Dark Energy

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Abstract- **In physical cosmology and astronomy, dark energy is an unknown form of energy which is hypothesized to permeate all of space, tending to accelerate the expansion of the universe. Dark energy is the most accepted hypothesis to explain the observations since the 1990s indicating that the universe is expanding at an accelerating rate. The cause of the accelerating expansion of the universe has drawn much speculation in recent years. Dark energy is the most popular explanation for this phenomenon. Using data from Type Ia Supernovae, models of a universe with and without dark energy are contrasted to determine which explanation is more accurate. While universes with dark energy model the data more closely than ones without, the possibility for viable alternatives through modifications to general relativity remains strong.**

Index Terms- **Dark Energy, Rate, Space.**

I. INTRODUCTION

Assuming that the standard model of cosmology is correct, the best current measurements indicate that dark energy contributes 68.3% of the total energy in the present-day observable universe. The mass–energy of dark matter and ordinary (baryonic) matter contribute 26.8% and 4.9%, respectively, and other components such as neutrinos and photons contribute a very small amount.[3][4][5][6] The density of dark energy (~ 7 × 10−30 g/cm3) is very low, much less than the density of ordinary matter or dark matter within galaxies. However, it dominates the mass–energy of the universe because it is uniform across space.[7][8][9] Two proposed forms for dark energy are the cosmological constant,[10][11] representing a constant energy density filling space homogeneously, and scalar fields such as quintessence or moduli, dynamic quantities whose energy density can vary in time and space. Contributions from scalar fields that are constant in space are usually also included in the cosmological constant. The cosmological constant can be formulated to be equivalent to the zero-point radiation of space i.e. the vacuum energy.[12] Scalar fields that change in space can be difficult to distinguish from a cosmological constant because the change may be extremely slow. The "cosmological constant" is a constant term that can be added to Einstein's field equation of General Relativity. If considered as a "source term" in the field equation, it can be viewed as equivalent to the mass of empty space (which conceptually could be either positive or negative), or "vacuum energy". The cosmological constant was first proposed by Einstein as a mechanism to obtain a solution of the gravitational field equation that would lead to a static universe, effectively using dark energy to balance gravity.[13] Einstein gave the cosmological constant the symbol Λ (capital lambda). The mechanism was an example of fine-tuning, and it was later realized that Einstein's static universe would not be stable: local in homogeneities would ultimately lead to either the runaway expansion or contraction of the universe. The equilibrium is unstable: if the universe expands slightly, then the expansion releases vacuum energy, which causes yet more expansion. Likewise, a universe which contracts slightly will continue contracting. These sorts of disturbances are inevitable, due to the uneven distribution of matter throughout the universe. Further, observations made by Edwin Hubble in 1929 showed that the universe appears to be expanding and not static at all. Einstein reportedly referred to his failure to predict the idea of a dynamic universe, in contrast to a static universe, as his greatest blunder.[14] Alan Guth and Alexei Starobinsky proposed in 1980 that a negative pressure field, similar in concept to dark energy, could drive cosmic inflation in the very early universe. Inflation postulates that some repulsive force, qualitatively similar to dark energy, resulted in an enormous and exponential expansion of the universe slightly after the Big Bang. Such expansion is an essential feature of most current models of the

