Primordial non-Gaussianity and non-Gaussian covariance

At high redshifts

Thomas Flöss - PNG2022, Madrid - 20/09/2022

Based on 2206.10458 (w/ Matteo Biagetti & Daan Meerburg)

About me

- PhD student @ University of Groningen
- Observational aspects of pnG (w/ Daan Meerburg & Léon Koopmans)
- Formal aspects of cosmological correlators (w/ Diederik Roest)
- Previously: MSc. @ Utrecht University (w/ Enrico Pajer & Garrett Goon)
- Collaborators:

  Matteo Biagetti, Will Coulton, Alba Kalaja, Paco Villaescusa-Navarro, Tom Westerdijk, Tim de Wild

Overview

I. Introduction

II. Non-Gaussian covariance

III. Implications for future observations: a case study

IV. Conclusions & Outlook

V. Lunch!

I. Introduction

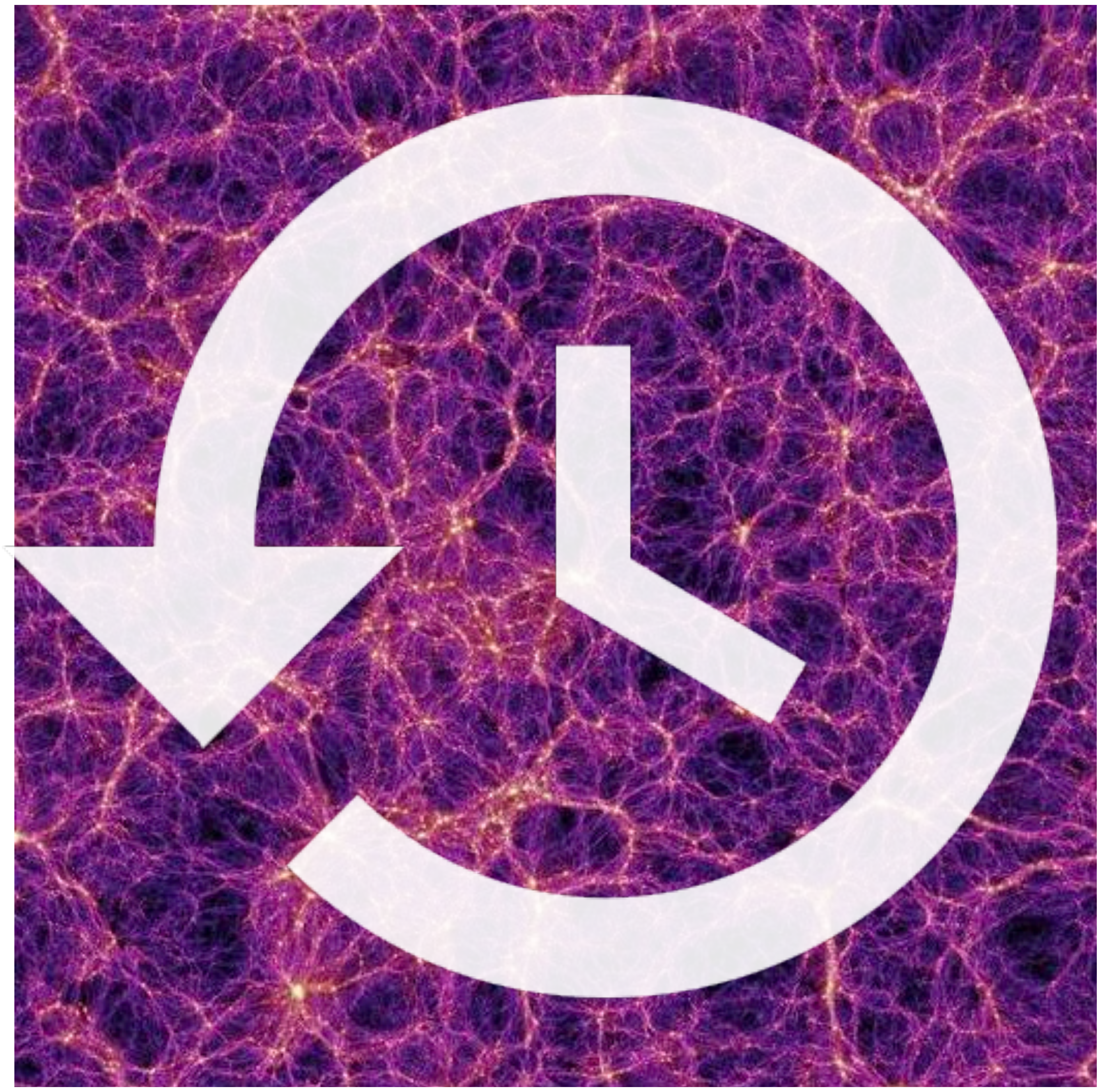
The name of the game

- Reconstruct the initial conditions of the universe (as set by e.g. inflation)
- Primordial non-Gaussianity (pnG) constrains the theory space

The name of the game

- Reconstruct the initial conditions of the universe (as set by e.g. inflation)
- Primordial non-Gaussianity (pnG) constrains the theory space

- Infer from the 'late'-time density distribution
- Complicated by non-linear and unknown physics



Non-linear evolution

- Induces (secondary) non-Gaussianities
    1. Swamps any weak primordial signal
    2. Couples modes of different wavelength (*off-diagonal covariance*)

Non-linear evolution

- Induces (secondary) non-Gaussianities
  1. Swamps any weak primordial signal
  2. Couples modes of different wavelength (*off-diagonal covariance*)

- Accurate modeling to infer primordial physics
- Less constraining power for $f_{\rm NL}$

Modeling gravity

- Gravitational evolution can be analytically modeled in perturbation theory on large scales (SPT)
- Breaks down on small scales

$$B_\delta^{\rm SPT}(\boldsymbol{k}_1, \boldsymbol{k}_2, \boldsymbol{k}_3) = F_2(\boldsymbol{k}_1, \boldsymbol{k}_2) P_\delta(\boldsymbol{k}_1) P_\delta(\boldsymbol{k}_2)$$

$$k_{\rm NL}(z) = \left[\frac{1}{6\pi^2} \int_0^\infty dk\, P_\delta^L(k, z) \right]^{-1/2}$$

