On the possibility of primordial features

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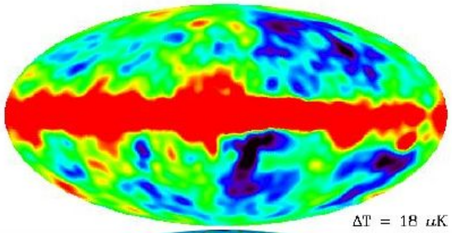
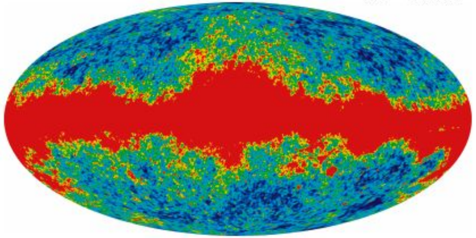
Physics of the Early Universe - An Online Precursor, August 31, 2020

Cosmic Microwave Background

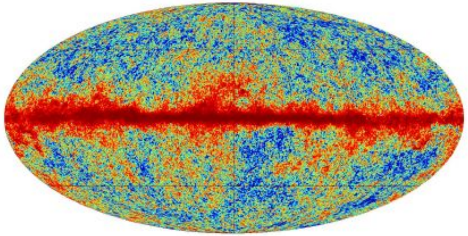
COBE

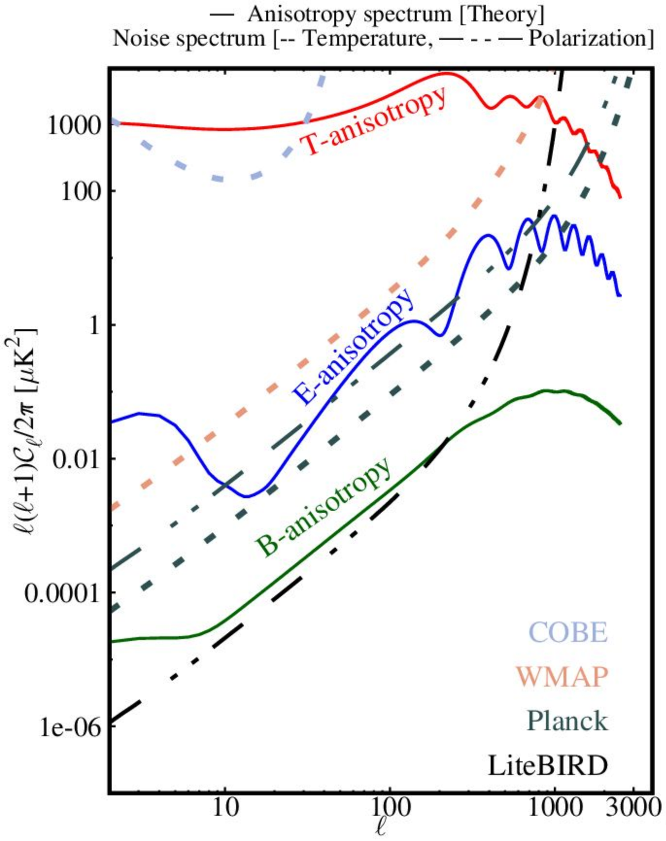


WMAP

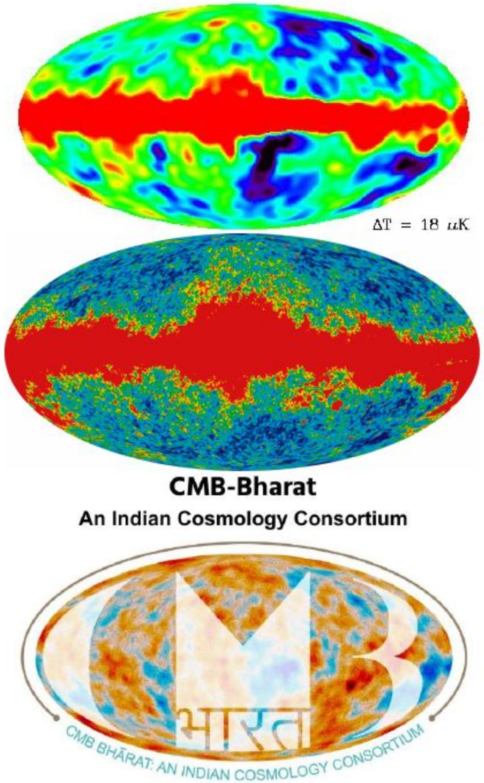


