Quasi-Single Field Inflation and Critical Test of Multi-Field Inflation

Xingang Chen

Center for Theoretical Cosmology,
DAMTP, Cambridge University

X.C., Yi Wang, 0909.0496; 0911.3380, 1205.0160
E. Sefusatti, J. Fergusson, X.C., P. Shellard, 1204.6318

In the last paragraph of my review article on Non-Gaussianity (1002.1416):

" …., **primordial non-Gaussianity** – the collider in the very early universe – is one of the few hopes (*to go beyond the ΛCDM standard model*). ……. We do not know which cards Nature is hiding from us, but we are hoping and preparing for the best."

This is exactly we are doing here:

In this workshop, we are a bunch of **OPTIMISTS**.

Working Assumption

Planck observes some non-Gaussianity, e.g. the local fNL, with more than 3σ, or even 5σ, confidence level.

What does this imply and what shall we do next?

Among many other things, …. (to be discussed in this conference) …,

this will be **the official establishment** of ……

… the Emerging Field of

Density Perturbation Phenomenology:

-- Learning fundamental physics from density perturbation maps --

Scattering amplitudes in colliders: $\, _{\mathrm{out}}\langle \mathbf{p}_1 \mathbf{p}_2 \cdots | \mathbf{k}_{\mathcal{A}} \mathbf{k}_{\mathcal{B}} \rangle_{\mathrm{in}}$

Particle physics phenomenology

Density perturbation phenomenology

Correlation functions in maps: $\, _{\mathrm{in}}\langle \frac{\delta\rho}{\rho}(x_1) \frac{\delta\rho}{\rho}(x_2) \cdots \rangle_{\mathrm{in}}$

In the previous working assumption, what we assumed to know, more precisely, is that, the non-G in data has a large local shape projection.

In this talk, **we probe the mass spectra of inflation models**

by asking: **What is the more precise shape of this non-Gaussianity?**

- **A key formula:**

$$\alpha = \frac{1}{2} - \sqrt{\frac{9}{4} - \frac{m^2}{H^2}}$$

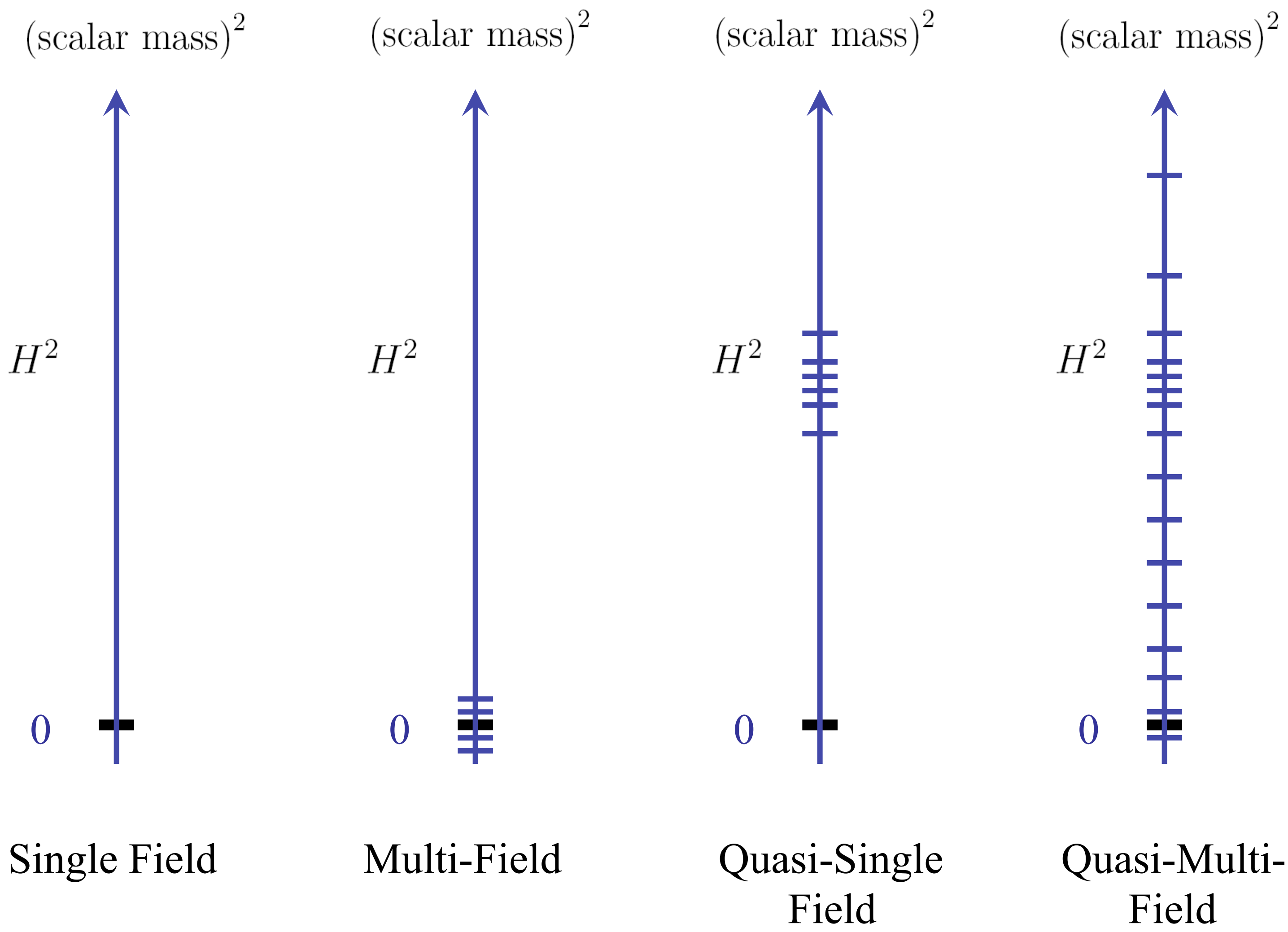
(X.C., Wang, 09)

