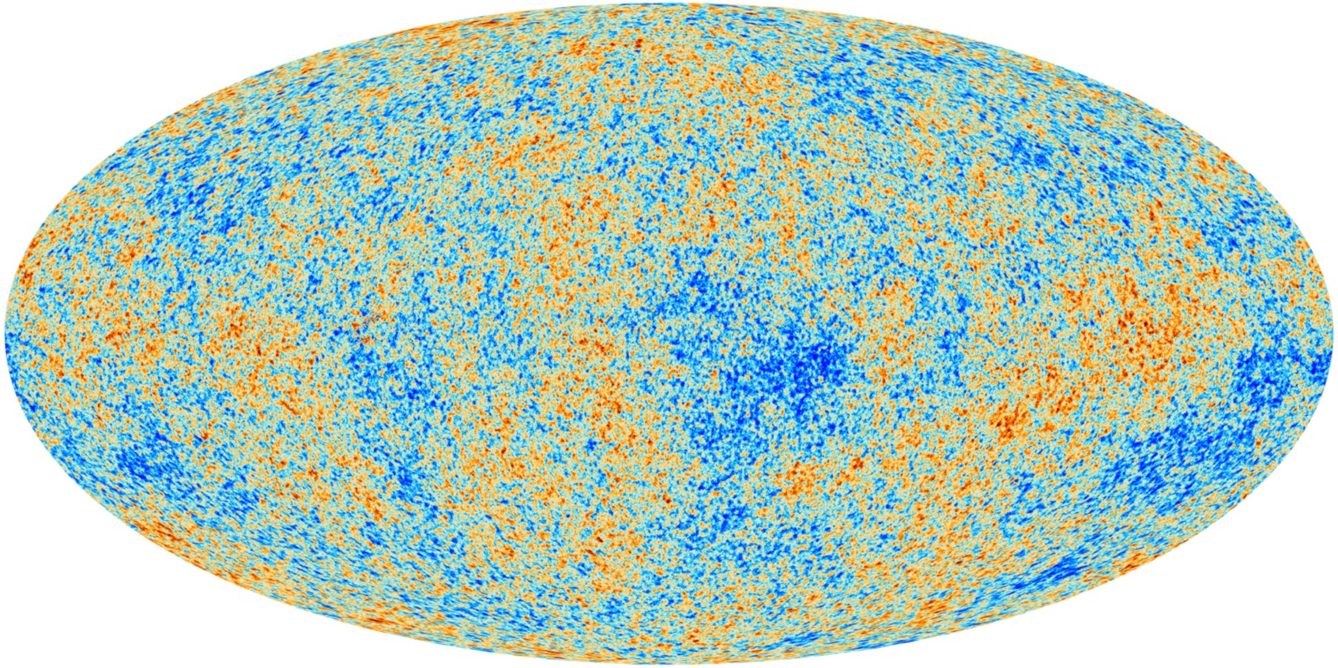
Current constraints on cosmic inflation and prospects for the next generation of probes



Credit: ESA & Planck Collaboration

Fabio Finelli

INAF / IASF Bologna

INFN Bologna

Fundamental Cosmology Meeting, Teruel, September 2017

Outline

Introduction and highlights of the Planck 2015 results for inflation

Planck 2015 results. XX. Constraints on inflation, Astron. Astrophysics 594 (2016) A20

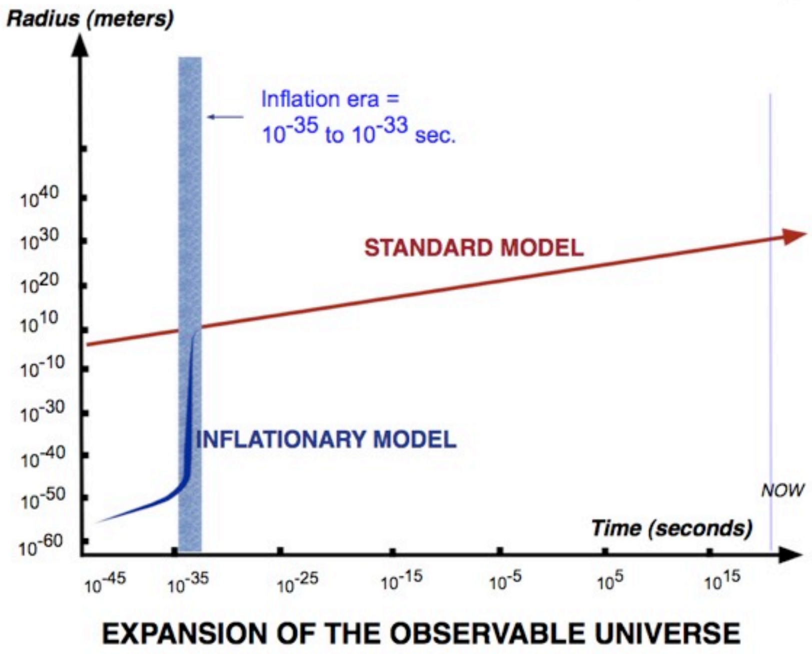
Probing primordial features with future galaxy surveys

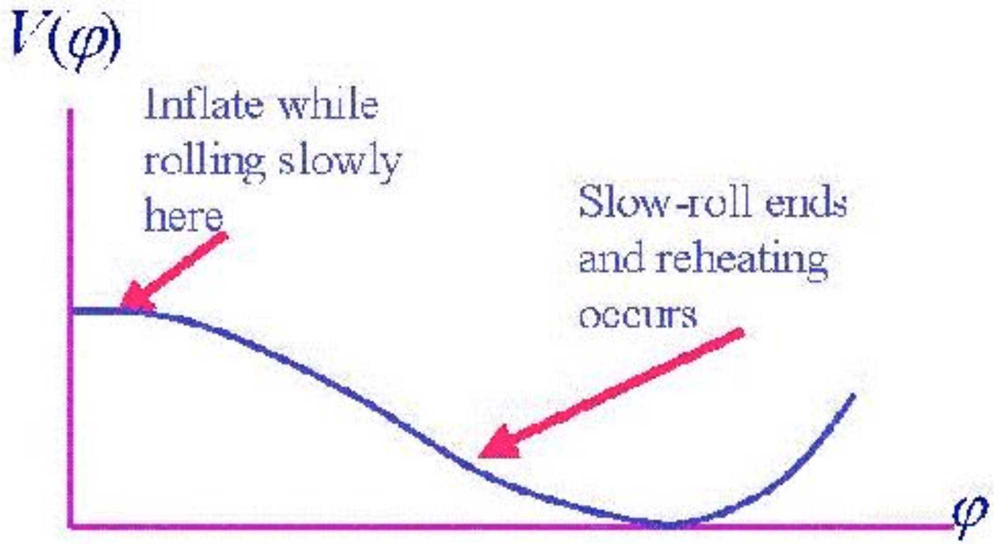
M. Ballardini, FF, C. Fedeli, L. Moscardini, JCAP 1016, (2016)

Perspectives for the physics of inflation with future CMB experiments

CORE collaboration; Exploring Cosmic Origins with CORE: Inflation, arXiv:1612.08270

Cosmic Inflation





Minimal early universe framework which solves puzzles of the Standard Big Bang model such as the flatness, horizon and monopole problems.

A standard scalar field with a potential which supports slow-roll inflation is the simplest example. Necessary conditions are:

$$\epsilon_V = \frac{M_{\rm pl}^2 V_\phi^2}{2V^2} << 1\,, \quad \eta_V = \frac{M_{\rm pl}^2 V_{\phi\phi}}{V} << 1$$

Generation of fluctuations

Inflation solves the puzzles of the Standard Big Bang model and at the same time generates the primordial spectra of gravitational waves and of density perturbations by quantum fluctuations.

Tensor perturbations
(gravitational waves)

$$\mathcal{P}_{\rm t}(k) = A_{\rm t}\left(\frac{k}{k_*}\right)^{n_{\rm t}+\frac{1}{2}\frac{{\rm d}n_{\rm t}}{{\rm d}\ln k}\ln\left(\frac{k}{k_*}\right)+\ldots}$$

$$A_{\rm t} \simeq \frac{2H^2}{\pi^2 M_{\rm pl}^2} \approx \frac{2V}{3\pi^2 M_{\rm pl}^4}$$

$$n_{\rm t} \simeq -2\epsilon_1 \approx -\frac{M_{\rm pl}^2 V_\phi^2}{V^2}$$

$$\epsilon_1 = -\frac{\dot{H}}{H^2} << 1$$

$$\frac{{\rm d}n_{\rm t}}{{\rm d}\ln k} \simeq -2\epsilon_1\epsilon_2$$

$$\epsilon_2 = -\frac{\dot{\epsilon}_1}{H\epsilon_1} << 1$$

Scalar perturbations

$$\mathcal{P}_{\mathcal{R}}(k) = A_{\rm s}\left(\frac{k}{k_*}\right)^{n_{\rm s}-1+\frac{1}{2}\frac{{\rm d}n_{\rm s}}{{\rm d}\ln k}\ln\left(\frac{k}{k_*}\right)+\ldots}$$

$$A_{\rm s} \approx \frac{V^3}{12\pi^2 M_{\rm pl}^6 V_\phi^2}$$

$$n_{\rm s} - 1 \simeq -2\epsilon_1 - \epsilon_2$$

$$\approx -3\frac{M_{\rm pl}^2 V_\phi^2}{V^2} + 2\frac{M_{\rm pl}^2 V_{\phi\phi}}{V}$$

$$\frac{{\rm d}n_{\rm s}}{{\rm d}\ln k} \simeq -2\epsilon_1\epsilon_2 - \epsilon_2\epsilon_3$$

$$r = \frac{\mathcal{P}_{\rm t}(k_*)}{\mathcal{P}_{\mathcal{R}}(k_*)} \simeq 16\epsilon_1 \simeq -8n_{\rm t}$$

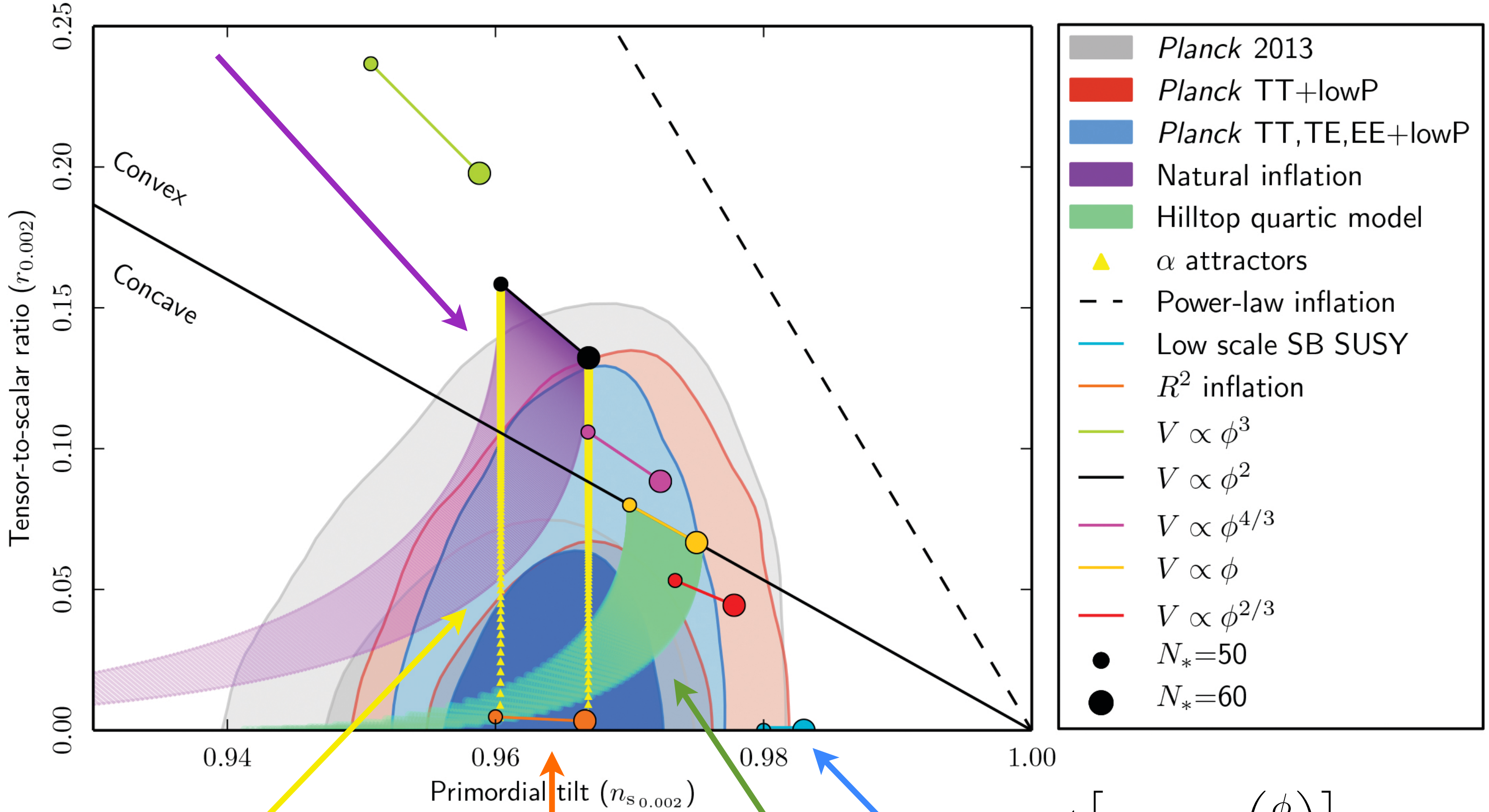
Planck 2015 results and inflation

A nearly flat Universe (incl. Planck lensing)	$\Omega_K = -0.005^{+0.016}_{-0.017}$	95%CL
A tilted power-law spectrum for density perturbations	$n_\mathrm{s} = 0.9655 \pm 0.0062$	68%CL
No statistical evidence of scale dependence of ns	$dn_\mathrm{s}/d\ln k = -0.0084 \pm 0.0082$	68%CL
Small relative amount of gravitational waves	$r_{0.002} < 0.10$	95%CL
Nearly Gaussian perturbations (incl. polarization)	$f_\mathrm{NL}^\mathrm{local} = -0.8 \pm 5.0$ $f_\mathrm{NL}^\mathrm{equil} = -3.7 \pm 43$ $f_\mathrm{NL}^\mathrm{ortho} = -26 \pm 21$	68%CL
No need for additional fields: nearly adiabatic fluctuations	$\beta_\mathrm{iso} < 0.035$	95%CL
No evidence of cosmic strings	$f_{10} < 0.020$ $(G\mu < 1.8\,10^{-7}$	95%CL 95% CL)

Inflationary models & Planck 2015

$$V(\phi) = \Lambda^4 \left[1 + \cos\left(\frac{\phi}{f}\right)\right]$$

Planck 2015 results. XX. Constraints on inflation, Astron. Astrophysics 594 (2016) A20



