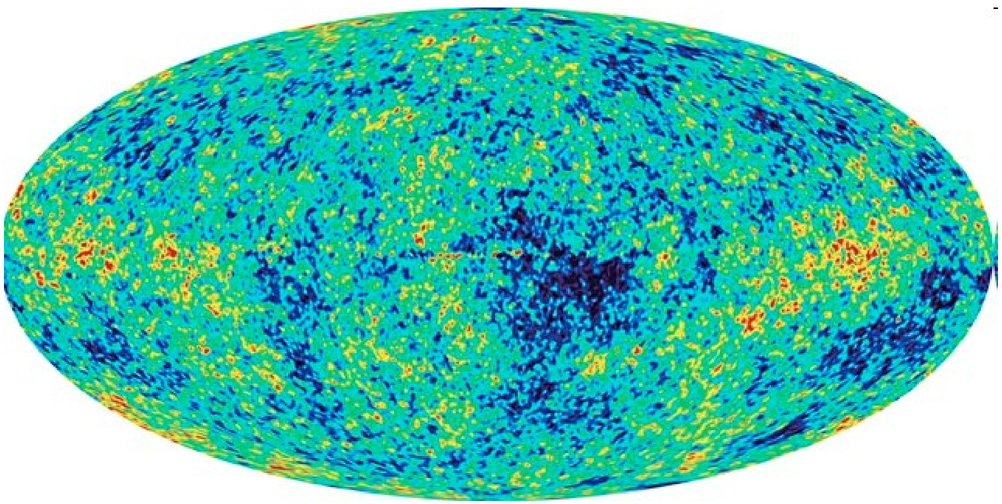
Constraints on the Inflation Model

from CMB and LSS data



Micol Benetti

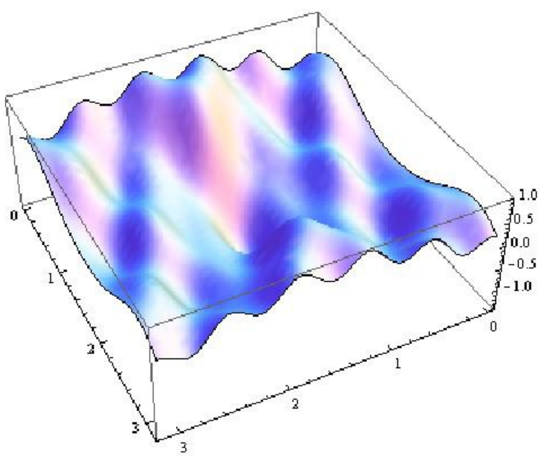
Observatório Nacional

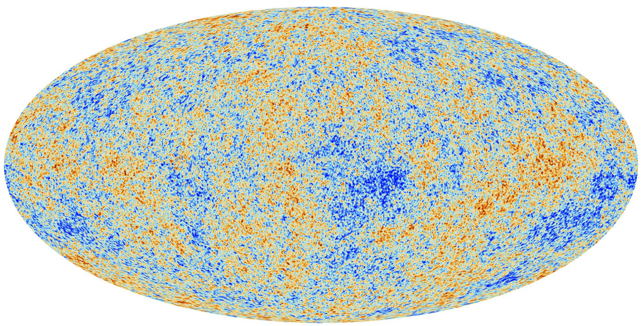
Meeting on Fundamental Cosmology

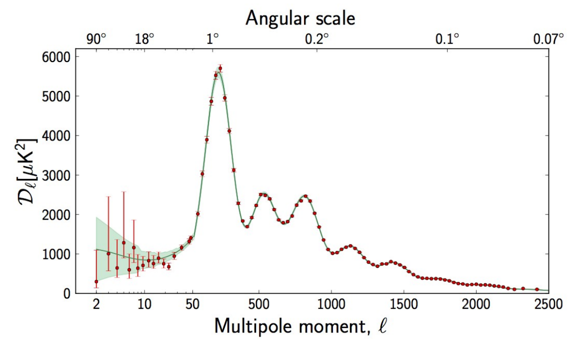
18 June 2015 – Santander

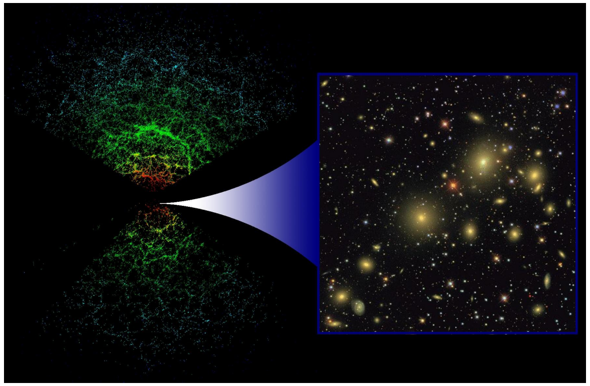
Primordial perturbations

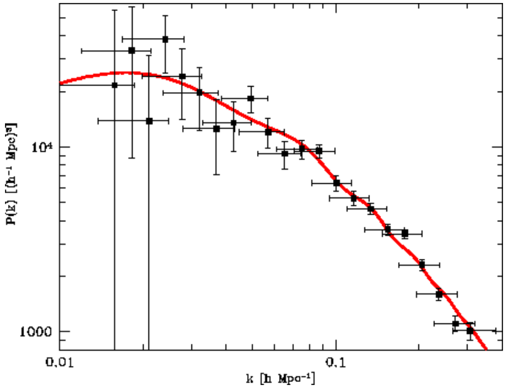
According to the inflationary paradigm, the Standard Cosmological Model considers the Primordial fluctuations (or density variations in the early universe) the seeds of all the universe structures.











The initial fluctuations are assumed **Gaussian**, **adiabatic** and with a **nearly scale invariant** spectrum. These were generated in the very early Universe via the amplification of the quantum fluctuation of a scalar field.

Inflation - Slow roll formalism

We need a **time-dependent cosmological constant**,
we require a **field with the same quantum numbers as vacuum**, i.e. a **scalar**.

We will consider a scalar field minimally coupled to gravity, with potential V(ϕ)

$$\mathcal{L}_\phi = \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi)$$

The equation of motion for a homogeneous mode of the field ϕ(t, x) is

$$\ddot{\phi} + 3H\dot{\phi} + V'(\phi) = 0$$

$$\rho_\phi = \frac{1}{2}\dot{\phi}^2 + V(\phi) \qquad H^2 = \frac{8\pi}{3m_{Pl}^2}\left[\frac{1}{2}\dot{\phi}^2 + V(\phi)\right]$$

$$p_\phi = \frac{1}{2}\dot{\phi}^2 - V(\phi) \qquad \left(\frac{\ddot{a}}{a}\right) = \frac{8\pi}{3m_{Pl}^2}\left[V(\phi) - \dot{\phi}^2\right]$$

$$3H\dot{\phi} + V'(\phi) \sim 0$$

$$H^2(t) \sim \frac{8\pi}{3m_{Pl}^2} V(\phi(t))$$

Slow roll approximation $(1/2)\dot{\phi}^2 \ll V(\phi)$

$$a(t) \propto \exp \int H(t')dt' \equiv e^{-N(t)}$$

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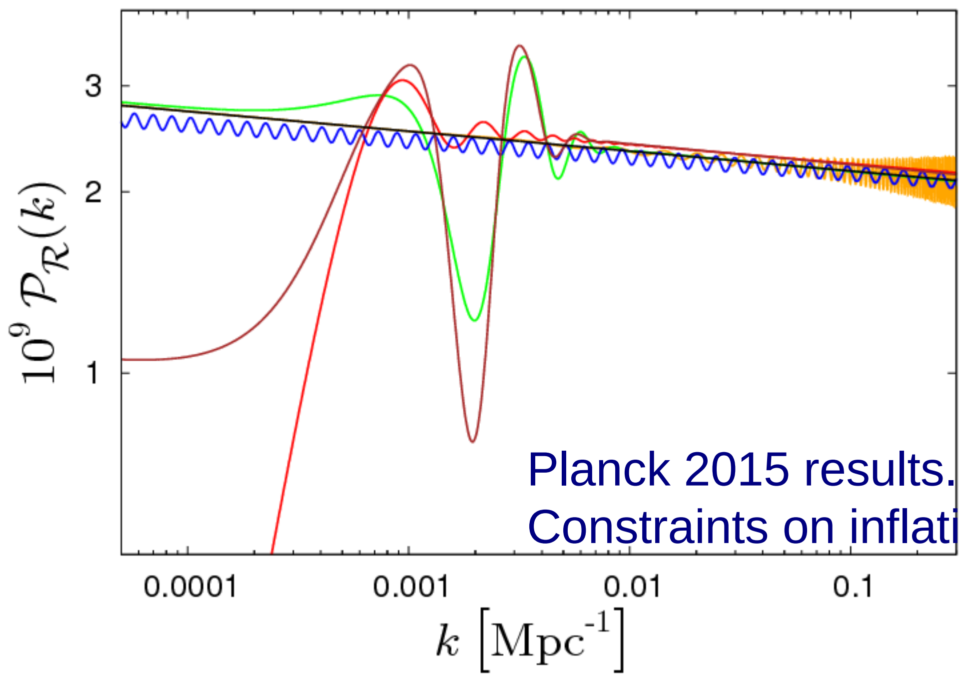
Inflationary models

Logarithmic oscillations

$$V(\phi) = V_0(\phi)\left[1 + A_{log}\cos\left(\omega_{log}\ln\left(\frac{k}{k_0}\right) + \varphi_{log}\right)\right]$$

Martin&Brandenberger (2003)



Planck 2015 results. XX. Constraints on inflation

Linear oscillations

$$V(\phi) = V_0(\phi)\left[1 + A_{lin}\left(\frac{k}{k_0}\right)^{n_{lin}}\cos\left(\omega_{lin}\left(\frac{k}{k_0}\right) + \varphi_{lin}\right)\right]$$

Meerburg&Spergel (2014)

Model	*Planck* TT+lowP $\Delta\chi^2_{\rm eff}$	*Planck* TT+lowP $\ln B$	*Planck* TT,TE,EE+lowP $\Delta\chi^2_{\rm eff}$	*Planck* TT,TE,EE+lowP $\ln B$
Step	−8.6	−0.3	−7.3	−0.6
Log osc.	−10.6	−1.9	−10.1	−1.5
Linear osc.	−8.9	−1.9	−10.9	−1.3
Cutoff	−2.0	−0.4	−2.2	−0.6

