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Dark Energy and the Accelerating Universe: Challenges and Opportunities

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Abstract:

The authors of this article start from the observation of unexpected luminosity of type la supernovae in 1998 Supernova Cosmological Project to the classification of dark energy in the ΛCDM model, and finally to the modern theory of dark energy model, including Dynamical Dark Energy, Interacting Dark Energy theory and Holographic Dark Energy theory. The concept of cosmological constant is illustrated, leading to the introducing of the two main problems encountered when investigating dark energy, Fine-tuning and coincidence problems. As possible solutions to these cosmological problems, Holographic Dark Energy and Interacting Dark Energy are introduced as a supplement to the theory of Dynamical Dark Energy, all of which are trending theory with the potential to provide a consistent explanation and model for dark energy and simultaneously accelerating expansion of the universe. Space observation projects and existing theories are combined to illustrate possible future developments in dark energy theories which also link back to the Standard Model of physics, such as Quantum Gravity theory.

Keywords: Dark energy, accelerating expansion, cosmological constant (Λ).

1. Introduction

Observations about the expansion of the universe indicate an accelerating expansion rate, based on the continuously increasing rate of the same distant galaxy receding from the same observer according to the increase in time. There were mainly 2 independent projects in 1998 that provided sufficient proof for this theory, namely the Supernova Cosmology Project and the High-Z Supernova Search Team, which made use of distant type la supernova to carry out the acceleration of the expansion. The topics relating the term type la supernova are to be expanded later in this novel, while in short, type la supernova refers to stellar explosions that act as a standard candle, since this type has a consistent peak brightness.

Before the Supernova Cosmology Project, in standard matter-dominated cosmology model, the expansion should be slowing down due to the gravity generated by matters that pulls the expansion back, and hence at a certain region in the space under a given redshift amount, type la supernova should have appeared brighter, which means a shorter distance between the supernova and the observer.

This result links to *dark energy* driving the acceleration of the rate of expansion of the universe, by considering the Friedmann equation, which can give out the expansion rate H(t):

$$(\frac{\dot{a}}{a})^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3} \tag{1}$$

Where a(t) refers to the scale factor, ρ refers to the matter/radiation density, k refers to the curvature and Λ refers to the cosmological constant. Also, H(t) relates to a(t) by

$$H(t) = \frac{\dot{a}}{a} \tag{2}$$

The accelerating equation is defined as below, which can be derived by differentiating the Friedmann equation:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda}{3} \tag{3}$$

Where p refers to the pressure of the cosmic fluid.

Indicated by equation (3), $-\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right)$ is always negative since baryonic matter and radiation have positive pressure and positive density, whereas the term Λ/3 is always positive which dominates the universe today. Moreover, in this model, since normal matter and radiation both appear to decelerate the expansion rate, dark energy with negative pressure must counteract and dominate the space to provide an accelerating expansion rate.

This topic makes Lambda-Cold Dark Matter (ΛCDM model) the most acceptable model nowadays. Λ here explains the accelerating expansion, and CDM explains galaxy formation and structure growth. However, this topic also leads to multiple questions, e.g.:

1) What exactly is Λ?

2) Why is dark energy density so small but nonzero?

Besides, it provides implications for the geometry of the universe. As inflation theory suggested, the universe is mostly flat with overall Ω = 1, where Ω refers to the overall density parameter. Supernova data indicates a density parameter of matter around 0.3, hence the cosmological constant Λ provides the rest 0.7, which then gives a self-consistent model: flat geometry, observed matter density and accelerating expansion.

Regarding implications for fundamental physics, this topic leads to the Cosmological Constant Problem. This problem arises from a calculated vacuum density 10^120 times larger than observed Λ, which became one of the greatest unsolved problems in physics. Besides, the nature of dark energy is also being discussed, which relates cosmology to high-energy physics. For example, if it is a non-changing constant or something dynamical.

