

**Jet Propulsion Laboratory**  
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# Biasing and the search for primordial non-Gaussianity beyond the local type

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# Surveys for Cosmology

Many new surveys to come online: LSST, WFIRST, EUCLID,...

What's causing the accelerated expansion of the Universe ?

Cosmological constant?

Dark Energy?

Modifications of General Relativity?

# And more

**Equivalence Principle (EP)** *with Creminelli, Hui, Simonović and Vernizzi, '13*

→ Do all objects fall the same way?

*Cornerstone of GR*

## Initial conditions

→ Is the distribution initially **Gaussian**?

*Prediction of simplest inflation models*

# Non Gaussianity and Inflation

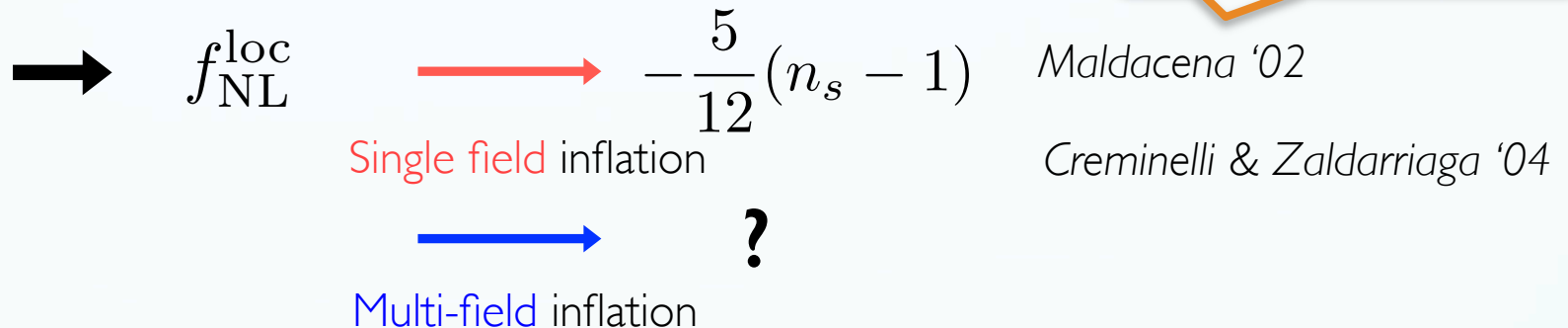
Scale dependent bias

Equilateral non-Gaussianity

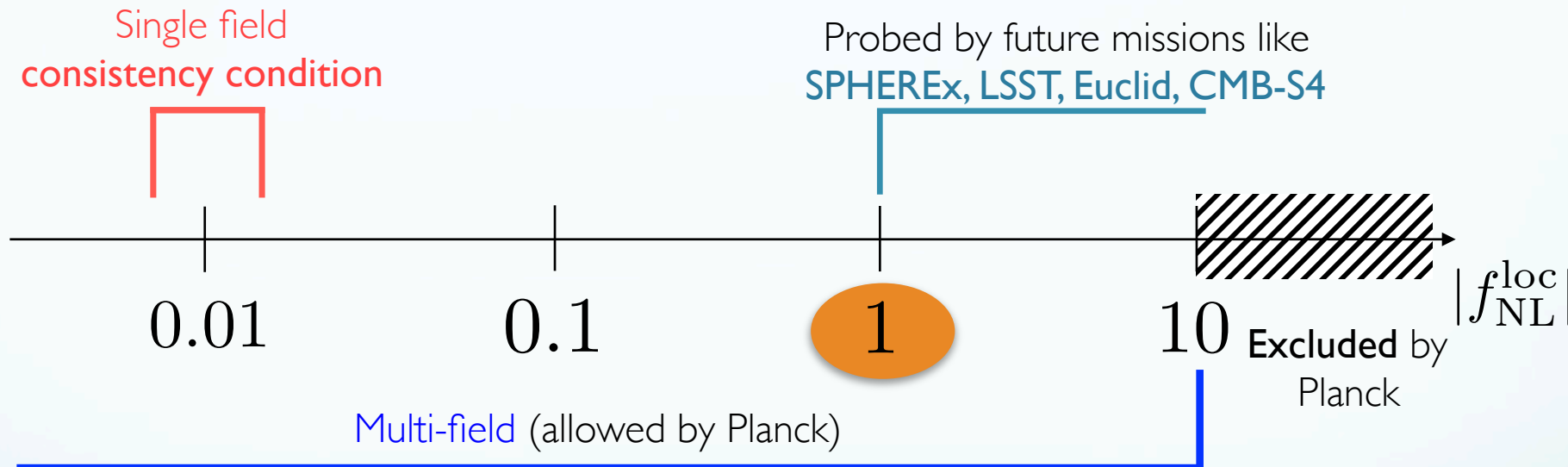
# Why study non-Gaussianity?

