Power spectrum and particle production in galileon bouncing cosmologies

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(Dated: November 4, 2017)

In this paper, we study the main features of the scalar and tensor power spectrum of primordial fluctuations during the classically stable bouncing phase recently proposed by Ijjas and Steinhardt in Ref. [1]. Following the suggested background history, we evaluated the tensor and scalar spectra during the bouncing phase characterized by the violation of null (and strong) energy condition. We found that the change of the speed of sound is the cause of the dominance of the tensor power spectrum over the scalar part through most of the bounce. Moreover, we observe that none of the spectra evaluated across the bouncing phase is scale invariant. In addition to this, we present our results for particle production by showing the evolution of the occupation number of scalar fluctuations through the bounce.

I. INTRODUCTION

The production of healthy bouncing trajectories is an important accomplishment in order to produce a sensible expansion history free of singularities. A satisfactory non-singular bounce might not require from a complete description of the theory in the ultraviolet limit – including Quantum Gravity – while remaining coherent with the observed stages of homogeneity and isotropy seen in Cosmic Microwave Background (CMB). It is possible to find recent progress in the approach described in Refs. [1, 2], wherein the expansion history and the running of the kinetic couplings are used as inputs to describe the full dynamics of a cubic galileon. This approach is exactly the inverse when compared to other methods in which a field with a non-canonical kinetic term is used as a source (for example, in Refs. [3, 4]) of the bouncing expansion history.

The study of scalar and tensor perturbations is remarked as important across the existing literature: it adds additional constraints to the notions of a stable bouncing trajectory by avoiding all forms of instabilities such as $c_s^2 < 0$, tachyonic and gradient. Nevertheless, the dynamical properties of these fluctuations are not fully explored. This might be due to either the cumbersome time dependence of the second-order expanded action or because of the need of expensive computational power to resolve at higher frequencies. In this paper, the numerical evolution of the scalar and tensor modes is optimized by implementing a simplified version of the separation technique described in Ref. [5], where each the equations of motion of each mode separates in two parts: one equation – with a reduced oscillation frequency – for the amplitude and another first-order equation for the phase. After the separation, the numerical treatment of the system not only permits to visualize the power spectrum of curvature scalar and tensor fluctuations at a given instant of time, but all across the bouncing phase with sufficient resolution in Fourier domain. Furthermore, the evaluation of the spectra throughout the bounce is relevant since the (de-)accelerating background has a continuous effect on the perturbations. A visible effect of this acceleration is the dynamical production of particles, which can also be studied as the background evolves and will also be reflected in the particular features of the spectra.

The plan of this paper is as follows, in section II, we review the features of the bouncing model explored in Ref. [1] and the suggested bouncing trajectory. We will study the forbidden regions of phase space for the cubic galileon, where the scalar perturbations are unstable. In addition to this, we will also find the location of the bouncing trajectories in phase space. In section III, we describe the the action, equations of motion and initial conditions required to find the spectrum of scalar and tensor fluctuations. It is widely known that the choice of initial conditions is not unique, our choice was a state of instantaneous minimal energy previous to the bouncing stage in order to have properly defined initial conditions at all wavelengths. We also review the standard definition of occupancy number as stated in Ref. [6]. In section IV, we show our results for the power spectra of primordial scalar and tensor fluctuations. We present two major results: (I) the power spectra are not scale invariant and (II) the scalar spectrum only dominates over the tensor by the end of the bouncing phase. In this section, we exhibit our results for the scalar particle creation and its effects in the spectrum. Finally, we discuss and conclude.

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II. BACKGROUND

III. SCALAR AND TENSOR FLUCTUATIONS

IV. POWER SPECTRUM OF SCALAR AND TENSOR FLUCTUATIONS

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