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Research on Conjecture of Dark Energy

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Abstract: An in-depth exploration of the origin of dark energy is undertaken. Dark energy is a fascinating and mysterious concept within the realm of astrophysics. It was discovered through a series of astronomical observations and theoretical studies. For instance, the observation of distant supernovae revealed the accelerating expansion of the universe, leading to the postulation of an unknown force—dark energy. The crucial role played by dark energy in the universe is then delved into. It is now widely accepted that dark energy is responsible for accelerating the expansion of the universe. This has significant implications for the understanding of the cosmos and its ultimate fate. Next, the relationship between other matter in relation to celestial bodies and dark energy is examined. Black holes and dark matter are two important components of the universe that have a complex interaction with dark energy. Having immense gravitational pulls, black holes and dark matter, which is believed to make up a large portion of the total matter in the universe, both influence the distribution and behavior of dark energy. The current inferences about dark energy and some famous hypotheses put forward by renowned scientists are also discussed. These hypotheses range from modifications of general relativity to the existence of extra dimensions and new forms of matter. Finally, personal thoughts and speculations on the relationship between dark energy and the higher-dimensional universe are offered. The idea of a higher-dimensional universe has intrigued scientists for decades, and there is growing interest in exploring whether dark energy could be related to these hidden dimensions. This could potentially open up new avenues for understanding the fundamental nature of the universe and its mysteries.

Keywords: Dark energy, holograhpic principle, black hole, high-dimensional universe, dark matter.

1. Introduction

Dark energy is a cosmological phenomenon that remains largely unexplained and is believed to be the primary cause of the accelerated expansion of the universe. The first observational evidence for the existence of dark energy came in 1998 [1] when Adam G. Riess and Saul Perlmutter et al. observed accelerating expanding supernovae. Type 1A supernovae have a constant luminosity, enabling them to be used as accurate distance measurements. Comparing this distance with the redshift indicates that the expansion of the universe is accelerating. Prior to this observation, scientists thought that the gravitational pull of matter and energy in the universe would cause the expansion of the universe to slow down over time. Since the discovery of accelerating expansion, several

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independent lines of evidence have been found to support the existence of dark energy. Although the nature and origin of dark energy remain unknown, it is believed to account for approximately 68% of the universe's energy density. This study is aims to explore what dark energy is, its possible origins, and the consequences of the continued accelerated expansion of the universe. By utilizing astronomical observational data and recent theoretical hypotheses, this research attempts to provide new insights into this cosmic mystery and examine how the universe may evolve if this trend persists. Scientists hope to gain a deeper understanding of the fundamental nature of the universe and put forward some possible hypotheses through these investigations.

2. The relation between the universe and higher-dimensional universe

The holographic principle presents a popular view that the three-dimensional universe we observe might be a “projection” of a higher-dimensional universe. Just as a three-dimensional object casts a shadow or projection onto a two-dimensional plane, the universe could be a simplified manifestation of a higher-dimensional reality.[2] This projection theory offers a new perspective on the nature of the cosmos and provides fresh avenues for exploring the true structure of the universe. Moreover, according to string theory, the universe may have more than four dimensions. The extra dimensions are potentially compactified at extremely small scales and are often described through complex geometric structures such as Calabi-Yau manifolds.[3] Although these curled-up dimensions are not directly observable at macroscopic scales, they can have profound effects on the laws of physics and the properties of the universe. Additionally, another piece of evidence supporting the existence of higher-dimensional universes comes from observations of dark matter and dark energy. These two mysterious forms of matter and energy make up the vast majority of the universe's total mass and energy (about 95%), yet they cannot be directly observed in daily life. Scientists speculate that dark matter and dark energy might exist in higher dimensions that cannot be perceived and influence the three-dimensional universe through gravitational and other interactions.[4]

3. Black holes: Gravitational traps of the universe

Black holes, the dense celestial objects predicted by general relativity, are known for their inescapable gravitational pull When a star reaches the end of its life and undergoes a supernova explosion, if its remaining mass is sufficiently large, a black hole will form. The boundary of a black hole, known as the event horizon, is a one-way membrane—anything that crosses this boundary, be it matter or information, is forever trapped by the black hole's immense gravitational force, even light cannot escape.[5] The existence of black holes not only reveals the most extreme physical conditions in the universe but also provides a unique perspective on the structure of spacetime.