Though the existence of dark energy is widely accepted and well-defended by theory, in modern cosmology, understanding the nature of dark energy is still the most challenging problem.

Apart from the cosmological constant problem mentioned above, determining whether dark energy is constant or not, distinguishing dark energy and modified gravity, and improving precision to measure the *equation of state parameter w* are the most challenging problem is cosmology. Notably the equation of state is highly related to the accelerating expansion of the universe, as the negative pressure generated by dark energy is governed by the equation of state parameter:

$$p = w\rho c^2 \tag{4}$$

Where p refers to the pressure, ρ refers to the energy density, c refers to the speed of light and w refers to the equation of state parameter. In ΛCDM model, w for dark energy is approximately -1.

2. Observational evidence for dark energy

2.1 Key observations and measurements

As mentioned in the introduction, the observation and theorization of dark energy started from the Supernova Cosmology Project 1998, with analysis already given, a deeper look is taken into the measurements of dark energy from the data generated from the Supernova Cosmology Project 1998, with the help of its official website.

Type la supernovae have constant luminosity; hence they are used as a standard candle in cosmological measurements and observations, and their luminosity distance is measured against the redshift factor z. Luminosity distance in standard ΛCDM model is given by the following equation:

$$d_L(z) = (1+z)\frac{c}{H_0}\int_0^z \frac{d\dot{z}}{\sqrt{\Omega_M(1+\dot{z}) + \Omega_\Lambda}} \tag{5}$$

Where z is the redshift factor, H_0 is the Hubble constant, c is the speed of light, Ω_M and Ω_Λ represent the density parameter for matter and dark energy respectively. In comparison to the observed data, the use of distance modulus is vital:

$$\mu = m - M = 5log\left(\frac{d_L}{10pc}\right) = 5log\left(\frac{d_L}{Mpc}\right) + 25 \tag{6}$$

Where m is the observed apparent magnitude and M is the absolute magnitude, notably M staying constant for type la supernovae. By comparing the observed and calculated distance modulus, the precision of the prediction of the theory and the model applied can be easily tested. The first expression of the formula can be used to carry out the

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observed distance modulus, whereas the calculated distance modulus can be gathered from the second or the last expressions, depending on whether Mpc is used in calculation or not.