Shape of non-G

$$S \to f_{NL} \left(\frac{p_L}{p_S} \right)^{\alpha}$$

Spectrum of inflation model

Mass Spectra Define Several Classes of Inflation Models

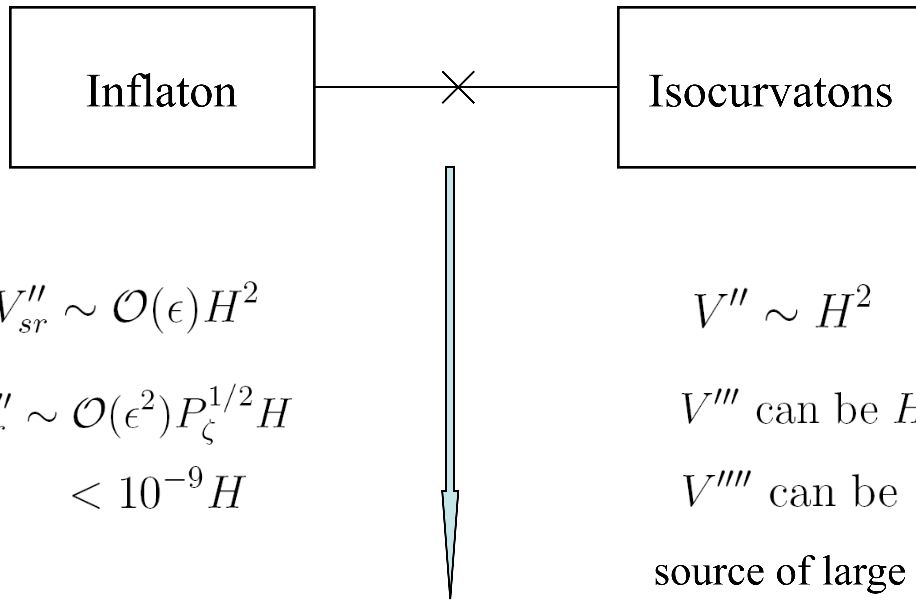


What are the Observable Signatures of These Isocurvatons $(0 < m < \sim H)$?

A special kind of large non-Gaussianities

Large

A New Sector



$V''_{sr} \sim \mathcal{O}(\epsilon) H^2$

$V'''_{sr} \sim \mathcal{O}(\epsilon^2) P_\zeta^{1/2} H$

$< 10^{-9} H$

$V'' \sim H^2$

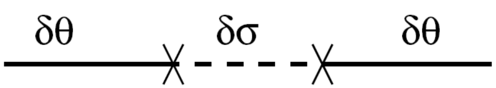
V''' can be H

V'''' can be 1 , etc

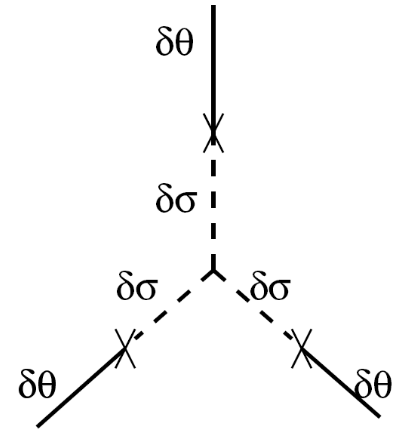
source of large non-G

Introducing coupling without spoiling the slow-roll conditions

Perturbation Method and Feynman Diagrams



Correction to 2pt



3pt

Perturbation theory: $\left(\frac{\dot{\theta}}{H}\right)^2 \ll 1 \ , \quad \frac{V'''}{H} \ll 1 \ .$