Step in the potential

$$V(\phi) = V_0(\phi)[1 + A_{step}\tanh\left(\frac{\phi - \phi_{step}}{d_{step}}\right)$$

Adams *et al.* (2001)

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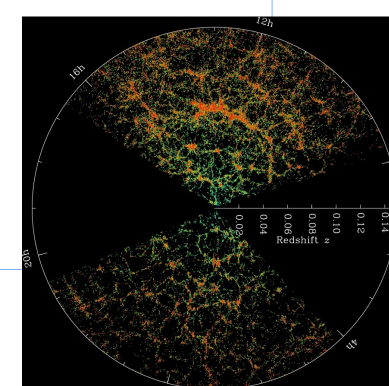
Method and dataset

CosmoMC code: Markov-Chain Monte-Carlo (MCMC) engine for exploring cosmological parameters space. (*Antony Lewis*)

BOBYQA algorithm: Bound Optimization BY Quadratic Approximation, is an optimized method for minimizing functions of more variables. (*Michael J. D. Powell*)

Planck data: high-l temperature and low-l temperature-polarization data

SDSS data: Data Release 11



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Bayesian information criterion

$$BIC = -2\ln L + k\ln N$$

Schwarz, Gideon E. (1978)

ΔBIC	Evidence against higher BIC
0 to 2	Not significant
2 to 6	Positive
6 to 10	Strong
>10	Very Strong

k=number of free parameters

N= number of data points

Model selection criteria for model with different parameters: resolve this problem by introducing a penalty term for the number of parameters in the model.

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Inflationary models

Logarithmic oscillations

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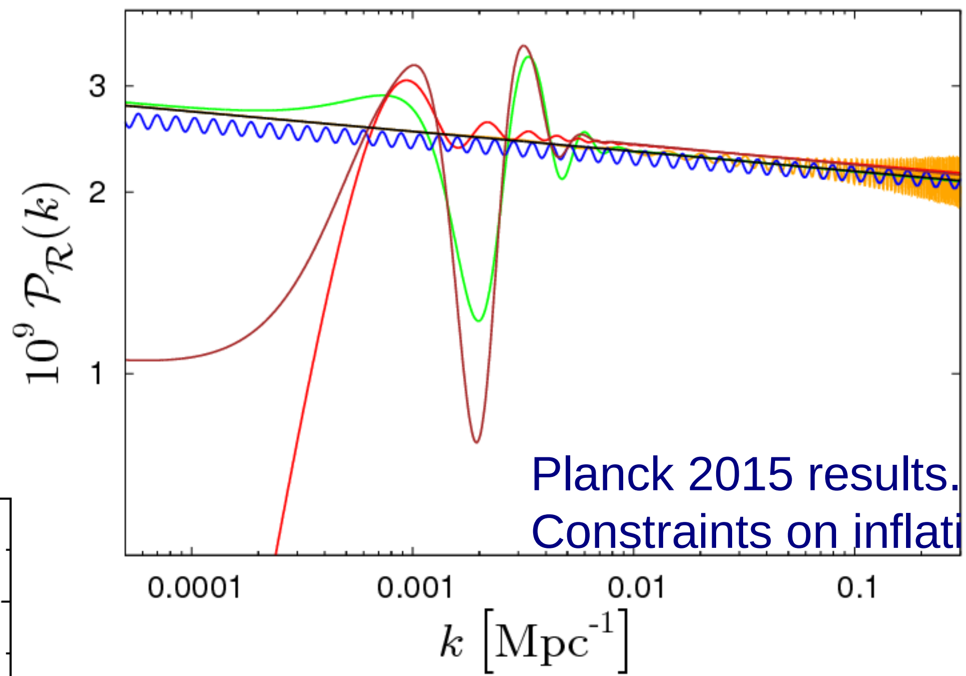

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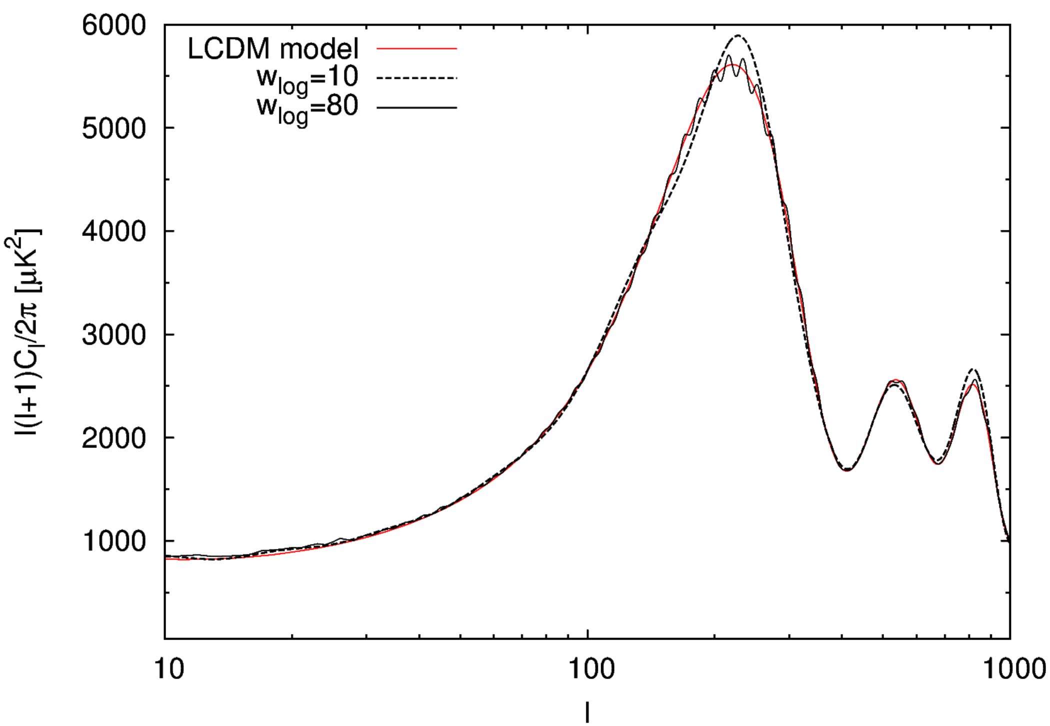