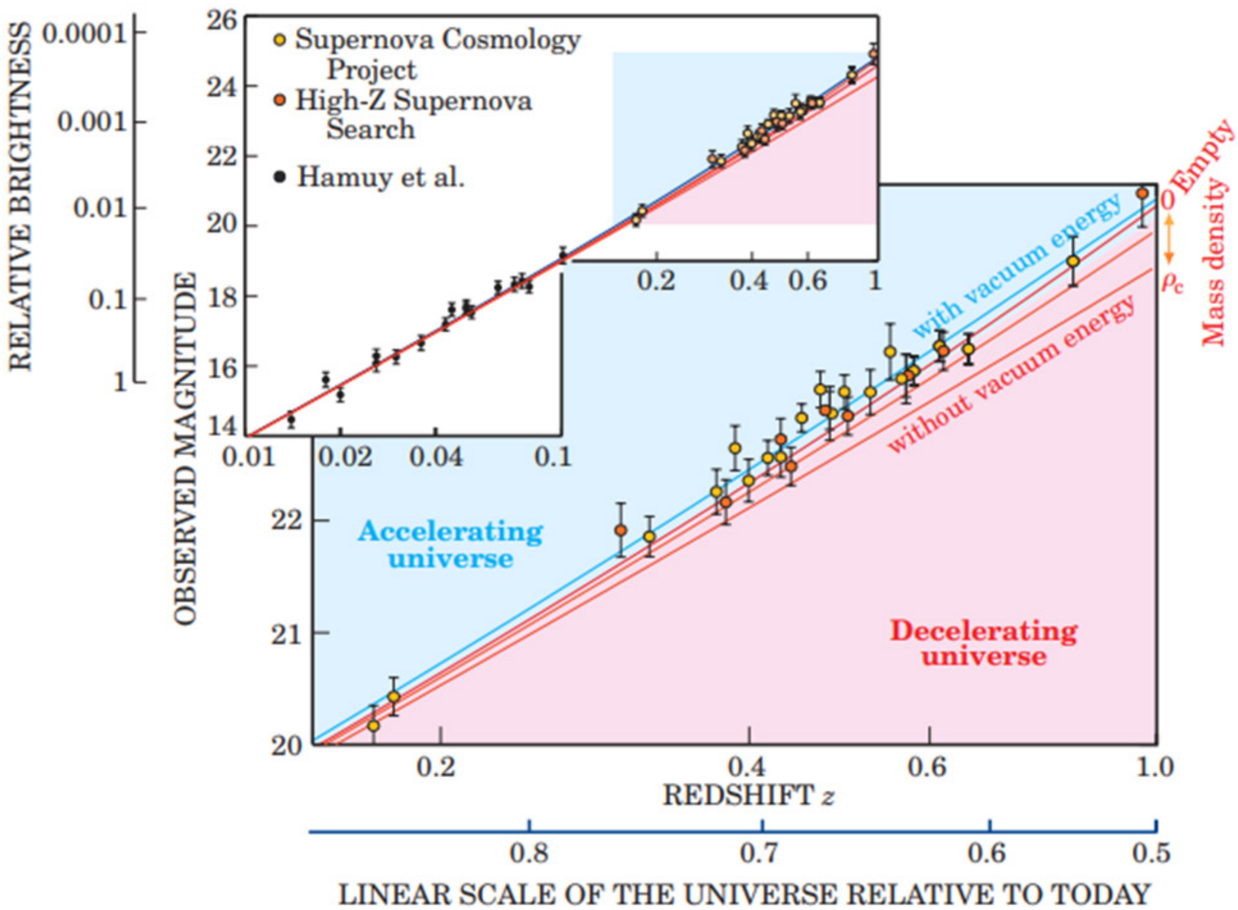

Figure 1: The observed luminosity from the official publication of Supernova Cosmology Project [1].

In the Supernova Cosmology Project 1998, the observed distance modulus is around 0.25 magnitude lower than calculated distance modulus by assuming a decelerating universe and in a matter-only universe model (Einstein-de Sitter universe) [2].

While in Figure 1, the unique blue line indicates the best fit line, where it assumes a density parameter of matter at around 0.28, with that of vacuum energy at about 0.72, which is very close to modern accepted values, leading a further interpretation into the finalized density parameters in ΛCDM model.

Apart from type la supernovae, *Cosmic Microwave Background (CMB) anisotropies* are also a primary source for studying dark energy. CMB is mostly isotropic, but with a slight fluctuation in temperature [1,3]:

$$\frac{\Delta T}{T} 10^{-5} \tag{7}$$

Hence CMB anisotropies refer to the tiny angular variations in the CMB temperature and polarization. CMB anisotropies lead to the following 2 topics that provide additional data on dark energy.

2.1.1 Distance consistency

The angular scale of the sound horizon at recombination measured by the primary CMB acoustic peak:

$$\theta_* = \frac{r_s(z_*)}{D_A(z_*)} \tag{8}$$

Where $r_s(z_*)$ is the comoving sound horizon and $D_A(z_*)$ is the angular diameter distance to the surface of the last scattering, with $z_* 1100$. The comoving sound horizon stands for the maximum distance that a sound wave in the photon-baryon fluid could have travelled from the Big Bang until the last scattering (where CMB generated), which is around 144 Mpc. The size of the sound on the image can be seen from θ_*. However, the magnitude of $D_A(z_*)$ cannot be measured only with θ_*, because it has

a dark-energy component that modifies its late-time expansion, defined as the geometric degeneracy.
However, with the addition of *Baryonic Acoustic Oscillation (BAO)* and type la supernovae into the model, break the degeneracy is broken. BAO is essentially of the same physical scale as $r_s(z_*)$, but projected at $z1.0$, which gives a low-redshift standard 'ruler', and type la supernovae, as mentioned above, has a relatively constant luminosity, so it serves as a standard candle. Above all the models, ΛCDM best describes the expansion of these aspects.