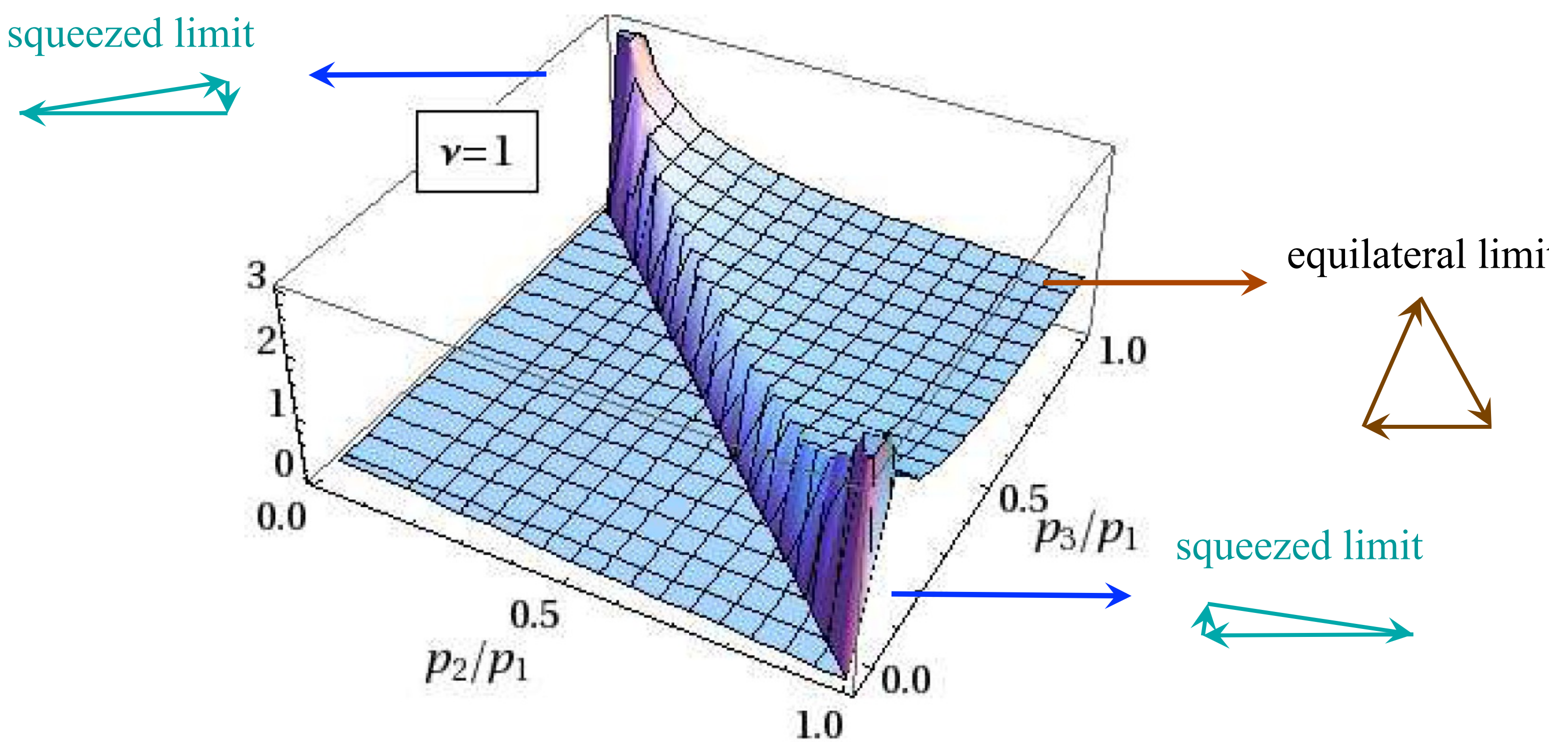
But not model-building requirements

Special

Shapes of Bispectra

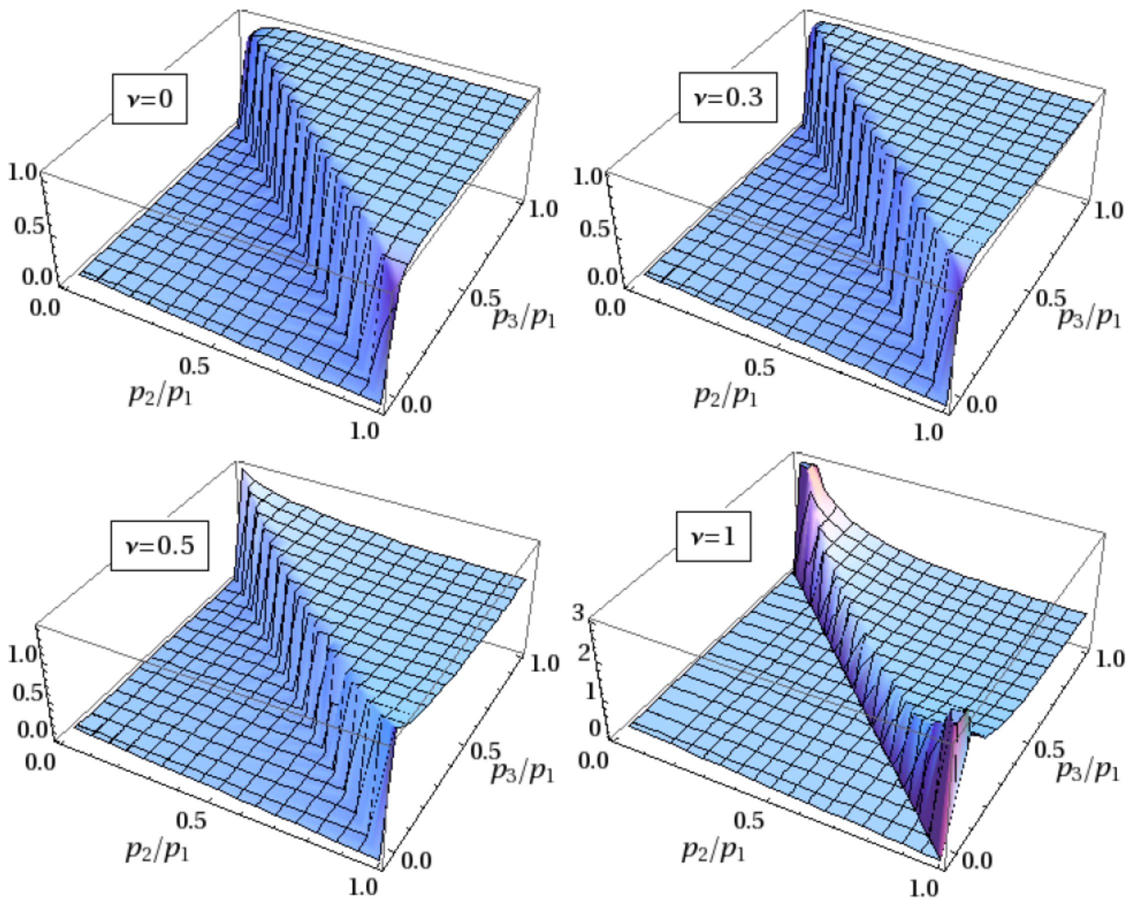
$$\langle \zeta^3 \rangle \equiv S(k_1, k_2, k_3) \frac{1}{(k_1 k_2 k_3)^2} \tilde{P}_\zeta^2 (2\pi)^7 \delta^3 (\sum_{i=1}^{3} \mathbf{k}_i)$$

$$S(p_1, p_2, p_3) \xrightarrow{\text{scale-invariance}} S(1, p_2/p_1, p_3/p_1)$$



Shapes of Bispectra

(X.C., Wang, 09)

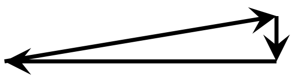


$$\nu \equiv \sqrt{\frac{9}{4} - \frac{m^2}{H^2}}$$

Shapes of bispectrum (in squeezed limit) directly measure the mass

Soft Limit

Squeezed-limit: $p_3 \ll p_1 = p_2$



Shape: $$S \to f_{NL} \left(\frac{p_3}{p_1} \right)^{\alpha}$$

$$\alpha = \frac{1}{2} - \sqrt{\frac{9}{4} - \frac{m^2}{H^2}}$$

$m: \; 0 \to 3H/2$ $\quad S: \; \left(\frac{p_3}{p_1} \right)^{-1} \to \left(\frac{p_3}{p_1} \right)^{1/2}$

Local shape

Underlying Physics

- Quasi-local: for lighter isocurvaton $m < \sqrt{2}H$, i.e. $3/2 > \nu > 1/2$

Fluctuations decay slower after horizon-exit

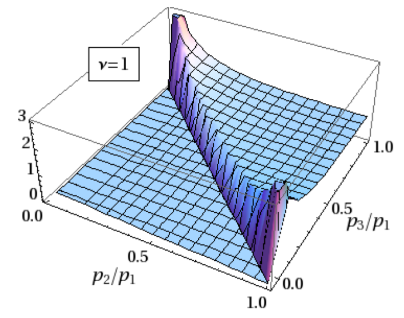
⇩

Non-G gets generated and transferred at more super-horizon scale

⇩

Closer to local shape.