Planck

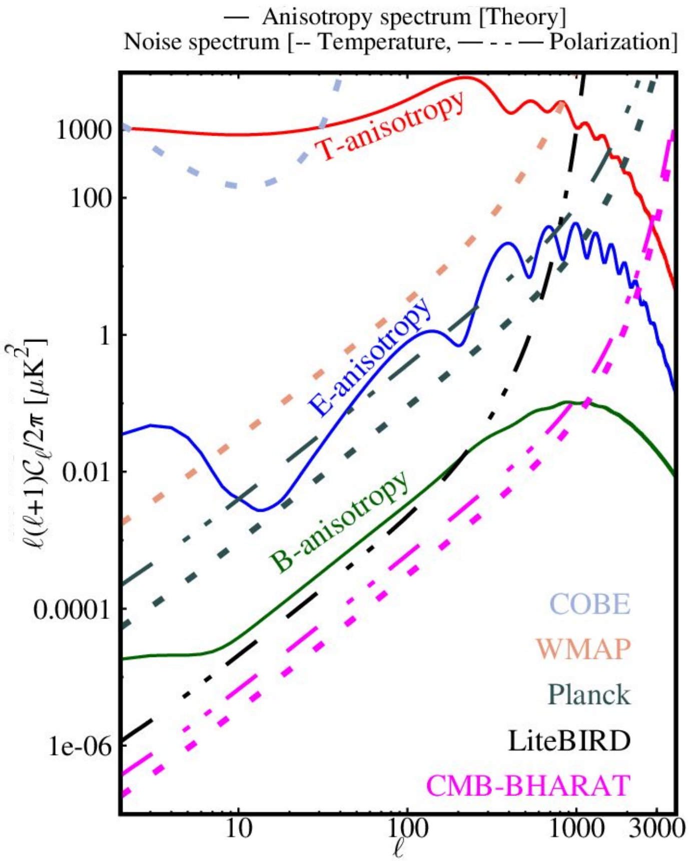




Cosmic Microwave Background

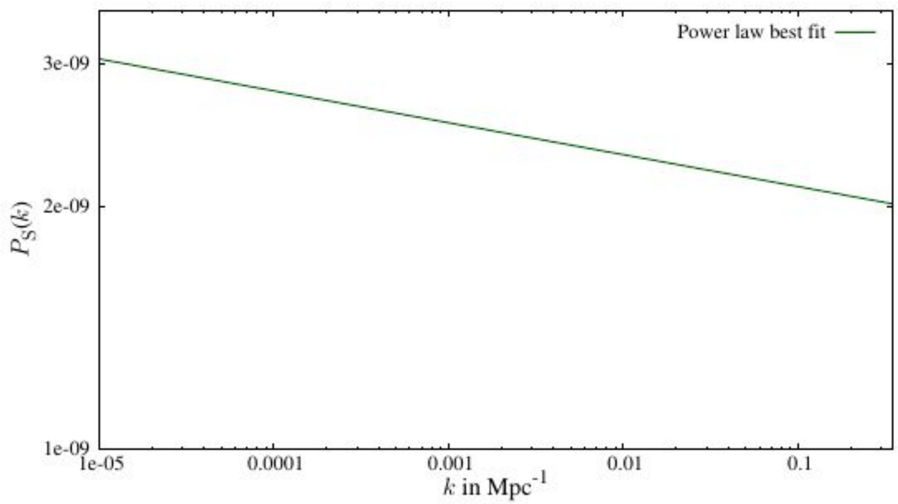


http://cmb-bharat.in/

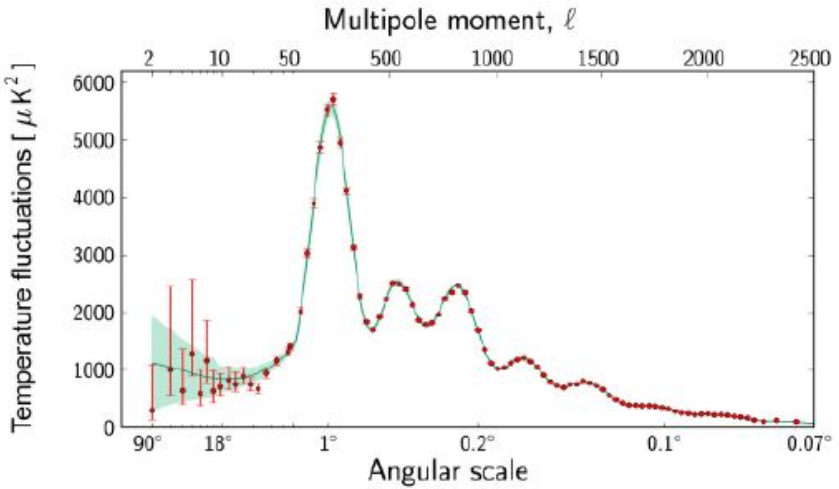


Primordial and angular power spectra

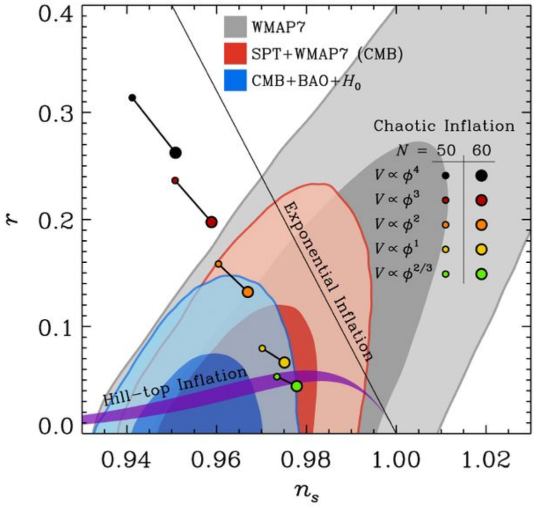
Primordial power spectrum



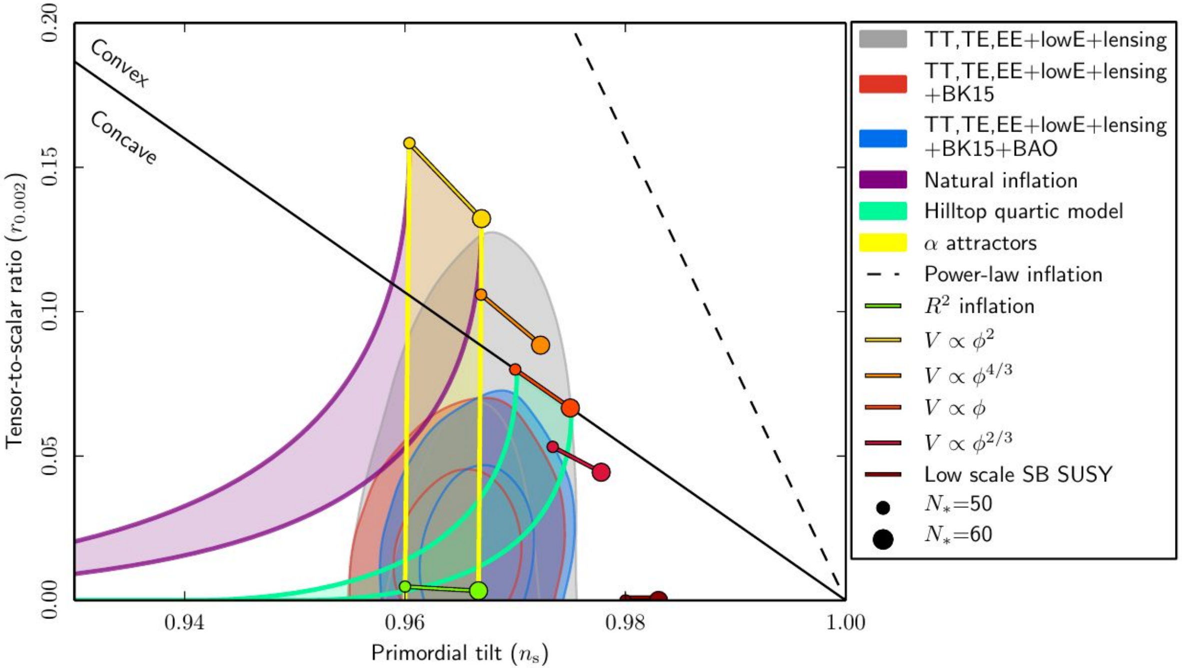
Angular power spectrum (Planck)



