Probing violations of slow-roll inflation at the largest observable scales with future galaxy surveys

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Abstract

We study the capability of the next generation of future spectroscopic galaxy surveys to probe departures from a power-law spectrum for primordial fluctuations on large scales. Focusing on the information from the galaxy clustering power spectrum up to quasi-linear scales, i.e. $k < 0.15$ h Mpc^{-1}, we present forecasts for DESI, Euclid and SPHEREx in combination with CMB measurements. As selected departures in the primordial power spectrum from a simple power-law which could improve the fit to CMB temperature anisotropies at $\ell < 40$, although not at statistical significant level because of cosmic variance, we consider three *Planck* 2015 best-fits motivated by inflationary models with a breaking of the slow-roll approximation as fiducial models for a Fisher matrix approach.

We find that for two models which presents oscillations in the primordial power spectrum, fitting better the dip at $\ell \sim 20$ in the CMB temperature anisotropies power spectrum, either of the three spectroscopic surveys considered can add significant information to better constrain the parameters of the model. For a model which instead presents a smooth exponential cut-off in the primordial fluctuations, none of the three LSS survey adds significant information to CMB because of the finite volume of the survey.

1 Introduction

The results from the ESA satellite Planck [1, 2] led to important progress in the context of inflation [3, 4]. The Planck results showed how the theoretical predictions of the simplest slow-roll inflationary models, such as a flat Universe with nearly Gaussian adiabatic perturbations and a tilted spectrum, provide a good fit to CMB temperature and polarization anisotropies. In combination with BICEP 2/Keck Array data [5], Planck has set $V_* < (1.76 \times 10^{16}\ \mathrm{GeV})^4$ as the 95 % confidence level (CL)

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upper bound to the energy scale of inflation ruling out archetypal models such as a quadratic potential or natural inflation [4].

Planck has also shown how the fit provided by a ΛCDM cosmology with the simplest power-law spectrum for primordial fluctuations is remarkable at high multipoles, but not as good otherwise, because of a dip at $\ell \sim 20$ and/or of a smaller average amplitude at $\ell < 40$ in the temperature power spectrum. These features at low multipoes in the CMB temperature power spectrum generate a particular pattern at $k < 0.008$ Mpc^{-1}, as shown consistently by three different methods used to reconstruct the primordial power spectrum of curvature perturbations in [4]. However, these puzzling features in the CMB temperature power spectrum do not constitute statistically significant departures from a simple power-law spectrum generated within the simplest slow-roll inflationary models because of cosmic variance.

There are several theoretically well motivated inflation predicting deviations from a simple power-law for the primordial fluctuations which provide a better fit to the temperature power spectrum at $\ell < 40$, leaving almost unaltered the fit at higher multipoles.

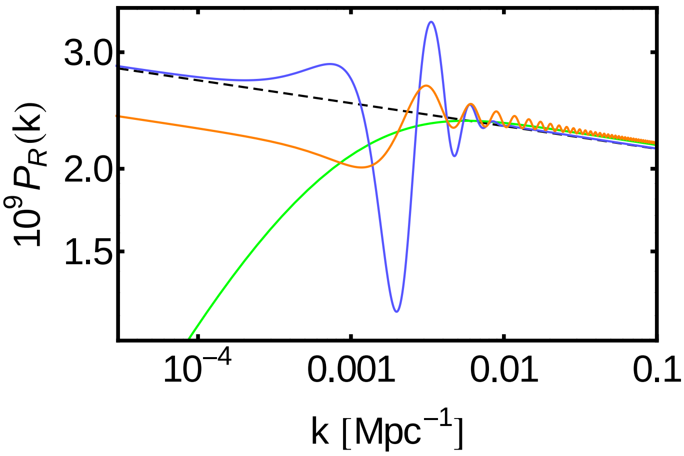

Figure 1: The primordial power spectrum for power-law (dashed black), for the model MI in green [6], for the model MII in orange [7] and the model MIII in blue [8]. Figure from [9].