Classical-like



- Quasi-equilateral: for heavier isocurvaton $m > \sqrt{2}H$, i.e. $\nu < 1/2$

Fluctuations decay faster after horizon-exit

⇩

Large interactions happens closer to the horizon scale

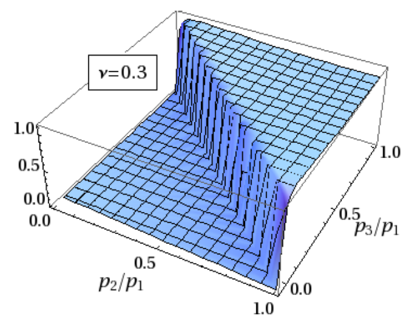
⇩

Modes have comparable wavelengths

⇩

Peaks at equilateral limit

Quantum-like



Critical Test of Multi-Field Slow-Roll Inflation Models

Multi-Field Inflation

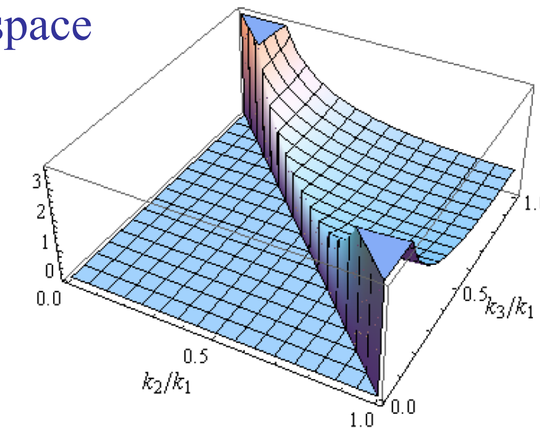
Isocurvaton mass: $m^2 = \mathcal{O}(0.01)H^2$

- Massless scalars fluctuations do not decay $\longrightarrow$ span multifield space
- Patches that are separated by horizon evolve independently (locally)

$$\zeta(\mathbf{x}) = \zeta_g(\mathbf{x}) + f_{NL}\zeta_g^2(\mathbf{x})$$

(Sasaki, Stewart,95;
Lyth, Rodriguez, 05)

Local in position space ⇨ Non-local in momentum space



From the above δN formalism: $S \propto \left(\frac{p_3}{p_1}\right)^{-1}$

From in-in formalism:

$$\alpha = \frac{1}{2} - \sqrt{\frac{9}{4} - \frac{m^2}{H^2}} \quad \xrightarrow{m \to 0} \quad \alpha \to -1$$

Critical Test from the Soft Limit

- $\alpha > -1$ will rule out all multi-field (slow-roll) models as source of density perturbations. I.e., massive isocuvaton is necessary.

  (Including: multifield turning trajectory, curvaton model, inhomogeneous reheating, …)

- Some quasi-single field models are very degenerate with multi-field models

E.g. $\alpha = -0.9 \Longleftrightarrow m = 0.54H$

Non-G is very close to local, but model is not multi-field slow-roll.

So a detection of a local component could mean either multi-field or QSF.

- Important to see what the experimental sensitivities are

How do We Measure the Shapes in the Sky?

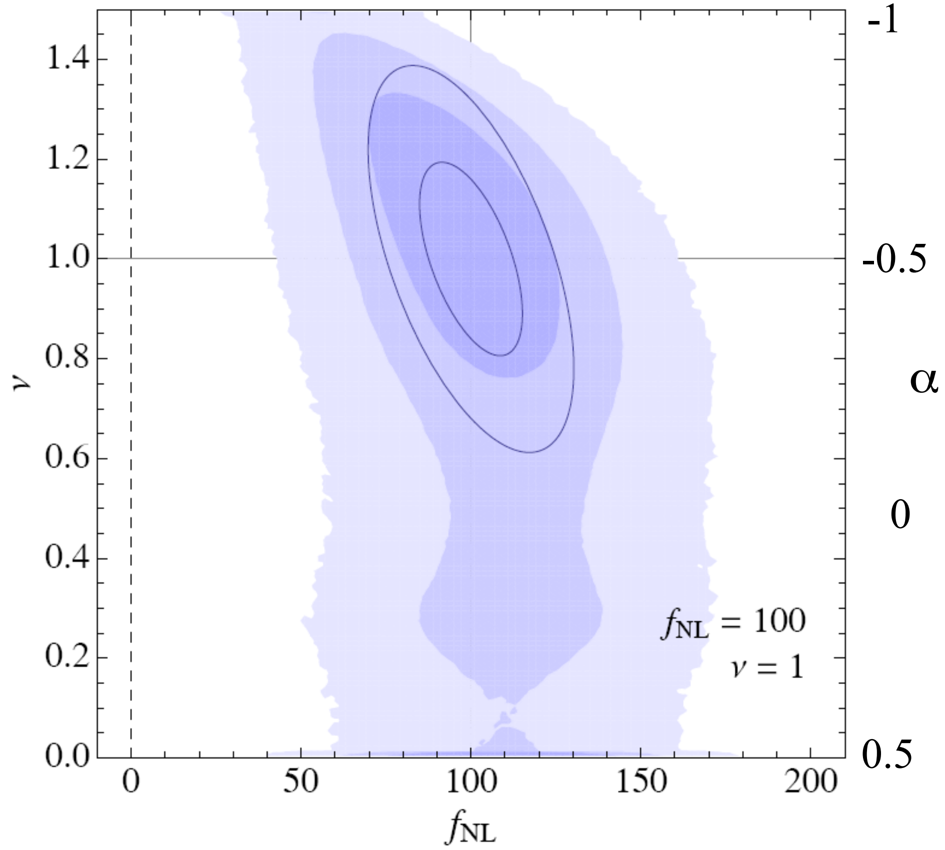
If a large non-Gaussianity f_{NL} is detected by Planck,

