

# Resonant Non-Gaussianity

Raphael Flauger  
Yale University/IPMU

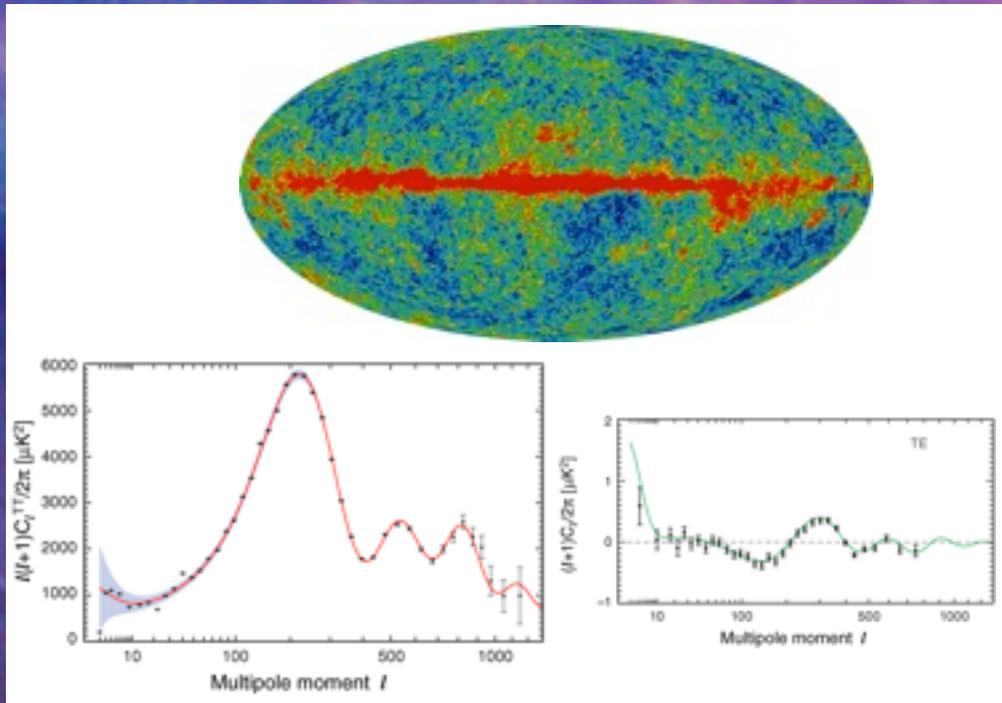
**arXiv:1002.0833**

w/  
Enrico Pajer

COSMO/CosPA 2010, September 27, 2010

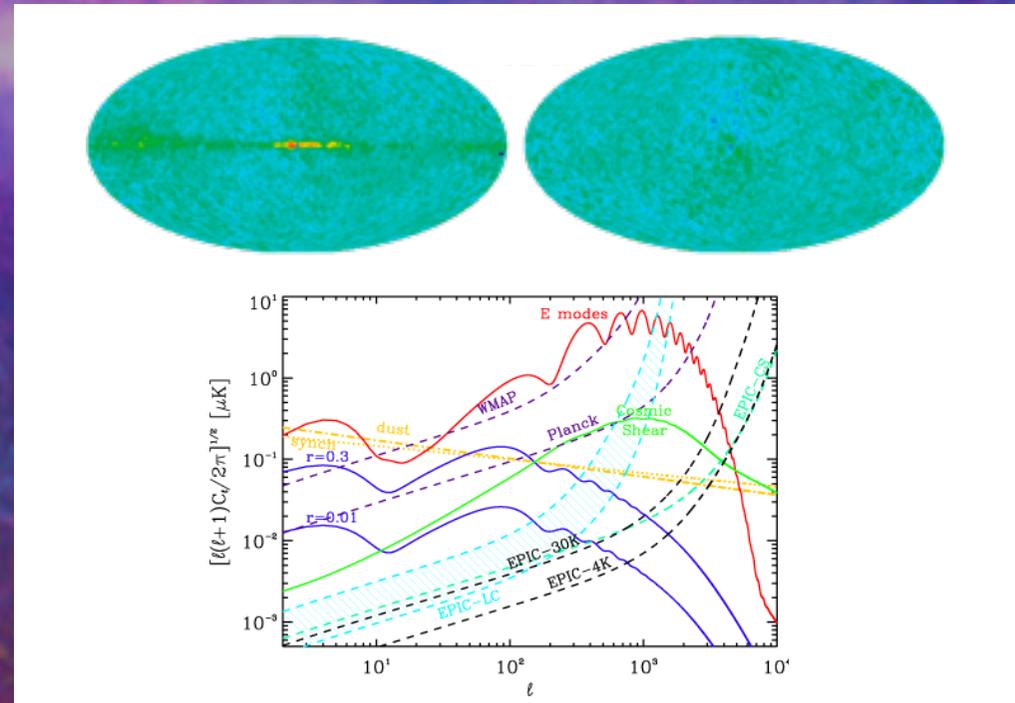
# Motivation

(Jarosik et al. 2010)



(Larson et al. 2010)

(Jarosik et al. 2010)



(Bock et al. 2009)

If a tensor signal is seen, the inflaton must have moved over a super-Planckian distance in field space\* (Lyth 1996)

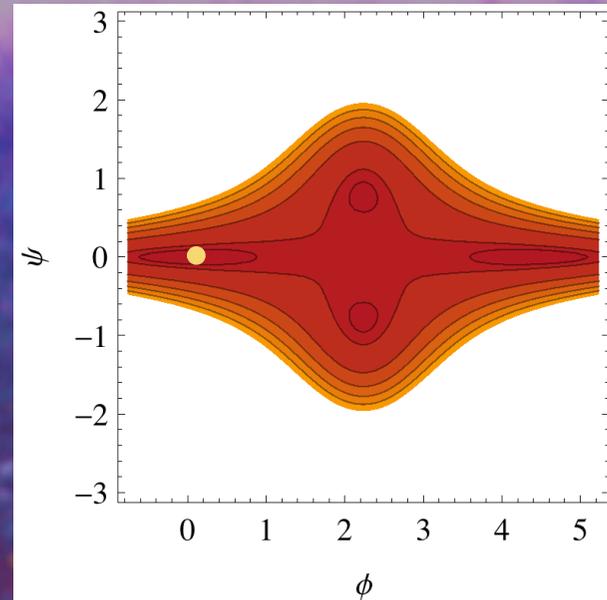
\* For single field models with canonical kinetic term

# Motivation

This is hard to control in an EFT field theory

$$V(\phi) = V_0 + \frac{1}{2}m^2\phi^2 + \frac{1}{3}\mu\phi^3 + \frac{1}{4}\lambda\phi^4 + \phi^4 \sum_{n=1}^{\infty} c_n (\phi/\Lambda)^n$$

$(\Lambda < M_p)$



The  $c_n$  are typically unknown.

Even if they were known, the effective theory is generically expected to break down for  $\phi > \Lambda$ , e.g. because other degrees of freedom become light.

# Motivation

Possible Solution:

Use a field with a shift symmetry, e.g. axion.  
Break the shift symmetry in a controlled way.

first example

Silverstein, Westphal, arXiv:0803.3085

If the inflaton is an axion, periodic contributions to the potential can arise leading to

$$V(\phi) = V_0(\phi) + \Lambda^4 \cos\left(\frac{\phi}{f}\right)$$

numerical studies

Chen, Easther, Lim, arXiv:0801.3295

Hannestad, Haugboelle, Jarnhus, Sloth, arXiv:0912.3527

# Summary of Results

## The primordial power spectrum

The usual slow-roll derivation breaks down because of parametric resonance, and the Mukhanov-Sasaki equation has to be solved.

