Abstract

Currently, inflation is the most promising paradigm to describe the origin of the perturbations in the early universe. Most models of inflation permit a sufficiently long epoch of slow roll inflation, which, in turn, leads to a featureless, nearly scale invariant, power law, primordial scalar spectrum. Such a spectrum, along with the assumption of a spatially flat, concordant $\Lambda$CDM [i.e. involving the cosmological constant $\Lambda$ and Cold Dark Matter CDM] background cosmological model, provides a good fit to the recent observations of the anisotropies in the Cosmic Microwave Background (CMB) by missions such as the Wilkinson Microwave Anisotropy Probe (WMAP).

Even though, as a broad paradigm, inflation can be termed as a success, it would be fair to say that we are still some distance away from converging upon a specific model or even a class of models. There exist a wide variety of inflationary models that remain consistent with the data. While a nearly scale invariant, power law, scalar spectrum fits the observations of the anisotropies in the CMB quite well, there exist a few data points at the lower multipoles, which lie outside the cosmic variance associated with the conventional power law primordial spectrum. Statistically, a few outliers in a thousand or so data points are always expected. However, these outliers can be handy from the phenomenological perspective of attempting to constrain the models from the data, since only a more restricted class of inflationary models can be expected to provide an improved fit to these outliers. Therefore, it is a worthwhile exercise to explore models that lead to certain deviations from the standard power law, inflationary perturbation spectrum, and also provide a better fit to the data.

Over the last few years, it has been recognized that primordial non-Gaussianity can act as a powerful probe to help us discriminate further between the various inflationary models. For instance, it is known that slow roll inflation driven by the canonical scalar fields leads only to a small amount of non-Gaussianity. But, recent analyses of the WMAP data seem to suggest that primordial non-Gaussianity may possibly be large. Ongoing missions such as Planck are expected to determine the extent of non-Gaussianity in the
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CMB more accurately. It is known that models which lead to features also generate a reasonably large amount of non-Gaussianity. One of the aims of this thesis work has been to systematically explore inflationary models that give rise to specific features in the perturbation spectrum which result in an improved fit to the data, and also lead to observed (or, observable) levels of non-Gaussianity.

Broadly, this thesis can be divided into two parts. While the first part can be said to be devoted to the signatures of features and non-Gaussianities on the CMB, the second focuses on their possible observational imprints in the matter dominated epoch. In the first part, we shall begin with a discussion on the generation of localized as well as non-local features (i.e. characteristic and repeated patterns that extend over a wide range of scales) in the inflationary scalar power spectrum that lead to a better fit to the CMB data than the more standard power law spectrum. We shall also investigate the bi-spectra that result in such scenarios, and study as to how they compare with the current observational limits on the non-Gaussianity parameter $f_{NL}$. In this context, we shall also discuss the effects of preheating in single field inflationary models on the evolution of the bi-spectrum. In the second part of the thesis, after considering the effects of primordial features on the formation of halos, we shall discuss the possibility of utilizing the observations of the Ly-$\alpha$ forest towards constraining primordial non-Gaussianity. In what follows, we shall provide a brief outline of these different issues. (The reference numbers that appear here correspond to the publications and preprints listed below.)

**Generation of localized features due to a step in the inflaton potential:** A short burst of oscillations over suitable scales in the primordial scalar power spectrum have been known to result in an improved fit to the outliers in the CMB data near the multipole moments of $\ell = 22$ and $40$. Typically, such features have been generated with the introduction of a step in the conventional, quadratic potential involving the canonical scalar field. Such a quadratic potential will cease to be consistent with the data, if the tensors remain undetected at a level corresponding to a tensor-to-scalar ratio of, say, $r \approx 0.1$. Apart from the popular quadratic potential, we investigate the effects of the introduction of the step in a small field model as well as a tachyon model [1]. Further, motivated by possible applications to future datasets (such as, say, Planck), we evaluate the tensor power spectrum exactly, and include its contribution in our analysis. We compare the inflationary models with the WMAP (five as well as seven-year), the QUEST at DASI (QUaD) and the Arcminute Cosmology Bolometer Array Receiver (ACBAR) data. As expected, a step at a particular location and of a suitable magnitude and width is found to fit the outliers (near $\ell = 22$ and $40$) better, in all the models that we consider. We highlight the fact that, if the
tensors prove to be small (say, \( r \lesssim 0.01 \)), the quadratic potential and the tachyon model will not remain viable, and one would have to pay more attention to examples such as the small field models.

**Non-local features in the primordial spectrum:** Apart from localized features, such as those arising due to a step in the inflationary potentials, it is interesting to examine if non-local features—i.e. certain characteristic and repeated patterns that extend over a wide range of scales—in the scalar power spectrum can also provide a better fit to the CMB data than the conventional, nearly scale invariant, primordial spectrum. With such a motivation in mind, we consider the model described by a quadratic potential which is superposed by a sinusoidal modulation and the recently popular axion monodromy model. The oscillatory terms in these inflaton potentials lead to modulations in the corresponding scalar power spectra that extend over a wide range of scales [2]. Evaluating the scalar power spectra numerically, we compare the models with the WMAP data. Moreover, as the oscillations continue even onto smaller scales, we also include the small scale data from the Atacama Cosmology Telescope (ACT) in our analysis. Though, both the models, broadly, result in oscillations in the spectrum, interestingly, we find that, while the monodromy model leads to a considerably better fit to the data in comparison to the standard power law spectrum, the quadratic potential superposed with a sinusoidal modulation does not improve the fit to a similar extent.

