Baryons and non-Gaussian statistics for weak lensing cosmology

Daniela Grandón
Leiden University

In collab with Elena Sellentin, Jia Liu, Gabriela Marques, Sihao Cheng, Joaquin Armijo++

arXiv:2308.10866, 2403.03807
Grandón & Sellentin in prep. 2024

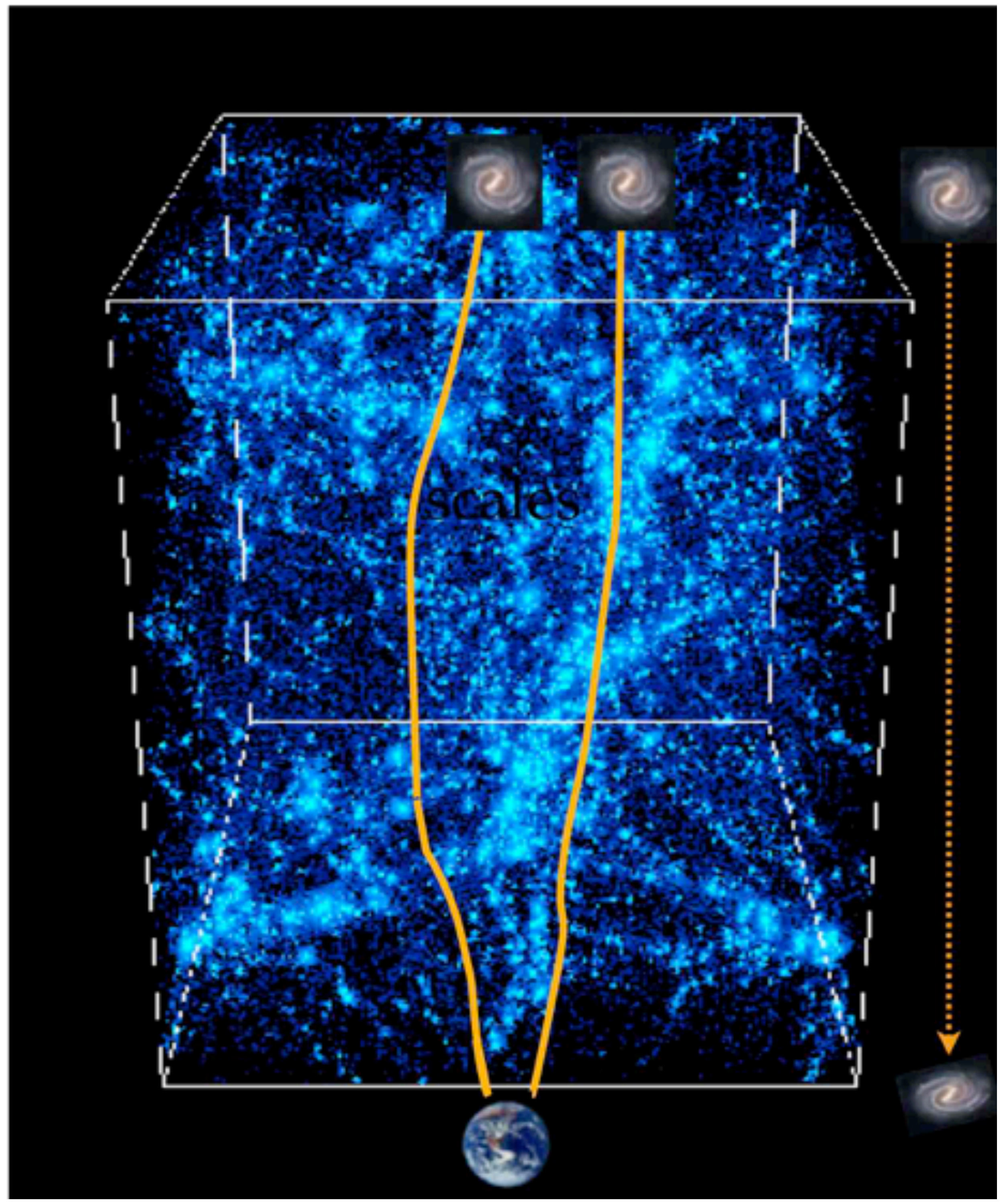
COSMO21, 21 May 2024, Chania 🇬🇷

Weak lensing cosmology and non-Gaussian fields

Weak gravitational lensing: convergence

Weak lensing convergence (κ) maps are 2D projections of the matter density along the line of sight.

$$\kappa(\boldsymbol{\theta}) = \frac{3H_0^2\Omega_m}{2c^2}\int_0^{\chi_{lim}} \mathrm{d}\chi g(\chi)\chi\frac{\delta(\chi\boldsymbol{\theta},\chi)}{a(\chi)}$$



