Constraining primordial non-Gaussianity via multitracer technique with *Euclid* and *SKA*

YAMAUCHI, Daisuke (RESCEU, U. Tokyo)

DY, K. Takahashi, M. Oguri, PRD<u>90</u> 083520 ,1407.5453

Plan

1. Brief introduction

✓ Primordial non-Gaussianity✓ Scale-dependent bias

2. Multitracer technique

3. Results

4. (Future plan)

Main Message

We can test the extremely small primordial non-Gaussianity at the level of $\sigma(f_{NL})=O(0.1)$ with Euclid and Square Kilometre Array (SKA).



What's Primordial non-Gaussianity?

Non-Gaussian initial fluctuations arise in several scenarios of inflation.

$$\Phi = \phi_{\rm G} + f_{\rm NL} \left(\phi_{\rm G}^2 - \left\langle \phi_{\rm G}^2 \right\rangle \right)$$

✓ Even the simplest model predicts small but non-vanishing $f_{\rm NL}$ of O(0.01).

- PNG has primarily been constrained from the bispectrum in CMB temperature fluctuations.
 - WMAP : $\sigma(f_{NL}) < 100$ [Bennet+, 2013]
 - Planck : $\sigma(f_{NL}) < 10$ [Planck collaboration, 2014]
 - Ideal : σ(f_{NL}) ~ 3 [Komatsu+Spergel, 2001]

PNG in Large Scale Structure

- Luminous sources such as galaxies must be most obvious tracers of the large scale structure.
- > The galaxy density contrast δ_{gal} is linearly related to the underlying dark matter density contrast δ_{DM} though the bias b_h :

$$\delta_{\text{gal}}(M, z, \boldsymbol{k}) = b_{\text{h}}(M, z, k)\delta_{\text{DM}}(z, \boldsymbol{k})$$

✓ In the Gaussian case, the bias is scale-invariant : $b_h = b_h(M,z)$.

PNG in Large Scale Structure

Primordial non-Gaussianity induces the scale dependent-bias such that the effect dominates at very large scales:

[Dalal+(2008), Desjacques+(2009)]



✓ Galaxy surveys can effectively constrain f_{NL} to the level comparable to CMB temp. anisotropies.

(amplitude)



Accessing ultra-large scales

Difficulties in cosmology

Nonlinear evolution of density perturbations

✓ Baryonic astrophysical process



Let us consider the ultra-large scales to avoid these difficulties !

[Perturbations can be safely treated in linear-regime. & There would be no baryonic process.]

Ultra-large scales v.s. cosmic variance

Measuring large scales has the advantage of accessing the non-Gaussianity , but...

> Constraints is limited due to cosmic variance (CV)

[Due to the lack of enough independent measurements on large scales]



Multitracer technique [Seljak(2009)] :

A method to reduce CV using multiple tracers with different biases

Multitracer technique

: The availability of multiple tracers with the different biases allows significantly improved statistical error in the measurement of ratio of biases.



[Seljak (2009)]

Multitracer technique

: The availability of multiple tracers with the different biases allows significantly improved statistical error in the measurement of ratio of biases.



$$\sigma(\ln P_{gal}) \sim 1/2 = \text{const.}$$

$$(N_{tot} \rightarrow \infty)$$
Limited due to CV!
$$\sigma(b_h/b_l) \sim (N_l^{-1} + N_h^{-1})^{1/2}$$

$$(N_l, N_h \rightarrow \infty)$$

There is no fundamental limit!



Survey design

- Optical/infrared photometric survey : Euclid
 - Covers 15,000 [deg²].
 - Provides redshift information via photometric redshifts
 - We use various galaxy properties to inter the halo mag
- Radio continuum survey : SKA phase-1/2
 - Covers 30,000 [deg²] out to high-z.
 - The redshift information is not available
 - Halo mass can be estimated from the [Ferramacho+ (2014)]
- SKA+Euclid : 9,000 [deg²]



Number density of galaxies



But, estimates of halo mass for gal. involves large uncertainties...