We consider three different models, showed in Fig. 1, based on a temporary violation of the slow-roll regime for the inflaton at the largest wavelengths, roughly corresponding to $k \sim 0.002$ Mpc^{-1} ($\ell \sim 20$). We first analyzed a power-law spectrum multiplied by an exponential cut-off (MI), first introduced in [6], motivated by models with a short inflationary stage preceeded by a kinetic-dominated regime. As second model (MII), we considered the case studied in [7] which predicts a step-like feature in the primordial power spectrum driven by a sudden change in the slope of the inflaton potential. Moreover, we consider another model derived by a transition in the inflaton potential (MIII), proposed in [8], with a more pronounced deep at $\ell \sim 20$.

At present, no inflationary model with a violation of the slow-roll regime fitting these features has been found to be preferred over the simplest power-law spectrum supported by a slow-roll regime over all the observable range of the potential [4]. Future CMB polarization data, as from the next Planck release, will provide complementary information to further test these deviations from a simple power-law spectrum at the largest scales [10].

Beyond the handle of better measurements of CMB polarization on large angular scales, the current snapshot of the primordial power spectrum taken by Planck [3, 4] will be further refined by future stage IV galaxy surveys as DESI [11], Euclid [12], SPHEREx [13]. Thanks to the different sensitity of the galaxy clustering power spectrum from cosmology, future galaxy surveys will be useful to break the degeneracy among cosmological parameters in the CMB power spectra of temperature and polarization.

2 Method

We use the Fisher matrix technique [14, 15] for our science forecasts. In this context the Fisher information matrix approximates the natural logarithm of the likelihood as a multivariate Gaussian in the parameters $\{\theta_i\}$ around a maximum. Starting from an unbiased estimator $\hat{D}$, for an observable quantity D_i, then:

$$\mathrm{F}_{ij} \leq \sum_{\alpha,\beta} \frac{\partial D_\alpha}{\partial \theta_i} \mathrm{Cov}(\hat{D})^{-1}_{\alpha\beta} \frac{\partial D_\beta}{\partial \theta_j} \,. \tag{1}$$

We include CMB information by considering Planck-like capabilities from noise sensitivities and angular resolution of the 70, 100, 143 GHz channels as presented in the 2015 release [2], which update the Scientific Program [16], with usable sky fraction 0.6 and multipoles [2-2000]. For this forecast, we use our conservative choice of Planck frequency balancing the neglection of polarized foregrounds at low multipoles or foreground residual/secondary anisotropies in temperature at high multipoles.

To compute the Fisher matrix we use Eq. (1) with the observables being the autocorrelators of temperature and E-mode polarization, and the cross-correlator between them. The covariance matrix for the observables is given by:

$$\mathrm{Cov}_\ell = \frac{2}{(2\ell+1) f_{\mathrm{sky}}} \begin{bmatrix} (\bar{C}_\ell^{TT})^2 & (\bar{C}_\ell^{TE})^2 & \bar{C}_\ell^{TT}\bar{C}_\ell^{TE} \\ (\bar{C}_\ell^{TE})^2 & (\bar{C}_\ell^{EE})^2 & \bar{C}_\ell^{EE}\bar{C}_\ell^{TE} \\ \bar{C}_\ell^{TT}\bar{C}_\ell^{TE} & \bar{C}_\ell^{EE}\bar{C}_\ell^{TE} & \left(\bar{C}_\ell^{TT}\bar{C}_\ell^{EE} + (\bar{C}_\ell^{TE})^2\right)/2 \end{bmatrix} \tag{2}$$

where $\bar{C}_\ell^X$ stands for the sum of the signal and the white noise.