$$\frac{d^2 \mathcal{R}_k}{dx^2} - \frac{2(1 + 2\epsilon + \delta)}{x} \frac{d\mathcal{R}_k}{dx} + \mathcal{R}_k = 0$$

with  $\epsilon = \epsilon_* - 3bf\sqrt{2\epsilon_*} \cos\left(\frac{\phi_k + \sqrt{2\epsilon_*} \ln x}{f}\right)$

$$\delta = \delta_* - 3b \sin\left(\frac{\phi_k + \sqrt{2\epsilon_*} \ln x}{f}\right)$$

$$x = k/aH \quad \text{and} \quad b = \Lambda^4/V'(\phi_*)f$$

# Summary of Results

## The primordial power spectrum

$$\frac{d^2 \mathcal{R}_k}{dx^2} - \frac{2(1 + \delta_{\text{osc}}(x))}{x} \frac{d\mathcal{R}_k}{dx} + \mathcal{R}_k = 0$$

Look for a solution

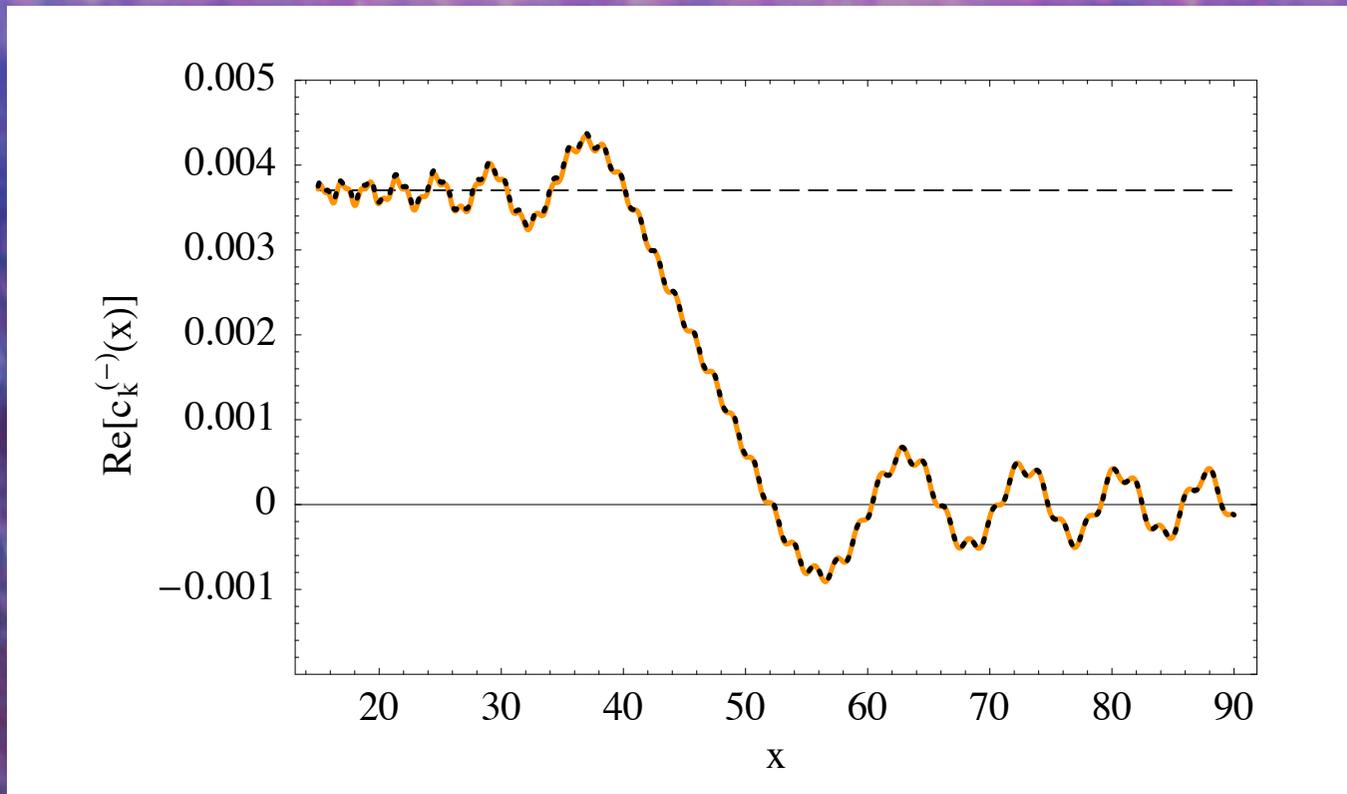
$$\mathcal{R}_k(x) = \mathcal{R}_{k,0}^{(o)} \left[ i \sqrt{\frac{\pi}{2}} x^{3/2} H_{3/2}^{(1)}(x) - c_k^{(-)}(x) i \sqrt{\frac{\pi}{2}} x^{3/2} H_{3/2}^{(2)}(x) \right]$$