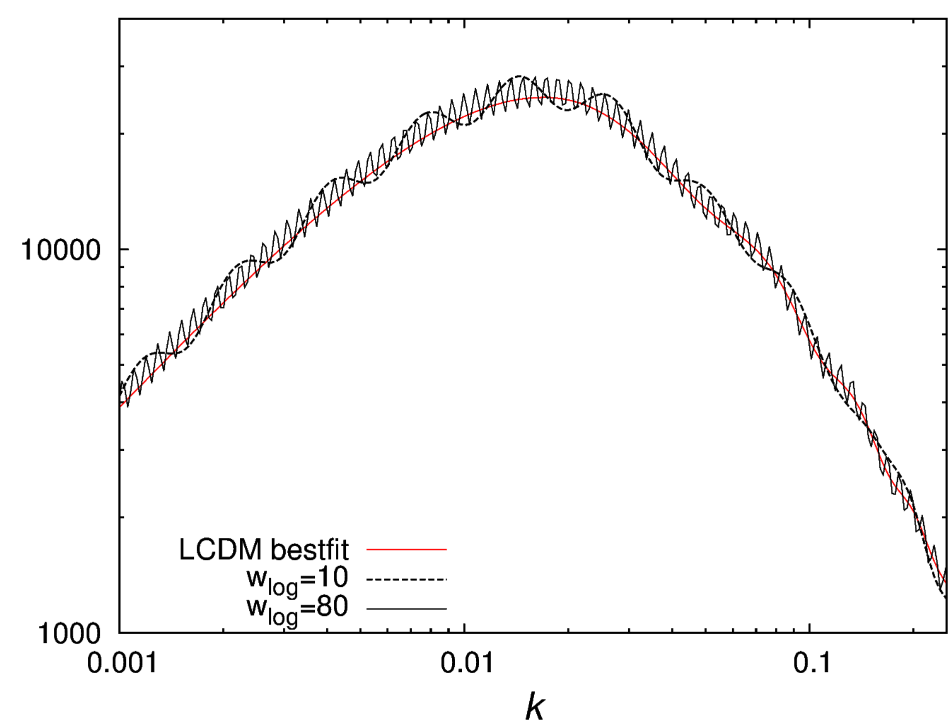

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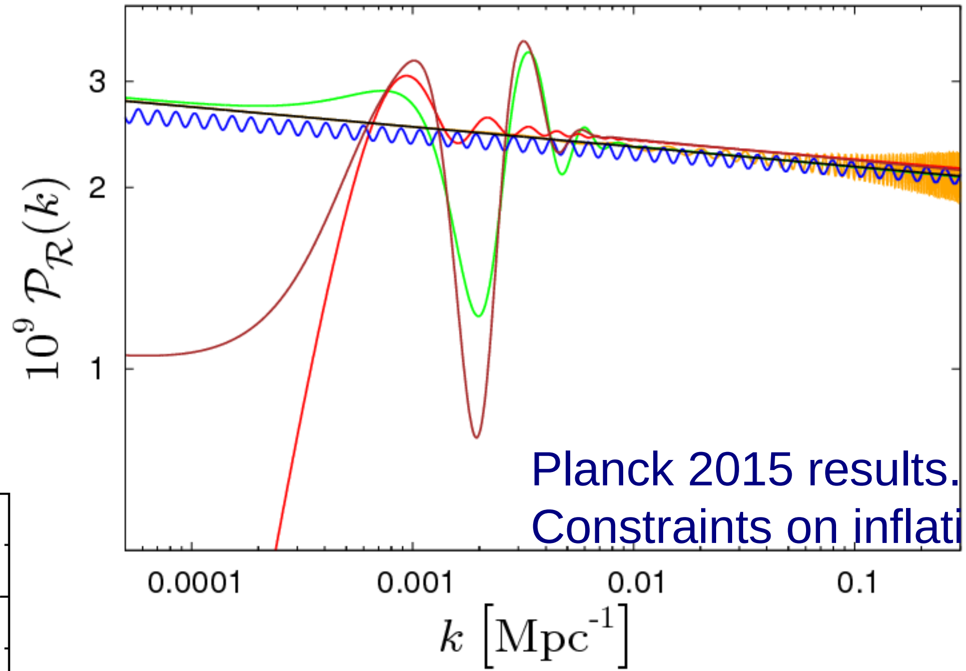
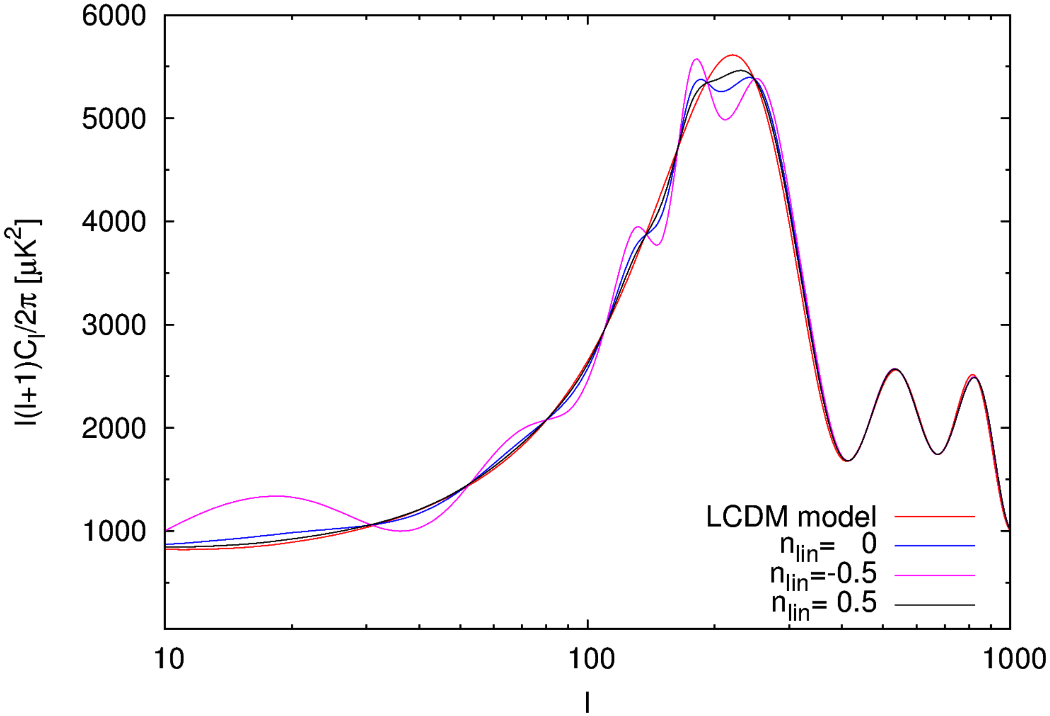
Inflationary models

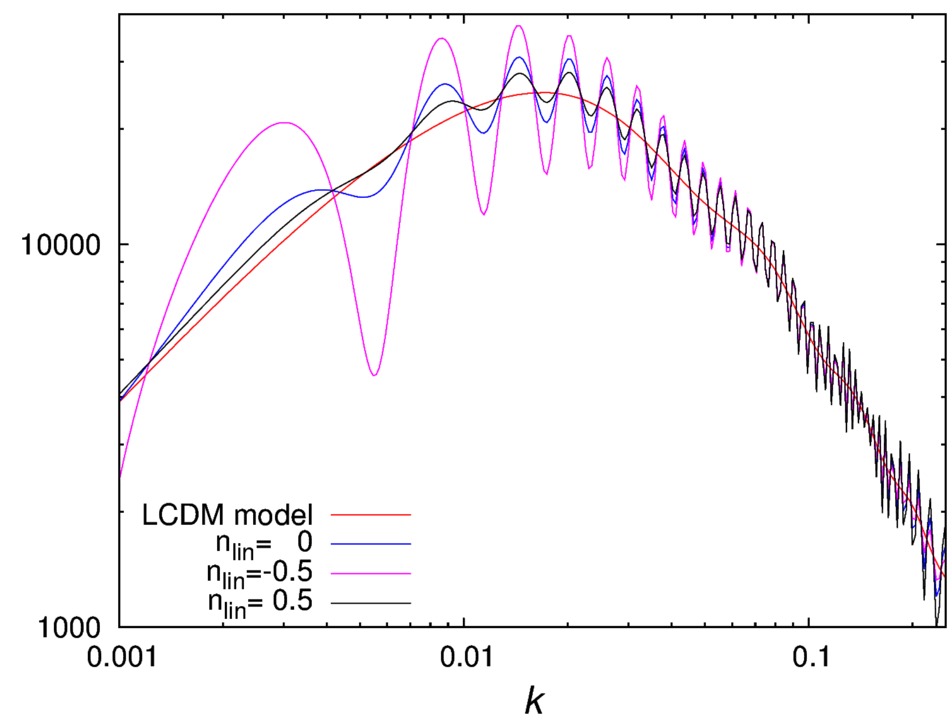
Linear oscillations

$$V(\phi) = V_0(\phi)\left[1 + A_{lin}\left(\frac{k}{k_0}\right)^{n_{lin}}\cos\left(\omega_{lin}\left(\frac{k}{k_0}\right) + \varphi_{lin}\right)\right]$$



Planck 2015 results. XX.
Constraints on inflation





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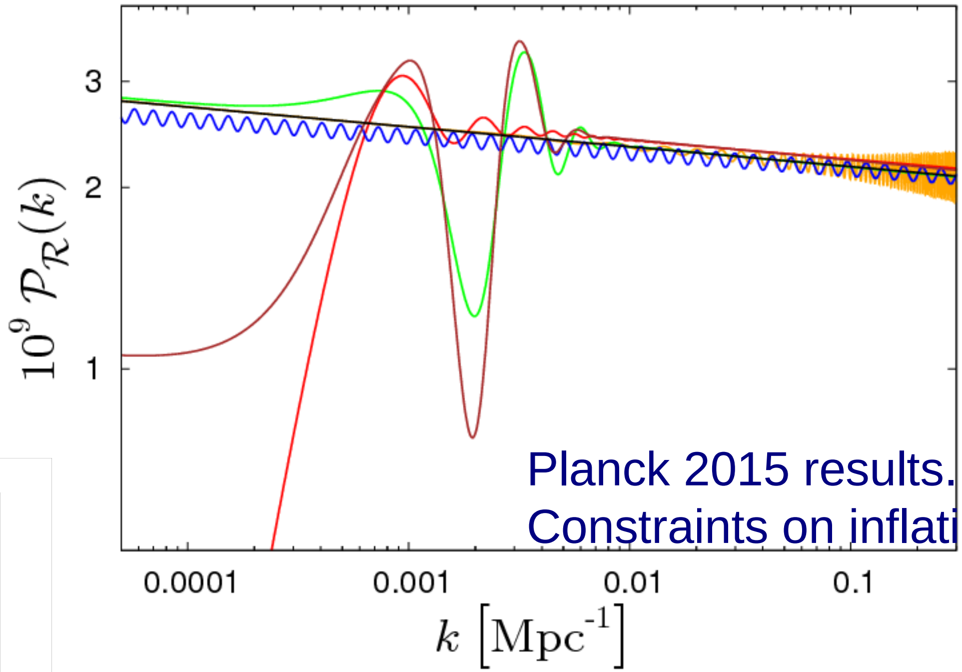
Inflationary models

Step in the potential

$$V(\phi) = V_0(\phi)[1 + A_{step} \tanh\left(\frac{\phi - \phi_{step}}{d_{step}}\right)$$



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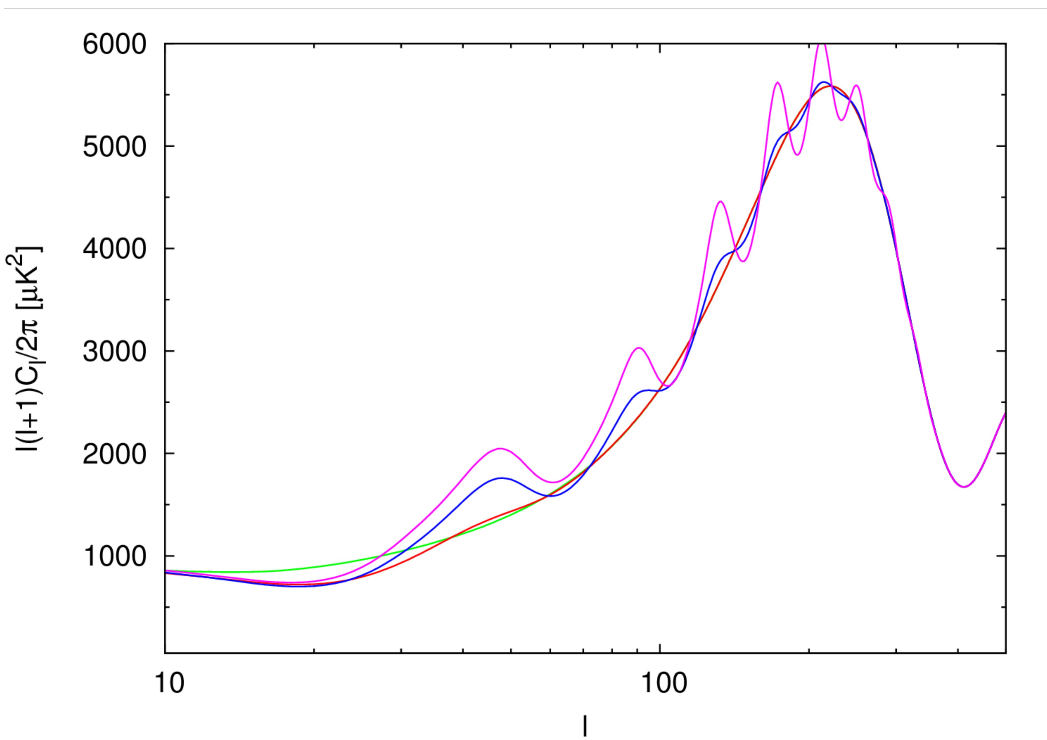

