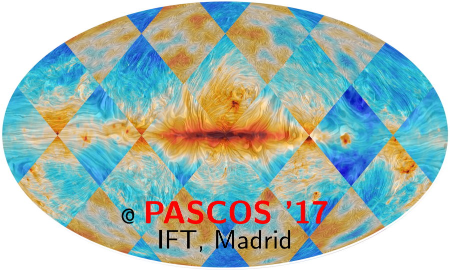
Cross-tests of CMB features in the primordial spectra

Spyros Sypsas
dfi, *fcfm*, UChile



Based on

1512.08977 (PLB), 1612.09253 (PRD), 1702.08756 (JCAP)

in collaboration with:

Gonzalo Palma, Jinn-Ouk Gong, Stephen Appleby, Dhiraj Kumar Hazra, Arman Shafieloo, Wálter Riquelme and Bastián Pradenas

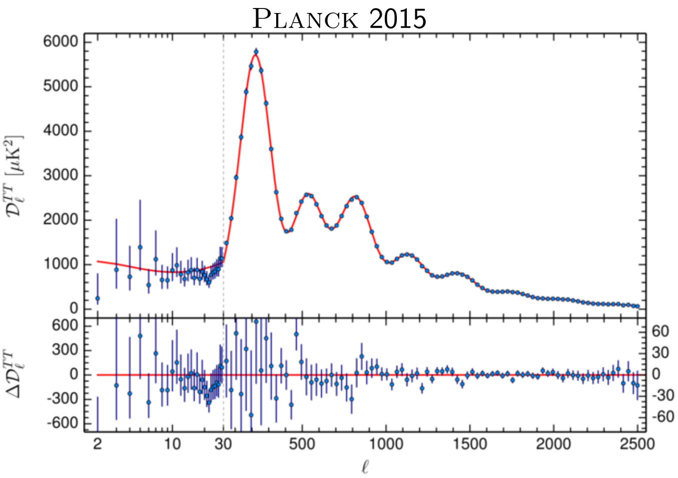
Outline

1. Intro
   - Scope
2. Inversion Method
3. Results
   - Bispectrum/Power Spectrum Correlation
   - Bispectrum/Bispectrum correlation
   - Scale Invariance of the Tensor Power Spectrum
4. Concluding Remarks

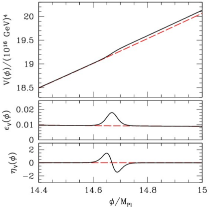
⋆ **Fact:** CMB temperature anisotropies follow nearly scale invariant, almost Gaussian statistics (Consistent with ΛCDM)

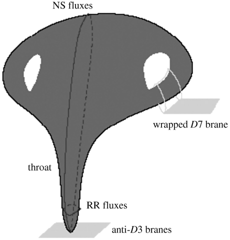
- **Fact:** CMB temperature anisotropies follow nearly scale invariant, almost Gaussian statistics (Consistent with ΛCDM)
- **Question:** Is there evidence of small deviations?

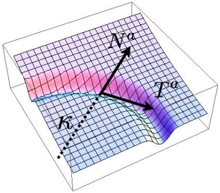
From the observational side

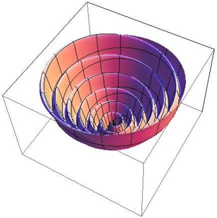


From the theoretical side

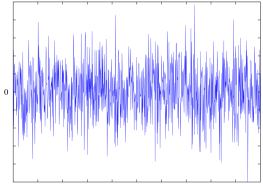






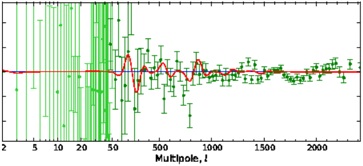


Is that noise?



Check different channels!

Or signal?



The aim is to...

see how **features** in the scalar power spectrum (data) propagate to other spectra:

- ⋆ Bispectrum/Power spectrum correlation
- ⋆ Bispectrum/Bispectrum correlation
- ⋆ Tensor/Scalar power spectrum correlation

General Idea

1. Split the theory into slow-roll/fast parts
2. Compute the fast corrections via in-in formalism / de Sitter mode function $\Rightarrow$ Fourier integrals
3. Invert

$$\Delta\mathcal{S}_i = \int A(t)$$

$$\Delta\mathcal{S}_j = \mathcal{S}_j(A)$$

$$\boxed{\Delta\mathcal{S}_i(A) \rightarrow A(\Delta\mathcal{S}_i) \rightarrow \Delta\mathcal{S}_j(\Delta\mathcal{S}_i)}$$

Bispectrum/Power Spectrum Correlation

The bispectrum template reads

Appleby/Gong/Hazra/Shafieloo/SS '15,

Palma '14

$B(P)$ with $k_1 = k,\ k_2 = xk,\ k_3 = yk$

$$B_{\mathcal{R}}(k_1, k_2, k_3) \propto \left[\left(1 + x^2 + y^2\right)\frac{x + y + xy}{16} + \frac{x^2 + y^2 + (xy)^2}{8} - \frac{xy}{8}\right](1 - n_{\mathcal{R}}) + \frac{xy}{8}\alpha_{\mathcal{R}}$$