$$\Phi = \Phi_G + f_{\text{NL}}^{\text{Loc}}(\Phi_G^2 - \langle \Phi_G \rangle^2)$$

Consistency relation



# Why study non-Gaussianity?



$$\text{Prob}(|f_{\text{NL}}^{\text{Loc}}| > 1) \gtrsim 50\%^* \quad \text{with de Putter and Doré arXiv:1612.05248}$$

\* : 2-field models with **spectator** field

# Measuring PNG from surveys

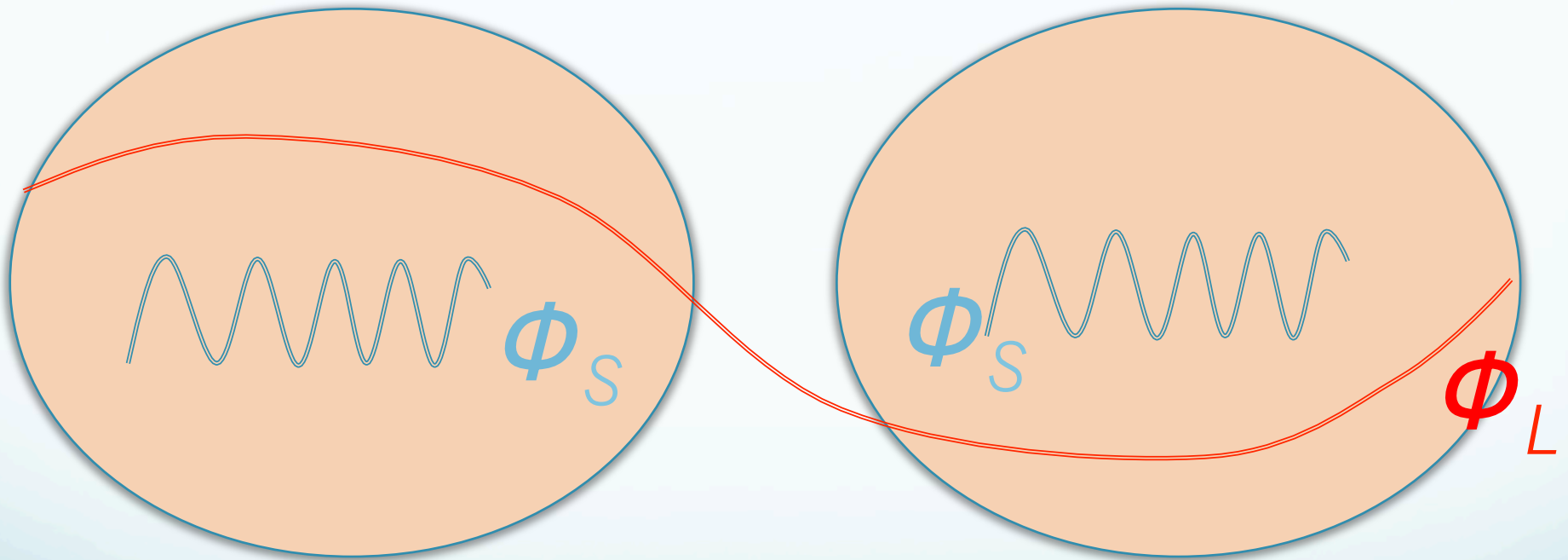
✧ CMB: Bispectrum

$$\sigma(f_{\text{NL}}^{\text{Loc}}) \sim 5$$

✧ Galaxy surveys: scale-dependent bias