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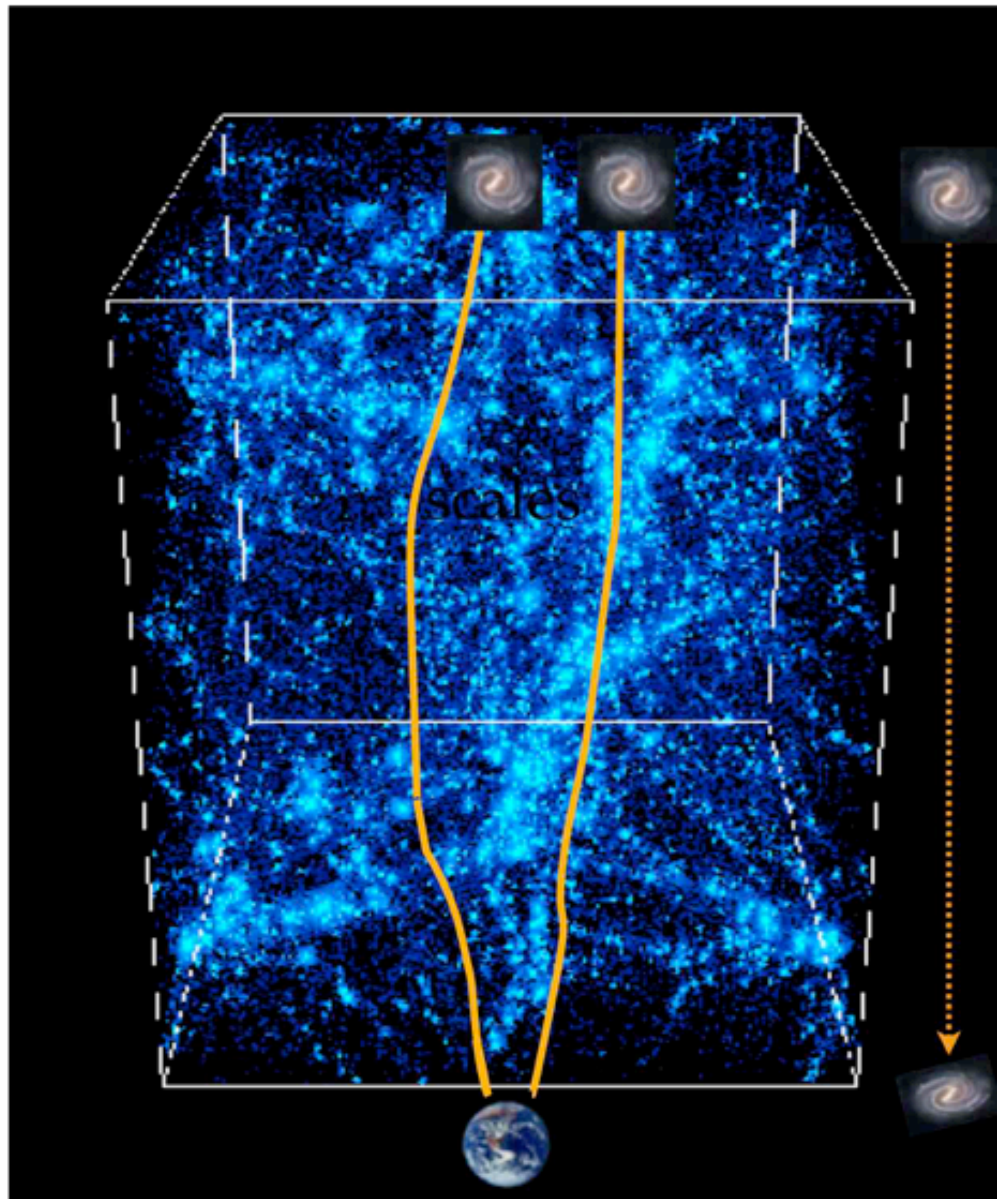