Modeling gravity

- Gravitational evolution can be analytically modeled in perturbation theory on large scales (SPT)

$$B_\delta^{\mathrm{SPT}}(\boldsymbol{k}_1, \boldsymbol{k}_2, \boldsymbol{k}_3) = F_2(\boldsymbol{k}_1, \boldsymbol{k}_2) P_\delta(\boldsymbol{k}_1) P_\delta(\boldsymbol{k}_2)$$

- Breaks down on small scales

$$k_{\mathrm{NL}}(z) = \left[\frac{1}{6\pi^2} \int_0^\infty dk\, P_\delta^L(k, z) \right]^{-1/2}$$

- Different approaches (e.g. EFTofLSS) can push to smaller scales
- But: biases to marginalize over, increasing $\sigma(f_{\mathrm{NL}})$

II. Non-Gaussian covariance

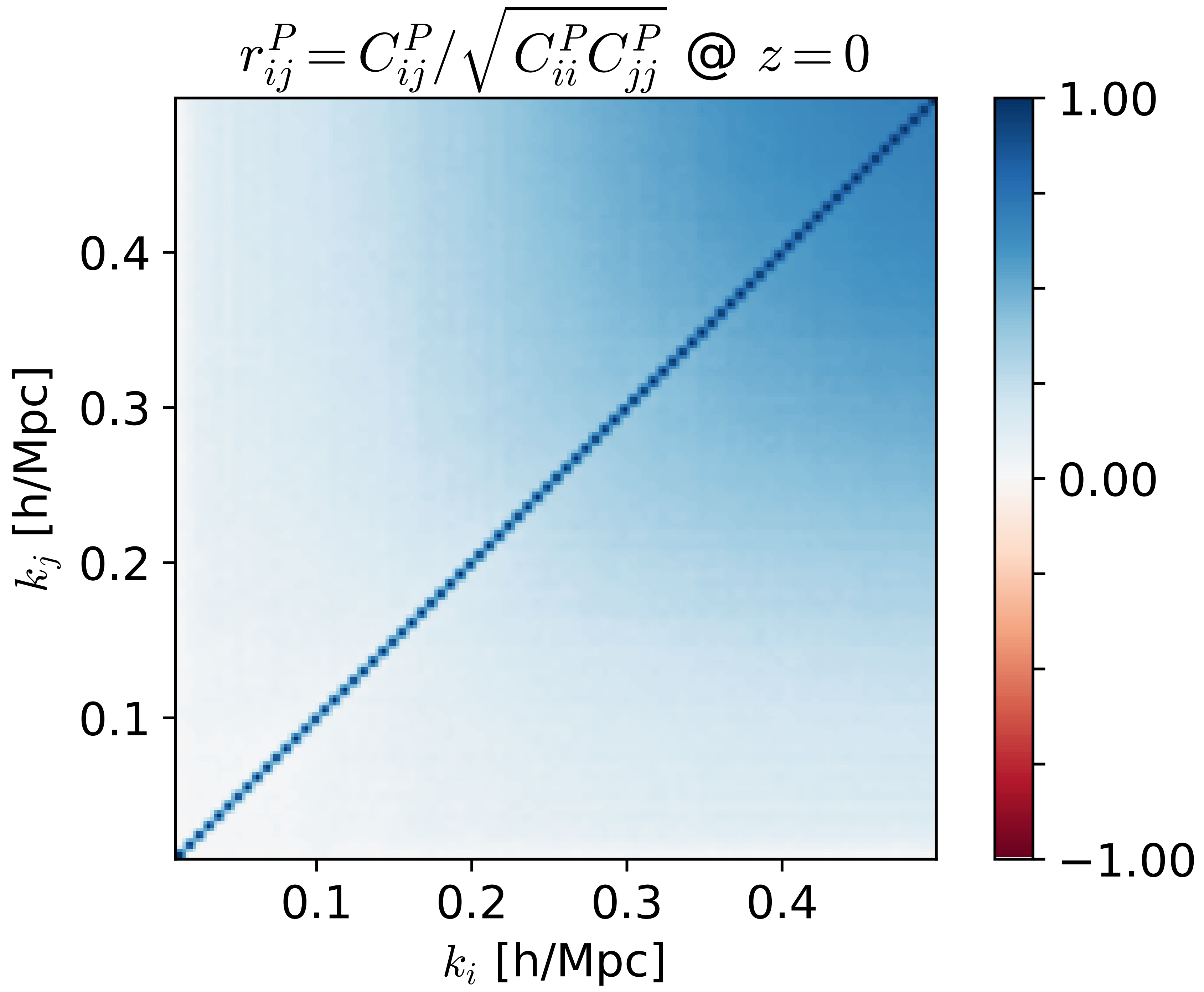
Mode coupling

- Non-linear evolution introduces non-Gaussian covariance

Mode coupling

- Non-linear evolution introduces non-Gaussian covariance

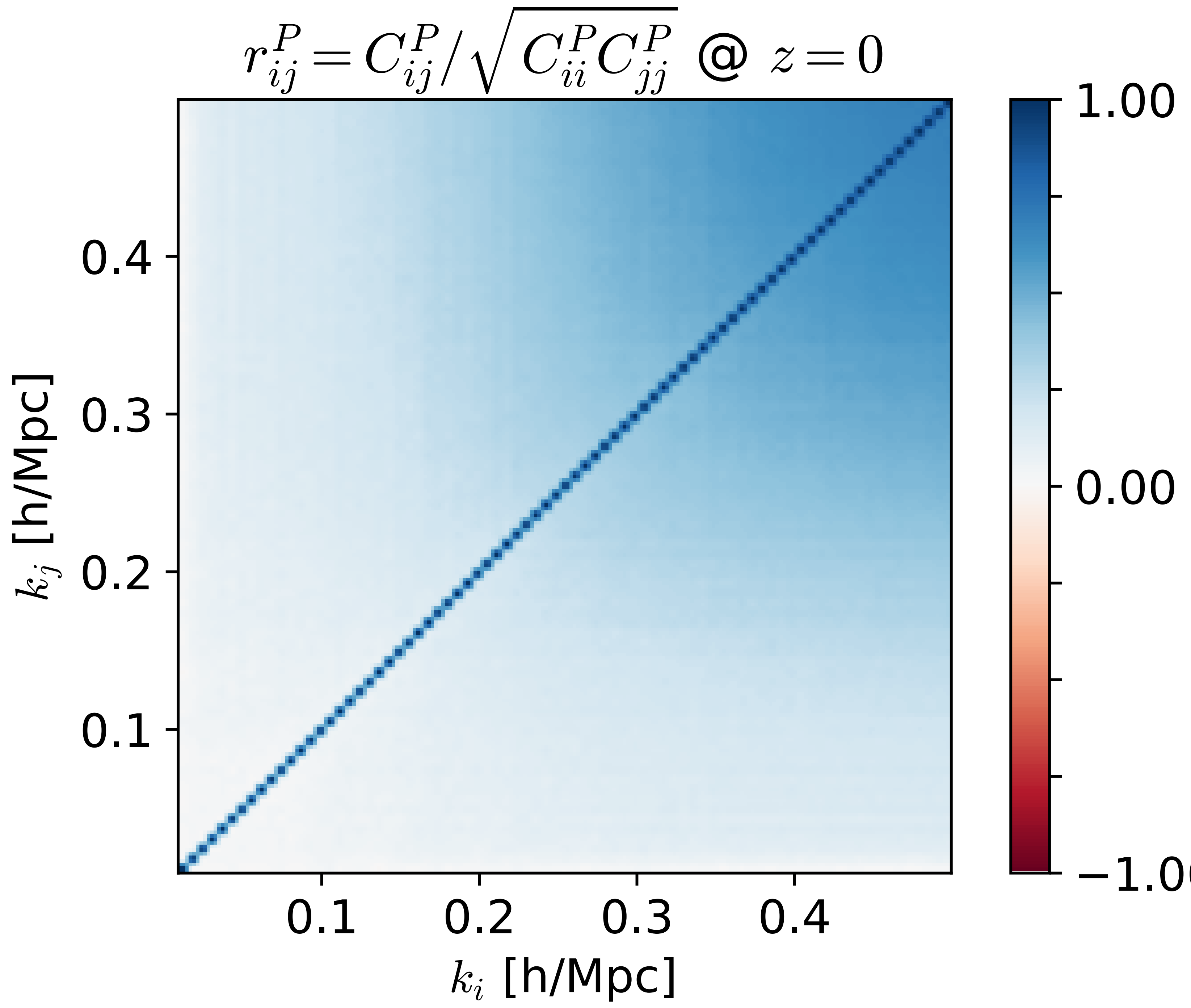
e.g. power spectrum: $C^P = \langle \hat{P}(k_i)\hat{P}(k_j) \rangle \sim P(k_i)^2 \delta_{ij} + T(k_i, k_j)$



Mode coupling

- Non-linear evolution introduces non-Gaussian covariance

  e.g. power spectrum: $C^P = \langle \hat{P}(k_i)\hat{P}(k_j) \rangle \sim P(k_i)^2 \delta_{ij} + T(k_i, k_j)$



- Affects (S/N) well below $k_{\rm NL}$
- Appreciated at low redshifts (e.g. Chan & Blot '16)

