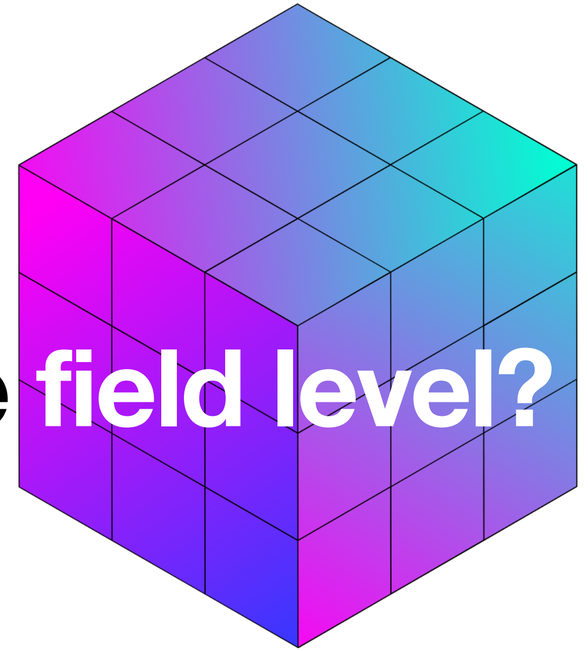
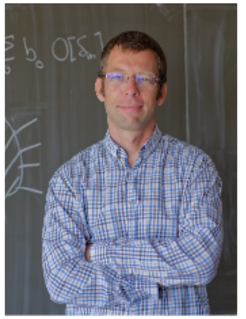
How much information can we extract from galaxy clustering at the field level?



Minh Nguyen (University of Michigan)
nguyenmn@umich.edu

Fabian Schmidt

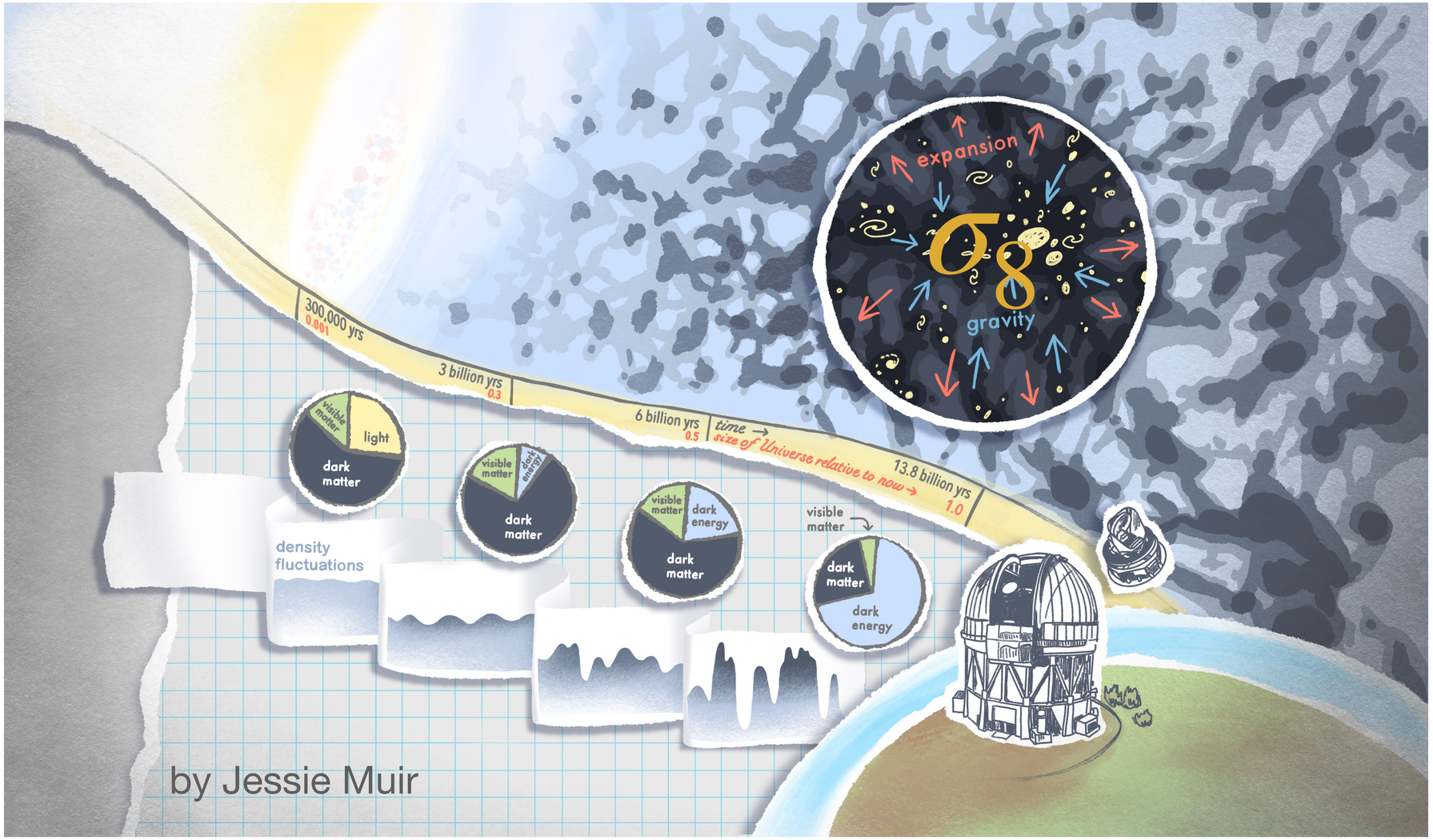


Beatriz Tucci

Fundamental Physics from Future Spectroscopic Surveys
LBNL, Berkeley, May 6-8 2024

