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Topic : Cosmological non-standard field dynamics in the light of observations

Findings

Physics is all about exploring things through experiments and ideas. This approach is also true in understanding the universe, known as cosmology. Cosmology is observing and understanding the universe as a whole. In the late 1990s, Adam G. Riess and Saul Perlmutter, along with their team, made a big discovery. They studied the brightness of supernovae Ia in space and realized something astonishing: instead of decelerating, the universe was actually accelerating in its expansion. This was a very remarkable discovery that changed how we think about the universe. The usual explanation we had, called the Big Bang model, couldn't explain this late time acceleration. So, physicists had to explore new ideas. They tried to solve this puzzle with two approaches. One way is to change the left hand side of Einstein's field equations that describe how gravity works, which is known as "modified gravity solutions". The other way was to add a new kind of energy into the right hand side of equation, called "Dark Energy," which is quite mysterious and different from anything we usually know. Overall, this discovery and its challenges pushed scientists to think differently and come up with new ways to explain the universe's behavior. It's a puzzle that scientists are still trying to solve today. In my Ph.D., I tried to address different issues related to this work.

In chapter 4, I discussed the modified gravity approach to explain the Universe's acceleration during its later stages. Our methodology involved examining the interaction between dark matter and baryons within the Einstein frame, subsequently translated to the Jordan frame through a disformal transformation. Interestingly, we discovered that while there was no acceleration evident in the Einstein frame, the coupling term behaved like an exotic fluid within the Jordan frame, ultimately giving rise to the observed acceleration. To assess this scenario's validity, we investigated two parameterizations: polynomial and exponential. We did the likelihood analysis utilizing the publicly accessible program **`EMCEE`** in PYTHON, utilizing data from Cosmic Chronometers (CC), Pantheon, Baryonic Acoustic Oscillations (BAO), and Megamasers. We analysed these Monte Carlo Markov Chain (MCMC) chains by the **`GetDist`** program.

In chapter 5, I discussed the dark energy approach to account for the late-time acceleration of the universe. While the cosmological constant term has conventionally served as a prominent candidate for Dark Energy, in light of "H_0 tension" and "S_8 tension", we explored the viability of introducing a Negative Cosmological Constant on top of a scalar field. We used the latest cosmological observations such as Planck, Pantheon, Baryonic Acoustic Oscillations (BAO), and SH0ES. We integrated the Planck likelihood using the publicly available **`CLASS`** and **`Monte-Python`** codes. Our analysis utilizing Planck data alone unveiled that the negative cosmological constant led to a higher value of H_0," a departure from the outcome observed in the ΛCDM scenario. Given that our model featured two additional degrees of freedom, we subjected it to a comparison against the ΛCDM model using the **AIC** and $\Delta\chi^2$ criteria to assess its relative merit. Additionally, we computed the Bayesian evidences for these models using the **MCEvidence** code. Across all the evidence estimators, we consistently found that the negative cosmological constant model was either more favorable or equally favored compared to the ΛCDM model.

In the context of addressing the H_0 tension, in chapter 6, I explored an extension of the negative cosmological constant model known as the Omnipotent Dark Energy model. This unique model features a phenomenon known as phantom crossing, which leads to an increase in the value of H_0 from observations during earlier epochs. Our investigation incorporated the latest data sets including Pantheon+, SH0ES, BAO DR16, Lyman-α, and Planck data. Our analysis yielded a value of $H_0 = 70.05 \pm 0.64$, with the occurrence of phantom crossing pinpointed at a scale factor of $a_m = 0.922^{+0.041}_{-0.035}$.

An interesting finding from the preliminary results of the James Webb Space Telescope (JWST) in 2023 points toward the presence of exceptionally massive galaxies within the redshift range of 7 to 15. The conventional ΛCDM model fell short in elucidating the abundance of these galaxies. This intriguing outcome hints at a distinct behavior of dark energy that deviates from the simplicity of the ΛCDM framework. In chapter 7, I study various models aimed at explaining the prevalence of these high-redshift galaxies. To begin, we illustrated how the growth rate evolves within these models. We identified negligible changes at lower redshifts, indicating that it is challenging to distinguish between these different dark energy models in the low-redshift regime. However, a stark contrast emerged in the growth rate at comparatively higher redshifts. Subsequently, we found out that a model featuring a negative cosmological constant on top of a scalar field featuring phantom crossing, effectively accounted for the abundance of these massive galaxies at high redshifts.

My research focuses on resolving the various "cosmological tensions" emerging from recent data by studying the non-standard cosmological models. Exciting new observations from surveys like the Dark Energy Survey (DES) and the South Pole Telescope (SPT)also indicate significant deviations from the standard ΛCDM model. The main aim of this thesis is to study the cosmological tensions through comprehensive analysis. Utilizing my expertise in advanced numerical tools like Cobaya, EMCEE, and CLASS, I investigated a range of dark energy and modified gravity models using robust Bayesian estimation techniques. My core focus lies in identifying "negative cosmological constant" signatures within various cosmological observations, particularly in the context of these apparent tensions. In an exciting new exploration, my future goal is to use Machine Learning (ML) techniques to gain insights into cosmological tensions without relying on a predefined background model. This unique approach promises to offer model-independent perspectives on these tensions, potentially leading to breakthroughs in understanding them. Additionally, this ML tool can be further developed to probe diverse dark energy models.