Primordial scalar spectral index: WMAP to Planck



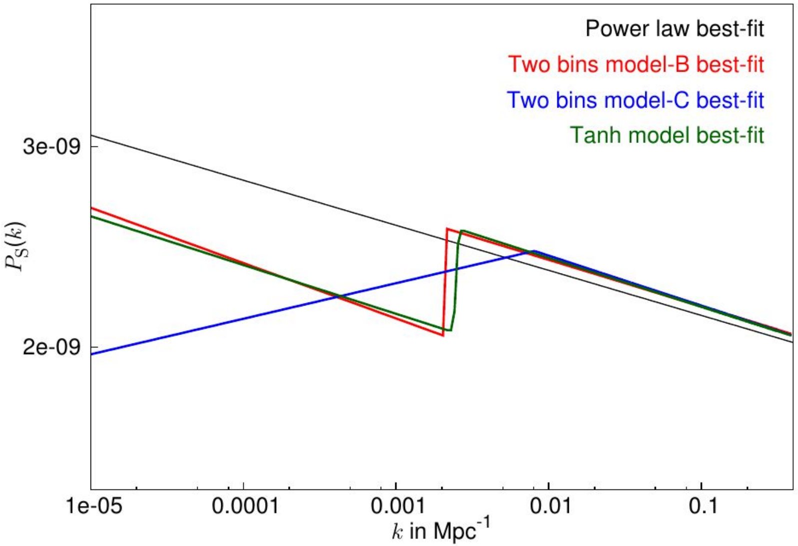
WMAP Seven Year

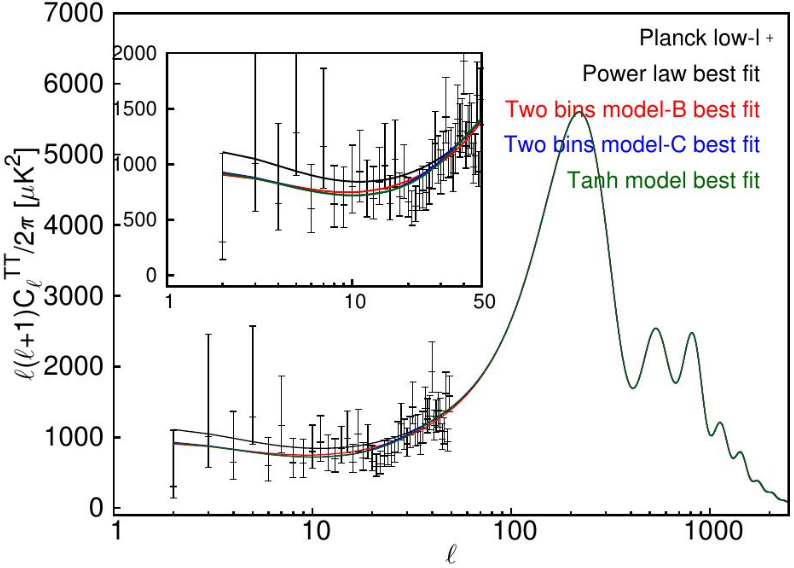


Planck 2018: Constraints on inflation

n_s=1 implies complete scale invariance

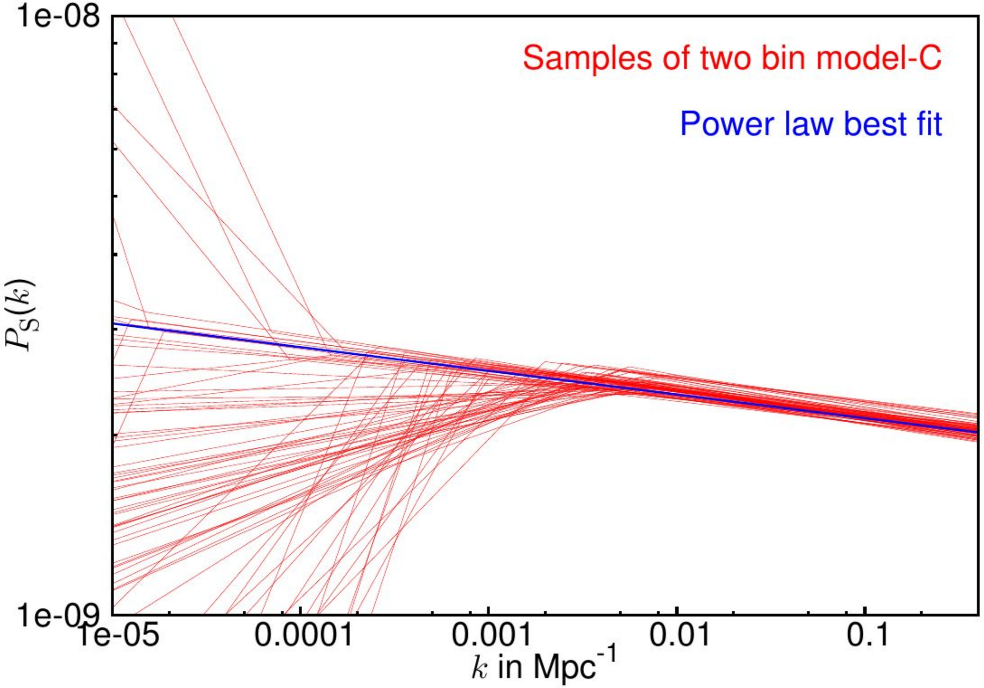
Simple test of scale dependence





Hazra, Shafieloo, Smoot JCAP 2013

Simple test of scale dependence



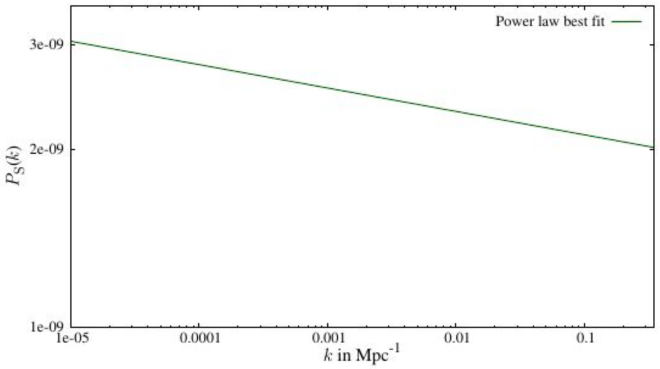
The spectral index is constrained to be 'red' after **0.01 Mpc^{-1}**

