Probing the Inflaton Coupling to Matter with Nongaussianity

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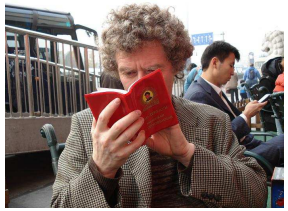
References & Collaborators

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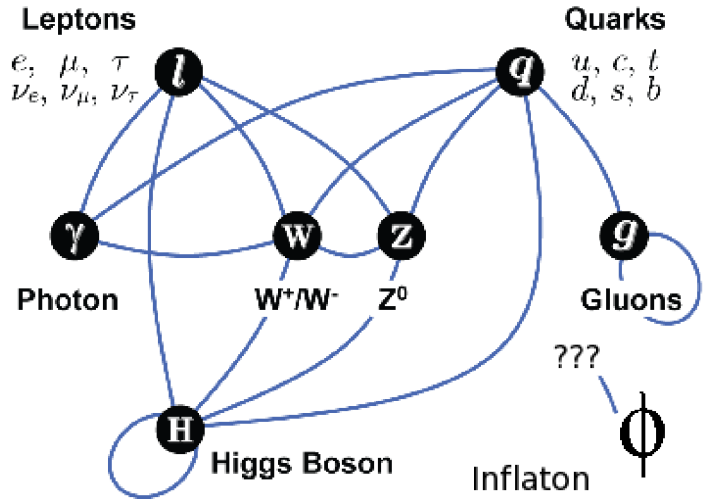
Primordial NG

- Powerful probe of inflation...
- ...but only if $f_{NL} \gtrsim 1$.
- What level can we expect?



Classifying Interactions

$$\mathcal{L} = \mathcal{L}_{\rm inf}\left[\phi, \cdots\right] + \underbrace{\mathcal{L}_{\rm matter}\left[\psi, A_\mu, \cdots\right]}_{\rm SM,DM,etc} + \mathcal{L}_{\rm coupling}$$

- **Self interactions of ϕ:**
  - Weak in simplest models: $f_{NL} \sim \mathcal{O}(\epsilon, \eta)$.
- **Coupling to Matter Sectors:**
  - Generic, necessary to reheat.
  - Less constrained by SR, promising source of NG.

Strategy

- "Matter" couplings depend on microphysics
- Two simple examples:
  1. Axion couplings:[a] $\phi F\tilde{F}$
  2. Coupling to heavy fields:[b] $\phi^2\chi^2$

[a] NB & Peloso (2011); NB, Namba & Peloso (2011).
[b] NB et al (2009); NB & Huang (2010); NB (2010).

Results

- $f_{NL} \gtrsim 1$ **from simple models of slow roll inflation.**[a]
  - Reason to be optimistic for detection?
- **Structure of "matter" couplings already constrained.**
  - Hints about particle physics identity of ϕ?

[a] "simple" = smooth $V(\phi)$, canonical kinetic term, Bunch-Davies, $\cdots$

First Example: Axion Couplings

Inflation with a Shift Symmetry

Flat $V(\phi)$ naturally protected by shift symmetry:[a]

$$\phi \to \phi + c$$

[a] eg - Natural Inflation (Freese et al, 1990). Also: Kim, Nilles & Peloso, N-flation, monodromy, Dante's inferno, 4-form mixing, $\cdots$

Effective Field Theory:

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 - \frac{1}{f}\phi G\tilde{G} - \frac{\alpha}{f}\phi F\tilde{F} + \cdots$$

- Soft breaking: $\delta V(\phi) = \mu^{4-p}\phi^p + \Lambda^4 \cos(\phi/f)$.
- Axion interactions:
  - unavoidable (no "extra" ingredients)
  - consistent with symmetry

Probing Axion Interactions with CMB?