how much can we refine our discovery to pin down the shapes α ?

Cosmic Microwave Background

Planck Forecast for Constraints on QSFI

(Sefusatti, Fergusson, X.C., Shellard, 12)



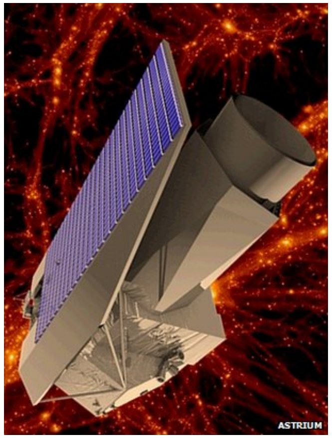
$\alpha = \frac{1}{2} - \nu$

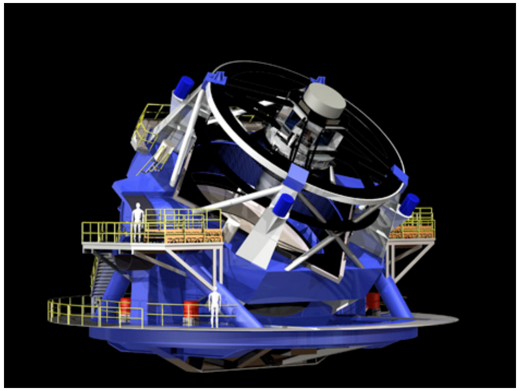
Constraint on f_{NL} will be better than constraint on ν

Lines: Fisher matrix
Shades: Monte Carlo

Normalization difference: $f_{NL}^{\nu=1} = 3.3 f_{NL}^{\text{loc}}$

Large Scale Structure Surveys





Euclid Satellite:

- 20,000 degree-squared
- 3D map, $0.4 < z < 2$
- Launch in 2019

Denote as V1

LSST telescope:

- 30,000 degree-squared
- 3D map, $0.3 < z < 3.8$
- Taking data in 2020

Denote as V2

Large Scale Structures

Halo Bias: $b = \dfrac{\text{halo overdensity}}{\text{matter overdensity}}$

Determined by the long wavelength modulation on short wavelength modes

For local shape: $b \propto f_{NL}\ k^{-2}$ (Dalal, Dore, Huterer, Shirokov, 07)