Big Bang. However, inflation must have occurred at a much higher energy density than the dark energy we observe today and is thought to have completely ended when the universe was just a fraction of a second old. It is unclear what relation, if any, exists between dark energy and inflation. Even after inflationary models became accepted, the cosmological constant was thought to be irrelevant to the current universe. Nearly all inflation models predict that the total (matter+energy) density of the universe should be very close to the critical density. During the 1980s, most cosmological research focused on models with critical density in matter only, usually 95% cold dark matter and 5% ordinary matter (baryons). These models were found to be successful at forming realistic galaxies and clusters, but some problems appeared in the late 1980s: in particular, the model required a value for the Hubble constant lower than preferred by observations, and the model under-predicted observations of large-scale galaxy clustering. These difficulties became stronger after the discovery of anisotropy in the cosmic microwave background by the COBE spacecraft in 1992, and several modified CDM models came under active study through the mid-1990s: these included the Lambda-CDM model and a mixed cold/hot dark matter model. The first direct evidence for dark energy came from supernova observations in 1998 of accelerated expansion in Riess et al.[15] and in Perlmutter et al.,[16] and the Lambda-CDM model then became the leading model. Soon after, dark energy was supported by independent observations: in 2000, the BOOMERanG and Maxima cosmic microwave background experiments observed the first acoustic peak in the CMB, showing that the total (matter+energy) density is close to 100% of critical density. Then in 2001, the 2dF Galaxy Redshift Survey gave strong evidence that the matter density is around 30% of critical. The large difference between these two supports a smooth component of dark energy making up the difference. Much more precise measurements from WMAP in 2003–2010 have continued to support the standard model and give more accurate measurements of the key parameters. The basis of the theory of dark energy begins with redshift. The expansion of the universe is detected through the distortion of the light emitted by the receding galaxies [3]. Due to Doppler shifts, wavelengths received from galaxies moving away from the Milky Way are elongated and contain less energy. The observed redshift indicates that most galaxies are moving away from the Milky Way. Comparison of galaxies' luminosity and apparent brightness to those of standard candles (galaxies of known luminosity and class) allows redshift to be related to the distance from the galaxy to Earth. In 1929, Hubble used these relationships to discover that a galaxy's recession velocity increase with its distance from Earth, thus establishing the expansion of the universe [4].

II. WHAT IS DARK ENERGY?

Faced with these uncomfortable results, theorists have re-visited the basics of modern physics – relativity and quantum theory – to find an explanation for dark energy. The simplest idea lies in Einstein's gravitational equations as applied to cosmology. Einstein had introduced a constant to keep the Universe static, but later discarded it when Edwin Hubble showed that galaxies were, in fact, flying apart. This Cosmological Principle has been attributed to the energy of virtual particles popping in and out of empty space – an intrinsic concept in quantum theory. Unfortunately, this simple interpretation predicts an energy density that is 120 orders of magnitude larger than is observed and would have been too large in the early Universe to allow galaxies to have formed under gravity. Another candidate is a dynamic form of energy called quintessence which evolves over time, working like a field of springs to exert a negative pressure on space. It is a gentler version of a phenomenon called 'inflation' – when the Universe blew up very rapidly just after the Big Bang to become spatially flat, with the structure we see now. Other, more exotic ideas have been proposed, such as phantom energy which gets stronger with expansion leading to a 'big rip' when all matter is just torn apart. Finally, it may be that Einstein's theory of gravity needs to be modified over large scales. One suggestion is that our four-dimensional Universe is embedded in higher dimensions; gravity leaks into them, so that its grip on matter weakens and causes the cosmic expansion rate to increase. Another speculative idea is that gravity could vary in different parts of the Universe and that we are just lucky to be in a region where the conditions are suitable for our existence.

III. HIGH ENERGY COSMIC RAYS

A significant problem in astronomy concerns the observation of numbers of very high-energy cosmic rays. The problem centres on the development of a suitable mechanism for the production of these since at present, no known physical process can account for the very high energies observed. The production of such cosmic rays follows quite naturally however from level decay within eigenstructures that possess a massive central core. In traditional atomic physics the energy release accompanying electron demotion within the atom is of the order of at most tens of electron volts and electromagnetic radiation is the only possible type of emission. Conservation laws could also be satisfied with the emission of electron-positron or proton-antiproton pairs instead of photons. The energy changes for the inner states near a massive but small central potential provide potentially vast amounts of surplus energy to be carried away as kinetic energy of the particles produced and one might expect to see such transitions if the lifetimes of these inner states are sufficiently short. Although such transitions would probably have taken place some time ago in the Milky Way, they may be observable in young objects such as quasars.

IV. THE FRIEDMANN EQUATION AND DARK ENERGY

In general relativity, the acceleration of the universe follows the Friedmann equation. It can be derived from both Newtonian physics and general relativity. For the universe, the general relativistic form of the Friedmann equation is given by [8]

$$\left(\frac{1}{a}\frac{da}{dt}\right)^2 = \frac{8\pi}{3}G\rho - \frac{k}{a^2}$$