For scales larger than 0.01 Mpc^{-1} the TT data prefers a blue tilt

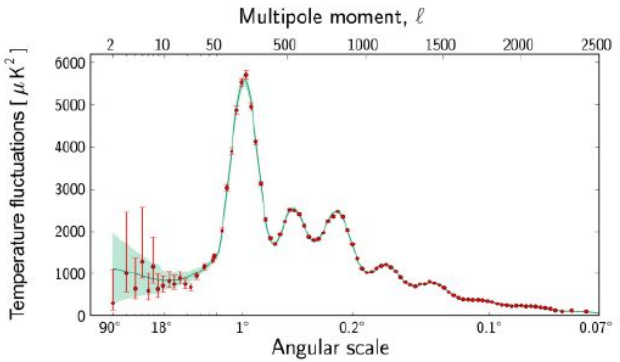
Hazra, Shafieloo, Smoot JCAP 2013

Reconstruction of localized features

Primordial power spectrum



Angular power spectrum (Planck)

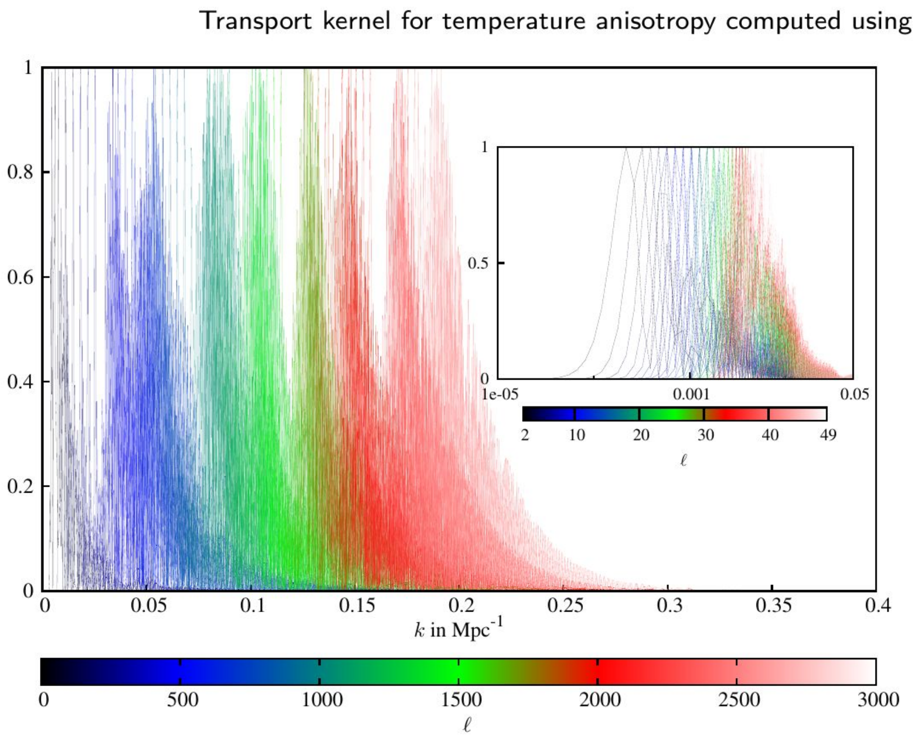


$$C_\ell^{\mathrm{T}} = \sum_i G_{\ell k_i} P_{k_i}$$

$G_{\ell k}$ is the radiative transport kernel

Hazra, Shafieloo, Souradeep JCAP 2014

Reconstruction of localized features



The transport kernel depends on background cosmology

Using a baseline cosmology we attempt to reconstruct the primordial power spectrum from the CMB angular power spectrum data

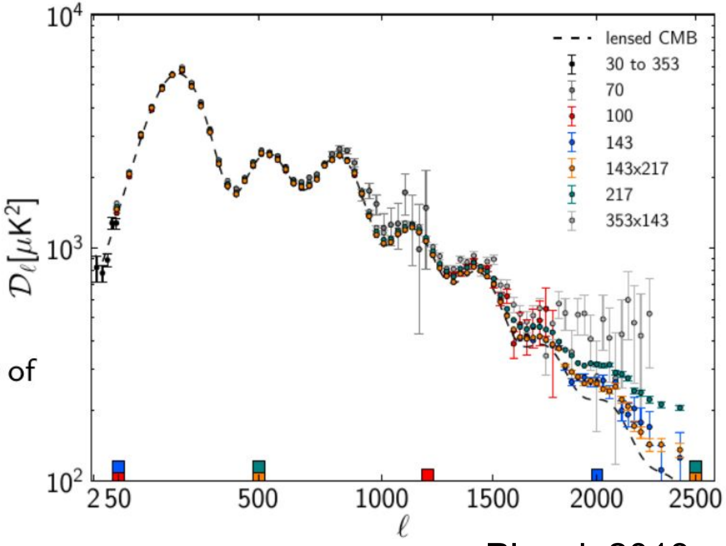
Hazra, Shafieloo, Souradeep JCAP 2014

Reconstruction (Richardson-Lucy algorithm)

Richardson (1972) and Lucy (1974)

$$P_k^{(i+1)} - P_k^{(i)} = P_k^{(i)} \times \left[\sum_{\ell} \widetilde{G}_{\ell k} \left(\frac{C_\ell^{\mathrm{D}} - C_\ell^{\mathrm{T}(i)}}{C_\ell^{\mathrm{T}(i)}} \right) \right]$$

Angular power spectra (in different Planck frequencies)

