Axion Landscape and CMB Statistics

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@ COSMO-18

Based on

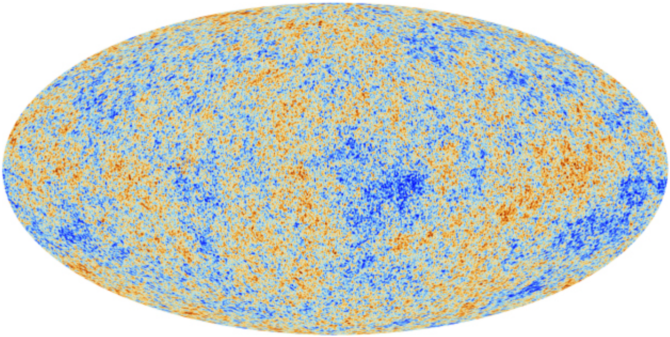
1804.07315

related to 1806.05202 Gonzalo Palma's talk

in collaboration with:

Xingang Chen, Gonzalo Palma, Wálter Riquelme and Bruno Scheihing

Outline



Measuring the distribution of these small anisotropies in the CMB has been our main window into the very early Universe

⋆ Second moment (Power spectrum) **Measured!**

$$\langle\zeta\zeta\rangle \sim \frac{H^2}{M_{\rm Pl}^2\epsilon} = 10^{-10}$$

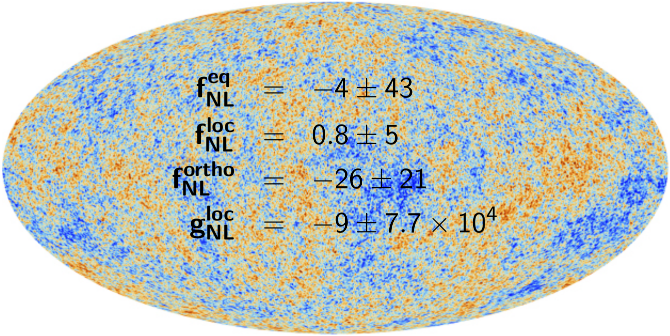
⋆ Third moment (Bispectrum) **Constrained!**

$$\langle\zeta(k_1)\zeta(k_2)\zeta(k_3)\rangle \sim f_{NL}(\epsilon)S(k_1, k_2, k_3)$$

⋆ Fourth moment (Trispectrum) **Constrained!**

$$\langle\zeta(k_1)\zeta(k_2)\zeta(k_3)\zeta(k_4)\rangle \sim g_{NL}(\epsilon)S(k_1, k_2, k_3, k_4)$$

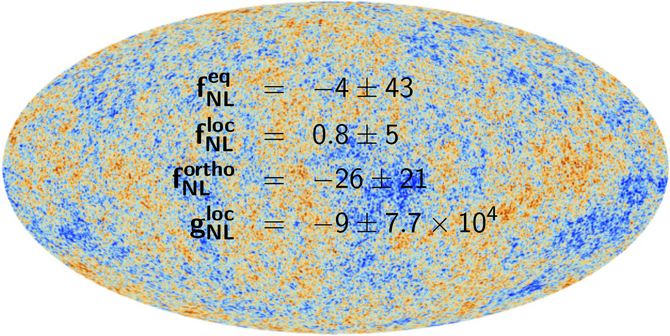
Planck 2015 @ 68% CL



$$
\begin{aligned}
f_{NL}^{eq} &= -4 \pm 43 \\
f_{NL}^{loc} &= 0.8 \pm 5 \\
f_{NL}^{ortho} &= -26 \pm 21 \\
g_{NL}^{loc} &= -9 \pm 7.7 \times 10^4
\end{aligned}
$$

- ⋆ CMB temperature anisotropies follow nearly scale invariant, almost Gaussian statistics (Consistent with ΛCDM)

PLANCK 2015 @ 68% CL



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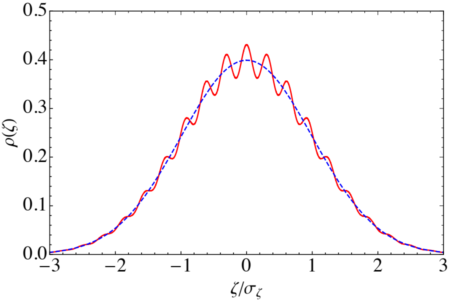
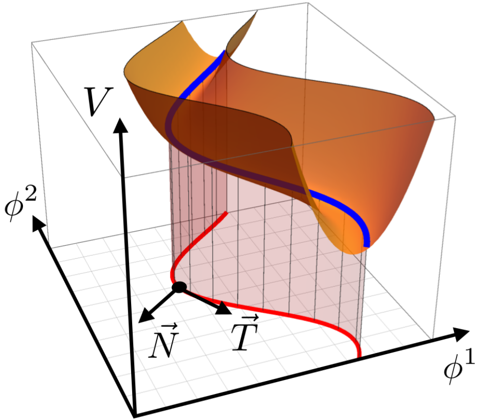
- ⋆ CMB temperature anisotropies follow nearly scale invariant, almost Gaussian statistics (Consistent with ΛCDM)
- ⋆ End of the story?

The PLANCK analysis is optimised for the search of nonzero moments of the PDF. What about this PDF for example?

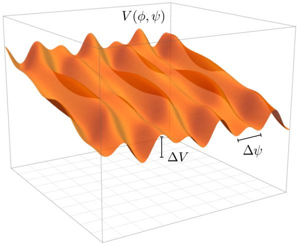


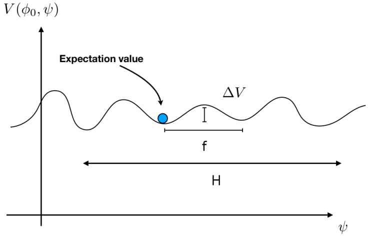
It is clearly non-Gaussian but has $f_{nl} = 0$
Can we get something like that?