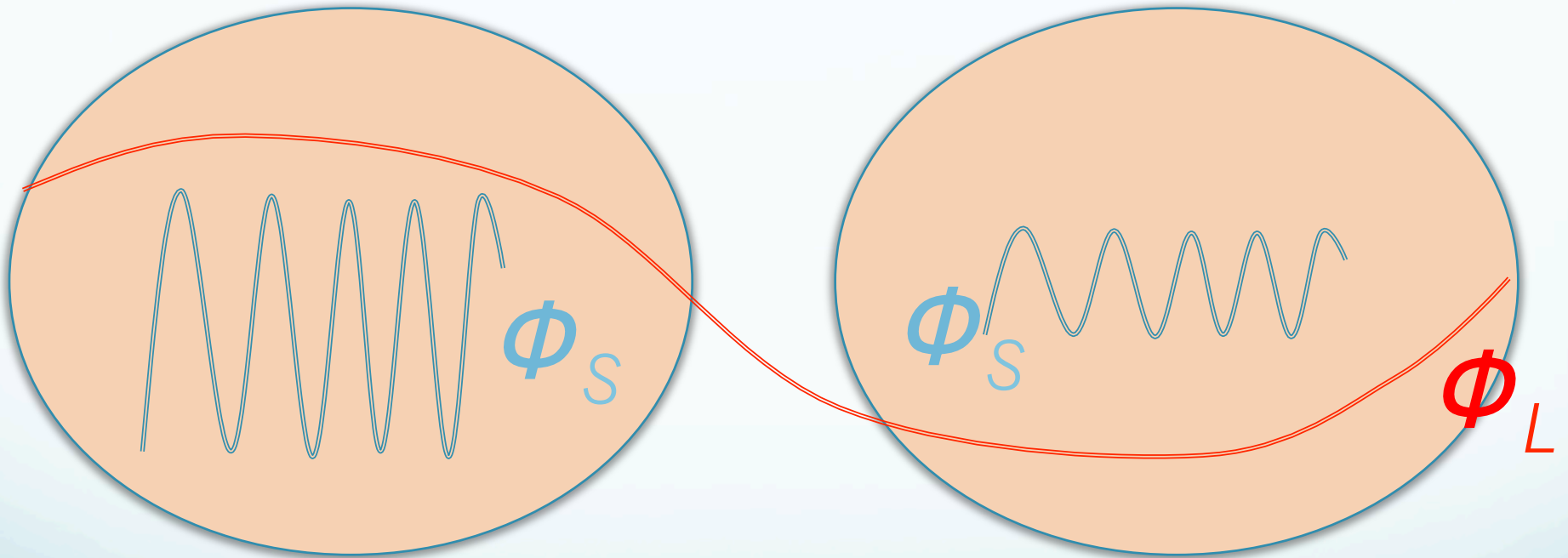
# Scale-dependent bias

## Single field inflation



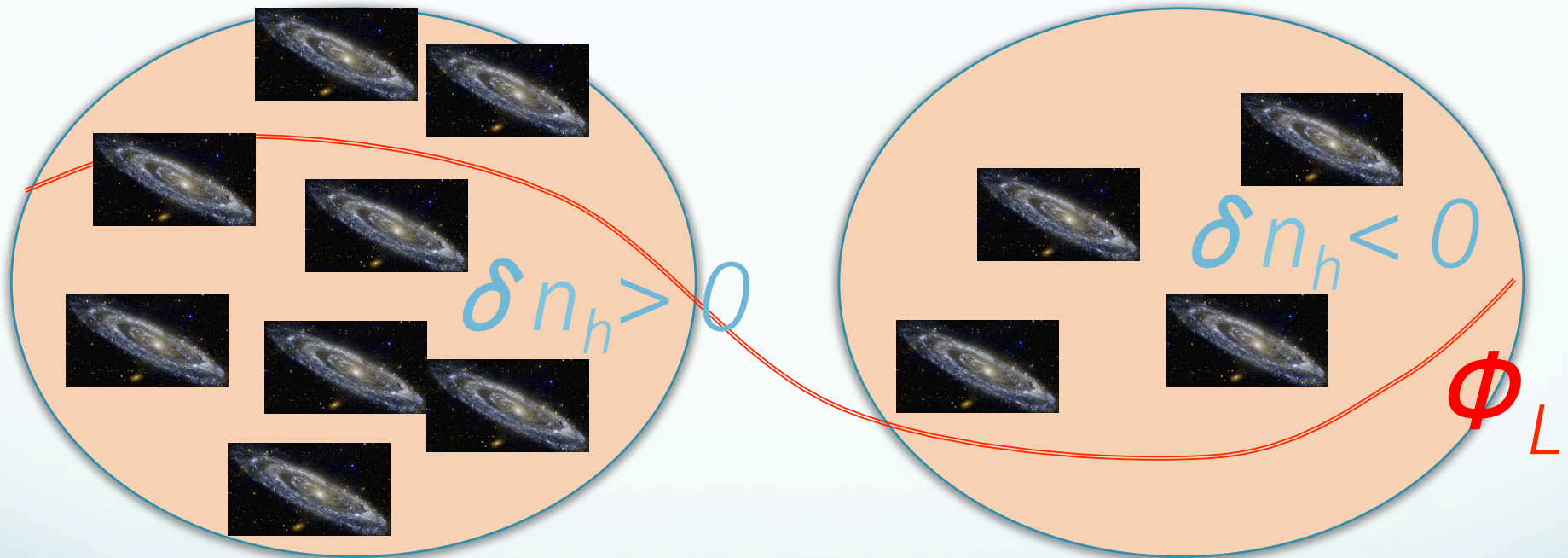
# Scale-dependent bias

## Multi-field inflation



# Scale-dependent bias

Multi-field inflation



Scale-dependent bias

# Scale-dependent bias

✧ Local PNG

$$\mathcal{M}(q) \equiv \frac{2q^2 T(q) D(z)}{3\Omega_m H_0^2}$$

$$b_{\text{NG}}(q) = 2 f_{\text{NL}}^{\text{Loc}} (b_\delta - 1) \delta_c \mathcal{M}^{-1}(q) \sim \frac{1}{q^2 T(q)}$$

✧ Equilateral PNG

Typical size of halos

$$b_{\text{NG}}(q) = 6 f_{\text{NL}}^{\text{Eq}} (b_\delta - 1) \delta_c (q R_*)^2 \mathcal{M}^{-1}(q) \sim \frac{1}{T(q)}$$

# Biasing and PNG

with de Putter, Green and Doré '16

✧ Generalized model of bias *McDonald & Roy '09, Assassi et al '15*

$\delta^2$

$$\delta_h = b_\delta \delta + b_{\text{NG}}(q) \delta + F_{\text{nonlocal}}[\nabla^2 \delta] + F_{\text{nonlinear}}[\delta]$$