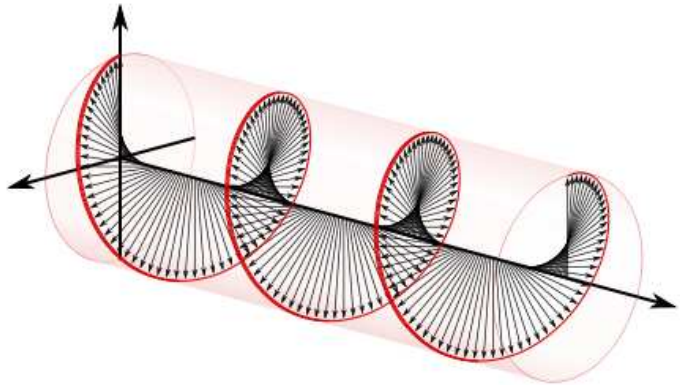
$$\mathcal{L}_{\rm int} \supset -\frac{\alpha}{f}\phi F\tilde{F} + \cdots$$

Coupling to $\phi(t) \Rightarrow$ particle production.

Gauge Field Production

$$\left[\frac{\partial^2}{\partial\tau^2} + k^2 \underbrace{\pm\frac{\alpha\dot{\phi}}{fH}\frac{k}{\tau}}_{\equiv m_{\rm eff}^2}\right] A_\pm(k,\tau) = 0$$

- One pol state has $m_{\rm eff}^2 < 0$.
- Tachyonic instability!



- Exponential growth of fluctuations δA_μ.

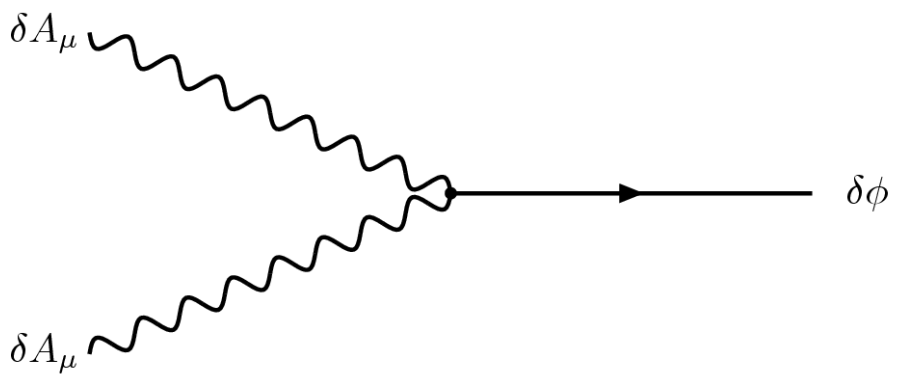
Produced Gauge Fluctuations Source Cosmol Perts (NB & Peloso, 2011)

$$\delta\ddot{\phi} + 3H\delta\dot{\phi} - \frac{\vec{\nabla}^2}{a^2}\delta\phi + m^2\delta\phi = \frac{\alpha}{f}F^{\mu\nu}\tilde{F}_{\mu\nu}$$

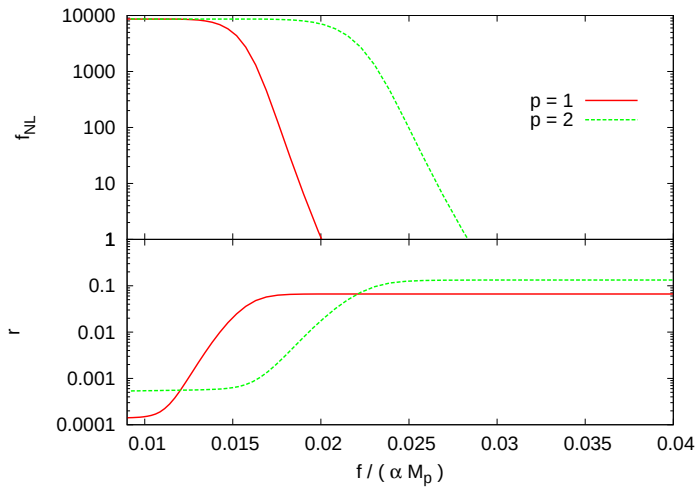
$$\delta\phi = \underbrace{\delta\phi_{\rm vac}}_{\text{homogeneous}} + \underbrace{\delta\phi_{\rm inv.decay}}_{\text{particular}}$$

- Vaccum fluct: $\delta\phi_{\rm vac} \sim H/(2\pi)$
- Inverse decay fluct are highly nongaussian!

