Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 12 ~ Issue 4 (April 2026) pp: 56-85
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Development of Modern Astro Physics and Evaluation of Universe's Termination

Dr Hossain KA
Vice Chancellor of Bangladesh Maritime University (BMU), Dhaka, Bangladesh

Abstract: *Modern Astro Physics is the branch of science that applies the laws of physics and chemistry to explain the birth, life, and death of stars, planets, galaxies, nebulae, and other objects in the universe. Unlike classical astronomy, which focuses on the positions and motions of celestial bodies, astrophysics seeks to understand their physical nature—what they are and how they work.As dark energy pushes galaxies apart, stars will run out of fuel, and black holes will evaporate via Hawking radiation. The universe will end in a state of maximum entropy, reaching a cold, dark, and dilute state. Modern Astro Physics suggests the universe will likely end in a Heat Death or Big Freeze, and that has driven by accelerating expansion from dark energy. However, modern cosmology directs the universe began around 13.8 billion years ago with the Big Bang, and that has been growing since, and is presently dominated by dark energy, causing enhanced expansion. However, If the universe's density were high enough, gravity could overcome the current expansion, causing the universe to stop expanding and eventually collapse back into a singular point. On the other hand,if the density of dark energy increases over time, it could become strong enough to tear galaxies, stars, planets, and eventually atoms apart. Again, a theory suggesting a, cyclical scenario where a Big Crunch is followed by a new Big Bang, implying a, series of universes. Actually, the future, of the universe is still a subject of research, with its final state depending heavily on the precise nature of dark energy and the total amount of matterin the cosmos. This researchpaper will depict the development of modern astrophysics and evaluate the consequence of universe with its final destination.*

Keywords: *Cosmology, astrophysics, dark energy, black hole, heat death*

Received 08 Apr., 2026; Revised 12 Apr., 2026; Accepted 18 Apr., 2026 © The author(s) 2026. Published with open access at ***www.questjournals.org***

I. Introduction

Modern Astro Physics or quantum cosmology is simply put the application of quantum principles to the whole universe. Nonetheless this highly ambitious mission statement, this task is at least to some extent; already within reach of current physics[1]. Unlike classical astronomy, which primarily concerns the positions and motions of celestial bodies, astrophysics focuses on understanding their physical properties and underlying mechanisms—what these objects are and how they function. The scope of astrophysics is extremely broad, encompassing phenomena from subatomic particles to the largest cosmic structures [2]. Within this field, cosmology plays a central role by investigating the origin and large-scale evolution of the universe, including concepts such as the Big Bang, dark matter, and dark energy. Other major branches include stellar astrophysics, which examines the life cycles of stars from their formation in nebulae to their endpoints as white dwarfs, neutron stars, or black holes; galactic astrophysics, which studies the structure and evolution of galaxies such as the Milky Way; and high-energy astrophysics, which focuses on extreme phenomena including quasars, gamma-ray bursts, and active galactic nuclei [3]. Quantum cosmology represents an effort within theoretical physics to construct a quantum description of the entire universe. In this framework, the universe is modeled not as classical spacetime but in terms of a wave function that encodes all possible configurations. More broadly, quantum cosmology treats the universe itself as a quantum system [4]. This area encompasses two primary lines of investigation. The first involves developing quantum versions of cosmological models that describe the universe's dynamics, often under the simplifying assumption of spatial homogeneity [5]. Classical models such as the Friedmann–Robertson–Walker metric are particularly important, as they successfully describe the large-scale structure of the universe and provide a foundation for their quantum counterparts [6].

The quantization of such models is valuable for several reasons [7]. It offers a simplified setting in which conceptual challenges associated with quantum gravity can be explored and potential solutions evaluated. Furthermore, these models allow researchers to investigate conditions near the Big Bang, where quantum gravitational effects are expected to dominate and classical theories break down [8].Regarding the long-term

evolution of the universe, current evidence suggests that its most probable fate is a 'Heat Death', and that characterized by continuous expansion leading to a cold, dark, and nearly empty state. This scenario is closely linked to the influence of dark energy, which drives the accelerated expansion of the cosmos [9].The emergence of General Relativity by Albert Einstein revitalized scientific interest in cosmology, the study of the universe on the largest scales. Within the framework of Newtonian physics, cosmology was largely confined to a single issue: determining how matter is distributed throughout an infinite, Euclidean space [10]. In contrast, Einstein's theory introduced a far richer and more complex picture. Cosmologists were now required to consider a wide range of possible matter distributions, spacetime geometries, and dynamical evolutions. These aspects are fundamentally linked through Einstein's gravitational field equations, which define how matter and energy determine the geometry of spacetime and, in turn, how this combined system evolves over time. Our understanding of the structure and evolution of the universe is further deepened through insights from nuclear physics and radiation physics.

These fields explain the processes by which matter is formed, how stars generate energy, and how chemical elements are synthesized over cosmic time [11]. By examining the behavior of protons and neutrons within atomic nuclei, along with the ionizing radiation emitted during stellar processes, scientists are able to reconstruct the history of the universe from the Big Bang to the present, and even make informed predictions about its future evolution. Phenomena such as stellar formation and evolution, gravitational collapse, neutron stars, black holes, galactic structure, cosmic expansion, the early universe, primordial and stellar nucleosynthesis, and attempts at unifying fundamental interactions within unified field theory are all addressed within these domains of physics. While these achievements significantly enhance our understanding of nature and open possibilities for technological advancement and the future expansion of human activity into space, it is equally important to recognize the limitations of current knowledge. Despite remarkable progress, many fundamental aspects of the universe and the nature of matter remain unknown. Acknowledging these gaps is essential for maintaining scientific objectivity [12]. Numerous profound questions—regarding the origin, composition, and ultimate fate of the universe—remain unanswered, and the list of such questions is far from complete. In this context, astrophysics in general, and quantum cosmology in particular, continue to seek deeper explanations. Ongoing research aims to address these unresolved issues and refine our understanding of the cosmos[13, 14].There is a strong consensus among cosmologists that the shape of the universe is considered flat, and the universe will continue to expand forever [15,].Observations made by Edwin Hubble during the 1930s–1950s found that galaxies appeared to be moving away from each other and that leading to the currently accepted Big Bang theory [16, 17].This suggests that the universe began very dense about 13.787 billion years ago, and it has expanded and become less dense ever since [18].We need to determine the universe's origin and ultimate fate and the average motions of galaxies [19].This paper will evaluate the origin and ultimate destiny of the universe, drawing upon modern developments and conceptual advances in astrophysics. Research will deal few questions as mention below.

a. How the universe has created?
b. The reason why matter curves spacetime in its surroundings is not known and how do "condensations" in the geometry of spacetime create what appears to us as matter?
c. Why is there a huge amount of matter and almost no antimatter in the universe?
d. Why is there a huge amount of matter and almost no antimatter in the universe?
e. What is the internal structure of the elementary particles of the microworld?
f. What is the ultimate fate of universe?
g. What is the shape and structure of the universe, and the amount of dark matter and dark energy that make up our universe?

II. Chronological Development of Concept of Astro Physics

Hypersphere World-Universe Model (WUM)

The Hypersphere World Universe Model (WUM) is a classical cosmological framework proposed as an alternative to the widely accepted Big Bang theory. In this model, the universe is described as a finite yet unbounded three-dimensional hypersurface—specifically, the surface of a four-dimensional expanding sphere referred to as the "Nucleus of the World."[20] This four-dimensional structure expands along a spatial dimension at a rate equal to the speed of light (c), which the model interprets as a fundamental 'GravitodynamicConstant'. As a result, the three-dimensional observable universe undergoes uniform expansion in all directions without possessing a central point within its own spatial domain. In contrast to the instantaneous origin implied by the Big Bang, WUM proposes a mechanism of continuous matter creation. According to this view, matter—predominantly dark matter—is generated persistently from the four-dimensional Nucleus and transferred into the observable three-dimensional universe through a process analogous to sublimation. The model further replaces the traditional concept of vacuum with a universal Medium composed of stable particles, including protons, electrons, photons, neutrinos, and dark matter particles. This Medium is considered to

function as an absolute frame of reference, within which all physical processes occur. WUM also asserts that approximately 92.8% of the universe consists of dark matter, which plays a central role in the formation of large-scale cosmic structures. Galaxies and superclusters are described as possessing dense dark matter cores that rotate and may undergo rotational fission, leading to the formation of smaller structures such as stars and planets. This perspective offers an alternative explanation for the hierarchical organization of matter in the universe [21]. More broadly, modern physics encompasses numerous theories and hypotheses that attempt to describe phenomena beyond the limits of direct observation, both at subatomic scales and across vast cosmic distances. Foundational theories such as Special Relativity and General Relativity are often regarded as conceptually challenging, yet ultimately comprehensible. In contrast, quantum physics—particularly in its astrophysical applications—can appear even more abstract and less intuitive, sometimes being described as fundamentally difficult to interpret. Despite its remarkable empirical success in explaining the structure of matter and enabling advanced technological applications, the deeper conceptual foundations of quantum physics remain only partially understood. In this context, early theoretical contributions such as the large number hypothesis proposed by Paul Dirac in 1937—including the idea of a varying gravitational constant and continuous matter creation—are particularly noteworthy. The WUM framework builds upon these ideas, although it introduces a distinct mechanism for matter generation within its own cosmological model [22].

The Hypersphere World–Universe Model (WUM) is a cosmological framework that describes the universe as a three-dimensional hyper-spherical surface expanding into a fourth spatial dimension, with its energy density consistently equal to the critical density. Within this model, dark matter particles are continuously generated from a four-dimensional nucleus [23]. Through processes such as annihilation, these particles give rise to luminous matter. WUM also offers a theoretical basis for estimating key cosmological parameters—such as the Hubble parameter and the temperature of the cosmic microwave background—that are broadly consistent with observational data. Conceptually, WUM can be viewed as an extension of classical physics and is proposed as an alternative to the prevailing Big Bang theory, which is fundamentally grounded in General Relativity. The two models differ in several essential respects. First, instead of an initial singularity characterized by infinite energy density and a phase of rapid inflation, WUM posits an initial fluctuation within an eternal universe [24]. This fluctuation corresponds to a four-dimensional nucleus with a finite extrapolated energy density—significantly lower than nuclear density—and a finite rate of expansion along the fourth spatial dimension at the speed of light, interpreted as a GravitodynamicConstant. Second, while the standard cosmological model assumes a nearly infinite, homogeneous, and isotropic universe originating from the initial singularity, WUM envisions a finite but unbounded three-dimensional world (a hyper-spherical surface of the 4D nucleus). In this framework, the large-scale structure of the universe resembles a "patchwork quilt," composed of numerous luminous superclusters (on the order of $\gtrsim 10^3$), which form at different locations and at different cosmological times [25]. The universal Medium—composed of protons, electrons, photons, neutrinos, and dark matter particles—is assumed to be homogeneous and isotropic, whereas the distribution of large-scale structures (macro-objects) is spatially inhomogeneous, anisotropic, and temporally non-simultaneous. The most direct observational arguments presented in support of WUM include its ability to reproduce key large-scale cosmological features and parameters within this alternative theoretical framework [26].

a. Microwave Background Radiation and Intergalactic Plasma speak in favor of existence of Medium.
b. Laniakea Supercluster with binding mass $\sim 10^{17} M_{\odot}$ is home to Milky Way (MW) and $\sim 10^5$ other nearby galaxies, which did not start their movement from Initial Singularity.
c. MW is gravitationally bounded with Virgo Supercluster (VS) and has Orbital Angular Momentum that far exceeds its rotational angular momentum [27].
d. Mass-to-light ratio of VS is ~300 times larger than that of Solar ratio. Similar ratios are obtained for other superclusters. These ratios are main arguments in favor of presence of significant amounts of Dark Matter in the World.
e. Astronomers discovered the most distant galaxy HD1 that is ~13.5 Bly away. WUM predicts discovery of galaxies with a distance of ~13.8 Bly. Medium of World, Dark Matter, and Angular Momentum are main Three Pillars of WUM [28].

In the 21st century, many researchers perceive a sense of stagnation in physics. In certain respects, this situation resembles the late 19th century, when it was widely believed that the foundations of physics were nearly complete. However, revolutionary developments like Special Relativity, General Relativity, quantum physics, and the discovery of elementary particles—profoundly transformed that perspective and initiated a century of rapid scientific progress [29]. Pioneering figures including Albert Einstein, Max Planck, Niels Bohr, Paul Dirac, Werner Heisenberg, and Erwin Schrödinger were able to formulate fundamentally new theories despite having limited experimental evidence at the time. Over the course of the 20th century, these theories were progressively validated and refined through extensive experimental investigation. In the present era, however, there is a growing concern that theoretical development may be constrained by an overreliance on

established frameworks. Rather than encouraging fundamentally new ideas, contemporary approaches often attempt to accommodate all observations within existing models [30]. In some cases, frameworks are adjusted to fit new data, while results that are difficult to reconcile may be marginalized. This situation suggests that the time may be appropriate for the development of new foundational models that are both conceptually simpler and capable of opening new directions for research. Within this context, the Hypersphere World–Universe Model (WUM) is proposed as an alternative to the prevailing Big Bang theory. In the standard cosmological framework, the origin of the universe is associated with an initial singularity—characterized by infinite energy density—and a subsequent phase of cosmic inflation, during which spacetime underwent extremely rapid exponential expansion [31]. This expansion is thought to have occurred within a fraction of a second ($t < 10^{-32}$ s), ultimately leading to an observable universe approximately 93 billion light-years in diameter, while the total extent of the universe may be much larger or even infinite. The concept of the initial singularity itself arises as a prediction of General Relativity, representing a state in which all matter, energy, and spacetime are compressed into an infinitely dense point prior to the Big Bang. From a physical standpoint, however, the presence of such a mathematical singularity is often regarded as a limitation of the theory [32]. It suggests that the model may be incomplete, failing to incorporate essential physical processes that could prevent the formation of such singular conditions [33].

Within the framework of the Big Bang theory, there is no established mechanism that prevents the occurrence of an initial singularity. From an alternative perspective, a finite universe may have originated through a fundamentally different process—namely, a fluctuation within an eternal universe characterized by finite size and energy density [34]. In such a scenario, the initial state evolves through expansion at a finite velocity, thereby removing the necessity for invoking a phase of cosmic inflation. However, this approach raises an important question regarding the mechanism responsible for the continuous creation of matter. Earlier theoretical efforts have addressed this issue. In 1964, Fred Hoyle and Jayant Vishnu Narlikar proposed the concept of a "creation field" (C-field) to account for the ongoing emergence of matter in the universe [35]. Later, in 1974, Paul Dirac explored the idea of continuous matter creation through two possible mechanisms: an additive process, in which matter is generated uniformly throughout space, and a multiplicative process, in which creation is proportional to the existing matter content. The Hypersphere World–Universe Model (WUM) adopts the concept of continuous matter creation in an additive sense, while introducing a distinct underlying mechanism consistent with its theoretical framework. A key distinction between WUM and the standard cosmological model lies in the introduction of a universal Medium, composed of protons, electrons, photons, neutrinos, and dark matter particles, which replaces the notion of an empty vacuum. Additionally, WUM attributes the origin of the universe's energy to an eternal background universe, rather than to an initial singular event [36]. Furthermore, WUM builds upon and extends ideas associated with several classical and early modern physicists, including Isaac Newton, Georges-Louis Le Sage, James MacCullagh, Bernhard Riemann, Oliver Heaviside, Nikola Tesla, Paul Dirac, and Andrei Sakharov. These foundational concepts are further developed within the WUM framework to construct an alternative interpretation of cosmic structure and evolution [37].

Nebular hypothesis. The most widely accepted model for the formation of the Solar System is the Nebular Hypothesis, initially proposed in 1734 by Emanuel Swedenborg and later developed by Immanuel Kant in 1755. According to this model, the Solar System originated approximately 4.6 billion years ago from the gravitational collapse of a molecular cloud extending over several light-years. The majority of the mass accumulated at the center, giving rise to the Sun, while the remaining material formed a rotating protoplanetary disk. Over time, this disk evolved into planets, moons, and other bodies that constitute the Solar System [38]. Despite its broad acceptance, the Nebular Hypothesis has faced criticism. In his workThe Wonders of Nature, Vance Ferrell presented several counterarguments. One criticism is that it appears to conflict with the physical expectation that diffuse in space tends to disperse rather than condense. Another concern is the diversity of planetary and lunar properties; if all Solar System bodies originated from the same nebula, their structural and compositional differences require further explanation. Additionally, there is a notable discrepancy in the distribution of angular momentum: while approximately 99.8% of the Solar System's mass resides in the Sun, about 98% of its angular momentum is concentrated in the planets, with Jupiter alone accounting for a substantial portion [39]. This imbalance has been cited as a challenge for traditional evolutionary models, which must explain how angular momentum was redistributed from the central mass to the surrounding planetary system. Another alternative perspective on planetary formation includes the Lunar Origin Fission Hypothesis, proposed in 1879 by George Darwin. This hypothesis suggests that the Moon originated from the Earth itself, when the early Earth was rotating so rapidly that centrifugal forces nearly overcame gravitational attraction at the equator, causing material to separate and eventually form the Moon [40].