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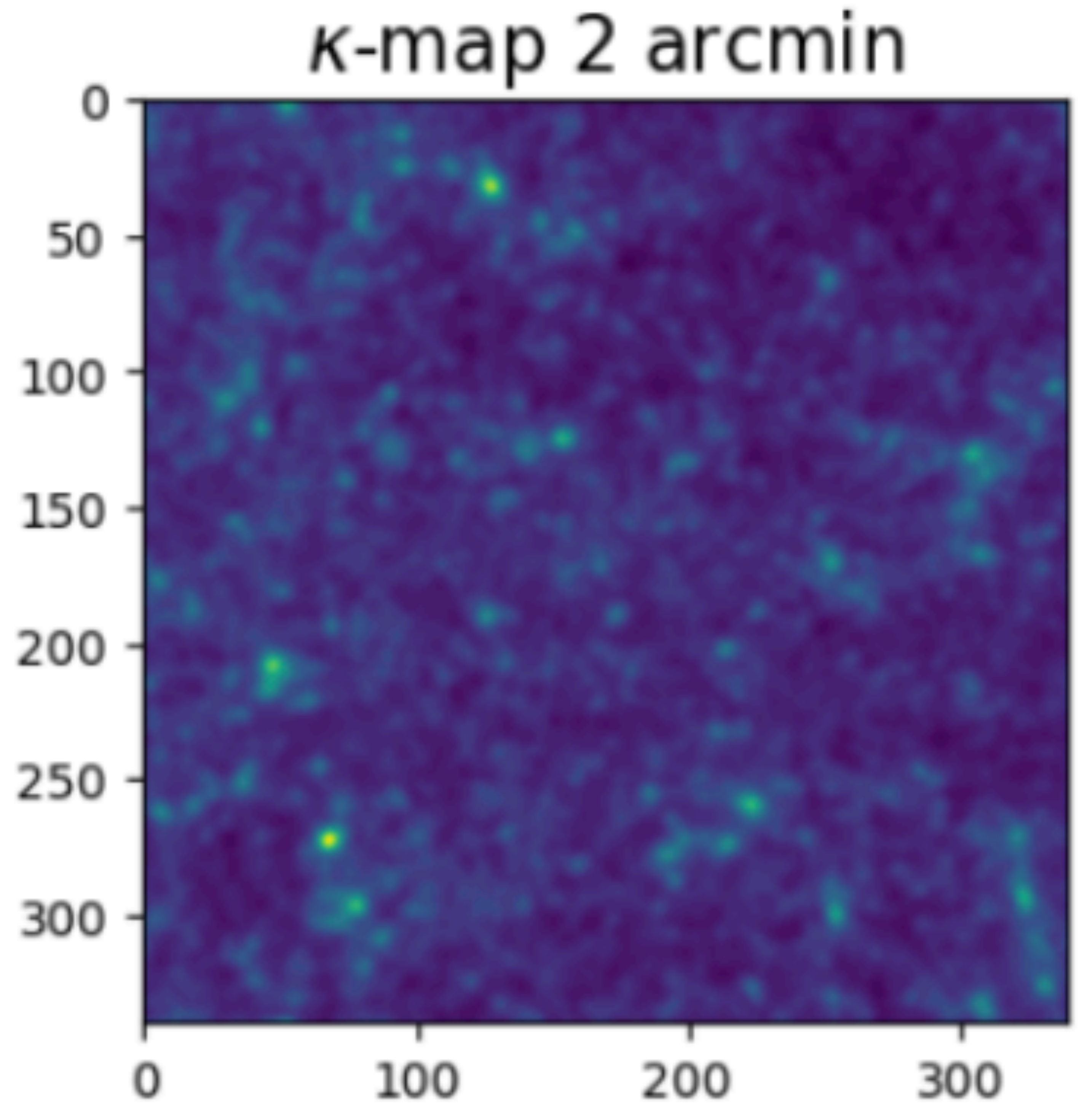
Convergence map