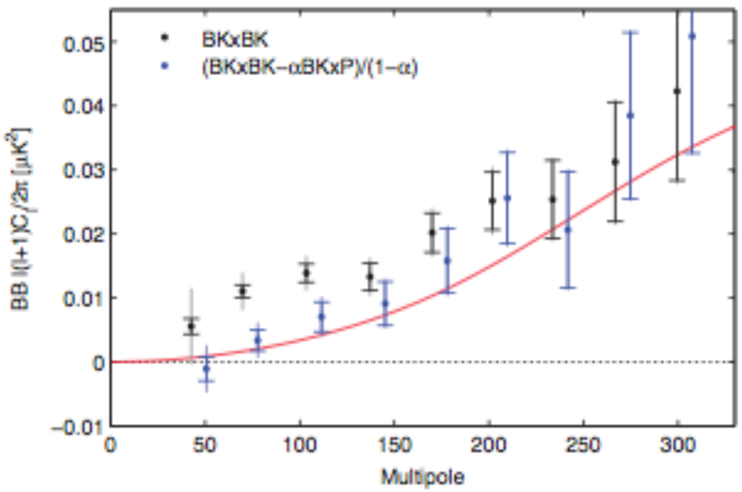
$$V(\phi) = \Lambda^4 \tanh^2\left(\frac{\phi}{\sqrt{6\alpha}M_{\rm pl}}\right)$$

$$V(\tilde{\phi}) = \frac{\Lambda^4}{4}\left(1 - e^{-2\tilde{\phi}/\sqrt{6}M_{\rm pl}}\right)^2$$

$$V(\phi) = \Lambda^4\left(1 - \frac{\phi^4}{\mu^4} + \dots\right)$$

$$V(\phi) = \Lambda^4 \left[1 + \alpha_{\rm h} \ln\left(\frac{\phi}{\mu}\right)\right]$$

Inflationary models incl. BKP joint analysis



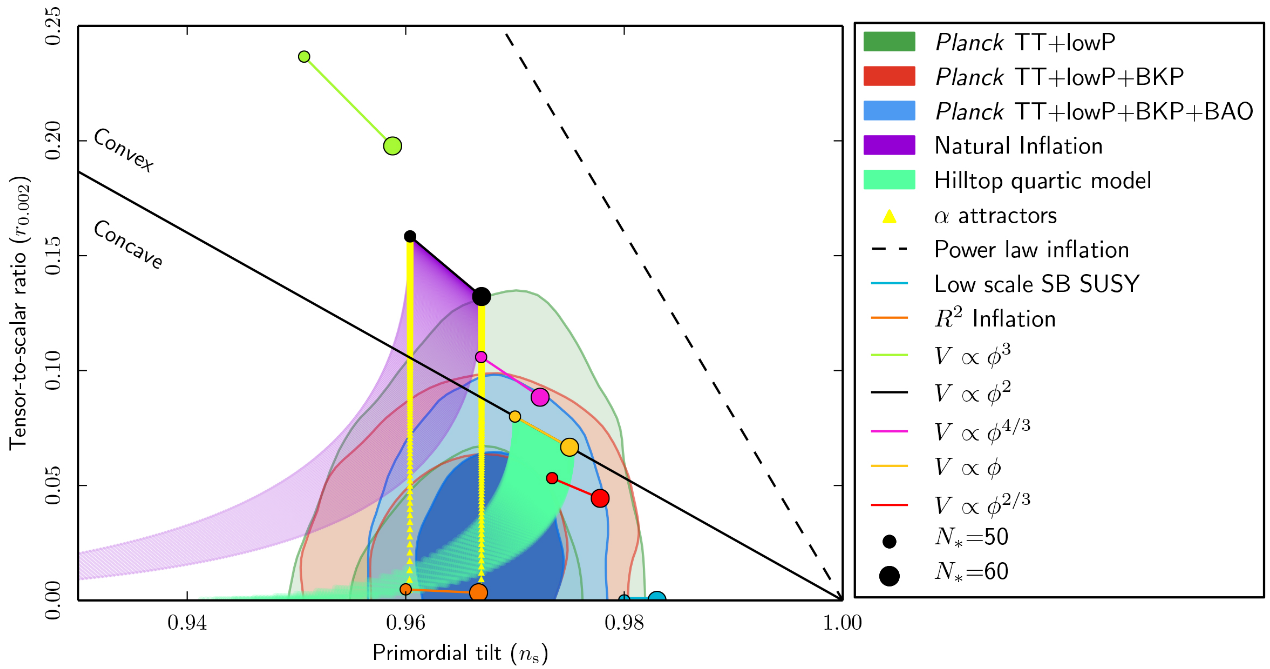
PRL 114 (2015) 101301

r < 0.12 at 95%CL

Same constraint as Planck 2013 + high-l but NOW from BB alone!

Planck TT + lowP + BKP

r < 0.08 at 95%CL



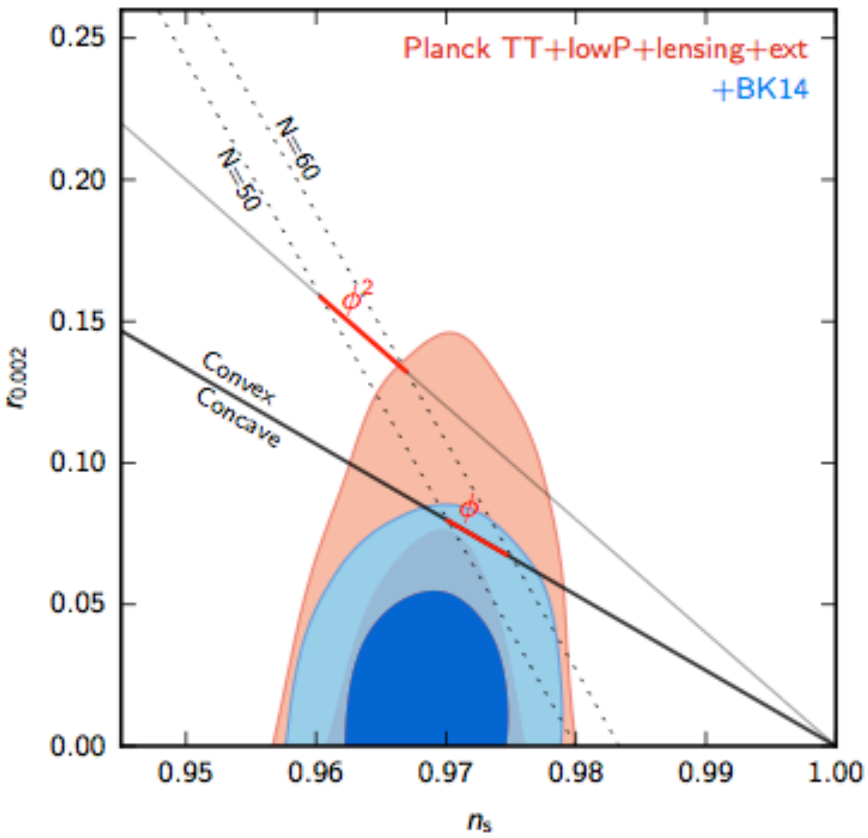
Planck 2015 results. XX. Constraints on inflation, A & A 594 (2016) A20

$$V^{1/4} \lesssim 1.8 \times 10^{16} \mathrm{GeV} \ (95\%\mathrm{CL})$$

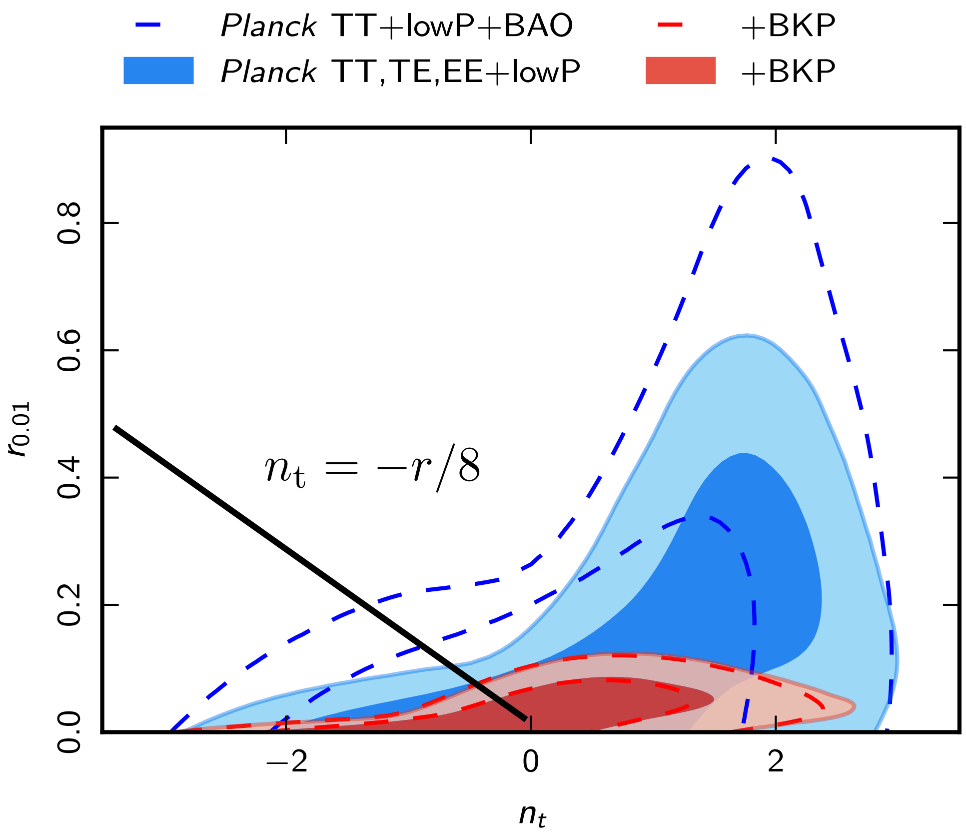
When including BKP quadratic potential and natural inflation also strongly disfavored.

The preference of concave over convex potentials is increased.

The constraint on r had been tightened by the latest release of Bicep 2/Keck Array including the Keck Array 95 GHz channel to $r_{005} < 0.07$ at 95 % CL (Ade et al., BICEP 2 and Keck Array collaborations, Phys.Rev.Lett. 116 (2016) 031302) and the previous conclusions are further strengthened.



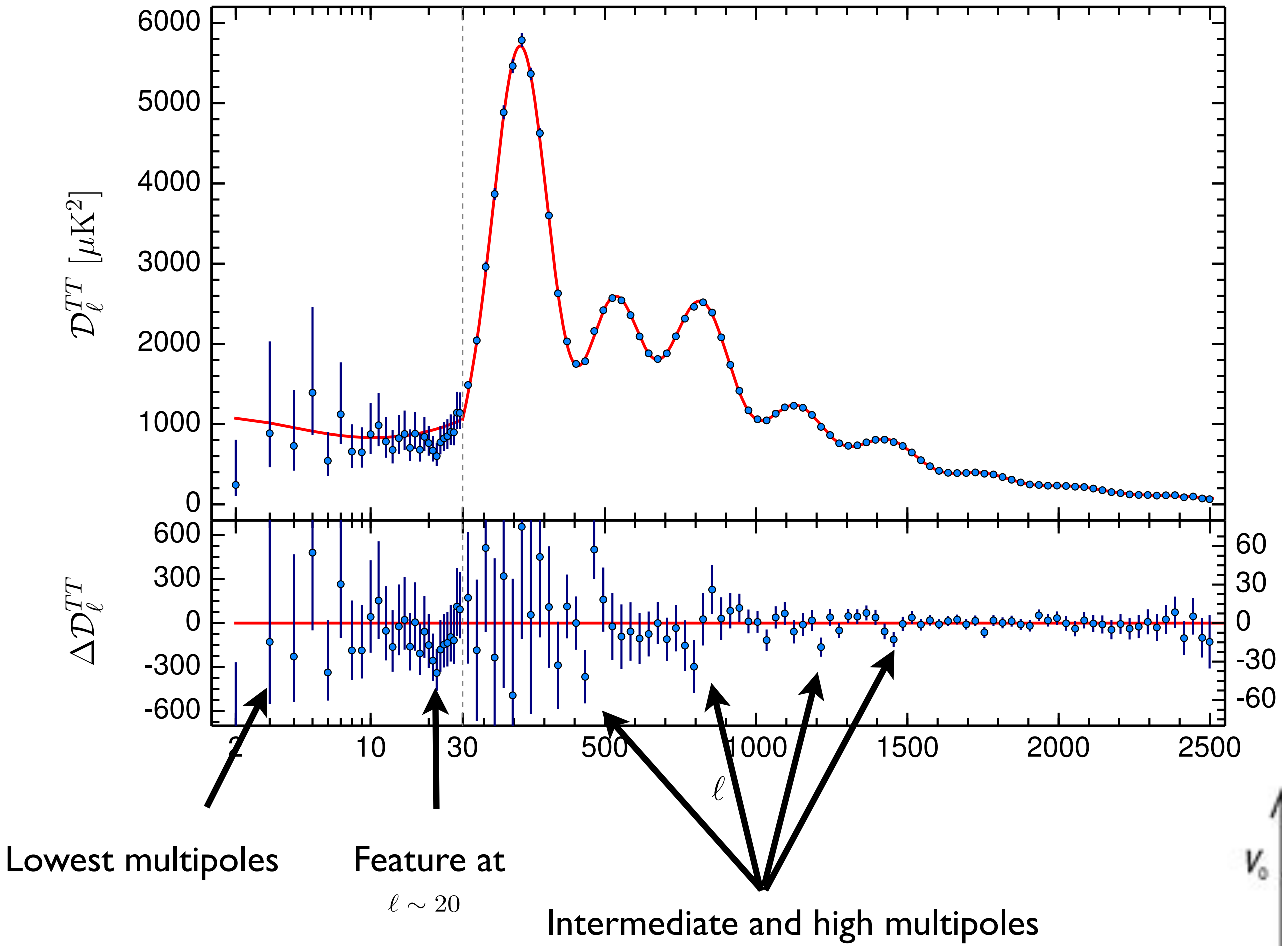
A test for the tensor consistency condition

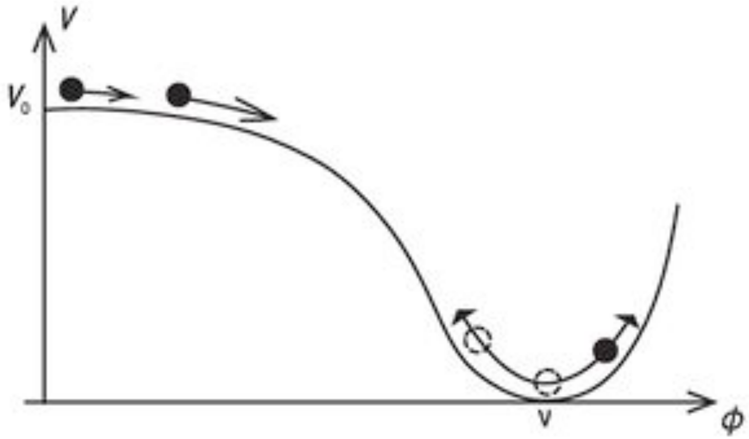


$$-0.38 < n_t < 2.6 \, (95\% \mathrm{CL})$$

Planck 2015 results. XX. Constraints on inflation, Astron. Astrophysics 594 (2016) A20

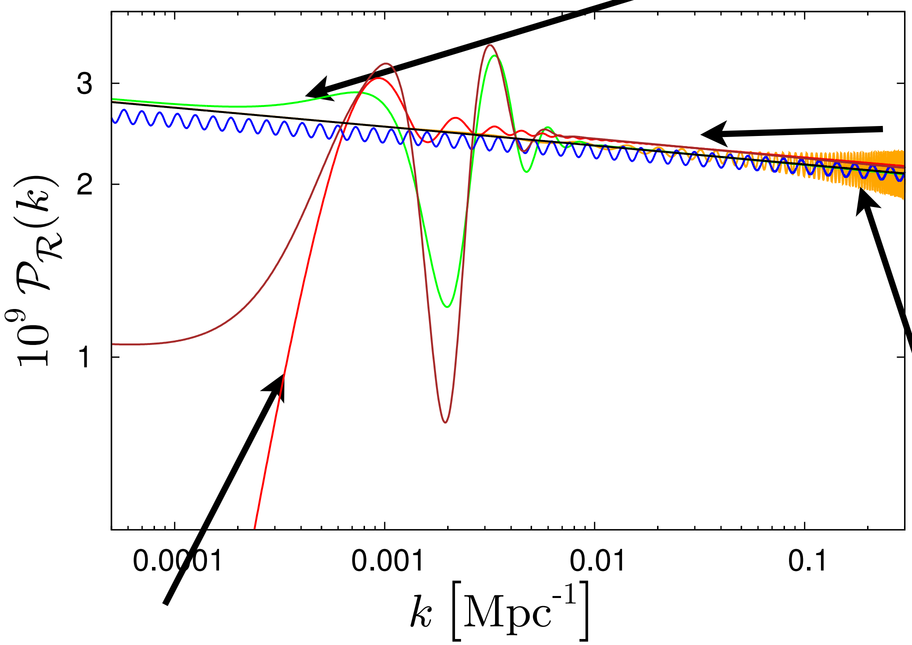
A smooth PPS?





