic time. This mysterious force is now known as dark energy, a form of energy that permeates space and counteracts the attractive force of gravity on large scales. Later Observations of Redshifts in various galaxies and galactic clusters further reinforced the presence of dark energy. Some of these observations and evidence involve the distribution of galaxies, acoustics oscillations and cosmic microwave background radiations.

- Large-Scale Distribution of Galaxies
  Cosmologists study how galaxies are distributed throughout the universe on extremely large scales.[10] By mapping the positions of millions of galaxies and calculating the distribution of matter, cosmologists can infer the gravitational forces at play. The key observation they made was that the galaxies appear to be moving away from each other. However, what was interesting

was the rate of expansion. Rather than slowing down due to the gravitational forces of attraction between galaxies, which would be considered the norm for a universe consisting mainly of matter, the expansion was accelerating. This further indicated to scientists that the dark energy was responsible for counteracting the attractive force of gravity.

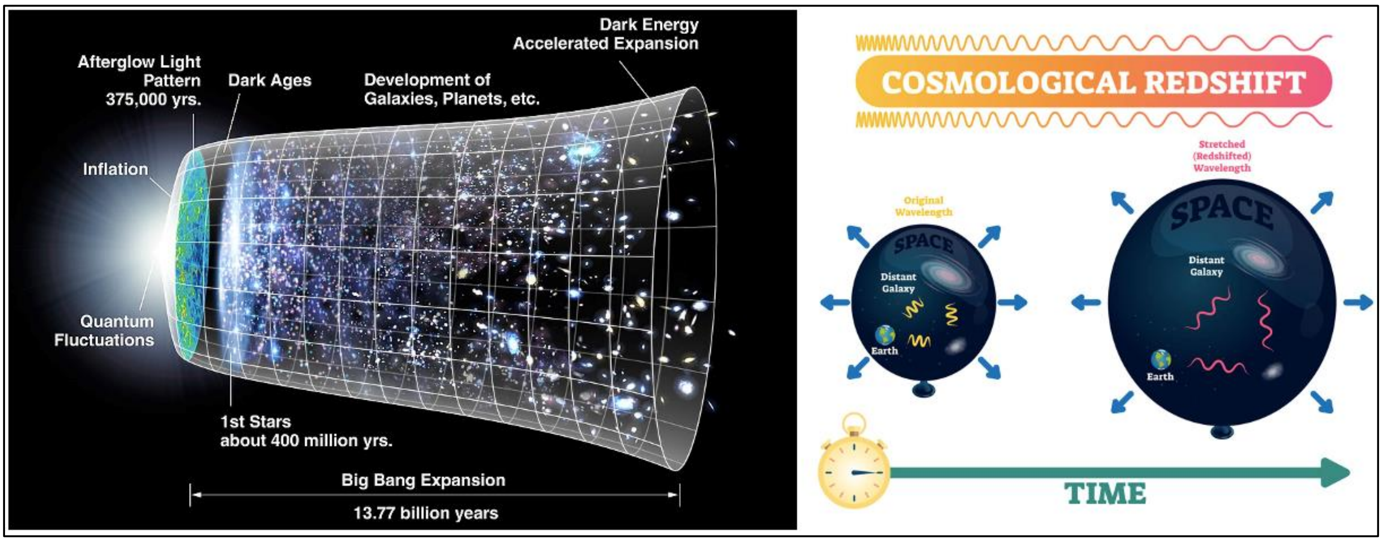

Fig. 3. An artist's rendition of the Big Bang cosmological model, widely regarded as the prevailing theory in physical cosmology, illustrates the effects of accelerated expansion attributed to dark energy. (Left) [Wikimedia Images], and Diagram showing how the expansion of space stretches the wavelength of light from distant galaxies, causing a redshift. (Right) [Getty Images]

- Baryon Acoustic Oscillations (BAO)
  The presence of dark energy in our universe was demonstrated convincingly by Baryon Acoustic Oscillations. BAO measurements are based on a distinctive scale imprinted in the early universe's large-scale dispersion of matter, when baryons and photons were strongly connected, resulting in pressure waves.[11] Pressure waves that are fixed in space during recombination determine the sound horizon. Following recombination, matter began to clump under gravity, resulting in the large-scale structure of the cosmos (European Space Agency).[12] The presence of BAO is indicated by a "bump" or "peak" in the correlation function or power spectrum of the galaxy distribution. When combined with other cosmological sensors such as cosmic microwave background radiation and supernova data, BAO observations provide constraints on cosmological parameters.
- Cosmic Microwave Background (CMB) Radiation
  CMBR radiation comes from the early universe, approximately 380,000 years after the Big Bang.[13] The patterns created by the temperature fluctuations in the CMB hold vital information about the composition of the universe. Specifically, the measurements of the CMB anisotropies, tiny temperature fluctuations observed in CMB radiation, which allow cosmologists to study the expansion rate of the universe at different cosmic rates and dark energy is what is attributed to the increased expansion rate of the universe.[14]

