Oxford Physics
email: txc@astro.ox.ac.uk

Cosmological Models Constraint with Galaxy Power Spectrum

T. Chantavat[1], C. Gordon[1], J. Silk[1]

[1] University of Oxford

We consider combinations of different redshift surveys and the Planck CMB experiment to probe the primordial power spectrum and deviations from a standard power-law model, including the spectral index and the running. In particular, we investigate a localised feature generated from an Infra-red cascading mechanism during an inflationary period [1]. We forecast the constraints on the parameters for a high redshift galaxy survey (CIP) and a cosmic variance limited survey (SKA) along with Planck. We have found that most information from the power spectrum can be obtained from high redshifts, which can break a degeneracy between the amplitude of the feature and the running on scale k ~ 0.1 h Mpc^{-1}.The effect of neutrino mass on the constraints for features in the power spectrum is negligible.

Motivations

- The primordial power spectrum, $\mathcal{P}_{\mathcal{R}}$, is only described by two parameters, $\Delta^2_{\mathcal{R}}$, and, n_s ,without any description of any localised features or deviation from a power law.
- Modifications of the primordial power spectrum can be made to fit the data better, especially the outliers in the CMB near ℓ = 22 and 40, which give rise to an improvement of $\Delta\chi^2 \sim \mathcal{O}(10)$ over a smooth power-law spectrum [2, 3].
- A recent inflationary mechanism which generates a bump-like feature through an IR-cascading has been proposed [1].

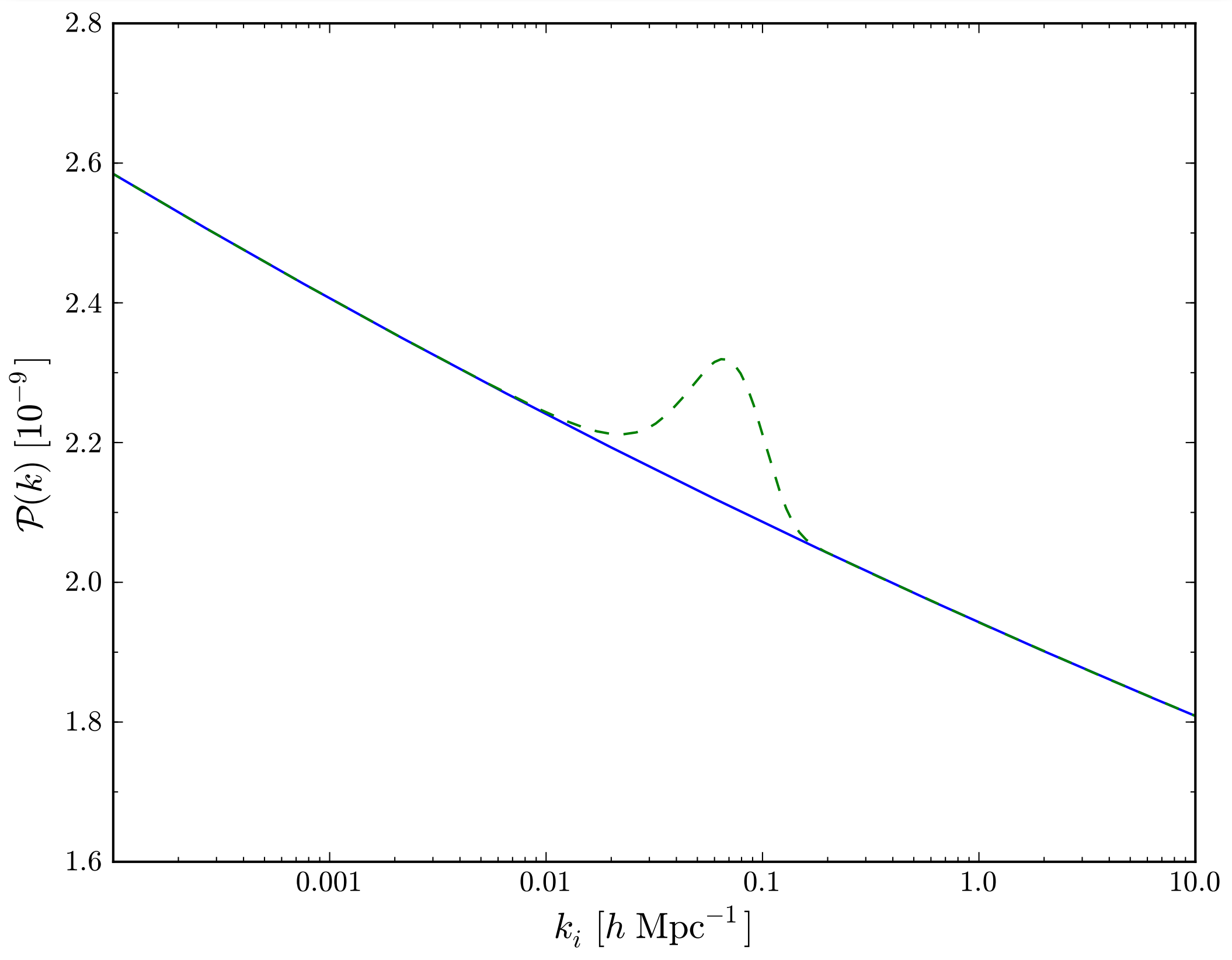

FIG. 1: The primordial power spectrum with WMAP7 max. likelihood (solid line) and with IR feature with $A_i = 1.25 \times 10^{-10}$ at position $k_i = 0.1\ h\ \mathrm{Mpc}^{-1}$ (dashed line).