Then for large  $x$

$$\frac{d}{dx} \left[ e^{-2ix} \frac{d}{dx} c_k^{(-)}(x) \right] = -2i \frac{\delta_{\text{osc}}(x)}{x}$$

# Summary of Results

## The primordial power spectrum



(Linear potential with  $f = 10^{-3} M_p$ ,  $b = 10^{-2}$ .)

# Summary of Results

## The primordial power spectrum

One finds

$$\Delta_{\mathcal{R}}^2(k) = \Delta_{\mathcal{R}}^2(k_*) \left( \frac{k}{k_*} \right)^{n_s - 1} \left[ 1 + \delta n_s \cos \left( \frac{\phi_k}{f} \right) \right]$$

with

$$n_s = 1 - 4\epsilon_* - 2\delta_* \quad \text{and} \quad \delta n_s = 3b \left( \frac{2\pi f}{\sqrt{2\epsilon_*}} \right)^{1/2}$$

(This assumes  $\frac{f}{\sqrt{2\epsilon_*}} \ll 1$ . For the general case see our paper.)

For constraints on these parameters from WMAP5 for a linear potential, see

Flauger, McAllister, Pajer, Westphal, Xu, arXiv:0907.2916

# Summary of Results

## The bispectrum

Models with large  $\dot{\delta}$  can lead to large non-Gaussianities

Chen, Easter, Lim, arXiv:0801.3295

$$\langle \mathcal{R}(\mathbf{k}_1, t) \mathcal{R}(\mathbf{k}_2, t) \mathcal{R}(\mathbf{k}_3, t) \rangle =^*$$

$$-i \int_{-\infty}^t dt' \langle [\mathcal{R}(\mathbf{k}_1, t) \mathcal{R}(\mathbf{k}_2, t) \mathcal{R}(\mathbf{k}_3, t), H_I(t')] \rangle$$

with

$$H_I(t) \supset - \int d^3x a^3(t) \epsilon(t) \dot{\delta}(t) \mathcal{R}^2(\mathbf{x}, t) \dot{\mathcal{R}}(\mathbf{x}, t)$$

\* with slight abuse of notation

# Summary of Results

## The bispectrum

After some algebra

$$\frac{\mathcal{G}(k_1, k_2, k_3)}{k_1 k_2 k_3} = \frac{1}{8} \int_0^\infty dX \frac{\dot{\delta}}{H} e^{-iX}$$

$$\left[ -i - \frac{1}{X} \sum_{i \neq j} \frac{k_i}{k_j} + \frac{i}{X^2} \frac{K(k_1^2 + k_2^2 + k_3^2)}{k_1 k_2 k_3} \right] + c.c$$

$$K = k_1 + k_2 + k_3$$

# Summary of Results

## The bispectrum

$$\frac{\mathcal{G}(k_1, k_2, k_3)}{k_1 k_2 k_3} = f^{\text{res}} \left[ \sin \left( \frac{\sqrt{2\epsilon_*}}{f} \ln K/k_* \right) + \frac{f}{\sqrt{2\epsilon_*}} \sum_{i \neq j} \frac{k_i}{k_j} \cos \left( \frac{\sqrt{2\epsilon_*}}{f} \ln K/k_* \right) + \dots \right]$$