**Bi-spectra associated with local and non-local features:** Presently, the primordial scalar bi-spectrum is often characterized by the parameter \( f_{\text{NL}} \), which is a suitable dimensionless ratio of the scalar bi-spectrum to the corresponding power spectrum. We present the first complete calculation of the parameter \( f_{\text{NL}} \) for a variety of single field inflationary models that lead to features in the scalar power spectrum [3]. The calculation is based on the formalism due to Maldacena to evaluate the bi-spectrum in a given inflationary model. It is performed numerically by means of a new, efficient and accurate Fortran code that can evaluate all the contributions to the bi-spectrum for any configuration of the wavenumbers. We consider different sets of models that lead to similar features in the scalar power spectrum, and investigate if \( f_{\text{NL}}^{\text{eq}} \) (viz. \( f_{\text{NL}} \) evaluated in the equilateral configuration) can help us discriminate between the models. We find that certain differences in the background dynamics—reflected in the behavior of the slow roll parameters—can lead to a reasonably large difference in the \( f_{\text{NL}}^{\text{eq}} \) generated by the models.

**The scalar bi-spectrum during preheating:** In single field inflationary models, preheating refers to the phase that immediately follows inflation, but precedes the epoch of reheating. During this phase, the inflaton typically oscillates at the bottom of its potential
and gradually transfers its energy to radiation. At the same time, the amplitude of the fields coupled to the inflaton may undergo parametric resonance and, as a consequence, explosive particle production can take place. A priori, these phenomena could lead to an amplification of the super-Hubble scale curvature perturbations which, in turn, would modify the standard inflationary predictions. However, remarkably, it has been shown that, although the Mukhanov-Sasaki variable does undergo narrow parametric instability during preheating, the amplitude of the corresponding super-Hubble curvature perturbations remain constant. Therefore, in single field models, metric preheating does not affect the power spectrum of the large scale perturbations. We investigate the corresponding effect on the scalar bi-spectrum [4]. Using the above-mentioned Maldacena’s formalism, we analytically show that, for modes of cosmological interest, the contributions to the scalar bi-spectrum as the curvature perturbations evolve on super-Hubble scales during preheating is completely negligible. Specifically, we illustrate that, certain terms in the third order action governing the curvature perturbations which may naively be expected to contribute significantly are exactly canceled by other contributions to the bi-spectrum. We corroborate selected analytical results by numerical investigations. We also discuss the possible wider implications of the results.

**Effects of primordial features on the formation of halos:** As we have repeatedly mentioned, features in the primordial scalar power spectrum provide a possible roadway to describe the outliers at the low multipoles in the WMAP data. Apart from the CMB angular power spectrum, these features can also alter the matter power spectrum and, thereby, the formation of the large scale structure. Carrying out a complete numerical analysis, we investigate the effects of primordial features on the formation rates of the halos. We consider a few different inflationary models that lead to features in the scalar power spectrum and an improved fit to the CMB data, and analyze the corresponding imprints on the formation of halos [5]. Performing a Markov Chain Monte Carlo analysis with the WMAP and the Sloan Digital Sky Survey (SDSS) data for the models of our interest, we arrive at the parameter space of the models allowed by the data. We illustrate that, inflationary potentials, such as the quadratic potential with sinusoidal modulations and the axion monodromy model, which generate certain repeated, oscillatory, features in the inflationary perturbation spectrum, do not induce substantial difference in the number density of halos at their best fit values, when compared with, say, a nearly scale invariant spectrum as is generated by the standard quadratic potential. However, we find that the number density and the formation rates of halos change by about 20% for halo masses ranging over $10^4 - 10^{14} M_\odot$, corresponding to potential parameters that lie within 2-$\sigma$ from
Imprints of primordial non-Gaussianity in the Ly-alpha forest: We investigate the possibility of constraining primordial non-Gaussianity using the three dimensional bispectrum of the Ly-$\alpha$ forest [6]. The strength of the quadratic non-Gaussian correction to an otherwise Gaussian primordial gravitational field is assumed to be dictated by the parameter $f_{NL}$. We present the first prediction for bounds on $f_{NL}$ using Ly-$\alpha$ flux spectra along multiple lines of sight. The three dimensional Ly-$\alpha$ transmitted flux field is modeled as a biased tracer of the underlying matter distribution sampled along one dimensional skewers corresponding to quasars sight lines. The precision to which $f_{NL}$ can be constrained depends on the survey volume, pixel noise and aliasing noise (arising from the discrete sampling of the density field). We consider various combinations of these factors to predict bounds on $f_{NL}$. We find that, in an idealized situation of full sky survey and negligible Poisson noise, one may constrain $f_{NL} \sim 23$ in the equilateral limit. Assuming a Ly-$\alpha$ survey covering large parts of the sky ($k_{\text{min}} = 8 \times 10^{-4} \text{Mpc}^{-1}$) and with a quasar density of $\bar{n} = 5 \times 10^{-3} \text{Mpc}^{-2}$, we show that it is possible to constrain $f_{NL} \sim 23$ for the equilateral configurations. The possibility of measuring $f_{NL}$ at a precision comparable to the large scale structure may be useful for joint constraining of inflationary scenarios using different data sets.
List of publications and preprints


