Constraining primordial non-Gaussianity via multi-tracer technique (with Euclid and SKA)
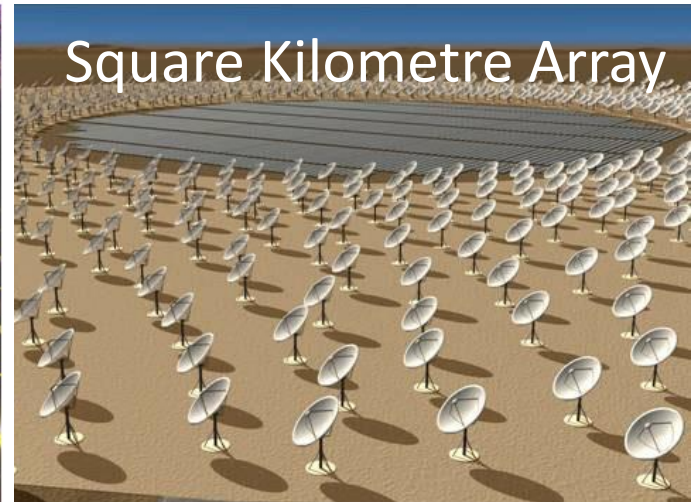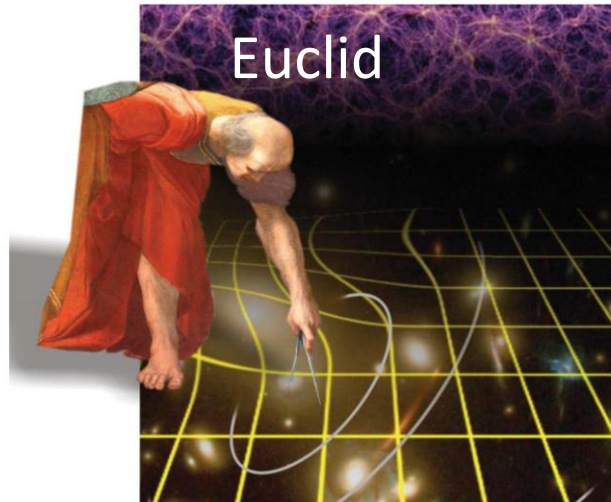
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Main Message

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.

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

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

➢ PNG has primarily been constrained from the bispectrum in CMB temperature fluctuations.

- WMAP : *σ(f_{NL}) < 100*   [Bennet+, 2013]

- Planck : *σ(f_{NL}) < 10*   [Planck collaboration, 2013]

- 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:

$$\delta_{\mathrm{gal}}(M, z, \boldsymbol{k}) = b_{\mathrm{h}}(M, z, k)\delta_{\mathrm{DM}}(z, \boldsymbol{k})$$
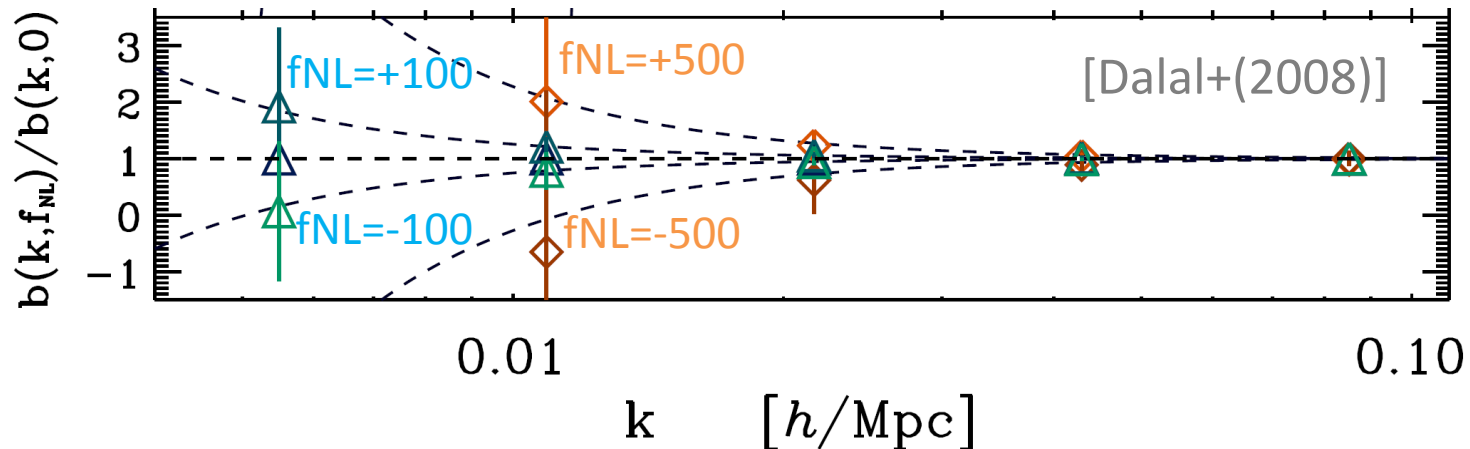
✓ In the Gaussian case, the bias is scale-invariant : $b_h = b_h(M,z)$.