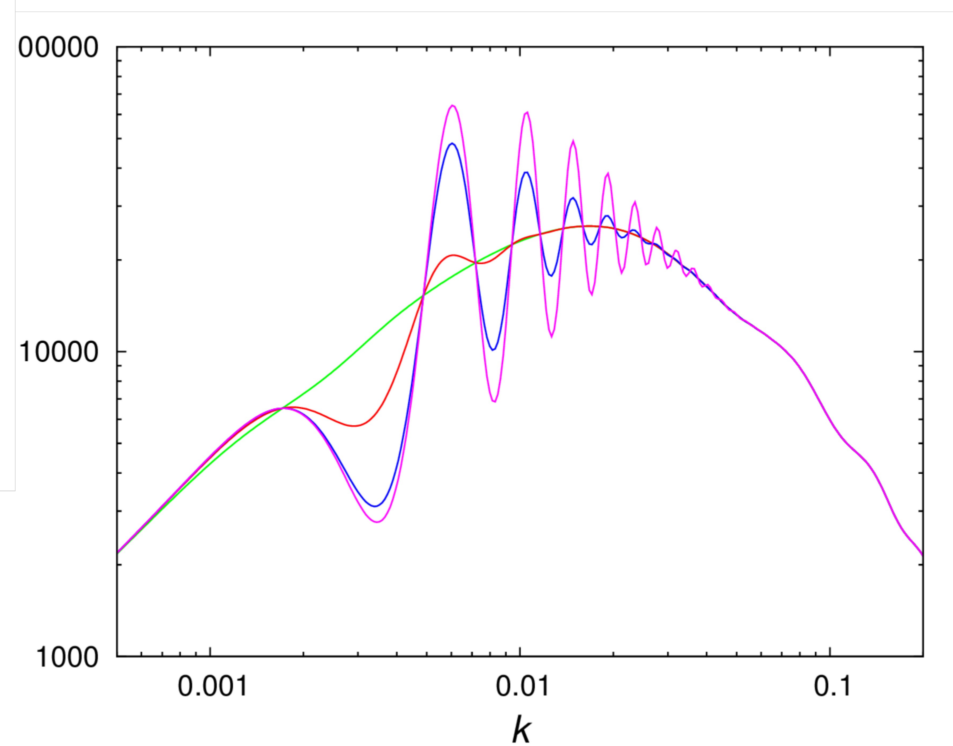

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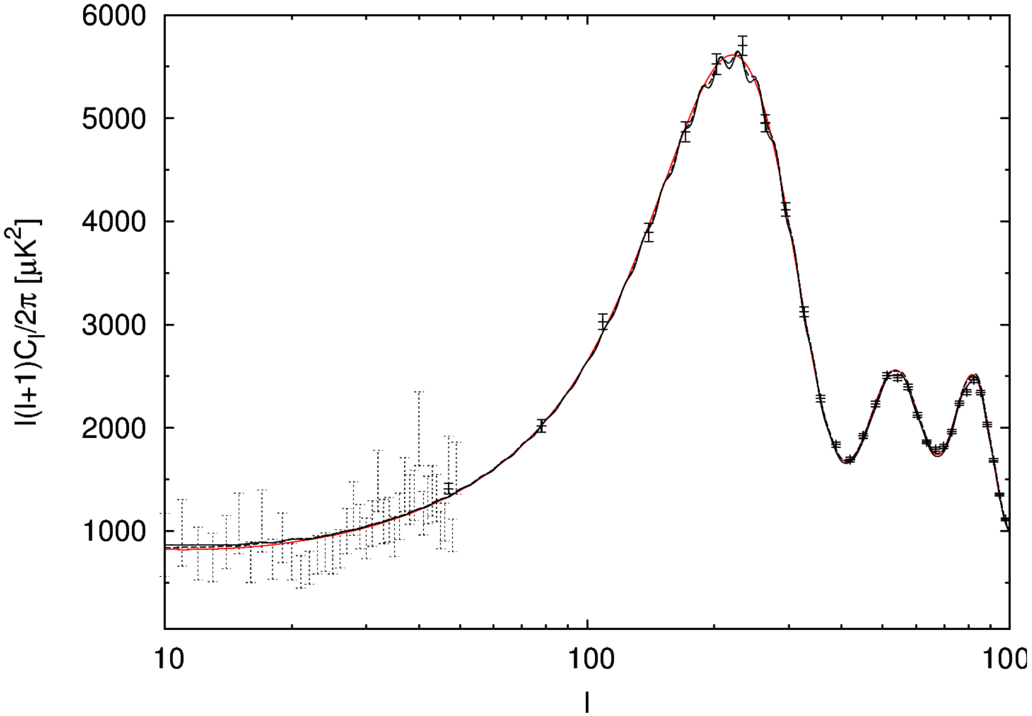
Inflationary models

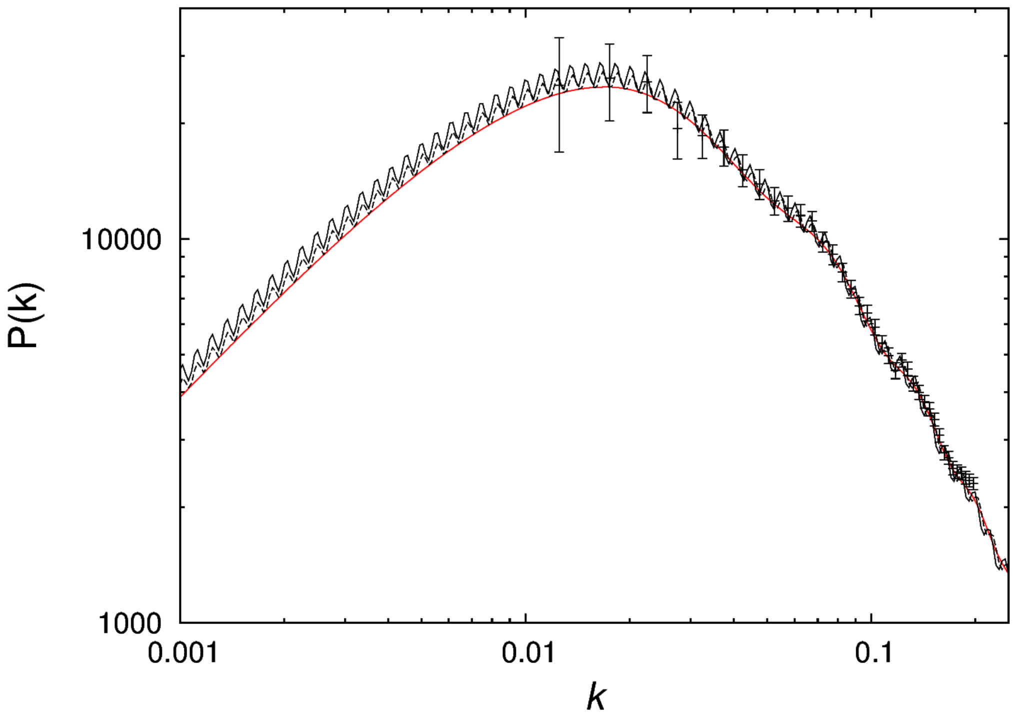
Logarithmic oscillations

$$V(\phi) = V_0(\phi)\left[1 + A_{log}\cos\left(\omega_{log}\ln\left(\frac{k}{k_0}\right) + \varphi_{log}\right)\right]$$

