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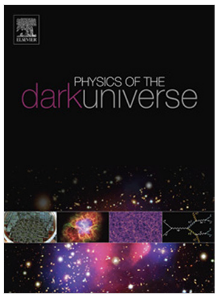

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Toward unbiased estimations of the statefinder parameters

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With the use of simulated supernova catalogs, we show that the statefinder parameters turn out to be poorly and biased estimated by standard cosmography. To this end, we compute their standard deviations and several bias statistics on cosmologies near the concordance model, demonstrating that these are very large, making standard cosmography unsuitable for future and wider compilations of data. To overcome this issue, we propose a new method that consists in introducing the series of the Hubble function into the luminosity distance, instead of considering the usual direct Taylor expansions of the luminosity distance. Moreover, in order to speed up the numerical computations, we estimate the coefficients of our expansions in a hierarchical manner, in which the order of the expansion depends on the redshift of every single piece of data. In addition, we propose two hybrids methods that incorporates standard cosmography at low redshifts. The methods presented here perform better than the standard approach of cosmography both in the errors and bias of the estimated statefinders. We further propose a one-parameter diagnostic to reject non-viable methods in cosmography.

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I. INTRODUCTION

The universe is currently undergoing a late-time speeding up phase [1, 2]. The component responsible for the acceleration is commonly named *dark energy* and manifests a negative equation of state providing gravitational repulsive effects. Nonetheless, a totally satisfactory fundamental description does not exist and dark energy still continues challenging the concordance paradigm [3, 4]. In addition, to characterize the dark energy evolution, one needs to postulate a model *a priori*. This leads to numerical constraints on the free coefficients of the model which are determined in a *model dependent way*. Hence, treatments which encapsulate different aspects of cosmology without calling any specific model become useful to understand whether dark energy evolves or not in time.

In the ΛCDM model, the accelerated expansion of the Universe is driven by a cosmological constant, while the clustering of matter at large scales is a consequence of the gravitational self-attraction of a stress-free and dust-like collection of particles dubbed cold dark matter. Although the ΛCDM model suffers from the cosmological constant and cosmic coincidence problems [5, 6], the cosmological constant is physically well-motivated as the minimal modification to General Relativity consistent with general covariance. Perhaps more intriguing is the nature of the dark matter sector: for example, today observations are not able to tell if it is really cold, or it is warm.

The success of the ΛCDM model is much more appreciable in the early universe (see, e.g., figures 1 and 3 in [7]), but it is still not very well tested at late times, where there is large room for evolving dark energy and several behaviors for the dark matter.[1] Hence, approaches beyond the ΛCDM model are widely investigated by the community.

Among general model independent treatments, *cosmography–on the background* (hereafter cosmography) attempts to reconstruct the expansion history of the universe in a model independent way; see [13] for a recent review. To do so, it usually takes into account a set of parameters, derivatives of the scale factor, related to the statefinders [14, 15] and generically named *cosmographic series*.[2] Such a procedure enables us to consider

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[1] Other possibilities are the existence of unified fluids for the whole dark sector [8, 9], that the laws of gravity are different at large scales or at late-times [10, 11], or even that dark energy comes from as a byproduct of quantum effects [12].

[2] In our paper we refer to the cosmographic series with the name statefinders, which slightly differs from the introduced first in [14]. For details see Appendix A.