Slow roll?

Search for parametrized features in the power spectrum



Step in the potential:

$$V(\phi) = \frac{m^2}{2}\phi^2\left[1 + c\tanh\left(\frac{\phi-\phi_c}{d}\right)\right]$$

Non vacuum initial conditions/instanton effects in axion monodromy (log wiggles)

$$V(\phi) = \mu^3\phi + \Lambda^4\cos\left(\frac{\phi}{f}\right)$$

$$\mathcal{P}_{\mathcal{R}}^{\log}(k) = \mathcal{P}_{\mathcal{R}}^{0}(k)\left[1 + \mathcal{A}_{\log}\cos\left(\omega_{\log}\ln\left(\frac{k}{k_*}\right) + \varphi_{\log}\right)\right].$$

Linear oscillations as from Boundary EFT (linear wiggles)

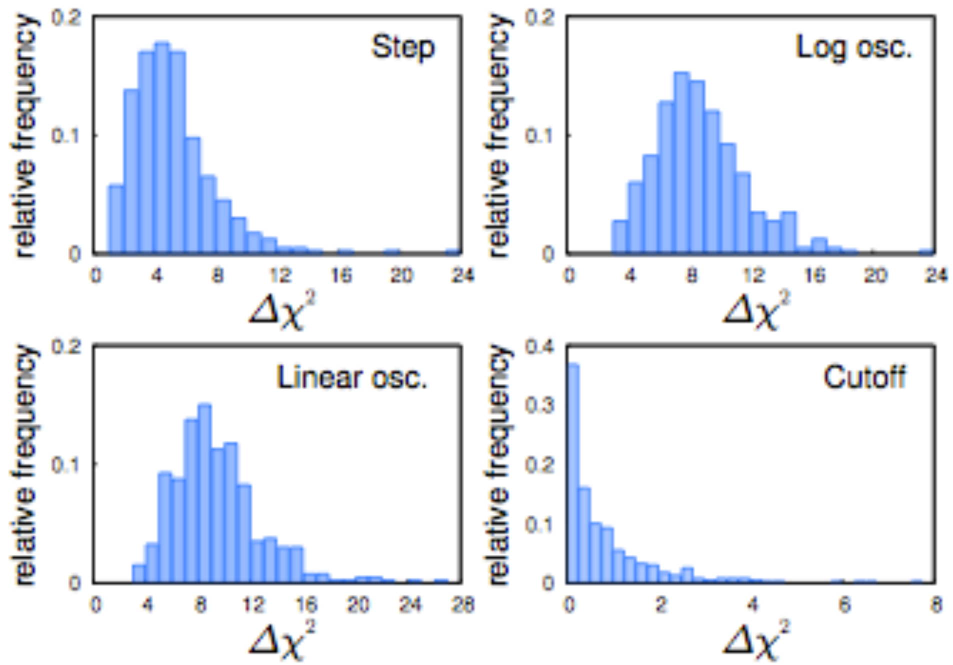
$$\mathcal{P}_{\mathcal{R}}^{\mathrm{lin}}(k) = \mathcal{P}_{\mathcal{R}}^{0}(k)\left[1 + \mathcal{A}_{\mathrm{lin}}\left(\frac{k}{k_*}\right)^{n_{\mathrm{lin}}}\cos\left(\omega_{\mathrm{lin}}\frac{k}{k_*} + \varphi_{\mathrm{lin}}\right)\right]$$

Short stage of inflation preceded by a kinetic stage

Bayesian & frequentist analysis

Model	*Planck* TT+lowP $\Delta\chi^2$	*Planck* TT+lowP $\ln B$	*Planck* TT,TE,EE+lowP $\Delta\chi^2$	*Planck* TT,TE,EE+lowP $\ln B$	PTE
Step	−8.6	−0.3	−7.3	−0.6	0.09
Log osc.	−10.6	−1.9	−10.1	−1.5	0.24
Linear osc.	−8.9	−1.9	−10.9	−1.3	0.50
Cutoff	−2.0	−0.4	−2.2	−0.6	0.12

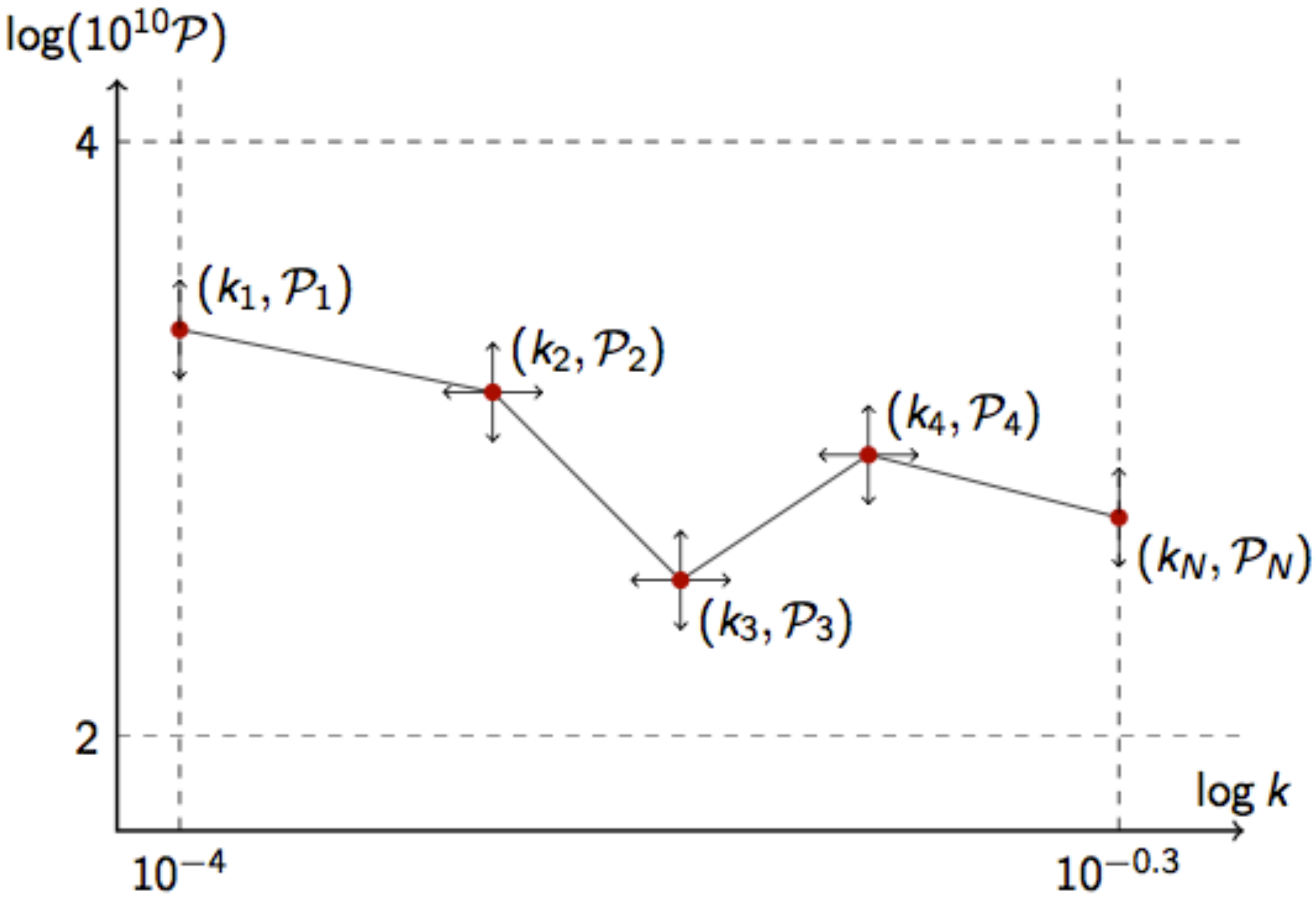
Table 13. Improvement in fit and Bayes factors with respect to power-law base ΛCDM for *Planck* TT+lowP and *Planck* TT,TE,EE+lowP data, as well as approximate probability to exceed the observed $\Delta\chi^2$ (p-value), constructed from simulated *Planck* TT+lowP data. Negative Bayes factors indicate a preference for the power-law model.



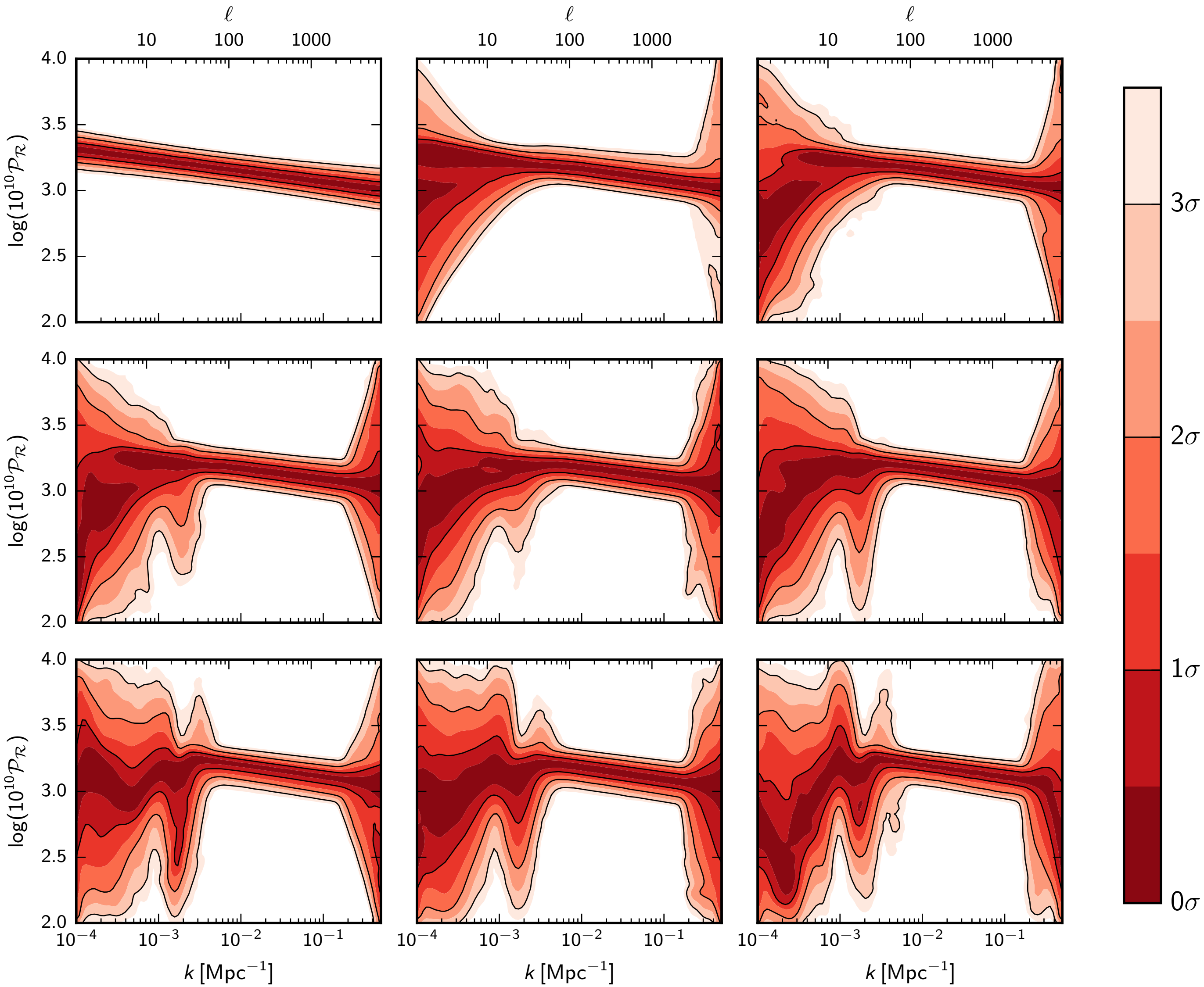
None of the models considered is statistically preferred to the baseline model
The improvement in the fit seems does is not statistically anomalous.