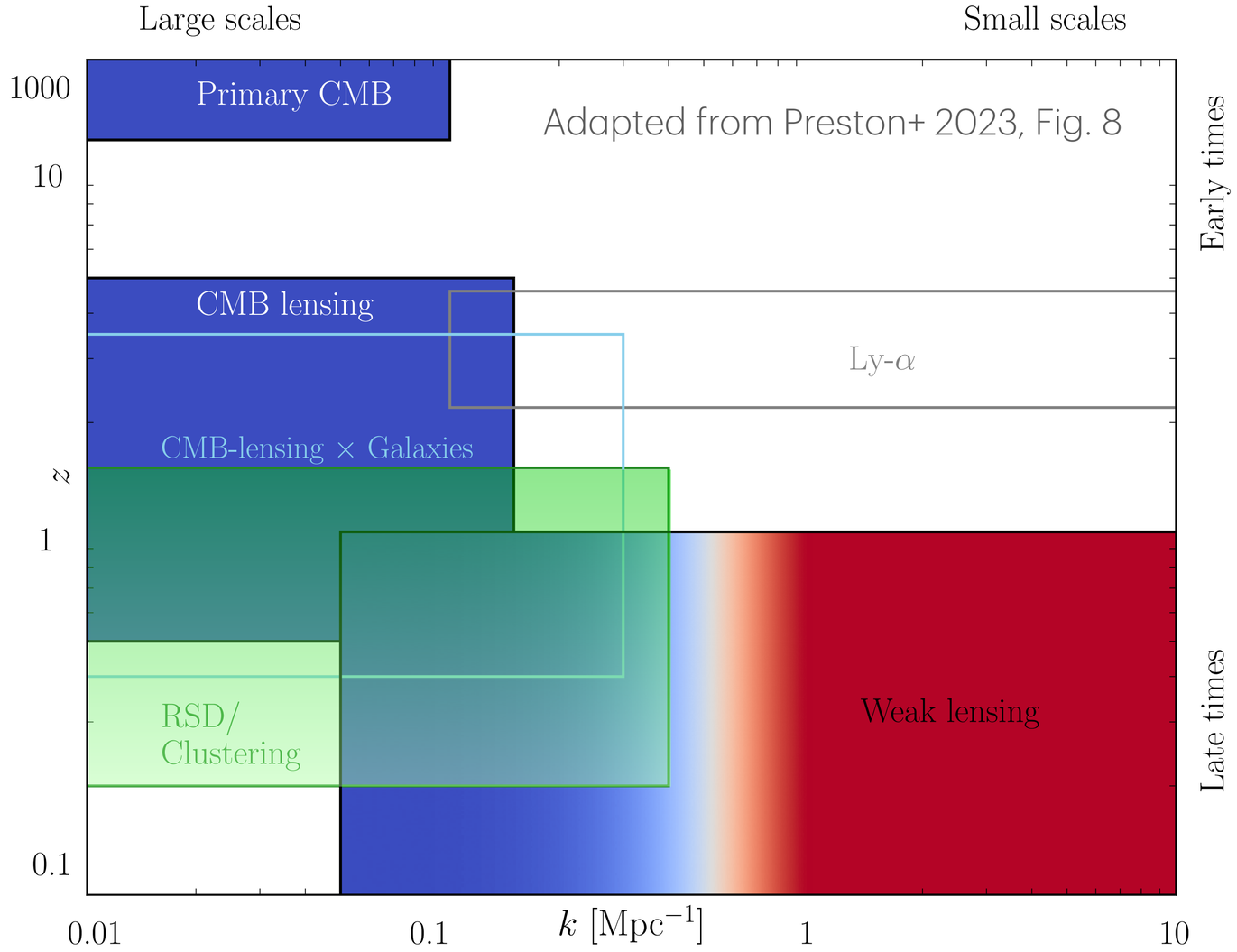
Growth of Structure from Galaxy Clustering

Dark Energy, Gravity and Dark Matter



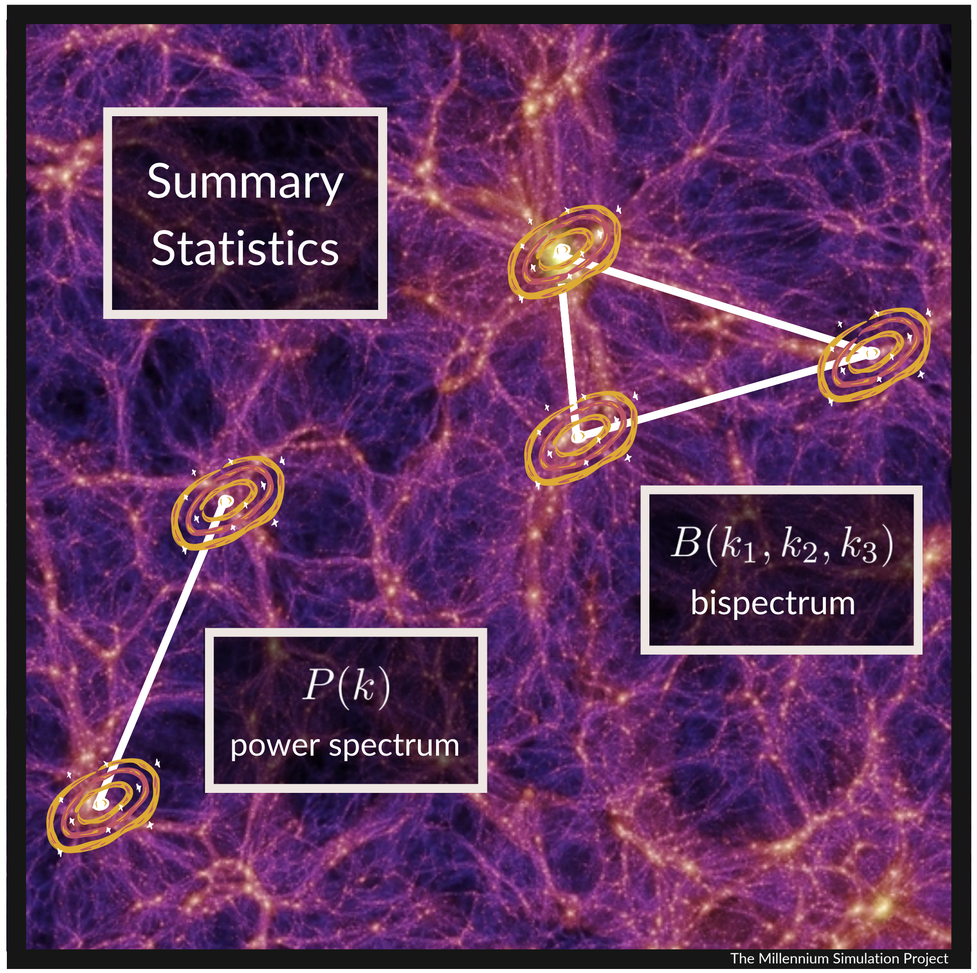
Growth of Structure from Galaxy Clustering