Scalar Perturbations in multifield inflation



CMB spectra


$V(\phi, \psi)$
ΔV
$\Delta\psi$


$V(\phi_0, \psi)$
Expectation value
ΔV
f
H
ψ

Ultralight ψ, $\mu = 0$

$$S = \int dx^4 a^3 \left[\epsilon \left(\dot{\zeta} - \alpha\psi \right)^2 - \epsilon a^{-2} (\nabla\zeta)^2 + \frac{1}{2} \left(\dot{\psi}^2 - a^{-2} (\nabla\psi)^2 \right) \right]$$

Symmetries:

$$\zeta \to \zeta + C$$

$$\psi \to \psi + C_1 \quad \& \quad \dot{\zeta} \to \dot{\zeta} + \alpha C_1$$

This leads to

$$\zeta \simeq \psi_0 \frac{\alpha}{H} \Delta N + \zeta_0 \Rightarrow \boxed{P_\zeta = \frac{\alpha^2}{H^2} \Delta N^2 P_\psi}$$

Chen, Palma, Riquelme, Scheihing, SS '18

What if we add a potential?

$$S = \int dx^4 a^3 \left[\epsilon \left(\dot{\zeta} - \alpha \psi \right)^2 - \epsilon a^{-2} (\nabla \zeta)^2 + \frac{1}{2} \left(\dot{\psi}^2 - a^{-2} (\nabla \psi)^2 - V(\psi) \right) \right]$$

Lets try something usual:

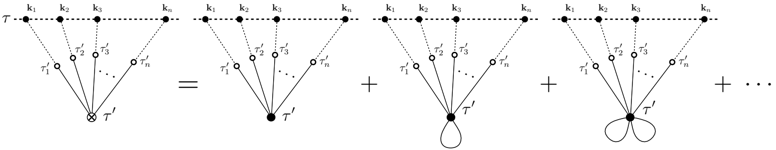
$$\boxed{V(\psi) = \Lambda^4 (1 - \cos(\psi / f))}$$

So by the same arguments we expect to transfer the ψ statistics to ζ. But now we have nonzero even n-point functions!

$$H_\alpha \propto \dot{\zeta}\psi, \qquad H_\Lambda \propto 1 - \cos(\psi/f) = -\sum_{m=1}^{\infty} \frac{(-1)^m}{(2m)!}(\psi/f)^{2m}$$

and compute the even n-point function using the in-in formalism:

$$\langle \zeta^n \rangle \propto \alpha^n \Lambda^4 \ \ \langle \hat{\zeta}_1 \ldots \hat{\zeta}_n \ \ \hat{\dot{\zeta}}_1 \hat{\psi}_1 \ldots \hat{\dot{\zeta}}_n \hat{\psi}_n \ \ \hat{\psi}_1 \ldots \hat{\psi}_n \ \hat{\psi}_{n+1} \ldots \hat{\psi}_{2m} \rangle$$



Loops can be resummed to $\exp(-\sigma^2/2f^2)$!

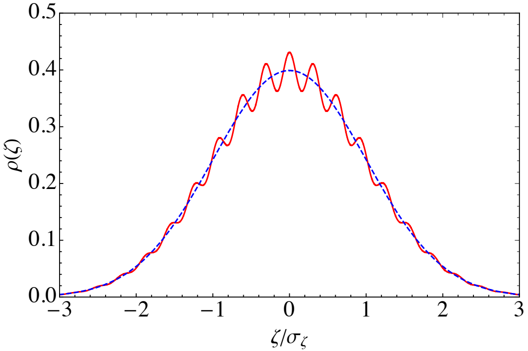
Having the n-th moment for arbitrary n (the n-point correlator) one can compute the whole PDF for the curvature perturbation ζ as

$$\langle \zeta^n \rangle = \int d\zeta \zeta^n \rho(\zeta)$$

$$\boxed{\rho(\zeta) = \frac{e^{-\zeta^2/2\sigma_\zeta^2}}{\sqrt{2\pi}\sigma_\zeta}\left[1 - A^2\left(\sigma_\zeta^2 \partial_\zeta^2 - \zeta\partial_\zeta\right)\cos(\zeta/f_\zeta)\right]}$$

where $\sigma_\zeta^2 = \alpha^2 \Delta N^2 \int_{k_L} \zeta\zeta^*$ and $A^2 = \frac{1}{6}\frac{\Lambda^4}{H^4} e^{-\sigma_S^2/2f^2}$.

This PDF has a Gaussian part plus a non-Gaussian correction. The Gaussian part comes out because we have only considered the cuadratic Lagrangian for ζ.



An example of the PDF for the choice of parameters $f_\zeta/\sigma_\zeta = 5 \times 10^{-2}$ and $B^2/\sigma_\zeta^2 = 10^{-6}$ (red solid curve). For comparison, we have plotted a Gaussian distribution of variance σ_ζ (blue dashed curve).

We have shown how the PDF of the curvature fluctuation can inherit a rich non-Gaussian structure due to axion dynamics.

To do:

- ⋆ Look for axionic signatures in the PDF
- ⋆ Late time signatures of tomographic NG? (exploiting e.g. LSST data)
- ⋆ How would this affect structure formation?
- ⋆ Simulate LSS with this initial condition?
- ⋆ How does this affect PBH distribution?

Thank you!