The forecast for the LSS has been done by considering the galaxies power spectrum as observable in Eq. (1). The simplest model for the observed galaxy (distribution) power spectrum is a linear and scale independent galaxy bias, with redshift space distorsion due to small peculiar velocities not associated to the Hubble flow [17] given by:

$$P_g(\mathbf{k}, z) = \left[b(z) + f(\mathbf{k}, z)\mu^2\right]^2 P_m(\mathbf{k}, z) \,, \tag{3}$$

with covariance matrix [18]:

$$\mathrm{Cov}_{\mathbf{k}}(z) = \frac{(2\pi)^3}{\pi k^2 \Delta k \Delta\mu} \frac{1}{V_{\mathrm{surv}}(z)} \left[P_g(\mathbf{k}, z) + P_{\mathrm{shot}}(z)\right] \,. \tag{4}$$

The limitation due to the finite volume of the survey affects the density field by selecting the accessible modes. Under this assumption we select an infrared cut-off given by $k_{\mathrm{min}} = 2\pi/\sqrt[3]{V_{\mathrm{surv}}}$ and we considered only discrete number of samples in k by taking integer of k_{min}. Moreover, we use 20 uniform μ-bins.

3 Results

The effective very large scale of the model MI [6] obtained as a best-fit for *Planck* 2015 data [4] is not reachable by future galaxy surveys, such as DESI, Euclid and SPHEREx. Such modification on large scales seems a better target for high-sensitivity current and future CMB polarization experiments which will provide an improved measurement of the E-mode polarization on large scales [9].

The model MII with a discontinuity in the first derivative of the potential [7] has also two parameters as MI, but the resulting power spectrum has super-imposed oscillations accompanying the change in the amplitude. These oscillations are non-zero at scales smaller than the change in amplitude and can be therefore a target for future galaxy surveys. Whereas CMB is sensitive to the preferred scale of the model, the matter power spectrum is much more sensitive to the change in the amplitude of the power spectrum: for this model the complementarity of CMB and LSS is important [9].

The third model, MIII, also benefits from the addition of LSS, as can be seen from Fig. 2. In this case the power spectrum of galaxy surveys is sensitive to either the amplitude and the width of the ringing features in the primordial fluctuations.

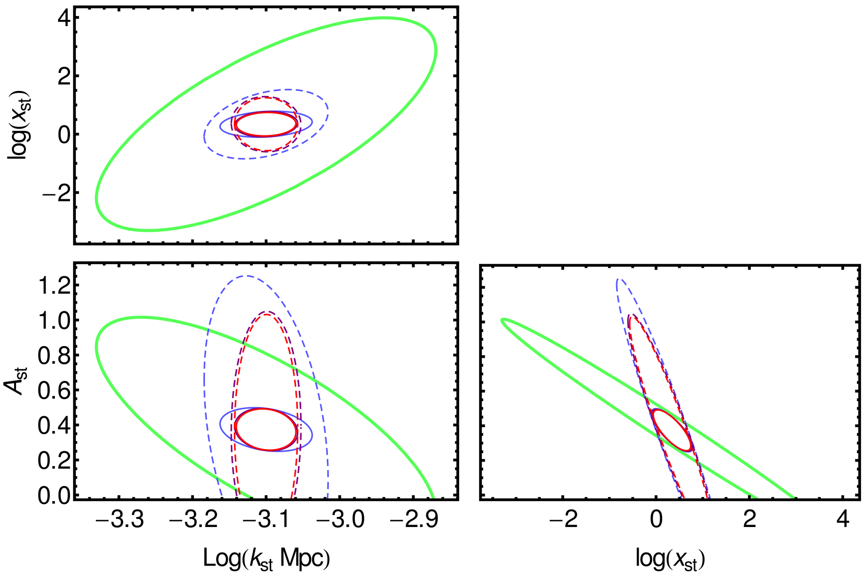

Figure 2: Marginalized contours at 68% CL for the model MIII: CMB (green), Euclid (red), DESI (blue) and SPHEREx (purple). The dashed contours represent the 2D constraints from LSS alone.

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