Dot line: Planck data

Line: Planck+DR11 data

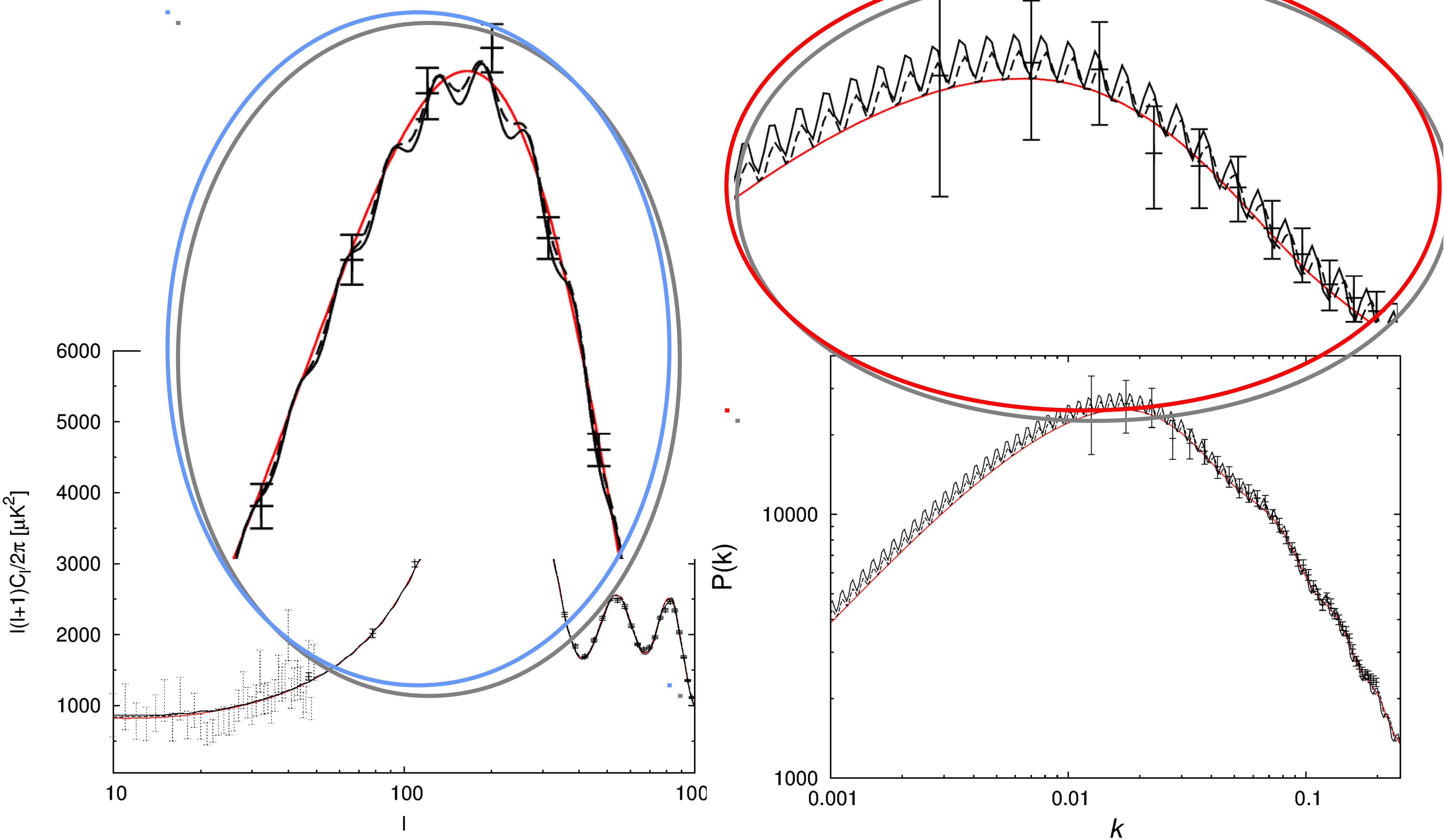




Using only Planck data ΔBIC = 0.4

Using Planck+ SDSS data ΔBIC = 2.7

Inflationary models



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Inflationary models

Logarithmic oscillations

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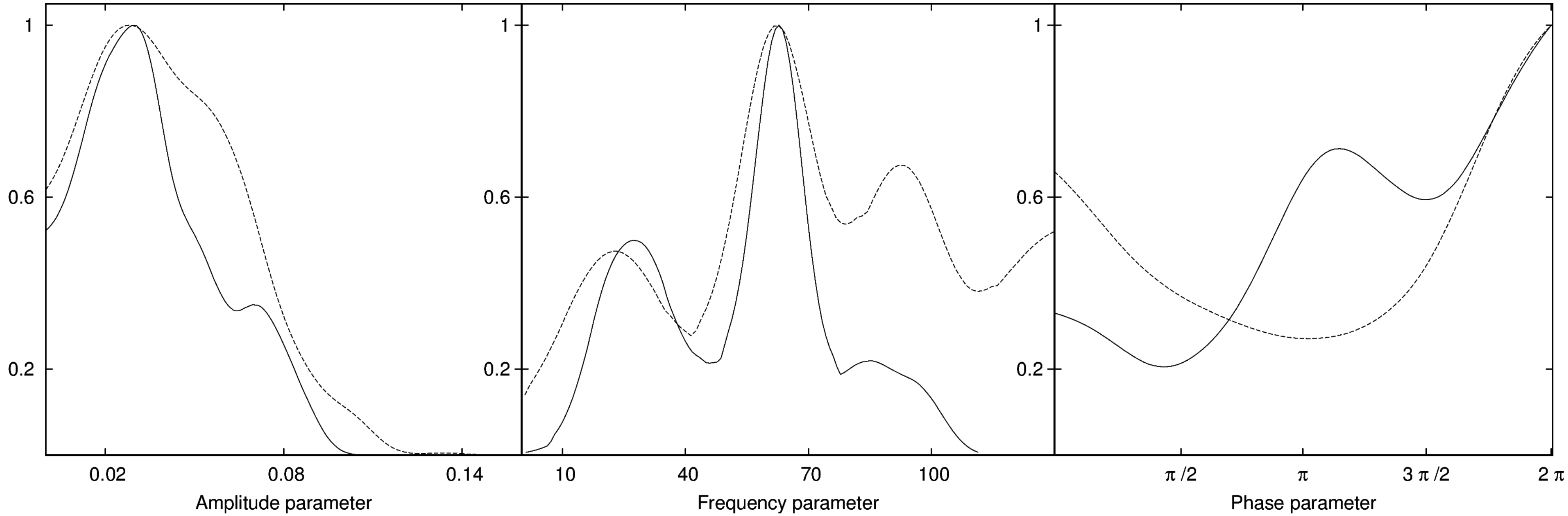

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Inflationary models

Linear oscillations

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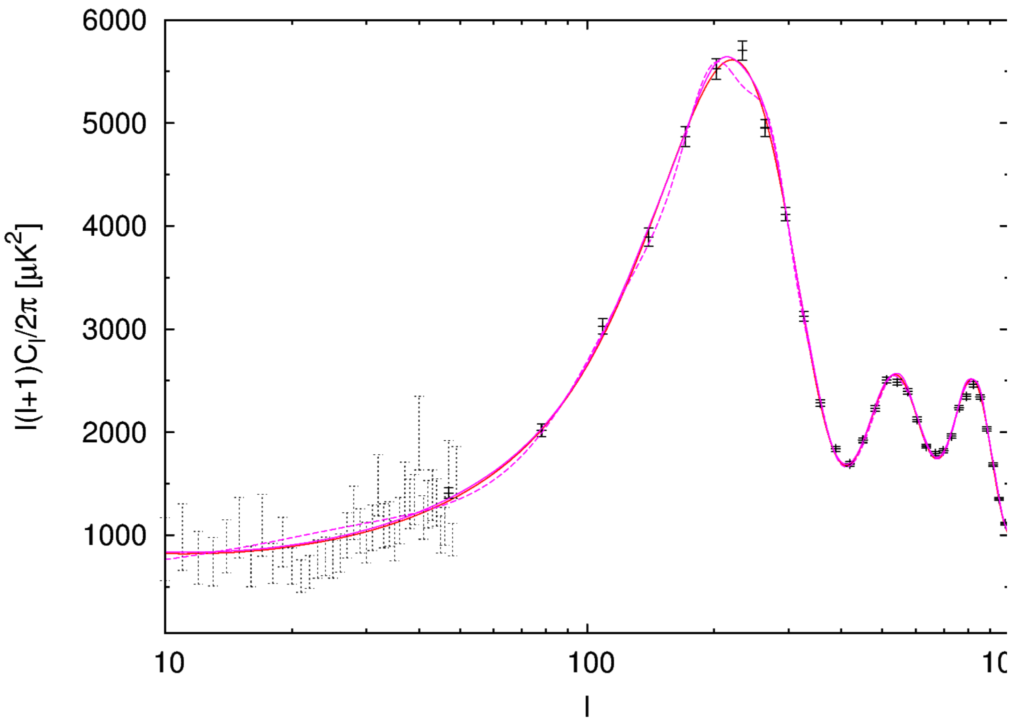
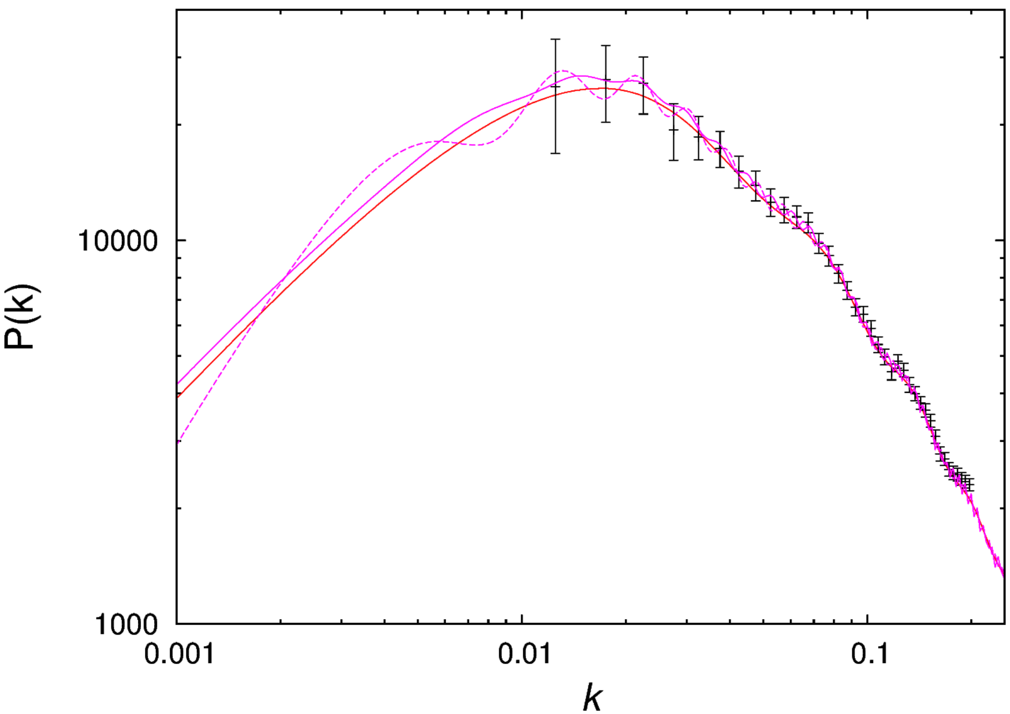
Dot line: Planck data

