Signatures of a discreet shift symmetry in the Effective Field Thoery of Inflation
(Single field) models of inflation with large NG

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work in progress in collaboration with
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Motivation

Need unified framework to compute observational signatures of various inflationary models

- Effective Field Theory of Inflation
  C. Cheung, P. Creminelli, A. L. Fitzpatrick, J. Kaplan, L. Senatore

Single field inflation normally yields small NG

- Periodic potential leads to resonant enchantment of signal – resonant NG
  - Periodic potential enhances signal
    X. Chen, R. Easther and E. Lim'08
  - String Theory model with periodic potential
    L. McAllister, E. Silverstein and A. Westphal'08
  - Analysis of resonant models, many point correlators
    R. Flauger and E. Pajer, L. Leblond and E. Pajer'10
  - Resonant model of scalar field with arbitrary kinetic term and potential
    X. Chen'10

Outline

How can we see signatures of resonance during inflation?

S. Behbahani, AD, M. Mirbabayi and L. Senatore, in progress

The model

- General principle behind resonance: discreet shift symmetry
- Discreet symmetry leads to naturalness (cf. models with Gallilean symmetry, talk by P. Creminelli)
- Add periodic time dependence to the Lagrangian in "unitary gauge"

Results

- Large observable non-Gaussianities
- Highly oscillating shape orthogonal to equilateral, local and orthogonal shapes
- *The signal of resonance behavior in power spectrum is (almost) always larger than the signal in bispectrum*

Details: EFT of (single field) Inflation

There is a plethora of single field models of inflation... How can one unify them: effective field theory

C. Cheung, P. Creminelli, A. L. Fitzpatrick, J. Kaplan, L. Senatore

- At low energies $H^2 \ll \epsilon M_{\rm Pl}^2$ physics is described by the Goldstone boson π
- Corrections from gravity modes are negligible (and can be systematically evaluated)
- Systematic expansion in π^n

$$\int d^4x\sqrt{-g}\left[-M_{\rm Pl}^2\dot{H}\left(\dot{\pi}^2-\frac{(\partial_i\pi)^2}{a^2}\right)+2M_2^4\left(\dot{\pi}^2+\dot{\pi}^3-\dot{\pi}\frac{(\partial_i\pi)^2}{a^2}\right)-\frac{4}{3}M_3^4\dot{\pi}^3+\dots\right]$$

- To yield predictions field theory has to be weakly coupled!

Discrete Shift Symmetry and resonance

Small oscillations on top of smooth history

$H = H_0 + H_{osc} \sin(wt)$ assuming $H_{osc} \ll H_0$ such that

$$\epsilon = -\frac{\dot{H}}{H^2} \sim -\frac{\dot{H}_0}{H_0^2} \ll 1$$

$$\alpha \equiv \frac{w}{H} \gg 1 \qquad \epsilon_{osc} = \frac{\alpha}{\epsilon} \frac{H_{osc}}{H_0} \ll 1$$

Oscillatory term dominates starting $\ddot{H}$ level

Power spectrum

$$\langle \zeta\zeta \rangle = (2\pi)^3 \delta(\mathrm{k} + \mathrm{k}') \frac{H^2}{4\epsilon M_{\mathrm{Pl}}^2 k^3} \left(1 + \epsilon_{osc} \alpha^{1/2} \cos\left(\alpha \log \frac{k}{k^*}\right)\right)$$

Bispectrum and n-point functions

Bispectrum

$$\langle\zeta^3\rangle \sim (2\pi)^3\delta(\sum \mathrm{k})\frac{c_s^4}{(1-c_s^2)}\epsilon_{osc}\alpha^{5/2}\frac{\zeta^4}{K^3\prod k_i}\cos\left(\alpha\log\frac{k}{k^*}\right)+\ldots$$

enhanced by α in the folded limit

Non-Gaussianity

$$\boxed{f_{NL} \sim \frac{\langle\zeta^3\rangle}{\zeta^4} \sim \epsilon_{osc}\alpha^{5/2}}$$

While $\epsilon_{osc}\alpha^{1/2} \ll 1$, f_{NL} can be observable

n-point function

$$\langle\prod\zeta_i\rangle = (2\pi)^3\delta(\sum \mathrm{k})\epsilon_{osc}\alpha^{2n-7/2}\frac{\zeta^{2(n-1)}}{K^{n-3}\prod k_i^2}\cos\left(\alpha\log\frac{k}{k^*}\right)+O(1/\alpha)$$

Shape of NG signal

- α enhancement in the folded limit
- rapid oscillations with momentum
- cos with local, equilateral and orthogonal shapes is suppressed as $\alpha^{-3/2}$

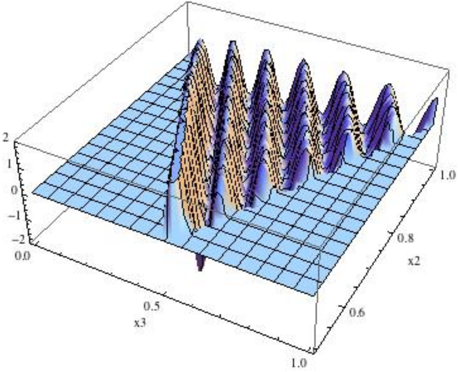

Figure: Shape of bispectrum for $\alpha = 50$ away from the folded limit.

Predictability: weak coupling regime

At what point theory enters strong coupling?

UV scale when coupling becomes of order one:

$L \sim \sum \varphi^n / \Lambda^{n-4}$

$$\cos(wt) \to \cos(wt)\cos(w\pi) \to \cos(w\varphi/(\epsilon^{1/2} H M_{\rm Pl}))$$

$$\boxed{\Lambda \sim \epsilon^{1/2}\alpha^{-1} M_{\rm Pl}}$$

Weak coupling (predictability) requires

$$\boxed{w < \Lambda \Rightarrow \alpha^2 < \epsilon^{1/2} M_{\rm Pl}/H \sim \zeta^{-1}}$$

Signal to noise ratio for n-point function

Brainteaser: Where's the strongest signature of resonance behavior? Answer: In the power spectrum

$$\frac{S}{N}\langle\zeta^n\rangle = \int^{k_{max}} d^{3n}k \frac{\langle\zeta^n\rangle\langle\zeta^n\rangle}{\langle\zeta^{2n}\rangle} \sim \left(\frac{\mathcal{L}_n}{\mathcal{L}_2}\right)^2 \sim \epsilon_{osc}^2(\alpha^2\zeta)^{2n}\alpha^{-7}\zeta^{-4}$$

but predictability (weak coupling) requires

$$\boxed{\alpha < \zeta^{-1/2} \sim 10^2}$$

The same result, more intuitively

$$\frac{\langle\zeta^n\rangle}{\langle\zeta^2\rangle^{n/2}} \sim \frac{\mathcal{L}_n}{\mathcal{L}_2} \simeq \left(\frac{\varphi}{\Lambda}\right)^{n-2} \simeq \left(\frac{w}{\Lambda}\right)^{n-2} < 1$$

Conclusions

We systematically analyze single field inflationary models with discreet shift symmetry

- reproduced previous results found in literature including n-point functions
- systematically investigated possible shapes of NG
- estimated corrections from slow roll and mixing with gravity
- outlined the range of parameters when theory is weakly coupled
- signal to noise ratio favors power spectrum over bispectrum etc. in the allowed range of parameters
  possible exceptions if speed of sound is small