3.1. Dark matter

Definition of dark matter: Unlike the directly perceivable nature of black holes, dark matter is a mysterious yet significant component of the universe. It neither emits, absorbs, nor reflects light, making it undetectable through direct observation. However, its existence can be indirectly detected through its gravitational effects.[6]

The scientific community has proposed various hypotheses regarding the true nature of dark matter: Weakly Interacting Massive Particles (WIMPs) ;Axion; MACHOs; Dark photon; MOND, etc.

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3.2. The Relationship Between Black Holes and Dark Matter: An Unsolved Mystery

Although black holes and dark matter are fundamentally distinct in nature, they play intertwined roles in the evolution of the universe. On the one hand, black holes, being gravitational traps, can attract and consume surrounding matter, including potential dark matter particles. Some theories even propose that black holes could be crucial locations for the production or annihilation of dark matter particles. [7] On the other hand, dark matter, through its gravitational effects, profoundly influences the formation and evolution of cosmic structures, and this influence indirectly affects the distribution and evolution of black holes. For example, the uneven distribution of dark matter could lead to certain patterns in the formation and distribution of black holes within galaxies. [8] However, as of now, scientists have not discovered a direct connection between black holes and dark matter. The relationship between them remains an unsolved enigma, awaiting revelation through future observations and experiments.

4. The conjecture about dark energy

At the end of the last century, astronomers discovered through observations of Type Ia supernovae that the universe is not only expanding but also that this expansion is accelerating [9]. This astonishing discovery directly challenged the steady-state universe model based on general relativity and the Big Bang theory, suggesting the existence of a mysterious form of energy in the universe capable of generating repulsive forces—dark energy.

First, let's look at the definition of dark energy. As the name suggests, dark energy is a form of energy that neither emits nor absorbs light and does not interact with electromagnetic waves. It is uniformly distributed throughout the universe, accounting for about 68% of the total energy in the universe and is the main driver of its accelerated expansion. Unlike visible matter (which makes up about 5% of the universe's total energy) and dark matter (which makes up about 27%), dark energy does not participate in gravitational interactions and therefore cannot be directly detected through astronomical observations. Its existence can only be inferred indirectly through its effects on the large-scale structure of the universe. The characteristic of dark energy is to produce a repulsive force that opposes gravity, accelerating the expansion of the universe [10]. Dark energy is believed to be associated with the cosmological constant (Λ), a concept introduced by Einstein in his theory of general relativity, representing a form of vacuum energy.

Next, regarding the current status of dark energy research. Observational Evidence and Model Construction: In addition to observations of Type Ia supernovae, phenomena such as the isotropy of the Cosmic Microwave Background (CMB), the distribution characteristics of Large Scale Structure (LSS) in the universe, and Baryon Acoustic Oscillations (BAO) also provide strong observational evidence for the existence of dark energy. To explain these observations, scientists have proposed various dark energy models, including the cosmological constant model (the simplest form of dark energy, equivalent to the cosmological constant Λ in Einstein's equations), dynamic dark energy models (such as scalar field models and holographic dark energy models), as well as modified gravity theories (such as f(R) gravity and the DGP model). However, these models currently have their own shortcomings in perfectly explaining dark energy. So, perhaps future space station measurements will be another complement.

4.1. Current Hypotheses on Dark Energy

Dark energy remains one of the greatest mysteries in modern cosmology, and several hypotheses have been proposed to explain its nature. Firstly, the "Cosmological Constant" (Lambda, Λ) is one of the most widely accepted explanations.[11] Einstein first introduced this theory in his General Relativity, suggesting that dark energy is a constant energy density uniformly distributed throughout the universe,