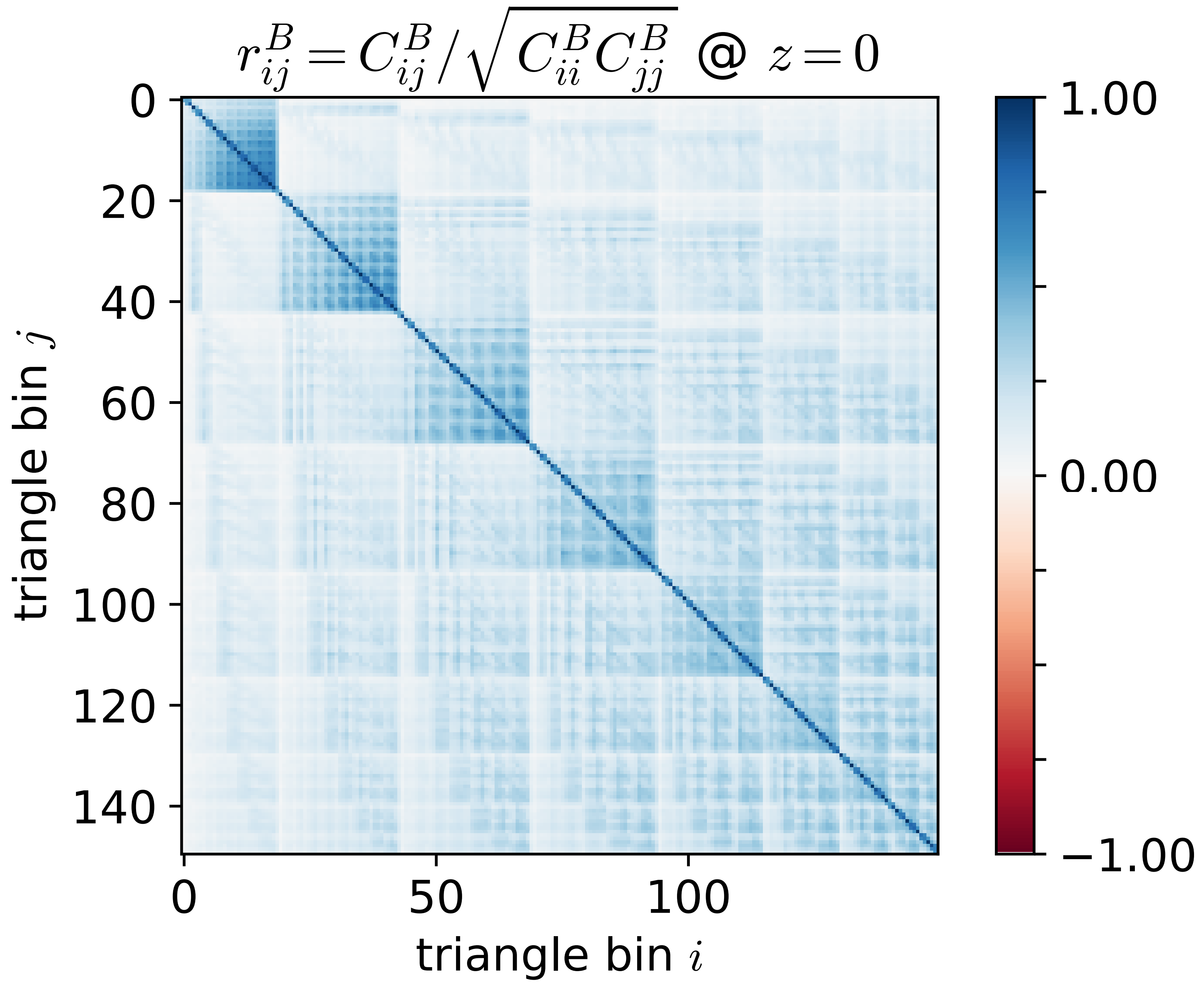
Primordial non-Gaussianity

- Primordial bispectra peak for specific triangle configurations

Primordial non-Gaussianity

- Primordial bispectra peak for specific triangle configurations

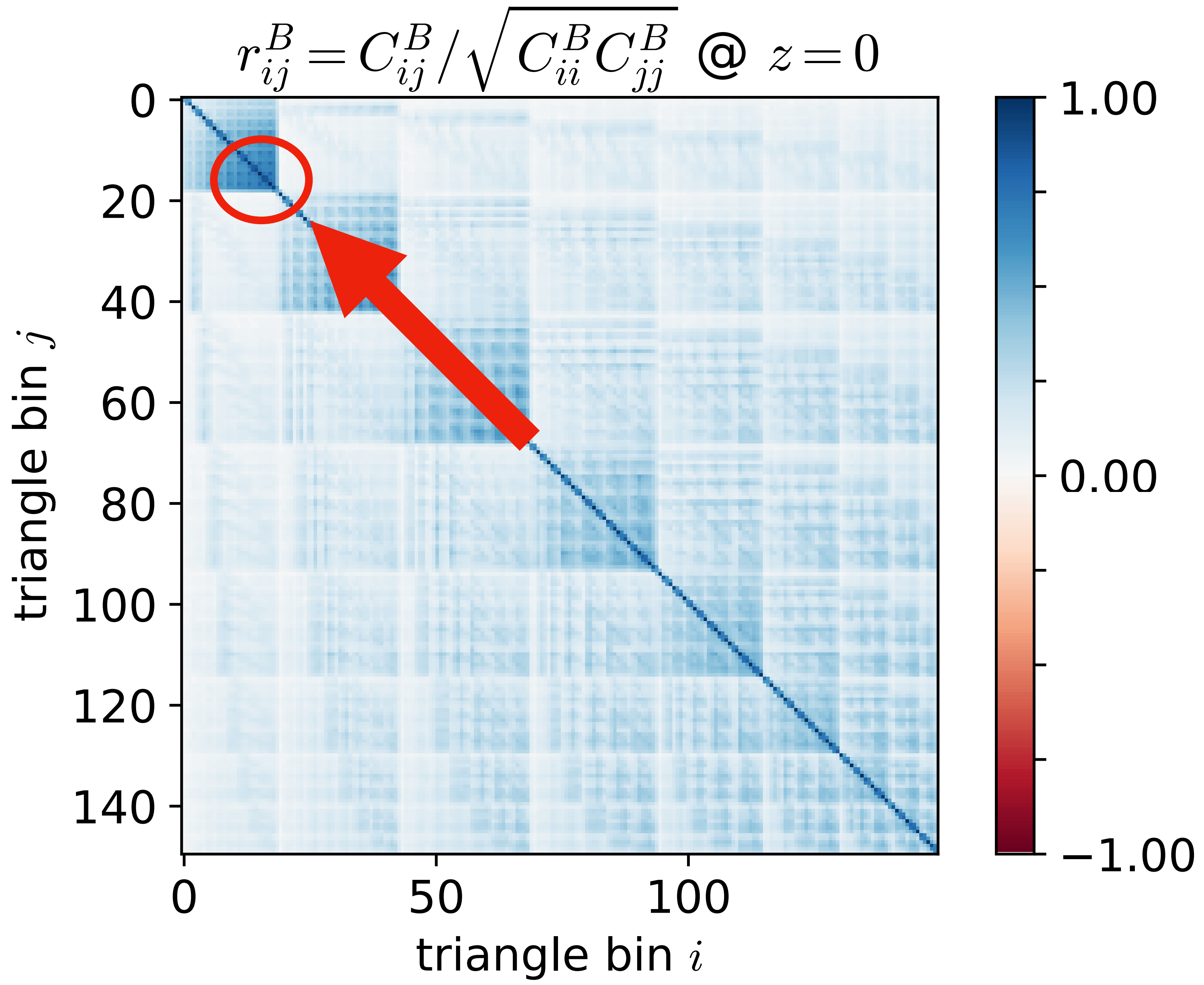
- Bispectrum covariance also has shape dependence
- Largest for squeezed triangle configurations (Biagetti et al. ’21)



Primordial non-Gaussianity

- Primordial bispectra peak for specific triangle configurations

- Bispectrum covariance also has shape dependence
- Largest for squeezed triangle configurations (Biagetti et al. ’21)



