Introduction to the nature of Dark Energy

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Abstract

We elaborated a study on the cosmological models which motivated the Standard Model, ΛCDM. A theoretical study and the revision of the most important experimental papers of Cosmology were the main goals of this project. Finally, we could understand the different interpretations of the cosmological constant and the basis of this being considered vacuum energy in the standard model of Cosmology, characterizing the basic concept of Dark Energy.

Key words:

Cosmology, Dark Energy, General Relativity.

Introduction

The first cosmological models relied on sky observations and philosophical concepts, in which the observable universe seemed to be static, homogeneous and isotropic. One of these models was made by A. Einstein which inserted on the Equation of General Relativity a constant Λ (the cosmological constant).

With the detection that the universe was expanding in a linear relation, Friedman-Lemaitrê-Robertson-Walker (FLRW) cosmological model was the better one to justify the experimental data. This model gave another interpretation for the cosmological constant.

In the 90's, however, some experimental data showed to us the universe is in accelerated expansion, not linearly. The Standard Model, ΛCDM, explains this data with a predominance of a type of vacuum energy entitled Dark Energy.

Our research proposed a study of the Einstein and FLRW models and to understand the different interpretations of the cosmological constant until the Standard Model, in which is posed as Dark Energy. Moreover, we studied the most important experimental results, which influenced the theoretical descriptions of the universe.

Results and Discussion

The first concept is the Cosmological Principle. It states the universe is homogeneous in space and time and isotropic in space. We used [1] to understand the historical origins of this principle. According to this, the line element to describe our universe needs to represent a spherically symmetric spacetime and also isotropy for free observers as we studied in [2].

One of this line element is the Einstein model, which the scale factor (a) is constant in time and the universe is filled with incoherent matter. The geometry of this model can be compared to a circular cylinder. In this case, the cosmological constant is interpreted as the cylinder radius. It has the form $\Lambda = 1/a^2$ [3].

Also we studied the FLRW model, in which the scale factor varies uniformly with time. As opposed to Einstein model, this one is stable under perturbation theory. According to FLRW universe, the cosmological constant can be considered as a vacuum energy with density contribution $\rho_\Lambda = \Lambda/8\pi G$ [4].

Regarding to experimental data, our first step was a study of the Hubble experiment [5]. It was a measurement of distances based on apparent luminosities of the brightest stars on extra-galactic nebulae. Hubble found a linear relation between distance and velocity: $\vec{v} = H\vec{r}$, where H is the Hubble constant.

Secondly, we studied the anisotropies on CMB (*Cosmic Microwave Background*). COBE collaboration was the first one to publish these measurements. Such anisotropies consisted in a proof of Cosmological Principle violaton [4]. The Modern Cosmology explains this result with the Cold Dark Matter model.

The last experimental result we worked on was the measurement of acceleration in our universe. The analysis of *redshift* on type 1a supernovae concluded our universe is in accelerated expansion. In a way of our universe is filled by massive matter, the expected result should be a deceleration [4]. The most acceptable explanation is that this expansion is caused by a physical quantity entitled Dark Energy, which is interpreted as vacuum energy and its density needs to be constant in space and time. The Cosmological constant is considered Dark Energy in the recent cosmology model, ΛCDM (Cosmological Constant, Cold Dark Matter).

Conclusions

This work made an intensive bibliographic research. We could understand the different interpretations for the cosmological constant and the physical meaning of Dark Energy.

The perspectives of this research constitute in a quantitative analysis of experimental data to verify the descriptions of recent cosmological models and the understanding of the Cosmological Constant Problem.

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