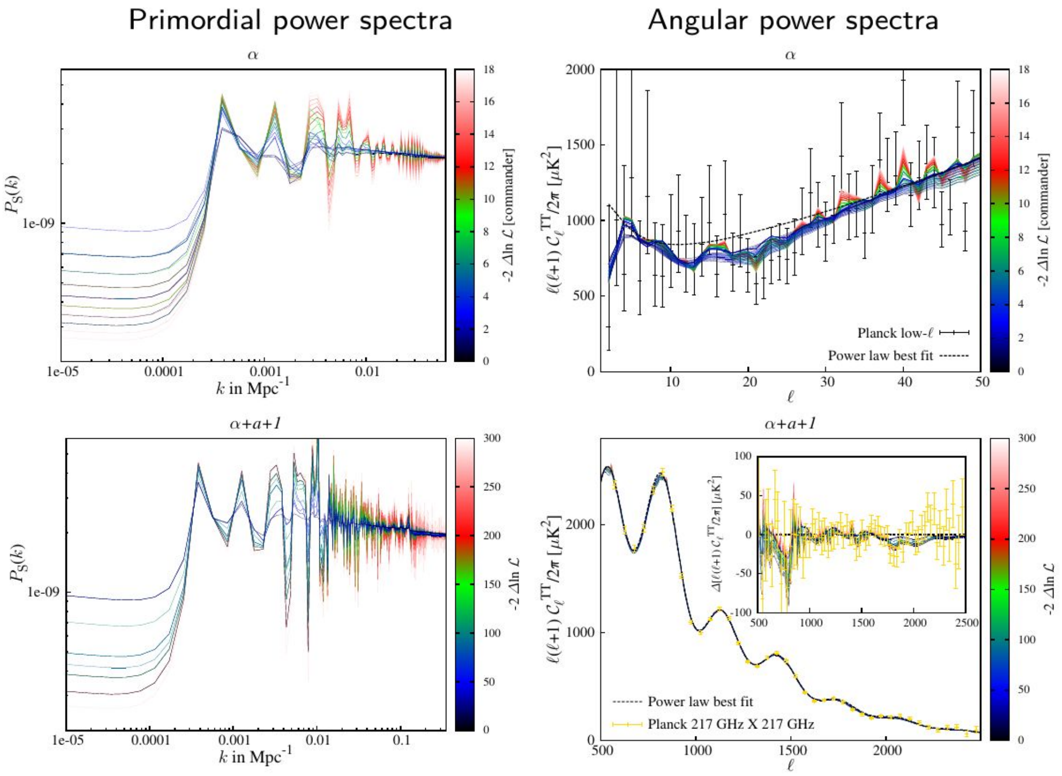


Planck 2013

- 5 different spectra for parameter estimation, calculated from combinations of maps in different frequency channels
- Foreground and calibration effects
- Substantial lensing

Hazra, Shafieloo, Souradeep JCAP 2014

Reconstruction (Modified Richardson-Lucy)



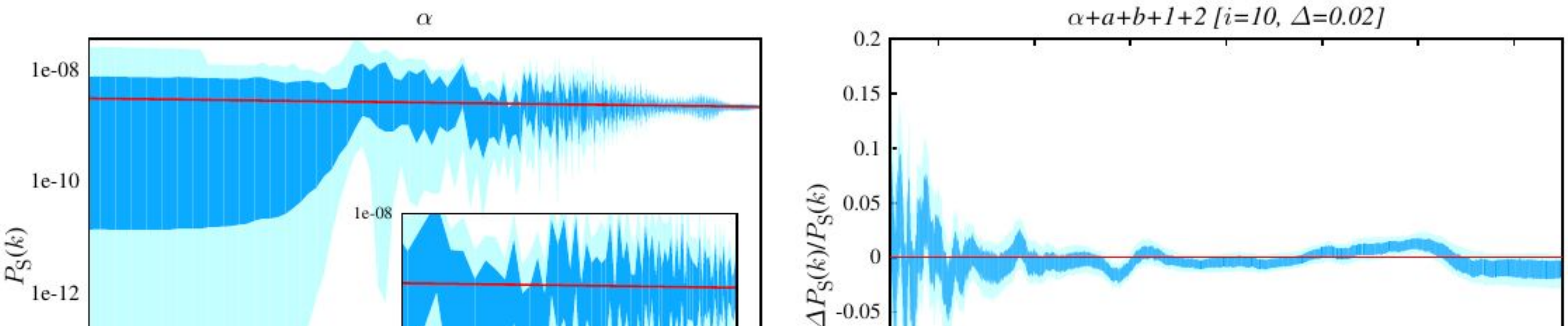
MRL reconstructs the free-form primordial power spectrum from different combinations of frequency channels

Helps to identify features present in all frequencies

Also helps to check consistencies between frequencies

Hazra, Shafieloo, Souradeep JCAP 2014

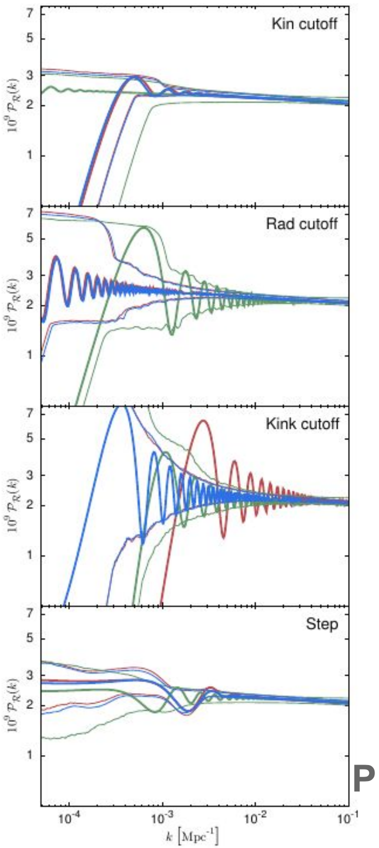
Features that seem ‘*important*’

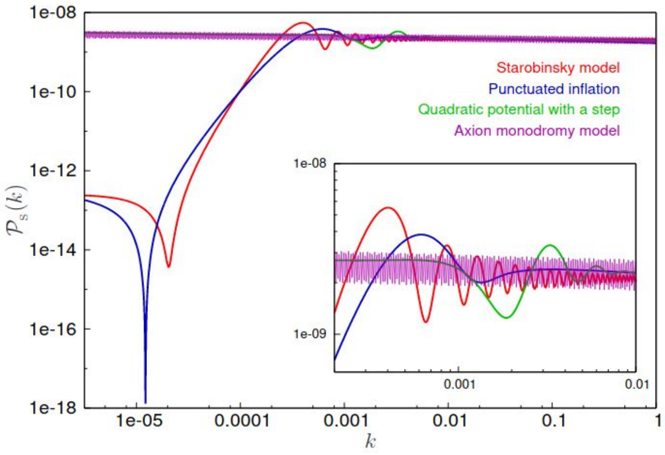


Standard model assumption, power law is consistent at all scales apart from few localized oscillations, near $\ell \simeq 22,\ 200-300,\ 750-850$