PNG in Large Scale Structure

➢ Primordial non-Gaussianity induces the scale dependent-bias such that the effect dominates at very large scales:
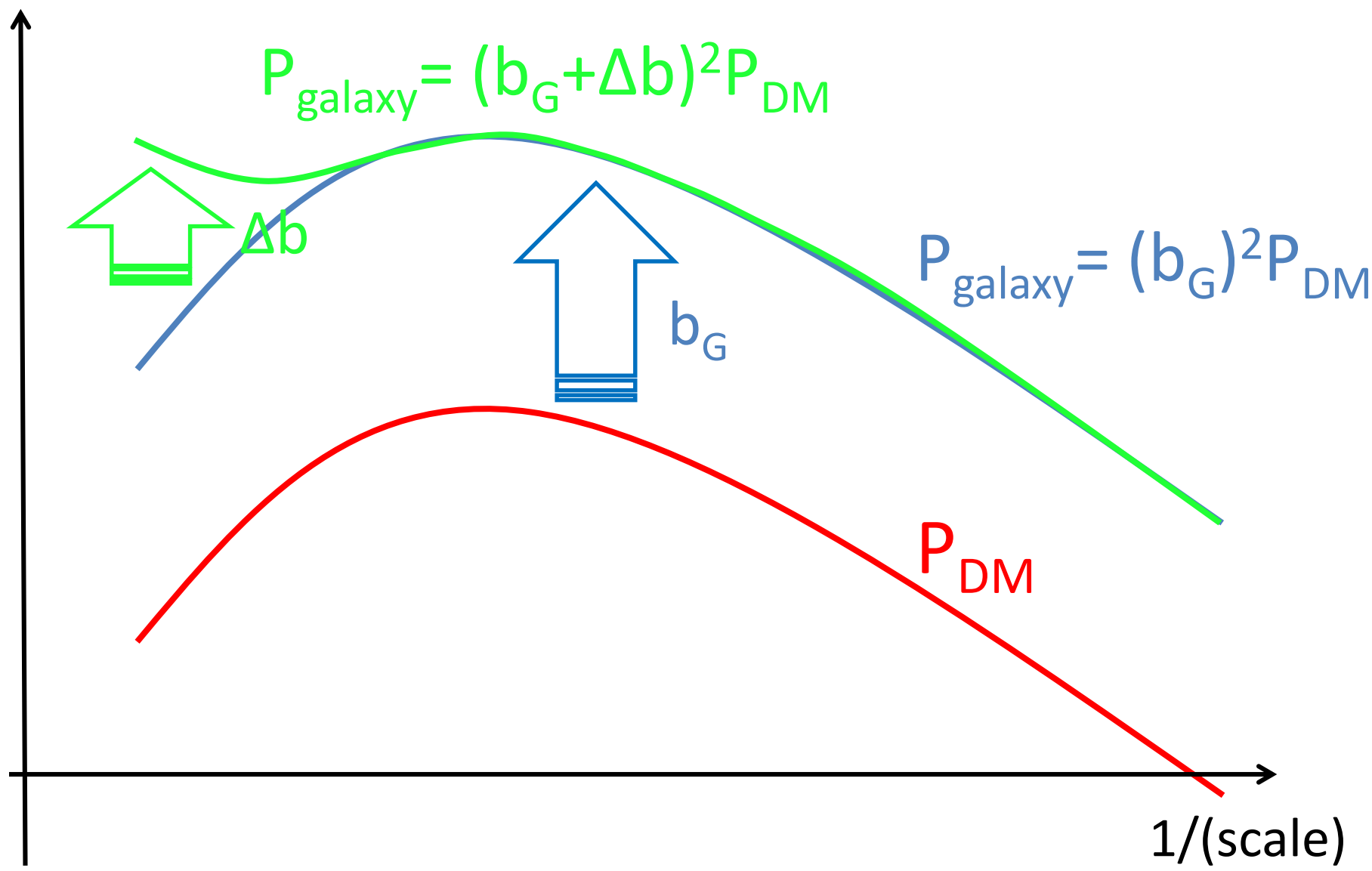
[Dalal+(2008), Desjacques+(2009)]