Primordial non-Gaussianity

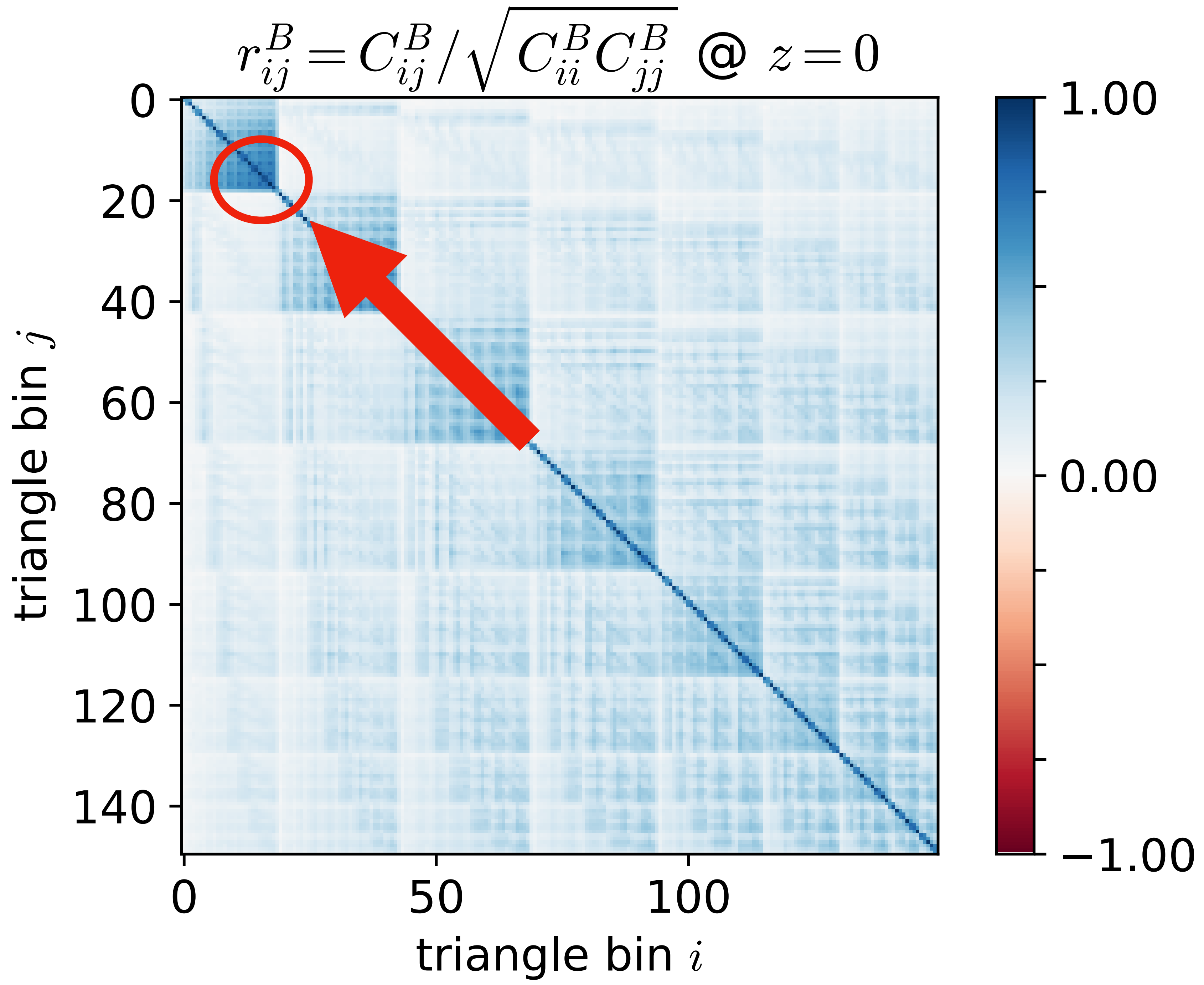
- Primordial bispectra peak for specific triangle configurations

- Bispectrum covariance also has shape dependence

- Largest for squeezed triangle configurations (Biagetti et al. '21)

1. Local pnG more affected?

2. What happens at high redshifts?



Our Approach

1. Analytically model covariance up to $k_{\rm NL}(z)$ using SPT

$$C^B_{T,T'} \sim P^3 \delta_{T,T'} + [BB]_{T,T'} + [PT]_{T,T'}$$

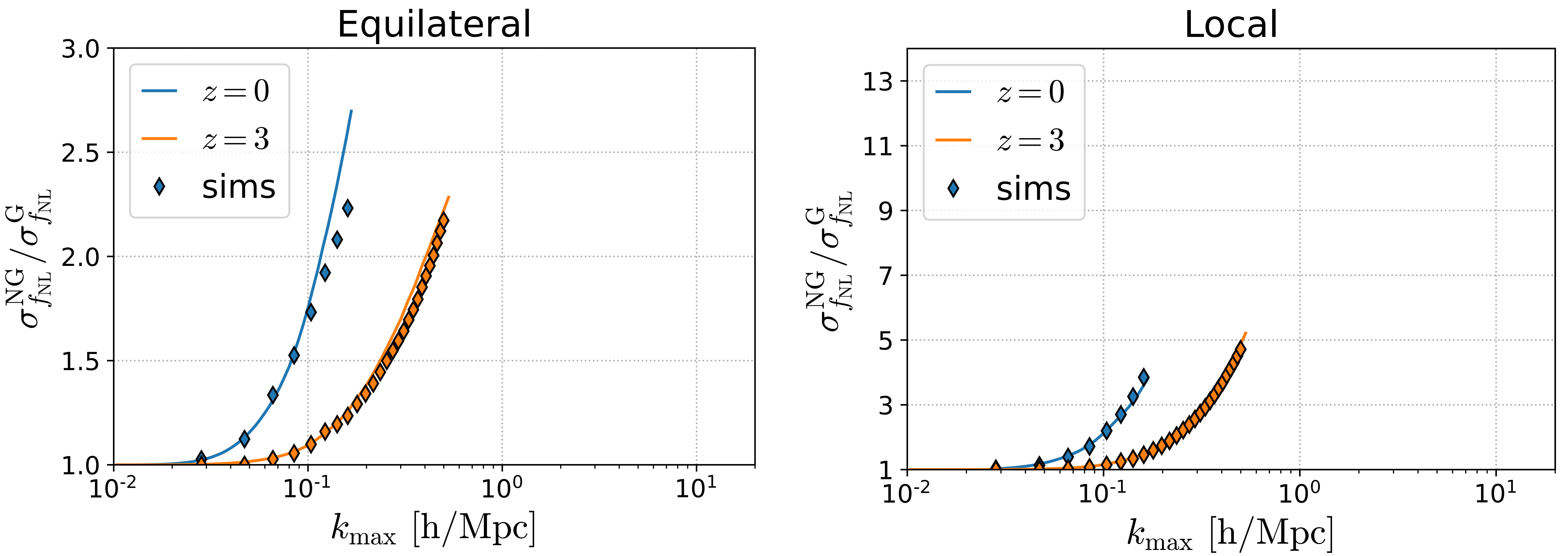
2. Fisher forecast $\sigma(f_{\rm NL})$ using tree-level pnG

$$F_{ij} = \sum_{T,T'} \frac{\partial B_T}{\partial f_{\rm NL}} \left(C^B_{T,T'}\right)^{-1} \frac{\partial B_{T'}}{\partial f_{\rm NL}}$$