As neither τ nor t can be measured by astronomers, if we can use redshift and changes in the scale factor a as relative measures of time, thereby replacing τ , then we can test the equation and thereby test general relativity and dark energy as a model of the accelerating universe.Written in terms of conformal time, equation (13) becomes

$$\left(\frac{1}{a^2}\frac{da}{d\tau}\right)^2 = \frac{8\pi}{3}G\rho - \frac{k}{a^2}$$

for τ yields the equation

$$\tau = \int_0^a \frac{da}{\sqrt{\frac{8\pi}{3}G\rho a^4 - ka^2}}$$

The total density of the universe is ρ = ρM + ρΛ. The amount of matter in the univers is a constant. As the volume of space in the universe increases, the mean density of matter (denoted by subscript “M”) decreases proportional to expansion, so ρ ≡ ρM,0a−3. The density of the dark energy, though, is a constant [8]. The symbol Λ has been introduced to represent dark energy; it is also known as the cosmological constant or vacuum energy. The ratios of matter and dark energy in the universe to the critical density, which determines curvature, are respectively given by

$$\Omega_M = \frac{8\pi}{3}\frac{G\rho_{M,0}}{H_0^2}\ , \qquad \Omega_\Lambda = \frac{8\pi}{3}\frac{G\rho_\Lambda}{H_0^2}\ .$$

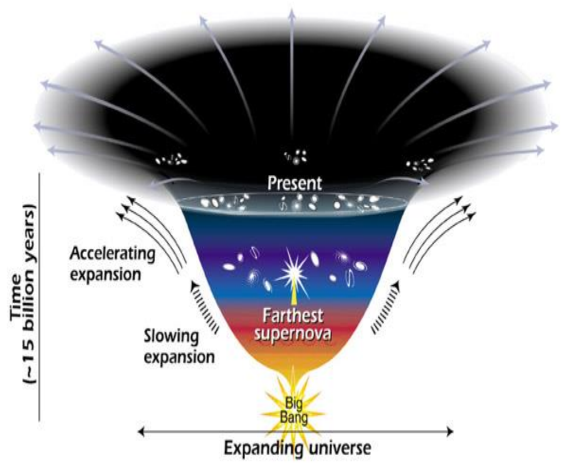
Assuming space is flat, ΩM +ΩΛ = 1. Then, if 8π
3 Gρa4 = H20 (ΩMa+ΩΛa4), where theHubble Constant H0 = 71 km s−1 Mpc−1 [3], substitution of χ for τ results in

$$\chi = \frac{c}{H_0}\int_a^1 \frac{da}{\sqrt{\Omega_M a + \Omega_\Lambda a^4}}\ .$$

The goal of the dark energy model in this paper is to compute the values of ΩM and ΩΛ which most accurately model the data from Type Ia Supernovae.

V. CHANGE IN EXPANSION OVER TIME

High-precision measurements of the expansion of the universe are required to understand how the expansion rate changes over time and space. In general relativity, the evolution of the expansion rate is estimated from the curvature of the universe and the cosmological equation of state (the relationship between temperature, pressure, and combined matter, energy, and vacuum energy density for any region of space). Measuring the equation of state for dark energy is one of the biggest efforts in observational cosmology today. Adding the cosmological constant to cosmology's standard FLRW metric leads to the Lambda-CDM model, which has been referred to as the "standard model of cosmology" because of its precise agreement with observations. As of 2013, the Lambda-CDM model is consistent with a series of increasingly rigorous cosmological observations, including the Planck spacecraft and the Supernova Legacy Survey. First results from the SNLS reveal that the average behavior (i.e., equation of state) of dark energy behaves like Einstein's cosmological constant to a precision of 10%.[12] Recent results from the Hubble Space Telescope Higher-Z Team indicate that dark energy has been present for at least 9 billion years and during the period preceding cosmic acceleration.



This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

VI. PUBLICATIONPRINCIPLES

In the months following Einstein's publication of general relativity, a mathematician named Hilbert formulated a concise derivation of the theory; it was called the least-action principle of gravity. The least-action principle requires one to minimize $\int \mathcal{L}\sqrt{-g}\, d^4x$, Lagrangian L = R · 16πG where R is the Ricci scalar, defined later in this section. The modifications to the General Theory of Relativity here are postulated in a natural way by replacing R in the Lagragian by an abitrary function f(R). In doing so, the original theory can be recovered in the event that there is no feasible alternative model by settingf(R) = R. The changes yield the following two equations:

$$-3\left(\frac{df}{dR}\right)\frac{d}{d\tau}\left(\frac{1}{a}\frac{da}{d\tau}\right)+\frac{1}{2}a^2 f = 8\pi G a^2 \rho \ ,$$

$$\frac{df}{dR}\left[\frac{d}{d\tau}\left(\frac{1}{a}\frac{da}{d\tau}\right)+2\left(\frac{1}{a}\frac{da}{d\tau}\right)^2+2k\right]-\frac{1}{2}a^2 f = 8\pi G a^2 \frac{P}{c^2} \ .$$