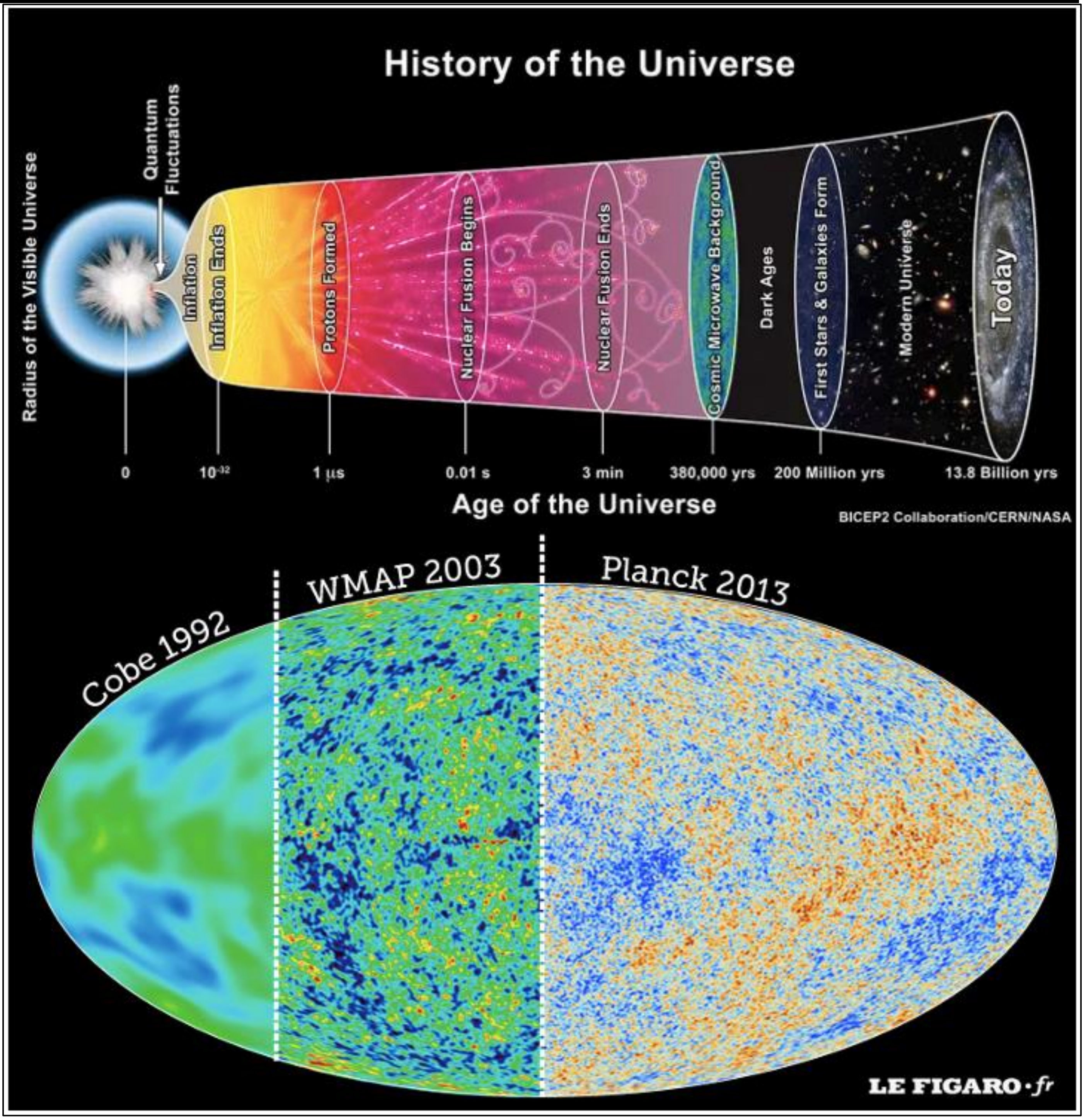

Fig. 4. Timeline of the Universe from the Big Bang to the present day, travelling almost 13.8 billion years. (Top) [NASA Images], Map of the Universe using by three different cosmic microwave background (CMB) space missions, Cosmic Background Explorer (COBE), Wilkinson Microwave Anisotropy Probe (WMAP), and Planck. (Bottom) [15]

All these observations combined provided undeniable evidence for the presence of dark energy, explaining the different expansion rates of the universe over cosmic time, and cosmologists determined that due to its dominant role in the universe, dark energy accounts for about 68.3% of the universe's total energy content.[16]

Dark Matter

Dark matter is like an invisible scaffolding holding the universe together. It's a mysterious substance that makes up most of the matter in the universe, estimated to be about five times more common than the stuff we can see. The strange thing is, that dark matter doesn't interact with light or regular matter, so we can't directly observe it.[17] We only know it exists because of its gravitational influence on visible matter. It's a bit like feeling an unseen force holding your hand while walking in the dark. Certain cosmological phenomena like rotation curves of galaxies and gravitational lensing brought out the possibilities of the presence of dark matter.

- Galaxy Rotation Curves
  In galaxies, stars and other visible matter are concentrated towards the centre. As stated in Newton's laws of motion and gravity, the stars closer to the centre should orbit at a faster velocity than stars further away.[18] In the 1930s, astronomer Fritz Zwicky studied the motion of galaxies within the Coma galaxy cluster and discovered that their velocities were much higher than expected based on visible matter alone, being the first to propose the existence of dark matter.[19] Later in the 1970s, astronomer Vera Rubin conducted studies on the rotation curves of spiral galaxies.[20] Her observations again revealed that the outer regions

of galaxies were rotating at higher velocities than predicted by the visible matter's distribution. This, again led to the proposal of an unseen mass - dark matter. The unexpected behaviour could only be explained if there is additional unseen mass that contributes to the stars moving at higher velocities and the gravitational pull.