2.1.2 Late-time Integrated Sachs-Wolfe (ISW) effect

In a universe with only matter (the density of matter equals the total density), gravitational potentials are constant. The process of photons falling into and out of a potential well does not alter their total energy, resulting in no CMB anisotropy. However, in a universe with dark energy, expansion accelerates to make large-scale gravitational potentials decay with time, making the photon loss less energy while getting out of the well than the gain in energy while falling into the well, as the potential becomes less after the period of the photon staying in the well, which results in a rise in the total energy. Seeing from the CMB, this effect contributes to the formation of CMB anisotropies.
Therefore, only within the model with the presence and existence of dark energy can the effect of CMB anisotropies be explained, and among all models, ΛCDM stands out, with massive amount of data proving its rightness. For example, numerical values of energy density parameters, $\Omega_M \approx 0.3166 \pm 0.0084$ and $\Omega_\Lambda \approx 0.6847 \pm 0.0073$, are illustrated in Planck mission publication, 2018 [4].

2.2 Constraints on dark energy

2.2.1 Current parameterization

As mentioned in Equation (4), dark energy can be characterized using the same technique. For dark energy, in ΛCDM model, w is around -1. Latest observation constrains a deviation at around ±0.10 [5].

2.2.2 Observational uncertainties and systematic errors

While measuring the luminosities from supernovae, cosmic dust can dim the light emitted from them, causing uncertainties and errors in the measurement. Besides, the difference of instrumentational set up alters the data most obviously, which means calibration error counts the largest partial in the errors and uncertainties.Regarding CMB, systematic uncertainties can happen due to beam calibration.

2.3 Challenges in observational data

Recent challenges in observational data mainly arise from redshift-dependent variations, calibration issues in supernova measurements and limitations of current deep-sky survey, which will be discussed separately.
Redshift-dependent variations consist of supernova and galaxy survey evolution. The formation of supernovae in high redshift regions may differ from local ones, causing difference in intrinsic brightness, and the supernova in different galaxies show a slightly different brightness, usually at around 0.05 magnitude, which can bias the observation of w if evolving with redshift. More importantly, the light observed is shifted in spectrum, higher redshift resulting in a higher uncertainty. Besides, in imaging surveys of galaxies, photometric z errors grow with redshift, promoting a higher uncertainty onto the inferred distance.
Calibration issues are more straight forward, as cross-calibration is obviously difficult since different set up is used by different instrumentation.
Survey limitation is more intriguing, as a lower-z region survey promotes a shallow but wide survey, whereas a higher-z region survey results in a much narrower scope and a much smaller volume of data.

3. Theoretical models of dark energy

3.1 The cosmological constant (Λ)

The cosmological constant originated from Einstein's work of General Relativity (GR), it functioned as an extra term into the equation to make the equation give out a static solution, in which Λ term works as a repulsive gravity to balance normal matter's attractive gravity [6]:

$$G_{\mu\nu} = 8\pi G(T_{\mu\nu} + \Lambda g_{\mu\nu}) \tag{9}$$

Where $G_{\mu\nu}$ is the Einstein tensor, Λ is the cosmological constant, $g_{\mu\nu}$ represents the space-time tensor and $T_{\mu\nu}$ is the stress-energy tensor. Since Λ relates to the vacuum energy density in this original work, therefore it can be characterized by linking its density to the pressure it generates:

$$p_\Lambda = -\rho_\Lambda \tag{10}$$

Where ρ_Λ is the vacuum energy density, p_Λ is the effective pressure generated by this vacuum energy, c is the speed of light. Equation (9) notably and highly relates to the equation of the state (Equation (4)), or in other words, Equation (9) is a segment of Equation (4) specified for dark energy. Notably, natural units are applied instead of SI units to Equation (8) and (9), hence c, the speed of light, is neglected in these equations.