The power spectrum is hidden in

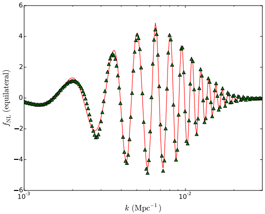
$$1 - n_{\mathcal{R}} = d \log P_{\mathcal{R}} / d \log k$$

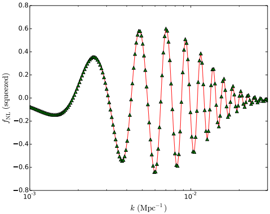
and

$$\alpha_{\mathcal{R}} = d^2 \log P_{\mathcal{R}} / d \log k^2$$

We may test this formula using numerical computation of the bispectrum for a known model with a feature in the potential:

$$V(\phi) = \frac{1}{2} m^2 \phi^2 \left[1 + \alpha \tanh\left(\frac{\phi - \phi_0}{\Delta\phi} \right) \right]$$





Prediction of $f_{\rm NL}^{\rm sq,eq}$

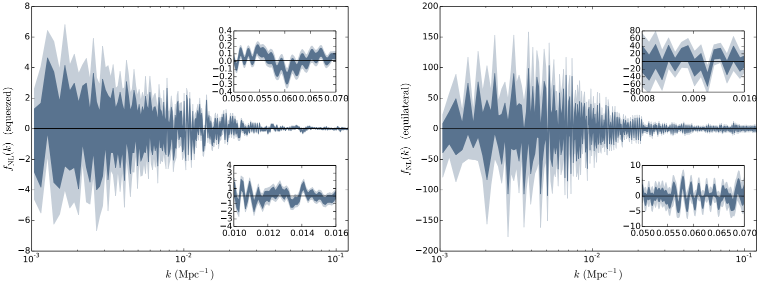


Figure: $f_{\rm NL}$ in the (left) squeezed and (right) equilateral limit. The dark (light) band encloses 68% (95%) of the reconstructed $\mathcal{P}_{\mathcal{R}}$. The plot covers the entire range considered in this work, $k = (10^{-3}, 0.12)$ Mpc^{-1}. The inset plots exhibit certain k-bands of interest.

Prediction of $f_{\rm NL}$

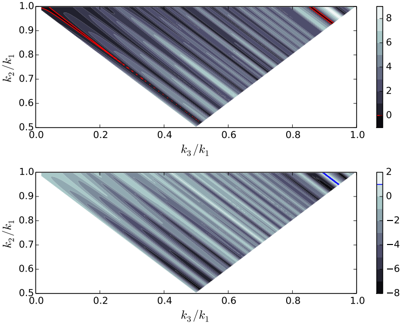


Figure: Heat maps of $f_{\rm NL}^{+2\sigma} - f_{\rm NL}^{\rm fid}$ (top) and $f_{\rm NL}^{-2\sigma} - f_{\rm NL}^{\rm fid}$ (bottom) as a function of k_3/k_1 and k_2/k_1, with $k_1 = 0.06{\rm Mpc}^{-1}$. Regions of interest are $f_{\rm NL}^{+2\sigma} - f_{\rm NL}^{\rm fid} < 0$ and $f_{\rm NL}^{-2\sigma} - f_{\rm NL}^{\rm fid} > 0$, red (blue) contours in the top (bottom) panel, indicating areas where the featureless expectation value lies outside the 95% contours.

Bispectrum Consistency Relations

Using these methods we can also produce 3-point consistency relations for a generic situation where there are features in both the potential and kinetic terms of the scalar perturbations

$$S_3 \supset \int d^4x a^3 \epsilon m_{\mathrm{Pl}}^2 \left[c_1 \dot{\mathcal{R}}^2 \mathcal{R} + \frac{c_2}{a^2} \mathcal{R} (\nabla \mathcal{R})^2 \right]$$

After computing with in-in and inverting with Fourier we get

$$\int_{-\infty}^{\infty} dk e^{-i(1+x+y)k\tau} \frac{S_{\mathcal{R}}(k,x,y)}{(2\pi)^4} k \frac{8}{2\pi i} = \frac{(1+x^2+y^2)}{2(xy)^2(1+x+y)^4} (c_2 \tau)''' - \frac{(x+y+xy)}{(xy)^2(1+x+y)^4} (c_1 \tau)'''$$

Main idea:

we may now fix 2 triangle configurations, solve the algebraic system for c_1, c_2, and plug them back to the bispectrum

An example of the concistency relation

In general: Gong/Palma/SS '17

Any 3 measurments of S at $\vec{k}$,$\vec{q}$,$\vec{p}$ are related:

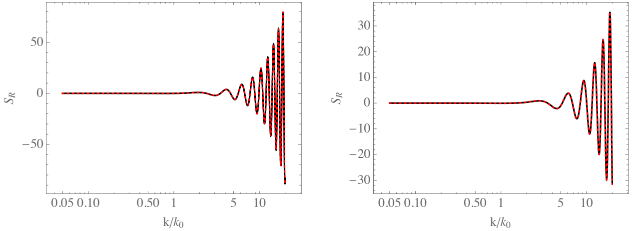
$$S_{\mathcal{R}}(k, xk, yk) = A_{\vec{x}|\vec{x}_1\vec{x}_2} S_{\mathcal{R}}\left(\omega_1 k, x_1 k, y_1 k\right) + B_{\vec{x}|\vec{x}_1\vec{x}_2} S_{\mathcal{R}}\left(\omega_2 k, x_2 k, y_2 k\right)$$

Example: Equilateral/Flattened

$$\begin{aligned} S_{\mathcal{R}}(k, x, y) = {} & \frac{18(x+y+xy) - 15(1+x^2+y^2)}{(1+x+y)^2} S_{\mathcal{R}}\left(\frac{1+x+y}{3}k, 1, 1\right) \\ & - 16\frac{x+y+xy-(1+x^2+y^2)}{(1+x+y)^2} S_{\mathcal{R}}\left(\frac{1+x+y}{2}k, 1/2, 1/2\right) \end{aligned}$$

Again, we may test these formulas using numerical computation of the bispectrum for a known model with a feature in the potential: $V(\phi) = \frac{1}{2}m^2\phi^2\left[1 + \alpha\tanh\left(\frac{\phi-\phi_0}{\Delta\phi}\right)\right]$.

For two sets of random values of x's and y's



Bispectrum Featured Templates

Inspired by the form of the consistency relation we can construct templates for the featured bispectrum:

$$\begin{aligned} S_{\mathcal{R}}(k,x,y) =& S_{\alpha_1,\alpha_2}(x,y)\sin[\omega_1 k(1+x+y)+\phi] \\ & S_{\beta_1,\beta_2}(x,y)\sin[\omega_2 k(1+x+y)+\phi] \end{aligned}$$

where

$$S_{\alpha_i,\beta_i}(x,y) \supset S_{\mathrm{eq}}, S_{\mathrm{ortho}}, S_{\mathrm{flat}}$$

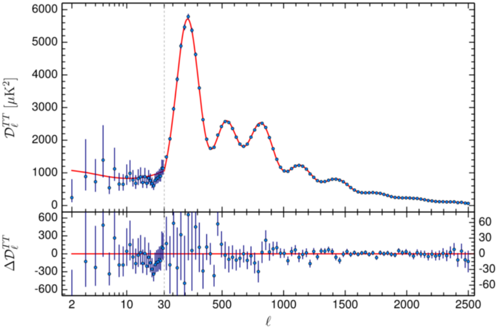
Multifrequency distribution favoured from Planck data.

We can play the same game for the tensor power spectrum:

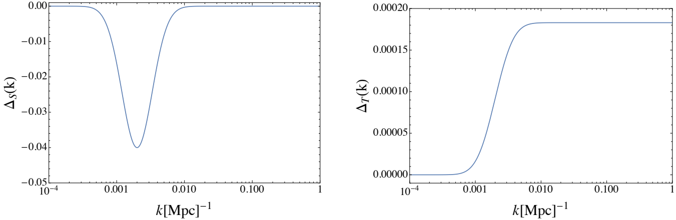
Result:

$$\frac{\Delta\mathcal{P}_T}{\mathcal{P}_0} = -6 \iint d\ln k \;\; \epsilon \frac{\Delta\mathcal{P}_S}{\mathcal{P}_0}$$

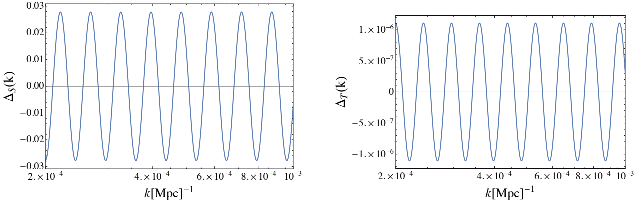
Palma/Pradenas/Riquelme/SS '16



Gaussian feature



Resonant feature



Conclusions

- ⋆ We have used inversion methods to study sharp features in the primordial spectra (supported at 2σ by PLANCK PPS data/well motivated theoretically)
- ⋆ Propagation of features in the bispectrum (potential features)
- ⋆ Propagation of features in the tensor power spectrum: persistence of scale invariance
- ⋆ Consistency relations/templates for the featured bispectrum

Future directions

- ⋆ This is a tool to produce multiple templates for any n-point function
- ⋆ Features in late-time observables? (matter power spectrum)

work in progress

¡Gracias!