The Ricci scalar for the Robertson-Walker metric is given by

$$R \equiv \frac{6}{a^2}\left[\frac{d}{d\tau}\left(\frac{1}{a}\frac{da}{d\tau}\right)+\left(\frac{1}{a}\frac{da}{d\tau}\right)^2+k\right]$$

In these modifications, f(R) is function which has units of [H20], or equivalently, 1/τ2. It is arbitrary because we don't know of any certain alternatives to dark energy in the universe. We assume that P = 0as dark energy is the only reason why P < 0in the universe. We also assume ρ = ρM as ρΛ = 0if there is no dark energy in the universe. The function f(R) must, though, have the property limf→∞ = R in order to recover Newtonian gravity.

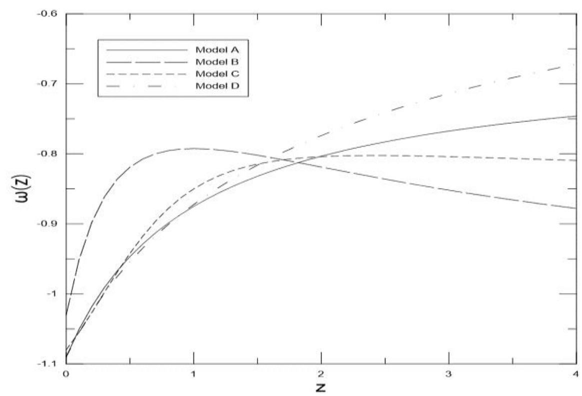
VII. SUPERNOVAE

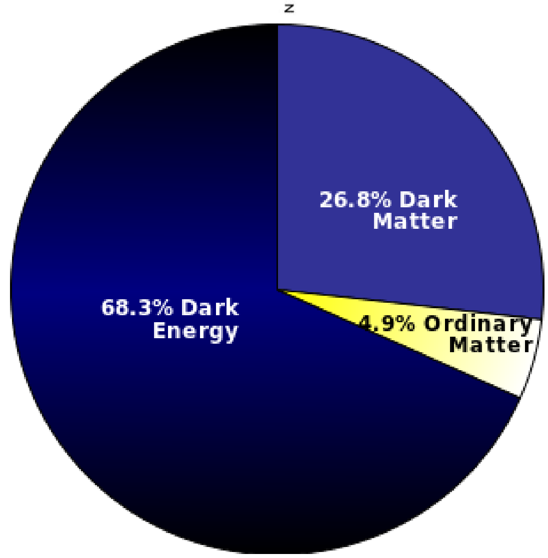
In 1998, the High-Z Supernova Search Team[15] published observations of Type Ia ("one-A") supernovae. In 1999, the Supernova Cosmology Project[16] followed by suggesting that the expansion of the universe is accelerating. The 2011 Nobel Prize in Physics was awarded to Saul Perlmutter, Brian P. Schmidt and Adam G. Riess for their leadership in the discovery. Since then, these observations have been corroborated by several independent sources. Measurements of the cosmic microwave background, gravitational lensing, and the large-scale structure of the cosmos as well as improved measurements of supernovae have been consistent with the Lambda-CDM model. Some people argue that the only indications for the existence of dark energy are observations of distance measurements and the associated redshifts. Cosmic microwave background anisotropies and baryon acoustic oscillations only serve to demonstrate that distances to a given redshift are larger than would be expected from a "dusty" Friedmann–Lemaître universe and the local measured Hubble constant.

Supernovae are useful for cosmology because they are excellent standard candles across cosmological distances. They allow the expansion history of the universe to be measured by looking at the relationship between the distance to an object and its redshift, which gives how fast it is receding from us. The relationship is roughly linear, according to Hubble's law. It is relatively easy to measure redshift, but finding the distance to an object is more difficult. Usually, astronomers use standard candles: objects for which the intrinsic brightness, the absolute magnitude, is known. This allows the object's distance to be measured from its actual observed brightness, or apparent magnitude. Type Ia supernovae are the best-known standard candles across cosmological distances because of their extreme and consistent luminosity. Recent observations of supernovae are consistent with a universe made up 71.3% of dark energy and 27.4% of a combination of dark matter and baryonic matter.