$$\Delta b = \frac{2 f_{\mathrm{NL}} \delta_c}{\mathcal{M} D_+} (b_{\mathrm{L}} - 1) - \frac{1}{\delta_c} \frac{\mathrm{d}}{\mathrm{d} \ln \nu} \left(\frac{\mathrm{d}n/\mathrm{d}M}{\mathrm{d}n_{\mathrm{G}}/\mathrm{d}M} \right)$$

fNL=+100 fNL=+500

[Dalal+(2008)]

fNL=-100 fNL=-500

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

(amplitude)

$P_{galaxy} = (b_G + \Delta b)^2 P_{DM}$

Δb

$P_{galaxy} = (b_G)^2 P_{DM}$

b_G

P_{DM}

1/(scale)

Accessing ultra-large scales

➢ Clustering analysis at large scales are limited due to cosmic variance.
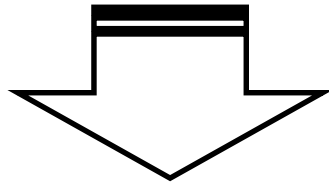
MULTI-TRACER TECHNIQUE [Seljak (2009)]

- a method to reduce the cosmic variance using multiple tracers with different biases.
- The availability of multiple tracers allows significantly improved statistical error in the measurement of f_{NL}.
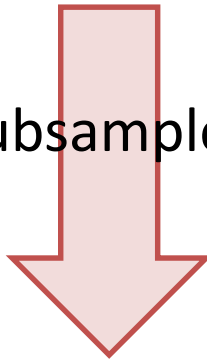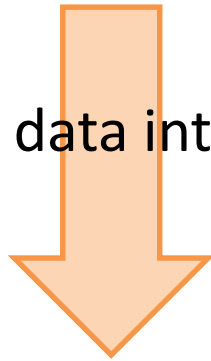
Multi-tracer technique [Seljak (2009)]

✓ If we treat the data as the single group, the galaxy survey can constrain f_{NL} to the level comparable to CMB:

Full galaxy samples

$\sigma(f_{NL}) = O(10)$

Splitting the data into subsamples…

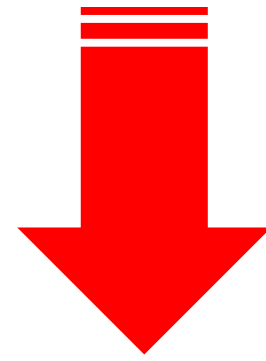Group 1   Group 2   Group 3   ...

$\sigma(f_{NL}) < 1$!