- Gravitational Lensing
  Einstein's theory of general relativity suggests that massive objects like stars, galaxies, and clusters of galaxies can warp the fabric of spacetime surrounding them.[21] Due to this curvature, the path of light passing near these objects bends like how light passing through a lens is bent, resulting in multiple arcs and images.[22] The degree of lensing is proportional to the mass of the object. Thus, by studying the lensing effects, scientists can estimate the mass of the object. In the mid-20th century, scientists, through gravitational lensing observations of galaxy clusters constantly noticed a discrepancy between the estimated mass through gravitational lensing and the estimated mass through visible matter alone.[23] The estimated mass through lensing was significantly higher than the mass estimated on purely visible matter, indicating the presence of unseen matter. [24] The observation of the Bullet Cluster provided one of the strongest pieces of proof.[25] This merging galaxy cluster showed a distinction between the lensing effects and the visible matter, which was seen in X-rays. Due to the electromagnetic nature of the visible matter, it had collided and interacted, but the lensing effects remained concentrated around the galaxies. It was evident from this "separation of mass" that a sizable percentage of the mass was not interacting electromagnetically, indicating the presence of invisible, dark matter.

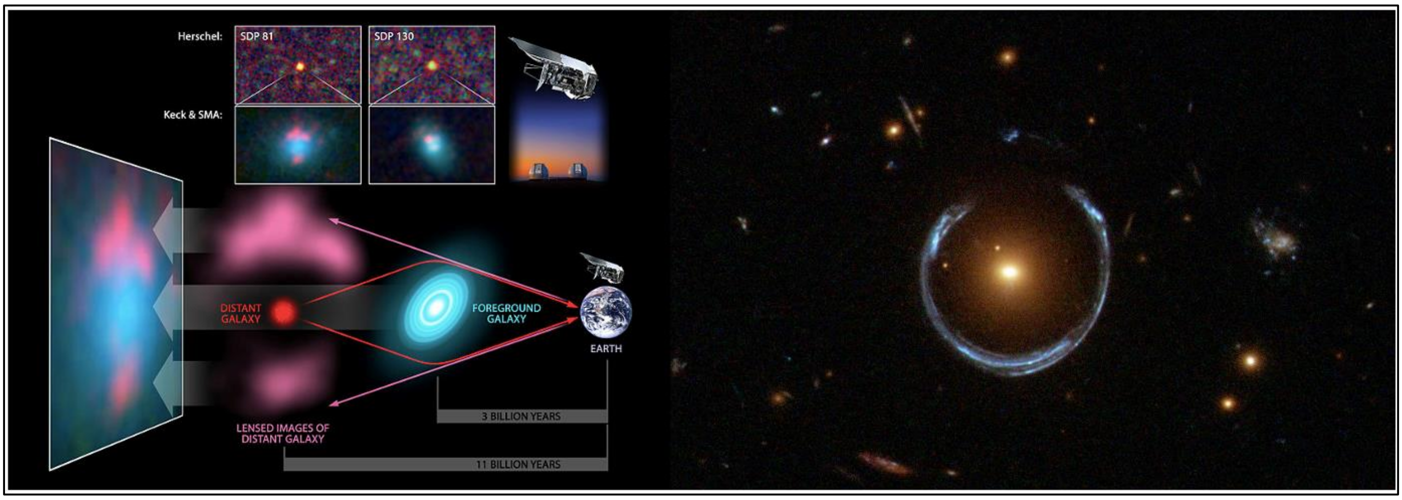

Fig. 5. The illustration depicting gravitational lensing, a cosmic phenomenon magnifying distant galaxies, with the Herschel Space Observatory (Left), and A Ring-like image formed due to gravitational lensing, popularly known as the Einstein Ring, captured by Hubble Space Telescope's Wide Field Camera 3. (Right) [Wikimedia Images]

The weak interaction characteristic of dark matter necessitates a multifaceted approach to unveil its nature. Scientists have theorised some possible candidates for Dark matter. One prominent theoretical candidate for dark matter is the Weakly Interacting Massive Particle (WIMP).[26] WIMPs possess significant mass, potentially exceeding that of a proton, while interacting with normal matter via the weak nuclear force. Deep underground experiments utilizing highly sensitive detectors aim to capture the subtle interactions that would occur when WIMPs from the galactic halo collide with atomic nuclei within the detector.[27] Beyond WIMPs, the realm of dark matter candidates is vast. Axions, for example, are theorized to be extremely lightweight particles possessing unique properties that necessitate alternative experimental strategies for detection.[28] The ongoing quest to identify dark matter necessitates continued exploration of various theoretical frameworks alongside the development of increasingly sophisticated experimental techniques. This multifaceted endeavour holds the promise of a ground-breaking revelation that would illuminate a substantial component of our universe and potentially lead to a paradigm shift in our understanding of fundamental physics.