Bing Bang Model (BBM)

In modern science, particularly within cosmology, the Big Bang theory is the leading framework for explaining the origin and evolution of the universe, which is estimated to have begun approximately 13.8 billion years ago. According to this model, the universe originated from a hot and dense initial state—often described as a singularity—and has been expanding and cooling ever since. One of the strongest observational supports for this theory is the discovery of cosmic microwave background radiation in the 1960s, along with the observation that galaxies are receding from one another, indicating an expanding universe. The theoretical foundations of this model were first proposed by Georges Lemaître and later developed and refined by scientists such as Stephen Hawking. Historically, early versions of this expanding-universe concept were independently formulated in the 1920s by Alexander Friedmann and Georges Lemaître. The modern version of the theory was further advanced in the 1940s by George Gamow and his collaborators [41]. The Big Bang model rests on two fundamental assumptions. First, General Relativity accurately describes gravitational interactions on cosmological scales. Second, the cosmological principle asserts that the universe is homogeneous and isotropic on large scales, meaning that its overall properties are independent of both location and direction of observation. According to this model, the universe underwent rapid expansion from a compressed primordial state, leading to a continuous decrease in temperature and density. During the earliest moments, a wide variety of elementary particles were present, and processes that led to the dominance of matter over antimatter likely occurred [42]. Within the first few seconds, conditions became suitable for the formation of light atomic nuclei through primordial nucleosynthesis, producing specific proportions of hydrogen, helium, and lithium—predictions that align closely with current observations. As the universe continued to cool, atoms formed after roughly one million years, allowing radiation to decouple from matter and travel freely through space. This relic radiation, now observed as the cosmic microwave background, was discovered in 1965 by Arno Allan Penzias and Robert Woodrow Wilson. It provides compelling evidence for the Big Bang model, representing a thermal snapshot of the early universe and serving as one of the most important observational pillars supporting modern cosmology.

Special Relativity. The principle of relativity originated with Galileo Galilei and was later incorporated into the framework of Newtonian mechanics. During the late 19^{th} century, however, the discovery of electromagnetic waves led physicists to propose the existence of a hypothetical medium known as the 'Aether'. This Aether was assumed to permeate all space and serve as the medium through which electromagnetic waves propagate. It was further regarded as an absolute reference frame, against which all motion could be measured, and was thought to remain stationary relative to the Earth or another fixed frame. At the same time, it was hypothesized to possess unusual properties—being sufficiently elastic to support wave propagation while offering no resistance to objects moving through it. Experimental investigations, most notably the Michelson–Morley experiment conducted in 1887, failed to detect any evidence of the Aether. These results played a crucial role in the development of Special Relativity, a theory that fundamentally redefined the relationship between space and time. In 1905, Albert Einstein formulated special relativity based on two key postulates: first, that the laws of physics are identical in all inertial frames of reference (i.e., non-accelerating frames), and second, that the speed of light in a vacuum is constant for all observers, regardless of the motion of the light source. A central feature of this theory is Lorentz invariance, which ensures that the fundamental laws of physics remain unchanged under transformations between inertial frames. Einstein's formulation eliminated the need for the Aether concept, rejecting the idea of an absolute state of rest. Instead, relativity establishes that all inertial reference frames are equivalent, and no preferred frame exists. Consequently, the speed of light in a vacuum is always measured as a constant value (c), even when observed from systems moving at different, but constantvelocities.

General Relativity. General Relativity (GR), formulated by Albert Einstein in 1915, is the modern geometric theory of gravitation. It extends Special Relativity and refines Newton's law of universal gravitation by describing gravity as a manifestation of the curvature of four-dimensional spacetime [43]. The core of GR is encapsulated in the Einstein field equations, which are highly nonlinear and challenging to solve in general. In 1916, Karl Schwarzschild discovered the first exact, non-trivial solution to these equations, known as the Schwarzschild metric. This solution provided the theoretical foundation for understanding the end stages of gravitational collapse, ultimately predicting objects that are now identified as black holes (BHs). A year later, in 1917, Einstein applied his theory to the universe as a whole, effectively founding the field of relativistic cosmology. To accommodate the then-prevailing assumption of a static universe, he introduced the cosmological constant into his equations. By 1929, however, observations by Edwin Hubble and others revealed that the universe is expanding. This expansion is naturally described by the cosmological solutions derived by Alexander Friedmann in 1922, which eliminate the need for a cosmological constant. Einstein himself later referred to the introduction of this constant as the "biggest blunder" of his career [44]. It is also notable that the concept of Aether had already been discarded by 1905 through the development of Special Relativity. The Friedmann equations, derived from Einstein's field equations, describe the evolution of the universe assuming a perfect fluid with a specified mass density (ρ) and pressure (p), providing the theoretical framework for the large-scale dynamics of cosmic matter.

Big Bang Model. The theoretical framework of the Big Bang model is grounded in General Relativity and relies on simplifying assumptions, including the homogeneity and isotropy of space. A widely used refinement of this framework is the Lambda Cold Dark Matter model (ΛCDM), which parametrizes the universe as composed of three principal components: first, the cosmological constant Λ associated with dark energy; second, a postulated cold dark matter component; and third, ordinary baryonic matter [45]. The concept of dark matter has been extensively reviewed by Gianfranco Bertone and Dan Hooper. Following the shortcomings of hot dark matter models, it became increasingly clear that cold dark matter (CDM) provided a far better explanation for the observed distribution of large-scale cosmic structures.[46] The term WIMPs (weakly interacting massive particles), introduced by Gary Steigman and Michael Turner in 1984, originally encompassed all potential dark matter candidates, including axions and gravitinos. Over time, however, WIMPs have come to denote specifically those particles that interact via the weak nuclear force. By the late 1980s, the consensus among many astrophysicists and particle physicists was that the majority of the universe's mass consists of cold, nonbaryonic particles, making CDM the leading paradigm for cosmic structure formation [46]. The ΛCDM model is characterized by six fundamental parameters: baryon density, dark matter density, dark energy density, scalar spectral index, curvature fluctuation amplitude, and the optical depth of reionization. Most of these parameters are empirically determined rather than theoretically predicted, while additional parameters are often fixed at "natural" values—for instance, the total density is set to unity and neutrino masses are considered negligible [47]. The model can be further extended to incorporate cosmological inflation. Owing to its comprehensive explanatory power, ΛCDM is frequently referred to as the Standard Model of Big Bang cosmology. The framework rests on four observational pillars: (1) the expansion of the universe, (2) the existence of cosmic microwave background radiation, (3) nucleosynthesis of light elements, and (4) the formation of galaxies and large-scale structures [48].

Expansion of Universe. There is now compelling observational support for Hubble's law, which states that the recessional velocity (v) of a galaxy is proportional to its distance (d) from the observer, expressed mathematically as (v = H d), where (H) is the Hubble constant. Tracing galaxy motions backward in time implies that all galaxies converge toward a cosmological singularity at (t = 0), representing a state of infinite energy density. This reveals a key limitation of the Standard Cosmology, known as the Horizon Problem: if the universe originated from causally disconnected regions, why does it appear so uniform in all directions? This uniformity is especially pronounced in the cosmic microwave background radiation, which exhibits remarkable smoothness. The Horizon Problem is addressed by the theory of cosmological inflation, which proposes an extremely rapid exponential expansion of space during the early universe. During this brief inflationary epoch, the linear dimensions of the universe increased by at least a factor of (10^26), corresponding to a volumetric expansion of at least (10^78). This phase occurred in a fraction of a second, lasting less than (10^-32) seconds after the initial singularity [49]. After inflation, the universe continued to expand, but at a much slower, more gradual rate. Recent discussions on observational tensions in cosmology were summarized by L. Verde, Tommaso Treu, and Adam Riess during the "Workshop at Kavli Institute for Theoretical Physics" in July 2019. While certain discrepancies in measured cosmological parameters have emerged, it remains unclear whether these differences result from systematic observational errors or indicate a more fundamental challenge to the current Standard Model of cosmology.

Origin of Cosmic Background Radiation. According to the Big Bang Model, roughly 380,000 years after the initial explosion, the temperature of the universe had decreased sufficiently to allow atomic nuclei to capture electrons and form neutral atoms [50]. This process, known as photon decoupling, caused photons to stop interacting frequently with matter, rendering the universe transparent and giving rise to the microwave background radiation (MBR). These photons, released at the moment of decoupling, have traveled through space ever since, gradually losing energy and shifting to longer wavelengths as a result of the universe's expansion. The same photons are observed today as the cosmic microwave background. A key question arises: why does the MBR exhibit a near-perfect black-body spectrum? Within the framework of the Hypersphere World-Universe Model (WUM), wavelength is considered a classical concept, whereas photons are fundamentally quantum objects characterized by four-momenta, and thus do not intrinsically possess wavelengths. From the WUM perspective, the black-body nature of the MBR is explained not by classical photon wavelengths but by the thermodynamic equilibrium between photons and the Intergalactic Plasma (IGP), the presence of which has been confirmed through experimental observations. This equilibrium accounts for the precise spectral distribution observed in the cosmic microwave background today.

Nucleosynthesis of Light Elements. Big Bang Nucleosynthesis (BBN) describes the formation of atomic nuclei other than hydrogen during the earliest phases of the universe. Primordial nucleosynthesis is thought to have occurred between roughly 10 seconds and 20 minutes after the Big Bang, producing the majority of helium in the form of the isotope helium-4, alongside small quantities of deuterium, helium-3, and trace amounts of lithium-7 [51]. All elements heavier than lithium are believed to have formed later through stellar nucleosynthesis within evolving and exploding stars. The history of BBN research began with calculations by

Ralph Alpher in the 1940s. By the 1970s, significant efforts focused on understanding processes capable of producing deuterium. While the observed abundance of deuterium aligns with the overall Big Bang framework, it is too high to be reconciled with a model in which the universe consists predominantly of protons and neutrons [52]. This discrepancy led to the current understanding that most of the universe's mass is composed of non-baryonic dark matter show anomalously high levels. M. Anders and colleagues reported the first measurement of the 2H(α, γ)6Li cross-section at Big Bang energies, conclusively ruling out BBN as a source of the observed 6Li. Within the framework of the Hypersphere World-Universe Model (WUM), nucleosynthesis of all elements—including light elements—occurs inside the dark matter cores of macro-objects (MOs) throughout their evolution [53]. While traditional stellar nucleosynthesis is well established, beginning with the foundational B2FH review, WUM extends this theory by incorporating the self-annihilation of heavy dark matter fermions within MO cores as an additional mechanism contributing to element formation.

Formation of Galaxies and Large-Scale Structures. The formation and evolution of galaxies can be understood primarily through gravitational interactions within a framework. The standard Hot Big Bang Model provides a theoretical basis for galaxy formation. Approximately 10,000 years after the Big Bang, the temperature of the universe had dropped sufficiently for its energy density to become dominated by massive particles rather than by light and other forms of radiation that had previously prevailed [54]. This transition in the dominant form of matter allowed gravitational forces between massive particles to become significant, enabling small initial density perturbations to grow over time and seed the formation of large-scale structures. However, this highlights a notable limitation of the Standard Cosmology—the density fluctuation problem. Analyses indicate that the so-called Four Pillars of Standard Cosmology are model-dependent and do not provide robust, independent support for the Big Bang Model. Furthermore, BBM faces challenges in reconciling with the law of angular momentum conservation. The model's conclusions are heavily reliant on a set of underlying assumptions, which must be critically examined to evaluate its consistency with fundamental physical laws [55]. Homogeneity and isotropy of space.

a. Laws of physics are invariant in all inertial systems.
b. The speed of light in a vacuum is the same for all observers.
c. Massless photons.
d. The existence of Cold Dark Matter is a principal point of BBM.

Angular Momentum Problem. The angular momentum problem represents one of the most critical challenges facing the Big Bang Model and must be addressed for the model to remain viable. Any cosmological theory describing the evolution of the universe that violates the law of conservation of angular momentum cannot be considered physically consistent and should therefore be rejected. Currently, the Standard Cosmology is unable to adequately answer several key questions related to angular momentum distribution and transfer in the universe, highlighting a fundamental limitation of the model [56, 57]. Sun accounts for ~0.3% of the total angular momentum of SS while about 60% is attributed to Jupiter.

a. SS has an orbital angular momentum that far exceeds Its rotational angular momentum;
b. MW galaxy is gravitationally bounded with Virgo Supercluster (VS) and has an orbital momentum, which far exceeds Its rotational angular momentum;
c. How did MW galaxy and SS obtain their substantial orbital angular momenta?
d. To the best of our knowledge, the Standard Model does not answer these questions. WUM is the only cosmological model in existence that is consistent with this Fundamental Law.

Astronomers need to answer some principal questions:

a. The age of Milky Way (MW) is similar to the Age of the World. The oldest star in MW (named Methuselah) is nearly as old as the World itself. If Sgr A is a SBH, then how it could grow so quickly?
b. What is the origin of the alleged SBH positive spin?
c. Their models in the "best-bet region" have low inclination 30˚ and 10˚ that contradicts the disk shape of the MW galaxy and bipolar astrophysical jets, which are astronomical phenomena where outflows of matter are emitted as the extended beams along the axis of rotation;
d. The MW galaxy (including Sgr A) is gravitationally bounded with VS and has a huge orbital angular momentum (Section 2.4). How did MW galaxy obtain this substantial orbital angular momentum?
e. What is the mechanism of gamma rays' emission from the Galactic Center?

In frames of WUM, the results obtained by the EHT Collaboration can be explained in the following way. However, the totality of all obtained experimental results testify in favor of the existence of the supermassive compact object made up of DMPs at MW Center [56].

a. The image is dominated by the bright, thick ring with the radius of 3.17×10^{10} m. The ring has a comparatively dim Interior that is made up of DM Fermions DMF1 (1.3 TeV) and DMF2 (9.6 GeV), which are responsible for the excess of gamma-ray emission from Sgr A.

b. Dark Matter Particles (DMPs) are continuously absorbing by the Interior of Sgr A. Ordinary Matter is a byproduct of DMPs self-annihilation. It is re-emitted by the Interior continuously into a Shell around it.
c. Powerful gamma quants with energy of at least 1.02 MeV in the vicinity of atomic nuclei of the Shell produce electron-positron pairs with high concentration;
d. The bright, thick area consists of Ordinary Matter and Electron-Positron plasma with the radius of 2.9×10^{10} m that is a compact nonthermal radio object responsible for the strongest radio emission.
e. The area from the radius of 3.17×10^{10} m to 1.88×10^{12} m is filled out with DM Fermions DMF3 (3.7 keV), which are responsible for X-rays from the center of MW due to their self-annihilation;
f. The enclosed mass of Supermassive Compact Object of $4.154 \times 106 M\odot$ is the mass of the MW DM Core made up of DMF1 and DMF2 with the Ordinary Matter and Electron-Positron Shell and DMF3 Shell;
g. Sgr A has gotten the rotational and orbital angular momenta as the result of the rotational fission of the DM Core of VS;
h. The inclination angle between the line of sight and the rotational angular momentum vector of Sgr A is about 90°.

Modern Relativistic Cosmology (MRC)

Modern relativistic cosmology has moved far beyond speculative ideas and idle theorizing, establishing itself as a rigorous and integral branch of astrophysics and the natural sciences. Today, it offers a coherent and scientifically grounded understanding of the structure and evolution of the universe, built on well-tested physical laws and supported by observations [57]. To understand the interplay between cosmology and physics, it is helpful to recall the methodology of physical inquiry, which rests on three pillars: observation, experimentation, and theory. In the early development of physics, observation was paramount—for instance, Newton formulated his law of gravitation based on the astronomical observations codified in Kepler's laws of planetary motion [58]. At the same time, Newton's mechanical experiments led to his three laws of motion. As physics advanced, experimental methods became increasingly sophisticated, particularly in the early 20th century, when probing the microstructure of matter required high-energy particle accelerators and sensitive detection equipment. Observation alone was no longer sufficient, and physics began to provide the foundational laws that explained astronomical phenomena [59]. However, in the 21st century, the relationship between physics and cosmology has become more reciprocal. The early universe, in its extremely hot and dense state, acted as a natural "laboratory" for high-energy physics, where processes occurred that are only now being probed experimentally. Theoretical developments, particularly in elementary particle and unitary field theories, can be confronted with astronomical observations, constraining their parameters or even allowing validation or rejection of certain models [60].

A major source of cosmological information comes from relic radiation. Observations of the cosmic microwave background (CMB) through optical, radio, and microwave measurements provide a fossil record of the early universe. Variations in the CMB temperature, caused by photons traversing regions of differing gravitational potential, serve as a snapshot of primordial structures [61]. This requires highly precise instrumentation, such as NASA's COBE (1989–1993), WMAP (2001–2010), and ESA's Planck (2009–2013) satellites, which progressively improved measurements of CMB anisotropies, polarization, and temperature. These observations reveal how fundamental particle physics and cosmology intersect, showing that processes at subatomic scales influence the largest structures in the universe.Although elementary particle physics studies the smallest constituents of matter while cosmology addresses the largest cosmic structures, the two fields converge in explaining the universe. Questions of matter's origin, its fundamental building blocks, and their interactions directly relate to the formation of galaxies, stars, planets, and ultimately life [62]. The earliest fractions of a second after the Big Bang were critical in setting the physical laws and interactions that govern the universe today. Current high-energy experiments aim to replicate aspects of these extreme conditions, probing the deepest structures of matter and, by extension, the initial moments of cosmic evolution. This interplay between the microworld, macroworld, and the cosmic mega-world forms a unified framework in contemporary fundamental physics. While humans are physically minuscule in the vast cosmos, intellectually and spiritually, we possess the capacity to understand the universe, its structure, and its evolution. In this article, the scientific narrative of the universe's origin, development, and ultimate fate will be explored in the context of modern astrophysical advancements [63].

Formation of First Galaxies and Large Black Holes

The current understanding of the formation of the first galaxies is rooted in astrophysical models describing the universe roughly 200 million years after the Big Bang, at the end of the cosmic "dark ages." During this period, clouds of hydrogen and helium gas began to cluster around initial density fluctuations left over from the post-inflationary epoch due to gravitational attraction [64]. Over time, these matter concentrations formed a large-scale cosmic web, with vast voids surrounded by filaments of clustered matter. Gravitational

contraction within these regions led to the formation of massive protostars, which evolved into the first generation of stars, eventually coalescing into galaxies. These primordial stars were typically much larger than present-day stars, with masses reaching several hundred solar masses (M⊙), and they lived relatively short lives—on the order of a few million years—before exploding as supernovae, enriching the interstellar medium with heavier elements. While this framework is broadly consistent with theory, recent observations suggest that some of the earliest galaxies appear more "mature" than expected, indicating that our models of galaxy formation may still be incomplete [65].