Line: Planck+DR11 data





Using only Planck data ΔBIC < 0

Using Planck+ SDSS data ΔBIC = 0.2

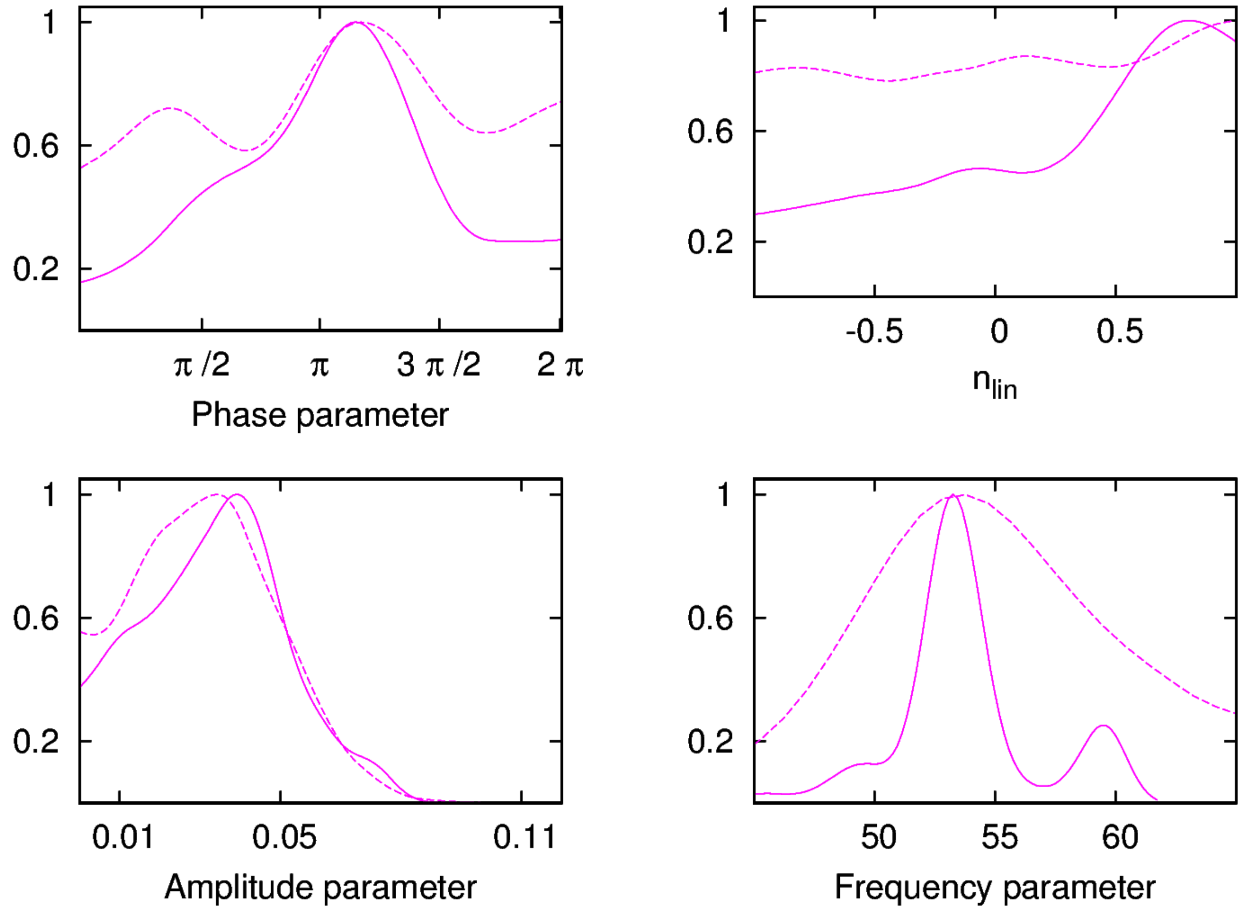
Inflationary models

Linear oscillations

$$V(\phi) = V_0(\phi)\left[1 + A_{lin}\left(\frac{k}{k_0}\right)^{n_{lin}}\cos\left(\omega_{lin}\left(\frac{k}{k_0}\right) + \varphi_{lin}\right)\right]$$

Dot line: Planck data

Line: Planck+DR11 data



Using only Planck data ΔBIC < 0

Using Planck+ SDSS data ΔBIC = 0.2

Inflationary models

Step in the potential

$$V(\phi) = V_0(\phi)[1 + A_{step} \tanh\left(\frac{\phi - \phi_{step}}{d_{step}}\right)$$

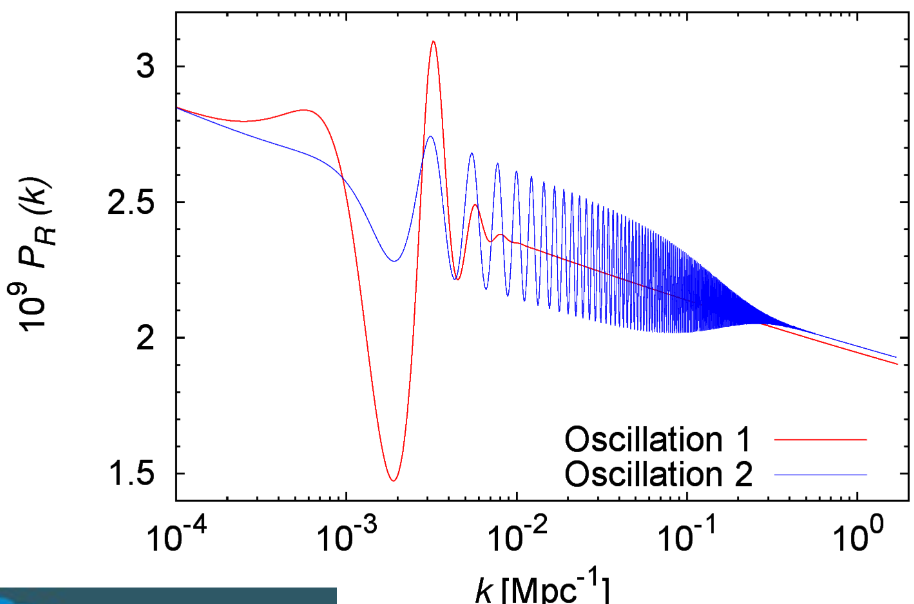
The analysis constrains two oscillations:

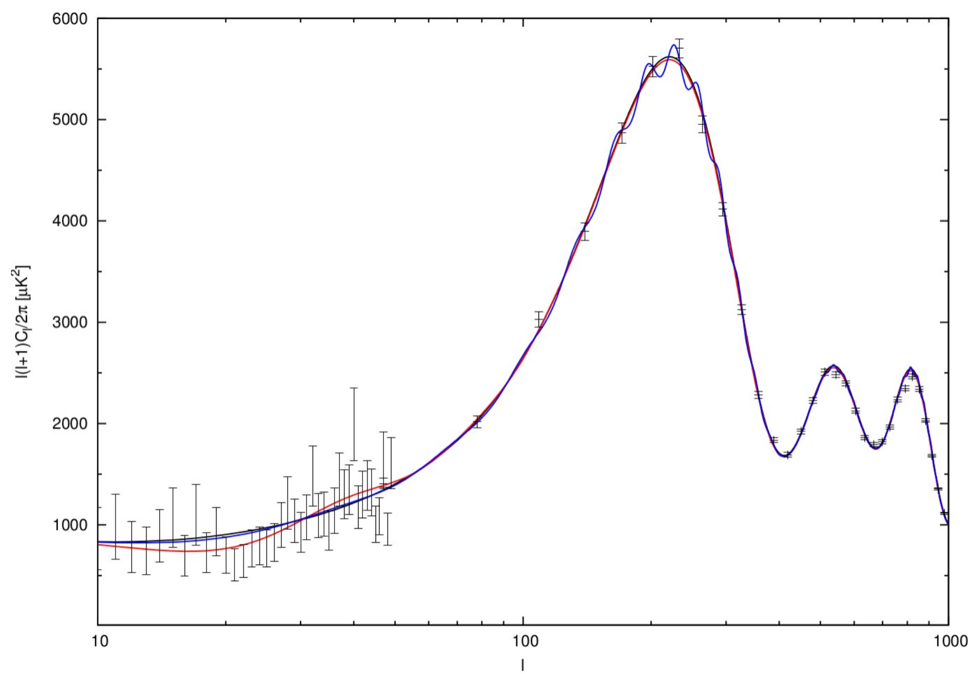
- Oscillation-1: oscillation in $20<\ell<60$
- Oscillation-2: oscillation in $100<\ell<300$

$\Delta\chi^2 = 11$

$\Delta\chi^2 = 10$

DATA: PLANCK I release





Benetti (2013)

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Inflationary models

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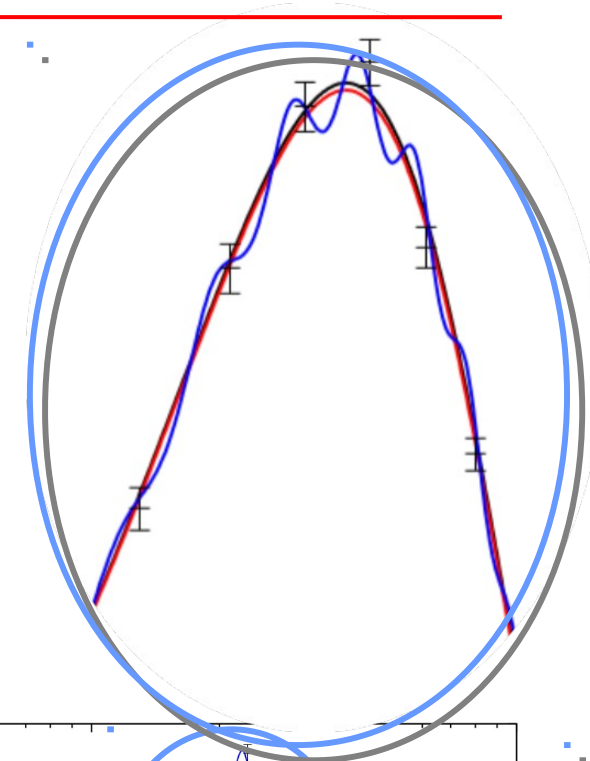

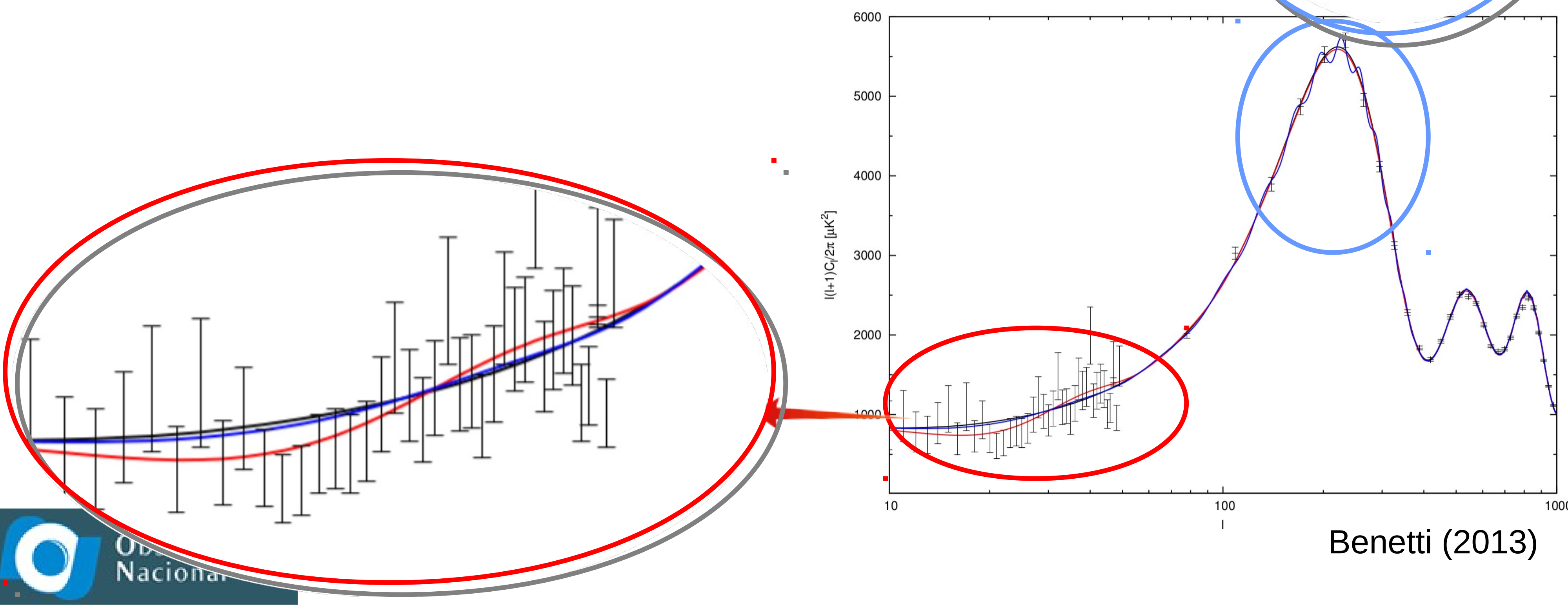

Benetti (2013)