Multi-tracer technique [Seljak (2009)]

✓ Angular power spectra

Group1 Group2 Shot noise

Group1
Group2

$$\begin{bmatrix} b_1^2 P_\delta + \dfrac{1}{N_1} & b_1 b_2 P_\delta \\ b_1 b_2 P_\delta & b_2^2 P_\delta + \dfrac{1}{N_2} \end{bmatrix}$$
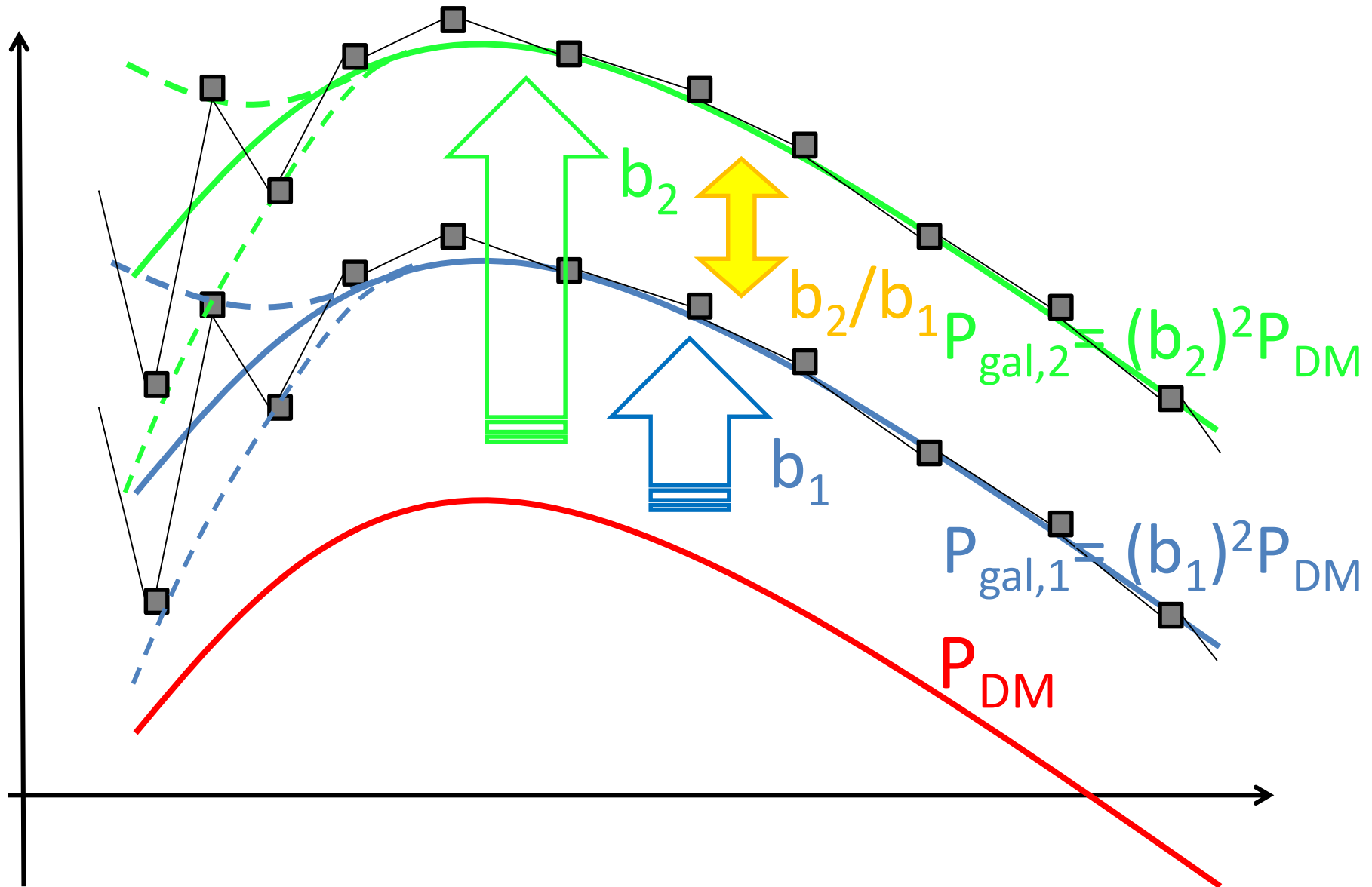
✓ Accuracy for b_2/b_1