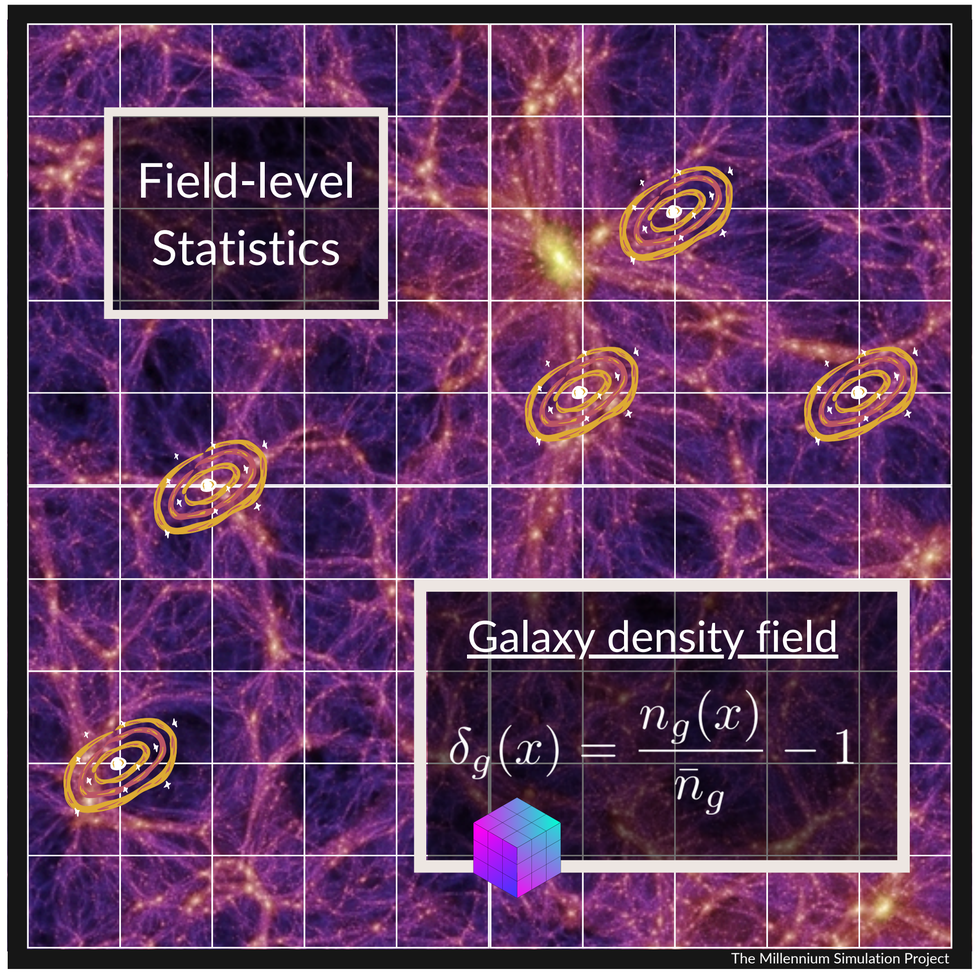
New Physics from late- vs early-time and small- vs large-scale



Galaxy Clustering analysis

From Summary Statistics to Field-level Statistics

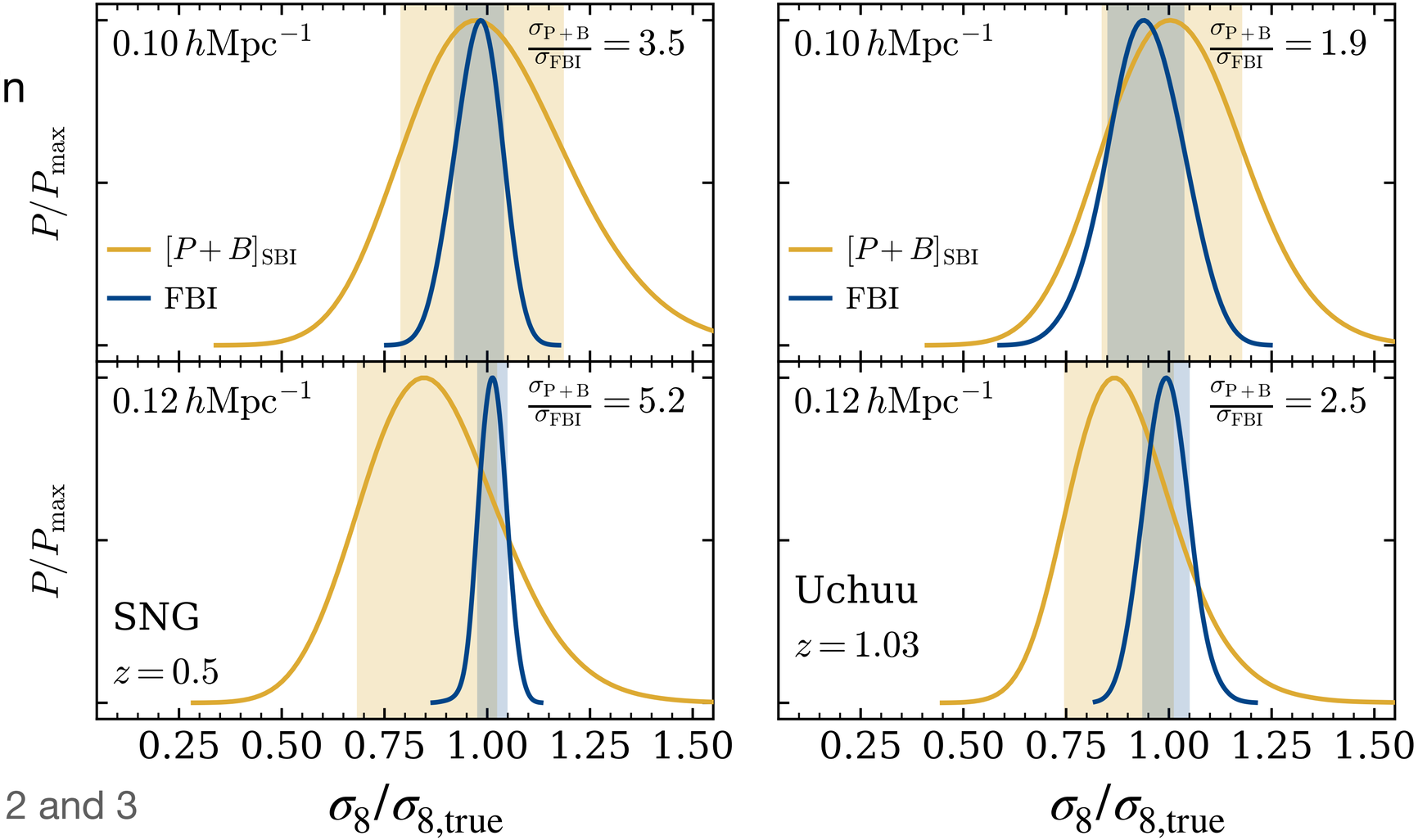




How much more (reliable) information?