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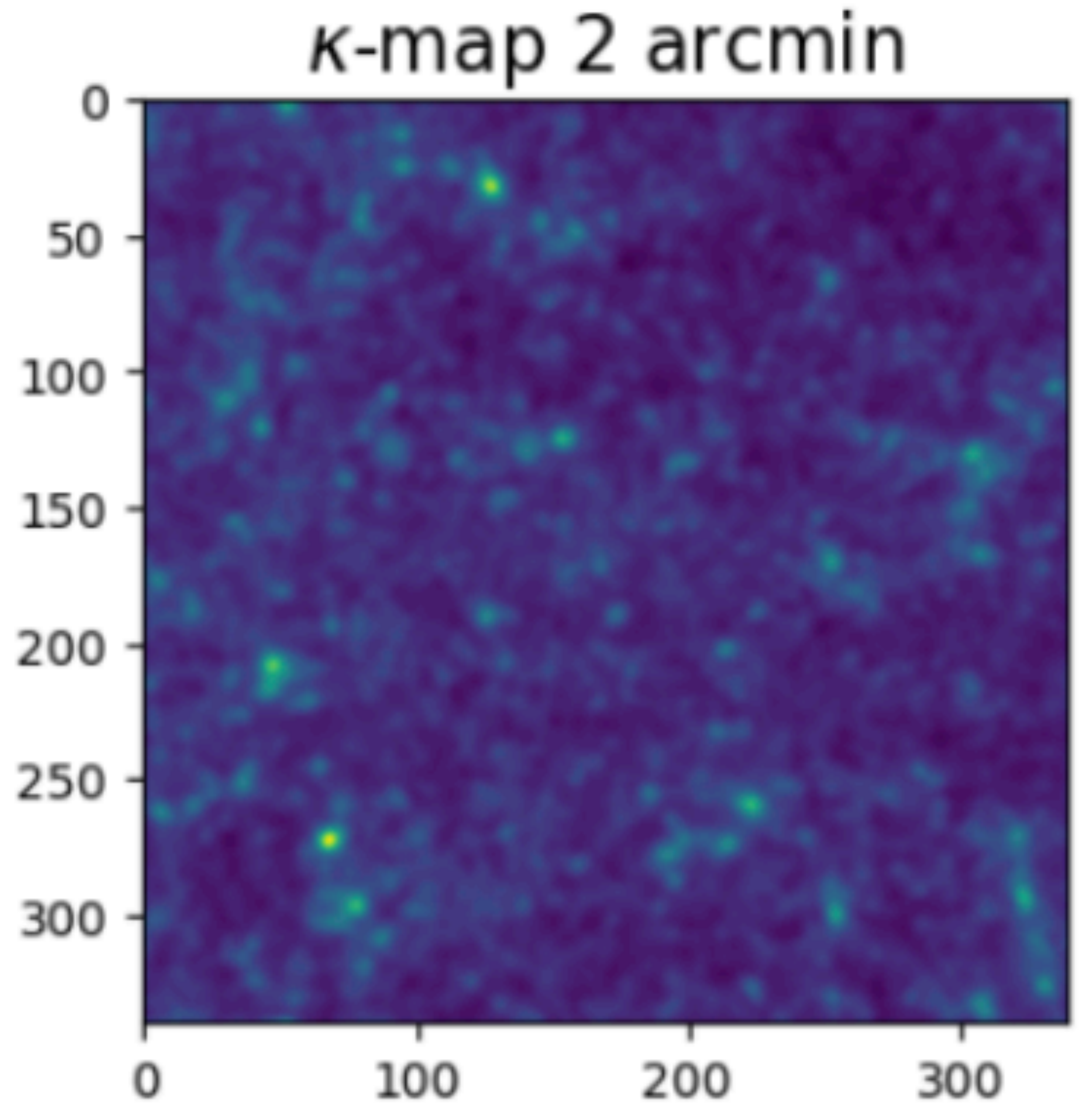
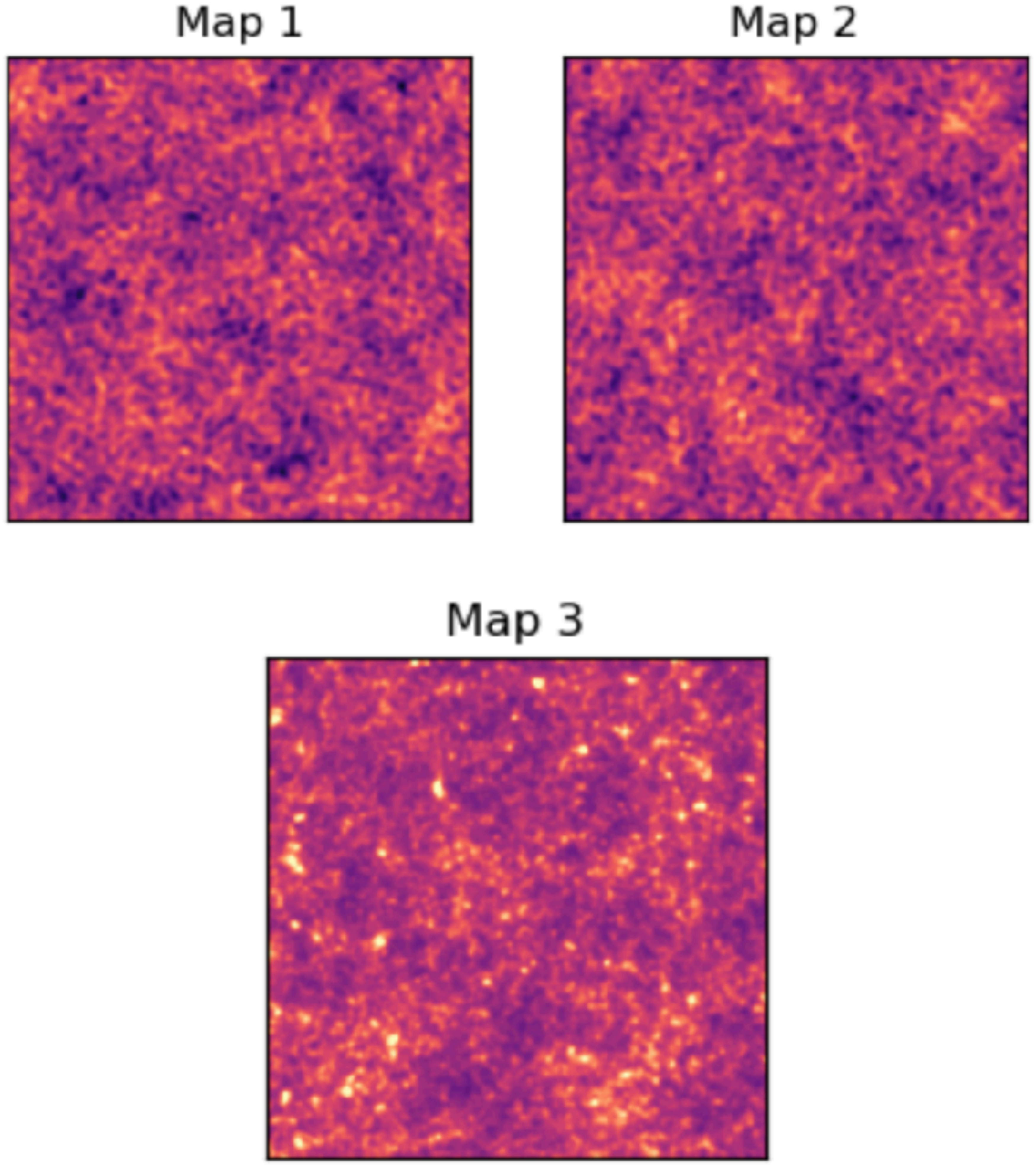
Convergence power spectrum