with

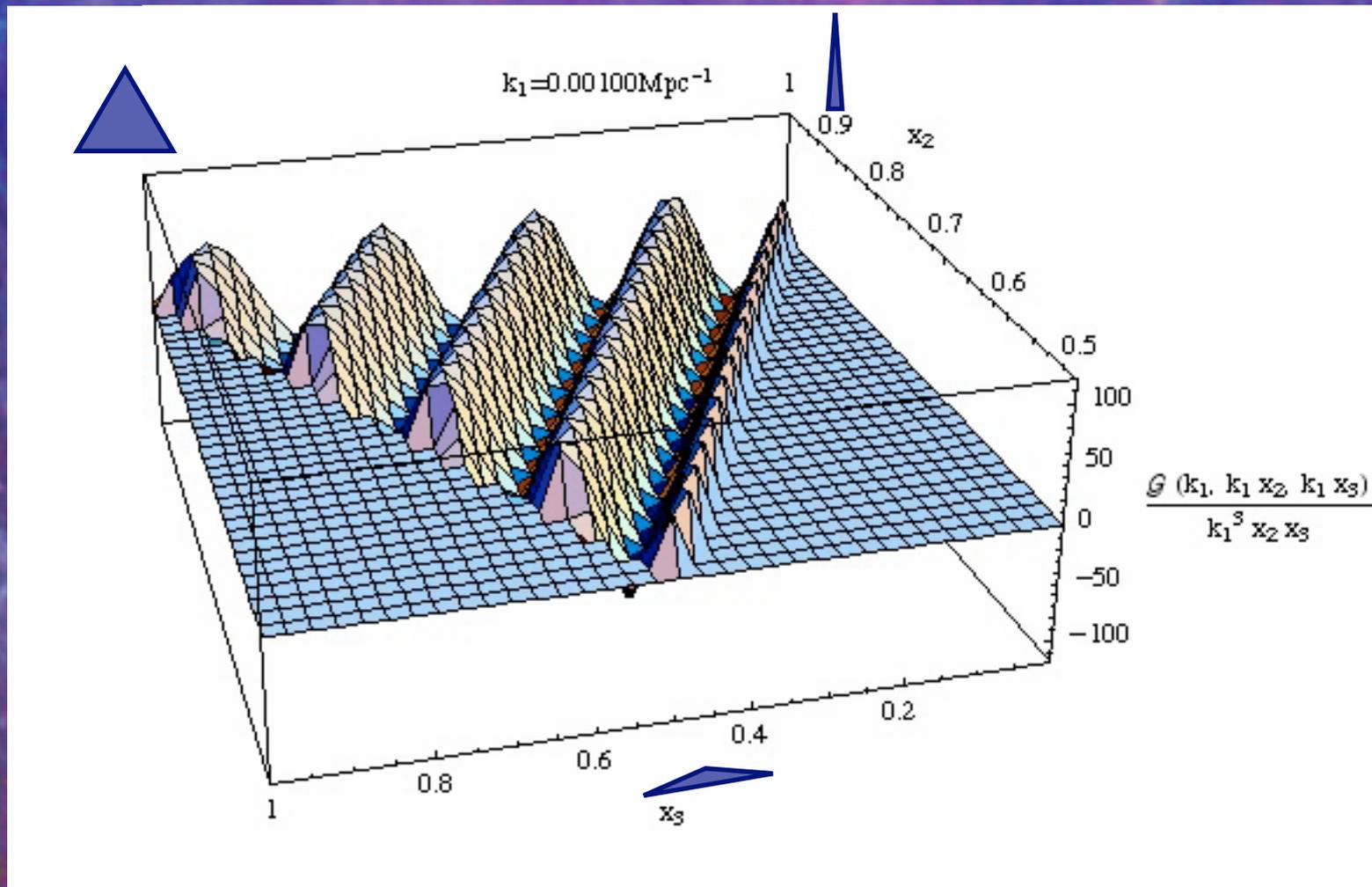
$$K = k_1 + k_2 + k_3$$

$$f^{\text{res}} = \frac{3b_* \sqrt{2\pi}}{8} \left( \frac{\sqrt{2\epsilon_*}}{f} \right)^{3/2}$$

This satisfies the consistency condition.

