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Primordial curvature perturbation during and at the end of multi-field inflation

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Abstract

We study the generation of the primordial curvature perturbation in multi-field inflation. Considering both the evolution of the perturbation during inflation and the effects generated at the end of inflation, we present a general formula for the curvature perturbation. We provide the analytic expressions of the power spectrum, spectral tilt and non-Gaussianity for the separable potentials of two inflaton scalars, and apply them to some specific models.

Keywords: Inflation; Cosmological perturbation theory; Non-Gaussianity

1. Introduction

The generation of the large scale structures and the anisotropy in the temperature of the cosmic microwave background (CMB) suggests that there was already small inhomogeneity in the early Universe, a few Hubble times before the observable scale enters the horizon. The time-independent curvature perturbation ζ sets the initial conditions for such inhomogeneity and the subsequent evolution of all the scalar perturbations. The resulting power spectrum and

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the spectral tilt of the primordial curvature perturbation are almost Gaussian, and so scale-independent with the size of $\mathcal{P}_\zeta = 2.43 \times 10^{-9}$ [1].

The perturbations necessary for the inhomogeneity can arise naturally from the vacuum fluctuations of light scalar field(s) during inflation and be promoted to classical one around the time of the horizon exit. In the single field inflation with the canonical kinetic term, the curvature perturbations produced at the horizon crossing are conserved after that and can explain the primordial curvature perturbation necessary for the observation.

Inflation with multiple scalar fields [2–4], however, can admit quite different inflationary dynamics and spectra of the primordial perturbations, which is impossible in single field inflationary models. The presence of multiple field induces non-adiabatic field perturbations and the evolution of the overall curvature perturbations during inflation, possibly leading to detectable non-Gaussianity [5]. The evolution of the curvature perturbation continues until the non-adiabatic perturbation is converted to the adiabatic one within the observational limit [6–8] before the cosmologically relevant scales enter the horizon again. Thus we need to track the evolution of the curvature perturbation until it becomes frozen.

The other dominant component of the curvature perturbation can be generated at the transition between inflation and non-inflation phase in the multi-field inflation models [9], during the reheating phase which is modulated by another scalar field [10–13], or by the curvaton field in the deep radiation-dominated era after inflation [14–19]. In the single-component inflation, the inflationary trajectory is unique and the inflation ends when the inflaton field φ has a value φ_e, which is controlled entirely by the inflation and independent of the position. With additional scalar fields, however, the trajectory is in the multi-dimensional field space and the inflation ends with different field values. Then the field values of the inflatons depend on the positions and the field space at the end of inflation is not in the uniform energy density any more. The relative differences of ending inflation make additional differences in the e-folding number and contribute to the curvature perturbations at the end of inflation.

A simple example of generating the curvature perturbation at the end of inflation is the hybrid inflation with sudden-end approximation [9,20]. In this case, the end of inflation occurs suddenly by the dynamics of waterfall fields, and the observable large non-Gaussianity can be generated. The realization in the string theory was considered in [20]. A specific analytic calculation was done for two-component hybrid inflations in Refs. [21–24] with an exponential potential, and they also found that large non-Gaussianity is possible for certain conditions at the end of inflation. The more general calculation was attempted in Ref. [25] for two-field hybrid inflation. They studied the generation of large non-Gaussianity both during the inflation and at the end of inflation. They found that the end condition of inflation can change the pre-existing large non-Gaussianity severely by changing the sign or the magnitude.

The generation of curvature perturbation can be understood geometrically. In [26], for simplicity, the straight trajectory was considered and the relation between the non-Gaussianity and the geometrical properties for the hyper-surface of the end of inflation were studied. The generation of the primordial statistical anisotropy at the end of inflation was also considered in [27] and [28].

Both the evolution of the curvature perturbation during inflation and the contribution at the end of inflation are the general properties in multi-field inflation models. To get the correct curvature perturbation after inflation, it is necessary to consider both of them in a consistent way. In this paper, we propose the general formula for the curvature perturbation after the end of inflation, considering both effects in the case of the separable potentials by product or sum. Here we will use δN-formalism and provide analytic formulae for the power spectrum, spectral index and