- $f_{NL} \gtrsim 1$ when $f \ll M_p$
- required anyway for EFT.



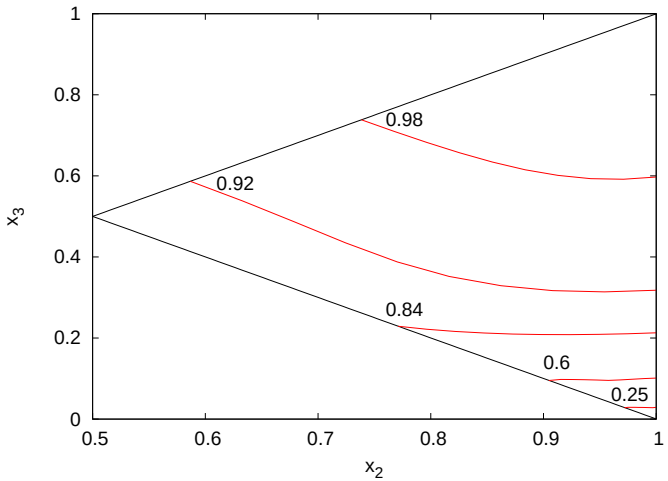
Phenomenology of Axion Couplings



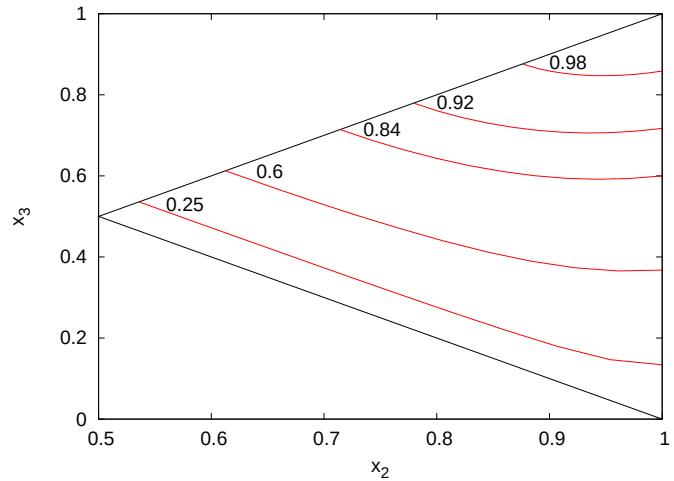
Bounds

- Axion Inflaton (from NG):
  - $\frac{\alpha}{f} \lesssim 10^{-16}\,\mathrm{GeV}^{-1}$
- QCD Axion (from stars):
  - $\frac{\alpha}{f} \lesssim 10^{-11}\,\mathrm{GeV}^{-1}$

Shape: Axion NG

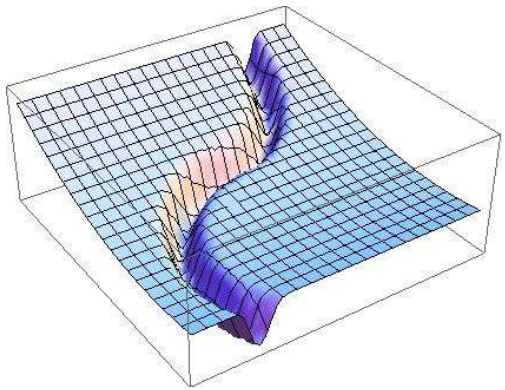


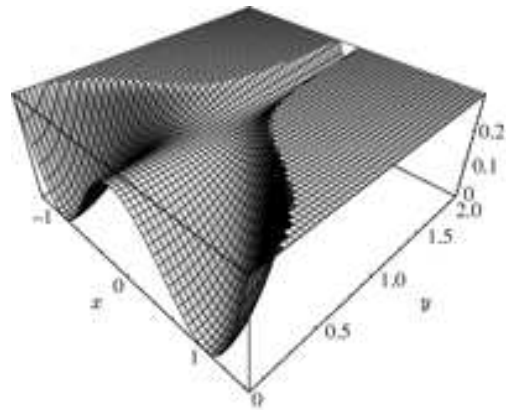
Shape: Equil Template



Second Example: Heavy Particle Production

- Nonadiabatic processes during inflation can excite heavy iso-curvature modes.
  - enhanced symmetry points[1]
  - sharp turn in multi-field inflation[2]
  - phase transitions, $\cdots$





Heavy χ Modes MUST Couple to ϕ

Can we probe observationally the $\phi \leftrightarrow \chi$ coupling?