Hazra, Shafieloo, Souradeep JCAP 2014

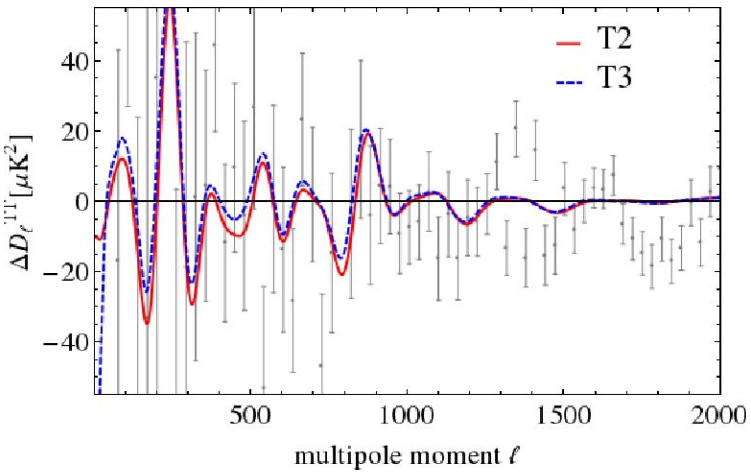
Possible *'features' (ref. to Fabio's talk)*





Hazra, Sriramkumar, Martin 2013

Hints: large scale suppression, few intermediate and smaller scale oscillations



Planck 2018: Constraints on Inflation

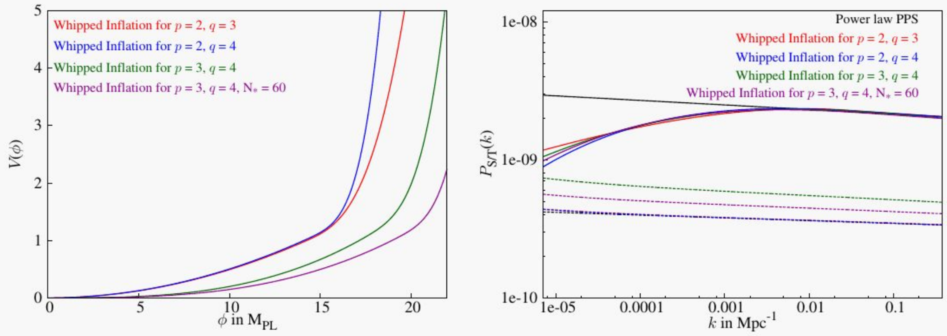
Chen et al. 2015

What about the potential ?

Whipped Inflation potential

$$V(\phi) = V_S(\phi) + \gamma V_R(\phi)$$

Moderate fast-roll $\Longrightarrow$ strict slow-roll



A plan to construct a framework of inflation potential that can generate features with the hints from reconstruction.

Hazra, Shafieloo, Smoot, Starobinsky PRL 2014

What about the potential ?

To have features in the PPS, generate low amplitude tensor perturbations we propose : **WWI**

$$V(\phi) = V_i\left(1-\left(\frac{\phi}{\mu}\right)^p\right) + \Theta(\phi_{\rm T}-\phi)V_i\left(\gamma(\phi_{\rm T}-\phi)^q+\phi_{01}^q\right),$$

and : **WWI′**

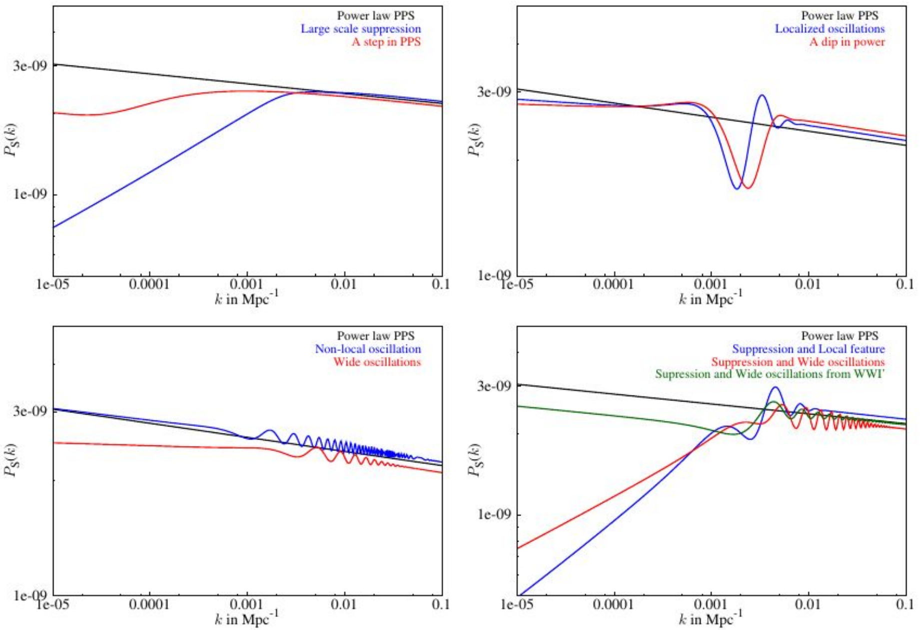
$$V(\phi) = \Theta(\phi_{\rm T}-\phi)V_i\left(1-\exp\left[-\alpha\kappa\phi\right]\right) + \Theta(\phi-\phi_{\rm T})V_{ii}\left(1-\exp\left[-\alpha\kappa(\phi-\phi_{01})\right]\right)$$

Inflaton transits from a **moderate fast roll** to a **strict slow roll** through a **discontinuity**

A plan to construct a framework of inflation potential that can generate features with the hints from reconstruction.