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providing a negative pressure to drive the accelerated expansion. It forms the basis of the "ΛCDM model" (Lambda Cold Dark Matter model), the standard cosmology model. However, due to issues like its value being 120 orders of magnitude smaller than expected vacuum energy density and potential instability, more observational data and theories are needed for verification. Secondly, another hypothesis is that black holes may slowly evaporate through "Hawking Radiation", with the lost energy potentially contributing to the universe's expansion. This idea is still in the early stages of exploration as it is extremely difficult to observe and may even contradict other theories.[12] Thirdly, "Vacuum Energy" is a candidate for dark energy. Quantum field theory indicates that the vacuum of space is filled with virtual particles constantly being created and annihilated, and this vacuum energy density may be the source of dark energy driving the accelerated expansion.[13] But it faces the cosmological constant problem. Subsequently, the "Chameleon Dark Energy" theory proposes that the properties of dark energy could vary with time or space. In this theory, dark energy behaves more weakly in high-density regions and more strongly in low-density regions. Although this complements the cosmological constant to a certain extent, there are new complexities and instabilities due to too many parameters and insufficient observational evidence.[14] Fourthly, unlike the cosmological constant, "Quintessence" suggests that dark energy is a dynamic, time-varying scalar field. The energy density of this field changes over time and space, allowing the universe's expansion rate to evolve.[15] This theory provides more flexibility than the cosmological constant but has problems such as fine-tuning and model arbitrariness, along with insufficient observational evidence.

In 2000, K-essence appeared as an extension of the quintessence model. Its non-standard kinetic term determines the dynamics of dark energy, allowing for more complex scalar field dynamics to explain dark energy and variations in the expansion rate. However, it has issues like a complex theory, conflicts with observations, and challenges in causality, making it difficult to become mainstream.

Some scientists propose that dark energy may not be a new form of energy but rather a modification of General Relativity on large scales. These "Modified Gravity" theories, such as "f(R) gravity" and the "DGP model", hypothesize that gravity behaves differently on cosmic scales, leading to the accelerated expansion of the universe. But this conjecture also faces problems like a complicated theory, too many degrees of freedom, and difficulties in matching small-scale experiment and gravitational wave observation data.[17]

Finally, in 2002, "Phantom Dark Energy" was proposed by Caldwell and other scientists. This is a more extreme theory where the equation of state for dark energy is less than -1, potentially leading to a "Big Rip". However, its state parameter $\omega<-1$ leads to instability in violation of energy conditions, and conflicts with observed data and the negative energy problem in quantum mechanics make it a highly uncertain hypothesis.[18]

These hypotheses are still being tested through theoretical studies and astronomical observations. As of now, no single model has fully explained the nature of dark energy or the accelerated expansion of the universe. Future observations and experiments may help distinguish between these theories and lead to a better understanding of dark energy.

4.2. The scientific significance of dark energy

The study of dark energy is a challenge and innovation to cosmological theory. The discovery of dark energy forced scientists to re-examine the existing theoretical framework of cosmology. It requires us to introduce new physical mechanisms or theories on the basis of general relativity to explain the accelerating expansion of the universe. This process not only promotes the in-depth development of cosmological theory, but also provides new perspectives and ideas for the research of frontier fields such as particle physics and quantum gravity. Because the nature of dark energy is directly related to the future fate of the universe. According to current observations, if dark energy continues to drive the expansion of the universe at its current rate, then the universe will continue to expand indefinitely,

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entering a "big rip" or "heat death" state. However, there are still many uncertainties about this conclusion, because we know very little about the nature and evolution of dark energy. Therefore, a deep study of dark energy is crucial to revealing the ultimate fate of the universe.

5. Conclusion

Dark energy might be a reflection of a higher-dimensional universe. The high-dimensional universe can be likened to a balloon, with our universe being the surface of the balloon. Just as blowing air into a balloon through a hole causes it to expand, perhaps black holes are the holes in our universe leading to the higher-dimensional universe, and the energy they absorb into the higher-dimensional universe expands our universe. The latest data from the Planck satellite suggest that when the cosmic microwave background radiation is released, the content of dark energy may not exceed 0.4 percent of the total energy, which is very possible as there were not many black holes in the early stage of the universe. Since all black holes link to the higher dimensional universe, the expansion of the universe can be isotropic. There are some issues with this hypothesis. Firstly, it is not known how the energy within 5-dimensional spacetime can affect our 4-dimensional spacetime universe, or whether the energy expression of our universe makes sense in higher dimensional spacetime. Secondly, due to general relativity, there are no efficient methods to calculate the distance between celestial bodies far away to know the rate of expansion of the universe. These issues may be possible directions for future research into dark energy.

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