- WIMP particle and its connection to Dark Matter
  Weakly Interacting Massive Particles, or WIMPs, are hypothetical particles that are one of the leading candidates for dark matter.[26] WIMPs are posited as subatomic particles, which are similar in size or larger than protons but significantly heavier. They don't carry an electric charge, and that is one of the reasons why they are considered "weakly interacting" as they don't interact via the electromagnetic force, which is the force responsible for almost all everyday interactions between matter particles.[29] Instead of the electromagnetic force, WIMPs are thought to interact via the weak nuclear force, one of the 4 fundamental forces of nature (along with strong nuclear force, gravity, and the electromagnetic force). The most significant interaction WIMPs have is through gravity. Like all forms of matter, WIMPs are influenced by gravity, and thus, they exert a gravitational force on other objects.[30] These gravitational interactions are one of the reasons why WIMPs are a potential candidate for dark matter as their gravitational effects can be observed even though they don't emit or absorb light. It is believed that they provided the initial density fluctuations within the universe, in which regions with higher densities were able to attract more matter around them to form galaxies, galaxy clusters, and large-scale cosmic structures.[31]

Baryonic Matter

Baryonic Matter, also known as ordinary matter, has been presented in early observations and theories of the universe. Baryonic matter contains protons, neutrons, and electrons, and it's the matter that makes up stars, planets, galaxies, and everything else that is observable in the universe.[32]

In the early 20th century, cosmologists such as Georges Lemaitre and Alexander Friedmann developed models based on Albert Einstein's theory of general relativity to describe the evolution of the universe.[33] The models suggested that the universe used to be much hotter and denser, and over time, it cooled down. As the universe cooled down after the accepted theory of the Big Bang, the conditions were ripe for the formation of light elements such as hydrogen and helium.[34] Specifically, approximately 3 minutes after the Big Bang, the universe was hot enough for nuclear fusion to take place, creating helium and minute amounts of other light elements. This is known as Big Bang nucleosynthesis and has a lasting imprint on the universe's elemental composition. [35] Cosmic Microwave Background (CMB) provides strong evidence for the Big Bang Theory.[36] As the hot, early cosmos's afterglow, the CMB's precision measurements showed its temperature and distribution, which were in line with the expectations of a universe dominated by baryonic matter.[37] Light elements like hydrogen and helium were abundantly discovered in the universe, and their abundances closely matched the predictions of Big Bang nucleosynthesis models that relied on the presence of baryonic matter.[38] The concept that baryonic matter comprised a large part of the universe was strongly supported by this uniformity. Observations of the large-scale distribution of galaxies and cosmic structures in the second half of the 20th century revealed patterns that might be attributed to the gravitational pull of baryonic matter. These patterns could be reproduced by computer simulations of structure development that took baryonic matter's gravitational pull into account.[39] Baryonic matter was directly observed in the interstellar medium, stars, galaxies, and other astronomical objects. Astronomers developed a profound grasp of the nature of baryonic matter and its function in the cosmos by investigating the characteristics, lifecycles, and interactions of these things. The presence of elements associated with baryonic matter was confirmed by spectroscopic examination of stars, galaxies, and interstellar gas.[40] These elements were proven to be present in these astronomical objects by the detection of spectral lines that corresponded to them.

