

Background Constraints on Dark Energy Models

Shruti Mishra, Dr. Avinash Singh

Department of Physics, Kalinga University, Naya Raipur (CG) India
492101

Corresponding author e-mail id: shrutimishra172017@gmail.com,
avinash.singh@kalingauniversity.ac.in

ABSTRACT: Due to the gravitational attraction of all the matter in the universe, the expansion rate of the cosmos has changed over time, decreasing (decelerating) in past, and more recently speeding up (accelerating). The hypothesis that the Universe is expanding quickly and is spatially nearing its limit now has a lot of cosmological evidence to back it up (assuming the density is at least somewhat time-independent). The majority of cosmologists believe that "dark energy" is to blame for the accelerated cosmological expansion that has been witnessed. The cosmological constant, an additional constant to the Einstein field equation, can be used to explain why the universe is expanding faster than before. The Λ CDM model is the simplest and most common model in use. Besides this, there are also dark energy models like the Barotropic fluid model, canonical scalar field model, and non-canonical scalar field model. We analyse the background constraints on dark energy models using current cosmological data available. We also present the comparison between dark energy models using Bayesian statistics.

1. INTRODUCTION

Currently, the universe is expanding at a faster rate than usual, according to recent cosmological studies, and dark energy makes up around 70% of the universe total density. The nature of dark energy is one of the most important questions in modern physics, and it has been the focus of extensive study. This component might be caused by the typical vacuum energy, which is symbolised by a typical cosmological constant and has a negative pressure. Right now there are many models accessible. The simplest and most frequently accepted is the cosmological constant hypothesis (CDM model). Energy density of vacuum is the only constant in the cosmos. For this component, equation of the state parameter is $w=-1$. This simple explanation sacrifices important theoretical problems like "the coincidence and fine tuning of paradox". Two scalar fields, one with classic kinetic energy and the other with negative kinetic energy, are described in cosmic history of dark energy. According to our findings, the equation of state w for such an exponential potential system changes from -1 to 1 over the lifetime of the universe, which is in line with recent discoveries. The scaling solution is shown to be the stable late-time attractor of the "phantom" that dominated this class of models. The situation for dark matter looks to be different as a result of the model-independent examination of its distribution within the Milky Way, even though there are currently no experimental methods for directly demonstrating the existence of dark energy. Dark matter is portrayed macroscopically in the



ColdDarkMatter (CDM) model as a pressureless fluid. Other microscopic explanations for dark matter, however, have been proposed, linking it to certain important ideas of atomic particles, such as big neutrinos, sterile neutrinos, axions, gravitinos, and neutralinos, to mention a few.[1-3]

2. HISTORY OF THE UNIVERSE

The Big Bang, an explosion of space, marked the beginning of our cosmos. Reionization is the process by which a cloud of cold hydrogen is burnt off the light from the first stars shortly after the big bang. Later on the black-hole-driven centers of active galaxies known as quasars produced enough ultraviolet radiation to re-ionize the primordial helium. Space expanded, the cosmos cooled, and the basic elements emerged from a very high density and temperature starting point. The earliest stars and galaxies were created as a result of the slow gathering of stuff by gravity. Groups, clusters, and superclusters formed as galaxies gathered. Supernova explosions caused the death of certain stars, and the chemical residues they left behind helped create new star generations and rocky planets.[4-7]