Black holes, which are among the most enigmatic objects in the universe, arise from the gravitational collapse of sufficiently massive stars once their thermonuclear fuel is exhausted. In the early galaxies, numerous stellar-mass black holes formed in this way. Through successive mergers, these black holes could accumulate into intermediate-mass black holes of several thousand M⊙. Over billions of years, some grew further into supermassive black holes with masses between 10^6 and 10^9 M⊙, which are commonly found at the centers of galaxies [66]. Observations, however, reveal that supermassive black holes already existed in some of the earliest galaxies, prompting speculation that they might form via alternative, non-stellar mechanisms, such as the direct collapse of massive, dense gas clouds. The precise processes leading to the formation of such enormous black holes remain an open question. A defining feature of all black holes is the event horizon, a boundary beyond which nothing—not even light—can escape [67]. Classical models, such as the Schwarzschild solution, predict that all matter falling into a black hole ends up in a singularity at its center, where spacetime curvature and gravitational gradients become infinite. Such singularities are physically problematic, suggesting a breakdown of classical theory [68]. Quantum considerations offer a possible resolution: near the black hole's core, quantum fluctuations in spacetime geometry would become extreme, potentially creating a "topological foam" that prevents a true singularity from forming. Consequently, the internal structure of black holes remains one of the most profound mysteries in modern astrophysics, with the true nature of their centers still unknown [69].

Formation of Dark Matter and Dark Energy

The concept of Dark Matter (DM) has a long history that can be traced back to the mid-19th century. Early indications arose when astronomers noticed discrepancies in the motions of celestial objects. In 1844, Friedrich Bessel suggested that the observed proper motions of stars like Sirius and Procyon could only be explained by unseen companions exerting gravitational influence [70]. Later, in 1846, Urbain Le Verrier and John Couch Adams proposed the existence of Neptune to account for anomalies in Uranus's orbit, showing that gravitational effects could hint at unseen mass. Beyond planets and stars, some 19thcentury astronomers considered dark "nebulae." For example, in 1877, Angelo Secchi noted dark regions in the sky that could not be explained by empty space or "black cavities," recognizing them as massive, unseen structures that influenced visible stars. With the advent of astronomical photography, these dark regions became more apparent in dense star fields [71].

In the early 20th century, Lord Kelvin (1904) applied the kinetic theory of gases to the stars in the Milky Way, showing that the relationship between the size of the galaxy and the velocity dispersion of stars implied additional, unseen mass. Henri Poincaré (1906) explicitly referred to "dark matter" in this context, suggesting that its quantity was likely comparable to that of visible matter. Observations since then have confirmed that the gravitational effects in galaxies and galaxy clusters are stronger than can be explained by visible matter alone. This led to the notion that there must exist a "dark" substance that interacts gravitationally but is otherwise invisible. Early candidates included faint stars, brown dwarfs, or black holes in galactic halos, but these were insufficient to account for the observed gravitational effects [72]. Modern physics suggests that dark matter could consist of Weakly Interacting Massive Particles (WIMPs), which interact primarily through gravity and possibly the weak nuclear force, making them extremely difficult to detect with laboratory experiments. Despite decades of effort, direct detection remains elusive. The discovery that the expansion of the universe is accelerating—observed through distant Type Ia supernovae—introduced the concept of Dark Energy (DE). Dark energy is thought to act opposite to gravity, driving the accelerated expansion of the cosmos. Its nature remains unknown: it could be related to the cosmological constant, an intrinsic property of space-time, or a dynamic field such as quintessence. Together, dark matter and dark energy make up about 95% of the total mass-energy of the universe, yet their fundamental properties remain among the greatest mysteries of modern cosmology.

III. The Evaluation and Arrow of Time

All fundamental physical laws are inherently time-invariant, meaning that the equations governing physical phenomena do not specify a preferred direction of time. These laws can be applied equally in forward or reverse temporal directions, without indicating which is physically realized. A notable exception, however, is the second law of thermodynamics [73]. This law, grounded in statistical principles, states that natural processes

tend to evolve toward states of increasing entropy, which is commonly interpreted as a measure of disorder. Statistical physics explains this tendency by demonstrating that disordered configurations of a system vastly outnumber ordered ones, making transitions toward disorder overwhelmingly more probable. Interestingly, the biochemical processes underlying life appear to locally counteract this trend by maintaining and generating order [74]. The concepts of time and its progression were further redefined by the special and general theories of relativity, which introduced new perspectives on the nature of time. Despite these advances, the fundamental nature of time itself remains poorly understood. Similarly, significant questions persist regarding the origin of life. While biologists have extensively documented the evolution and diversity of living organisms, and chemists have elucidated many complex biochemical processes at the molecular and cellular levels, the emergence of primordial life from pre-cellular chemical systems remains unresolved. In particular, the processes leading to the development of self-replication and inheritance mechanisms involving RNA and DNA are not yet fully understood. Furthermore, it remains uncertain whether life can originate beyond Earth, how it might evolve under different conditions, and what methods are most effective for detecting it in extraterrestrial environments [75]. From the perspective of general relativity, the initial singularity represents not only the origin of the universe but also the beginning of time itself. The fate of time in the later stages of cosmic evolution raises equally profound questions. In a closed universe, the final stages are, in some sense, the inverse of the beginning.

As the universe approaches a final singularity, all causal relationships terminate and cannot be extended beyond this point, marking the end of time. In contrast, in an open universe, coordinate time continues indefinitely from a mathematical standpoint. However, from a physical or operational perspective, as the universe approaches a state of "thermal death," where no significant events or measurable processes occur, time loses its practical meaning. Without events to measure, time effectively ceases to have relevance, suggesting that even in an open universe, the concept of time may come to an end [76]. A fundamental question arises: what distinguishes the past from the future, and what determines the direction of time? This temporal asymmetry, often referred to as the 'arrow of time,' is central to human experience. Despite this, the fundamental laws of physics are time-symmetric. They permit not only a given sequence of events but also its exact time-reversed counterpart. For example, the laws of mechanics allow any motion to occur equally well in reverse, and the equations of electrodynamics do not inherently differentiate between past and future. Consequently, at the most fundamental level, physical laws exhibit time symmetry. However, real-world phenomena display a clear directionality. Events in nature consistently unfold in one temporal direction and not the other. For instance, a glass bottle may fall from a table and shatter, but the reverse process which shattered fragments spontaneously reassembling into a whole bottlenever occurs. The mechanisms underlying this observed temporal directionality in natural processes can be broadly classified into four categories:

a. The radiation arrow of time (electromagnetic arrow). The radiation arrow of time, also known as the electromagnetic arrow, arises from the behavior of accelerating electric charges, which emit electromagnetic radiation. These waves propagate away from the source at the speed of light, carrying energy into the future and eventually interacting with distant systems. As a consequence, the emitting system loses energy over time. Although the formalism of electrodynamics permits both "retarded" waves (propagating forwards in time) and "advanced" waves (incoming from infinity and converging upon the source), only retarded waves are observed in physical reality. This asymmetry is similarly evident in the emission of gravitational radiation, where energy is transmitted away from the source towards the future.

b. The thermodynamic arrow of time. The thermodynamic arrow of time is defined by the second law of thermodynamics, which states that the entropy of an isolated system near equilibrium increases monotonically. This direction corresponds to the observable progression of natural processes: objects age, hot bodies cool, and systems evolve towards greater disorder. The biological arrow of time derives from this principle, reflecting both evolutionary processes and the life cycles of living organisms, including ageing. Although the microscopic laws governing particle motion permit processes that decrease entropy, such occurrences are statistically highly improbable. Statistical mechanics explains this by demonstrating that disordered states vastly outnumber ordered ones, making transitions towards higher entropy overwhelmingly more likely. This tendency is largely determined by initial conditions, in which high-entropy states dominate. Consequently, most physical changes lead to an increase in disorder. Local and temporary decreases in entropy may occur on small spatial and temporal scales—for instance, when a molecule briefly gains or loses kinetic energy through collisions—but such fluctuations are short-lived and statistically insignificant.

c. The cosmological arrow of time. The cosmological arrow of time is associated with the large-scale evolution of the universe, particularly its expansion. Observational evidence indicates that as time progresses, the universe continues to expand, thereby providing a macroscopic direction to time.The cosmological arrow of time points in the direction of the expansion of universe. It may be linked to the thermodynamic arrow, with the universe heading towards a heat death as the amount of Thermodynamic free energy becomes almost negligible. Otherwise, it may be an artifact of our place in the universe's evolution, with this arrow reversing as gravity

pulls everything back into a Big Crunch. If this arrow of time is related to the other arrows of time, then the future is by definition the direction towards which the universe becomes bigger. So, by definition the universe expands rather than shrinks.

d. The psychological arrow of time. The psychological arrow of time is rooted in human perception and cognition. Memory enables us to recall past events, but not future ones, thereby creating a clear distinction between past and future in our conscious experience. This subjective perception gives rise to our intuitive sense of the passage of time. An important question is whether these various arrows of time are fundamentally interconnected, or whether a single universal arrow underlies them all. The thermodynamic and psychological arrows appear to be closely related. The psychological arrow may be regarded as a consequence of thermodynamic irreversibility, since cognitive processes—such as memory formation and information processing—are governed by physical and chemical mechanisms that increase entropy. The storage of information requires energy, a portion of which is inevitably dissipated as heat, thereby increasing the overall disorder of the system. Consequently, the direction in which memory is formed coincides with the direction of increasing entropy. It may even be argued that our very conception and measurement of time are intrinsically linked to this increase in entropy. By contrast, establishing a direct relationship between the radiation (electromagnetic) and thermodynamic arrows of time is more challenging. The electromagnetic arrow is closely associated with causality within Minkowski spacetime, where electromagnetic interactions propagate in accordance with Maxwell's equations.

The thermodynamic arrow, however, emerges from statistical behavior under specific initial conditions that favor disorder. Although both are related to causality, their connection is not straightforward. It is conceivable that a deeper theoretical framework, possibly within a unified field theory, may eventually clarify their relationship. The cosmological arrow of time, which presently aligns with the thermodynamic arrow, may not be fundamentally connected but rather coincidental. We exist during a phase of cosmic expansion, and thus the observed direction of time appears consistent with this expansion. In a closed universe, where expansion might eventually be replaced by contraction, local physical laws—and hence local arrows of time—would remain unchanged, even if they no longer coincide with the global evolution of the universe. Earlier hypotheses, including those once considered by Stephen Hawking, suggested that the direction of time might reverse during a contracting phase. However, this view has largely been abandoned in favor of interpretations proposed by Yakov Zeldovich and Igor Novikov, who argued that the cosmological arrow is not fundamental. In the early development of quantum theory, antiparticles such as the positron were sometimes interpreted as particles moving backwards in time or possessing negative energy, based on formal solutions of the Dirac equation. Although these interpretations played a useful heuristic role, they are no longer regarded as physically meaningful. In contemporary particle physics, particles and antiparticles are treated symmetrically within the Standard Model, with no intrinsic connection to the direction of time.

So, the relationship between the arrow of time and the anthropic principle offers further insight. The apparent agreement between the thermodynamic, cosmological, and psychological arrows may be understood in terms of the conditions necessary for the existence of life. Intelligent observers can only arise during a particular stage of cosmic evolution, when free energy is available and entropy gradients persist. In the distant future, as stars exhaust their energy, galaxies decay, and the universe approaches thermal equilibrium, entropy will reach near-maximum levels. Under such conditions, no significant physical processes or life-supporting environments will remain, and the thermodynamic arrow of time will effectively disappear. Consequently, life and organized information processing will cease. It may therefore be concluded that the various "partial" arrows of time are manifestations of a deeper underlying principle—namely, causality within locally inertial frames of reference. These local arrows collectively establish a consistent temporal direction across spacetime, propagated through the transformation laws of special and general relativity, and forming a coherent causal structure throughout the universe.

e. Final Analysis. There exist several competing perspectives concerning the ultimate fate of the universe. Some of these originate from theoretical interpretations of the universe's beginning, while others arise from modern developments in particle physics. Certain models are grounded primarily in mathematical formulations, whereas others derive support from observational evidence [77]. Despite significant progress, a definitive conclusion remains elusive, and the search for a comprehensive understanding continues. Current observations indicate that the universe is expanding at an accelerating rate. The long-term consequences of this expansion—or a possible future contraction—are central to determining its ultimate fate. A number of theories suggest that the present universe may represent a transitional phase within a broader "bubble universe" framework. According to the prevailing cosmological paradigm, the universe originated from the Big Bang and has evolved continuously since that event. Its eventual fate may involve self-destruction or may result from other large-scale cosmic processes.[78] A substantial body of observational evidence supports the existence of dark matter, which appears to play a crucial role in the dynamics of cosmic expansion. Future results from particle physics experiments may provide new insights into this issue and refine existing models [79, 80]. Although

observational data, supported by applied mathematical analysis, lends credibility to current theories, predictions regarding the ultimate fate of the universe remain largely extrapolations based on theoretical reasoning [81, 82]. Within the framework of Big Bang cosmology, the expanding universe is a well-established observational result. In 1929, Edwin Hubble demonstrated that galaxies are receding from one another, with their velocities proportional to their redshift. This discovery laid the foundation for modern cosmology and is now formalized within the ΛCDM (Lambda Cold Dark Matter) model. The ΛCDM model provides a comprehensive description of cosmic expansion and serves as the standard model of cosmology. In this context, the cosmological constant (Λ) represents a form of repulsive energy—often associated with dark energy—that drives the accelerated expansion of the universe, while cold dark matter refers to matter moving at speeds much lower than that of light during the epoch of radiation–matter equality [83, 84]. Together, these components govern the large-scale structure and evolution of the universe, with Λ driving expansion and dark matter contributing to structure formation. As the universe continues to expand, its average temperature is expected to decrease progressively as it approaches an increasingly diffuse and extended state. Based on this evolution, several possible scenarios for the ultimate fate of the universe have been proposed, most notably the Big Crunch, the Big Freeze, and the Big Rip. These scenarios will be examined in detail later in the article. Alternative models, such as the Big Bounce—which proposes that the current expansion phase follows a prior contraction—and the Big Slurp, which arises from considerations related to the Higgs boson and vacuum stability, offer additional perspectives and will also be discussed subsequently. If the universe is spatially closed, its total lifetime—from the Big Bang to a potential Big Crunch—could be relatively short compared with the characteristic timescales of many physical processes. Another important consideration is the possibility that the universe exists in a metastable, or "false vacuum," state. In such a scenario, a lower-energy vacuum state may exist, into which the universe could transition through a quantum tunnelling process. This issue, concerning the stability and fate of the false vacuum, has been explored quantitatively and remains an important topic in cosmology. Additional factors, including gravitational effects and finite-temperature corrections, further complicate these considerations and will be addressed later in the discussion [85].

IV. Development of Universein Future

The future evolution of the universe remains highly uncertain, and it is difficult to determine which of the principal evolutionary pathways is realized in reality. A key limitation arises from the insufficient precision in measuring the deceleration parameter (q), as well as from uncertainties in estimating the average matter density (ρ) of the universe. In particular, the presence of non-luminous or "dark" matter introduces significant complications in determining the total mass content of the cosmos [86, 87]. If one were to consider only the visible, or "luminous," matter contained within galaxies and galaxy clusters, the resulting estimates would suggest an open universe. However, it has become evident that this luminous component represents only a small fraction of the total matter [89, 89]. Observational studies of galactic rotation provide compelling evidence for the existence of substantial amounts of unseen mass. Measurements of rotational dynamics indicate that the true gravitational mass of galaxies is approximately an order of magnitude greater than the mass inferred solely from their luminosity. Furthermore, contemporary observations suggest that galactic haloes extend far beyond their previously estimated boundaries and likely contain a significant proportion of a galaxy's total mass [90, 91]. An even greater discrepancy is observed in galaxy clusters, where the difference between luminous and gravitationally inferred mass can approach two orders of magnitude. This additional mass is necessary to explain the observed velocities of galaxies within clusters, ensuring that these systems remain gravitationally bound. These findings strongly support the presence of dark matter as a dominant component in the large-scale structure of the universe [92, 93].

This is evidenced by the analysis of the motion of glowing very sparse gas around galaxies. If the mass of the galaxy were concentrated only in the visible region, the orbital velocity of the surrounding glowing gas would be inversely proportional to the square root of the distance from the center of the galaxy (according to Kepler's law) [94, 95]. In a simplified spherically symmetric model, at a distance r from the center of the galaxy, the orbital velocity of a substance will be given by the relation $v^2 = G.M(r)/r$, where M(r) is the mass contained in a sphere of radius r. For a constant density of matter r(r) = r then inside will be $v^2 = (4/3)\ pr\ G.r^2$ (orbital velocity will increase in direct proportion to the distance r), while outside the galaxy the dependence $v^2 = G.M/r$ will apply, where M is the total mass of the galaxy. Outside the galaxy, according to Newton's laws, the orbital velocity of matter (gases) should decrease with the square root of the distance.