IR-cascading Feature

- In this scenario, the production of massive iso-curvature particles by quantum effects scatter and draw energy from the inflaton field. The multiple scattering process alters the motion of the field away from a slow-roll inflation. The overall result leads to an observable feature of the form in FIG 1:

$$\mathcal{P}_{\rm IR}(k) = A_i \left(\frac{\pi e}{3}\right)^{3/2} \left(\frac{k}{k_i}\right)^3 e^{-\frac{\pi}{2}\left(\frac{k}{k_i}\right)^2}.$$

Survey	z	$V_{\rm survey}$ $(h^{-3}\ \mathrm{Gpc}^3)$	$\bar{n}$ $(h^3\ \mathrm{Mpc}^{-3})$	$k_{\max}$ $(\,h\,\mathrm{Mpc}^{-1})$	$f_{\rm sky}$
Galaxy Survey					
CIP	4.25	15.0	$1.0\ \times 10^{-2}$	2.0	0.024
SKA	1.0	100	∞	0.4	0.5

TABLE I: Details of the galaxy redshift surveys.

Fisher Matrix Calculations

- We use the Fisher matrix of the power spectrum described by [4] which is given by:

$$F_{\mu\nu} = \frac{1}{2}\int_0^{k\max} \frac{d^3\mathbf{k}}{(2\pi)^3}\frac{\partial \ln P_s(\mathbf{k})}{\partial\theta_\mu} V_{\rm eff}(\mathbf{k}) \frac{\partial \ln P_s(\mathbf{k})}{\partial\theta_\nu},$$

where $k_{\rm max}$ is the maximum scale beyond which non-linear scales become dominant.

- $V_{\rm eff}(k,\mu)$ is the effective survey volume taking shot-noise into account:

$$\begin{aligned} V_{\rm eff}(k,\mu) &= \int d^3\mathbf{r}\left[\frac{n(\mathbf{r})P_s(k,\mu)}{n(\mathbf{r})P_s(k,\mu)+1}\right]^2 \\ &\approx \left[\frac{\bar{n}P_s(k,\mu)}{\bar{n}P_s(k,\mu)+1}\right]^2 V_{\rm survey}. \end{aligned}$$

- $P_s(k,\mu)$ is the redshift-space power spectrum and is given by [5]:

$$P_s(k,\mu) = \left[1+\beta\mu^2\right]^2 b^2 P(k).$$

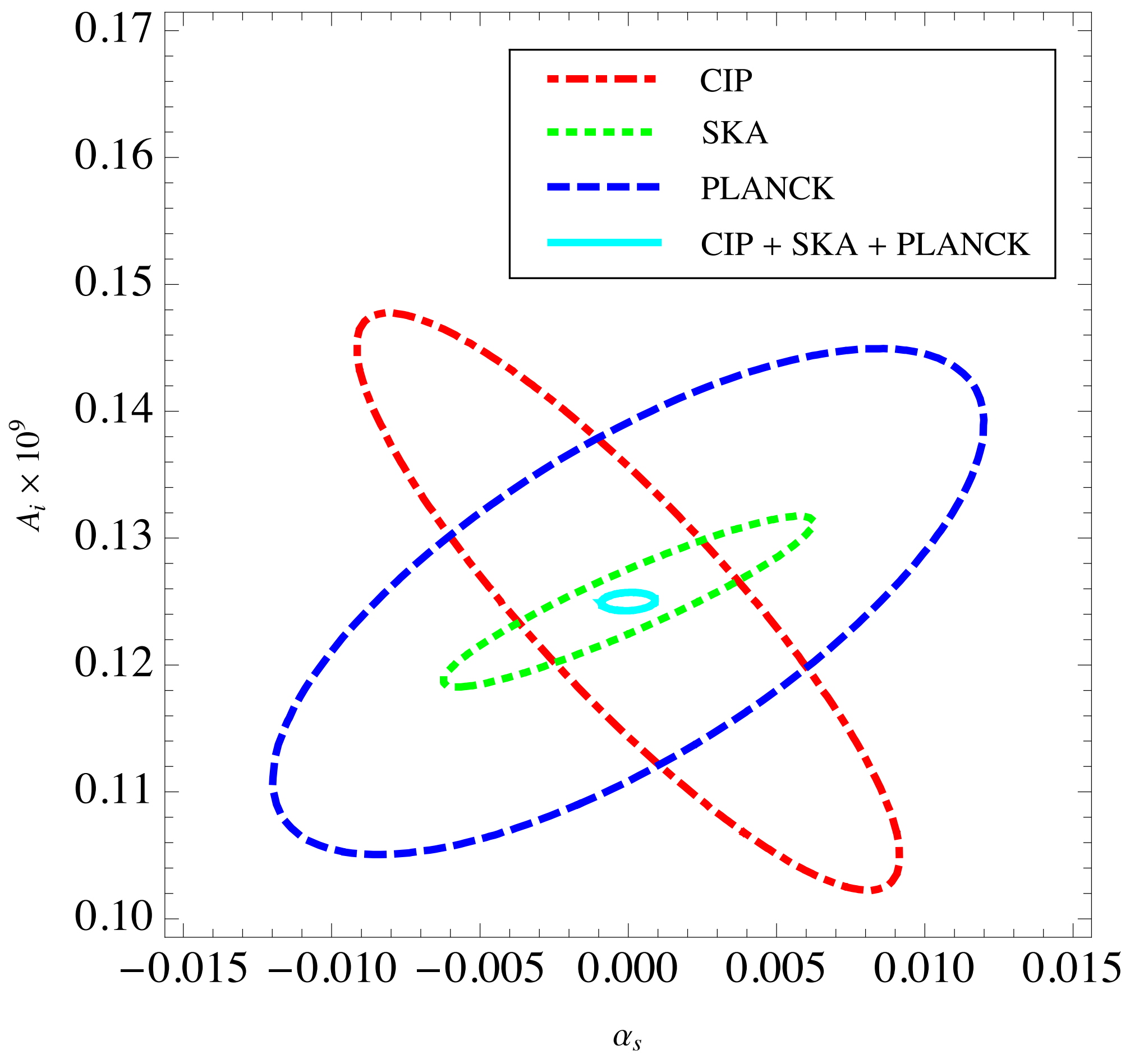

FIG. 2: Marginalised probability contours containing 68% of the posterior probability between α_s and A_i.

Forecast Constraints

- Our fiducial set of parameters are $(\omega_b,\,\omega_c,\,\Omega_\Lambda,\,n_s,\,\alpha_s,\,\Delta^2_{\mathcal{R}},\,\tau)$ = $(0.0227, 0.1107, 0.738, 0.969, 0.0,$ $2.38 \times 10^{-9}, 0.086)$ and our fiducial feature parameters are $A_i = 1.25 \times 10^{-10}$ at position $k_i = 0.1\ \ h\,\mathrm{Mpc}^{-1}$ which is consistent with WMAP7. Forecasted constraints of our fiducial parameters for CIP, SKA, WMAP and Planck are shown in TABLE II.

Survey	σ_{A_1} $(\times 10^{-9})$	σ_{k_1} $(\,h\,\mathrm{Mpc}^{-1})$	σ_{n_s}	σ_{α_s}
Galaxy Survey				
CIP	0.015	0.0034	0.024	0.006
CIP + WMAP	0.0069	0.002	0.0037	0.0013
CIP + PLANCK	0.0052	0.0012	0.002	0.00086
SKA	0.0044	0.00092	0.0073	0.0041
SKA + WMAP	0.0029	0.00089	0.0027	0.0023
SKA + PLANCK	0.0026	0.00080	0.0016	0.0017
CMB				
WMAP	0.19	0.027	0.064	0.035
PLANCK	0.013	0.0023	0.0044	0.0079

TABLE II: Forecasted 1-σ marginalised uncertainties for our fiducial feature $k_1 = 0.1\,h\,\mathrm{Mpc}^{-1}$, $A_1 = 0.125 \times 10^{-9}$.

Discussion

- The quality of the constraints depends largely on the depth of the survey. CIP, which is the deepest survey, provides better constraints than SKA, which is modelled as a mid-redshift cosmic variance limited survey. This is due to the fact that CIP gains more information from being able to probe into small scales which would have been non-linear at low redshifts.
- The degeneracy between α_s and A_i as measured from CMB Planck and SKA can be broken by inclusion of CIP on small scales (See FIG 2.).
- The direction of the principle axis of the ellipsoidal 1-σ contour plot could be explained by a complicated compensation of variations in n_s, α_s, $\Delta^2_{\mathcal{R}}$ and A_i in order to preserve the power spectrum on small scales.
- Since CIP and SKA have a different redshift range, they both provide an independent result which would be able to be combined with Planck to give much tighter constraints on the primordial power spectrum.

Reference

[1] N. Barnaby and Z. Huang, Phy. Rev. D **80**, 126018 (2009)
[2] C. Dvorkin and W. Hu, Phys. Rev. D **81**, 023518 (2010)
[3] P. Mukherjee and Y. Wang, Astrophys. J. **598**, 779 (2003)
[4] M. Tegmark, Physical Review Letters **79**, 3806 (1997)
[5] N. Kaiser, Mon. Not. R. Astron. Soc. **321**, 372 (2001)

Oxford Astrophysics