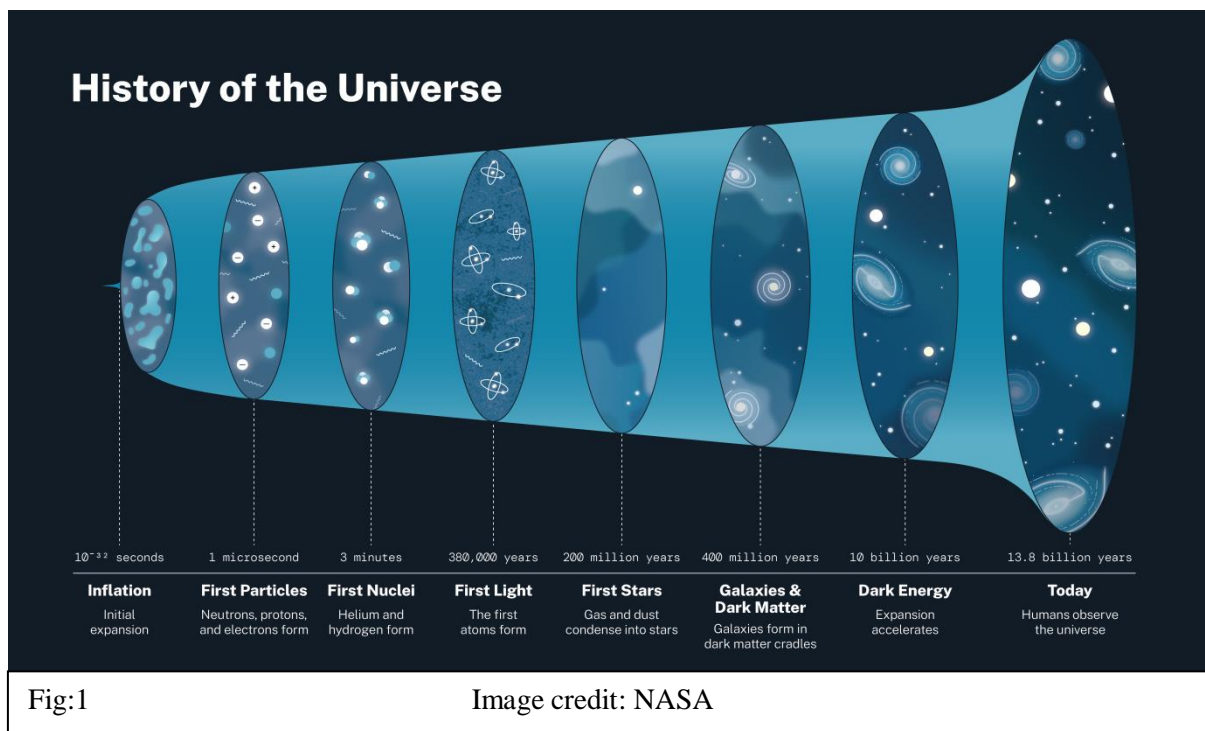


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3. DARK ENERGY MODELS

3.1. Λ CDM model

The cold dark matter (CDM) is a parameterization of Big Bang cosmological model that holds that universe is made up of three main elements: ordinary matter, the cosmological constant Λ linked with dark energy, and the theorized cold dark matter. The cosmological constant, which is added to the Einstein field equations, can be used to explain why the

universe's expansion rate is accelerating. It was initially proposed by Einstein in 1917 to provide a solution for a static universe, but it was abandoned after Hubble discovered that the cosmos was expanding. Addition of constant Λ in the source part of Einstein field equations, alter the Friedmann equations in the form, given by

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

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3} (\rho + 3p) + \frac{\Lambda}{3} \quad (2)$$

According to the Cold Dark Matter theory, there is a dark energy fluid that enters the Einstein field equations that is analogous to a cosmological constant component, and the two dark fluids are independently preserved, meaning they do not interact through an energy exchange. The dark energy equation of state parameter may need some redshift evolution, nevertheless, according to a coherent joint interpretation of Planck results and weak lensing data. It is commonly known that the CDM model faces serious challenges as a outcome of the Hubble tension in cosmology. The Hubble tension may be solved if the cosmological principle is found to be incorrect, which will require a revision of the Hubble constant and Hubble tension interpretations.[8-9]

3.2. Barotropic Fluid Model

We examine the group of Barotropic fluid dark energy models, where the expression $p=f(\rho)$ indicates that the pressure is an explicit function of density. In terms of the cosmological model, the simplest alternative is one in which the dynamical nature of the state equation's parameter is established by taking into account a functional form or parameterization of w . With $w=1$, the scale factor or redshift affects the equation of the state of the situation.[10-12]

The restriction on sound speed for the entire fluid of the Universe and for the dark energy fluid (assuming they are both barotropic) rules out the feasibility of a barotropic fluid model for the unified dark sector and a barotropic fluid model for dark energy. This is because limitations from low-redshift data make variations in these fluids unstable.

3.3. Canonical Scalar Field Model

The quintessence field is commonly referred to being the standard scalar field, a well-researched model for dark energy. In scalar field theories, a slow rolling field drives the universe's rapid expansion. A canonical Lagrangian describes the essence field,

$$L = \mp \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \quad (3)$$

where $V(\phi)$ denotes any potential.

The quintessence of the models roughly categorised as "freezing" or "thawing" models depending on how the state-parameter equation evolves. Due to significant Hubble damping, the first class of models' equation of state parameter value freezes at its initial value ($w \simeq 1$).