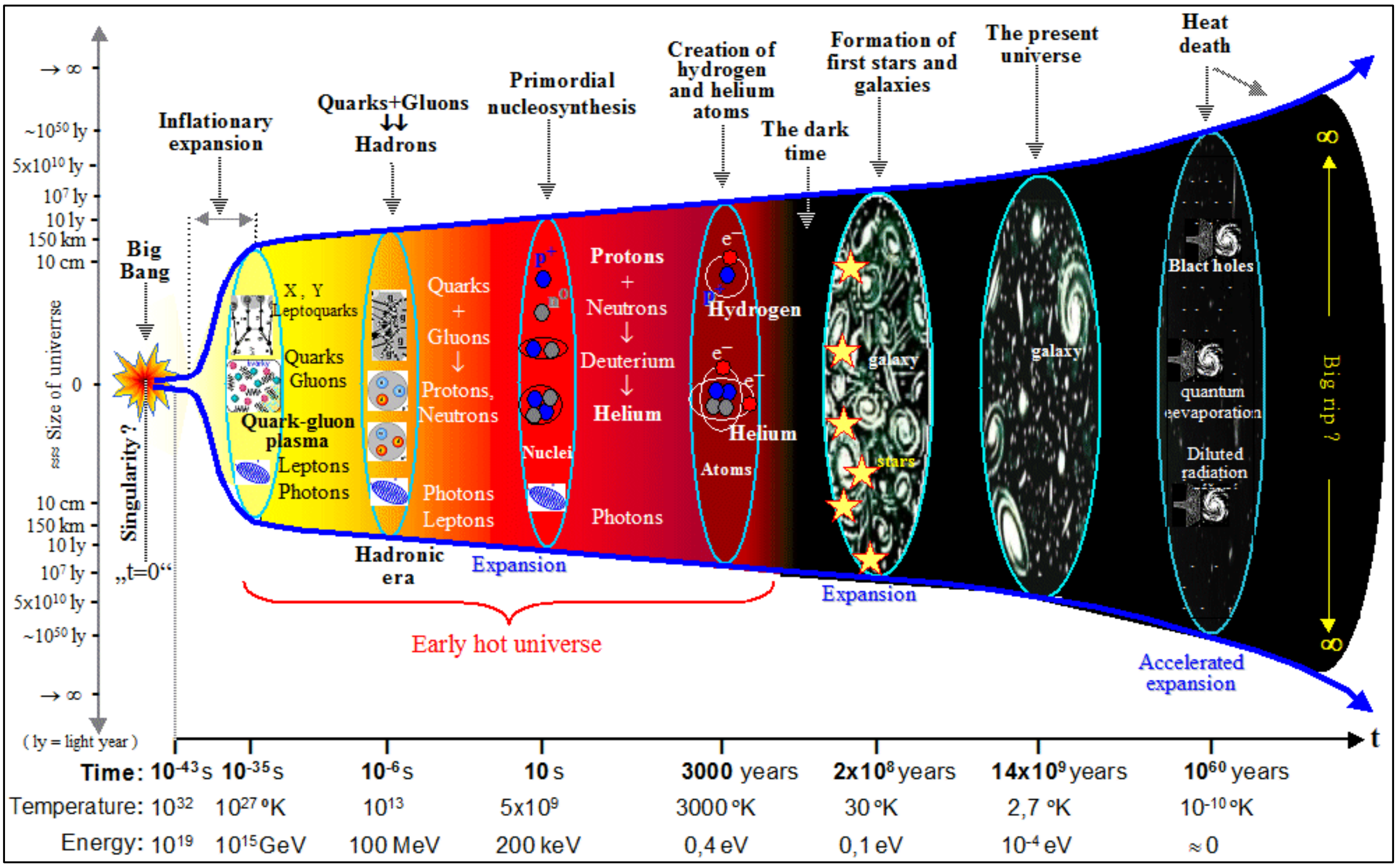

Fig. 6. A concise schematic diagram outlining the origin and evolution of the universe, and various baryonic matter particles emerging, following the standard cosmological model LDCM. The diagram illustrates the gradual cooling of the early universe, with colours transitioning smoothly from white near the big bang, through yellow to red, gradually darkening to black.[41]

Hubble's Discovery and Hubble Constant

Edwin Hubble's ground-breaking observations in the 1920s revealed a relationship between the distance to galaxies and their redshifts.[42] He found that the velocity at which galaxies were moving away from us was directly proportional to their distance. This relationship is now known as Hubble's Law [43]:

$$v = H_0 \times d \qquad \text{Equation 2.}$$

where,

v = Velocity of recession

H_0 = Hubble Constant

d = Proper distance

Proper distance represents the distance between two regions of space at a constant cosmological time. This discovery granted strong evidence for the Big Bang theory, which states that the universe began as an extremely hot and dense state that has been expanding and cooling ever since.[44] The Hubble Constant quantifies the current rate of cosmic expansion.[45] It tells us how fast the universe is stretching or expanding with time. Mathematically, it is represented as H_0, and it is measured in kilometres per second per megaparsec (km/s/Mpc). This means that for every megaparsec, a unit of cosmological distance, we move away from an object in the universe, the object appears to be retreating from us at a speed of H_0 kilometres per second.[46]

Antimatter

Matter is a substance made up of various types of particles that occupy physical space and have inertia. According to the principles of modern physics, there are various types of matter particles each having a specific mass and size.[47] Antimatter is another form of baryonic matter that is composed of antiparticles, the counterparts of particles that make up ordinary matter.[48] These antiparticles contain the same mass but the opposite electrical charge and other quantum properties when compared to their corresponding particles in ordinary matter. Matter makes up the visible universe, including galaxies and everything within. Since antimatter isn't found in significant quantities around the universe, its origin remains one of the many mysteries of physics.

Stability and Production: Ordinary matter is vast in the universe and is stable under the right conditions. It can exist in various forms, such as plasmas, gases, liquids, and solids.[49] On the other hand, antimatter is extremely rare in the universe, and it isn't stable when it encounters matter, which is, as stated, abundant in the universe. It's produced during high-energy processes like particle collisions in accelerators and some types of radioactive decay. [50]