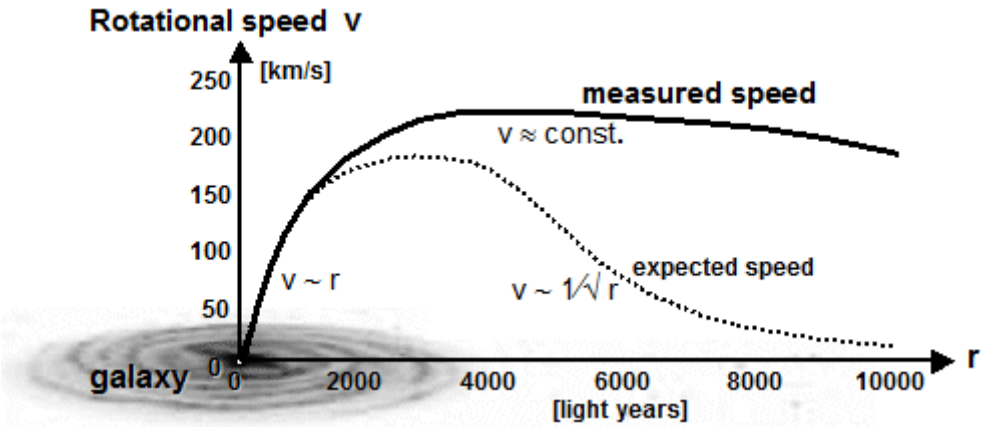

Figure 1: Typical rotation curve - dependence of the orbital velocity of matter on the distance from the center of the galaxy [96, 97].

Observations indicate that, at distances extending several times beyond the visible radius of a galaxy, the orbital velocity of gas remains approximately constant, producing a so-called "flat" rotation curve. This behavior suggests that, even in these non-luminous regions, the mass density is comparable to that within the visible of the galaxy. In other words, the distribution of matter extends well beyond the regions occupied by stars and observable gas [98, 99]. It can therefore be inferred that stars within galaxies, and galaxies within clusters, move at velocities that would be sufficient to disperse them into space under the influence of centrifugal force and inertia alone, were it not for the presence of an additional gravitational component. This discrepancy was first highlighted in 1934 by Fritz Zwicky, who, through spectroscopic observations at the Mount Wilson and Mount Palomar observatories, found that galaxies at the clusters—and stars in the outer regions of galaxies—move significantly faster than would be expected based solely on the gravitational influence of observable ("luminous") matter [100].

To resolve this inconsistency, it is necessary to assume the existence of a much stronger gravitational field than can be accounted for by the classical mass of electrons, nucleons, atoms, and ions that constitute stars, planets, and interstellar. This implies the presence of a substantial of non-radiating, or dark, matter that exerts gravitational influence [101]. Empirical studies of galactic rotation curves indicate that ordinary galaxies contain at least 70% dark matter, with the proportion rising to as much as 90% in dwarf galaxies. Observations of the dynamics of galaxy clusters further reveal that dark matter is not confined to individual galaxies but is distributed throughout the universe, albeit with varying local densities [102]. Due to gravitational attraction, however, dark matter can accumulate in significantly higher concentrations, particularly in the central regions of galaxies. Conversely, in large cosmic voids, its density may be an order of magnitude lower [103].

This hidden mass is thought to consist of particles that interact primarily through gravity, and possibly via the weak nuclear force, although such interactions are negligible due to their short range and low interaction cross-section. These particles do not participate in strong or electromagnetic interactions, or at least do not produce observable electromagnetic effects. Consequently, dark matter both influences and is influenced by the surrounding universe almost exclusively through gravitational interaction. The observed rotational velocities of galaxies cannot be explained by the gravitational effects of visible matter alone. This necessitates the existence of an unseen gravitational "binding agent" that stabilizes galaxies and galaxy clusters. Without this dark matter component, such large-scale structures would be dynamically unstable, and their constituent stars and galaxies would disperse into the surrounding [104].

Dark Matter. Dark matter remains difficult to detect in laboratory settings because it is not known to interact with ordinary baryonic matter or radiation, except through gravitational force. The prevailing theoretical consensus suggests that dark matter consists of as-yet-undiscovered subatomic particles, primarily weakly interacting massive particles (WIMPs) or axions, though an alternative hypothesis proposes it may be composed of primordial black holes [105]. Defined as a hypothetical form of matter distributed across vast cosmic regions, dark matter provides the gravitational scaffolding required to hold galaxies together. This is evidenced by galactic rotation curves, where peripheral regions orbit at velocities exceeding those predicted by the gravity of visible matter alone; a similar discrepancy is observed within galaxy clusters. The term "dark" refers to its inability to emit, absorb, or reflect electromagnetic radiation, rendering it invisible to traditional telescopes [106]. Nevertheless, its existence and spatial distribution can be inferred from its gravitational influence on baryonic matter, radiation, and the large-scale structure of the universe. The formation of galaxies and clusters during the matter-dominated era was significantly dictated by the universe's composition. Had the cosmos

consisted solely of protons, electrons, and light atoms, the intense radiation from the preceding era would have inhibited the formation of large-scale structures, resulting in a homogeneous and smooth universe [107]. However, the presence of dark matter—which does not interact directly with radiation—allowed gravitational contractions to overcome these radiative pressures early on. Consequently, the observed early formation of galactic structures necessitates the existence of additional gravitationally interacting matter. This constitutes a vital cosmological indicator for hidden matter; it facilitated the development of our Galaxy and, by extension, the conditions necessary for the evolution of the solar system and terrestrial life [108].

In galaxies and clusters, dark matter is estimated to be approximately ten times more abundant than luminous matter, making it the dominant component on large scales. It is important to clarify that "dark matter" is a misnomer if it implies the absorption of light, as seen in interstellar dust clouds. On the contrary, dark matter is perfectly transparent to all electromagnetic radiation [109]. Beyond universal gravitation, it likely only engages in the weak interaction. Due to this lack of electromagnetic interaction, dark matter cannot dissipate internal energy or "settle" in significant quantities near stellar bodies, leading to negligible accretion rates. Instead, it aggregates into massive formations, acting as a "backbone" upon which ordinary luminous matter is deposited [110]. While a massive star embedded within a dark matter halo may theoretically absorb a small volume via spherical accretion, the dynamics differ for compact objects. Around supermassive black holes, a gravitationally bound, rotating disk of dark matter may form. However, due to a lack of internal friction, this dark matter cannot shed angular momentum to descend into lower orbits or be consumed by the black hole; consequently, it remains in continuous orbit. Such massive dark-matter disks can significantly perturb the structure and dynamics of the surrounding baryonic accretion disk. Beyond its influence on stellar and galactic motion, dark matter is detectable through gravitational lensing. Since the curvature of spacetime affects electromagnetic rays regardless of whether the source mass is luminous or dark, lensing allows researchers to map dark matter distributions independently of visible light. While dark matter could potentially include "hidden" baryonic forms—such as ionized intergalactic gas, molecular clouds, or stellar remnants—these are classified as baryonic dark matter. Because these objects originate from standard atomic matter, they are fundamentally distinct from the non-baryonic particles thought to constitute the bulk of the universe's hidden mass [111].

Black Holes (BH). A black hole is a gravitational singularity so compact that its escape velocity exceeds the speed of light. In Albert Einstein's general theory of relativity, which interprets gravity as the curvature of spacetime, any sufficiently dense mass is predicted to undergo gravitational collapse into such a state. Mathematically, a black hole is a solution to Einstein's field equations; the Schwarzschild solution provides the simplest model, describing a static, spherically symmetric gravitational field in a vacuum characterized solely by its mass. While it is widely accepted that supermassive black holes reside at the centers of most galaxies—a view supported by the Event Horizon Telescope's (EHT) recent imaging of the accretion disk around Sgr A—some contradictory evidence and theoretical challenges exist [112]. For instance, the observation of radio galaxy NGC1534 suggests a central region significantly fainter than expected for an active black hole, and certain mathematical models argue that Hawking radiation could cause a star to lose mass too rapidly to ever reach the density required for black hole formation. Black holes of small to medium mass are theoretical candidates for dark matter, as they are essentially invisible and occupy negligible spatial volumes. While stellar-mass black holes are too infrequent to account for the required dark matter density, primordial black holes (PBHs) offer a compelling alternative. These could have formed from microscopic quantum fluctuations that expanded to a macroscopic scale during the inflationary epoch, creating high-density regions in the early universe's plasma that collapsed before nucleosynthesis. Such PBHs would be non-baryonic in origin and could be detected via gravitational microlensing—the transient brightening of a distant star as a compact object passes through the line of sight [113]. Confirming the existence of PBHs would provide a plausible origin for dark matter without necessitating the discovery of new particles beyond the Standard Model.

The structural distribution of dark matter is governed by its lack of electromagnetic interaction. Unlike interstellar gas, which can dissipate kinetic energy through radiation to condense into stars and planets, dark matter cannot lose energy through friction or cooling. Consequently, it remains spread out in vast, diffuse clouds of galactic proportions rather than forming compact, star-sized structures. This also renders dark matter accretion highly inefficient; while baryonic matter loses angular momentum through electromagnetic friction and spirals into black holes, dark matter particles likely maintain stable orbits [114]. However, in the high-density environment of the early universe, dark matter may have acted as a gravitational "skeleton," initiating the formation of the first galaxies and potentially contributing to the rapid growth of supermassive black holes and first-generation stars. Current cosmological models involving inflationary expansion suggest that the total radius of the universe may be several orders of magnitude larger than the observable horizon. This implies that the local density observed within our horizon might not represent the global average. Consequently, even a precise measurement of the local density near the critical threshold cannot definitively determine whether the universe is open or closed. While current quantum cosmology and inflation models suggest a closed universe

that is geometrically near-flat, the long-term evolution of the universe remains tied to how these local and global densities eventually interact over vast timescales [115].

V. Probabilities of End of Universe

Astrophysics and cosmology are concerned in detail with the study of the evolution of space objects and the universe as a whole. The basic astronomical knowledge is the current expansion of the universe where individual possibilities are analyzed before.An equally interesting and fundamental problem, such as the origin and early stages of the evolution of the universe, is the question of where the evolution of the universe is headed in the future? What happens to all the amazing structures and matter in space? Leaving aside unlikely scenarios (such as a stationary or oscillating universe), according to the standard cosmological model, the further fate of the universe depends on whether the average density of the cosmic mass r is less or greater than the critical density [116].

Closed universe. A closed universe is a cosmological model characterized by a finite volume and positive spatial curvature, effectively creating a space without boundaries, analogous to the surface of a sphere. In this scenario, the density of matter and energy exceeds the critical threshold required to sustain eternal expansion. Consequently, the gravitational pull eventually overcomes the initial expansionary momentum, leading the universe to reach a maximum size before undergoing a contraction phase. During this contraction, the cosmological redshift observed in distant galaxies would transition into a blueshift [117]. The temperature of the cosmic microwave background radiation would begin to rise, initially at a gradual pace and later with increasing intensity. This process culminates in a "Big Crunch"—a final singularity of extreme density and temperature where all cosmic structures are annihilated. In a broad sense, the final stages of a closed universe mirror the early Big Bang in reverse: rising radiation levels would dismantle atoms back into their constituent elementary particles. However, a significant distinction in the final collapse is the presence of numerous compact objects, such as neutron stars and black holes [118]. These objects would grow rapidly through the accretion of surrounding matter and radiation before eventually merging into a single final state. Despite the theoretical depth of the closed universe model, contemporary astronomical observations suggest it is unlikely. The prevailing Lambda-CDM model indicates a flat universe with a density very near the critical value. While certain analyses of data from the Planck mission have prompted discussions regarding potential positive curvature, the consensus within the scientific community remains that the universe is geometrically flat, though the debate regarding these subtle topological measurements continues [119].

Open Universe. If the cosmic matter density remains below the critical threshold, the universe will expand indefinitely. While the standard cosmological model predicts that gravity will decelerate this expansion, it will never halt. This vast timescale allows for protracted astrophysical evolutionary scenarios. In approximately 5 to 7 billion years, the Sun will exhaust its hydrogen reserves and transition into a red giant, likely engulfing the inner planets, including Earth [120]. Subsequently, it will collapse into a white dwarf. During this period, gravitational instabilities may also cause several planets to be ejected from the solar system. Over the next 10 to 30 billion years, successive generations of stars will continue to enrich the interstellar medium with heavier elements through nucleosynthesis. However, as hydrogen—the fundamental stellar fuel—is depleted, the galactic birthrate of stars will steadily decline. Within 100 billion years, most galaxies will go dark, punctuated only briefly by occasional supernovae from the final massive stars [121]. Eventually, the universe will be populated only by stellar remnants: white dwarfs, neutron stars, and black holes. These compact objects will orbit supermassive black holes at galactic centers, gradually cooling to the ambient temperature of the expanding cosmos. On even more extreme timescales, the fate of matter depends on the stability of the proton. If protons are stable, as current observations suggest, these structures might persist indefinitely. However, quantum tunneling could theoretically enable "cold nuclear fusion", eventually converting all lighter nuclei into iron. Conversely, if Grand Unification Theories are correct and protons decay, the matter within gas clouds and compact bodies will slowly decompose into leptons and radiation [122].

Simultaneously, galaxies will collapse into giant black holes as orbital energy is dissipated through gravitational waves. By roughly 10^35 years, the universe will be dominated by black holes. While these initially grow through accretion, they will eventually succumb to Hawking radiation. After approximately 10^60 to 10^100 years, even these black holes will evaporate [123]. The universe will then consist of a highly diluted mixture of electrons, positrons, photons, and neutrinos, drifting in an eternal, freezing wasteland. This state, known as "heat death" or the "Big Freeze," represents a point of maximum entropy where all usable energy is exhausted, and biological or chemical processes become impossible.Currently, the scenario of a "Big Crunch" has largely been discounted. Observations of Type Ia supernovae indicate that cosmic expansion is not merely continuing but accelerating, driven by the elusive properties of dark energy. Whether this leads to a perpetual "Great Cooling" or a more violent "Big Rip"—where the fabric of spacetime is eventually torn apart—remains an open question. Acknowledging these limitations in our current understanding is essential, as the resolution of

fundamental cosmological problems frequently reveals new, deeper mysteries regarding the essence of the universe [124].

Loss of Information in a Black Hole. The fundamental properties of black holes suggest that during gravitational collapse, nearly all information regarding the specific characteristics of the progenitor matter is lost to the external universe. According to the "no-hair theorem," a black hole is uniquely defined by only three externally observable classical parameters: mass, electric charge, and angular momentum. This lack of microscopic structure leads to the "information loss paradox," as the detailed history of the collapsed matter becomes inaccessible [125]. In the framework of classical (non-quantum) general relativity, analogies were drawn between black hole mechanics and the laws of thermodynamics, linking surface gravity to temperature and the event horizon's area to entropy. However, this classical interpretation is inherently inconsistent. In classical physics, a black hole is a perfect absorber that emits nothing; therefore, its temperature should be absolute zero. Furthermore, its entropy would theoretically be infinite, as a black hole could be formed from an infinite number of infinitesimal particles [126]. Without quantum considerations, these thermodynamic similarities remain merely formal rather than physically substantive. Because a complete theory of quantum gravity remains elusive, physicists employ a "semi-classical" approach to resolve these inconsistencies. In this model, the gravitational field (spacetime geometry) remains unquantized, while other physical fields (matter and radiation) are treated using quantum mechanics [127]. This approximation is highly effective for describing physical reality at scales significantly larger than the Planck length 10^-35 m), failing only in the immediate vicinity of a singularity. From the perspectives of statistical mechanics and information theory, entropy represents a measure of a system's internal disorder or hidden information. When matter crosses the event horizon, the massive amount of information it carries becomes unavailable to the outside world; this lost information is quantified as the black hole's entropy. This relationship, where the information content of a 3D volume is proportional to its 2D boundary surface (the event horizon), is known as the holographic principle. Under the semi-classical approach, it was famously demonstrated that black holes are not truly black but undergo "quantum evaporation"—now known as Hawking radiation—whereby they emit thermal radiation and possess a finite, non-zero temperature and entropy [128].

Holographic Principle. In optics, a holographic image is produced by splitting a beam of coherent laser light is directed straight onto a photographic medium, while the other is reflected from the object being imaged before reaching the same surface. The interference between these two beams generates a pattern of fine interference fringes on the photographic emulsion, encoding information about their phase differences. When this two-dimensional pattern is later illuminated with coherent laser light, the reflected waves reconstruct the original phase relationships, thereby creating the perception of a three-dimensional image of the object [129]. A notable property of holograms is that even a fragment of the holographic plate can reproduce the entire three-dimensional image, although at reduced resolution. By analogy, the two-dimensional surface of a black hole's event horizon can be considered to encode information about the three-dimensional matter that has fallen into it. This idea is often associated with the statement that "a black hole has no hair," meaning that only a limited set of parameters—mass (M), angular momentum (J), and electric charge (Q)—characterize the black hole. However, unlike a true hologram, the detailed information about the internal configuration of the absorbed matter is not recoverable; it is effectively lost [130]. Despite this limitation, the holographic analogy has attracted considerable interest in theoretical physics. Notably, Gerard 't Hooft and Leonard Susskind extended this idea, proposing that the information content of physical systems might be encoded on the boundary surfaces enclosing them. A conceptual illustration involves a sufficiently large black hole, near whose event horizon the laws of physics would approximate those in a freely falling, locally inertial frame, with only minimal tidal effects. From the observed proportionality between the surface area of a black hole's horizon and its entropy, one may infer that information about the matter within the black hole could be associated with its boundary surface. However, this interpretation is not strictly accurate, as both the "no-hair" theorem and the entropy–area relationship applies to the external properties of the black hole rather than to its internal structure [131].