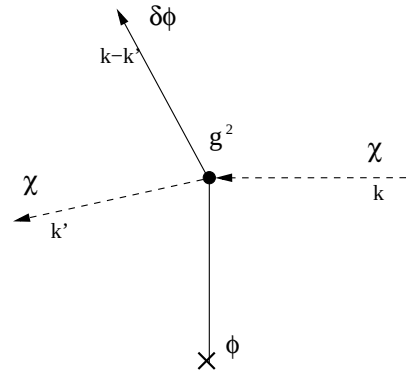
[1] Kofman et al; Chung, Kolb, Riotto & Tkatchev; Romano & Sasaki; Green, Horn, Senatore & Silverstein; NB et al

[2] Achucarro et al, X. Chen, Shui & Xu, $\cdots$

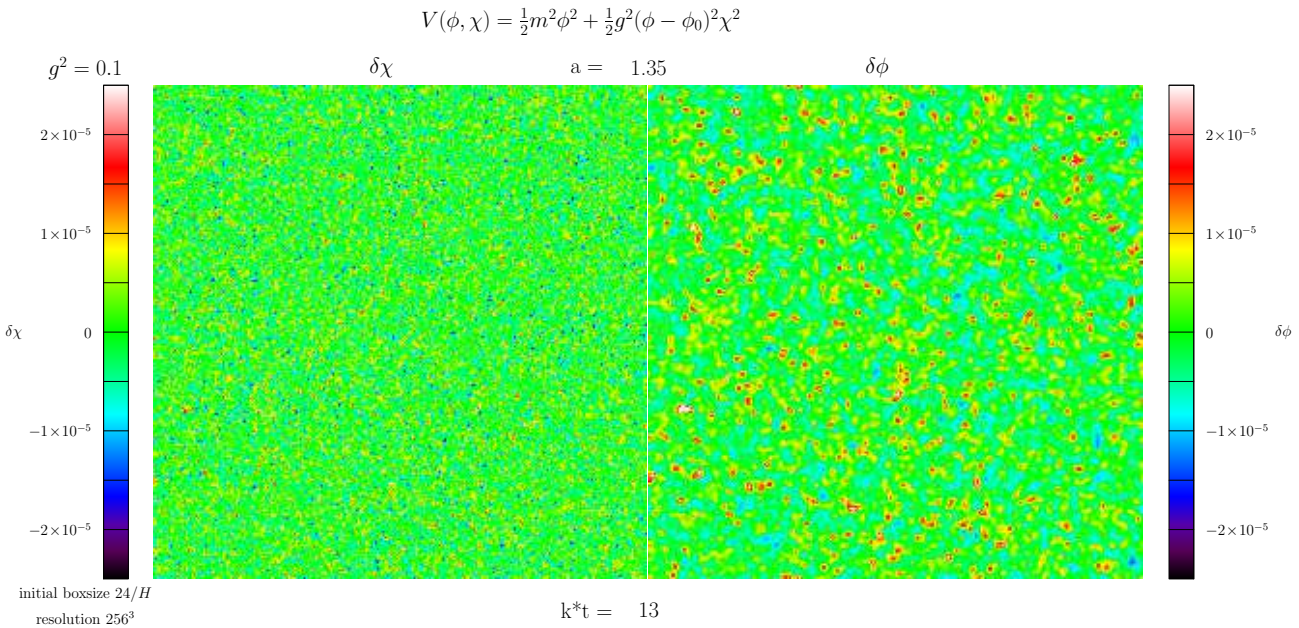
Heavy Particle Production: A Toy Model

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 - V(\phi) - \frac{1}{2}(\partial\chi)^2 - \frac{g^2}{2}(\phi-\phi_0)^2\chi^2$$