$$\left[ b_{q^2} (q R_*)^2 + b_{q^4} (q R_*)^4 \right] \delta$$

Seen in simulations *Chan et al '12, Baldauf et al '12*

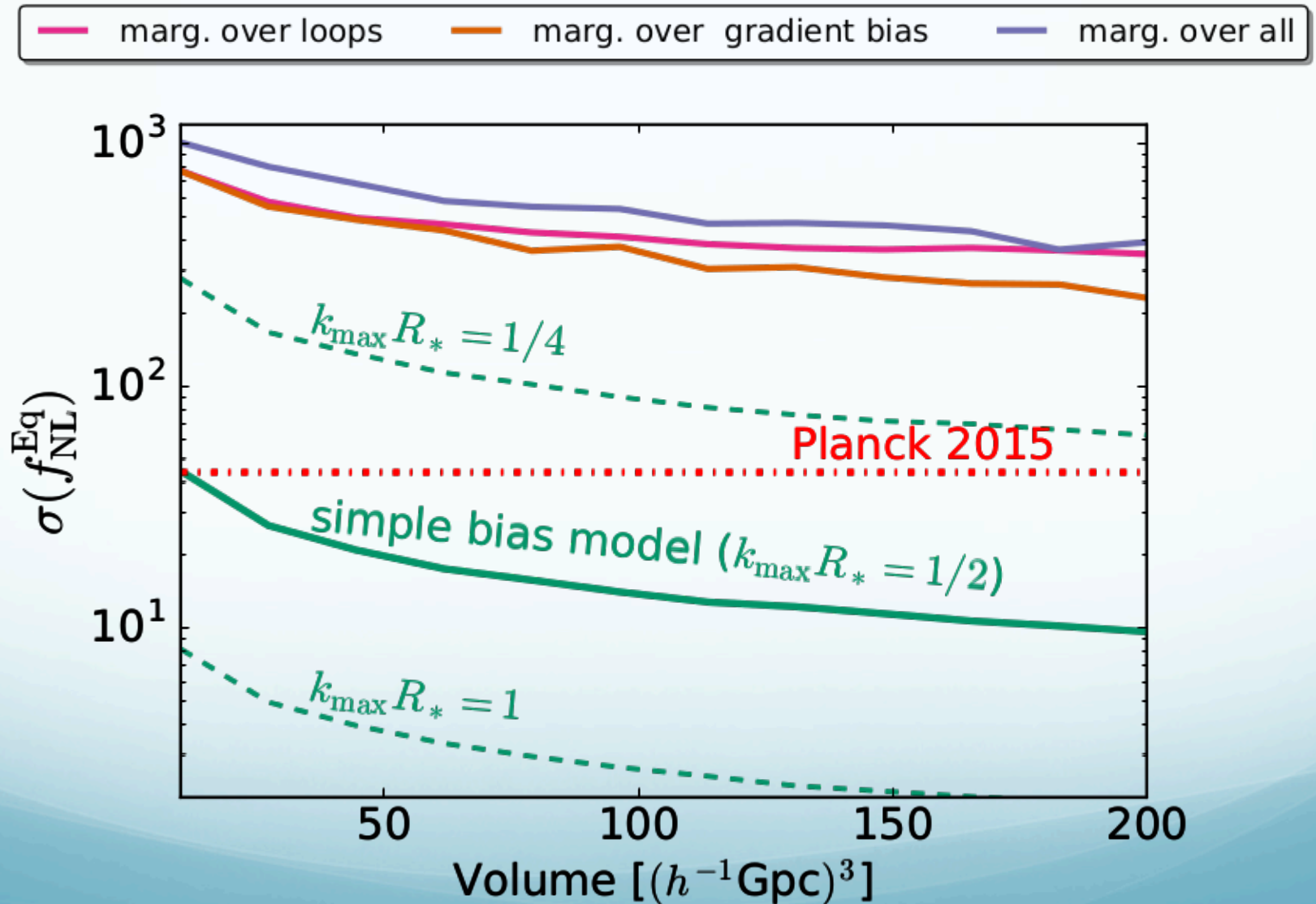
✧ Evolution or PNG?