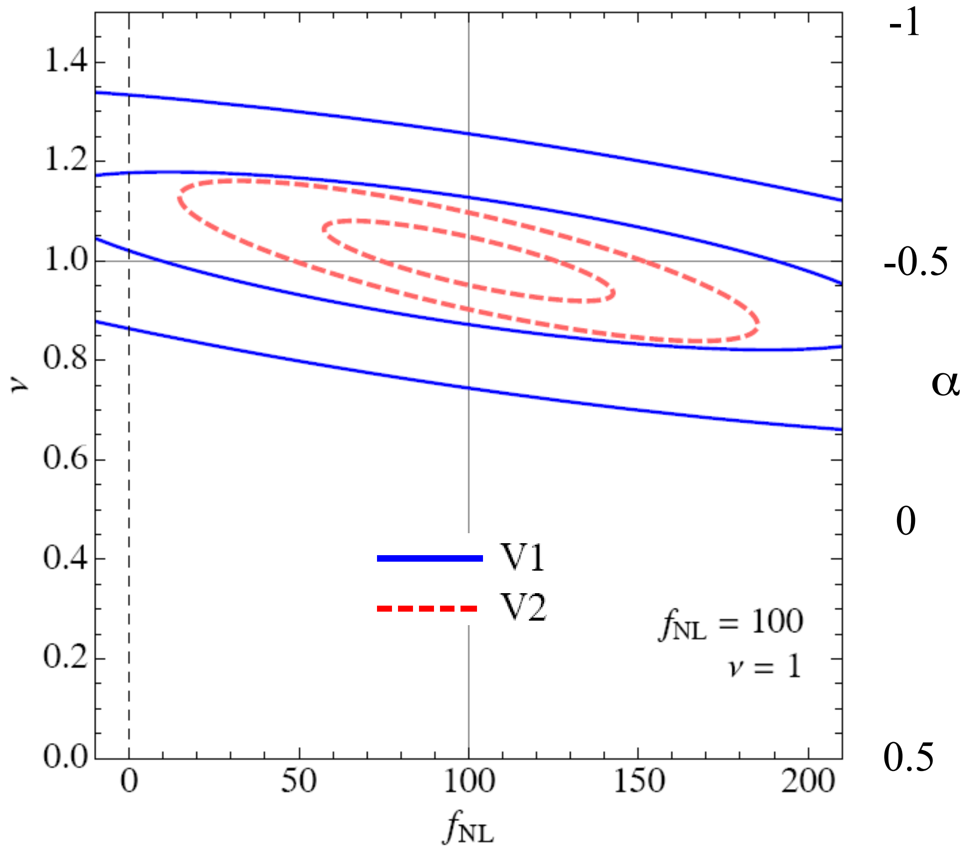
squeezed-limit of 3pt

For QSFI: $b \propto f_{NL}\ k^{-1/2-\nu}$

(Scoccimarro, Manera, Hui, Chan, 11;
Emiliano, Fergusson, X.C., Shellard, 12, Norena, Verde, Barenbiom, Bosch, 12)

Large Scale Structure Forecast for QSFI

(Sefusatti, Fergusson, X.C., Shellard, 12;
Norena, Verde, Barenbiom, Bosch, 12)

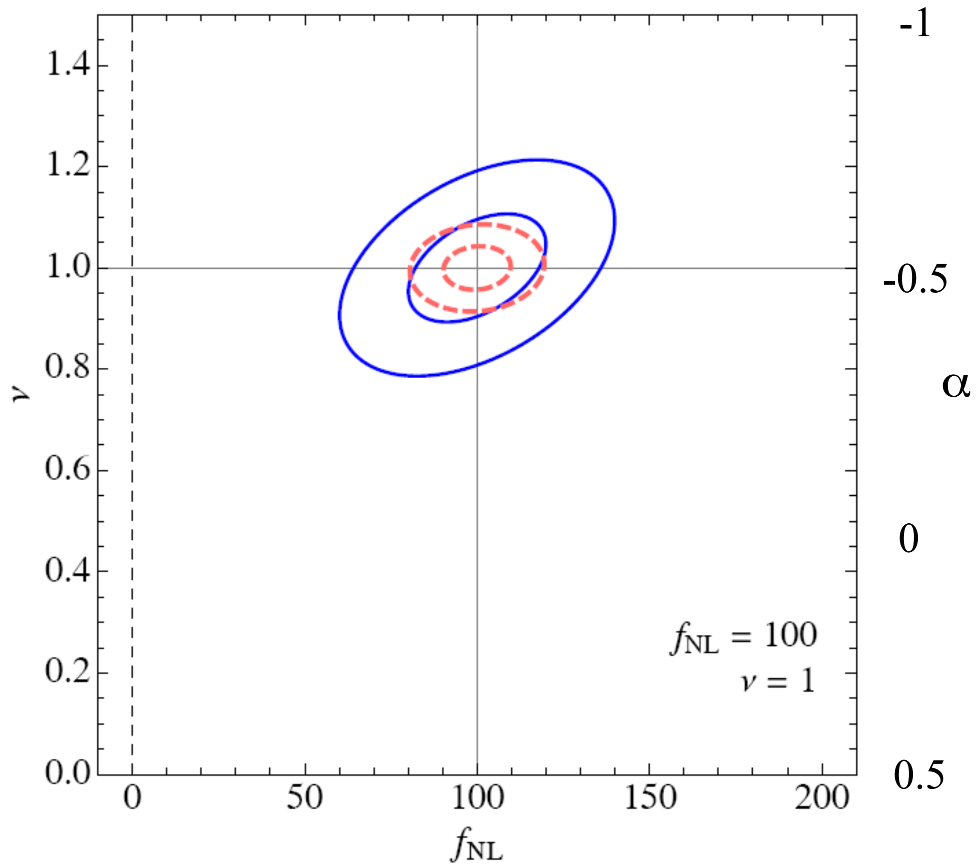


$$k_{max}(0) = 0.075\, h\, \mathrm{Mpc}^{-1}$$

Halo bias is more sensitive to the shapes than the size of 3pt

Large Scale Structure Forecast for QSFI

(Sefusatti, Fergusson, X.C., Shellard, 12)