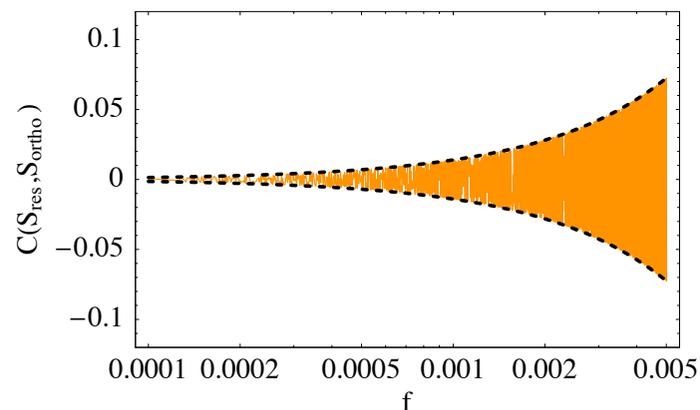
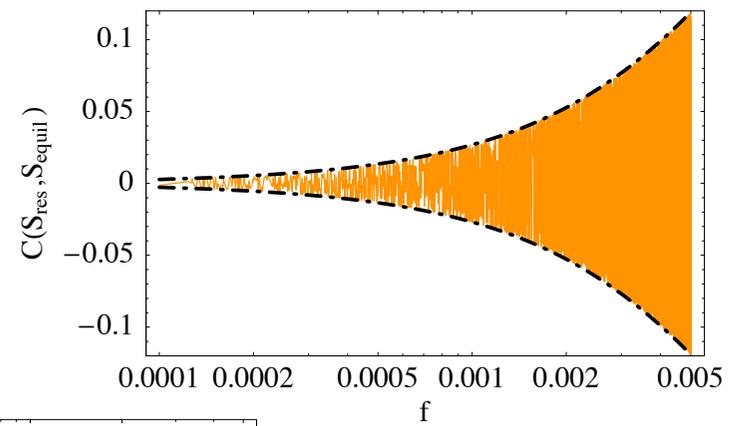
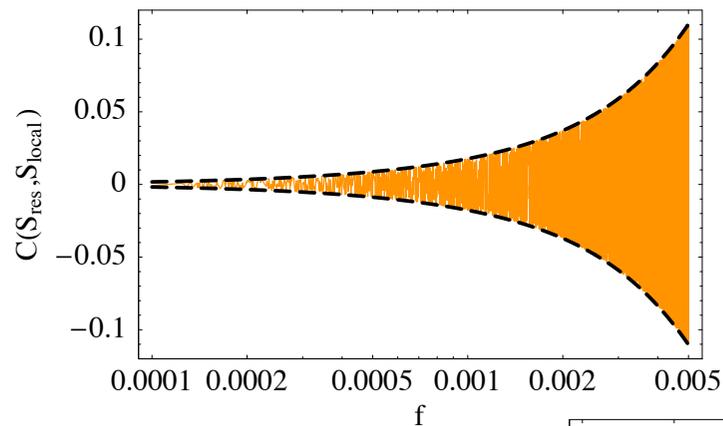
# Summary of Results

## The bispectrum



# Summary of Results

Existing constraints on local, equilateral, and orthogonal shapes cannot be used to infer constraints on this shape.



# Conclusions

- This shape of non-Gaussianities might be present in the case of large field inflation, but is currently essentially unconstrained.
- Techniques to measure this shape, or better yet general shapes are desirable. E.g.

Fergusson, Liguori, Shellard, arXiv:0912.5516

Meerburg, arXiv:1006.2771

- Our analytic results will hopefully aid in constraining this shape.
- Still more work to be done...



Thank you

ご静聴ありがとうございました。