Several-factor improvement from P+B to field-level statistics

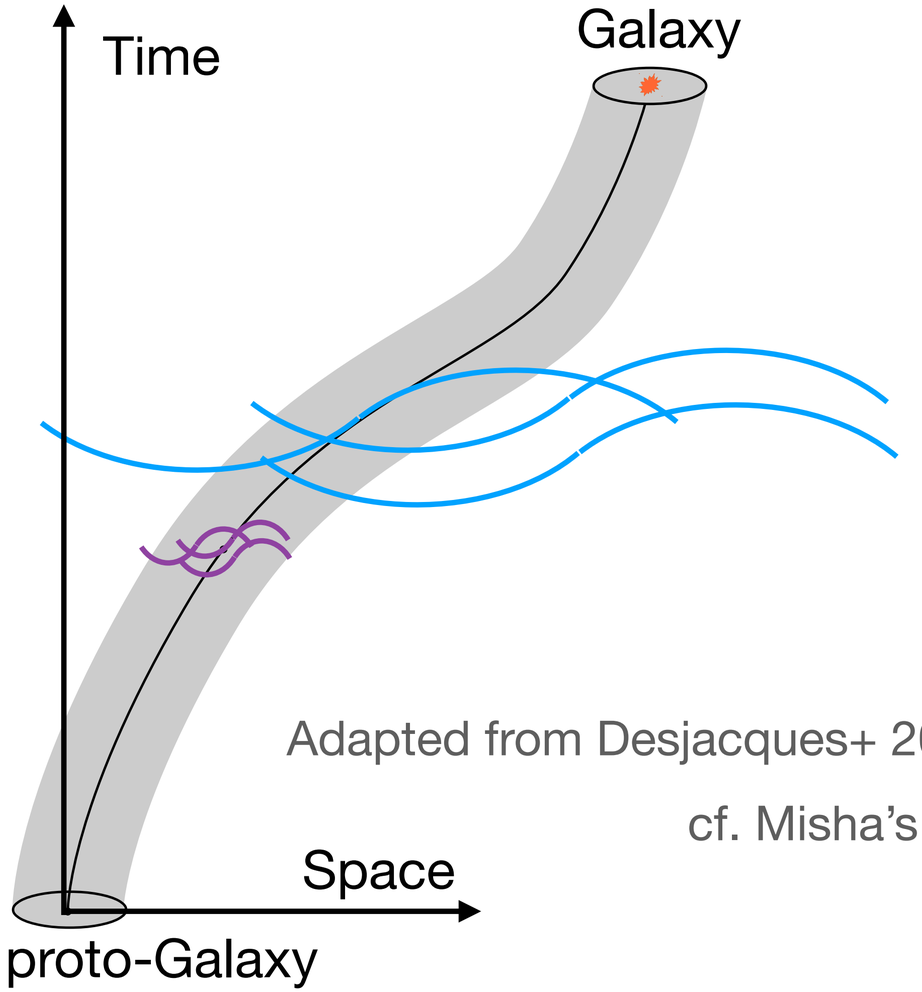
- Different samples of halos in different cosmologies [2403.03220]
- Exact *same* modes
- Constraints do not include information from RSD



MN+ 2024, Fig. 2 and 3

Field-level Model for Galaxy Clustering

Lagrangian, EFT-based forward model (LEFTfield)



Adapted from Desjacques+ 2016, Fig. 6

cf. Misha's talk

Field-level EFT bias expansion

$$\delta_g(\theta, \hat{s}) = \sum_O b_O O(\theta, \hat{s}) + \epsilon$$

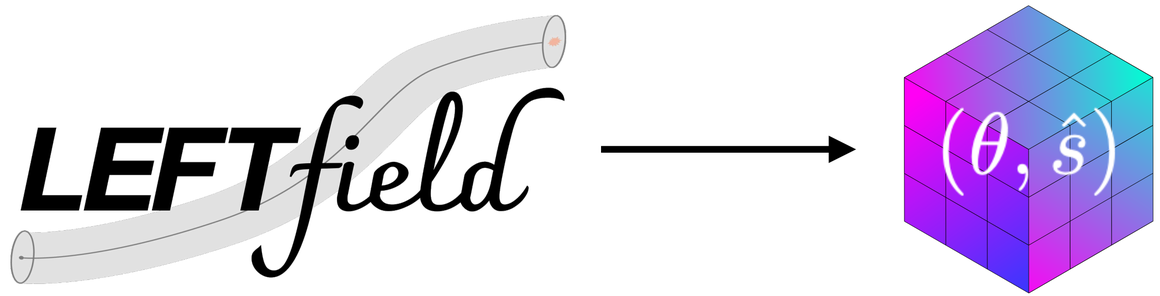
+

n^{th}-order **Lagrangian** displacement field

=

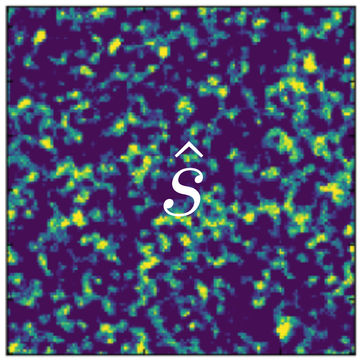
Field-level Inference from Galaxy Clustering