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Having gone through the origin of cosmological constant, investigating this certain constant in today's ΛCDM model becomes essential for later illustration. ΛCDM model is the most widely accepted universe model that assumes appropriate density parameters for both dark energy and matters, which have been talked about previously. In ΛCDM model, dark energy dominates the universe and is the source of the accelerating universe. However, it comes with several unsolved problems: Fine-tuning and Coincidence problems.

Regarding the Fine-tuning problem, it describes the mismatch of vacuum energy density of dark energy value calculated by Quantum Field Theory (QFT) and by observation. To clarify this, by QFT, calculated ρ_Λ is expected to be around $2\times10^{71}GeV^4$, but the observed term $\rho_\Lambda+\frac{\lambda}{8\pi G}<10^{-47}GeV^4$, which requires the later term to cancel the this term to about 120 decimal places [7]. Even in another approach that the zero-point energies in quantum chromodynamics are the only concerns, a cancelation of 41 decimal places is required to give the observed value. This huge mismatch is unnatural, which leaves the Fine-tunning problem.

Notably, the values are not given to the most accurate place but instead are for representative purpose. Before moving on, a reasonable and numerical measurement onto the energy density of dark energy is required, which is $(60.3\pm1.3)\times10^{-31}g/\mathrm{cm}^3$ [8]. Therefore, a relatively lower energy density for dark energy compared to matter and radiation can lead to a consensus on the fact the reason for dark energy dominating the universe is that its distribution is uniform across the entire universe.

Turning to the coincidence problem, this problem is highly related to the Fine-tuning problem. But before stepping into this problem, the density variations of matter, radiation and dark energy against time, need to be carried out. Friedmann Equation can be expressed in the following form, assumed in the ΛCDM model:

$$H^2(a)=(\frac{\dot{a}}{a})^2=H_0^2\left(\Omega_r a^{-4}+\Omega_m a^{-3}+\Omega_\Lambda\right) \tag{11}$$

Where H_0 is the Hubble constant, a is the scale factor, Ω_r is the energy density parameter of radiation, Ω_m is the energy density parameter of matter, and Ω_Λ is the energy density parameter of dark energy. With separating each term of the right-hand side of Equation (10), the following relationships of a(t) against t and thus get the following relationships relating the energy density to time variation are shown:

$$a_r(t)\propto t^{\frac{1}{2}}\Rightarrow\rho_r(t)\propto t^{-2} \tag{12}$$

$$a_m(t)\propto t^{\frac{2}{3}}\Rightarrow\rho_m(t)\propto t^{-2} \tag{13}$$

Where Relationship (12) and (13) describes the energy density evolution of radiation and matter respectively, while the energy density of dark energy staying constant. From these relationships, a conclusion can be reached that billions of years ago, the universe was overwhelmingly dominated by matter and radiation, while after billions of years, dark energy will be overwhelmingly dominating the universe. Hence, it is curious that, given right now the energy density of matter and dark energy are of the same level of magnitude, human beings live in a such coincident era, which relates back to the Fine-tuning problem by that the universe and era human beings were born and live in is so coincident.

The described problems are still left unsolved, with multiple approaches being rejected or being unproven, such as Dynamical dark energy theory.

3.2 Dynamical dark energy

Dynamical dark energy theory differs from current dark energy theory in a way that the equation of state parameter $w_\Lambda(z)$ in this theory is assumed to vary with redshift factor z. The current widely used parametrization is the Chevallier-Polarski-Linder (CPL) parametrization [9].

$$w_{DE}(z)=w_0+w_a\frac{z}{1+z} \tag{14}$$

Where w_0 represents the present-day equation of state parameter of dark energy, w_a represents the evolution of the parameter with time, and z is the redshift factor.