$$\sigma\left(\frac{b_2}{b_1}\right) \propto \sqrt{N_1^{-1} + N_2^{-1}} \quad (N_1, N_2 \gg 1)$$

We can make a measurement of the ratio of two biases that is only limited by shot noise and hence beats cosmic variance!
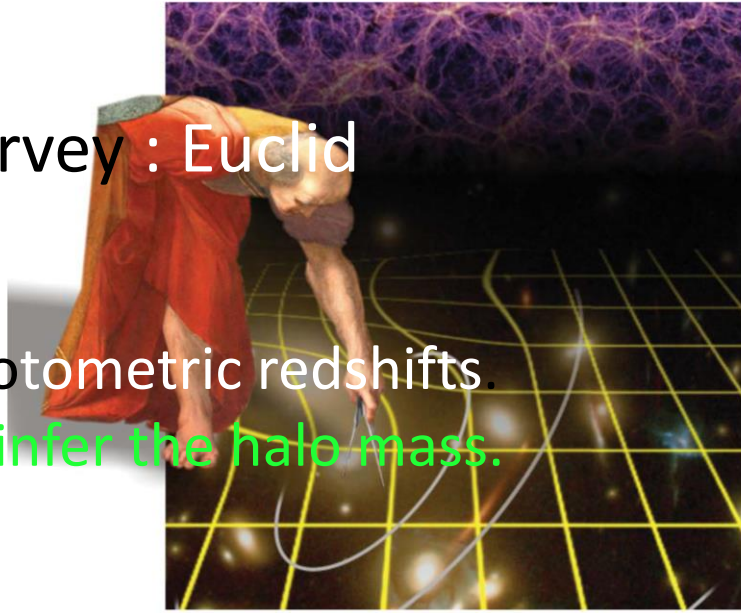
The accuracy of the amplitude itself is limited by CV, but for the ratio between the powers there is NO fundamental limit!

b_2

b_2/b_1 $P_{gal,2} = (b_2)^2 P_{DM}$

b_1

$P_{gal,1} = (b_1)^2 P_{DM}$

P_{DM}

Survey design

➢ Optical/infrared photometric survey : Euclid

- Covers 15,000 [deg^2].
- Provides redshift information via photometric redshifts.
- We use various galaxy properties to infer the halo mass.