$$\boxed{C_\kappa(\ell) = \frac{9H_0^4\Omega_m}{4c^4}\int_0^{\chi_s} \mathrm{d}\chi\frac{g^2(\chi)\chi}{a^2(\chi)}P_\delta\left(k=\frac{\ell}{\chi},\chi\right)}$$

Convergence map



Extracting non-Gaussian information



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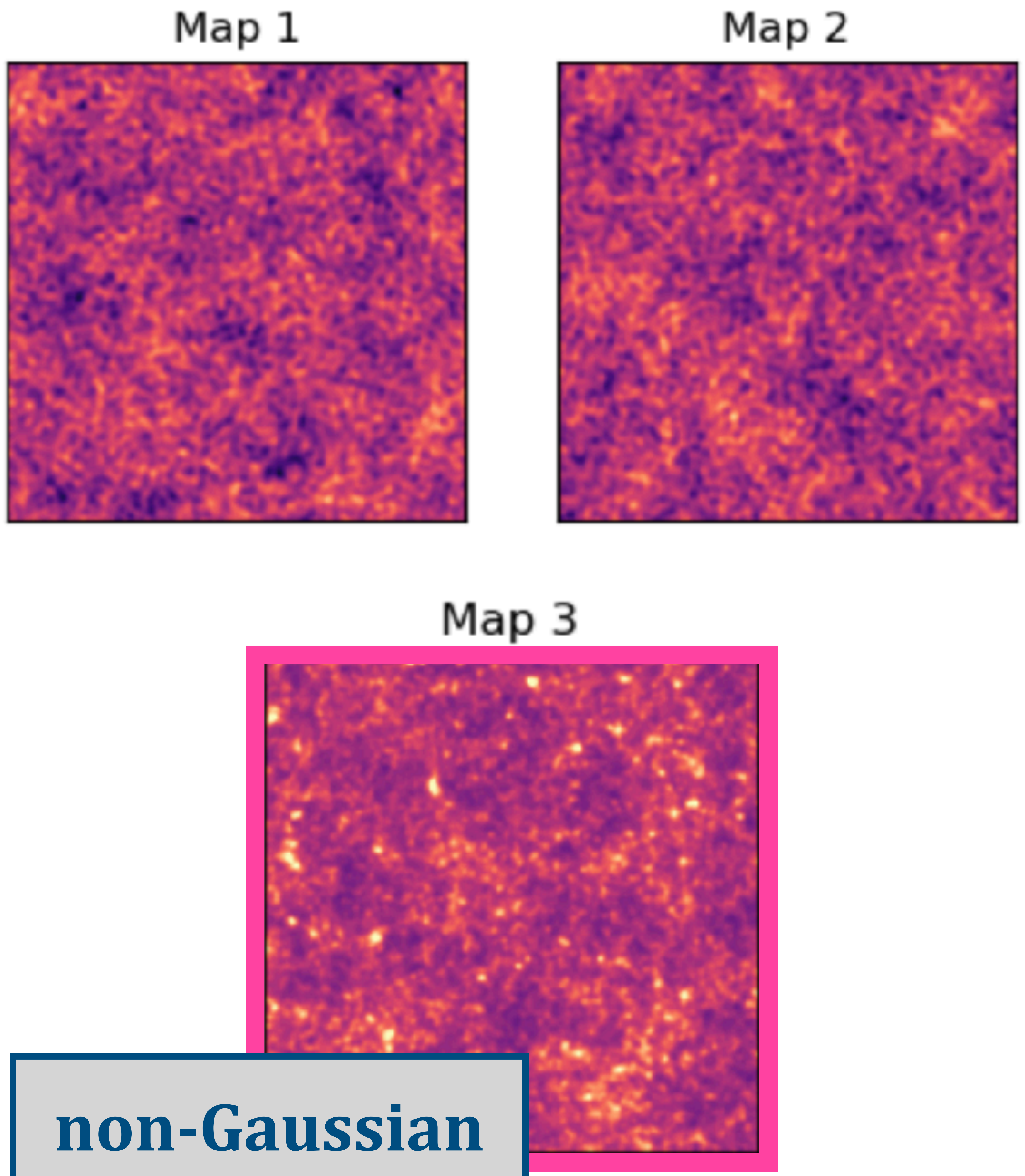