Hazra, Shafieloo, Smoot, Starobinsky JCAP 2016

Wiggly Whipped Inflation

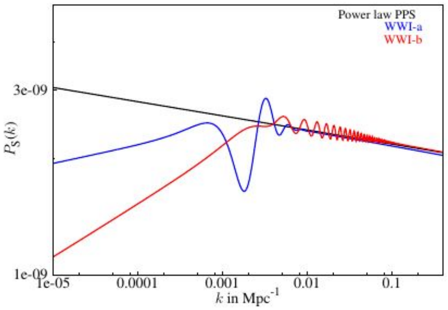


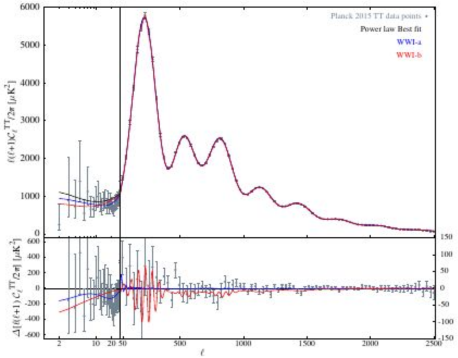
Several classes of features can be generated with WWI, such as large scale suppression, localized and non-local oscillations

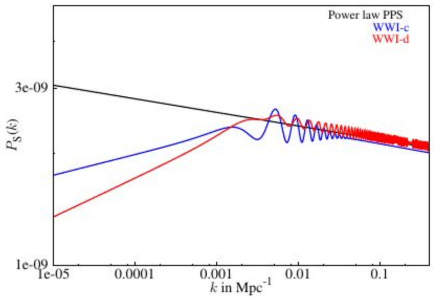
Hazra, Shafieloo, Smoot, Starobinsky JCAP 2016

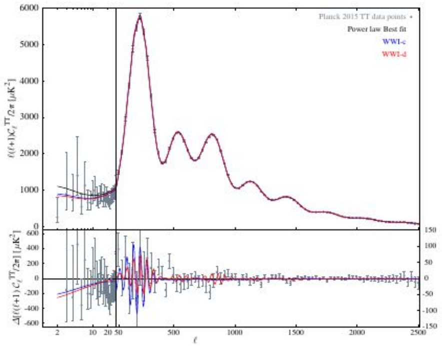
Wiggly Whipped Inflation

Identified four best fit features : WWI-[a,b,c,d]





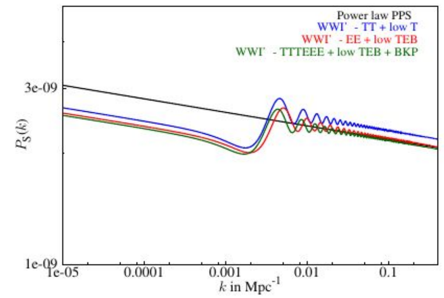


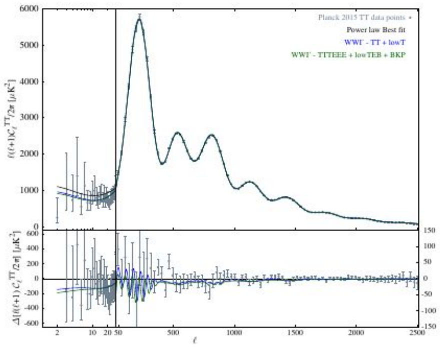


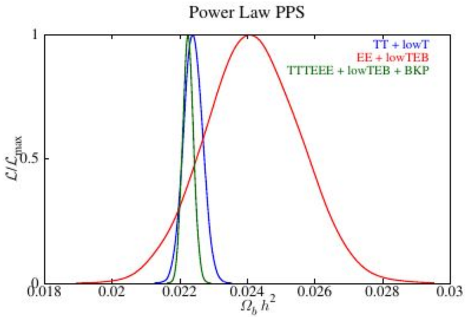
4 local best fits that provide 7-14 improvement in the fit to the data compared to baseline

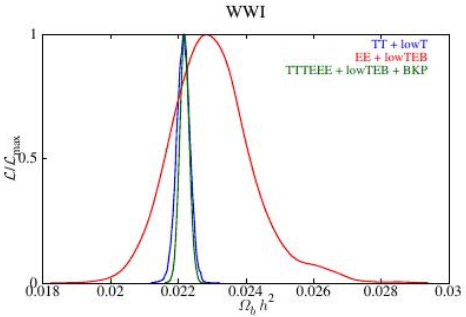
Hazra, Shafieloo, Smoot, Starobinsky JCAP 2016

Wiggly Whipped Inflation (baryon density)





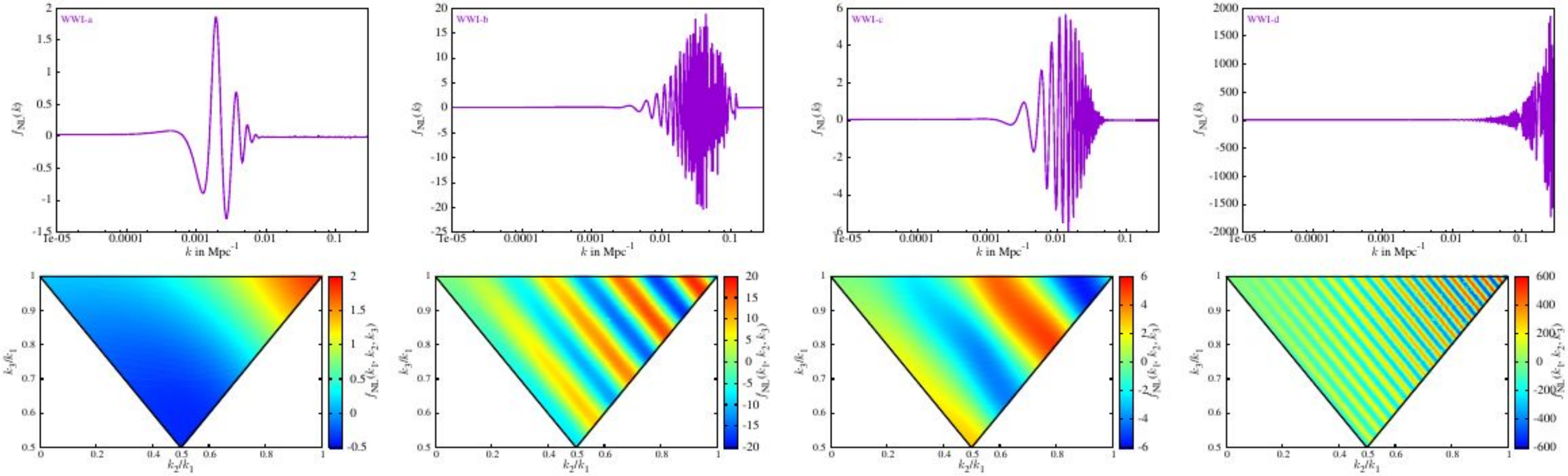




4 local best fits that provide 7-14 improvement in the fit to the data compared to baseline