Inflationary models

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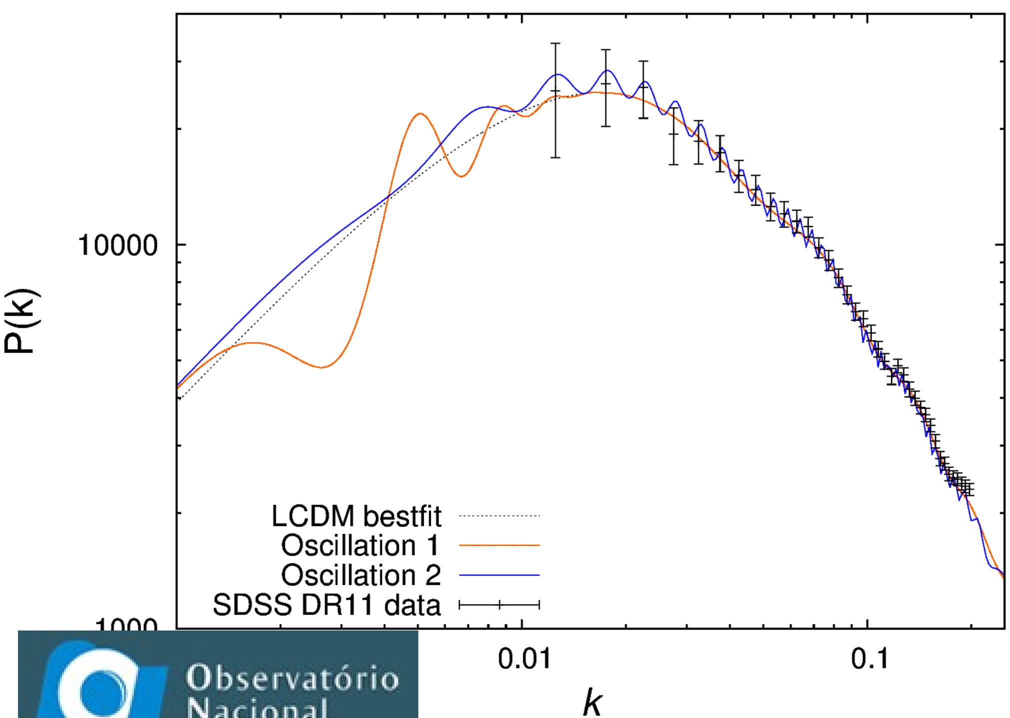

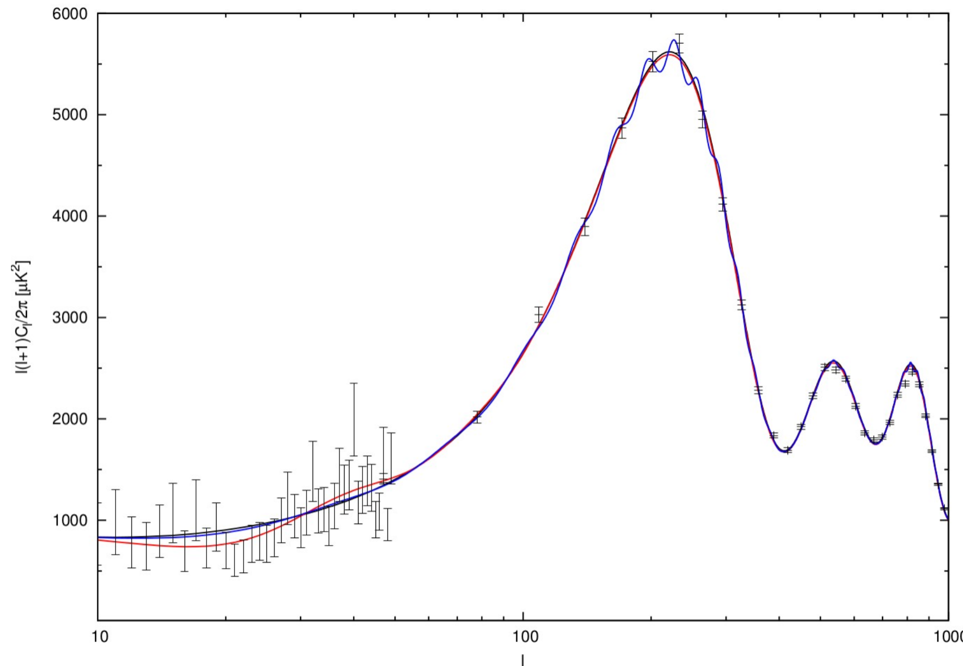

Benetti (2013)

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Inflationary models

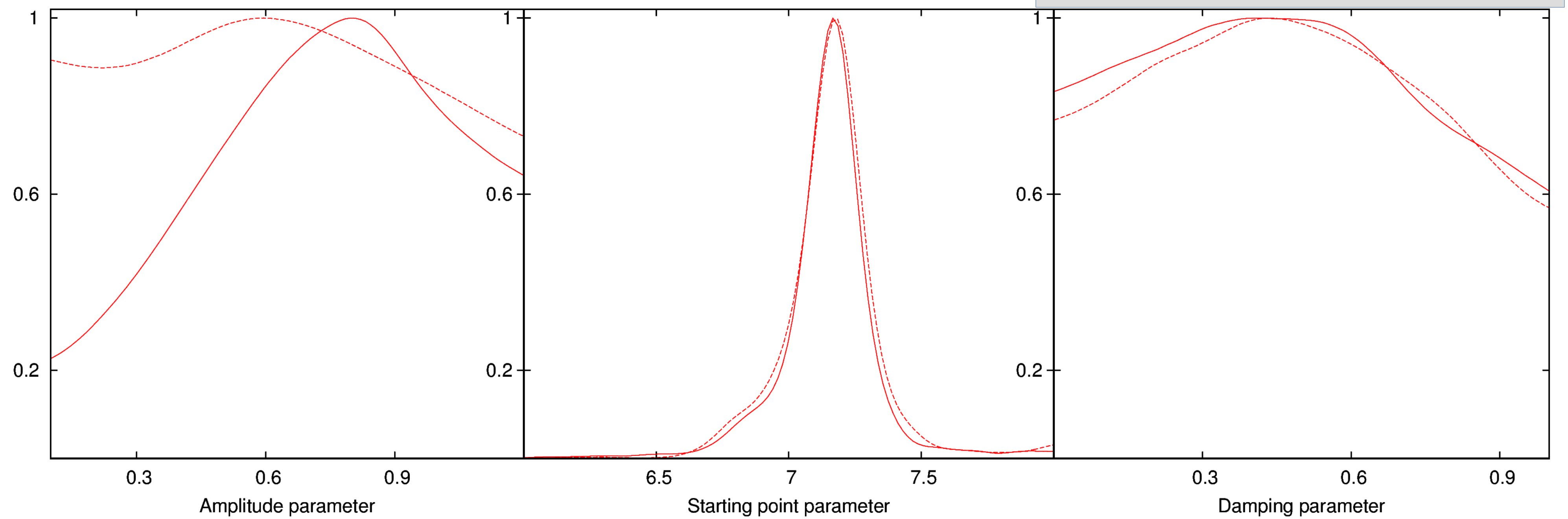
Step in the potential

Oscillation-1: oscillation in 20<ℓ<60

$$V(\phi) = V_0(\phi)[1 + A_{step} \tanh\left(\frac{\phi - \phi_{step}}{d_{step}}\right)$$

Dot line: Planck data

Line: Planck+DR11 data



Using only Planck data ΔBIC = 1

Using Planck+ SDSS data ΔBIC = 1

Inflationary models

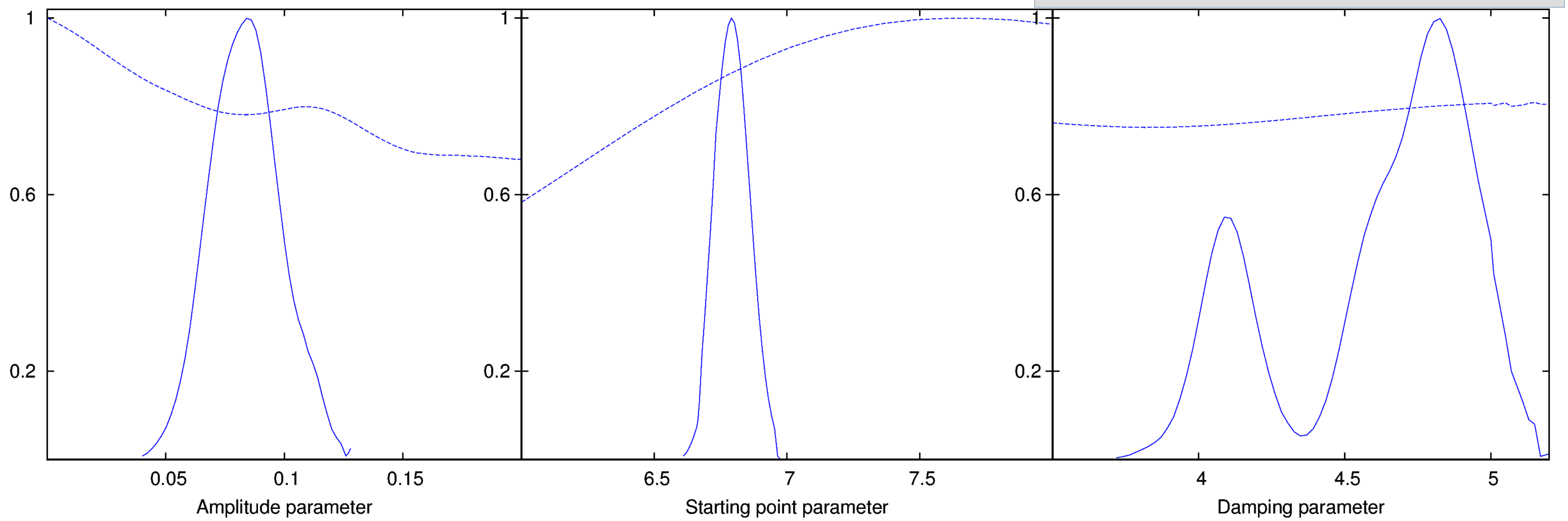
Step in the potential

Oscillation-2: oscillation in 100<ℓ<300

$$V(\phi) = V_0(\phi)[1 + A_{step} \tanh\left(\frac{\phi - \phi_{step}}{d_{step}}\right)$$

Dot line: Planck data

Line: Planck+DR11 data



Using only Planck data ΔBIC = 1

Using Planck+ SDSS data ΔBIC = 2.5

J-PAS is a new astronomical facility dedicated to mapping the observable Universe. The 2.5m mirror of the main telescope, combined with a 1.2 Giga-pixel camera containing an array of 14 CCDs.

it will produce **high-quality images** and a **unique spectral resolution** over the whole area of the survey, casting a new picture of the cosmos.