Most importantly, dynamical dark energy has a scalar field model named quintessence. Quintessence model replaces the constant Λ with a canonical scalar field φ that evolves with time, which governs the following relationship:

$$w_\varphi=\frac{p_\varphi}{\rho_\varphi}=\frac{\frac{1}{2}\dot{\varphi}^2-V(\varphi)}{\frac{1}{2}\dot{\varphi}^2+V\left(\frac{1}{2}\dot{\varphi}^2\right)} \tag{15}$$

Where $V(\varphi)$ is the quintessence potential. This parameterization is more adequate:

1) If $\dot{\varphi}^2\ll V(\varphi), w\approx-1$, just like the Λ constant.

2) If $\dot{\varphi}^2\gg V(\varphi), w\approx1$

3.3 Emerging theory

Emerging theory addresses both coincidence problem and fine-tuning problem, motivated by high-energy theory. The concepts of Holographic Dark Energy theory and Interacting Dark Energy are discussed separately in this segment.

3.3.1 Holographic Dark Energy (HDE) theory

Before introducing HDE, an investigation on the famous Holographic Principle (HP) is required, as it states that all the information contained in a volume of space can be represented as a hologram [10]. HDE is a theory combining HP with dark energy and uses dimensional analysis to construct. Any quantity including the energy density of dark energy of the universe can be described, by using some quantities on the boundaries of the universe. First set the total mass of dark energy inside a given scale or region must not exceed the mass of a black hole of the same scale L.

$$L^3 \rho_{DE} \leqslant M_{Pl}^2 L \tag{16}$$

Where M_{Pl} represents the reduced Planck mass around $2.435\times10^{18} GeV/c^2$. To clarify, natural units are applied to equations in 3.3.1 instead of SI units, where $\left[\frac{1}{E}\right][m][s]$. Then, the energy density of dark energy can be derived by rearranging Equation (16):

$$\rho_{DE} = 3C^2 M_{Pl}^2 L^{-2} \tag{17}$$

Where C has no dimension and represents a constant parameter. Comparing to the ΛCDM model, a model of variable energy density of dark energy that evolves with time is constructed, and the equation of state parameter of dark energy w can be something not -1.

3.3.2 Interacting Dark Energy (IDE) theory

IDE aims to address the coincidence problem to explain why $\Omega_\Lambda \Omega_m$ today, and it is constructed on the principle that if energy exchange between dark energy and dark matter happens, their density can stay comparable for much longer time, as dark matter is also a form of matter. Besides, instead of working out a perfectly fine-tuned and bullet-proof constant Λ, IDE emphasizes the relation between dark energy and dark matter and may be able to provide reasonable explanation for cosmic acceleration, which sounds more applicable. Much alike ΛCDM model, tests can be done on the model with CMB anisotropies and additionally structure growth since dark matter is related with dark energy according to IDE [11].

IDE constructs on two essential equations that describe the energy transfer between dark matter and dark energy:

$$\dot{\rho}_c + 3H\rho_c = Q \tag{18}$$

$$\dot{\rho}_{de} + 3H\left(1+w\right)\rho_{de} = -Q \tag{19}$$

Where ρ_c represents the cold dark matter density, ρ_{de} represents the dark energy density, H represents the expansion rate, Q represents the energy flow, and $w = \frac{p_{de}}{\rho_{de}} c^2$ represents the equation of state parameter of dark energy in IDE. By investigating the sign of Q, whether energy flow to dark matter or to dark energy can be presented:

1) $Q > 0 : DE \rightarrow DM$, energy flows from dark energy to dark matter.

2) $Q < 0 : DM \rightarrow DE$, energy flows from dark matter to dark energy.