Planck 2015 results. XX. Constraints on inflation, Astron. Astrophysics 594 (2016) A20

Reconstruction of the primordial power spectrum

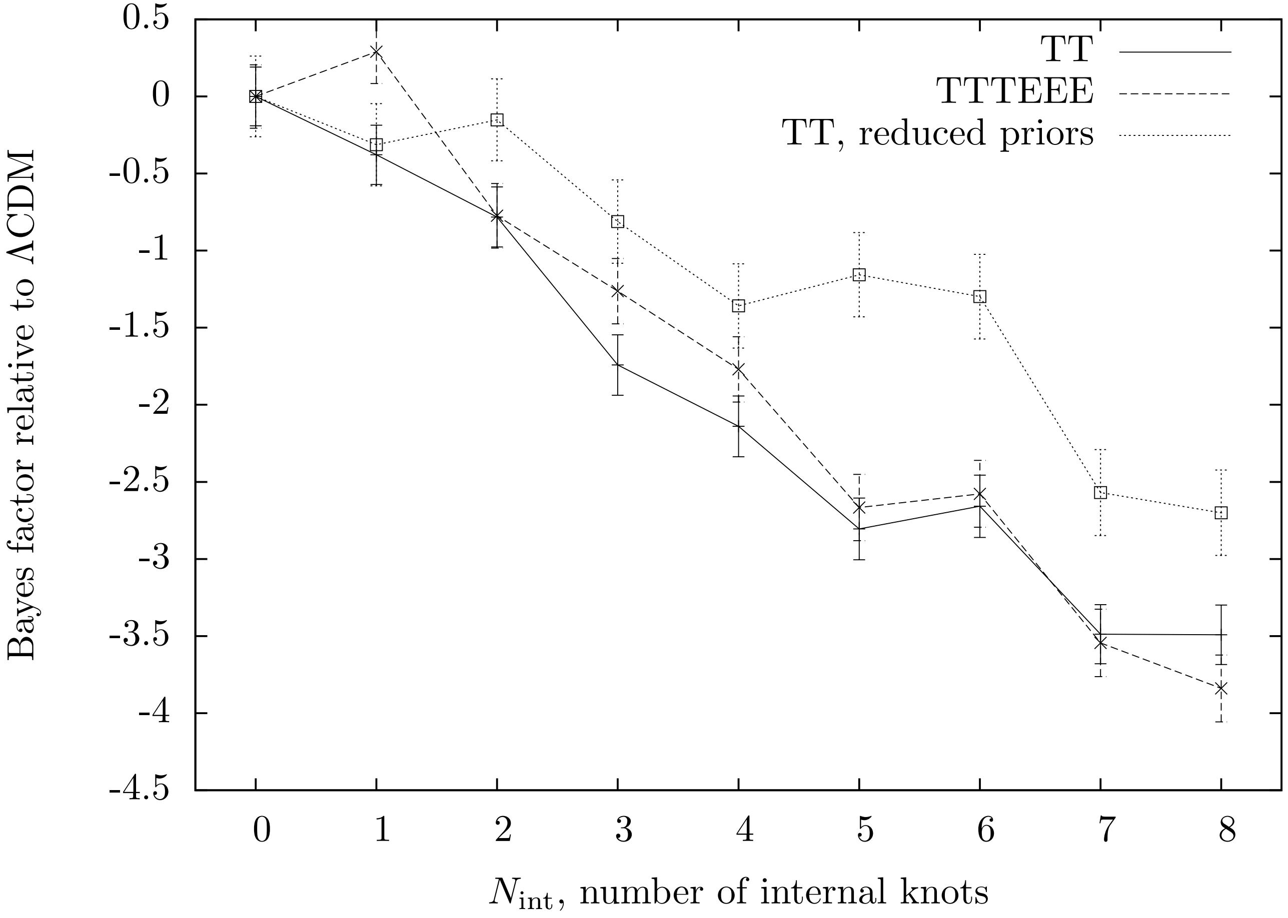


Reconstruction of the primordial power spectrum (2)



Planck 2015 results. XX. Constraints on inflation, Astron. Astrophysics 594 (2016) A20

Reconstruction of the primordial power spectrum (3)



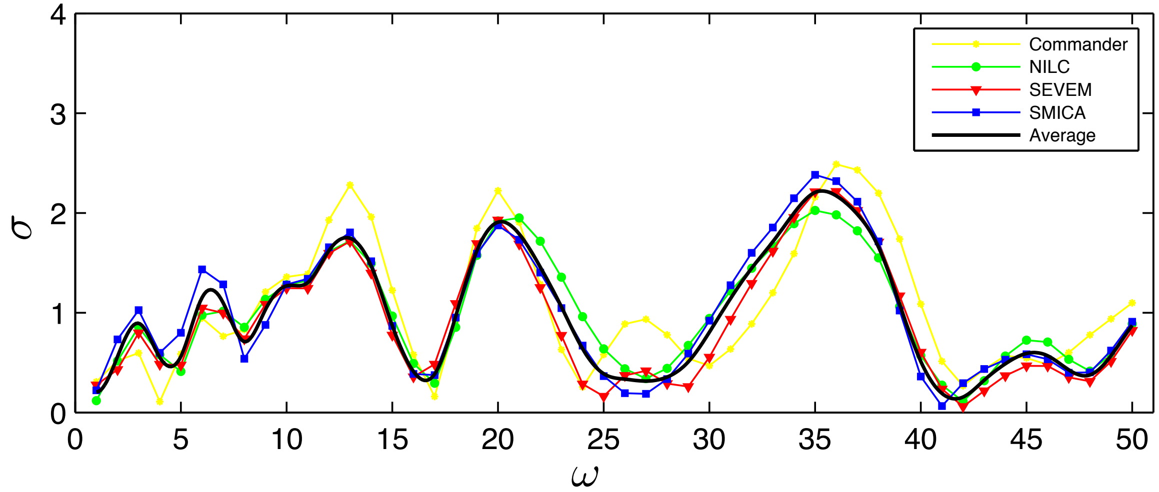
Planck 2015 results. XX. Constraints on inflation, Astron. Astrophysics 594 (2016) A20

Bispectrum

$$V(\phi) = \frac{1}{2} m^2 \phi^2 \left[1 + c \sin\left(\frac{\phi}{\Lambda}\right)\right]$$

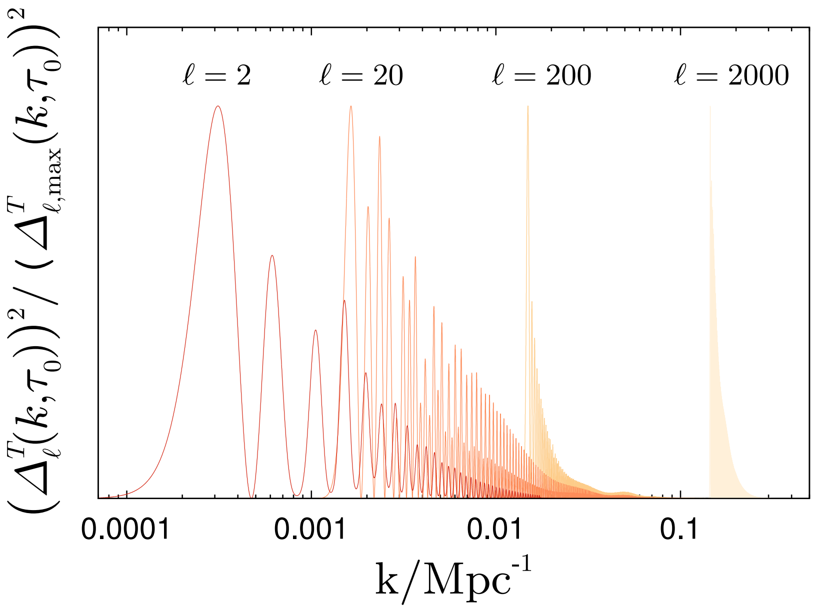
$$B^{\rm feat}(k_1, k_2, k_3) = \frac{6A^2 f_{\rm NL}^{\rm feat}}{(k_1 k_2 k_3)^2} \sin\left[\omega(k_1 + k_2 + k_3) + \phi\right]$$

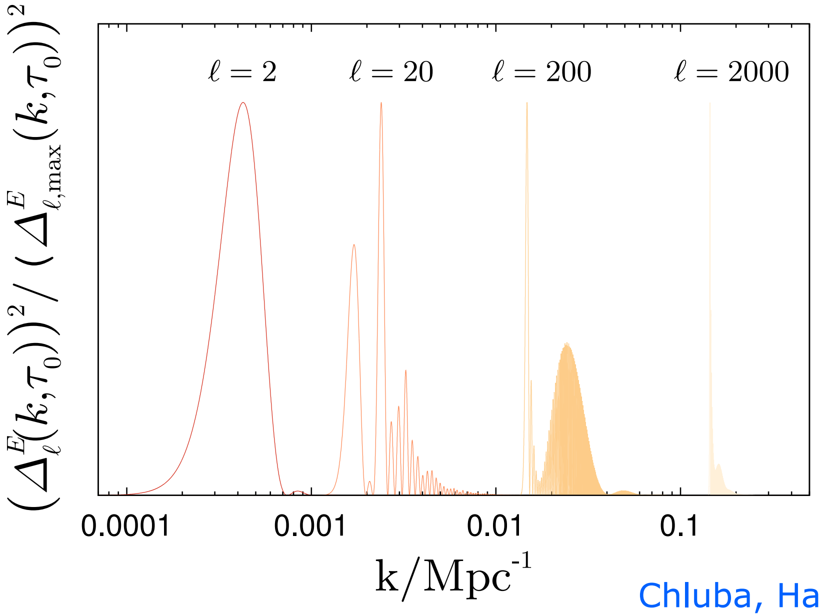
Chen, Easther, Lim, JCAP 0804 (2008)



Planck 2015 results. XVII. Constraints on primordial non-Gaussianity, Astron. Astrophysics 594 (2016) A17, Fig. 24

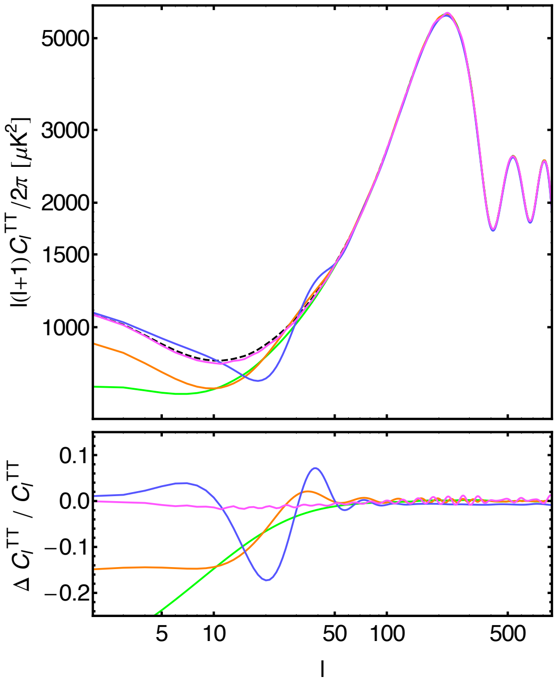
CMB Polarization

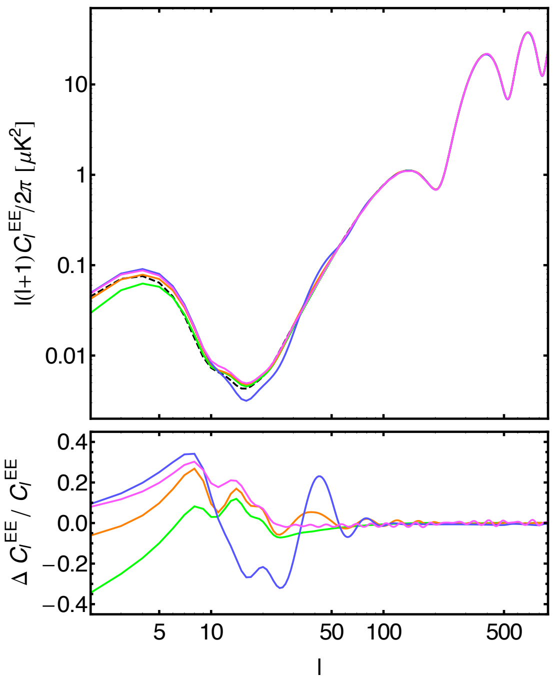


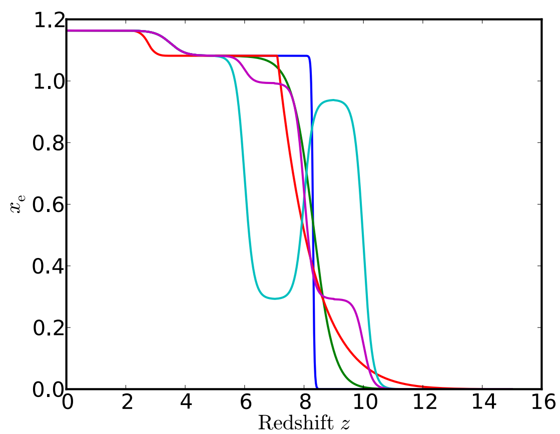


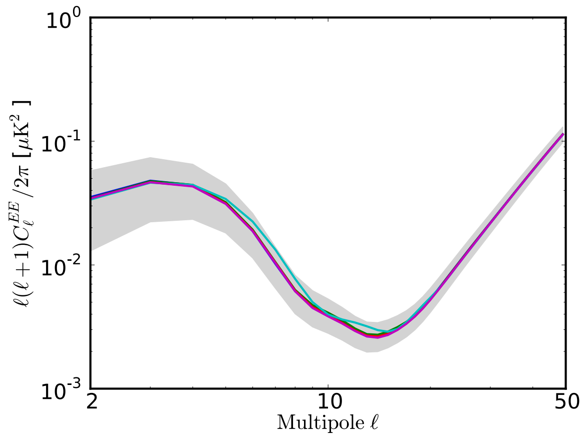
Chluba, Hamann, Patil, IJMPD 24 (2015) 1530023

CMB Polarization (2)