The holographic principle has been further generalized within the framework of superstring theory. In this context, it asserts that the informational degrees of freedom within a volume (V) can be encoded on its boundary surface, with a maximum information density of approximately one bit per Planck area. More broadly, the principle suggests that the physical description of an (N)-dimensional region can be represented by data defined on its ((N-1))-dimensional boundary [132]. Within general relativity, however, this concept is rigorously supported only in the case of black hole horizons. In other situations, it remains a theoretical extrapolation and an unverified hypothesis. Consequently, the notion that the entire universe is holographic remains speculative. Although holographic ideas are employed in certain formulations of superstring theory, their physical realization is not yet established. Superstring theory itself posits that the fundamental constituents of the universe are not point-like particles but extremely small, one-dimensional vibrating strings. It seeks to unify quantum mechanics and general relativity, incorporating the concept of supersymmetry to account for both bosons and fermions, and is often regarded as a candidate for a "Theory of Everything." Nevertheless, the question of whether the

universe is fundamentally holographic remains unresolved, and a cautious, evidence-based conclusion would be that such a scenario is unlikely [133].

Universe may inside a Gigantic Black Hole. The proliferation of black hole astrophysics between the 1960s and 1980s gave rise to several speculative hypotheses, including the "black hole cosmology" model. This theory suggests that our observable universe—comprising all known galaxies, stellar structures, and radiation—resides within the interior of a gargantuan black hole, which itself may be part of a broader multiverse. A corollary to this idea posits that the Big Bang was actually a "Big Bounce," where a gravitational collapse in a precursor universe transitioned through a wormhole to form our expanding spacetime. However, these assumptions remain unverified and face significant empirical challenges. Specifically, this model conflicts with the cosmological principle, which mandates global homogeneity and isotropy [134]. If the universe were inside a black hole, observations would reveal a gradient in galactic density, with matter thinning out toward the event horizon and condensing toward a central singularity. No such "edge" or central concentration has been detected. While the concept remains a popular fixture in philosophical and cultural discourse due to its inherent mystery, it does not align with the isotropic universe currently observed by astrophysicists [135].

Computational and Information-Theoretic Perspectives. The success of high-fidelity computer simulations in modelling cosmic evolution has led some to metaphorically suggest that the universe functions as an "autodidactic" software system or a giant quantum computer. While the "simulation hypothesis"—popularized by media such as The Matrix—suggests we live in a digital construct, most experts regard this as a literal impossibility. Instead, a more grounded interpretation is that many physical processes are mathematically algorithmizable. This suggests that the universe is inherently knowable and that future advancements in quantum computing will allow for even more precise extrapolations of cosmic phenomena, reinforcing the concept of the material unity of the world [136].

The Concept of Cosmic Consciousness. Another non-standard hypothesis is that of "Cosmic Consciousness," which views the universe as a self-aware, living entity. From the rigorous perspective of astrophysics and cosmology, this idea is considered overly subjective and anthropomorphic. Scientific consensus defines the universe as a largely inanimate and inhospitable expanse, where life is an exceptionally rare and precious consequence of matter reaching high levels of complexity through specific evolutionary mechanisms. While some environmentalists and alternative naturalists embrace the "living universe" model to promote ecological harmony and a sustainable future, there is no objective evidence to support it. Furthermore, a distinction must be made between "enlightened scientific materialism"—which seeks to protect the natural world through a deeper understanding of reality—and "vulgar materialism," which is associated with consumerism and environmental degradation. Ultimately, while these philosophical and science-fiction-inspired ideas provide positive social motivation, they lack the empirical foundation required for formal astrophysical theory [137].

VI. Evaluation of the 'End of Universe'

The ultimate destiny of the universe is a central question in physical cosmology, with the outcome largely depending on the behavior of dark energy and the universe's overall density. Based on current observations, there are several scientifically proposed scenarios for how the cosmos might end. Whatever the ultimate fate of the universe, it is clear that the universe does not allow for the possibility of eternal life. The question of how the universe will ultimately end remains one of the most profound problems in modern cosmology [138]. Scientists believe that the answer depends primarily on two major factors: the nature of dark energy and the total density of matter and energy in the universe. Observational data gathered over recent decades has led to multiple theoretical possibilities regarding the universe's long-term evolution and eventual conclusion. Regardless of which scenario proves correct, one consistent implication emerges: the universe is not structured to sustain life indefinitely. Everything that exists within it is subject to change, decay, and eventual cessation [139].

"Phantom" dark energy is a theoretical, highly unstable form of dark energy with density that increases as the universe expands, potentially leading to a Big Rip. It is a hypothetical extension beyond standard dark energy (which has constant density) and is labeled "phantom" because its properties are bizarre, suggesting repulsive pressure exceeding the energy density itself. Now, at the scales of galaxies and galaxy clusters, gravity appears stronger than would correspond to astronomically observed "luminous" or absorbing matter composed of electrons, protons, and neutrons. So gravitational dark-hidden matter is added. One particularly speculative idea in cosmology is the concept of "phantom" dark energy. Unlike ordinary dark energy, which is thought to maintain a constant density throughout cosmic expansion, phantom dark energy would actually grow stronger as space expands. This unusual characteristic could result in extreme consequences, such as the eventual tearing apart of all structures in the universe in an event known as the Big Rip [140]. The term "phantom" reflects the strange and counterintuitive nature of this energy, whose repulsive pressure may exceed its own energy density. At smaller cosmic scales, such as galaxies and galaxy clusters, observations indicate that gravity behaves more

strongly than can be explained by visible matter alone. The matter we can detect—composed of protons, neutrons, and electrons—accounts for only a fraction of the gravitational effects observed. To resolve this discrepancy, scientists propose the existence of dark matter, an unseen form of matter that contributes additional gravitational influence [141].

On the larger cosmological scales, where the universe expands, gravity, on the other hand, appears weaker than would correspond to the overall attraction of particles of ordinary and dark matter. Therefore, "dark energy" is added - a weak antigravity, a force that acts against gravity and independently of matter. Conversely, when examining the universe on its largest scales, gravity appears insufficient to explain the observed rate of cosmic expansion. Instead of slowing down due to gravitational attraction, the expansion of the universe is accelerating. To account for this, scientists propose the existence of dark energy—a mysterious force that acts in opposition to gravity. Unlike dark matter, which enhances gravitational attraction, dark energy produces a repulsive effect, effectively driving galaxies apart and influencing the large-scale structure of the cosmos [142]. Current models of the universe require dark energy to explain the observed acceleration of space expansion resulting from measurements of supernova distances in distant galaxies (which appear to be more distant than they should be if the expansion of the universe did not accelerate). However, the issues of dark matter and dark energy are still being discussed, new measurements are being evaluated, and alternative options are being explored?

Modern cosmological models rely heavily on dark energy to explain observations such as the brightness and distance of distant supernovae. These measurements reveal that galaxies are farther away than expected under a non-accelerating expansion model, providing strong evidence that the universe's expansion is speeding up. Despite this, both dark matter and dark energy remain poorly understood. Scientists continue to refine measurements, test competing theories, and explore alternative explanations in an effort to better understand these fundamental components of the universe [143]. Now question is how will the universe extinct? Or what is the ultimate fate of universe? From all our observation of nature and life follows the experience that everything that has originated, exists and is evolving, must have its end - extinction. We also attribute this property to the whole universe. In this article, in a number of places, it has been investigated astrophysical processes, which in the distant future may gradually end the existing processes and the existence of the universe as we know it and cause its 'extinction or death'. Here, for clarity, let's summarize the basic ways in which, according to current astrophysics and cosmology, our universe could to extinct or destroy or die:

This leads to the central question: how will the universe ultimately end? Observations of nature suggest a universal principle—everything that begins, evolves, and exists will eventually cease. Applying this reasoning to the cosmos as a whole, scientists have proposed several possible scenarios for its eventual demise [144]. These scenarios are based on known physical laws and theoretical extensions of current models, and they attempt to describe how the processes sustaining the universe might gradually come to an end. Below is a summary of the primary hypotheses regarding the universe's ultimate fate [145].

a. Infinite Expansion of the Universe or Thermal/Heat Death or Big Freeze. If the gravitational pull of matter is insufficient to halt cosmic expansion, the universe will continue expanding indefinitely. Over time, this expansion will cause matter to become increasingly diluted, and temperatures will steadily decline toward absolute zero. This process leads to what is known as the "Big Freeze" or heat death of the universe. As expansion continues, energy becomes more evenly distributed, and all thermodynamic processes gradually cease. Stars will exhaust their nuclear fuel over tens to hundreds of billions of years, and no new stars will form due to the scarcity of gas. Stellar remnants such as white dwarfs, neutron stars, and planets will slowly decay through processes like proton decay. Even black holes, once thought to be eternal, will eventually evaporate through Hawking radiation. After an unimaginably long period—on the order of $10^{6^{0}}$ years—the universe will consist mostly of extremely low-energy radiation and sparse particles. It will approach a state of maximum entropy, where energy differences no longer exist to drive physical processes. Since life and information processing depend on such gradients, this state effectively marks the end of all activity. Although theoretical fluctuations could, over infinite time, briefly reduce entropy, such events would be extraordinarily rare. The heat death scenario is widely considered the most probable outcome given current evidence, especially if dark energy continues to drive expansion [146].

b. The Collapse of the Universe or Big Crunch. In contrast to endless expansion, the Big Crunch scenario proposes that the universe could eventually stop expanding and begin contracting. This would occur if the total density of matter and energy were high enough for gravity to overcome expansion. In this model, the universe's expansion slows, halts, and reverses. Over time, galaxies move closer together, temperatures rise, and matter becomes increasingly compressed. In the final stages, extreme heat and density would break apart atoms and subatomic particles. Eventually, all matter and space-time would collapse into a singularity—a state of infinite density and temperature similar to the conditions at the Big Bang. Some theories suggest that such a collapse could be followed by another Big Bang, initiating a new universe in a cyclical process. However, this idea

remains speculative and lacks direct evidence. Current observations indicate that the universe is likely not dense enough to trigger such a collapse, making this scenario less probable [147].

c. Infinite Accelerated Expansion of the Universe or Big Rip. The Big Rip scenario extends the idea of cosmic expansion by suggesting that it could accelerate without limit. If dark energy grows stronger over time, the expansion rate could eventually become so extreme that it overcomes all forms of binding forces. Initially, galaxy clusters would disperse, followed by the disintegration of individual galaxies. Later, stars would lose their planetary systems, and eventually even atoms and subatomic particles would be torn apart. In the final moments, space-time itself could be ripped apart. If phantom dark energy exists, this process could occur relatively quickly on cosmic timescales—possibly within tens or hundreds of billions of years. In this case, the universe would end in a singularity-like state where distances and energies become infinite [148].

d. The collapse of a previous universe- Big Bounce. The Big Bounce theory suggests that the universe undergoes repeated cycles of expansion and contraction. Instead of a single beginning, the universe may have emerged from the collapse of a previous universe. According to this model, a contracting universe reaches a minimum size before "bouncing" back into expansion. This avoids the problem of infinite density by incorporating quantum effects, which may prevent the formation of a true singularity. This cyclical view of the universe was less favored after the development of inflation theory but has regained some interest as a possible solution to unresolved cosmological problems. In this framework, each cycle could produce a new universe with different properties [149].

e. Vacuum instability - quantum transition of False Vacuum. Another intriguing possibility arises from quantum field theory. It suggests that our universe may currently exist in a metastable state known as a "false vacuum." This state is not the lowest possible energy configuration. If a transition to a "true vacuum" were to occur, it could begin with the formation of a tiny bubble of lower-energy space. This bubble would expand at nearly the speed of light, transforming everything it encounters [150]. The laws of physics inside this new vacuum could differ drastically, making the existing universe unrecognizable or destroying it entirely. Although this scenario is theoretically possible, the fact that the universe has remained stable for over 13 billion years suggests that such a transition is extremely unlikely in the near future. Some theories even propose that such an event could give rise to an entirely new universe rather than simply ending the current one.

f. Final Analytical Summery. It is likely misleading to claim that we can determine the universe's exact fate with certainty. What we can do, however, is use observational evidence to make informed predictions about the long-term consequences of cosmic expansion. Current data does not point to a single, definitive outcome; instead, it supports several possible scenarios, each consistent with observations to varying degrees. These possibilities reflect different assumptions about the behavior of dark energy and the large-scale dynamics of the universe. Some interpretations of recent findings have led to increased interest in the Big Rip scenario, particularly in discussions about the role of dark energy in accelerating cosmic expansion [151]. If this acceleration continues to intensify, it could suggest a future where the expansion becomes so extreme that it ultimately disrupts all structures in the universe. However, this conclusion is not firmly established, and it remains one of several competing hypotheses rather than a confirmed outcome. If, on the other hand, future observations reveal that the rate of expansion slows down over time, alternative scenarios such as the Big Crunch or even a cyclic Big Bounce could become more plausible. In such cases, gravitational forces might eventually overcome expansion, leading to a contraction phase or even repeated cosmic cycles. Still, it is important to stress that no single scenario can currently be stated with certainty [152].

At present, scientists remain deeply engaged in exploring these possibilities, especially those that differ significantly from earlier ideas of either a collapsing universe or one that simply cools forever. The classic phrase often used by cosmologists as "some say the world will end in fire, some say in ice". It may need to be expanded, as newer theories introduce outcomes that are far more complex and unexpected. For example, a study published in Physical Review Letters in May 2023 examined predictions of the Big Bounce model. According to this idea, if the universe had previously undergone a contraction followed by a rebound, this event should have left detectable imprints in the cosmic microwave background (CMB), the faint radiation left over from the early universe. However, when scientists compared observational data from the Planck satellite with simulations of such a bounce, they did not find the expected signatures [153]. This absence of evidence makes the single-bounce version of the Big Bounce scenario less convincing, at least based on current data. Similarly, the Big Crunch scenario—in which gravitational forces eventually reverse expansion and cause the universe to collapse—has become less favored. Although it remains theoretically possible and could, in principle, lead to another Big Bang and the birth of a new universe, present observations suggest that the universe is not dense enough for such a reversal to occur. The Big Rip, while dramatic and intriguing, is also not strongly supported by existing measurements.

Although it cannot be entirely ruled out, current evidence does not indicate that dark energy is increasing in strength to the extent required for such a catastrophic end. Based on the best available astrophysical data, the most likely fate of the universe appears to be the Heat Death or Big Freeze scenario. As

noted by astrophysicist Katie Mack, observations suggest that dark energy behaves like a cosmological constant—a steady force that drives continuous, accelerating expansion. Under this model, the universe will gradually become colder and more diffuse, rather than ending in a sudden collapse or violent disruption. It is crucial, however, to acknowledge the significant uncertainties that remain in cosmology. Our understanding of the universe's large-scale structure, its long-term evolution, and especially the true nature of dark matter and dark energy is still incomplete. The data we currently rely on represents only a limited portion of the observable universe, and conditions may evolve in ways we cannot yet predict. Because of these uncertainties, none of the proposed end-of-the-universe scenarios can be considered definitive. Even models that seem unlikely today could gain support with new evidence, while currently favored theories might need revision. In some cosmological frameworks, particularly those involving a closed universe, the idea of an oscillating cosmos is still conceivable. In such models, a Big Crunch at the end of one cycle could lead to a Big Bounce, giving rise to a new universe in an ongoing sequence of cosmic generations [154].

g. Revision of Accelerated Expansion of Universe. The idea that the universe is undergoing accelerated expansion was first established in the late 1990s, based on observations of around 60 Type Ia supernovae. These stellar explosions appeared dimmer than expected, implying that they were farther away than predicted in a uniformly expanding universe. This led to the conclusion that cosmic expansion is speeding up, a result that quickly gained widespread acceptance in cosmology. However, more recent studies using a much larger dataset—hundreds of Type Ia supernovae observed across different regions of the sky—suggest that the rate of acceleration may be lower than initially estimated. Some analyses even indicate that this acceleration might not be perfectly uniform in all directions. Instead, there are hints of anisotropy, meaning the expansion could vary depending on direction. Interestingly, this variation appears to align with our own motion relative to the cosmic microwave background (CMB), raising the possibility that at least part of the observed acceleration could be influenced by our local position and motion in the universe. If this directional dependence is confirmed, it could challenge the assumption that the acceleration is caused by dark energy, which in standard cosmological models should act uniformly in all directions. This has led some researchers to consider whether the observed acceleration might partially be an observational artifact rather than a fundamental property of the universe [155]. In an extreme interpretation, such findings could even call into question the necessity of dark energy itself—though this remains a controversial and far from widely accepted view.

Additional skepticism comes from improved understanding of the astrophysical sources used in these measurements—namely, Type Ia supernovae. These events have long been treated as "standard candles," meaning their intrinsic brightness is assumed to be consistent, allowing astronomers to estimate distances based on how bright they appear. However, newer and more detailed studies suggest that their brightness may not be as uniform as once thought. In particular, the properties of the white dwarfs that produce Type Ia supernovae appear to play a significant role. Younger white dwarfs—formed from later generations of stars enriched with heavier elements (higher metallicity)—tend to produce more luminous supernovae. In contrast, older white dwarfs, composed mostly of hydrogen and helium, tend to produce less energetic explosions [156]. This variation in intrinsic brightness can mimic the observational effects attributed to cosmic acceleration. As a result, the apparent dimming of distant supernovae may not be solely due to the expansion of the universe. Instead, part of this effect could arise from differences in stellar evolution and composition. If not properly accounted for, these factors could lead to overestimating distances to faraway supernovae, thereby exaggerating the evidence for accelerated expansion. To resolve these uncertainties, astronomers emphasize the need for more precise and extensive observations. Large-scale surveys, such as those conducted by advanced spectroscopic instruments and next-generation telescopes, aim to measure thousands of supernovae and other distant cosmic objects with greater accuracy [157]. These efforts will help disentangle cosmological effects from astrophysical variables and provide a clearer picture of the universe's expansion history. Despite these ongoing debates and refinements, the concept of accelerated expansion remains a cornerstone of modern cosmology. The dark energy model, while not fully understood, continues to provide the most consistent explanation for a wide range of observational data. Nevertheless, the situation remains open to revision, and future discoveries may significantly reshape our understanding of the universe's dynamics [158].