4. Implications for Fundamental Physics

4.1 Connection to the Standard Model of Particle Physics

An important theory in the Standard Model of Particle Physics is Higgs field. The Higgs field is a scalar quantum field, without any direction, unlike vector fields, and only its magnitude matters, highly like the Quintessence that defines dark energy as a scaler field varies with redshift. To be more specific, this scalar field gives particles mass via spontaneous symmetry breaking. Currently, vacuum energy coming from the Higgs field contributes to the overall energy density of the universe, which is calculated to about $10^8 GeV^4$, while the observed dark energy density stays around $10^{-47} GeV^4$, between which there is an enormous gap in magnitude, counting a portion of the Cosmological Constant problem [12].

Since the Higgs field relates mass, any new scalar field, like the Quintessence, can naturally connect to the Standard Model via this theory, creating a portal between Standard Model and Dynamical Dark Energy.

High-energy physics seems unrelated to dark energy models, since it is just another name of Particle Physics, which is only curious about the interactions happening in the scale of fundamental particles (extremely small comparing to cosmological scale). However, dark energy as a scalar field might couple to Standard Model particles, and High-energy physics experiments also focus on some low-energy experiments with extreme precision required, such as atomic clock. An atomic clock aims at measuring time by monitoring the resonant frequency of atoms, which requires a very specific frequency of electromagnetic radiation and a very specific energy level of atoms, and thus any energy into the electron or the atom needs to be extremely precise. Therefore, any little change in the energy absorbed can affect the precision and the result,

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and modifications to the experiment are required based on dark energy scalar field models.

4.2 The future of Cosmological Models

Regarding the ΛCDM model, as mentioned multiple times in fronter sections, parameters like the dark energy density parameter and the dark energy equation of state parameter need to be tested and updated to better-fit values. For example, HDE and Dynamical dark energy theory both modify them to look for a way to solve problems like the Fine-tunning problem, which is the modification to current ΛCDM model. Besides, space missions, like Planck missions mentioned which verified and updated the magnitude of the dark energy density parameter in its 2018 publication, gather data about dark energy to better integrate the ΛCDM model.

The final fate of the universe using dark energy models can be depicted. Either with the widely used dark energy model that dark energy behaves like a constant or with Dynamical dark energy model, the dark energy density stays constant in late universe, while matter and radiation energy density continues decaying with time, making universe expand with accelerating speed forever. After an extremely enormous period, star formation ends due to lack of matter, stellar remnants like white dwarf and black hole dominate the observable matter, and the universe finally reaches its final state with only low-energy photons and leptons detectable and without any observable structure or matter, at which the universe reaches thermal equilibrium. Since no heat is transferred while in thermal equilibrium, this prediction of the final state of the universe is called the Big Freeze, or Heat Death of the universe.

5. Opportunity for advancement

5.1 Next-generation observation

Survey done on the universe are of 2 different types: space-based missions and ground-based missions. Space-based missions usually refer to those spacecraft instrumentations launched into space, while ground-based missions stay on the ground and observers use telescopes on Earth.

In the next generation of space-based missions, for example, Euclid spacecraft and mission, launched in 2023, investigate the image of galactic shapes and their corresponding redshift, and use the observation result to show how dark matter contributes to the accelerating universe, by using a higher resolution and a more advanced technique. Gravitational lensing is usually applied in the analysis of the next generation observation results, as it states that the path of light ray is bent by gravitational potential mostly due to dark matter, which can provide new observational evidence for models like IDE.

Turning to ground-based missions, the strength of this type of observation is that it can keep track on a certain region of the universe from a certain place on Earth, and a large volume of data can be gathered from it. The most relevant ground-based mission is Dark Energy Spectroscopic Instrument (DESI). DESI enables observation with the probe to the expansion history of universe, and it enables a three-dimensional map of an extremely volume of universe to be built, which enables an investigation into the role of dark energy playing in the expansion of the universe verses a cosmic-scale modification of General Relativity. The modification of GR was also assumed to be a reason of the accelerating expansion of the universe. This assumption originates from the observation that dark matter is not within the scope of Standard Model of Particle Physics, which is also supportive of the expansion problem.