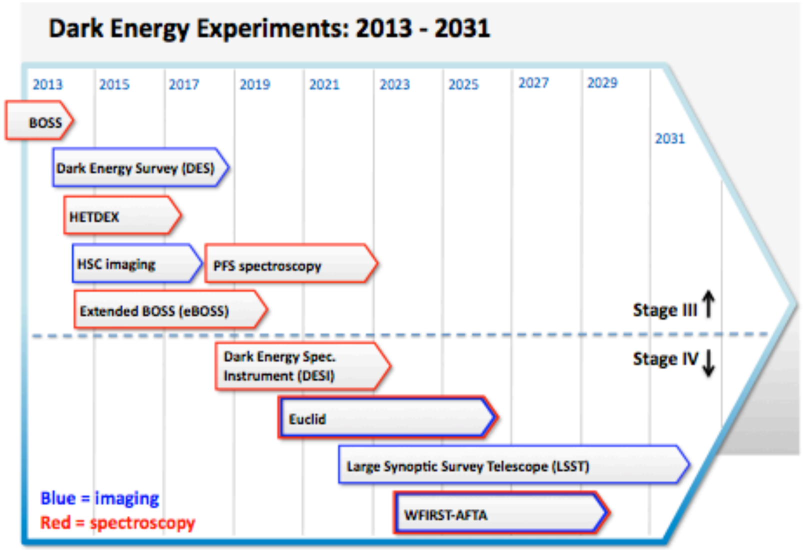




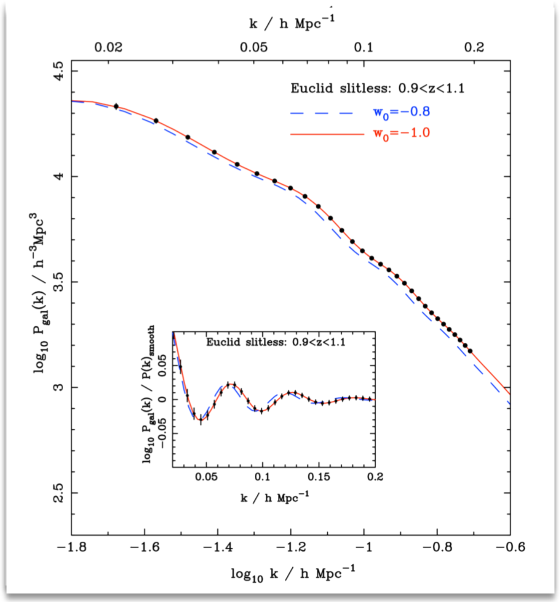


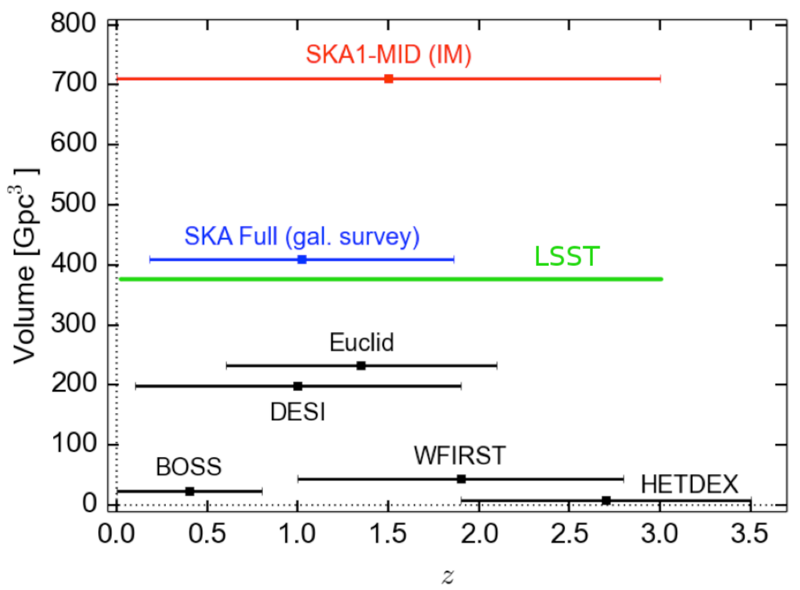
Planck intermediate results XLVII. Planck constraints on reionization history

Future Large Scale Structure Surveys



Dodelson et al., arXiv:1309.5386 (2013)



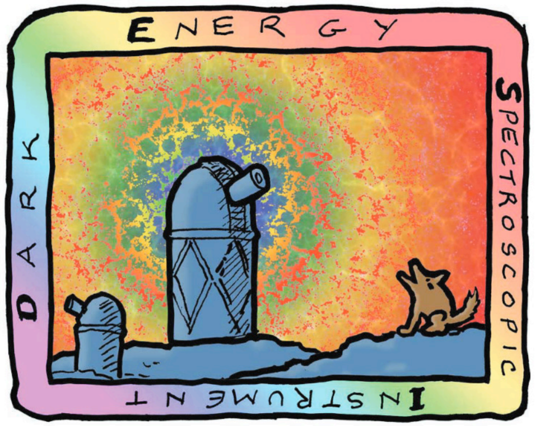


Probing primordial features with future galaxy surveys

Ballardini, FF, Fedeli, Moscardini, JCAP 1610 (2016) 041

We consider four current best-fits for models with parametrized features presented in Planck 2015. XX. Constraints on Inflation.

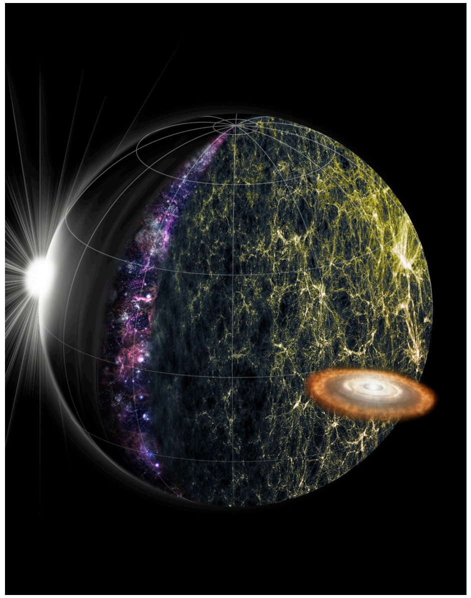
We use a combined Fisher approach for CMB and the expected clustering power spectrum (conservatively to linear scales, i.e. $k < 0.1$ Mpc^{-1}) from three future galaxy surveys as DESI, Euclid (spectroscopic survey) and SphereX to forecast the uncertainties on feature parameters and on the cosmological parameters.



http://desi.lbl.gov/

http://sci.esa.int/euclid/

Euclid consortium



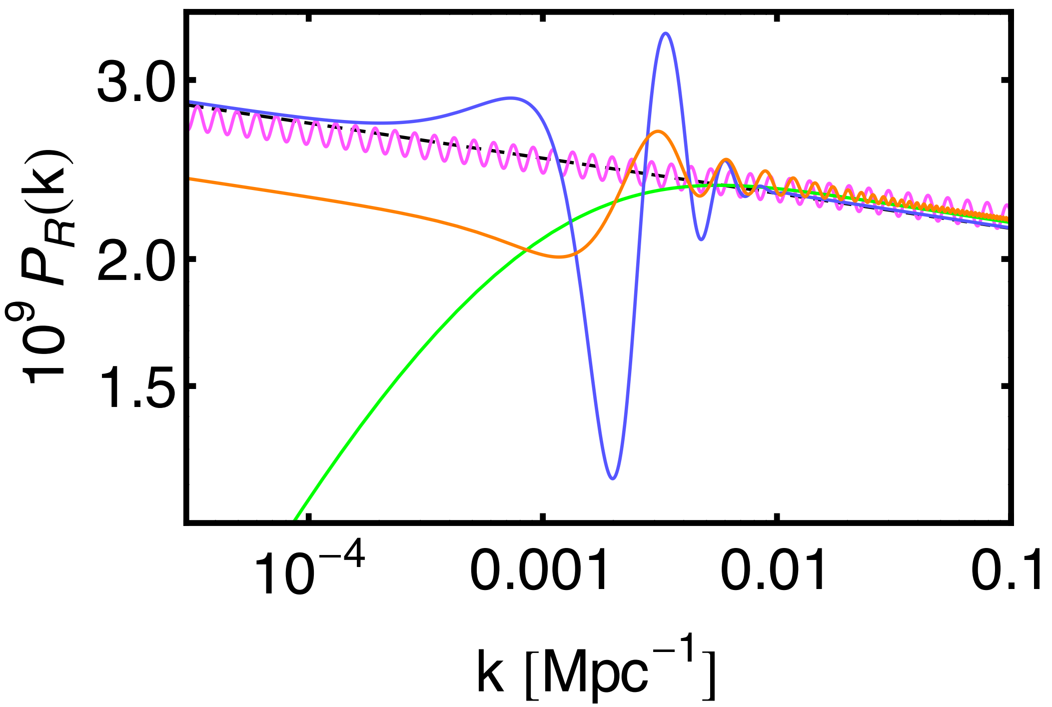
http://spherex.caltech.edu/

Models

Exponential cut-off

$$\mathcal{P}_{\mathcal{R}}(k) = \mathcal{P}_{\mathcal{R},0}(k)\left\{1-\exp\left[-\left(\frac{k}{k_c}\right)^{\lambda_c}\right]\right\}$$

(Contaldi, Peloso, Kofman & Linde, 2003)



Discontinuity in the first derivative of the potential

$$V(\phi) = \begin{cases} V_0 + A_+(\phi-\phi_0)\,, & \phi \gg \phi_0 \\ V_0 + A_-(\phi-\phi_0)\,, & \phi \ll \phi_0 \end{cases} .$$

Analytic approximation for the power spectrum (Starobinsky, 1993).

Step in the potential

$$V(\phi) = \frac{m^2}{2}\phi^2\left[1 + c\tanh\left(\frac{\phi-\phi_c}{d}\right)\right]$$

(Adams, Cresswell & Easther, 2003)

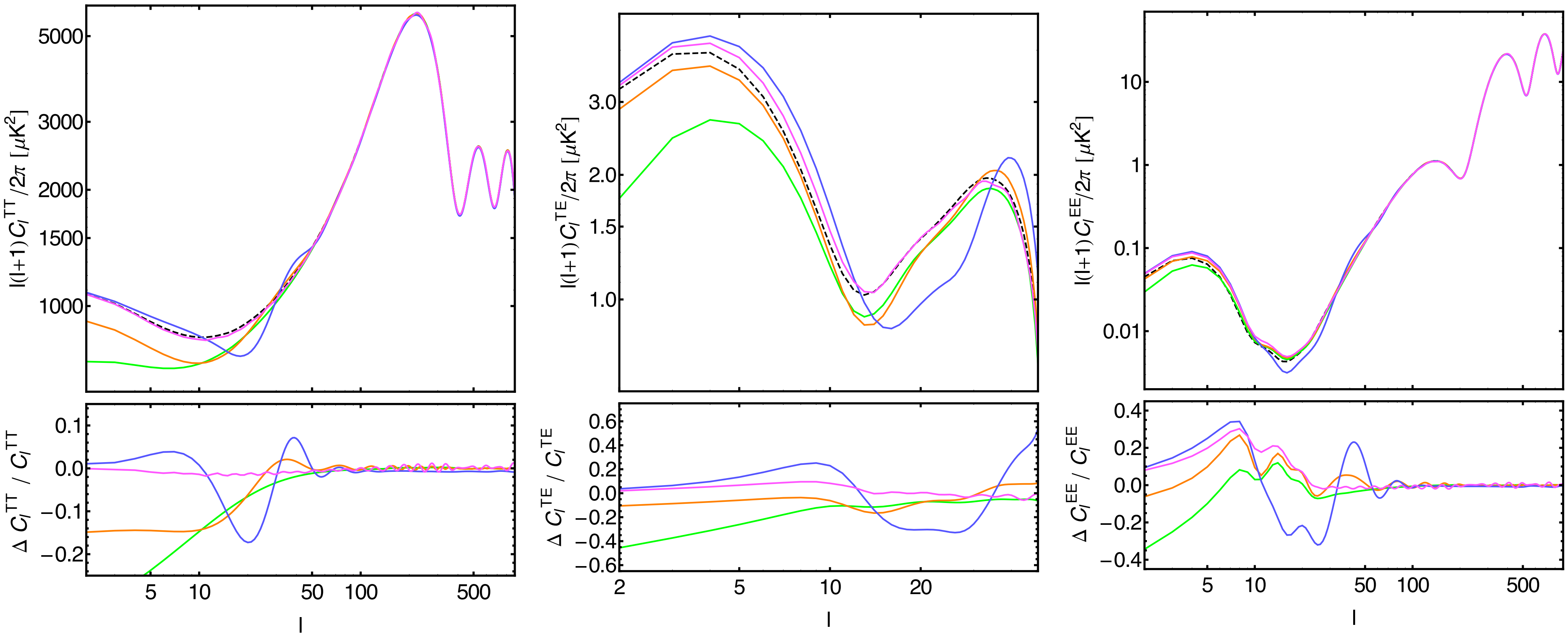
Second-order analytic approximation for the power spectrum (Miranda & Hu, 2014)

Logarithmic wiggles

$$\mathcal{P}_{\mathcal{R}}^{\log}(k) = \mathcal{P}_{\mathcal{R}}^{0}(k)\left\{1 + \mathcal{A}_{\log}\cos\left[\omega_{\log}\ln\left(\frac{k}{k_*}\right) + \varphi_{\log}\right]\right\}$$

(Chen, Easther & Lim, 2008; Flauger, McAllister, Pajer, Westphal, Xu, 2009)

Imprints in the CMB

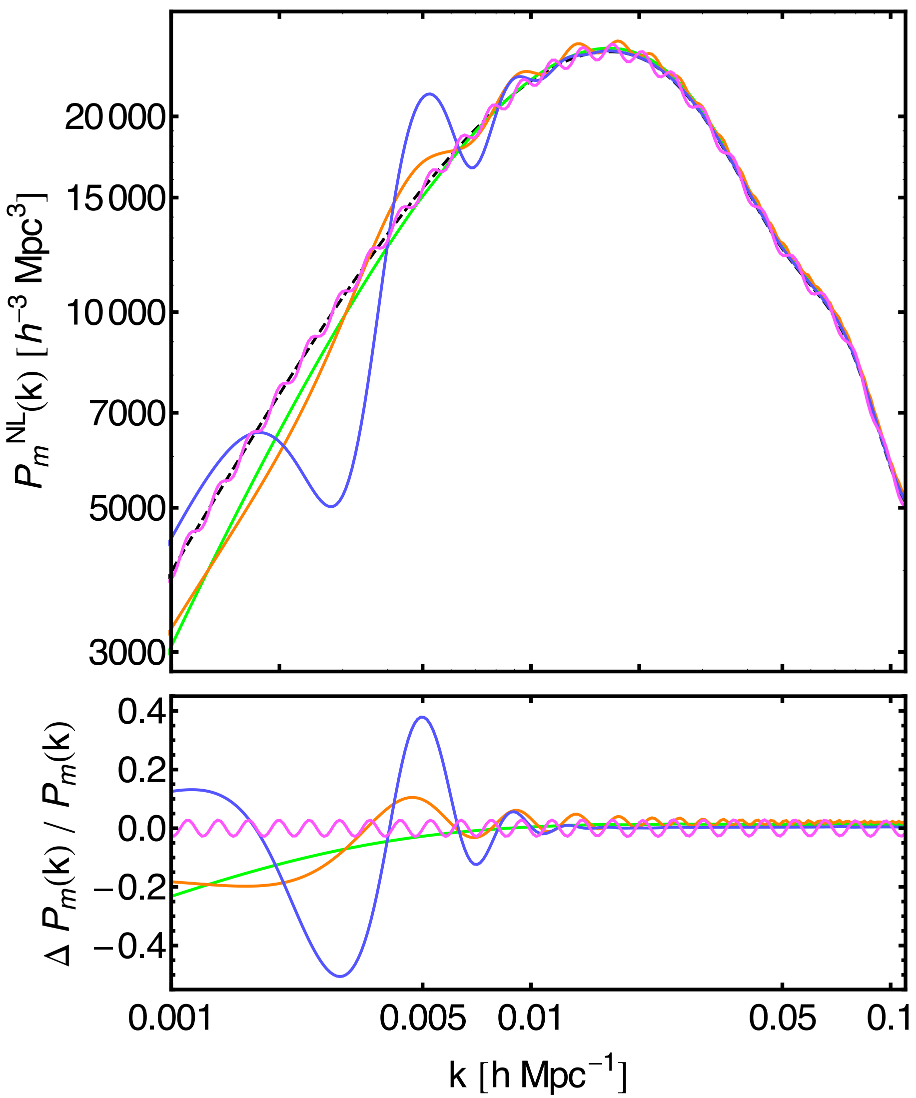


	$-2\Delta \ln \mathcal{L}_{\rm max}$
Exponential cut-off	-3.4
Discontinuity in V'	-4.5
Step in the potential	-8.6
Logarithmic wiggles	-10.6