Constraining both cosmology and initial conditions with LEFTfield



gradient-based sampling

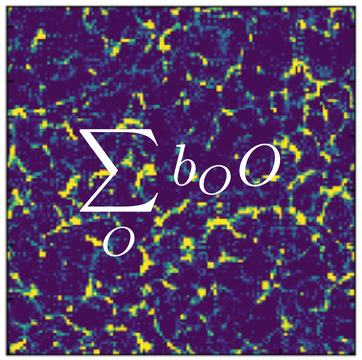
Gaussian



θ

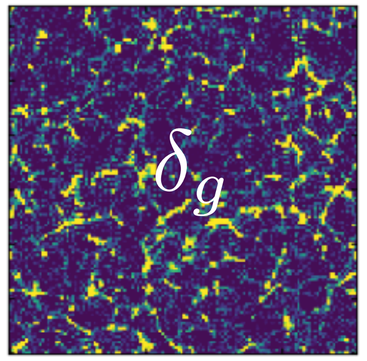
forward model

2012.09837



EFT likelihood

1909.04022

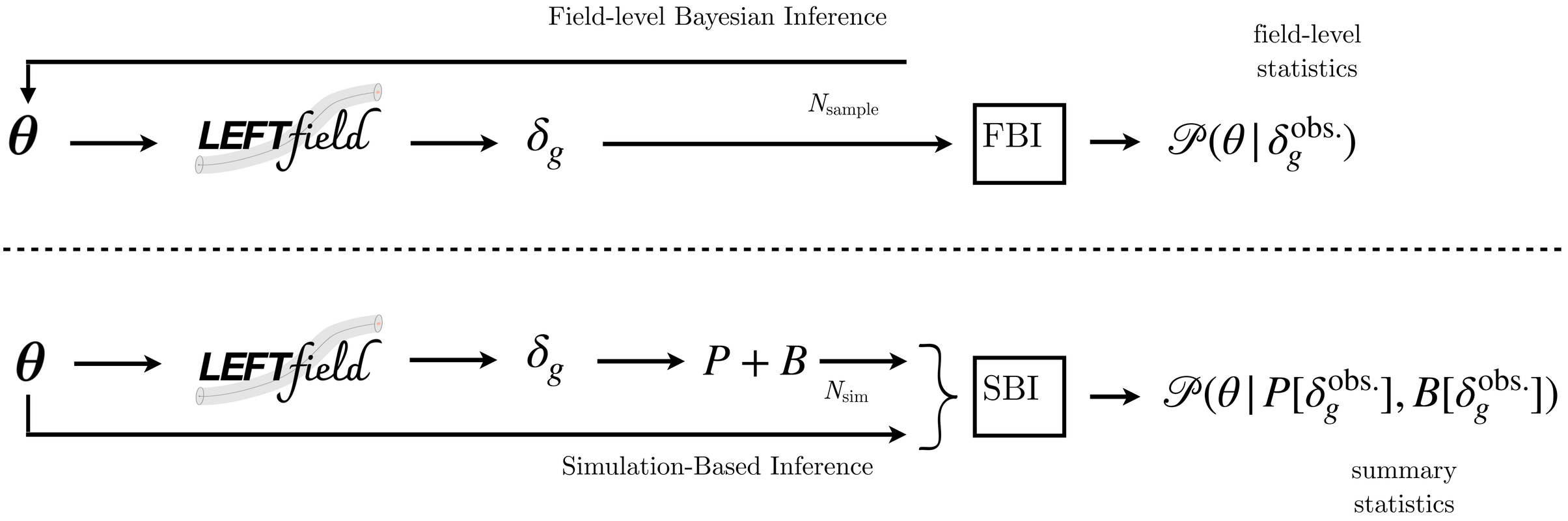


non-Gaussian

Adapted from Julia Stadler

Universal cosmological inference framework

Supporting both sampling & simulation-based inference



MN+ 2024, Fig. 1

Outlook for future survey data application

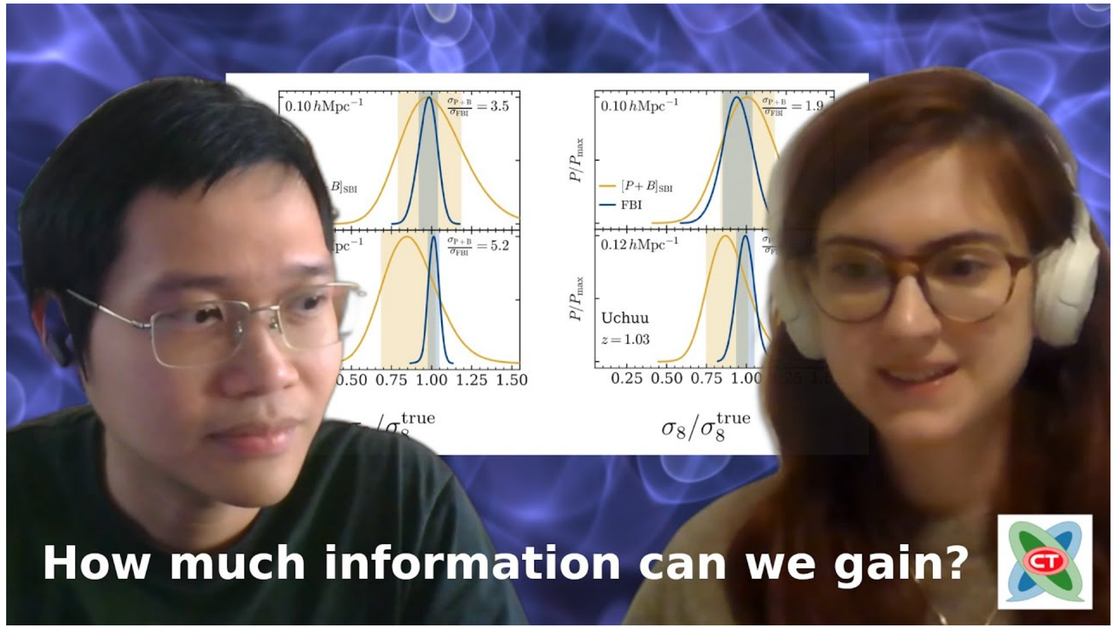
Connecting LEFTfield to spectroscopic surveys

- A lot of information can be (robustly) extracted from galaxy spectroscopic surveys, even at quasi-linear regime
- Apple-to-apple comparison show field-level statistics can improve several factors over P+B, implying order of magnitude increase of survey volume
- **Spec-S5**: **Higher galaxy density** and **more survey synergies**
- To-do #1: Extend parameter and observable space (e.g. shape, velocity)
- To-do #2: Include observational effects and survey systematics

Thank you!

Details? Please check out these Cosmology Talks interviews!

Questions? nguyenmn@umich.edu



MN+ 2024 [2403.03220]