Given M_{est}, the probability that the true mass is M is assumed to be given by log-normal distributions with the variance (σ_{InM})² and the bias InM_{bias}: [Lima+Hu (2004)]

$$p(M_{\text{est}}|M) = \frac{1}{\sqrt{2\pi\sigma_{\ln M}}} \exp\left[-\left(\frac{\ln M_{\text{est}} - \ln M - \ln M_{\text{bias}}}{\sqrt{2}\sigma_{\ln M}}\right)^2\right]$$
14 nuisance
parameters for
each survey
$$\int_{ach M} \frac{14 \operatorname{nuisance}}{\sigma_{\ln M} = \sigma_{\ln M,0}} + \sum_{i=1}^{3} \frac{q_{b,i}}{\sigma_{\ln M,i}} \left[\ln \frac{M}{M_{\text{piv}}}\right]^i + \sum_{i=1}^{3} \frac{s_{b,i}}{s_{i=1}} z^i$$

...We introduce a large number of parameters that model the uncertainty of the halo mass estimate, which are fully marginalized over when deriving constraints.

Fisher matrix analysis

$$F_{\alpha\beta} = \sum_{\ell=\ell_{\min}}^{\ell_{\max}} \sum_{I,J} \frac{\partial C_{I}(\ell)}{\partial \theta^{\alpha}} [\operatorname{Cov}(\boldsymbol{C}(\ell), \boldsymbol{C}(\ell))]_{IJ}^{-1} \frac{\partial C_{J}(\ell)}{\partial \theta^{\beta}}$$

- I, J run over the redshift and mass bin
- Θα are model parameters
- ✓ To calculate the Fisher with several surveys, we have to derive covariant matrix generalized to multiple tracers with different sky areas with some overlap:

$$\begin{split} & \operatorname{Cov}[C_{i(bb\prime)}(\ell), C_{j(\tilde{b}\,\tilde{b}\,\prime)}(\ell\prime)] \\ &= \frac{\delta_{ij}^{\mathrm{K}} \delta_{\ell\ell\prime}^{\mathrm{K}}}{(2\ell+1)\Delta\ell} \underbrace{\frac{4\pi \Omega_{w}^{(bb\prime\tilde{b}\,\tilde{b}\,\ell)}}{\Omega_{w}^{(bb\prime)} \Omega_{w}^{(\tilde{b}\,\tilde{b}\,\prime)}}} [C_{i(b\tilde{b})}(\ell) C_{i(b\prime\tilde{b}\prime)}(\ell) + C_{i(b\tilde{b}\prime)}(\ell) C_{i(b\prime\tilde{b})}(\ell)] \end{split}$$

Effect of different sky areas

[DY+Takahashi+Oguri (2014)]

Efficiency of mass-binning

- Nonvanishing overlap leads to improved constraints on f_{NL}, which becomes smallest in the case of maximal overlap.
- There is a critical value of mass ratio which results in the tightest constraint.



The tightest constraint would be obtained when the two shot noises become comparable.

[Changing the value of the mass ratio leads to the larger shot noise for one of the mass-bins and smaller for the other.]

[DY+Takahashi+Oguri (2014)]



- ✓ Combining multiple z-bins improves substantially $\sigma(f_{NL})$.
- ✓ Galaxy samples as far as z=3.2 contribute to the constraint.
- ✓ Realistic: z_{max} =2.7 → $\sigma(f_{NL})$ =0.66

- ✓ The constraining power increases with N_M.
- ✓ Even 2-tracers drastically improve the constraint.



[DY+Takahashi+Oguri (2014)]

Expected marginalized error



Euclid SKA1 Euclid+SKA1 SKA2 Euclid+SKA2

The constraints of $\sigma(f_{\rm NL})=O(1)$ can be obtained even with a single survey. Combining Euclid and SKA, even stronger constraints of $\sigma(f_{\rm NL})=O(0.1)$ can be obtained.

Summary

Splitting the galaxy samples into the subsamples by the inferred halo mass and redshift, constraints on $f_{\rm NL}$ drastically improve.

The constraints of $\sigma(f_{\rm NL})=O(1)$ can be obtained even with a single survey. Combining Euclid and SKA, even stronger constraints of $\sigma(f_{\rm NL})=O(0.1)$ can be obtained.



Thank you!