3. Verify with Quijote ($z = 0, 3$) and 3LPT ($z = 10$)

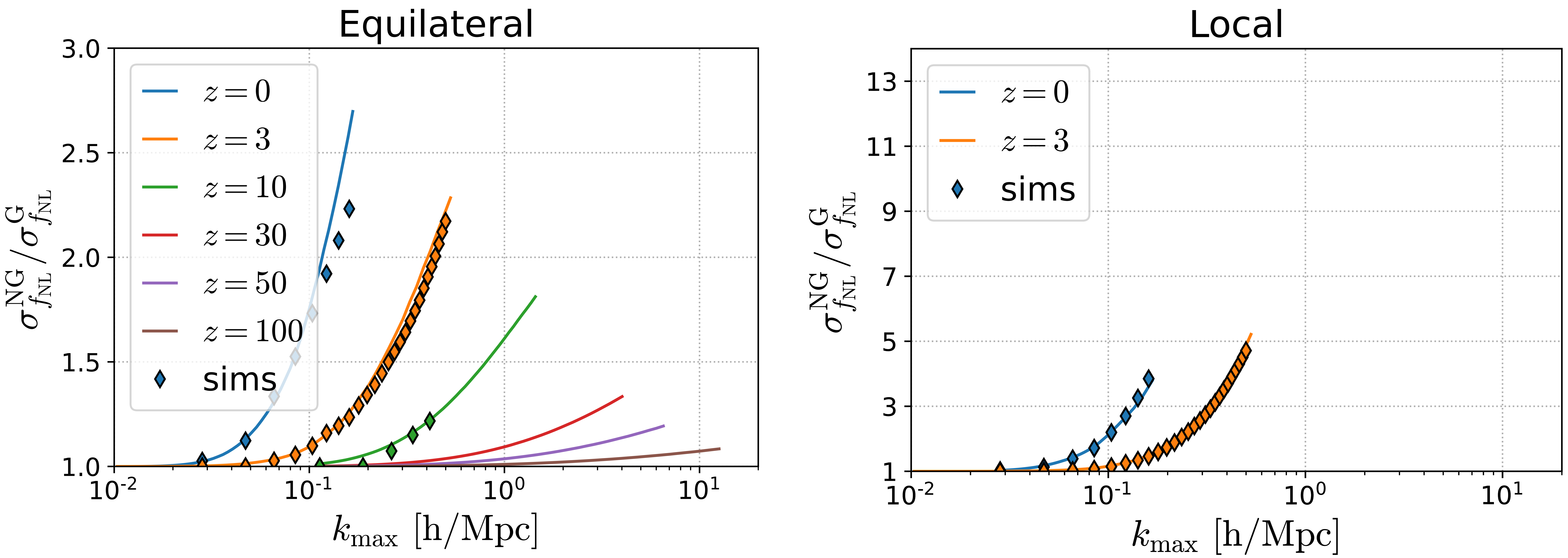
4. High redshifts (e.g. Dark Ages)

Results



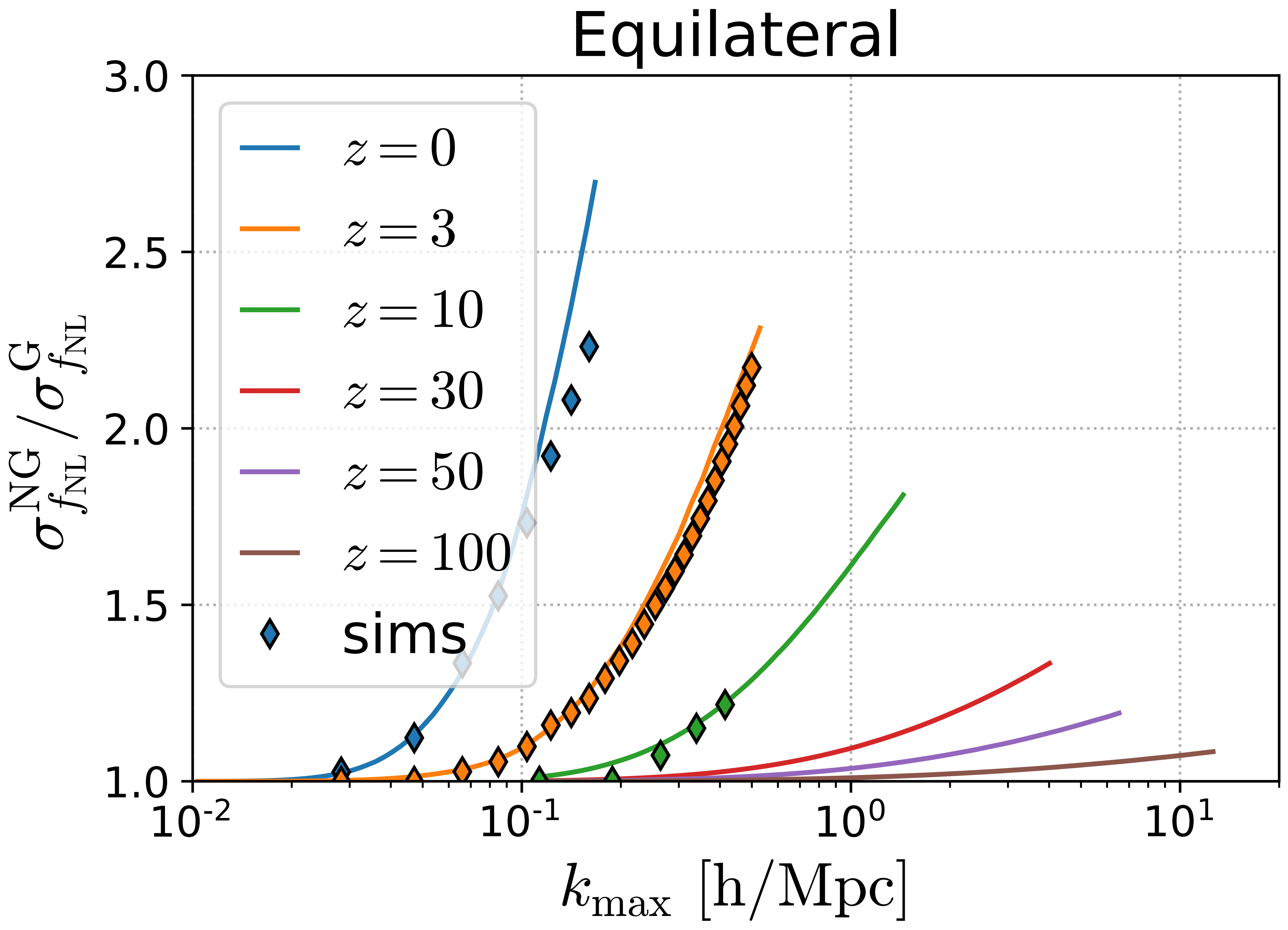
Figures: ratio of $\sigma(f_{\rm NL})$ with and without non-Gaussian covariance for local and equilateral primordial bispectra at different redshifts