non-Gaussian

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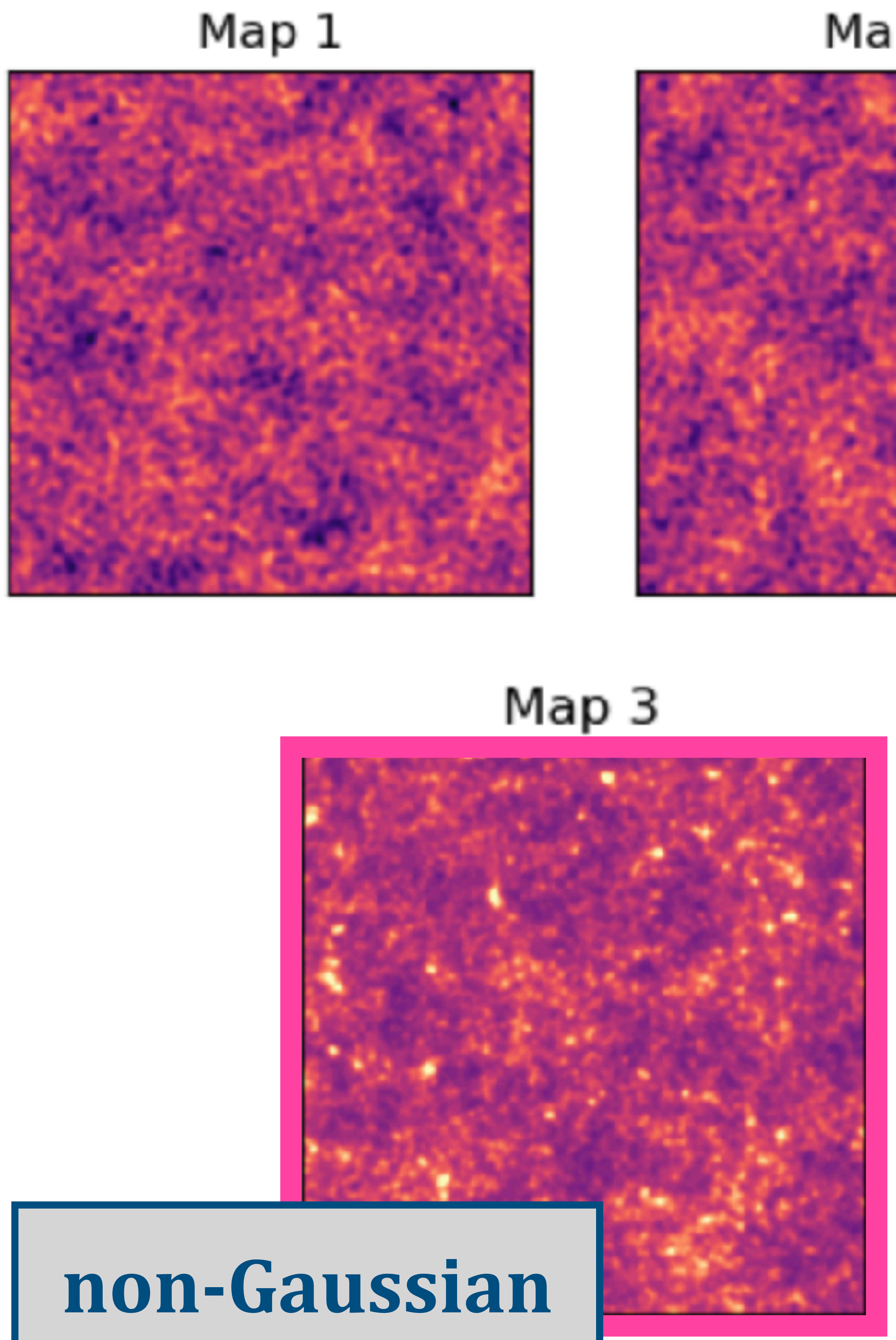
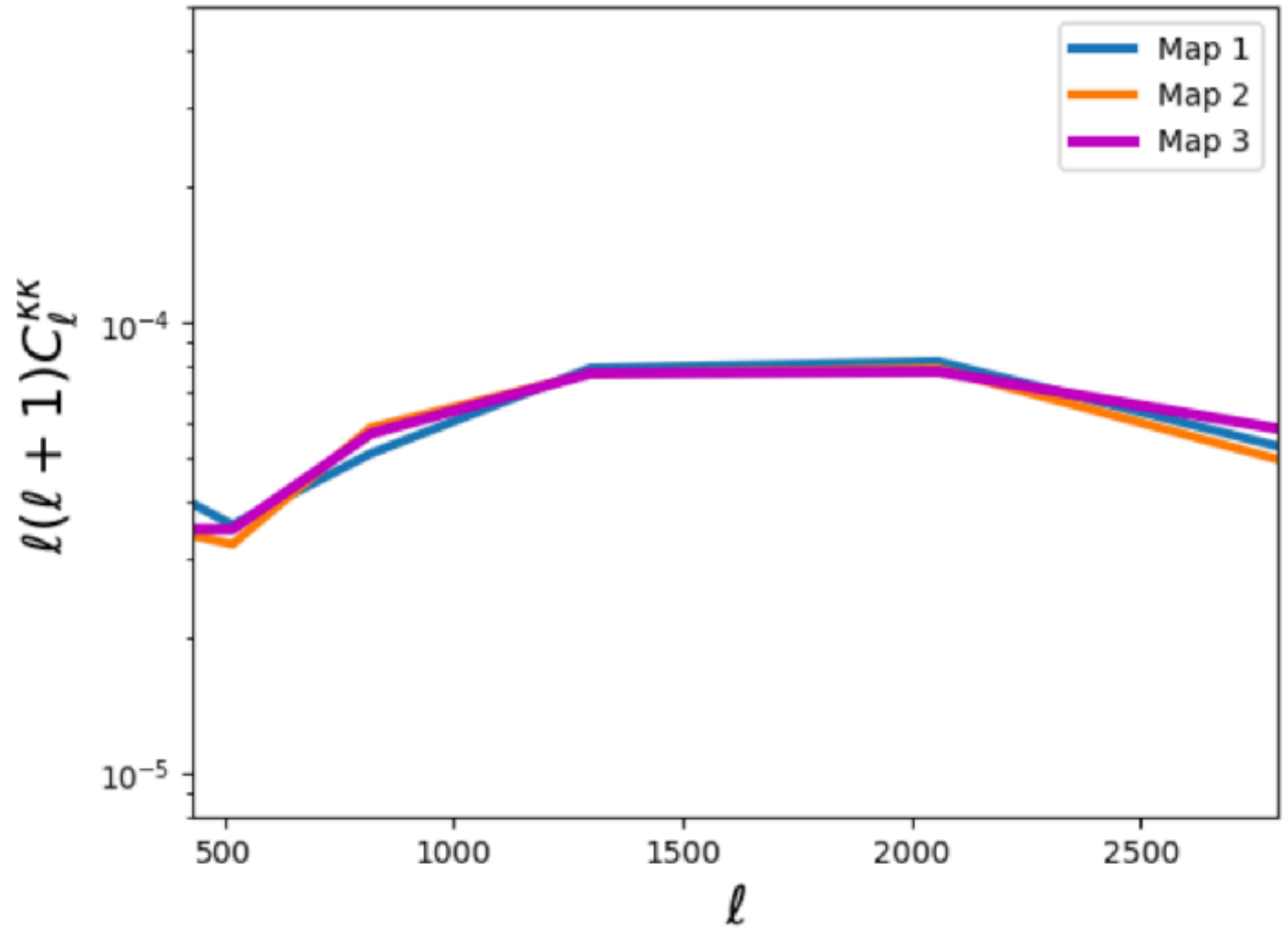