Planck TT + lowP

Planck 2015 results. XX. Constraints on inflation

Imprints in the Matter Power Spectrum



Baseline

Exponential cut-off

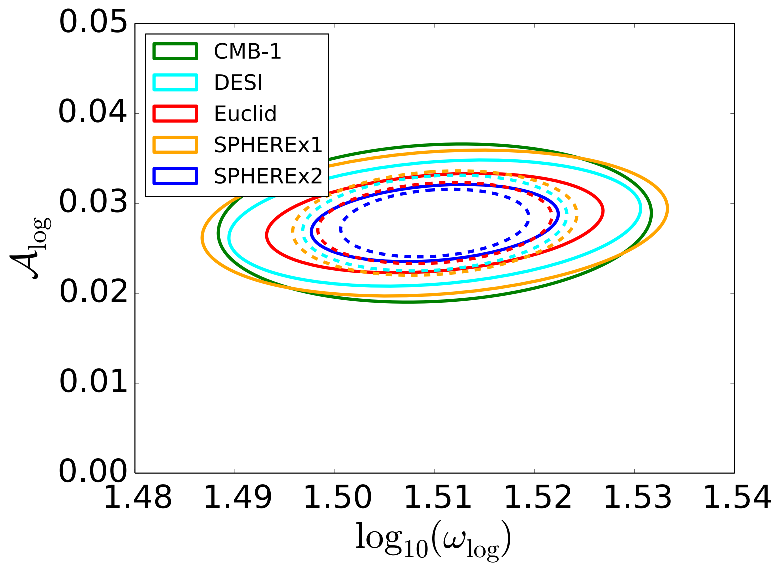
Discontinuity in the first derivative of the potential

Step in the potential

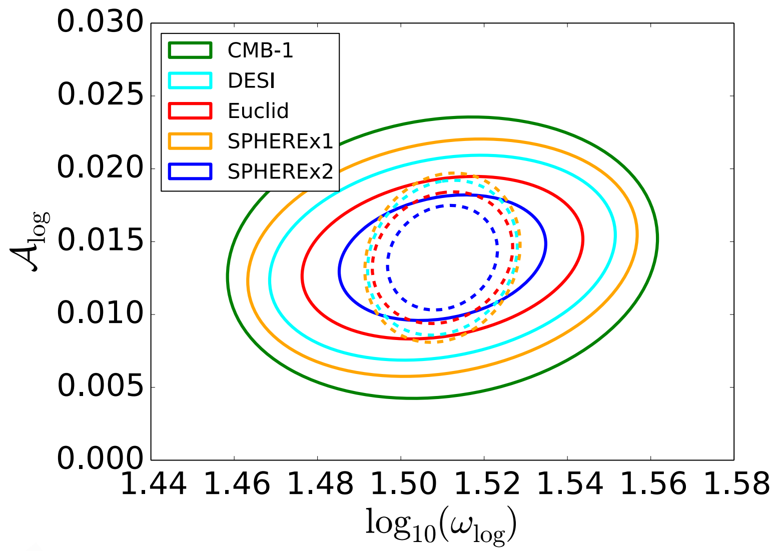
Logarithmic wiggles

Few analysis pre-Planck (Huang, Verde and Vernizzi, 2009; Gibelyou, Huterer & Fang, 2010) and post-Bicep 2 (Hazra, Shafieloo, Smoot and Starobinsky, 2014) with different parameters producing very large features, which would be ruled out by Planck 2015 data. Analysis more similar to Chen, Dvorkin, Huang, Namjoo, Verde, JCAP 1611 (2016) 014.

Logarithmic wiggles



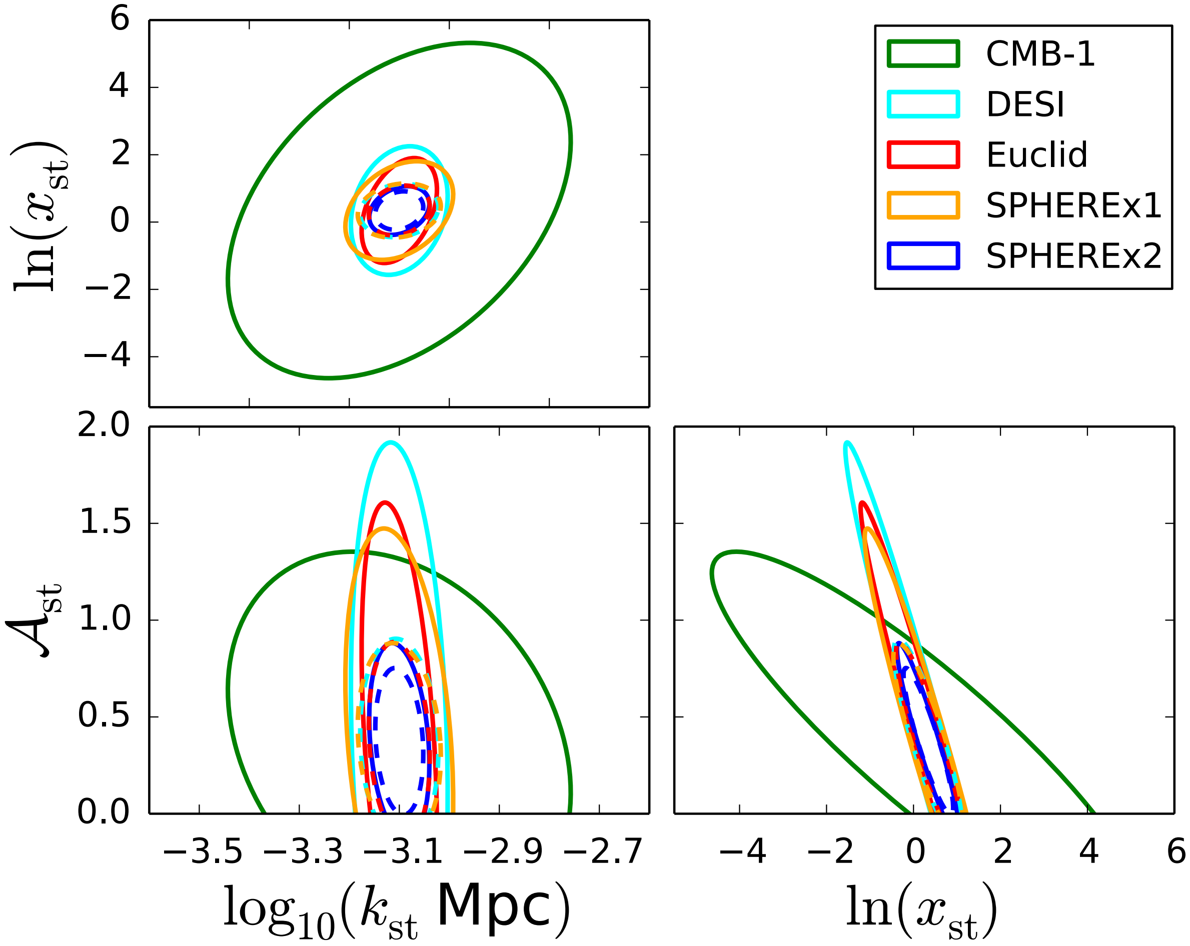
Constraints from LSS surveys alone can be tighter than those from CMB for these type of features appearing on all scales (global features).



Combined constraints from CMB and LSS could detect wiggles with amplitude smaller than the current Planck best-fits.

Dashed: combined with CMB

Step in the potential



Dashed: combined with CMB

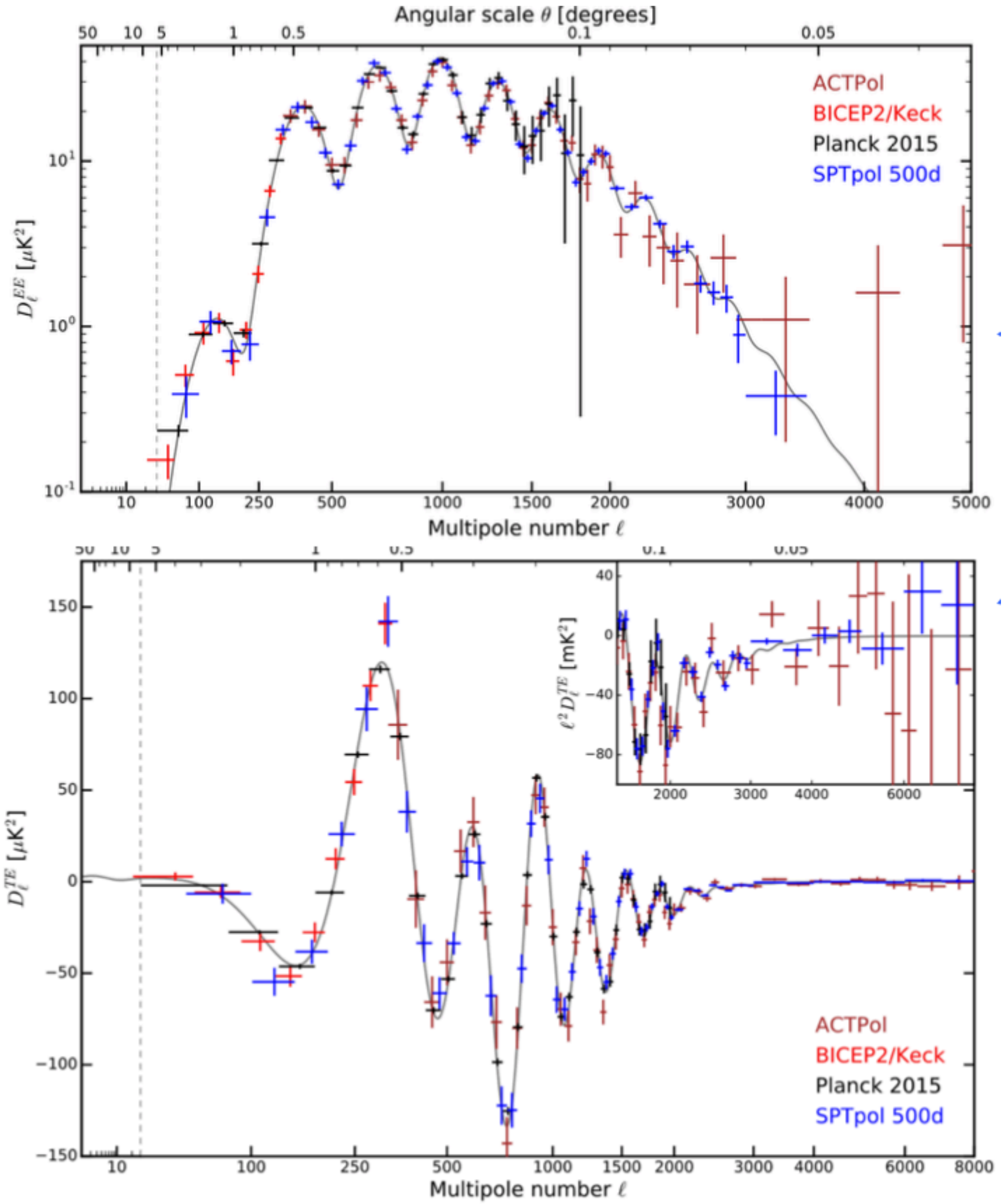
Future galaxy surveys will be of key importance also for this type of features on large scales, i.e. k approximately few in 10^{-3} Mpc^{-1}. However, these large scales are at the boundary of the redshift volume probed by the surveys considered.

Other future photometric or radio surveys will probe even larger volumes and will be more relevant for these type of features (Ballardini et al. 2017).

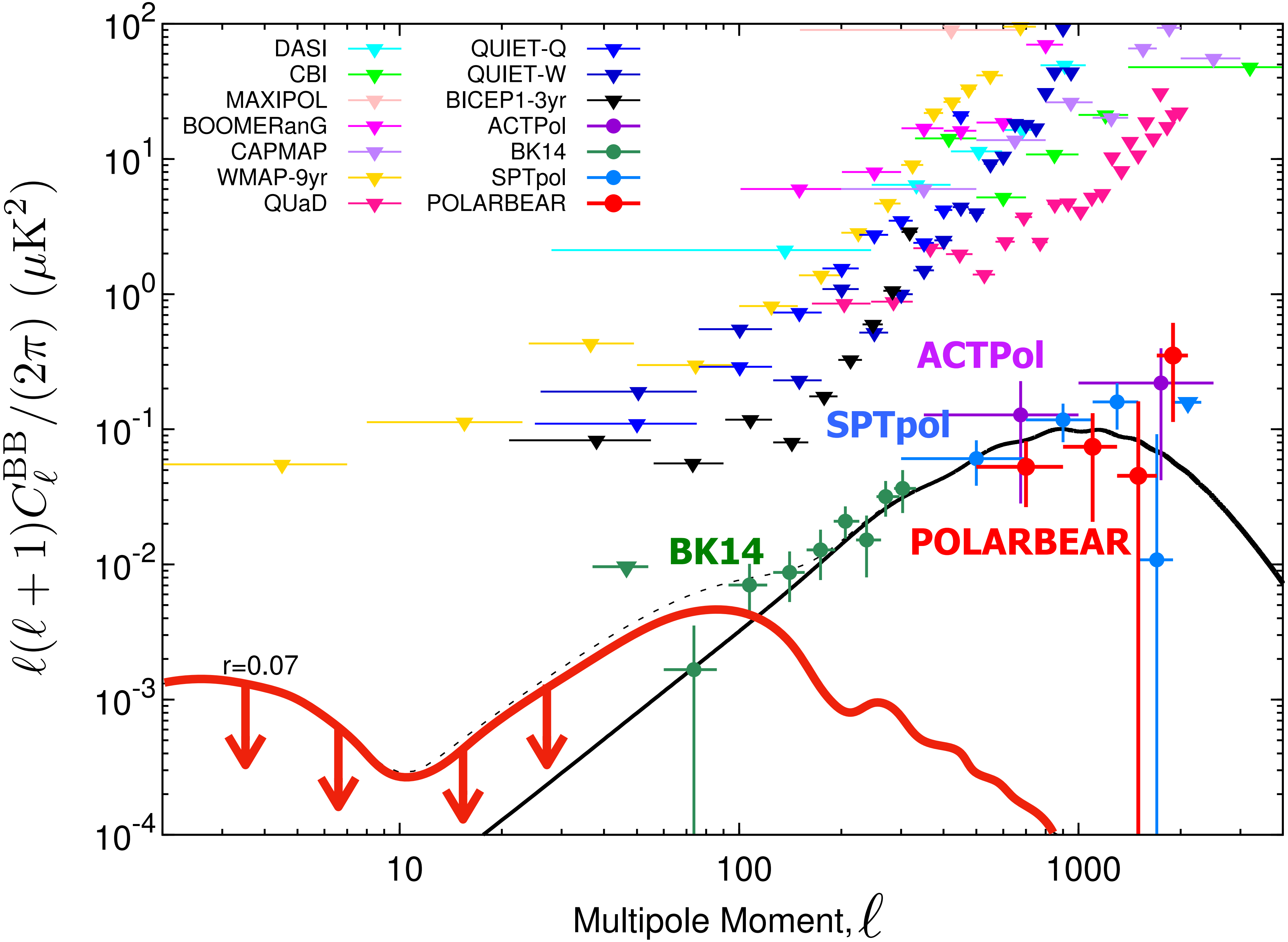
A_{st} corresponds to the amplitude of the feature
k_{st} corresponds to the scale
x_{st} is connected to the width of the feature