➢ Radio continuum survey : SKA phase-1/2

- Covers 30,000 [deg^2] out to high-z.
- The redshift information is not available.
- Halo mass can be estimated from the galaxy type.
  [Ferramacho+ (2014)]
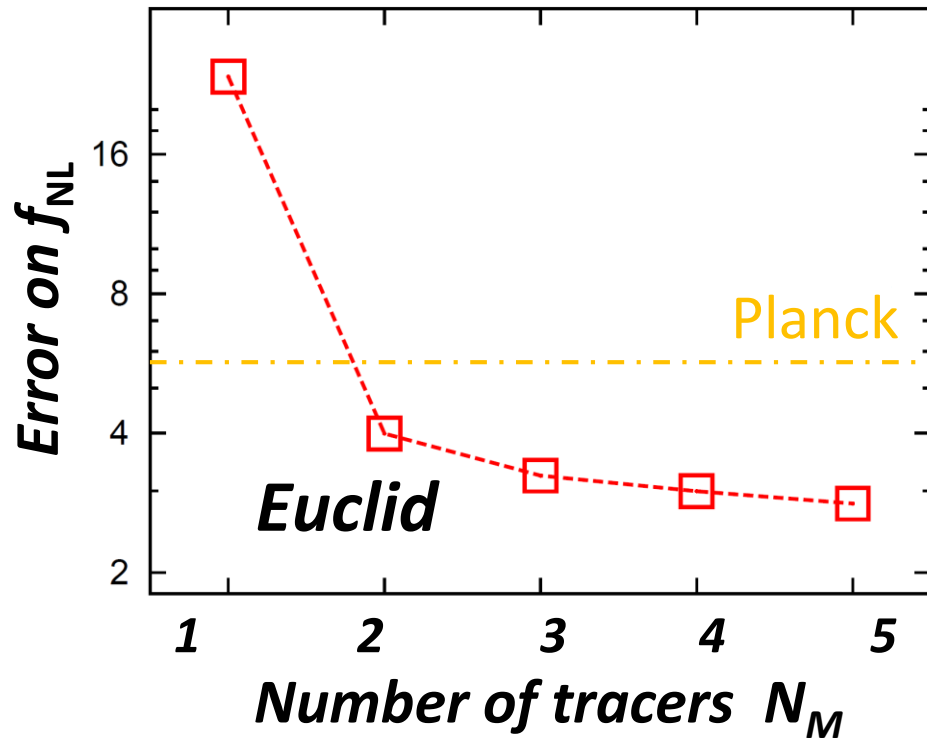
➢ SKA+Euclid : 9,000 [deg^2]

Fisher matrix analysis

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

✓ Covariant matrix generalized to multiple tracers with different sky areas with some overlap:
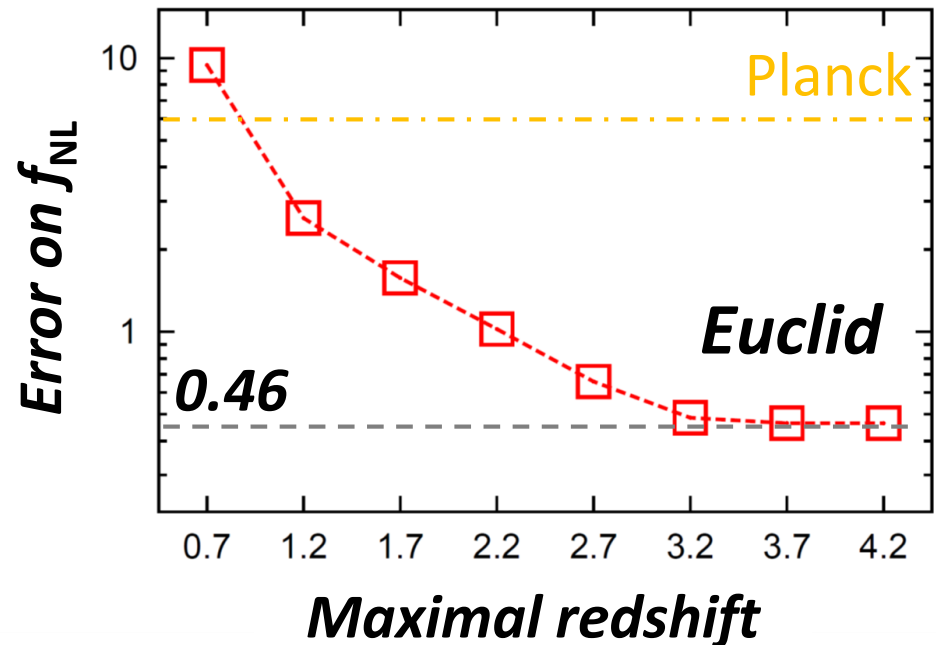
[**DY**+Takahashi+Oguri (2014)]