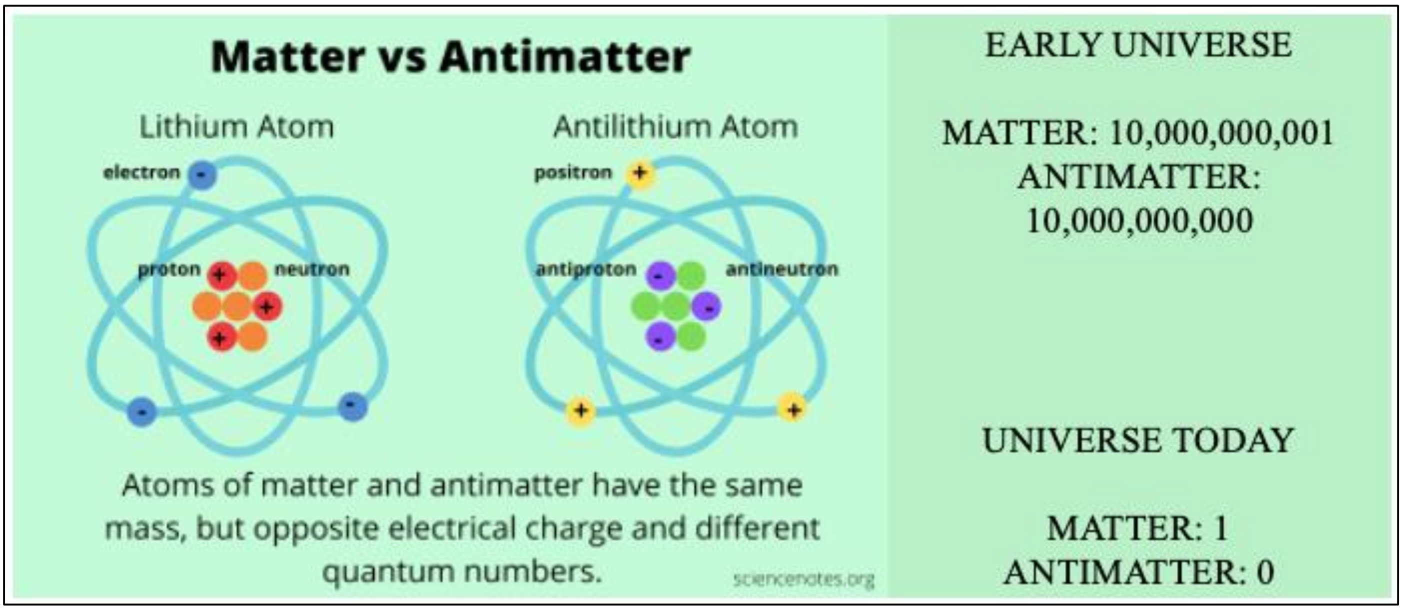

Fig. 7. Image showing the matter particle Lithium Atom and Antimatter particle Antilithium Atom (Left) [Science Notes], and the imbalance equation of the number of matter particles vs number of antimatter particles leading to the dominance of matter today.

IV. Standard Model of Physics and Particles in the Universe:

Particle physics is a branch of physics that explores the fundamental constituents of matter and the forces that govern their interactions. It plays a crucial role in understanding the smallest building blocks of the universe and their behaviour, which in turn has profound implications for cosmology.[51] By studying particles and their interactions, particle physicists seek to unravel the mysteries of the universe's structure, composition, and evolution. The most important model in physics is the Standard Model, a theoretical framework that describes the fundamental particles and three of the four fundamental forces—electromagnetic, weak, and strong nuclear forces.[52] The Standard Model classifies particles into two main categories: fermions and bosons.[53] Fermions, including quarks and leptons, are the building blocks of matter and make up all known particles in the universe. Bosons, on the other hand, are force carriers responsible for mediating interactions between particles. The Standard Model successfully explains a wide range of phenomena observed in particle physics experiments. It predicts the existence of particles such as the Higgs Boson, which was experimentally confirmed in 2012 at the Large Hadron Collider (LHC). Additionally, the model explains the interactions between particles and provides insights into the behaviour of matter at the smallest scales.[54][55]

Some key particles described by the Standard Model include quarks, which are elementary particles that combine to form protons and neutrons, the building blocks of atomic nuclei.[56] Leptons, such as electrons and neutrinos, are another class of fundamental particles with important roles in particle interactions.[57] Bosons, including photons responsible for electromagnetic interactions and W and Z bosons mediating weak nuclear interactions, complete the roster of particles described by the Standard Model.[58] Together, these particles and their interactions form the foundation of our understanding of the universe at the subatomic level.

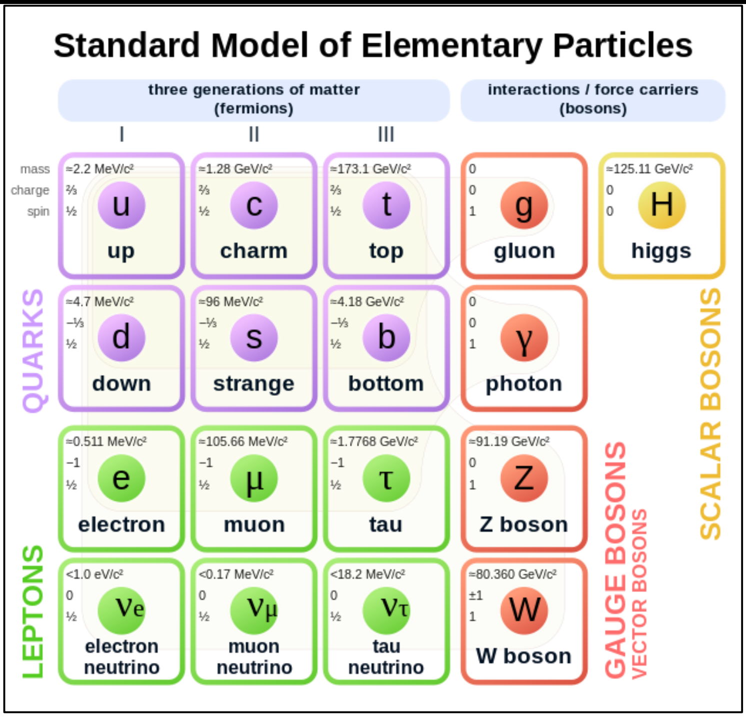

Fig. 8. The Standard model of elementary particles in particle physics showing the 12 fundamental fermion particles categorised in three generations and 5 fundamental boson particles. [Wikimedia Images]