Ongoing and future CMB experiments

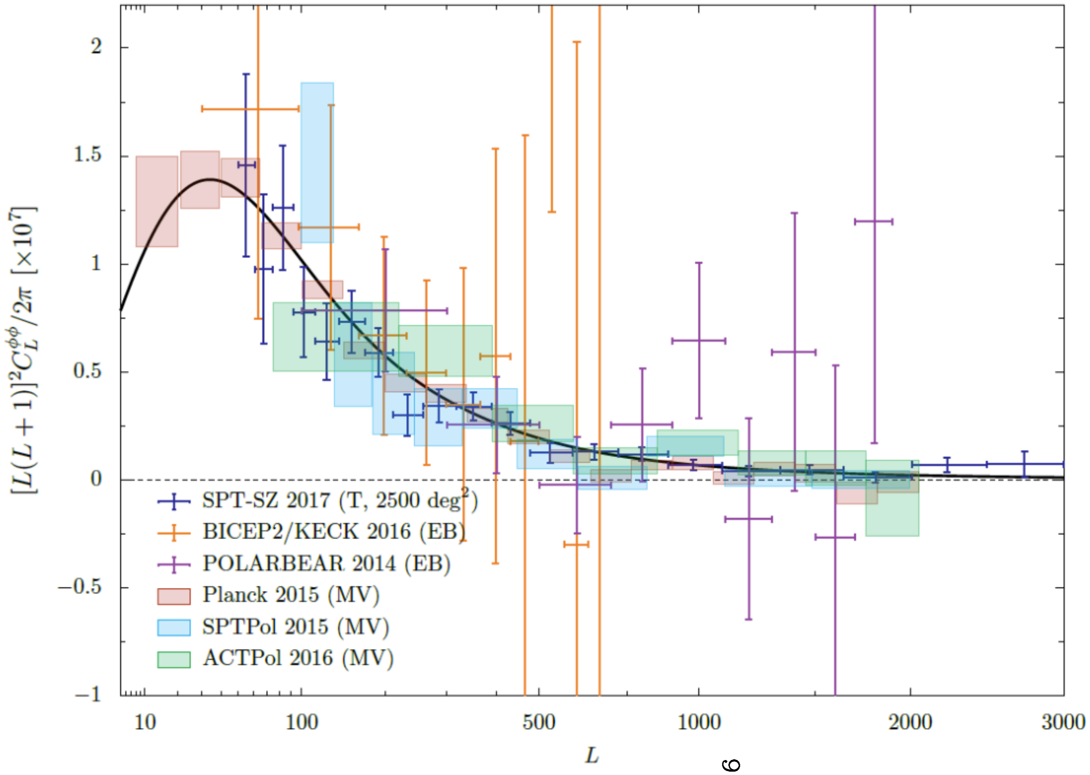
- Ground: BICEP 3, QUIJOTE, Polarbear/Simons Array, ACTPol, SPT-3G, ABS, CLASS, Simons Observatory, S4
- Balloon: EBEX, Spider, LSPE
- Space: LiteBird (phase A), Pixie, CORE

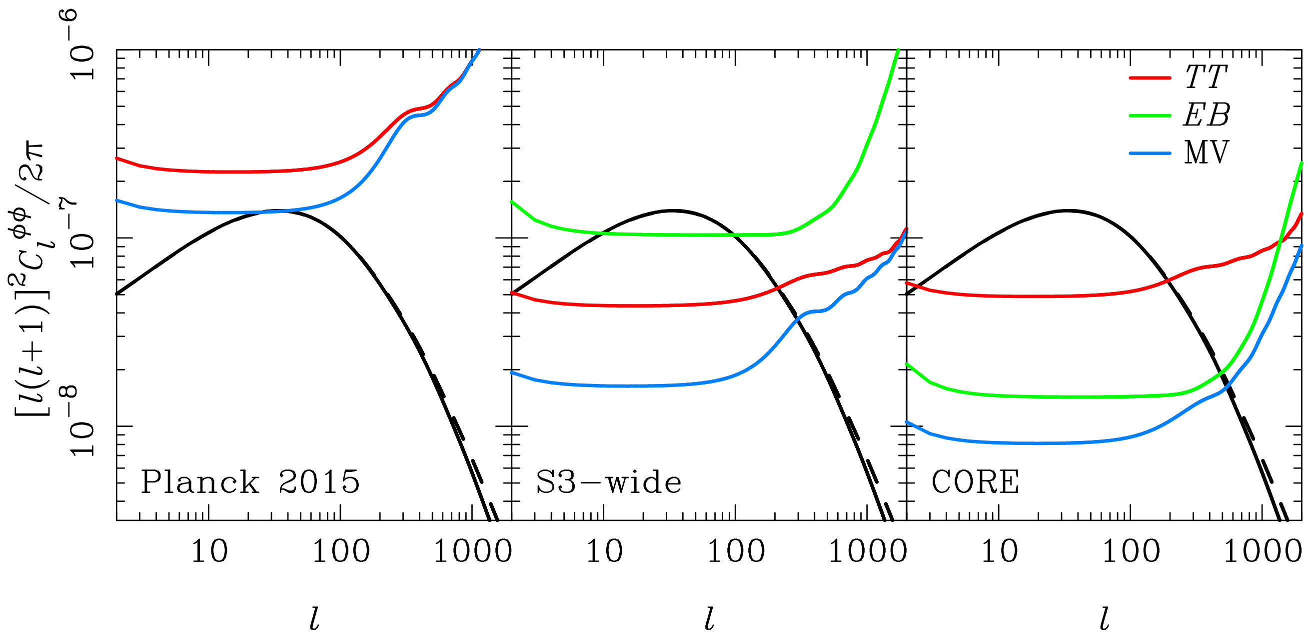


SPTpol Collaboration: Henning et al. , arXiv:1707.09353



Courtesy J. Errard





Exploring Cosmic Origins with CORE: gravitational lensing of the CMB, A. Challinor et al., JCAP (2017)

LambdaCDM with future CMB experiments

Table 8-1. *Forecasted LCDM parameters*

	fiducial	*Planck*	S4+*Planck*	Improvement factor
$100\Omega_b h^2$	2.22	±0.017	±0.003	5.7
$\Omega_c h^2$	0.120	±0.0014	±0.0006	2.3
H_0	69.0	±0.7	±0.24	2.9
$10^9 A_s$	2.2	±0.039	±0.021	1.9
n_s	0.966	±0.004	±0.002	2
τ	0.06	±0.01	±0.006	1.7

CMB-S4
Next Generation CMB Experiment

CMB-S4 Science Book, First Edition, CMB-S4 Collaboration, K. N. Abazajian et al. arXiv:1610.02743

Parameter	Results from *Planck* 2015 release	CORE expected uncertainties	Improvement factor
ΛCDM model			
A_s	$A_s = (2.130 \pm 0.053) \times 10^{-9}$ (68 % CL) [4]	$\sigma(A_s) = 0.0073$	7.3
n_s	$n_s = 0.9653 \pm 0.0048$ (68 % CL) [4]	$\sigma(n_s) = 0.0014$	3.4
$\Omega_b h^2$	$\Omega_b h^2 = 0.02226 \pm 0.00016$ (68 % CL) [4]	$\sigma(\Omega_b h^2) = 0.000037$	4.3
$\Omega_c h^2$	$\Omega_c h^2 = 0.1193 \pm 0.0014$ (68 % CL) [4]	$\sigma(\Omega_c h^2) = 0.00026$	5.4
τ	$\tau = 0.063 \pm 0.014$ (68 % CL) [4]	$\sigma(\tau) = 0.002$	7.0
H_0 [km/s/Mpc]	$H_0 = 67.51 \pm 0.64$ (68 % CL) [4]	$\sigma(H_0) = 0.11$	5.8

Exploring Cosmic Origins with CORE: Inflation, F. Finelli et al., arXiv:1612.08270 , in press on JCAP (2017)

The scalar spectral index and its scale dependence

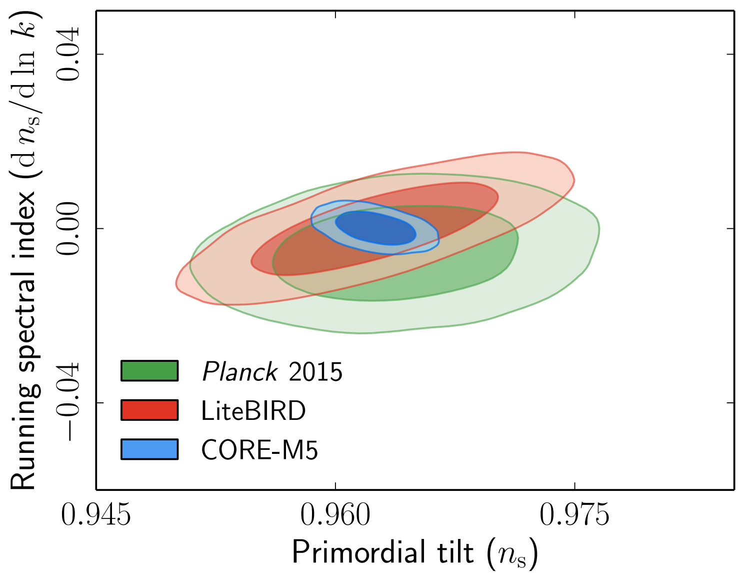
In the LambdaCDM model:

$$\sigma(n_\mathrm{s}) = 0.0014 \quad \text{(CORE TEP)} \; n_\mathrm{s} = 0.9653 \pm 0.0048 \quad (68\,\%\ \text{CL, Planck 2015 TEP})$$

$$\mathcal{P}_\mathcal{R}(k) = A_\mathrm{s}\left(\frac{k}{k_*}\right)^{n_\mathrm{s}-1+\frac{1}{2}\frac{\mathrm{d}n_\mathrm{s}}{\mathrm{d}\ln k}\ln(k/k_*)}$$

$$\sigma(\mathrm{d}n_\mathrm{s}/\mathrm{d}\ln k) = 0.0023 \quad \text{(CORE TEP)}$$

$$\mathrm{d}n_\mathrm{s}/\mathrm{d}\ln k = -0.0023 \pm 0.0067 \quad (68\,\%\ \text{CL, Planck 2015 TEP})$$



Exploring Cosmic Origins with CORE: Inflation

Sensitivity to the running of the scalar spectral index will improve approximatively by a factor 3. This uncertainty is still larger than the value of the running in the standard slow-roll inflationary models which are currently favoured, $\mathrm{d}n_\mathrm{s}/\mathrm{d}\ln k \sim (n_\mathrm{s}-1)^2/2 \sim 0.0008$. The typical values predicted by slow-roll will be reached by CORE in combination with future galaxy surveys (see Munoz et al. for a similar study applied to S4).

The scalar spectral index and its scale dependence (2)

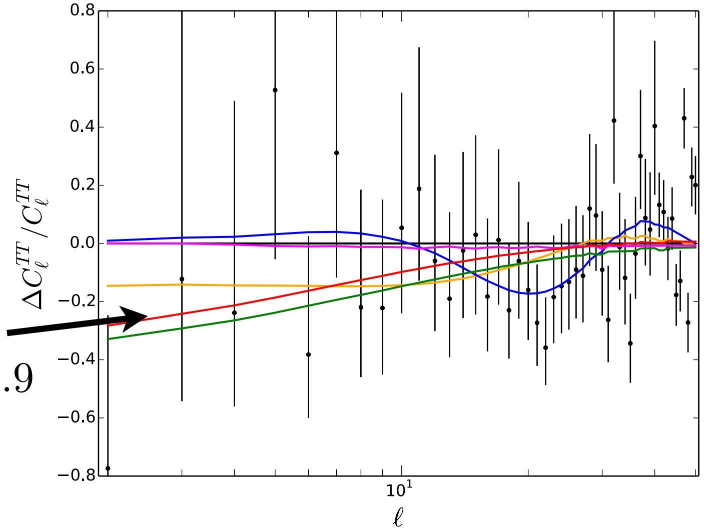
$$\mathcal{P}_{\mathcal{R}}(k) = A_{\rm s}\left(\frac{k}{k_*}\right)^{n_{\rm s}-1+\frac{1}{2}\frac{{\rm d}n_{\rm s}}{{\rm d}\ln k}\ln(k/k_*)+\frac{1}{6}\frac{{\rm d}^2 n_{\rm s}}{{\rm d}\ln k^2}\ln(k/k_*)^2}$$

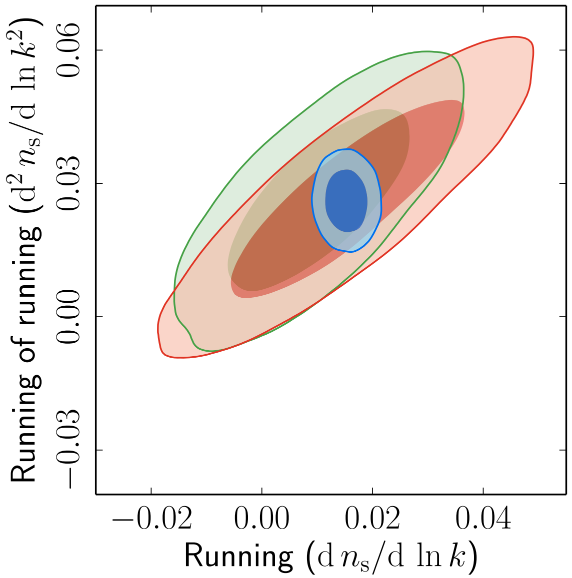
$$\sigma({\rm d}^2 n_{\rm s}/{\rm d}\ln k^2) = 0.0046 \quad \text{(CORE TEP)} \qquad {\rm d}^2 n_{\rm s}/{\rm d}\ln k^2 = 0.025 \pm 0.013 \,(68\%\text{CL, Planck 2015 TE})$$

The interest in the so-called running of running the spectral index has grown with the Planck release since a combination of running and running of running can fit the low amplitude at low multipoles.