$$\text{Cov}\left[C_{i(bb')}(\ell), C_{j(\tilde{b}\tilde{b}')}(\ell') \right]$$

$$= \frac{\delta_{ij}^{\text{K}} \delta_{\ell\ell'}^{\text{K}}}{(2\ell+1)\Delta\ell} \boxed{\frac{4\pi \Omega_w^{(bb'\tilde{b}\tilde{b}')}}{\Omega_w^{(bb')} \Omega_w^{(\tilde{b}\tilde{b}')}}} \left[C_{i(b\tilde{b})}(\ell) C_{i(b'\tilde{b}')}(\ell) + C_{i(b\tilde{b}')}(\ell) C_{i(b'\tilde{b})}(\ell) \right]$$
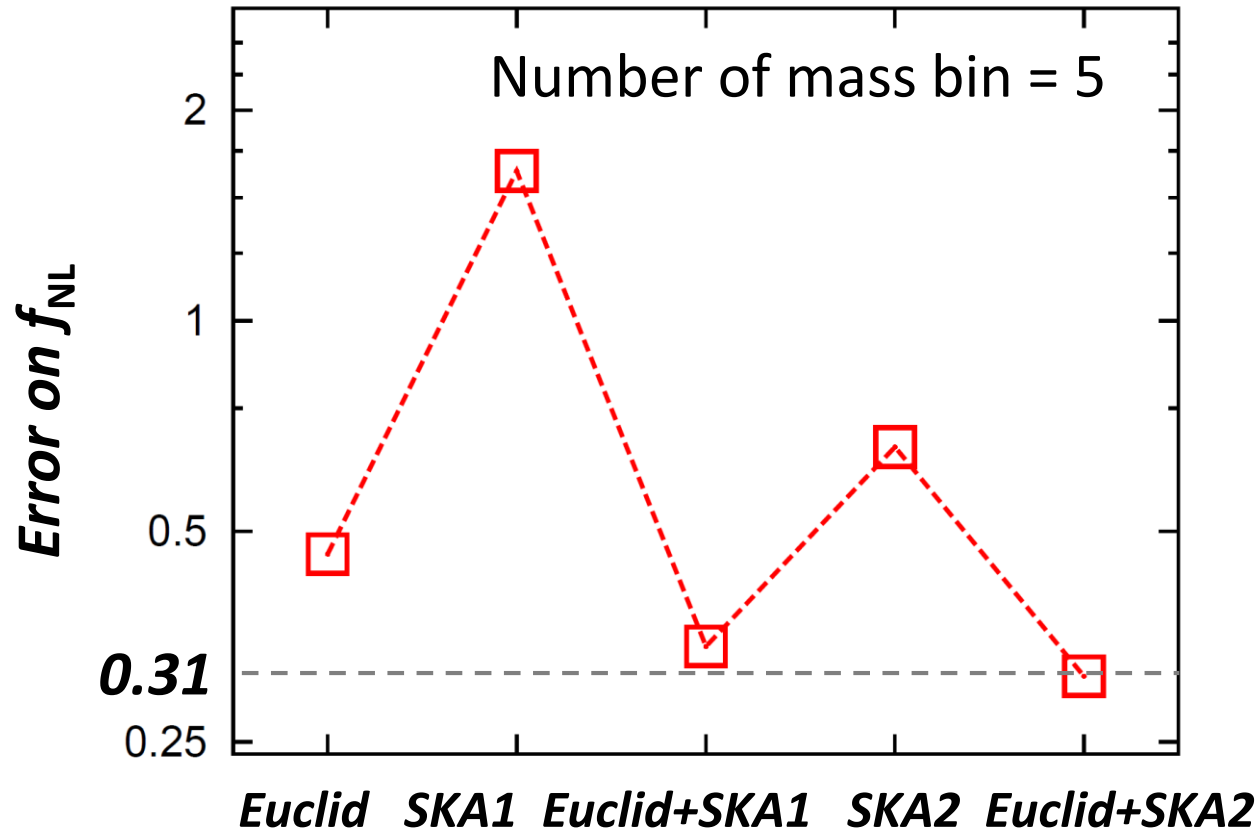
Effect of different
sky areas

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

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

Expected marginalized error

Number of mass bin = 5

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

Summary

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

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

Thank you!