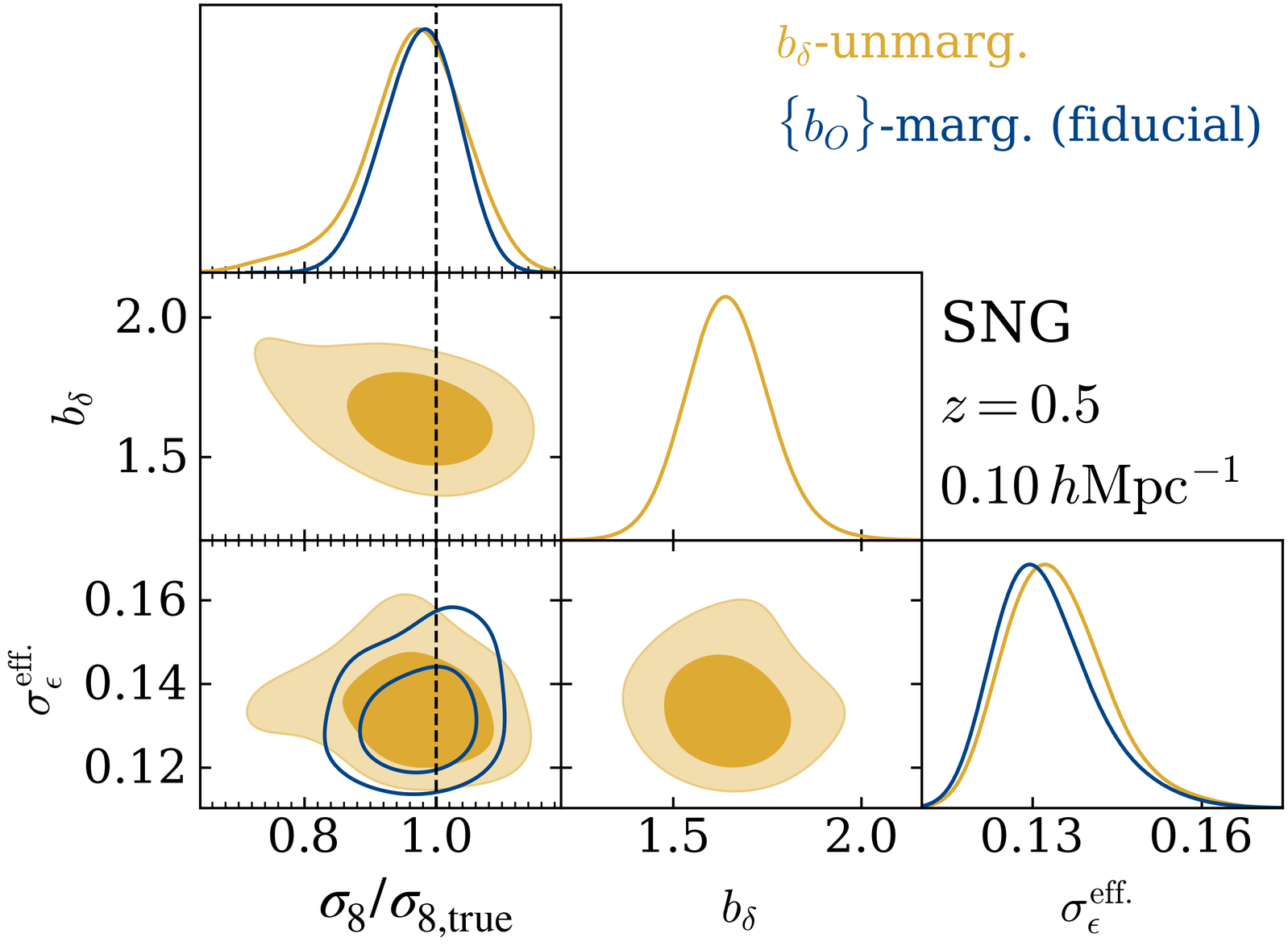
Beyond-2pt

Parameter-masked Mock Data Challenge

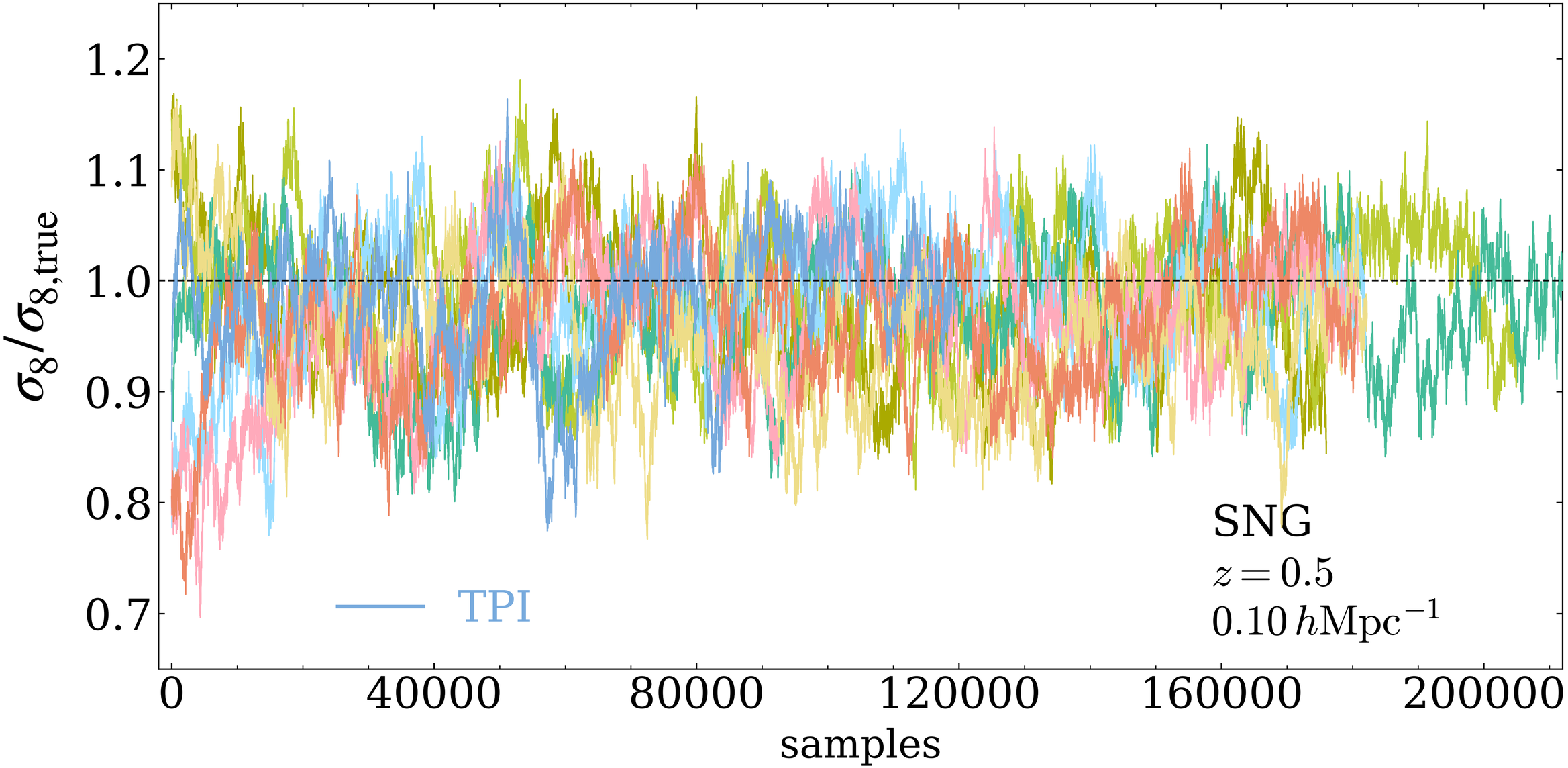
Beyond-2pt Collaboration [2405.02252]