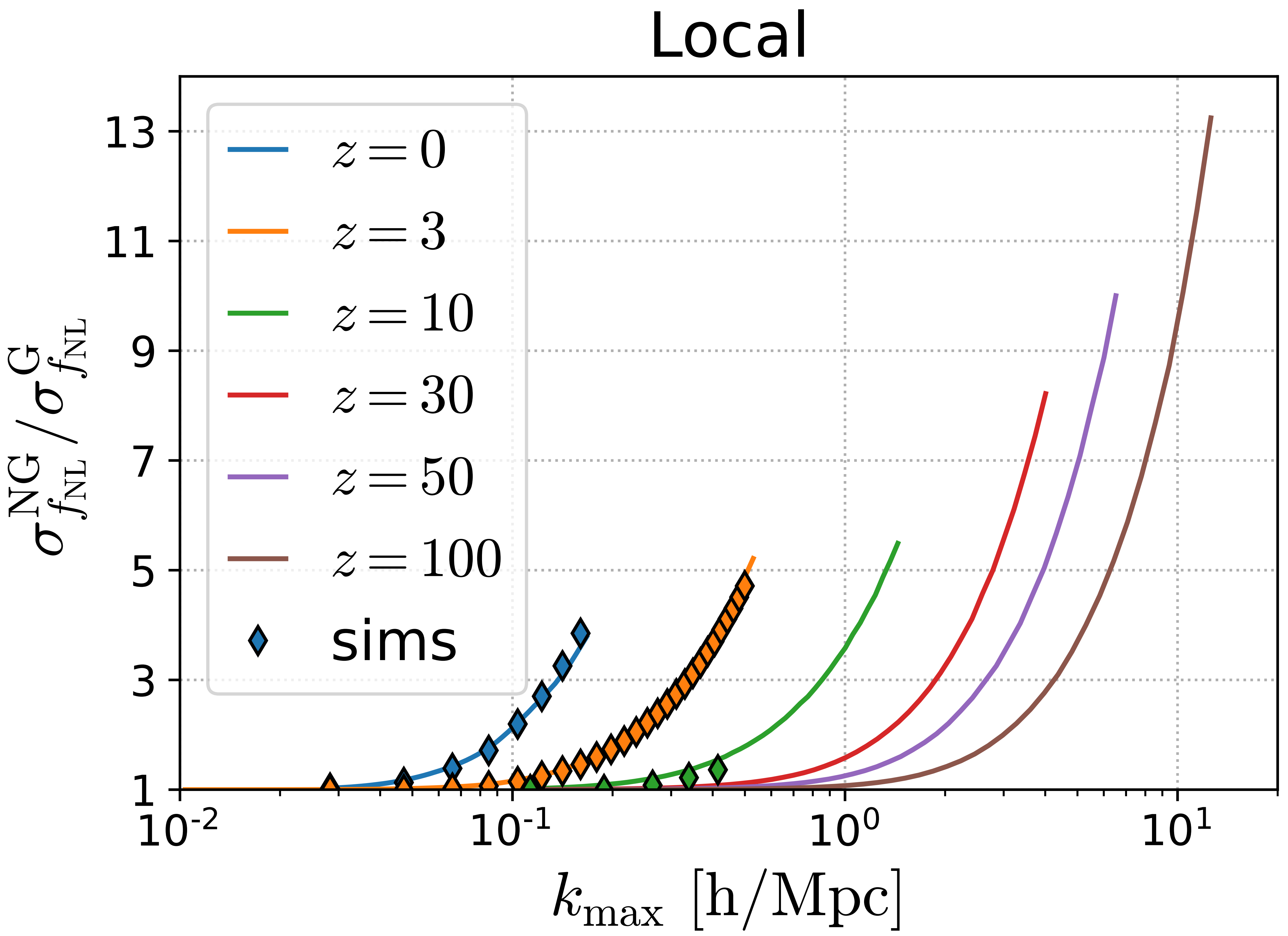
Results



Figures: ratio of $\sigma(f_{\rm NL})$ with and without non-Gaussian covariance for local and equilateral primordial bispectra at different redshifts