VIII. THEORIES OF DARK ENERGY

Dark energy's status as a hypothetical force with unknown properties makes it a very active target of research. The problem is attacked from a great variety of angles, such as modifying the prevailing theory of gravity (general relativity), attempting to pin down the properties of dark energy, and finding alternative ways to explain the observational data. The simplest explanation for dark energy is that it is an intrinsic, fundamental energy of space. This is the cosmological constant, usually represented by the Greek letter Λ (Lambda, hence Lambda-CDM model). Since energy and mass are related according to the equation E = mc2, Einstein's theory of general relativity predicts that this energy will have a gravitational effect. It is sometimes called a vacuum energy because it is the energy density of empty vacuum. The cosmological constant has negative pressure equal to its energy density and so causes the expansion of the universe to accelerate. The reason a cosmological constant has negative pressure can be seen from classical thermodynamics. In general, energy must be lost from inside a container (the container must do work on its environment) in order for the volume to increase. Specifically, a change in volume dV requires work done equal to a change of energy −P dV, where P is the pressure. But the amount of energy in a container full of vacuum actually increases when the volume increases, because the energy is equal to ρV, where ρ is the energy density of the cosmological constant. Therefore, P is negative and, in fact, P = −ρ. There are two major advantages for the cosmological constant. The first is that it is simple. Einstein had in fact introduced this term in his original formulation of general relativity such as to get a static universe. Although he later discarded the term after Hubble found that the universe is expanding, a nonzero cosmological constant can act as dark energy, without otherwise changing the Einstein field equations. The other advantage is that there is a natural explanation for its origin. Most quantum field theories predict vacuum fluctuations that would give the vacuum this sort of energy. This is related to the Casimir effect, in which there is a small suction into regions where virtual particles are geometrically inhibited from forming (e.g. between plates with tiny separation). A major outstanding problem is that the same quantum field theories predict a huge cosmological constant, more than 100 orders of magnitude too large.[11] This would need to be almost, but not exactly, cancelled by an equally large term of the opposite sign. Some supersymmetric theories require a cosmological constant that is exactly zero, which does not help because supersymmetry must be broken. Nonetheless, the cosmological constant is the most economical solution to the problem of cosmic acceleration. Thus, the current standard model of cosmology, the Lambda-CDM model, includes the cosmological constant as an essential feature.





The evidence for dark energy is heavily dependent on the theory of general relativity. Therefore, it is conceivable that a modification to general relativity also eliminates the need for dark energy. There are very many such theories, and research is ongoing. The measurement of the speed of gravity with the gravitational wave event GW170817 ruled out many modified gravity theories as alternative explanation to dark energy.

Astrophysicist Ethan Siegel states that, while such alternatives gain a lot of mainstream press coverage, almost all professional astrophysicists are confident that dark energy exists, and that none of the competing theories successfully explain observations to the same level of precision as standard dark energy.

IX. CONCLUSION

This paper has not attempted to prove or disprove the existence of macroscopic gravitational Eigen structures but rather to show, our first alternative model to dark energy was indistinguishable from dark energy, dozens of other possibilities such as the second alternative posed here remain to be explored and analyzed. Continued exploration into the nature of R1and other functions of f(R) will reveal more about the use of dark energy and general relativity in modeling the universe. The data collected from the Type Ia supernovae indicate that the theory of dark energy, despite its lack of physical proof, provides a very accurate model of the universe when 70% of the mass-energy density of the universe is dark energy. The evidence for dark energy is heavily dependent on the theory of general relativity. Therefore, it is conceivable that a modification to general relativity also eliminates the need for dark energy. There are two major advantages for the cosmological constant. The first is that it is simple. Einstein had in fact introduced this term in his original formulation of general relativity such as to get a static universe. Although he later discarded the term after Hubble found that the universe is expanding, a nonzero cosmological constant can act as dark energy, without otherwise changing the Einstein field equations. Dark energy's status as a hypothetical force with unknown properties makes it a very active target of research. The problem is attacked from a great variety of angles, such as modifying the prevailing theory of gravity (general relativity), attempting to pin down the properties of dark energy, and finding alternative ways to explain the observational data. The simplest explanation for dark energy is that it is an intrinsic, fundamental energy of space.

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