5.2 Advancement in computational techniques

With the recently highly important actualization of AI models, AI models in the future can be trained to identify cosmological images, like the curvature of light ray path due to gravity and the classification of supernova, which can accelerate the speed of cosmologic studies and the inference of the cosmological constants or parameters.

Besides, a much more important part of the advancement is that more precise simulations on the universe can be actualized. Since human beings cannot touch the galaxies or any other cosmological contents from Earth right now, experimenters cannot do any modification to the existing experiment environment and values, like changing the value of cosmological constant, making it unable to do cosmological experiments like any other fields of physics. Hence, simulations are extraordinarily vital, since they allow the building up of a universe model with similar behaviors to the universe using the principle of astrophysics and make modifications to see the impact of each on the model. For example, THESAN project builds different models with different set ups, like THESAN-SDAO-2 replacing BAO with Dark Acoustic Oscillation which describes the acoustic density oscillation of dark matter in early universe, and which prevents the formation of some low-mass dark matter halos in the model [13].

Consequently, dark energy behaviour and the visualization of different dark energy theoretical models can be more easily illustrated.

5.3 Testing the Fundamental Model of Physics

As specified fronter in this novel, implications to the Standard Model of physics result from dark energy theories addressing the Fine-tuning and coincidence problems. By using new observation data, the solidity of dark energy theories can be tested and hopefully, a final dark energy theory that is validated and widely accepted can come out, so that the Standard Model can be better tested and implemented.

Among all new aspects in modern physics, Quantum Gravity (QG) and String theory are most relevant to dark energy.

QG aims at explaining physics at the scale of which Quantum Field Theory (QFT) or General Relativity cannot explain on each's own, or at Planck scale. As mentioned in Fine-tunning problem, QFT predicted an unexpectedly enormous value of cosmological constant compared to observed value, hence QG is expected to be able to explain why the dark energy density is so small but nonzero, if any theory regarding OG wants to be consistent [14].

String theory tries to replace point-like particles in the Standard Model of particle physics with a one-dimensional line called string and is a theory of QG [15]. It probes a scale smaller than particle scales, stating that strings behave like particles when the scale grows larger. The vibrational state of strings corresponds to graviton, a type of quantum particle with gravitational energy. Since String theory combines gravitational force with other three fundamental forces, it is a candidate as Theory of Everything that can describe everything inside the scope of Standard Model of physics. Therefore, String theory is still required to solve Fine-tunning problem and the coincidence problem, if it wants to be consistent.

6. Conclusion

Current understanding of the nature of dark energy is inadequate, even if the dark energy equation of state parameter is still under discussion and without finalized confirmation. Additionally, no consistent theory existed can solve Fine-tunning problem, the calculated value of dark energy density 120 times larger than observed, and the coincidence problem, the matter energy density parameter being around of the same order of dark energy density parameter. A correct and adequate understanding of the role that dark energy played in the evolution of the universe is lack; despite having already agreed that dark energy drives the accelerating expansion of the universe.

As stated, the new observation results are expected to provide important data to dark energy models, and hopefully, a final dark energy model that is able to explain Fine-tunning and the coincidence problem and is also consistent within the cross-investigation of different observation results.

Therefore, the existence of dark energy plays a vital role in the evolution of the universe from the 1998 Supernova Cosmological Project to the late-time Integrated Sachs-Wolfe effect. It also links to the Theory of Everything as mentioned with String theory, as an essential cosmological content. Hopefully, with a well-defined and consistent theory of dark energy, the universe can be described and understand to a unpreceded precision, and a later highly likely behaviour of the universe can be predicted, and then a final Theory of Everything, well tested and well describing all the aspect of Standard Model of physics, is also possible, so that the universe hide no more secret.

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