$$T(q) \sim 1 + T_1 q^2 + T_2 q^4$$

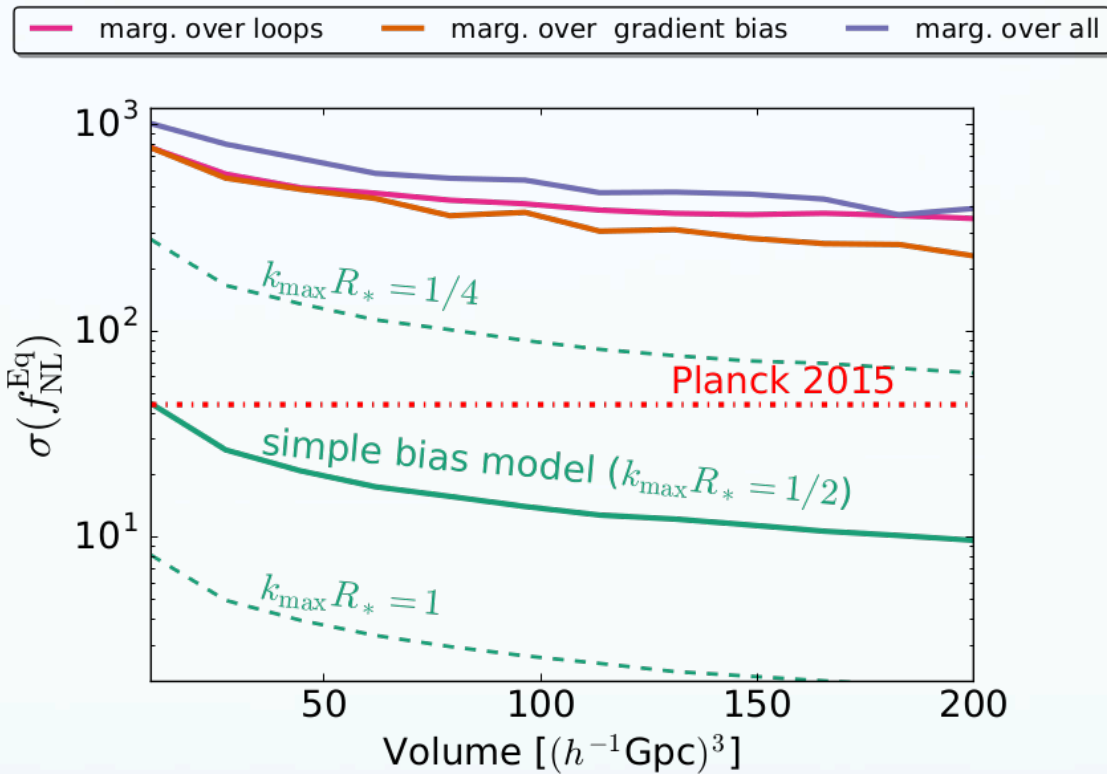
$$b_{\text{NG}}^{\text{Loc}} \sim q^{-2} \quad \checkmark$$