The starting date for this multi-purpose astrophysical survey is 2015, and during 5-6 years.

It will observe more than 8500 square degrees (about 1/5 of the whole sky), using **54 narrow-band filters** and two broad-band filters, covering the entire visible region of the electromagnetic spectrum (3500 Å to 10000 Å).

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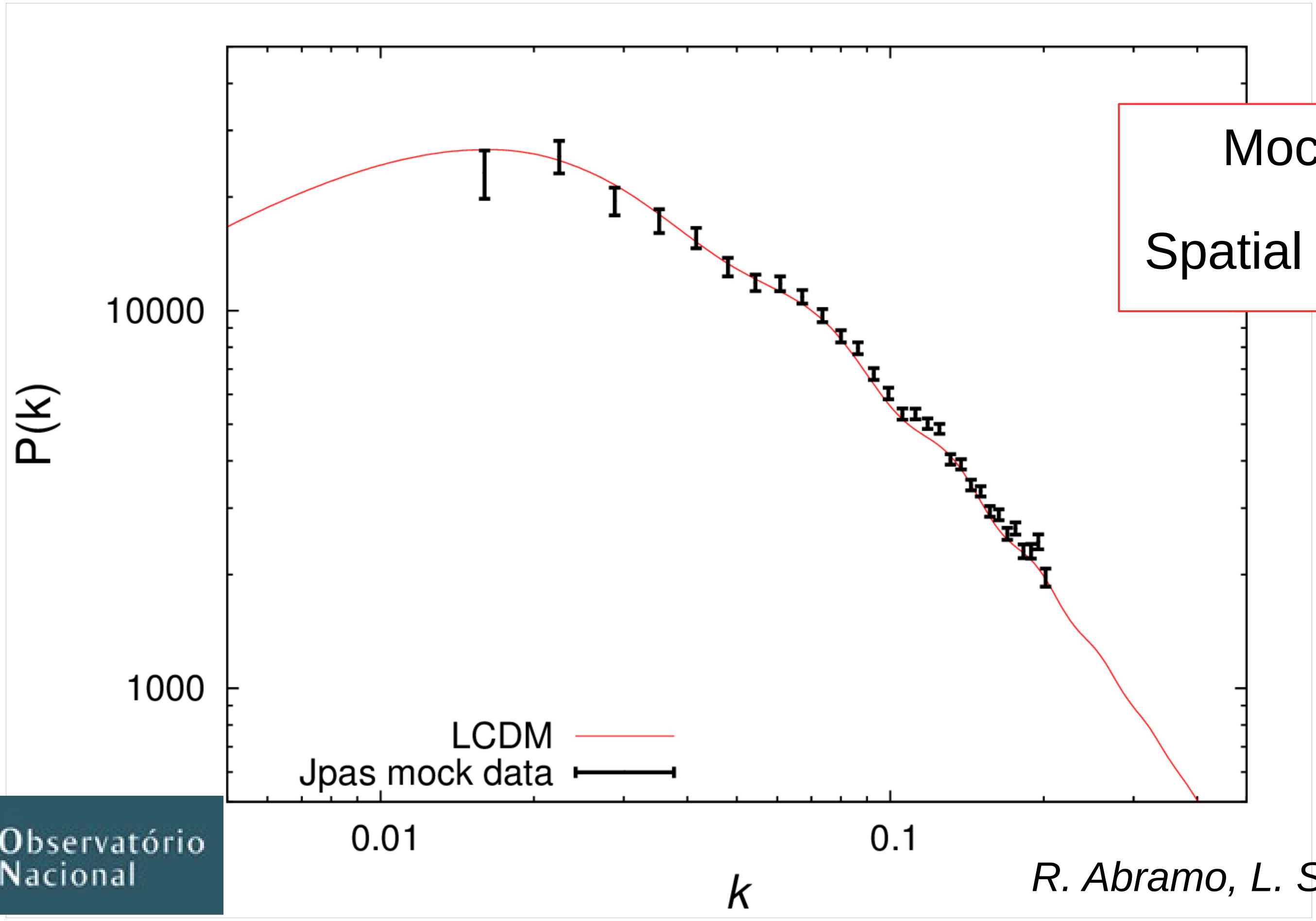
It is a J-PAS log-normal mock data with selection of red massive galaxies, expected for the first experiment release.



Mock volume ~ 4 Gpc^3

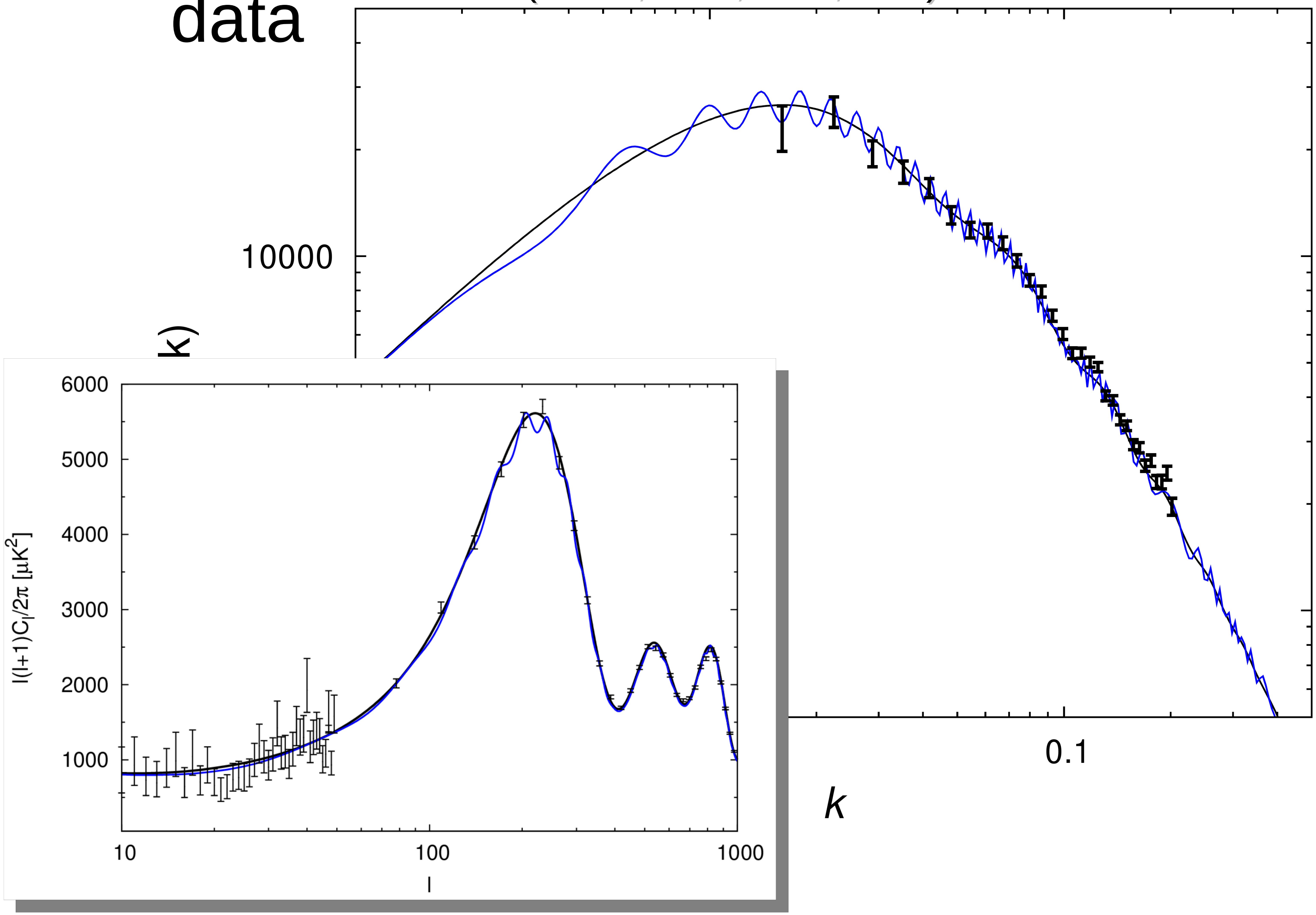
Spatial resolution ~ 20 Mpc/h

R. Abramo, L. Secco, A. Loureiro

Oscillation 2: oscillation in 100<ℓ<300

Planck + Jpas mock data

+HST +UNION 2.1 +BAO (DR11, DR8, DR7, 6DF)



Conclusions

- We explored some class of models with departure from the near-scale-invariant power-low spectrum. These models are able to produce oscillations in the TT-spectrum of CMB and in the matter power spectrum P(k) at the cost of 3 (or 4) more parameters.

- These oscillations don't improve the data best-fit respect to the ΛCDM minimal model using the only the CMB data ….

  … BUT, using CMB+LSS data, the BIC criteria shows an evidence of improvement.

- To use the LSS data improve the constraints on the inflationary oscillation-parameters.

- To confirm or discard these models we can use other different tools like the Ngs, the T-E and the polarization spectra.

eBOSS

- eBOSS experiment will explore the range **$0.6<z<2$** and will create the largest volume survey of the Universe. One of its goals is putting new constraints on the Inflation from limits on non-Gaussianity in the primordial density field.

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