Mass categorisation of Particles based on the Standard Model [59]

- Light Mass
  Light Mass refers to objects that have a relatively low mass compared to other objects. Light mass objects typically exhibit characteristics such as high mobility, rapid motion, and a greater influence of quantum effects due to their low mass. Examples of light mass include subatomic particles like electrons and neutrinos, which have lower masses compared to atomic nuclei.
- Medium Mass
  Medium mass, as the name suggests, is in the middle of light masses and heavy masses. This mass is stable under normal conditions and can include average-sized celestial objects such as asteroids, comets, and some planets. The atomic nuclei, which consist of protons and neutrons, are also considered to be medium-mass objects
- Heavy Mass
  Heavy masses are the heaviest possible masses when compared to other objects. They exhibit strong gravitational effects on their surroundings due to their mass. Furthermore, they are less influenced by quantum effects and are often related to massive celestial bodies like planets, stars, and large particles in high-energy experiments. In addition, heavy atomic nuclei are those that are dense and have many protons and neutrons.

Table. 1. Table showing the elementary particles in the Standard Model of particle physics and their characteristics. [60]

Particle Type	Particle	Symbol	Electric Charge (e)	Mass (GeV/c²)	Spin	Interaction
Quarks	Up Quark	u	+2/3	0.0022	1/2	Strong, Electromagnetic, Weak (via W boson)
	Down Quark	d	-1/3	0.0047	1/2	Strong, Electromagnetic, Weak (via W boson)
	Charm Quark	c	+2/3	1.27	1/2	Strong, Electromagnetic, Weak (via W boson)
	Strange Quark	s	-1/3	0.095	1/2	Strong, Electromagnetic, Weak (via W boson)
	Top Quark	t	+2/3	173.1	1/2	Strong, Electromagnetic, Weak
	Bottom Quark	b	-1/3	4.18	1/2	Strong, Electromagnetic, Weak

Leptons	Electron	e	-1	0.000511	1/2	Electromagnetic, Weak
	Electron Neutrino	νe	0	<0.000002	1/2	Weak
	Muon	μ	-1	0.106	1/2	Electromagnetic, Weak
	Muon Neutrino	νμ	0	<0.000002	1/2	Weak
	Tau	τ	-1	1.777	1/2	Electromagnetic, Weak
	Tau Neutrino	ντ	0	<0.000002	1/2	Weak
Gauge Bosons	Photon	γ	0	0	1	Electromagnetic
	Gluon	g	0	0	1	Strong
	W Boson	W±	±1	80.4	1	Weak
	Z Boson	Z0	0	91.2	1	Weak
Higgs Boson	Higgs Boson	H0	0	125.1	0	Provides mass via Higgs field (Weak, Electromagnetic)
Graviton (Hypothetical)	Graviton	-	0	Not detected yet	2 (theoretical)	Hypothetical, Gravity (not part of Standard Model)

Within the Standard Model of particle physics, two notable particles emerge, which are the Higgs Boson[61], empirically confirmed in 2012, and the theoretical Graviton[62]. The Higgs Boson reveals the mechanism by which particles acquire mass, a pivotal aspect of the Standard Model. Conversely, the graviton, although predicted theoretically, has yet to be empirically detected. It is postulated to serve as the mediator of gravitational interactions, representing a fundamental component in the quest for a unified understanding of the fundamental forces of nature.

- Higgs Boson
  The Higgs Boson is a fundamental force-carrying particle of the Higgs field, a field responsible for granting other particles their mass.[63] It is referred to as the "God Particle" due to its fundamental importance in explaining the origins of mass in the universe. The Higgs field, which the Higgs Boson is associated with, is a field of energy that permeates all of space. As claimed by the theory, particles gain mass by interacting with this field. The more a particle interacts with this field, the heavier it is. The Higgs Boson is a subatomic particle with a specific mass. Its mass is approximately 125 giga-electron volts (GeV/c^2), which is around 133 times the mass of a proton.[64] Furthermore, it has no electric charge and zero spin. Immediately after being produced, the particle decays into other particles as it is extremely unstable. When particles move through the Higgs field, they experience a resistance or a drag, which is essentially the same as acquiring mass, and those particles that interact more strongly with the Higgs field gain more mass, while others remain lighter.[65] This explains why some particles such as the W and Z bosons are heavy, while others like electrons are relatively light.
- Graviton
  The graviton is a particle that is thought to be responsible for carrying the force of gravity. It is a hypothetical elementary particle and is similar to how the photons mediate the electromagnetic force.[66] The idea of the graviton is rooted in the concept of gauge bosons, the particles that mediate the fundamental forces. One example of this is the W and Z bosons mediate the weak nuclear force and another example is the photon which, as mentioned before, is responsible for moderating the electromagnetic force.[67] The gravitational force is one of two fundamental forces in the standard model of particle physics that does not have a confirmed mediator. The way that gravitons work is that when objects with mass interact with each other, they do so by exchanging gravitons. A massive object, such as a planet, generates a gravitational field, and that field is made known to other objects through the exchange of virtual gravitons.