Hazra, Shafieloo, Smoot, Starobinsky JCAP 2016

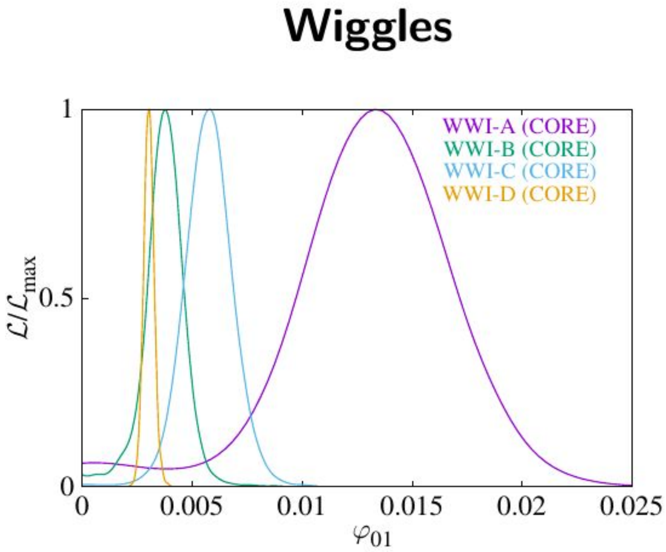
Wiggly Whipped Inflation (f_{NL})

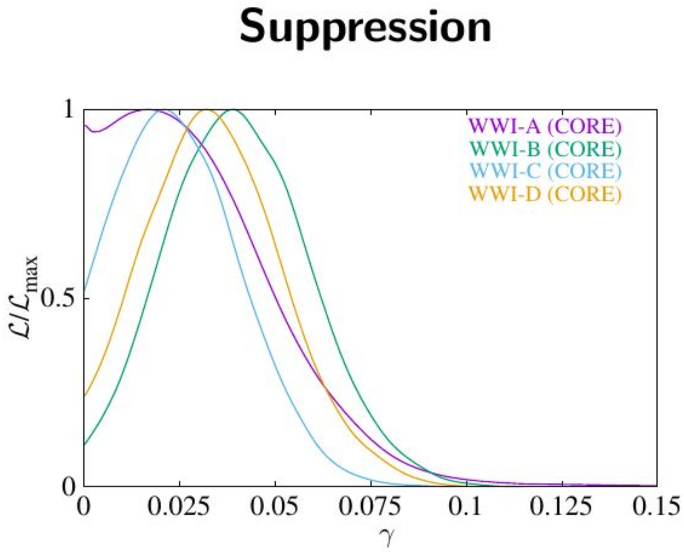


Computed using **BINGO,** Hazra, Sriramkumar, Martin JCAP 2013

Hazra, Shafieloo, Smoot, Starobinsky JCAP 2016

Features in the future (CORE forecast)



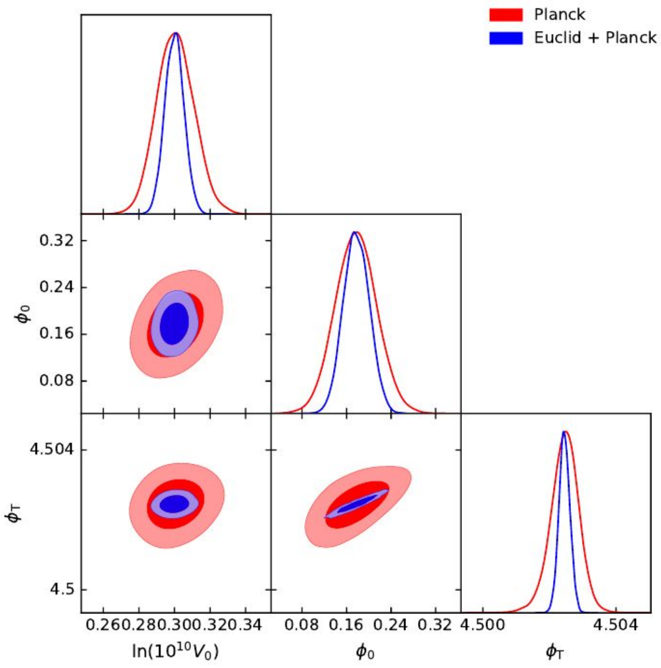


Even with Cosmic Variance limited surveys, it will be difficult to detect large scale suppression.

Intermediate and small scale oscillations, if present, can be detected with high significance

Hazra, Paoletti, Ballardini, Finelli, Shafieloo, Smoot, Starobinsky JCAP 2017

Features in the future (Euclid-like forecast)



Large Scale Structure survey such as Euclid can help in detecting features that are present within 0.02-0.2 Mpc^{-1}

Larger scale features will be hard to detect with Euclid as well

Fabio discussed Euclid-like forecast for some features

Debono, Hazra, Shafieloo, Smoot, Starobinsky MNRAS 2020

To summarize

The *baseline model (power law/slow roll)* is consistent with the data at all scales

With the present data the features are not detected at high significance

However, the hints are strong

With future CMB and LSS data we can detect the primordial features at ***intermediate and small scales***

-- physics ***beyond the slow roll inflation***

Large scale features, however can not be detected beyond moderate significance

Thank You

CORE specifications

$$\text{Frequency [GHz]} = \{100, 115, 130, 145, 160, 175, 195, 220\}$$
$$\text{FWHM [Arcmin]} = \left\{8.51, 7.68, 7.01, 6.45, 5.84, 5.23\right\}$$
$$\Delta\text{T}\,[\mu\text{K arcmin}] = \left\{3.9, 3.6, 3.7, 3.6, 3.5, 3.8\right\}$$
$$\Delta\text{P}\,[\mu\text{K arcmin}] = \left\{5.5, 5.1, 5.2, 5.1, 4.9, 5.4\right\}$$

Euclid specifications

Sheer and Galaxy clustering likelihood from MontePython package

For cosmic shear we use $n_{\rm gal} = 30\,{\rm arcmin}^{-2}$

Noise $N_\ell^{ij} = \delta_{ij}\sigma^2_{\rm shear} n_i^{-1}$; $\sigma_{\rm shear}$ = 0.3

Redshift number density distribution

$$\frac{{\rm d}n_{\rm gal}}{{\rm d}z} = z^\beta \exp\left[-\left(\frac{z}{\alpha z_{\rm m}}\right)^\gamma\right]$$

For spectroscopic galaxy clustering we use minimum redshift z_{min} = 0.75 and a maximum redshift z_{max} = 1.95; $\sigma_z = 0.001(1 + z)$

Cutoff wavenumber = 0.02 Mpc^{-1}