VII. Composition and Shape of Universe

a. Basic Composition. In addition to understanding the large-scale structure and evolution of the cosmos, one of the central goals of physical cosmology is to determine what the universe is fundamentally made of—its matter, fields, and particles. Scientific evidence shows that the composition of the universe has undergone significant changes throughout its history.In the earliest moments after the Big Bang, the universe was dominated by fluctuating quantum fields and elementary particles. As it expanded and cooled, these gave rise to quarks, which then combined to form baryons such as protons and neutrons. Alongside these were photons, electrons, muons, and neutrinos. As conditions stabilized further, the first atomic nuclei—primarily hydrogen and helium—formed during primordial nucleosynthesis [159]. Much later, within stars and during supernova

explosions, heavier elements were created through stellar nucleosynthesis processes. Today, the observable (or "ordinary") matter in the universe consists mostly of about 75% hydrogen and 25% helium, with only trace amounts of heavier elements. This familiar matter includes baryons, electrons, and radiation such as photons. For a long time, scientists assumed that by studying luminous objects—stars, galaxies, and gas clouds—across various wavelengths of electromagnetic radiation (optical, infrared, radio, X-ray, and gamma-ray), we would eventually uncover the full composition of the universe. However, modern cosmology has dramatically revised this picture.

The introduction of dark matter and dark energy has fundamentally changed our understanding of what the universe is made of. Current models indicate that ordinary matter accounts for only about 4–5% of the total mass-energy content of the universe. Dark matter contributes roughly 25%, while dark energy makes up about 70%. This realization has profound implications. It means that everything we can directly observe—stars, nebulae, galaxies—is only a tiny fraction of the universe. The vast majority of its content is invisible and not directly detectable with conventional instruments. In this sense, observable matter is merely the "tip of the iceberg," while the bulk of the universe remains hidden and largely mysterious. This situation also carries an important philosophical (or epistemological) dimension. It highlights the limitations of our knowledge and observational capabilities. Despite the sophistication of modern telescopes and detectors, we are still unable to directly probe most of the universe's contents. Dark matter has not yet been directly detected, and dark energy remains even more elusive, with its nature almost entirely unknown. The current estimates of the universe's composition are not arbitrary; they are derived from highly detailed comparisons between theoretical models—particularly the Lambda-CDM (ΛCDM) model—and a wide range of precise astronomical observations. These include measurements of galaxy distributions, gravitational effects, and especially the intensity, spectrum, and tiny fluctuations in the cosmic microwave background radiation—the relic radiation from the early universe [160].

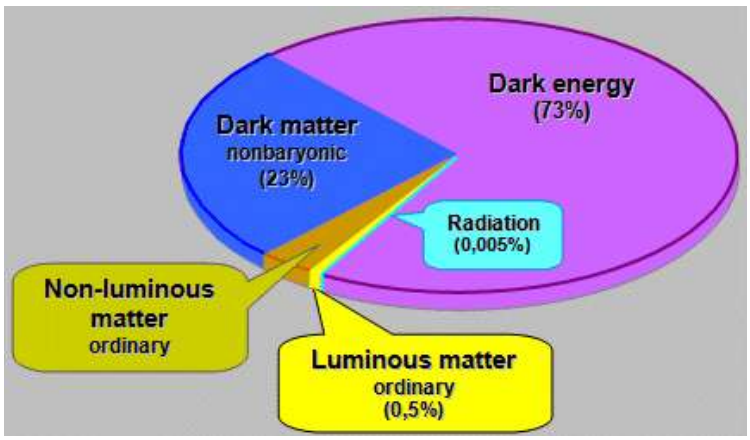

Figure2: Basic composition of universe [161]

b. Shape of Universe. The idea that traveling far enough in one direction through the universe might eventually bring you back to your starting point arises from the possibility that the universe has a closed, curved geometry rather than being perfectly flat. This question about the universe's shape is a fundamental issue in cosmology because it directly affects how space, time, and cosmic evolution behave on the largest scales. Data from the Planck space observatory provided some of the most precise measurements of the cosmic microwave background (CMB)—the faint radiation left over from the early universe [162].By analyzing this ancient light, scientists can infer the geometry of the universe. One intriguing result from these observations was the detection of slightly more gravitational lensing than expected. Gravitational lensing occurs when massive structures bend the path of light due to the curvature of spacetime. Researchers, including Alessandro Melchiorri and his collaborators, suggested that this extra lensing signal might indicate that the universe is not perfectly flat. Instead, it could be "closed," meaning it has a spherical geometry. In such a universe, space curves back on itself. As a result, if you could travel in a straight line for an immense distance, you might eventually return to your original location—similar to circumnavigating the surface of the Earth, but in three-dimensional space. This interpretation challenges the standard cosmological model, which assumes a flat universe—one with no overall curvature, extending infinitely in all directions. Most other cosmological observations, including galaxy distributions and large-scale structure measurements, strongly support this flat geometry. That's why the Planck result is both intriguing and controversial. The reasoning behind the "closed universe" interpretation is that the additional lensing could imply more total matter—particularly dark matter—than previously estimated. A higher matter density would increase gravitational effects and could curve the universe into a finite, spherical shape rather than leaving it flat. However, it is important to treat this conclusion with caution. While the Planck data is

अत्यंत precise, the indication of a closed universe is not universally accepted. Many scientists believe the result may arise from statistical anomalies, systematic uncertainties, or limitations in the data analysis rather than reflecting the true geometry of the cosmos [163].

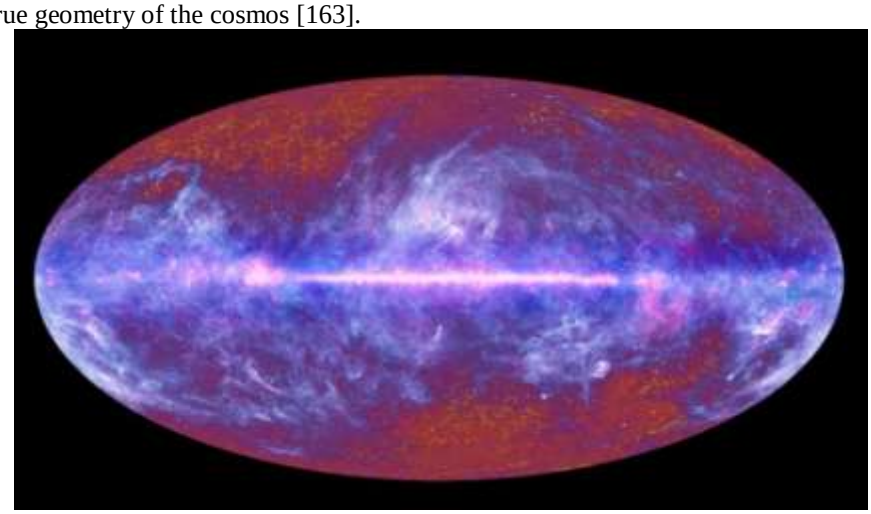

Figure 3: What is the shape of universe: a sphere or round or flat? [164]

VIII. Astro Physicsand the Human Hope

Astrophysics can indeed be seen as a source of hope, but it also confronts us with difficult, sometimes unsettling perspectives. On one hand, it helps us understand our origins, anticipate cosmic dangers, and develop technologies that improve life on Earth. It offers a "cosmic perspective," encouraging humanity to think beyond borders and recognize a shared destiny. On the other hand, when we reflect deeply on what modern cosmology tells us about the long-term evolution of the universe, it can evoke a sense of existential uncertainty about the ultimate meaning and future of human existence. From a human standpoint, the challenges we face are not only cosmic but also self-created. Many of the most immediate threats to civilization arise from human behavior—conflict driven by power, inequality, and ideological divisions. History shows that greed, nationalism, and rigid belief systems can lead to destructive wars. In the modern era, the existence of weapons of mass destruction means that such conflicts could have catastrophic, even civilization-ending consequences [165]. Environmental degradation is another major concern. Industrialization and overconsumption have led to pollution, depletion of natural resources, and disruption of ecosystems. Climate change is linked in large part to greenhouse gas emissions like carbon dioxide, as it is widely recognized as a serious global issue. While scientific discussions continue about the scale and pace of different contributing factors, there is strong consensus that human activity plays a significant role in altering Earth's climate systems [166].

a. Population growth also raises complex challenges. Rapid increases in population can place strain on resources, infrastructure, and ecosystems if not accompanied by sustainable development, education, and economic opportunity. However, it is important to approach this issue carefully and responsibly. Framing populations or regions as inherently "unproductive" or harmful is not accurate and can lead to harmful generalizations. In reality, the key factors influencing sustainability are access to education, healthcare, economic systems, governance, and technology—not inherent traits of particular groups. Solutions typically focus on improving education (especially for women), access to healthcare, and economic development, which historically lead to stable population growth and improved quality of life. For humanity to progress peacefully, efforts are needed to reduce inequality, promote critical thinking, and encourage cooperation across cultures and beliefs. Social systems that foster fairness, scientific understanding, and mutual respect are more likely to support long-term stability. Division—whether political, economic, or religious—can weaken our collective ability to address global challenges [167].

b. Earth's Atmosphere. Earth's atmosphere is essential for maintaining conditions suitable for life, including temperature regulation, air pressure, and protection from harmful radiation. One major concern today is the increase in greenhouse gases, particularly carbon dioxide (CO_2), which contributes to global warming. If left unchecked, rising temperatures could disrupt ecosystems, raise sea levels, and create conditions that are increasingly difficult for many species, including humans. Over extremely long timescales, Earth may also gradually lose parts of its atmosphere to space. This is a natural process influenced by solar radiation and the planet's gravity. While this is not an immediate concern on human timescales, it highlights that planetary habitability is not permanent [168].

c. Planet Earth. Earth itself is a dynamic and sometimes dangerous system. We live on a relatively thin crust divided into tectonic plates that move slowly over time. Their interactions cause earthquakes and volcanic activity. Beneath the surface, the mantle contains hot, flowing rock driven by convection currents. In rare cases, massive volcanic eruptionsoften referred to as super-volcanoes and that can have global consequences. These eruptions can release enormous amounts of ash and gas into the atmosphere, potentially blocking sunlight and causing significant climate disruptions. Yellowstone National Park is one of the most well-known regions associated with such volcanic potential, although any eruption on that scale would be extremely rare. Another long-term risk involves Earth's magnetic field, which shields the planet from harmful charged particles emitted by the Sun (the solar wind). This field is generated by the motion of molten material in Earth's outer core. Over geological timescales, changes in the core could weaken this magnetic field. If significantly reduced, more high-energy radiation could reach the surface, posing risks to life and potentially contributing to atmospheric loss. Loss of the atmosphere would have severe consequences. Without it, liquid water would gradually disappear, temperatures would fluctuate dramatically, and the planet would become increasingly inhospitable—similar to conditions observed on Mars [169].

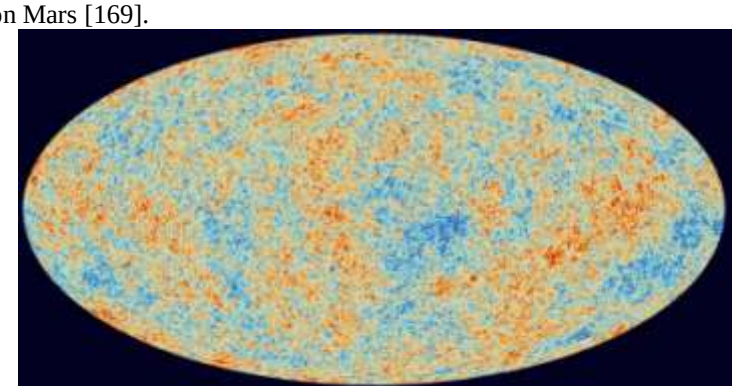

Figure 4: The Planck satellite's map of the cosmic microwave background [170]

d. A Balanced Perspective. While these scenarios—cosmic, environmental, and geological—can seem overwhelming, it is important to keep perspective. Many of the most dramatic cosmic events will occur over timescales far beyond human civilization. More immediate challenges, such as climate change, conflict, and sustainability, are areas where human action can make a meaningful difference. Astrophysics does not only highlight our fragility; it also emphasizes our uniqueness and interconnectedness. The same science that reveals the eventual fate of stars and galaxies also shows that life on Earth is rare and precious. Rather than leading only to pessimism, this knowledge can motivate cooperation, responsibility, and long-term thinking.

e. Near Space (e.g. Asteroids). Near-Earth Objects (NEOs) are asteroids or comets that travel within 1.3 astronomical units (approximately 195 million kilometers) of the Sun, often bringing them into the vicinity of Earth's orbit. More than 37,000 near-Earth asteroids (NEAs) have been identified, many of which are remnants from the early formation of the Solar System. Within the Solar System, not only do the well-known planets, including Earth, orbit the Sun, but there also exists a vast number of smaller bodies of varying sizes. These range from microscopic particles and small meteorites to objects measuring tens or even hundreds of kilometers in diameter, commonly referred to as asteroids. The term "asteroid", meaning "star-like", originates from their appearance through early telescopes, where they resembled faint points of light similar to distant stars, although unlike stars, they move across the sky like planets.Some of these bodies intersect planetary orbits and may collide with planets, be captured by their gravitational fields, or strike their surfaces at extremely high velocities—often tens of kilometers per second. As a result, all terrestrial planets are heavily marked with impact craters formed by such collisions. Thousands of these objects also cross Earth's orbit. Smaller bodies typically burn up in the atmosphere as meteors, contributing an estimated millions of tons of material annually. The Earth's atmosphere provides effective protection against these smaller "space projectiles", as they disintegrate before reaching the surface. Even larger meteorites generally pose limited danger, as they lose most of their kinetic energy due to atmospheric friction, with much of their mass vaporizing before impact.

However, larger asteroids also occasionally intersect Earth's orbit. While such encounters are usually harmless due to timing, there remains a measurable probability of collision. Astronomers often describe this situation metaphorically by stating that we "live in a cosmic shooting range". Objects measuring tens of meters in diameter and weighing over 1,000 tons could cause significant local destruction. In contrast, the impact of a body several kilometers in size would release energy exceeding 10^{22} joules—equivalent to more than a million thermonuclear explosions. Such an event would not only devastate regions spanning thousands of kilometers but also eject vast quantities of rock, gas, and dust into the atmosphere. Molten debris falling back to Earth could ignite widespread fires, while atmospheric dust could block sunlight for years, leading to severe climate disruption. This could result in a global environmental catastrophe potentially threatening the survival of

humanity. A similar event is believed to have occurred approximately 65 million years ago, leading to the extinction of the dinosaurs and many other species. Earth has experienced multiple such collisions in the past and is likely to do so again in the future. Currently, humanity lacks reliable means to prevent such large-scale cosmic impacts.Advances in astronomical observation are gradually improving our ability to detect hazardous asteroids and predict potential collisions. Two primary strategies have been proposed to mitigate such threats:
1). If sufficient warning is available—potentially several years—it may be possible to alter an asteroid's trajectory by applying force, ideally perpendicular to its motion. Proposed methods include the use of nuclear devices to create a propulsion effect through material ejection, high-powered laser systems, or spacecraft positioned nearby to exert gravitational influence.
2). Alternatively, the asteroid could be fragmented using explosives. However, this approach is less desirable, as the resulting fragments may still follow similar trajectories and impact Earth. While smaller fragments may burn up in the atmosphere, this method remains uncertain and is considered less effective.
At present, technological limitations prevent the practical implementation of these strategies, leaving humanity largely dependent on observation and early warning systems.

f. Distant Universe (e.g. Supernovae and Gamma-Ray Bursts). If a nearby star within approximately 30 light-years were to explode as a supernova, the immense release of energy—particularly in the form of high-energy ionizing radiation—could have catastrophic consequences for life on Earth. Even more distant phenomena, such as gamma-ray bursts (GRBs) occurring hundreds or thousands of light-years away, may pose significant risks if their emission is directed towards Earth. These bursts are typically produced by events such as the collapse of massive stars, neutron star mergers, or matter accretion around black holes. Their effects could extend across the entire Solar System. Gamma-ray bursts are among the most powerful and energetic events known in the universe, capable of releasing more energy in a few seconds than the Sun will emit over its entire lifetime. They are classified into long-duration (greater than two seconds) and short-duration (less than two seconds) bursts. Although no GRBs originating within the Milky Way have been conclusively observed, the possibility of past or future occurrences remains under investigation. Long-duration GRBs are often associated with exceptionally luminous supernovae (hypernovae), while certain massive stars like luminous blue variables (LBVs) and rapidly rotating WolfRayet starsare believed to end their life cycles in such events.
g. The Sun and Its Future. In approximately five billion years, the Sun will exhaust its hydrogen fuel and expand into a red giant, potentially engulfing the inner planets, including Earth, before eventually collapsing into a white dwarf. Even if humanity were able to avoid other existential threats—such as asteroid impacts, global conflicts, super-volcanic eruptions, ecological crises, or cosmic radiation—Earth's long-term survival remains limited by the evolution of the Sun. Over the next three billion years, the Sun's energy output is expected to increase by roughly 40%, raising global temperatures, evaporating the oceans, and rendering the planet uninhabitable. During its red giant phase, the Sun may expand sufficiently to engulf Mercury, Venus, Earth, and possibly Mars. However, mass loss through intensified solar wind could increase planetary orbital distances, potentially allowing Earth to escape direct engulfment. Even in such a scenario, Earth would remain a barren and lifeless world. As hydrogen fusion in the Sun's core declines, it will lose hydrostatic equilibrium, causing its outer layers to expand. Eventually, the Sun will shed these layers, forming a planetary nebula, while its core becomes a white dwarf—a dense, cooling stellar remnant that emits residual heat for trillions of years. In the extremely distant future, it may cool further into a theoretical black dwarf. Maintaining Earth's habitability over long timescales would require gradually increasing its orbital distance from the Sun. While currently beyond technological capability, such adjustmentson the scale of millimeters per year. It could theoretically be achieved using gravitational interactions with asteroids or other massive bodies. However, even if such interventions were possible, later stages of solar evolution would present further challenges. Increased radiation, high-energy particle emissions, and eventual cooling of the Sun would create conditions unsuitable for life. Any surviving civilization would likely need to undergo profound transformation to endure such an environment.
h. Global Evolution and Extinction of the Universe. By the time the Solar System reaches its end, humanity may attempt to escape Earth and colonize other potentially habitable regions of space. However, at present, such prospects remain highly uncertain. This raises a further question: what ultimately lies ahead for civilization?If the universe were closed and eventually collapsed into a highly dense, high-energy state—a so-called "big crunch"—there would be little prospect for survival. Conversely, if the universe is open and continues expanding indefinitely, an immediate catastrophic end may not occur. Nevertheless, in a perpetually expanding and cooling universe, it would become increasingly difficult to locate regions where usable energy remains available.This scenario leads to the concept of the "thermal death" of the universe, in which all energy becomes evenly distributed and no useful work can be performed. Under such conditions, the continuation of human civilization would be impossible. Living systems rely on ordered forms of energy like food, which are inevitably converted into disordered energy (heat), thereby increasing overall entropy.Even in a distant future where

civilization might transform into advanced forms—perhaps involving highly efficient information processing or even non-biological, electronic systems—the fundamental laws of thermodynamics would still apply. Although energy efficiency could improve significantly, energy would still be required to maintain any structured system, including memory storage. Inevitably, some of this energy would be dissipated as heat, increasing disorder. According to thermodynamic principles, the increase in entropy always exceeds the local increase in order, meaning that such advancements could only delay, rather than prevent, eventual decline.A speculative, though largely theoretical, source of hope lies in the concept of the multiverse. This idea suggests that our universe may be just one of an infinite number of universes, each with its own physical properties. Collectively, these universes—often referred to as parallel or "bubble" universes and that would encompass all of existence, including space, time, matter, and energy.

