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Falsifying Cosmological Constant

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Abstract

One of the main goals of physical cosmology is to reconstruct the expansion history of the universe and finding the actual model of dark energy. In this article I review the difficulties of understanding dark energy and discuss about two strategic approaches, 'reconstructing dark energy' and 'falsifying dark energy models'. While one can use the data to reconstruct the expansion history of the universe and the properties of dark energy using novel approaches, considering the data limitations and its uncertainties we have to deal with cosmographic degeneracies that makes it difficult to distinguish between different dark energy models. On the other hand one can use the power of the data to falsify an assumed model using advanced statistical techniques. Within all these issues, focusing on falsification of cosmological constant has a particular importance since finding any significant deviation from Λ would result to a break through in theoretical physics, ruling out the standard concordance model of cosmology.

Keywords: Cosmological Constant, Dark Energy, Standard Model of Cosmology, Statistical Methods

1. Introduction

The standard model of cosmology is based on the general theory of relativity. Einsteins discovery of general relativity enabled us to develop a theory of the universe which is testable and can be falsified. So cosmology has become a proper science which can predict events and explain observations. The Big Bang model of the universe which is based on general relativity and is in fact the standard model of the universe at present, has successfully passed several important tests include the expansion of the universe as exhibited by the Hubble diagram; light element abundances which are in concordance with Big Bang nucleosynthesis predictions; observations of the cosmic microwave background which is a black body radiation left over from the young universe when the latter was only a few hundred thousand years old, etc. The standard cosmological model also needs to account for the origins of inhomogeneities such as galaxies, stars and planets. In the early 1980s the inflationary model was suggested [1, 2, 3] and subsequently shown to be able to successfully seed galaxy formation [4, 5, 6, 7]. Besides the key issues of seed initial conditions for galaxies, the standard model must also account for dark matter and dark energy. Currently it is felt that the dark components of the universe, dark matter and dark energy, constitute around 96% of the total energy density of the universe. However, it could also be that the presence of an unseen component implies a crises for the standard model of cosmology and calls for a revision of the general theory of relativity as advocated by some researchers. To determine which is the correct direction for theory to take one must develop sophisticated statistical methods and apply these to observational data in order to get a bias free picture of cosmological observations. The standard model of cosmology, known as 'Vanilla model' because of its simplicity can be summarised as a spatially flat homogeneous and isotropic on large scales Friedman-Lometre-Robertson-Walker (FLRW) universe with power-law form of the primordial spectrum for the initial fluctuations and constitute of baryonic matter, cold dark matter and cosmo-

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logical constant as dark energy. The standard model of cosmology is in fact based of many assumptions that leaves us with only 6 parameters to explain the universe and its dynamic. Ω_{bm} and Ω_{dm} (baryonic and dark matter densities) are two of these parameters and $\Omega_\Lambda = 1 - (\Omega_{bm} + \Omega_{dm})$ since the universe is assumed to be spatially flat. τ represents the epoch of reionization, H_0 the Hubble constant at $z = 0$, n_s the spectral index of the primordial fluctuations and A_s the overall amplitude of the initial fluctuations are the other 4 key parameters. Out of all these, the first 4 parameters govern the dynamic of the universe and the background evolution and the last two represent the initial condition through power spectrum given by $P_R(k) = A_s[\frac{k}{k_*}]^{n_s-1}$ (k_* is just a pivot point). One should admit that despite of simplicity of the concordance model, most cosmological observations are in good agreement with this model and in fact there is no strong evidence against it at current status of observations. However, agreement of this model with most cosmological observations does not necessarily mean that we have found the actual model of the universe. Different assumptions of the standard model can be independently tested using different statistical methods applied on various cosmological data, e.g, look at [8, 9] for testing the isotropy of the universe, [10] for testing the structure formation suggested by the standard model, [11, 12, 55] for testing flatness of the universe and [13] for testing the power-law form of the primordial spectrum. In this article we focus on one the important aspects of the standard model of cosmology, namely, cosmological constant as dark energy. We first discuss about reconstructing dark energy and its difficulties using parametric or non-parametric approaches. Then we overview the theoretical cosmographic degeneracies between different cosmological quantities. Next we discuss about a different strategic approach to assume and falsify Λ using cosmological observations rather than reconstructing the universe and at the end we conclude.

2. Reconstructing Dark Energy

The cosmological constant was originally introduced by Einstein in 1917 [14]. The cosmological constant has a constant equation of state of $w = -1$. Although introduced in 1917 the so called Λ-term has had a checkered history. Its recent prominence in cosmological literature is largely due to supernovae observations [15, 16] (look at [17] for the most recent compilation) supported by CMB and other datasets [18, 19, 20], which points to the interesting fact that the universe may currently be accelerating. To generate this acceleration one requires a component with a negative pressure and with a relatively large value of the energy density as compared with dark and baryonic matter. Currently it is our belief that the cosmological constant density must be as least 2/3 of the total energy budget of the universe. However many other theoretical candidates for a matter component with similar characteristics to the cosmological constant have been proposed [21, 22, 23, 24]. All these candidates together are called dark energy. One of the challenges of cosmology is to define which one is in fact responsible for the acceleration of the universe.

In this regard reconstructing the expansion history of the universe and properties of dark energy has become one of the main goals of todays cosmology to understand our universe and its components. There have been many approaches in last decade proposed to do the reconstruction of the expansion history and one can generalise them in two categories of parametric and non-parametric methods. Parametric methods are viable approaches if we know the actual class-form of the phenomena we are studying and we can use them to put constraints on the parameters of the model. See [25, 26, 27, 28, 29, 30] for details of data analysis and methods of parametric reconstruction of the properties of dark energy using supernovae data. However dealing with a phenomena that we have no clear idea about its nature and behaviour, using parametric methods can be misleading since the underlying actual model might not be covered by the assumed parametric form. Dealing with uncertainties in the dispersion of the data adds another complication to the analysis and leave us with no clear way to find this fact that we might have chosen an inappropriate parametric form. This raises the importance of the non-parametric and model independent approaches to find out the behaviour of a phenomena in a more direct way by avoiding parametrizing cosmological quantities [31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 49, 50, 51]. In figure.1 we can see such a case that using a parametric form of dark energy $w(z) = w_0 + \frac{w_1 z}{1+z}$ [43, 44] to fit a simulated data based on a brane cosmology model which has a singularity in its effective equation of state [45] results to something very much different from the actual fiducial model while a direct non-parametric smoothing method can find the strange feature hidden in the data [31, 32]. However one should note that non-parametric approaches have their own shortcomings. For instance, estimation of the errors can be a tricky task in many cases since in some methods one cannot easily assign the degree of freedom in the likelihood analysis. For a review over this subject look at [46]. Recently there have been attempts to com-