$$b_{\text{NG}}^{\text{Eq}} \sim c + c_1 q^2 + \dots \quad ?$$

# Equilateral PNG and bias



# Equilateral PNG and bias

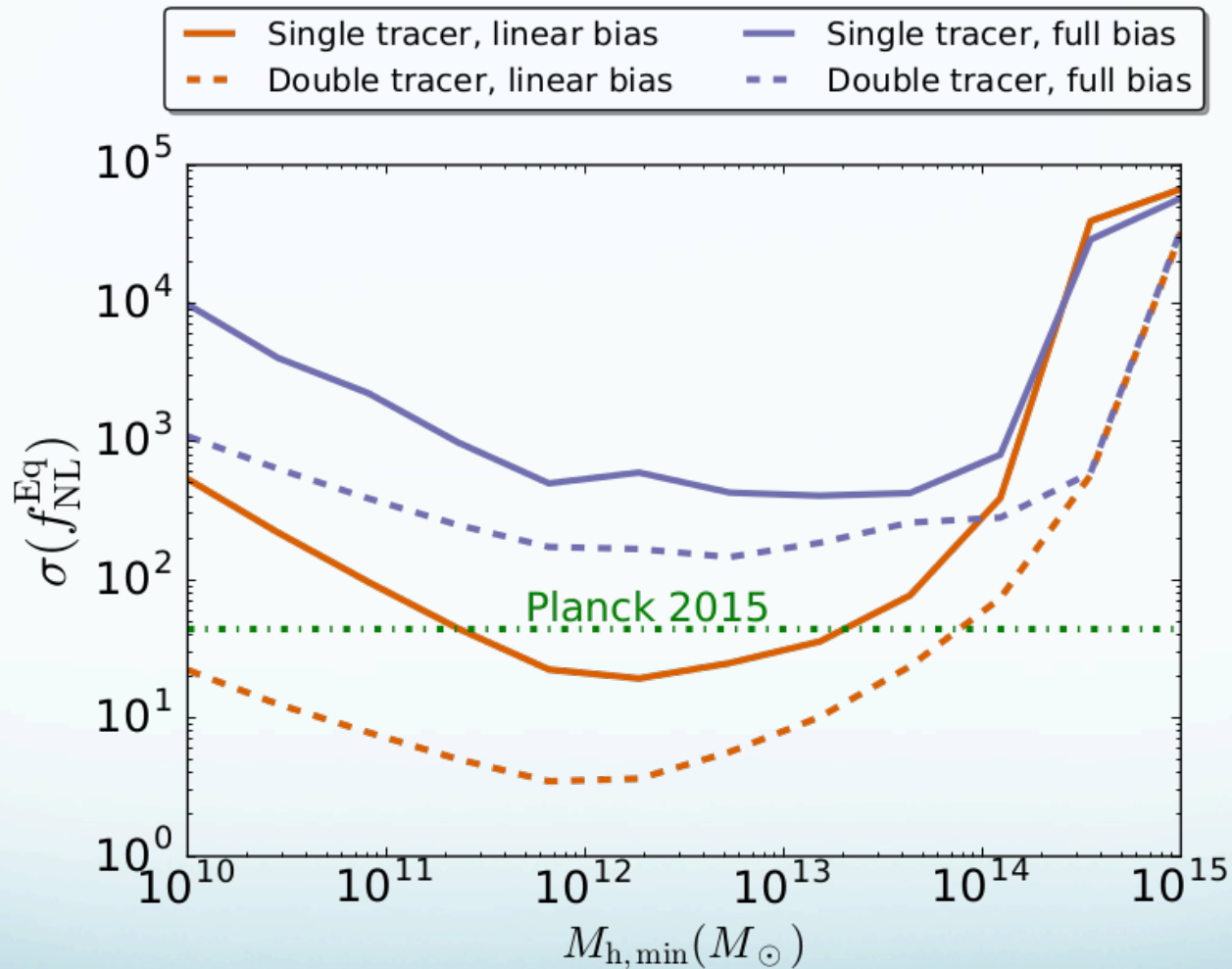


What is helping us

$$F_{\text{nonlocal}}[\nabla^2 \delta] \quad \longrightarrow \quad R_*^{-1} > k_{\text{max}}$$

$$T(q) \quad \longrightarrow \quad k_{\text{eq}} \sim 10^{-2} h/\text{Mpc} < k_{\text{max}} \sim 10^{-1} h/\text{Mpc}$$

# Beating cosmic variance



Two tracers: dark matter, and galaxies with  $M_{\text{h}} \geq M_{\text{h,min}}$

# Conclusions

Non gaussianity probes inflation, with  $f_{\text{NL}}^{\text{Loc}} \sim 1$  motivated target

Equilateral PNG is degenerate with evolution

Multi-tracer approach powerful, but not enough for equilateral

Bispectrum more appropriate for PNG beyond local ?

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