Only recently has the formula of state begun to change from a value that is comparable to a cosmic constant, as Hubble damping lowers and the potential begins to roll to its minimum. In the freezing models, the kinetic term rolls down towards its minimum but is not zero early on because of the steep potential. Later on, the potential shallows and the kinetic term is barely noticeable. The result is, $w = -1$ is the value at which the state-parameter equation asymptotically freezes. The freezing models are further divided into "tracking" and "scaling" models derived from specifics of the dynamics. However, quintessence models have their own tuning issues and do not share the Λ CDM model's fine-tuning issue. They need an ad-hoc potential to achieve the modern fast expansion.[13-15]

3.4. Non Canonical Scalar Field Model

String theory naturally gives rise to the non canonical scalar field known as tachyon as a D-brane decay model. The Lagrangian describes the tachyon scalar field

$$L = -V(\varphi)\sqrt{(1 \mp g^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi)} \quad (4)$$

where $V(\varphi)$ denotes any potential.

The non-canonical scalar field model is allowed to interact with dark matter by assuming a certain kind of coupling term. The generalized second law of thermodynamics' application is investigated using the first law of thermodynamics and the assumption that the universe is encircled by an apparent horizon.[16-17]

4. NUMERICAL SIMULATION

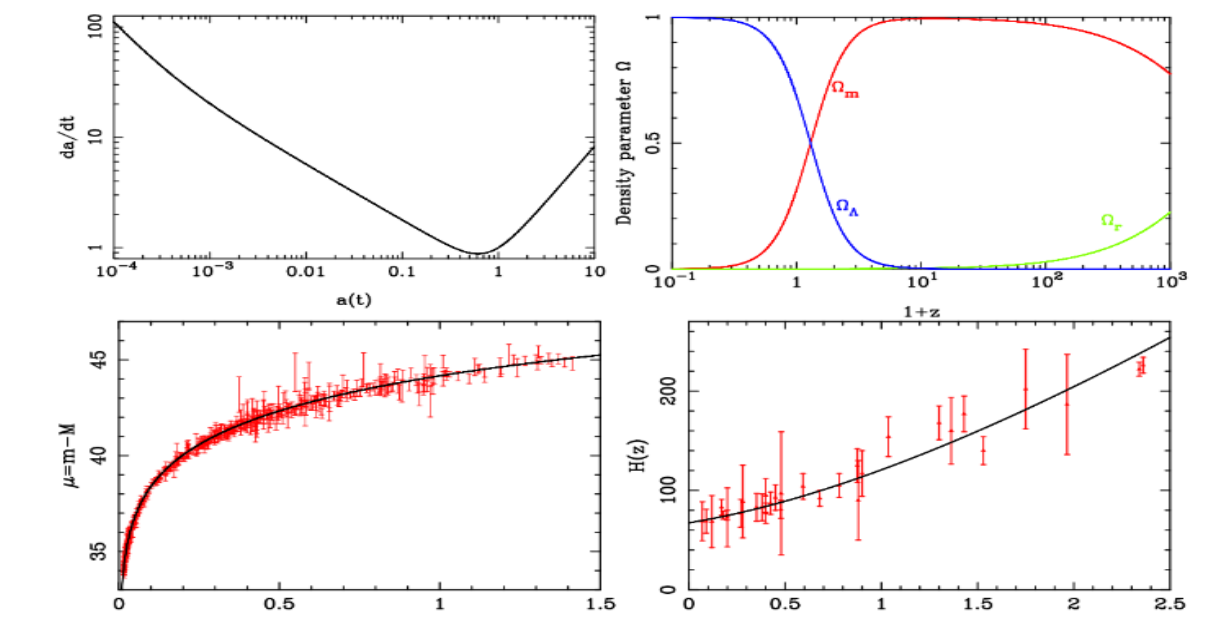


Figure 2: In the top left panel, we show the phases of evolution of the Universe for the Λ CDM model. The evolution of the density parameters of matter (in red), vacuum (in blue), and radiation (in orange)

are shown in top right panel. In these plots, we set the parameter $\Omega_{m0} = 0.315$ and $H_0 = 67.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (Planck-2018 best fit values). In the bottom left and right panels, we show comparison of this model with SN-Ia union 2.1 data and direct measurements of Hubble parameter $H(z)$.

5. SUMMARY

On a broad scale, the universe is shown to be uniform and isotropic. The universe's characteristics, like as its density and temperature, are therefore constant everywhere and in all directions. This observable homogeneity and isotropy must be supported by any dark energy model. The expansion rate of the cosmos throughout time can be calculated from observations of far-off supernovae. These findings, which indicate that the universe is expanding more quickly than previously believed, demand that dark energy models be in agreement with them. Baryon acoustic oscillations are regular differences in the matter density in the early cosmos that can be seen in the universe's large-scale structure. The observed baryon acoustic oscillations must be consistent with dark energy theories.

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