Details for Experts

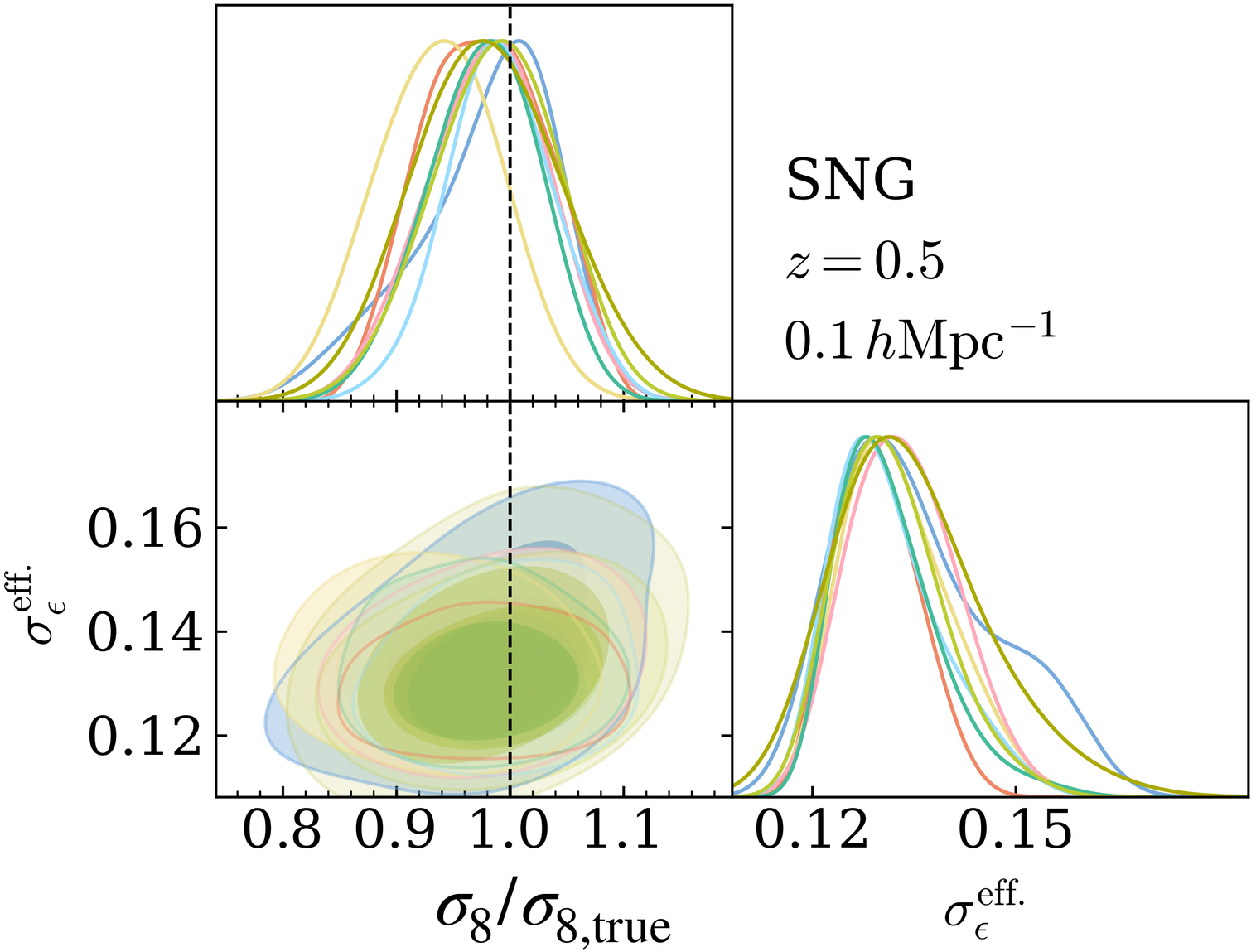
FBI - Breaking bias—σ_8 degeneracy



FBI - MCMC convergence with raw samples



FBI - Posterior consistency between MCMC chains



SBI P+B - Including non-Gaussian noise

Bispectrum stochasticity contains non-Gaussian contributions

Perturbation Theory

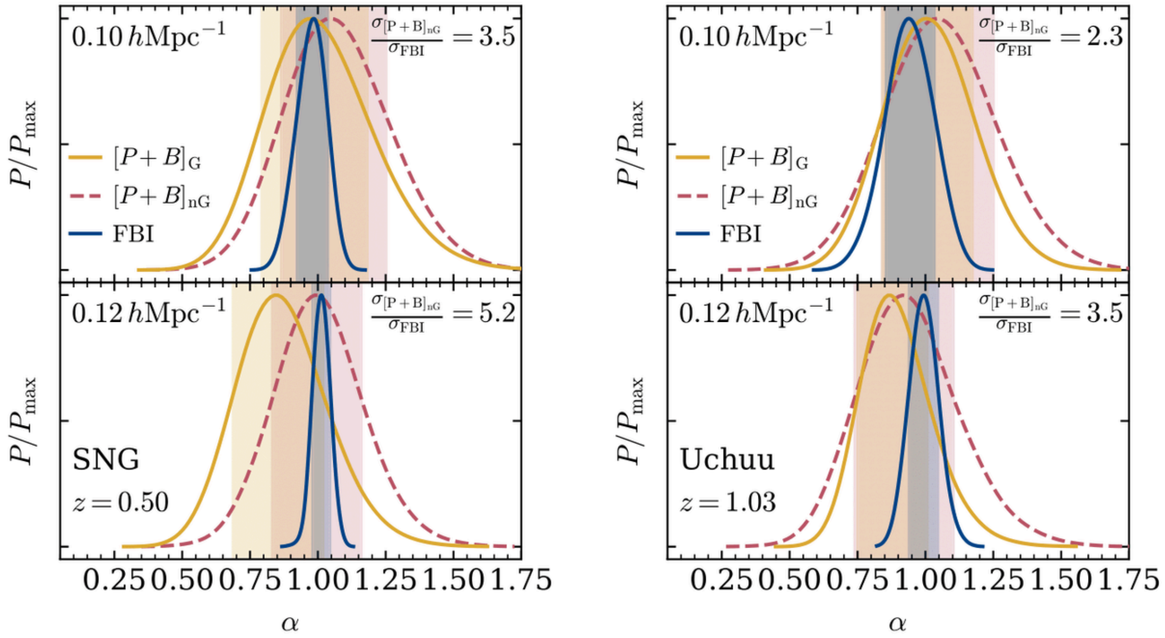
$$\langle \delta_g(k_1)\delta_g(k_2)\delta_g(k_3)\rangle'^{\rm LO}_{\rm stoch} = B_\varepsilon + 2b_1 P_{\varepsilon\varepsilon_\delta}(P_{\rm m}(k_1) + 2 \text{ perm.})$$

Forward Model

$$\langle \delta_g(k_1)\delta_g(k_2)\delta_g(k_3)\rangle'^{\rm LO}_{\rm stoch} = 6c_\varepsilon^{\rm NG} P_\varepsilon^2 + 2b_1 P_\varepsilon \sigma_{\varepsilon\delta}(P_{\rm m}(k_1) + 2 \text{ perm.})$$

$$\delta_g(\mathbf{x},\tau) = \delta_{g,\rm det}(\mathbf{x},\tau) + \varepsilon(\mathbf{x},\tau) + \sigma_{\varepsilon\delta}(\tau)\varepsilon(\mathbf{x},\tau)\delta(\mathbf{x},\tau) + c_\varepsilon^{\rm NG}(\tau)\varepsilon^2(\mathbf{x},\tau)$$

What if we account for that in our SBI P+B analysis?