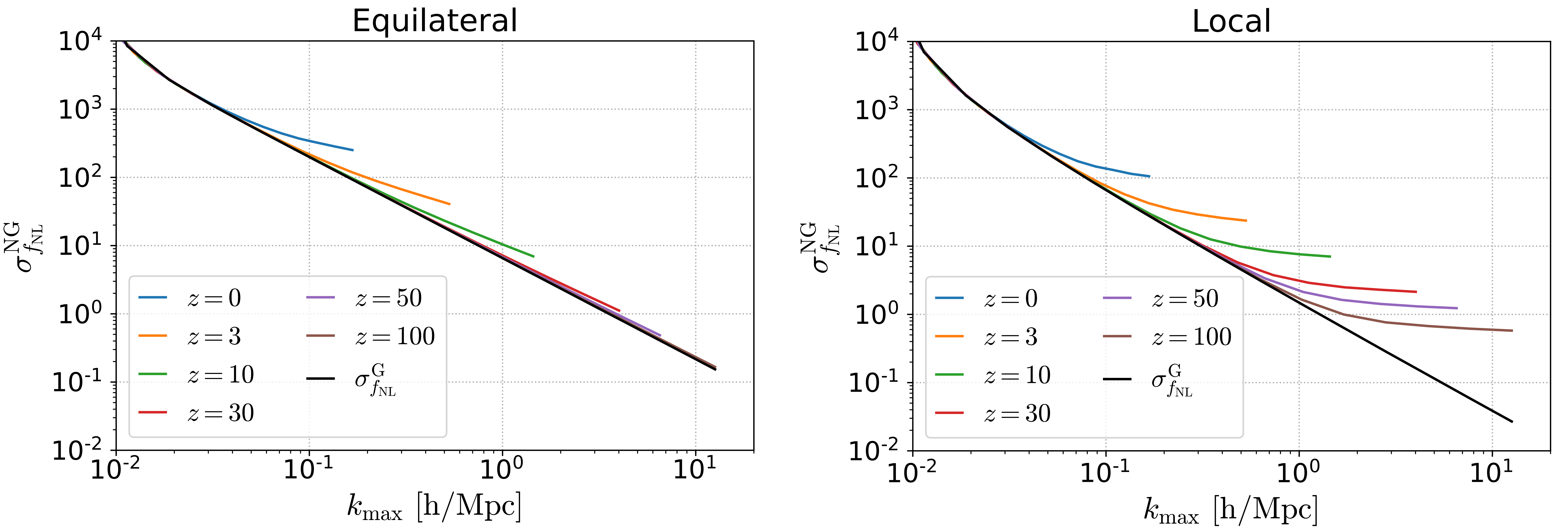
Results





Figures: ratio of $\sigma(f_{\rm NL})$ with and without non-Gaussian covariance for local and equilateral primordial bispectra at different redshifts

Results



Figures: $\sigma(f_{NL})$ with nG covariance for local and equilateral primordial bispectra for a fictitious survey of $V = (1\,\mathrm{Gpc})^3$ at different redshifts up to k_{NL}

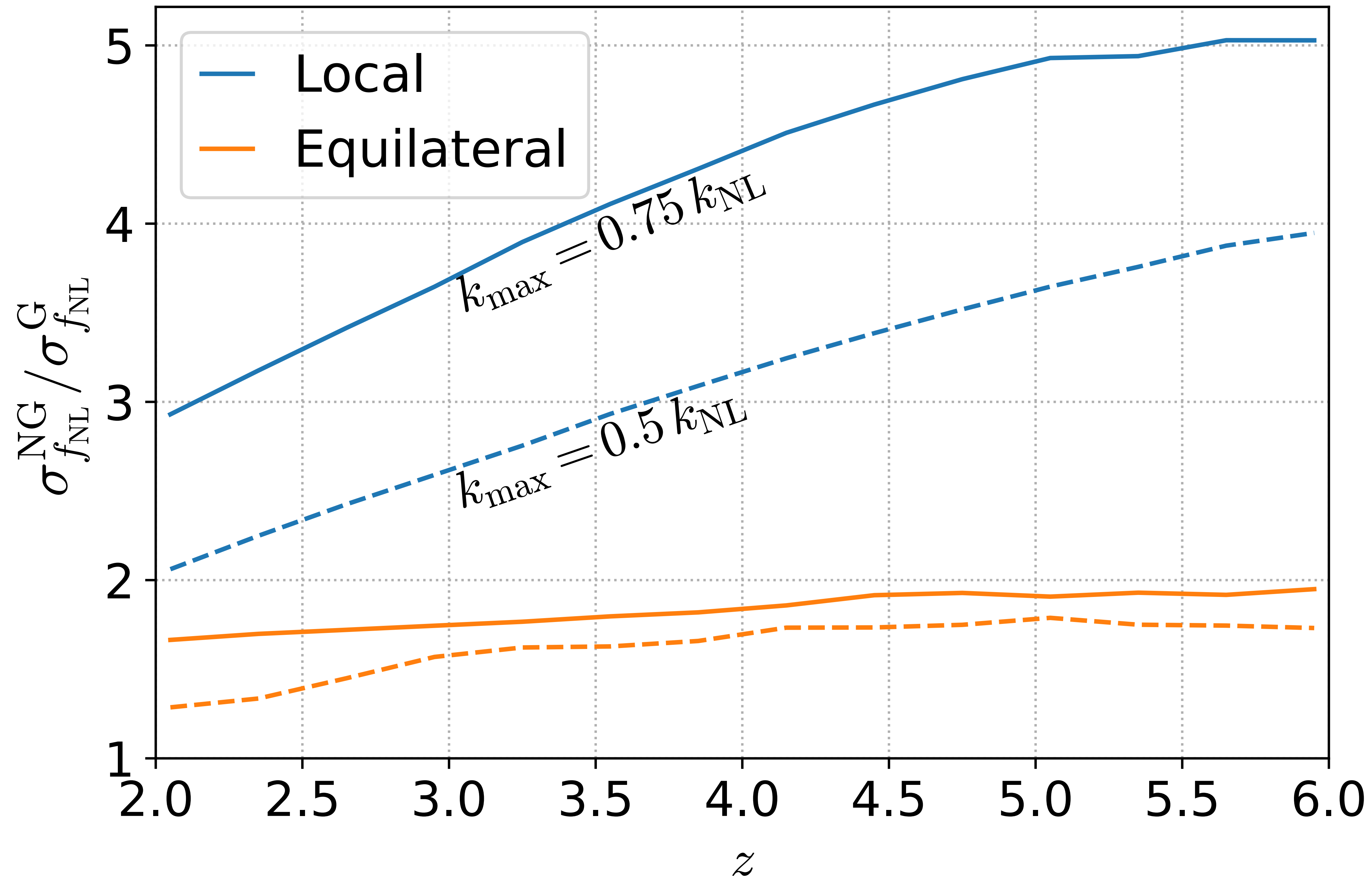
III. Implications for future observations

Revisiting the PUMA forecast

- PUMA is a proposed high-z ($2 < z < 6$) 21-cm intensity mapping experiment
- Forecast without off-diagonal covariance (Karagiannis et al. ’19)

Revisiting the PUMA forecast

- PUMA is a proposed high-z $(2 < z < 6)$ 21-cm intensity mapping experiment
- Forecast without off-diagonal covariance (Karagiannis et al. '19)
- Our nG covariance model:



IV. Conclusions and Outlook

Conclusion & Outlook

- Non-Gaussian covariance limits our ability to constrain (local) primordial non-Gaussianity
- High redshift surveys might not perform as well as we had hoped

Conclusion & Outlook

- Non-Gaussian covariance limits our ability to constrain (local) primordial non-Gaussianity
- High redshift surveys might not perform as well as we had hoped

- Based on summary statistics
- We know how gravity acts on large scales
- ‘De-gravitate’ (reconstruct) density field