V. Important International Partners and Milestones in the Timeline of Cosmology

Cosmology and particle physics are propelled forward by a global network of institutions and agencies collaborating to unravel the mysteries of the universe. Major contributors include NASA [68] and Fermilab [69] from the United States, ESA [70] from Europe, ISRO [71] from India, JAXA [72] from Japan, Roscosmos [73] from Russia, CSIRO [74] from Australia, CERN [75] from Switzerland, and the Large Hadron Collider (LHC) [76] spanning multiple European countries. From pioneering research initiatives to ambitious missions, these organizations lead the forefront of scientific discovery, alongside collaborations like the Event Horizon Telescope (EHT) [77] and international partnerships such as the International Space Station (ISS) [78]. Together, they push the boundaries of human knowledge in understanding cosmological phenomena and the fundamental building blocks of matter.

- 1900 - 1970:
  Particle physics underwent a revolutionary period in the early 20th century with the clarification of special relativity and quantum mechanics. The theoretical groundwork for Carl Anderson's 1932 discovery of the positron was established in 1928 by Paul Dirac's derivation of the Dirac equation, which predicted antimatter.[79][80] At the same time, the 1932 discovery of the neutron by James Chadwick laid the groundwork for later advances in our understanding of nuclear forces.[81]
- 1970 - 2023:
  The development of potent particle accelerators in the second half of the 20th century brought about a paradigm change. Since its founding in 1954, CERN has become a major international hub for particle physics research. Quark flavour unwrapping [82] began with the discovery of the charm quark at SLAC and Brookhaven in 1974 [83]. Important discoveries were made possible by CERN's Super Proton Synchrotron (SPS) and Large Electron-Positron Collider (LEP), notably the discovery of the W and Z bosons in 1983.[84] With the introduction of the Large Hadron Collider (LHC) at CERN in the 21st century, a new era was ushered in and validated the Standard Model with the ground-breaking discovery of the Higgs boson in 2012.[54] Space agencies were instrumental in this as well. NASA's Fermi Gamma-ray Space Telescope (2008)[85] investigated high-energy gamma rays, while ESA's Planck satellite (2009) [86] used cosmic microwave background radiation to improve our understanding of the early cosmos.[87]
- The Future:
  Forward-looking, ambitious missions characterise the course of particle physics research. In addition to ground-based observatories, Many advanced Earth and Space observatories are set to debut soon and offer previously unheard-of glimpses into the early universe. With its planned operation, CERN's High-Luminosity LHC [88] is expected to improve our ability to investigate uncommon processes and discover new particles.

Discussion: Challenges and Possibilities

Significant progress has been made in the field of cosmology towards solving the puzzles surrounding the origins, evolution, and makeup of the universe. The observation of the expanding universe, which was based on the motion of far-off galaxies, was one important finding that drastically changed our conception of cosmic dynamics. Furthermore, strong evidence for the Big Bang theory was provided by the discovery of Cosmic Microwave Background Radiation (CMB), which offered a window into the early cosmos and confirmed important tenets of cosmological models. The discovery of dark matter and dark energy has been another significant advancement in cosmology. Although their presence is suggested by observations of galactic rotation curves and the universe's accelerated expansion, their exact nature is still unknown, which presents a major obstacle to our understanding of the cosmos. Comprehending the basic characteristics of these mysterious objects is crucial to building a more comprehensive representation of the universe. Moreover, thorough mapping of the distribution of cosmic structures and galaxies has provided insight into the genesis and development of large-scale structures in the universe. Our comprehension of the complex web of structure and organisation that makes up the universe has improved as a result of these findings, which have offered insightful information on the fundamental mechanisms guiding cosmic evolution. Additionally, our current understanding of the early moments of the universe is yet incomplete, and it requires further theoretical investigation and advancements in technology to overcome the same Theorists and experimentalists must work together from all over the world to solve these obstacles. Further developments in observational methods, made possible by space missions and next-generation telescopes, will offer clearer understanding of cosmic processes. Creating and evaluating newer models that bridge the gap between quantum mechanics and gravity would require incorporating knowledge from particle physics, astrophysics, and cosmology. Cosmology still has to overcome several obstacles. Bringing general relativity and quantum mechanics together to create a coherent theory of quantum gravity is one of the biggest obstacles. The complexity of this endeavour is highlighted by the fact that while existing theoretical frameworks, including loop quantum gravity and string theory, attempt to address this problem, a final answer is still elusive.

Conclusion

This paper goes through the composition of the universe and the cosmology techniques that were responsible for determining it. As mentioned throughout the paper some of these concepts are purely theoretical, and there isn't concrete evidence available to verify and validate their existence. Thus, it's important to further investigate this universe to find the necessary evidence that can prove once and for all the existence of them much like what occurred with the Higgs Boson article which was initially purely theoretical instead of real. To further expand this paper, there should be more investigation into particles that could potentially make up the universe. As mentioned previously, the Graviton is still a hypothetical particle because it has not yet been discovered by scientists, and any evidence of it right now is just scientific speculation. We still await solid and undeniable proof that the Graviton truly exists. Furthermore, there may be other particles that scientists have yet to discover and hypothesise. In addition, we still await the day when cosmology will allow us to physically observe and harness the capabilities of dark matter and dark energy for now we only know that they exist but are unable to interact with them in the same way we can with baryonic matter.

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