See also Misha's talk, Ivanov+, Philcox+Ivanov

SBI P+B - Training with *LEFT*$field$ data

$$\boldsymbol{\theta} \equiv \{\alpha, \{b_O\}, \{\sigma_\epsilon\}\}$$

$$\boldsymbol{\theta} \sim \mathcal{P}(\alpha, \{b_O\}, \{\sigma_\epsilon\})$$

parameters drawn from prior

δ_g

samples

$\{P[\delta_g], B[\delta_g]\}_{N_{\rm sim}}$

power spectrum + bispectrum

sbi: A toolkit for simulation-based inference
Tejero-Cantero et al. (2020)

density estimator

SBI posterior

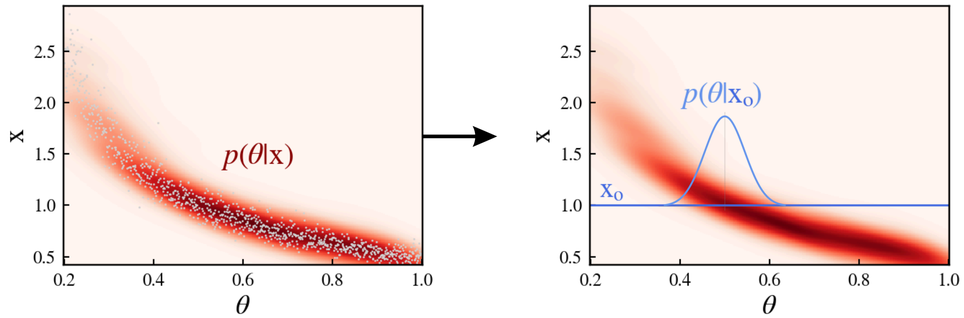
$$\mathcal{P}_{\rm P+B}\left(\boldsymbol{\theta}\middle|P[\delta_g^{\rm obs}], B[\delta_g^{\rm obs}]\right)$$

data

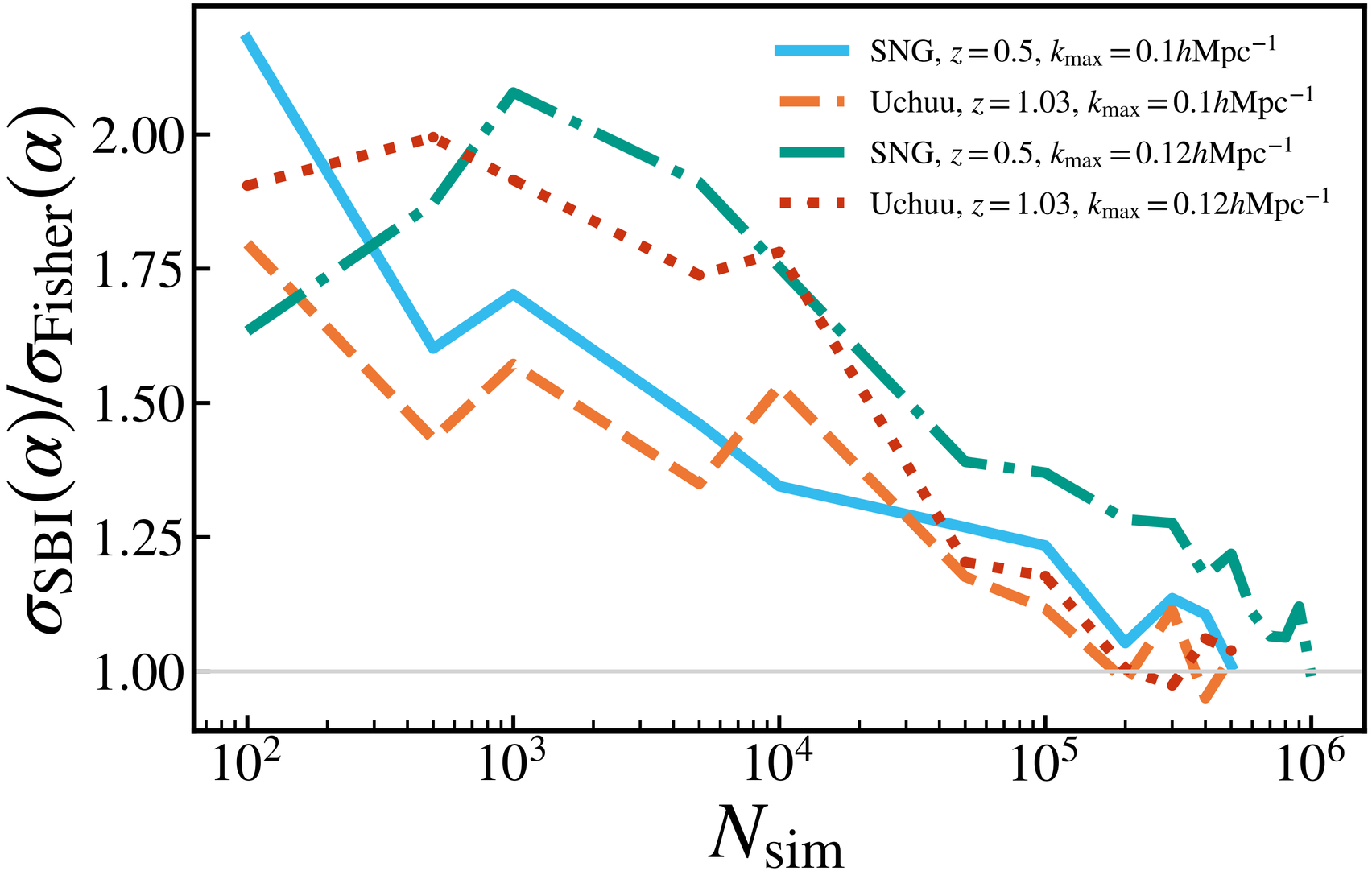
$\delta_g^{\rm obs}$

observed power spectrum + bispectrum

$P[\delta_g^{\rm obs}], B[\delta_g^{\rm obs}]$



SBI P+B - Convergence with $N_{\rm sim}$



SBI P+B - Coverage tests (Simulation-based calibration)

$$\alpha = \sigma_8/\sigma_{8,\mathrm{true}}$$

No sign of over- or under-estimation of parameter uncertainties