- χ-particle production at $\phi = \phi_0$.
- rescattering of produced quanta $\Rightarrow \delta\phi$



NB, Huang, Kofman & Pogosian (2009)



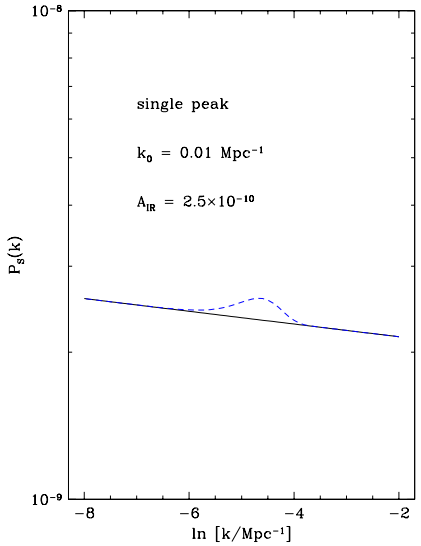
Rich Dynamics

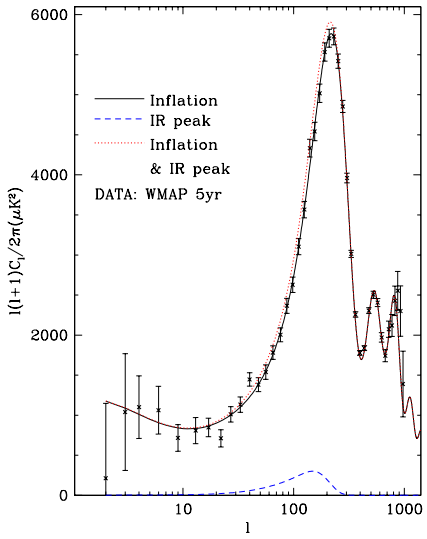
- turbulence
- IR cascading

Observational Signatures

- Bump-like feature in $P(k)$.
- Compatible with CMB for $g^2 \lesssim 0.01$.[a]

[a] NB & Huang 2009; Chavat, Gordon & Silk 2010

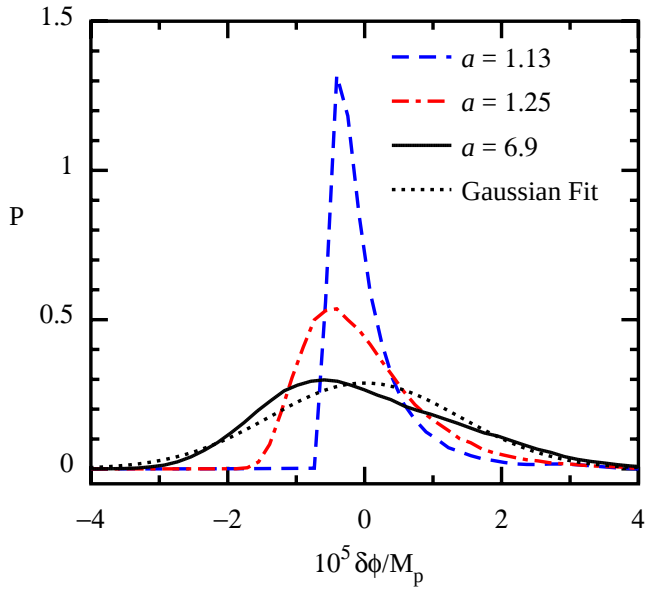




Nongaussian Features

- Unusual NG signature[a]
  - localized, uncorrelated
- Skewness equiv to $f_{NL}^{\rm local} = -53$.
  - Plausibly detectable.

[a] NB 2010



Conclusions

- ϕ couples to "matter" fields.
  - natural place to look for NG, unconstrained by SR
  - minimalist, previously overlooked
- Probe couplings with NG.
  - already interesting constraints
  - hints of particle physics identity of ϕ?
- Challenge to conventional lore.
  - **Observable NG from simple, slow-roll, single-field inflation.**

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Thank you!