Exploring Cosmic Origins: Inflation

$\Delta\chi^2 \simeq -4.9$





Exponential cut-off
Discontinuity in the first derivative of the potential
Step in the potential
Logarithmic wiggles
Running of the running

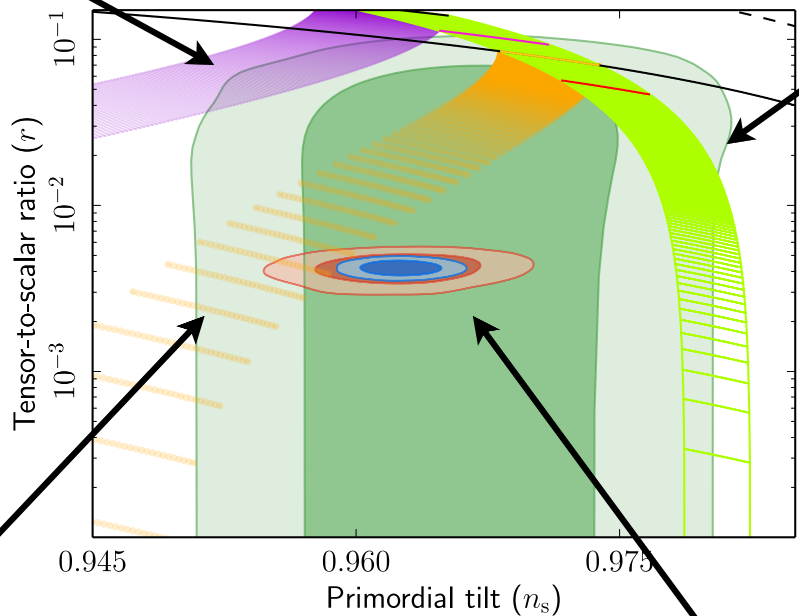
$${\rm d}n_{\rm s}/{\rm d}\ln k = 0.0153 \pm 0.0025 \,(68\%\text{CL, CORE TEP})$$

$${\rm d}^2 n_{\rm s}/{\rm d}\ln k^2 = 0.0261 \pm 0.0045 \,(68\%\text{CL, CORE TEP})$$

Inflationary Models with CORE

$$V(\phi) = \Lambda^4 \left[1 + \cos\left(\frac{\phi}{f}\right)\right]$$

$$V(\phi) = \Lambda^{4-p} \frac{\phi^p}{M_{\rm pl}^p}$$



Planck 2015 + BKP

LiteBIRD

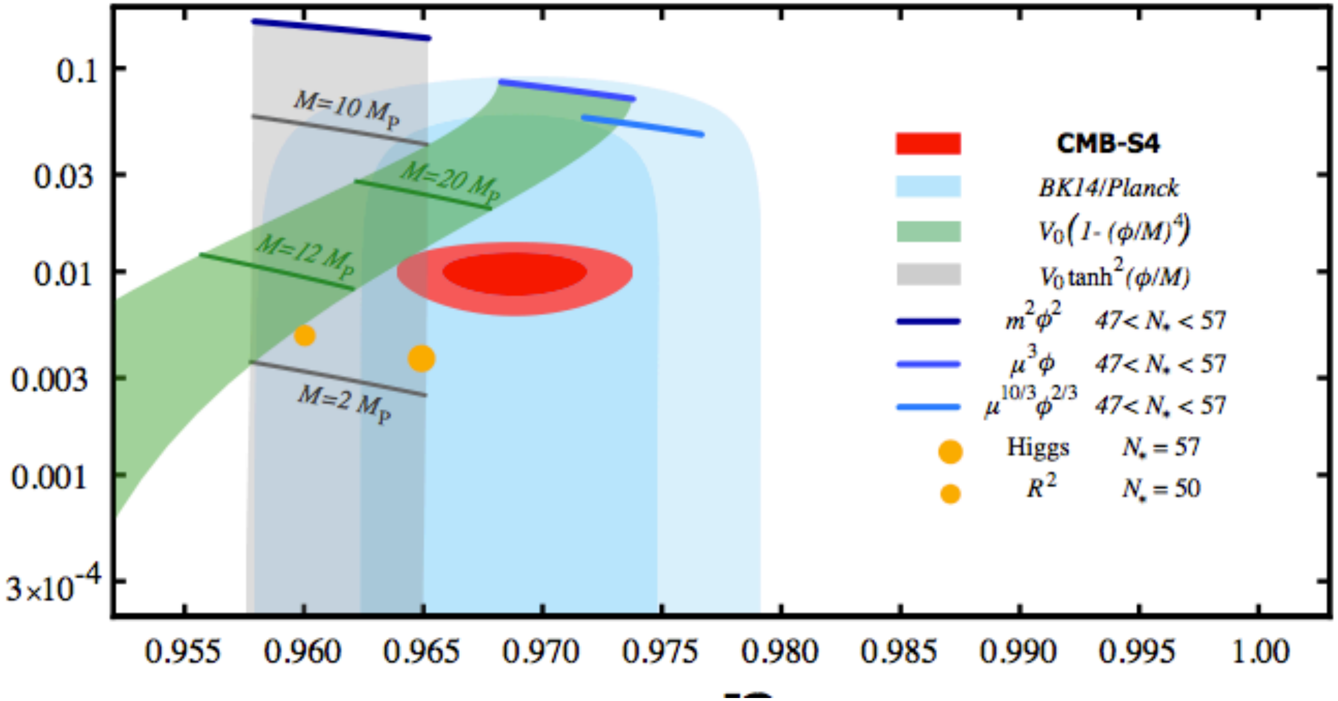
CORE (incl. delensing)

$$V(\phi) = \Lambda^4 \left(1 - \frac{\phi^4}{\mu^4} + \dots\right)$$

$$V(\tilde{\phi}) = \frac{\Lambda^4}{4} \left(1 - e^{-2\tilde{\phi}/\sqrt{6}M_{\rm pl}}\right)^2$$

CMB-S4

Next Generation CMB Experiment



CMB-S4 Science Book, First Edition, CMB-S4 Collaboration, K. N. Abazajian et al. arXiv:1610.02743

Beyond the tensor-to-scalar ratio r

What happens if we relax the consistency condition for the tensor tilt n = - r / 8 motivated by inflation driven a canonical scalar field during slow-roll?

$$\mathcal{L} = X - V(\phi)$$
$$X = -g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi/2$$

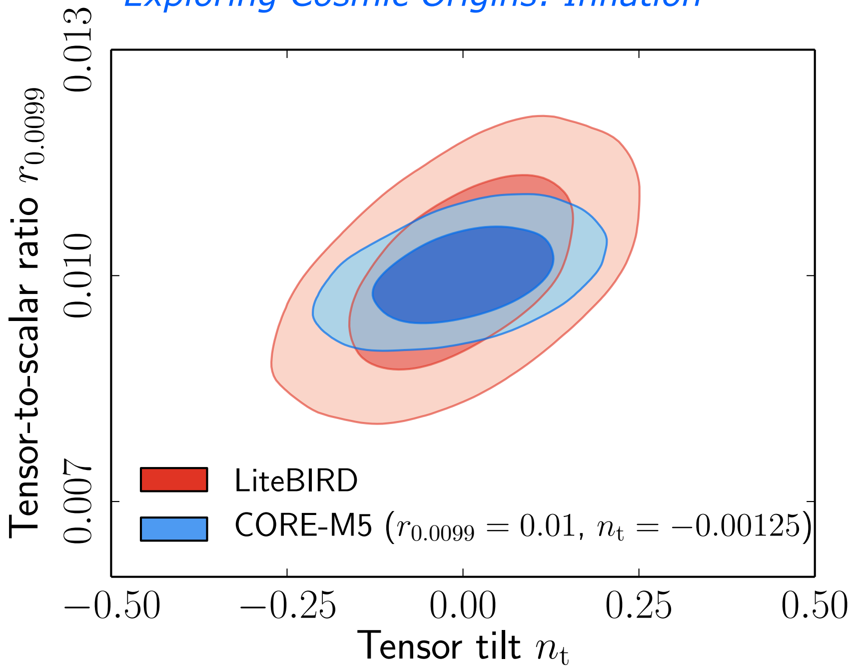
→ $\mathcal{L} = P(\phi, X)$ $\quad c_s^2 = \frac{P_{,X}}{P_{,X} + 2XP_{,XX}}$

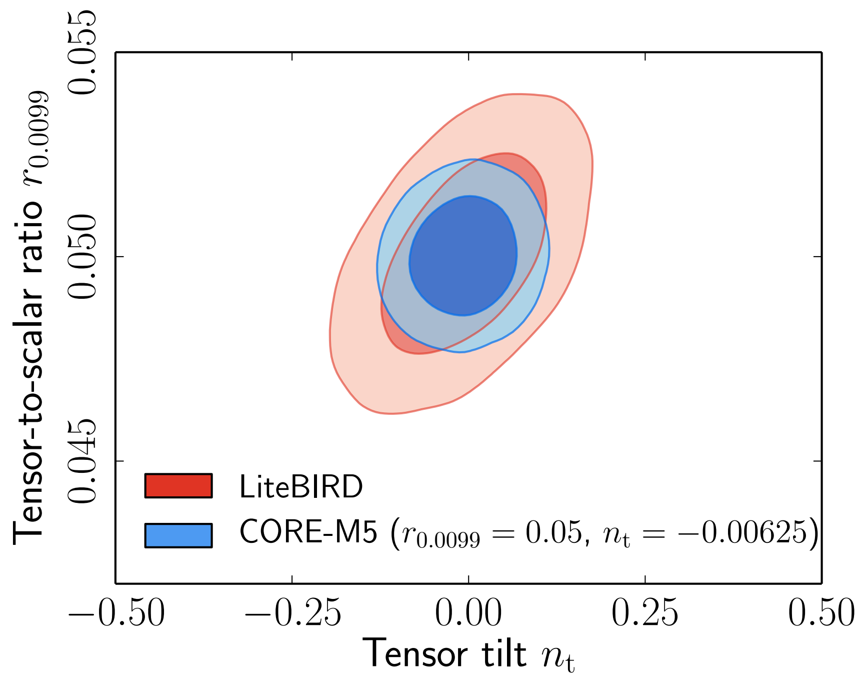
DBI: $P(\phi, X) = -f(\phi)^{-1}\sqrt{1-2f(\phi)X} + f(\phi)^{-1} - V(\phi)$

→ Galileon-like action, Horndeski theories

→ $\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F_a^{\mu\nu} + \frac{\kappa}{384}(\epsilon^{\mu\nu\lambda\sigma}F^a_{\mu\nu}F^a_{\lambda\sigma})^2$

Exploring Cosmic Origins: Inflation





$\sigma(n_t) = 0.08$ $(r_{\rm fid} = 0.01)$

$\sigma(n_t) = 0.05$ $(r_{\rm fid} = 0.05)$

fNL

	LiteCORE 80	LiteCORE 120	**CORE M5**	COrE+	Planck 2015	LiteBIRD	ideal 3000
T local	4.5	3.7	**3.6**	3.4	(5.7)	9.4	2.7
T equilat	65	59	**58**	56	(70)	92	46
T orthog	31	27	**26**	25	(33)	58	20
T lens-isw	0.15	0.11	**0.10**	0.09	(0.28)	0.44	0.07
E local	5.4	4.5	**4.2**	3.9	(32)	11	2.4
E equilat	51	46	**45**	43	(141)	76	31
E orthog	24	21	**20**	19	(72)	42	13
E lens-isw	0.37	0.29	**0.27**	0.24		1.1	0.14
T+E local	2.7	2.2	**2.1**	1.9	(5.0)	5.6	1.4
T+E equilat	25	22	**21**	20	(43)	40	15
T+E orthog	12	10.0	**9.6**	9.1	(21)	23	6.7
T+E lens-isw	0.062	0.048	**0.045**	0.041		0.18	0.027

Table 17: Forecasts for the 1σ $f_{\rm NL}$ error bars for the standard primordial shapes as well as for the lensing-ISW shape for the indicated configurations. Results are given for T-only, E-only and full $T+E$. The results for *Planck* have been put between parentheses because they are not forecasts but real measured error bars. See the main text for further details.

Parameter	Results from *Planck* 2015 release	CORE expected uncertainties	Improvement factor
ΛCDM model			
A_s	$A_s = (2.130 \pm 0.053) \times 10^{-9}$ (68 % CL) [4]	$\sigma(A_s) = 0.0073$	7.3
n_s	$n_s = 0.9653 \pm 0.0048$ (68 % CL) [4]	$\sigma(n_s) = 0.0014$	3.4
$\Omega_b h^2$	$\Omega_b h^2 = 0.02226 \pm 0.00016$ (68 % CL) [4]	$\sigma(\Omega_b h^2) = 0.000037$	4.3
$\Omega_c h^2$	$\Omega_c h^2 = 0.1193 \pm 0.0014$ (68 % CL) [4]	$\sigma(\Omega_c h^2) = 0.00026$	5.4
τ	$\tau = 0.063 \pm 0.014$ (68 % CL) [4]	$\sigma(\tau) = 0.002$	7.0
H_0 [km/s/Mpc]	$H_0 = 67.51 \pm 0.64$ (68 % CL) [4]	$\sigma(H_0) = 0.11$	5.8
$dn_s/d\ln k$	$dn_s/d\ln k = -0.0023 \pm 0.0067$ (68 % CL) [4, 5]	$\sigma(dn_s/d\ln k) = 0.0023$	2.9
$d^2n_s/d\ln k^2$	$d^2n_s/d\ln k^2 = 0.025 \pm 0.013$ (68 % CL) [5]	$\sigma(d^2n_s/d\ln k^2) = 0.0046$	2.8
Ω_k	$\Omega_k = -0.0037^{+0.0083}_{-0.0069}$ (68 % CL) [4]	$\sigma(\Omega_k) = 0.0019$	4
r	$r < 0.08$ (95 % CL) [5, 48]	$\sigma(r) = 4 \cdot 10^{-4}$ ($r_{fid} = 0.01$)	10^2
n_t	$-0.38 < n_t < 2.6$ (95 % CL) [5]	$\sigma(n_t) = 0.08$ ($r_{fid} = 0.01$, $n_{fid\,t} = -r_{fid}/8$)	10
β_{iso}	$\beta_{iso}^{curvaton} < 0.0013$ (95 % CL) [5]	$\beta_{iso}^{curvaton} < 0.00026$ (95 % CL)	5.0
	$\beta_{iso}^{axion} < 0.038$ (95 % CL) [5]	$\beta_{iso}^{axion} < 0.018$ (95 % CL)	2.1
f_{NL}	$f_{NL}^{local} = 0.8 \pm 5.0$ (68 % CL) [46]	$\sigma(f_{NL}^{local}) = 2.1$	2.4
	$f_{NL}^{equil} = -4 \pm 43$ (68 % CL) [46]	$\sigma(f_{NL}^{equil}) = 21$	2.0
	$f_{NL}^{ortho} = -26 \pm 21$ (68 % CL) [46]	$\sigma\left(f_{NL}^{ortho}\right) = 9.6$	2.2
	$f_{NL}^{ISW-lens} = 0.79 \pm 0.28$ (68 % CL) [46]	$\sigma\left(f_{NL}^{ISW-lens}\right) = 0.045$	6.2
c_s	$c_s > 0.023$ (95 % CL) [46]	$c_s > 0.045$ (95 % CL)	2.0
$G\mu$	$G\mu < 2.0 \times 10^{-7}$ (95 % CL) [333]	$G\mu < 2.1 \times 10^{-8}$ (95 % CL)	9.5

Table 27: Summary of the current results based on the latest *Planck* 2015 release and CORE forecasts presented in this paper. In the third column we quote the figure of merit of the improvement expected with CORE.

CORE collaboration; Exploring Cosmic Origins with CORE: Inflation, F. Finelli et al., arXiv:1612.08270, JCAP (2017)

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada.

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.