i. Final Analysis. Although individual universes may eventually end through collapse or heat death, the multiverse as a whole could persist indefinitely, with new universes potentially giving rise to new forms of life. However, this offers no direct assurance for the survival of humanity within our own universe.At present, the universe is believed to be in the Stelliferous Era and that is the age in which stars actively form and shine. Over immense timescales, it is expected to transition into a Dark Era, characterized by maximum entropy, the absence of usable energy, and the eventual cessation of all astrophysical activity. Some speculative theories, such as the "dead universe" hypothesis, even propose that our current universe may have originated from the collapse of a previous one. The result of expansion the temperature of universe will have been getting down, as universe achieving maximum size of universe [171, 172].Consequently, two possibilities emerged to deciding the ultimate fate of universe:Big Crunch or Big Freeze and Big Rip [173, 174].Both will be discussed later of the article. On the other hand,Big Bounce (in this theory of big bounce, the present universe is a phase of expanding or contracting universe. This theory explains about the expansion, as big bang come subsequently after big crunch) [175] and Big Slurp theory (where a new possibility about the fate of universe arises after the conception of Higgs Boson particle)[176, 177] have explained different concept and also will be discussed later.If the universe is closed, then the total lifetime of the universe, from Big Bang to Big Crunch, can be relatively short in comparison with the characteristic time scales of many of the physical processes.The universe is currently in a false vacuum state. In other words, a lower energy vacuum state exists and the universe can someday tunnel to that lower energy state [178, 179]. This problem, the fate of the false vacuum, was first explored quantitatively later in this article [180]. Additional effects have also been discussed subsequently, including gravity and finite temperature effects.

IX. Conclusion

The development of modern astrophysics and cosmology concerning the ultimate fate of the universe has evolved from largely theoretical speculation, based primarily on gravity, to a data-driven discipline dominated by the study of dark energy. Current scientific consensus, supported by observations of the accelerating expansion of the universe, strongly favors a cold, diffuse end-state. However, recent preliminary findings have introduced the possibility of a future cyclical collapse. With these approximations, researchers are also able to explore quantum effects in the early universe. Contemporary approaches to quantum gravity, including holographic principles, suggest that classical spacetime and even Einstein's field equations may emerge from fundamentally quantum processes such as entanglement. These ideas have been applied in cosmological models describing expanding universes originating from a Big Bang. Nevertheless, certain formulations of holographic gravity appear limited in realism, particularly because they often assume a negative cosmological constant. More general cosmological solutions within such frameworks may involve time-dependent scalar fields, which could allow for more realistic cosmic evolution, including late-time accelerated expansion. Observationally, these models might be distinguished from the standard ΛCDM framework by features such as a decreasing dark energy component. Early cosmological models, developed between the 1920s and 1980s by figures such as Georges Lemaître and Albert Einstein, focused on whether gravitational attraction would eventually halt cosmic expansion, leading to a Big Crunch, or whether expansion would continue indefinitely, resulting in a "Big Chill". During this period, the prevailing model assumed a hot Big Bang followed by gradual cooling.A major shift occurred after 1998, when observations revealed that the expansion of the universe is accelerating rather than slowing. This discovery redirected scientific consensus towards a future dominated by dark energy, making the "Big Freeze" or heat death scenario the most widely accepted outcome. In the framework of precision cosmology, particularly the ΛCDM model, modern observations and that using instruments such as the Hubble Space Telescope and missions like Wilkinson Microwave Anisotropy Probe—indicate that the universe is spatially flat and will continue expanding indefinitely. This would ultimately result in a state of maximum entropy: a cold, dilute distribution of particles. As expansion proceeds, galaxies will recede ever further from one another under the influence of dark energy. Stars will exhaust their nuclear fuel, and black holes will gradually evaporate through Hawking radiation.

The universe will therefore approach a cold, dark, and highly diffuse condition. In more extreme scenarios, if dark energy were to intensify, it could overcome all gravitational binding, tearing apart galaxies, stars, planets, and even atomic structures in a so-called Big Rip. Although considered unlikely, some recent analyses for example, those associated with DESI and DES surveys suggest that dark energy may not be constant. If it were to weaken, gravitational forces could eventually dominate, potentially reversing expansion in approximately 20 billion years and leading to a renewed collapse followed by another Big Bang. If the universe were to enter a future inflationary phase, the scale factor would increase at an accelerated, effectively superluminal rate. As a consequence, distant astrophysical objects would move beyond the observable horizon and become causally disconnected. From the perspective of any observer, the visible universe would appear to shrink, as galaxies and stars cross beyond the so-called cosmological horizon and their emitted light becomes infinitely redshifted.In the most probable scenario, however, expansion continues indefinitely. Stellar processes will cease, galaxies will fade, and the universe will evolve into a cold, dark void characterized by maximum entropy. The Big Freeze, therefore, remains the most widely supported long-term outcome. Alternative possibilities still exist. If the density of the universe were sufficiently high, gravitational forces could eventually halt and reverse expansion, leading to a collapse into a high-density, high-temperature state. Such a process might give rise to a cyclical model, in which a Big Crunch is followed by a new Big Bang, potentially repeating indefinitely. Ultimately, the fate of the universe depends critically on both its overall density and the behavior of dark energy, which remains poorly understood. While current observations favor a flat, ever-expanding universe, these conclusions rely on simplified assumptions about the equation of state of dark energy. If the theory of cosmic inflation is correct, the early universe experienced a phase dominated by a different form of dark energy. The eventual end of inflation suggests that the properties of dark energy may be more complex than currently assumed. It is therefore conceivable that its behavior could change again in the future, leading to outcomes that are difficult to predict or model. Given that both dark energy and dark matter remain largely enigmatic, the ultimate fate of the universe is still, to some extent, an open scientific question. Modern astrophysics has shifted from expectations of a fiery end, like a Big Crunch, to a "cold" conclusion in the form of a Big Freeze. Some scientists, including Roger Blandford, have suggested that this pursuit provides a source of intellectual and cultural hope, encouraging curiosity and offering a sense of purpose that extends beyond mere survival.However, ongoing research continues to refineand occasionally challengethis picture. Beyond its scientific implications, astrophysics also offers a broader philosophical perspective.

References

[1]. Zeilik, M., & Gregory, S. A. (1998). Introductory astronomy and astrophysics (4th ed.). Saunders College Publishing.
[2]. Keeler, J. E. (1897). The importance of astrophysical research and the relation of astrophysics to the other physical sciences. The Astrophysical Journal, 6(4), 271–288. https://doi.org/10.1086/140401
[3]. Cambridge University Press. (n.d.). An introduction to modern astrophysics. Retrieved March 11, 2026, from https://www.cambridge.org/highereducation/books/an-introduction-to-modern-astrophysics/140DDF8A480C3841DCCD76D66984D858/contents/351D92F23E4D4016D6261254E763B10E
[4]. Maoz, D. (2016). Astrophysics in a nutshell. Princeton University Press.
[5]. Bojowald, M. (2015). Quantum cosmology: A review. Reports on Progress in Physics, 78(2), 023901. https://doi.org/10.1088/0034-4885/78/2/023901
[6]. He, D., Gao, D., & Cai, Q. (2014). Spontaneous creation of the universe from nothing. Physical Review D, 89(8), 083510. https://doi.org/10.1103/PhysRevD.89.083510
[7]. Klebanov, I., & Maldacena, J. (2009). Solving quantum field theories via curved spacetimes. Physics Today, 62(1), 28. https://doi.org/10.1063/1.3074260
[8]. ResearchGate. (n.d.). Lectures on classical and quantum cosmology. Retrieved March 11, 2026, from https://www.researchgate.net/publication/358918610_Lectures_on_classical_and_quantum_cosmology
[9]. Norton, J. D. (n.d.). Relativistic cosmology. University of Pittsburgh. Retrieved March 11, 2026, from https://sites.pitt.edu/~jdnorton/teaching/HPS_0410/chapters/relativistic_cosmology/index.html
[10]. Mayer, M. G. (1949). On closed shells in nuclei II. Physical Review, 75(12), 1969–1970. https://doi.org/10.1103/PhysRev.75.1969
[11]. Rugh, S., & Zinkernagel, H. (2001). Studies in History and Philosophy of Modern Physics, 33, 663–705.
[12]. Feynman, R. P. (2011). Six easy pieces: Essentials of physics by its most brilliant teacher. Basic Books.
[13]. Einstein, A. (1905). Annalen der Physik, 17, 891–921.
[14]. Segal, I. E. (1993). Geometric derivation of the chronometric redshift. Proceedings of the National Academy of Sciences, 90(23), 11114–11116. https://doi.org/10.1073/pnas.90.23.11114
[15]. CERN. (n.d.). Matter–antimatter asymmetry problem. Retrieved March 12, 2026, from https://home.cern/science/physics/matter-antimatter-asymmetry-problem
[16]. Freedman, W. L., et al. (2001). Final results from the Hubble Space Telescope key project to measure the Hubble constant. The Astrophysical Journal, 553(1), 47–72. https://doi.org/10.1086/320638
[17]. Wollack, E. J. (2010). Cosmology: The study of the universe. NASA. Retrieved March 12, 2026.
[18]. NASA. (n.d.). Dark matter. Retrieved March 12, 2026, from https://science.nasa.gov/dark-matter/
[19]. Tegmark, M. (2014). Our mathematical universe. Knopf.
[20]. Netchitailo, V. (2015). 5D world-universe model space-time-energy. Journal of High Energy Physics, Gravitation and Cosmology, 1, 25–34.
[21]. Netchitailo, V. (2017). Mathematical overview of hypersphere world-universe model. Journal of High Energy Physics, Gravitation and Cosmology, 3, 415–437.

[22]. Valev, D. (2019). Evidence of Dirac large numbers hypothesis. Proceedings of the Romanian Academy, 20(4), 361–368.
[23]. Poulin, V., Smith, T. L., Karwal, T., &Kamionkowski, M. (2019). Early dark energy can resolve the Hubble tension. Physical Review Letters, 122, 221301. https://doi.org/10.1103/PhysRevLett.122.221301
[24]. Netchitailo, V. (2020). World-universe model predictions. Journal of High Energy Physics, Gravitation and Cosmology, 6, 282–297.
[25]. Netchitailo, V. (2016). Overview of hypersphere world-universe model. Journal of High Energy Physics, Gravitation and Cosmology, 2, 593–632.
[26]. University of British Columbia. (n.d.). Quantum gravity and cosmology. Retrieved March 12, 2026, from https://phas.ubc.ca/quantum-gravity-and-cosmology
[27]. Netchitailo, V. (2017). Mathematical overview of hypersphere world-universe model. Journal of High Energy Physics, Gravitation and Cosmology, 3, 415–437.
[28]. Scientific Research Publishing. (n.d.). Paper information. Retrieved March 12, 2026, from https://www.scirp.org/journal/paperinformation?paperid=120558
[29]. Case, S. (2015). 'Land-marks of the universe': John Herschel against the background of positional astronomy. Annals of Science, 72(4), 417–434. https://doi.org/10.1080/00033790.2015.1034588
[30]. Hearnshaw, J. B. (1986). The analysis of starlight. Cambridge University Press.
[31]. Hetherington, N. S. (2015). Spectroscopy and the birth of astrophysics. American Institute of Physics.
[32]. Ricard, Y. (2007). Physics of mantle convection. In D. Bercovici & G. Schubert (Eds.), Treatise on geophysics (Vol. 7, pp. 31–87). Elsevier.
[33]. Uzan, J. P. (2003). The fundamental constants and their variation: Observational status and theoretical motivations. Reviews of Modern Physics, 75(2), 403. https://doi.org/10.1103/RevModPhys.75.403
[34]. Dirac, P. A. M. (1974). Cosmological models and the large numbers hypothesis. Proceedings of the Royal Society A, 338, 439.
[35]. Netchitailo, V. (2020). World-universe model—Alternative to Big Bang model. Journal of High Energy Physics, Gravitation and Cosmology, 6, 133–258.
[36]. Netchitailo, V. (2020). World-universe model predictions. Journal of High Energy Physics, Gravitation and Cosmology, 6, 282–297.
[37]. Netchitailo, V. (2019). High-energy atmospheric physics: Ball lightning. Journal of High Energy Physics, Gravitation and Cosmology, 5, 360–374.
[38]. Netchitailo, V. (2016). Overview of hypersphere world-universe model. Journal of High Energy Physics, Gravitation and Cosmology, 2, 593–632.
[39]. Netchitailo, V. (2019). Solar system: Angular momentum. New physics. Journal of High Energy Physics, Gravitation and Cosmology, 5, 112–139.
[40]. Netchitailo, V. (2018). Hypersphere world-universe model: Tribute to classical physics. Journal of High Energy Physics, Gravitation and Cosmology, 4, 441–470.
[41]. Encyclopaedia Britannica. (n.d.). Big Bang model. Retrieved March 14, 2026, from https://www.britannica.com/science/big-bang-model
[42]. GMAT Club. (n.d.). The Big Bang model posits that the universe was created…. Retrieved March 14, 2026, from https://gmatclub.com/forum/the-big-bang-model-posits-that-the-universe-was-created-in-a-primordia-282470.html
[43]. Netchitailo, V. (2021). Hypersphere world-universe model: Evolution of the world. Journal of High Energy Physics, Gravitation and Cosmology, 7, 508–530.
[44]. Couronne, I., & Ahmed, I. (2019). Top cosmologist's lonely battle against "Big Bang" theory. Retrieved from https://phys.org/news/2019-11-cosmologist-lonely-big-theory.html
[45]. Netchitailo, V. (2020). World-universe model—Alternative to Big Bang model. Journal of High Energy Physics, Gravitation and Cosmology, 6, 133–258.
[46]. Netchitailo, V. (2022). Decisive role of dark matter in cosmology. Journal of High Energy Physics, Gravitation and Cosmology, 8, 115–142.
[47]. Netchitailo, V. (2022). Hubble tension. Journal of High Energy Physics, Gravitation and Cosmology, 8, 392–401.
[48]. Lewis, A., & Bridle, S. (2002). Cosmological parameters from CMB and other data: A Monte Carlo approach. Physical Review D, 66, 103511.
[49]. Conover, E. (2019). Debate over the universe's expansion rate may unravel physics. ScienceNews. Retrieved from https://www.sciencenews.org/article/debate-universe-expansion-rate-hubble-constant-physics-crisis
[50]. Netchitailo, V. (2021). Solar system: Angular momentum. Dark matter reactors. Journal of High Energy Physics, Gravitation and Cosmology, 7, 1353–1372.
[51]. Netchitailo, V. (2021). From the beginning of the world to the beginning of life on Earth. Journal of High Energy Physics, Gravitation and Cosmology, 7, 1503–1523.
[52]. Netchitailo, V. (2020). World-universe model predictions. Journal of High Energy Physics, Gravitation and Cosmology, 6, 282–297.
[53]. Verde, L., Treu, T., & Riess, A. G. (2019). Tensions between the early and the late universe. Nature Astronomy, 3, 891–895.
[54]. Netchitailo, V. (2020). Hypersphere world-universe model: Basic ideas. Journal of High Energy Physics, Gravitation and Cosmology, 6, 710–752.
[55]. Netchitailo, V. (2021). Hypersphere world-universe model. Journal of High Energy Physics, Gravitation and Cosmology, 7, 915–941.
[56]. Ludwig, G. O. (2021). Galactic rotation curve and dark matter according to gravitomagnetism. The European Physical Journal C, 81, 186.
[57]. Netchitailo, V. (2022). Hypersphere world-universe model: Centre of our galaxy. Journal of High Energy Physics, Gravitation and Cosmology, 8, 25–55.
[58]. Cambridge University Press. (n.d.). Relativistic cosmology. Retrieved March 14, 2026, from https://www.cambridge.org/core/books/relativistic-cosmology/7CBB180DDF5B86C0BDB11390CC9FDEED
[59]. Qian, W. H. (2023). Journal of Modern Physics, 14, 271–286.
[60]. Lopez-Corredoira, M. (2017). Tests and problems of the standard model in cosmology. Foundations of Physics, 47, 711–768.
[61]. Netchitailo, V. (2019). Solar system: Angular momentum. New physics. Journal of High Energy Physics, Gravitation and Cosmology, 5, 112–139.
[62]. Qian, W. H. (2022). Journal of High Energy Physics, Gravitation and Cosmology, 8, 417–431.