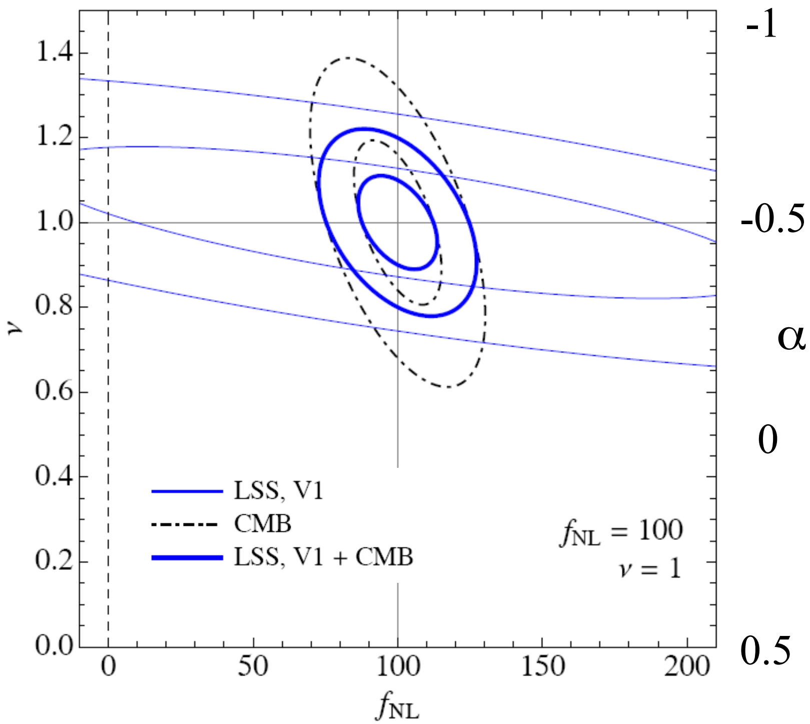
$k_{max}(0) = 0.15\,h\,\mathrm{Mpc}^{-1}$

An interesting **Cosmic Complimentarity!**

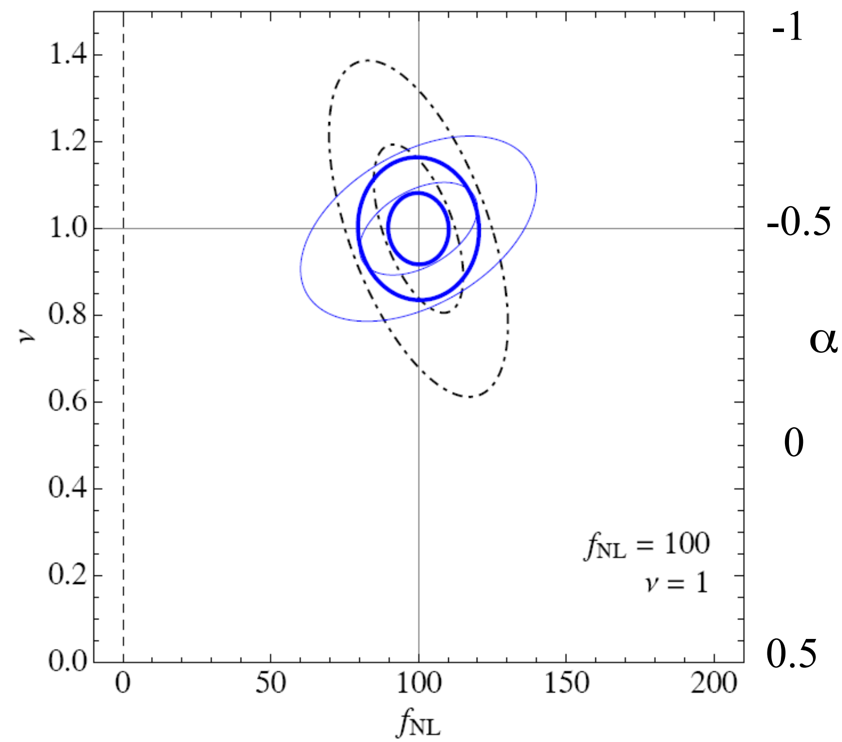
CMB: better at size of non-Gaussianitiy:
less differentiating away from squeezed limit.

Halo bias: better at the shapes at squeezed limit:
its physics entirely depends on squeezed limit shape

Combining CMB and LSS



$$k_{max}(0) = 0.075\, h\, \mathrm{Mpc}^{-1}$$



$$k_{max}(0) = 0.15\, h\, \mathrm{Mpc}^{-1}$$

We can also add: polarization data; LSS bispectra; beyond bispectra, …..

So, if α is not very close to -1, we can hope to separate two important classes of models, by measuring the mass spectrum, like in particle physics.

Establishment of such spectra will have important implications on fundamental physics, such as model building and supersymmetry.

(X.C., Wang, 09; Baumann, Green, 12, McAllister, Renaux-Petal, Xu, 12)

Thank You !