non-Gaussian

Same power spectrum



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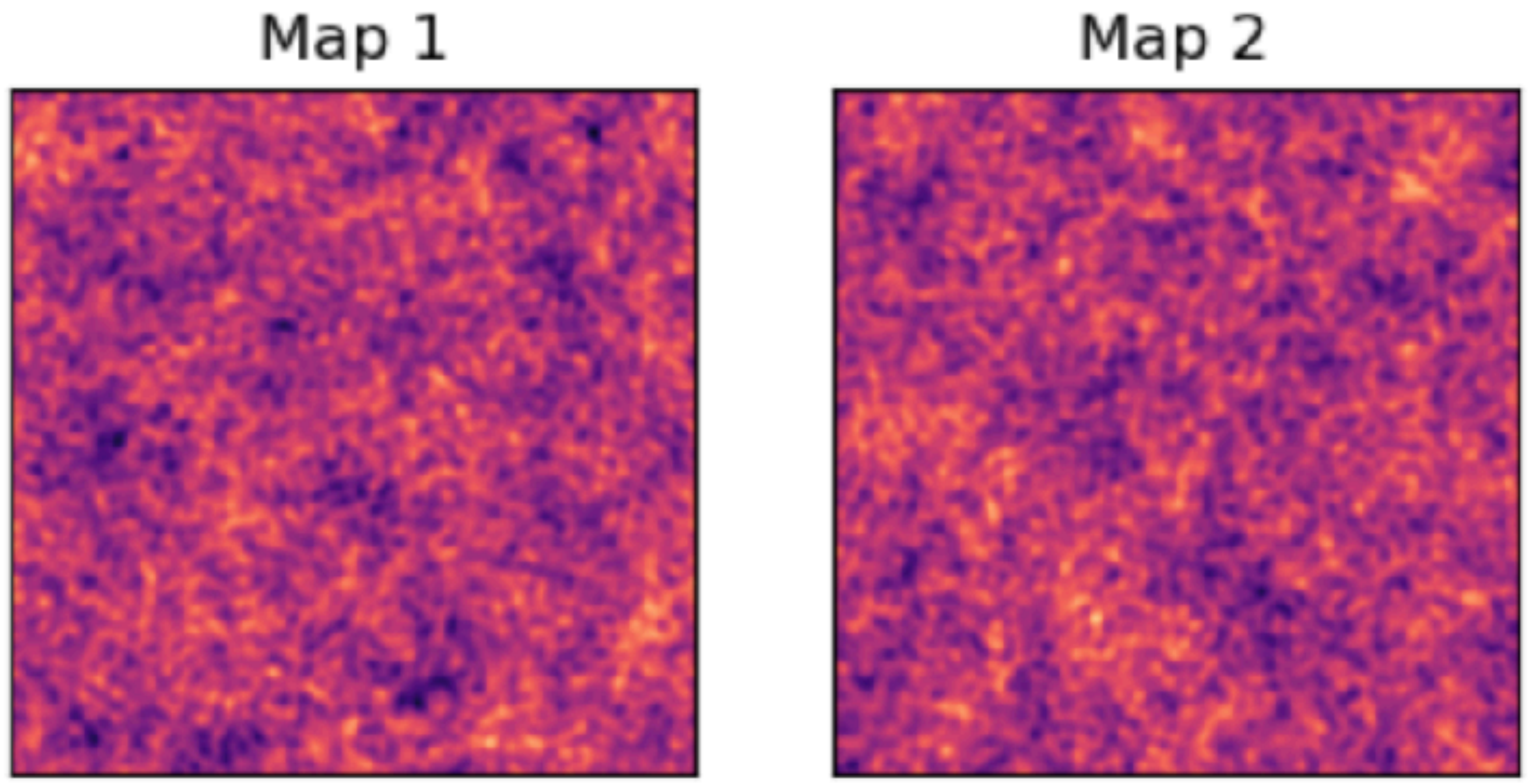