[63]. Netchitailo, V. (2018). Analysis of Maxwell's equations: Cosmic magnetism. Journal of High Energy Physics, Gravitation and Cosmology, 4, 1–7.
[64]. Arny, T. T. (2002). Explorations: An introduction to astronomy (3rd ed.). McGraw-Hill.
[65]. Beringer, J., et al. (2013). Astrophysics and cosmology. Review of Particle Physics.
[66]. NASA. (n.d.). Planck mission overview. Retrieved March 14, 2026, from https://www.nasa.gov/mission_pages/planck/overview.html
[67]. Braibant, S., Giacomelli, G., &Spurio, M. (2009). Particles and fundamental interactions: An introduction to particle physics. Springer.
[68]. Yukawa, H. (1935). On the interaction of elementary particles I. Proceedings of the Physico-Mathematical Society of Japan, 17, 48–57.
[69]. Radvanyi, P. (2011). Physics and radioactivity after the discovery of polonium and radium. Chemistry International, 33(1).
[70]. Carr, B., Kühnel, F., &Visinelli, L. (2021). Constraints on stupendously large black holes. Monthly Notices of the Royal Astronomical Society, 501, 2029–2043.
[71]. Mehrgan, K., Thomas, J., Saglia, R., Mazzalay, X., Erwin, P., Bender, R., et al. (2019). A 40-billion solar mass black hole in the extreme core of Holm 15A. The Astrophysical Journal, 887, 195.
[72]. Hawking, S. W. (1998). A brief history of time: From the Big Bang to black holes. Bantam Dell Publishing Group.
[73]. Netchitailo, V. (2022). Unidentified infrared discrete emission bands. Journal of High Energy Physics, Gravitation and Cosmology, 8, 243–253.
[74]. Netchitailo, V. (2019). Dark matter cosmology and astrophysics. Journal of High Energy Physics, Gravitation and Cosmology, 5, 999–1050.
[75]. Netchitailo, V. (2019). High-energy atmospheric physics: Ball lightning. Journal of High Energy Physics, Gravitation and Cosmology, 5, 360–374.
[76]. Netchitailo, V. (2019). Dark matter cosmology and astrophysics. Journal of High Energy Physics, Gravitation and Cosmology, 5, 999–1050.
[77]. Astronuclear Physics. (n.d.). Anthropic principle. Retrieved March 17, 2026, from https://astronuclphysics.info/AntropPrincip.htm
[78]. Peebles, P. J. E., & Ratra, B. (2003). The cosmological constant and dark energy. Reviews of Modern Physics, 75(2), 559–606. https://doi.org/10.1103/RevModPhys.75.559
[79]. Tsujikawa, S. (2003). Introductory review of cosmic inflation. Retrieved from https://arxiv.org/abs/hep-ph/0304257
[80]. Trimble, V. (1987). Existence and nature of dark matter in the universe. Annual Review of Astronomy and Astrophysics, 25, 425–472.
[81]. Allanach, B. C., Lester, C. G., Parker, M. A., & Webber, B. R. (1999). Measuring sparticle masses in nonuniversal string inspired models at the LHC.
[82]. NBC News. (2013). Big slurp theory about universe. Retrieved from http://cosmiclog.nbcnews.com
[83]. Hubble, E. (1929). A relation between distance and radial velocity among extra-galactic nebulae. Proceedings of the National Academy of Sciences, 15(3), 168–173.
[84]. Overbye, D. (2017). Cosmos controversy: The universe is expanding, but how fast? The New York Times.
[85]. Peebles, P. J. E. (1982). Large-scale background temperature and mass fluctuations. The Astronomical Journal.
[86]. Swinburne University of Technology. (2023). Hubble flow. Retrieved from https://wikivisually.com/wiki/Hubble%27s_law
[87]. Scharping, N. (2017). Gravitational waves and universe expansion. Retrieved from http://blogs.discovermagazine.com
[88]. Kragh, H. (1996). Cosmology and controversy. Princeton University Press.
[89]. Lachièze-Rey, M., &Luminet, J. P. (1995). Cosmic topology. Physics Reports, 254(3), 135–214.
[90]. Ellis, G. F. R., Maartens, R., & MacCallum, M. A. H. (2012). Relativistic cosmology.
[91]. Caldwell, R. R., Kamionkowski, M., & Weinberg, N. N. (2003). Phantom energy and cosmic doomsday. Physical Review Letters, 91, 071301. https://doi.org/10.1103/PhysRevLett.91.071301
[92]. Landau, E., & Bandos, E. (2017). Found: Most distant black hole. NASA. Retrieved from https://www.nasa.gov
[93]. Seidel, J. (2017). Black hole at the dawn of time challenges our understanding. Retrieved from http://www.news.com.au
[94]. Venemans, B. P., Walter, F., Decarli, R., Bañados, E., Carilli, C., Winters, J. M., et al. (2017). Copious amounts of dust and gas in a z = 7.5 quasar host galaxy. The Astrophysical Journal Letters, 851(1).
[95]. Higgs, P. W. (1964). Broken symmetries and the masses of gauge bosons. Physical Review Letters, 13(16).
[96]. Allison, K., Hill, C. T., & Ross, G. G. (2014). Ultra weak sector, Higgs boson mass, and the dilation. FERMILAB Report.
[97]. Voloshin, M. B., Kobzarev, I. Y., & Okun, L. B. (1975). Soviet Journal of Nuclear Physics, 20, 644.
[98]. Coleman, S. (1977). Physical Review D, 15, 2929.
[99]. Coleman, S., & De Luccia, F. (1980). Physical Review D, 21, 3305.
[100]. Linde, A. D. (1983). Nuclear Physics B, 216, 421.
[101]. Timmer, J. (2023). No WIMPs! Heavy particles don't explain gravitational lensing oddities. Ars Technica.
[102]. Carr, B. J., Clesse, S., García-Bellido, J., Hawkins, M. R. S., & Kühnel, F. (2024). Observational evidence for primordial black holes. Physics Reports, 1054, 1–68.
[103]. Bird, S., Albert, A., Dawson, W., Ali-Haïmoud, Y., Coogan, A., Drlica-Wagner, A., et al. (2023). Primordial black hole dark matter. Physics of the Dark Universe, 41, 101231.
[104]. Carr, B., & Kühnel, F. (2022). Primordial black holes as dark matter candidates. SciPost Physics Lecture Notes, 48.
[105]. Hossenfelder, S., & McGaugh, S. S. (2018). Is dark matter real? Scientific American, 319(2), 36–43.
[106]. Bertone, G., & Hooper, D. (2018). History of dark matter. Reviews of Modern Physics, 90(4), 045002.
[107]. Overbye, D. (2015). Black hole hunters. NASA.
[108]. Netchitailo, V. (2022). Center of Milky Way galaxy. Journal of High Energy Physics, Gravitation and Cosmology, 8, 657–676.
[109]. Montgomery, C., Orchiston, W., & Whittingham, I. (2009). Michell, Laplace and the origin of the black hole concept. Journal of Astronomical History and Heritage, 12(2), 90–96.
[110]. Janssen, M., & Renn, J. (2015). Arch and scaffold: How Einstein found his field equations. Physics Today, 68(11), 30–36.
[111]. Overbye, D., & Taylor, D. B. (2020). Nobel Prize in Physics awarded for work on black holes. The New York Times.
[112]. Bartusiak, M. (2015). Black hole: How an idea became loved. Yale University Press.
[113]. Astronuclear Physics. (n.d.). Quasar mechanism. Retrieved from https://astronuclphysics.info
[114]. Yang, X., Tang, M., & Xu, Z. (2024). Testing the no-hair theorem with hairy black holes. The European Physical Journal C, 84, 977.
[115]. Astronuclear Physics. (n.d.). Retrieved from https://astronuclphysics.info

[116]. Astronuclear Physics. (n.d.). Retrieved from https://astronuclphysics.info
[117]. Corda, C. (2009). Interferometric detection of gravitational waves. International Journal of Modern Physics D, 18, 2275–2282.
[118]. CSIRO. (n.d.). Universe overview. Retrieved from https://www.parkes.atnf.csiro.au
[119]. Linde, A. (2007). Sinks in the landscape and cosmological constant problem. Journal of Cosmology and Astroparticle Physics, 2007(1), 022.
[120]. Tegmark, M. (2003). Parallel universes. Scientific American, 288(5), 40–51.
[121]. Werlang, T., Ribeiro, G. A. P., &Rigolin, G. (2013). Interplay between quantum phase transitions and quantum correlations. International Journal of Modern Physics B, 27, 1345032.
[122]. Glanz, J. (1998). Breakthrough of the year 1998: Cosmic motion revealed. Science, 282(5397), 2156–2157.
[123]. Wang, Y., Kratochvil, J. M., Linde, A., &Shmakova, M. (2004). Current observational constraints on cosmic doomsday. Journal of Cosmology and Astroparticle Physics, 2004(12), 006.
[124]. Adams, F. C., & Laughlin, G. (1997). A dying universe: The long-term fate of astrophysical objects. Reviews of Modern Physics, 69(2), 337–372.
[125]. Linde, A. (2007). Sinks in the landscape, Boltzmann brains, and the cosmological constant problem. Journal of Cosmology and Astroparticle Physics, 2007(1), 022.
[126]. Yurov, A. V., Astashenok, A. V., & González-Díaz, P. F. (2008). Astronomical bounds on a future Big Freeze singularity. Gravitation and Cosmology, 14(3), 205–212.
[127]. Perlmutter, S. (2003). Supernovas, dark energy, and the accelerating universe. Physics Today, 56(4), 53–60.
[128]. Davies, P. (1997). The last three minutes: Conjectures about the ultimate fate of the universe. Basic Books.
[129]. Adams, D. (1995). The restaurant at the end of the universe. Ballantine Books.
[130]. Harrison, E. (1992). The redshift-distance and velocity-distance laws. The Astrophysical Journal, 403, 28–31.
[131]. Croton, D. J. (2013). Damn you, little h! Publications of the Astronomical Society of Australia, 30, e052.
[132]. Braibant, S., Giacomelli, G., &Spurio, M. (2009). Particles and fundamental interactions: An introduction to particle physics. Springer.
[133]. Ludwick, K. J. (2017). The viability of phantom dark energy: A review. Modern Physics Letters A, 32(28), 1730025.
[134]. Baum, L., & Frampton, P. H. (2007). Turnaround in cyclic cosmology. Physical Review Letters, 98, 071301.
[135]. Abelev, B., et al. (2014). Beauty production in pp collisions. Physics Letters B, 738, 97–108.
[136]. Novello, M., &Bergliaffa, S. E. P. (2008). Bouncing cosmologies. Physics Reports, 463(4), 127–213.
[137]. Finelli, F., & Brandenberger, R. (2002). Scale-invariant spectrum generation. Physical Review D, 65, 103522.
[138]. Ashtekar, A., Pawlowski, T., & Singh, P. (2006). Quantum nature of the Big Bang. Physical Review D, 74, 084003.
[139]. Brandenberger, R., & Peter, P. (2017). Bouncing cosmologies: Progress and problems. Foundations of Physics, 47, 797–850.
[140]. Halliwell, J. J. (1991). Quantum cosmology and the creation of the universe. Scientific American, 265(6), 76–85.
[141]. Lehners, J. L., & Steinhardt, P. J. (2013). Planck results support the cyclic universe. Physical Review D, 87, 123533.
[142]. McKee, M. (2014). What's wrong with inflation theory. Nautilus.
[143]. Steinhardt, P. J., & Turok, N. (2005). The cyclic model simplified. New Astronomy Reviews, 49, 43–57.
[144]. Ijjas, A., & Steinhardt, P. J. (2022). Entropy, black holes, and cyclic universe. Physics Letters B, 824, 136823.
[145]. Page, D. N., & McKee, M. R. (1981). Physical Review D, 24, 1458.
[146]. Van Tent, B., Delgado, P. C. M., & Durrer, R. (2023). Constraining bispectrum from bouncing cosmologies. Physical Review Letters, 130, 191002.
[147]. Sutter, P. (2023). Dark energy and multiple Big Bangs. Space.com.
[148]. Space.com. (n.d.). How will the universe end? Retrieved March 17, 2026.
[149]. CBC Radio. (n.d.). Retrieved March 17, 2026, from https://www.cbc.ca
[150]. Lemaître, G. (1933). Annales de la Société Scientifique de Bruxelles.
[151]. Tolman, R. C. (1934). Relativity, thermodynamics, and cosmology. Clarendon Press.
[152]. Astronuclear Physics. (n.d.). Retrieved from https://astronuclphysics.info
[153]. Unsöld, A., &Baschek, B. (2002). The new cosmos (5th ed.). Springer.
[154]. Rice University. (n.d.). Universe lecture notes. Retrieved from https://www.ruf.rice.edu
[155]. New Scientist. (n.d.). Planck shows almost perfect cosmos. Retrieved from https://www.newscientist.com
[156]. New Scientist. (n.d.). Mini-universes exploding. Retrieved from https://www.newscientist.com
[157]. Space.com. (n.d.). Shape of the universe. Retrieved from https://www.space.com
[158]. Medium. (n.d.). Why astrophysics matters. Retrieved from https://medium.com
[159]. Genzel, R., & Ghez, A. (2020). Discovery of a supermassive compact object. Nobel Prize.
[160]. Cahill, D. (2014). Radio galaxy discovery near Earth. Retrieved from https://phys.org
[161]. Quanta Magazine. (2019). What shape is the universe? Retrieved from https://www.quantamagazine.org
[162]. Chapman, C. R. (2004). Hazard of near-Earth asteroid impacts. Earth and Planetary Science Letters, 222(1), 1–15.
[163]. Rumpf, C. M., Lewis, H. G., & Atkinson, P. M. (2017). Asteroid impact effects. Geophysical Research Letters, 44(8), 3433–3440.
[164]. Burbidge, E. M., Burbidge, G. R., Fowler, W. A., & Hoyle, F. (1957). Synthesis of elements in stars. Reviews of Modern Physics, 29, 547.
[165]. Hlavacek-Larrondo, J., et al. (2020). Runaway gas cooling. The Astrophysical Journal Letters, 898, L50.
[166]. Fuge, L. (2018). Milky Way star supernova. Cosmos.
[167]. Vink, J. S. (2013). Gamma-ray burst progenitors. Philosophical Transactions of the Royal Society A, 371, 20120237.
[168]. Crane, L. (2024). How big is the universe? New Scientist.
[169]. Barnhart, R. K. (1995). The Barnhart concise dictionary of etymology. HarperCollins.
[170]. Zeilik, M., & Gregory, S. A. (1998). Introductory astronomy & astrophysics. Saunders College Publishing.
[171]. Hubble Flow, (2023), The Swinburne Astronomy Online Encyclopedia of Astronomy. Swinburne University of Technology. Retrieved 2013-05- 14.https://wikivisually.com/wiki/Hubble%27 s_law, accessed on 18 Mar 2026.
[172]. K. Allison, Christopher T. Hill, Graham G. Ross, (2014), "Ultra weak sector, Higgs Boson Mass, and the dilation", Report of FERMILAB, R.no. FERMILAB-PUB-14-086-T, accessed on 19 Mar 2026.
[173]. Kragh, Helge, (1996), "cosmology and controversy". Princeton university press.1996, p.p. 318-319, accessed on 18 Mar 2026.
[174]. M. Lachieze-Rey, J. PLuminet (1995), "cosmic topology" physics reports 254 (3) ,p.p. 135-214, accessed on 18 Mar 2026.
[175]. Ellis, George F.R., Maartens, roy& Mac Callum, Malcolm A.H. (2012), Relativistic cosmology, p.p. 146- 147, accessed on 18 Mar 2026.
[176]. Voloshin, M. B., I. Yu. Kobzarev, and L. B. Okun, (1975), Sov. J. Nucl. Phys. 20, 644, accessed on 17 Mar 2026.

[177]. landau, Elizabeth, Bandos, Eduad, (Dec. 2017), "Found: Most Distant Black Hole", available from: https://www.nasa.gov/feature/jpl/found-mostdistant-black-hole, accessed on 19 Mar 2026.
[178]. Jamie Seide, (Dec. 2017), "Black hole at the dawn of time challenges our understanding of how the universe was formed" http://www.news.com.au/technology/science/sp ace/black-hole-at-the-dawn-of-time-challengesour-understanding-of-how-the-universe-wasformed/, accessed on 19 Mar 2026.
[179]. Bram P. Venemans, Fabian Walter, Roberto Decarli, Eduardo Bañados, Chris Carilli, Jan Martin Winters, Karl Schuster, Elisabete da Cunha, Xiaohui Fan, Emanuele Paolo Farina, (Dec. 2017) "Copious Amounts of Dust and Gas in a z = 7.5 Quasar Host Galaxy". The Astronomical Journal Letters, volume 851, no.1, available from: http://iopscience.iop.org/article/10.3847/2041- 8213/aa943a/pdf, accessed on 19 Mar 2026.
[180]. Peter w. Higgs, (1964), "Broken symmetries and the masses of gauge Bosons". Physical review Letters, vol-13, no.-16,(19 oct. 1964), accessed on 19 Mar 2026.