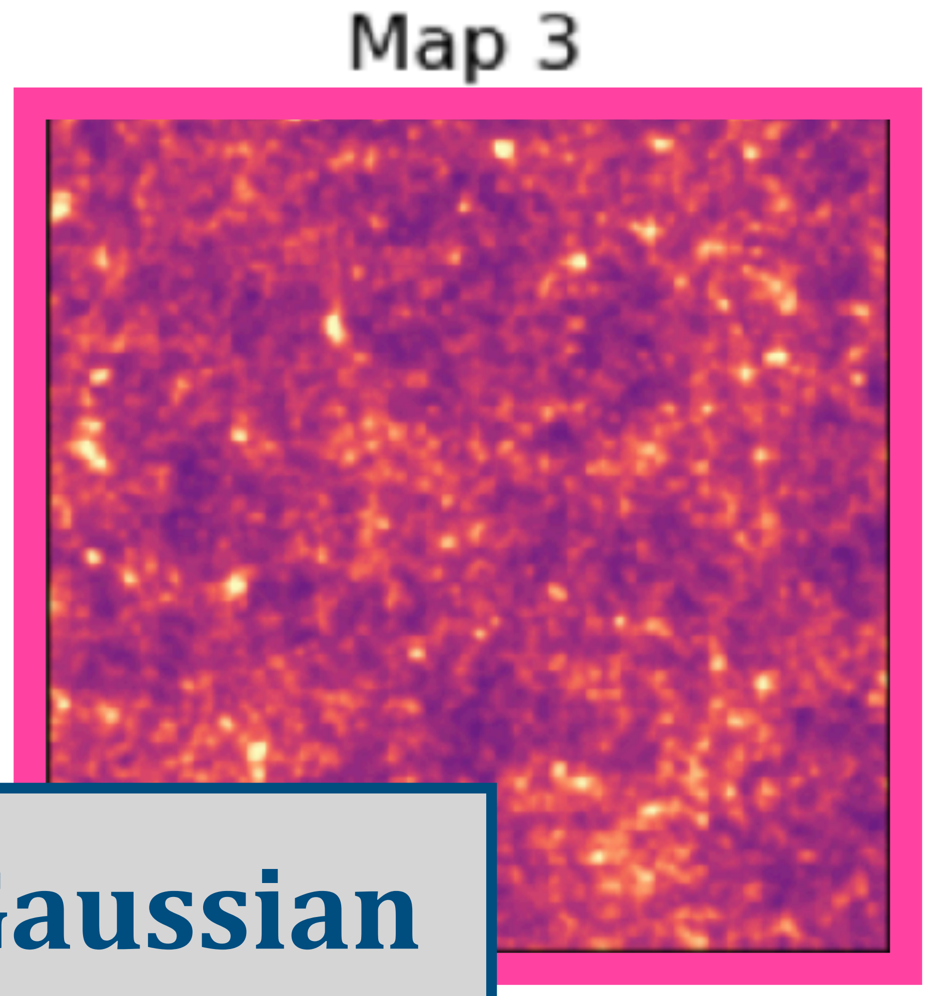

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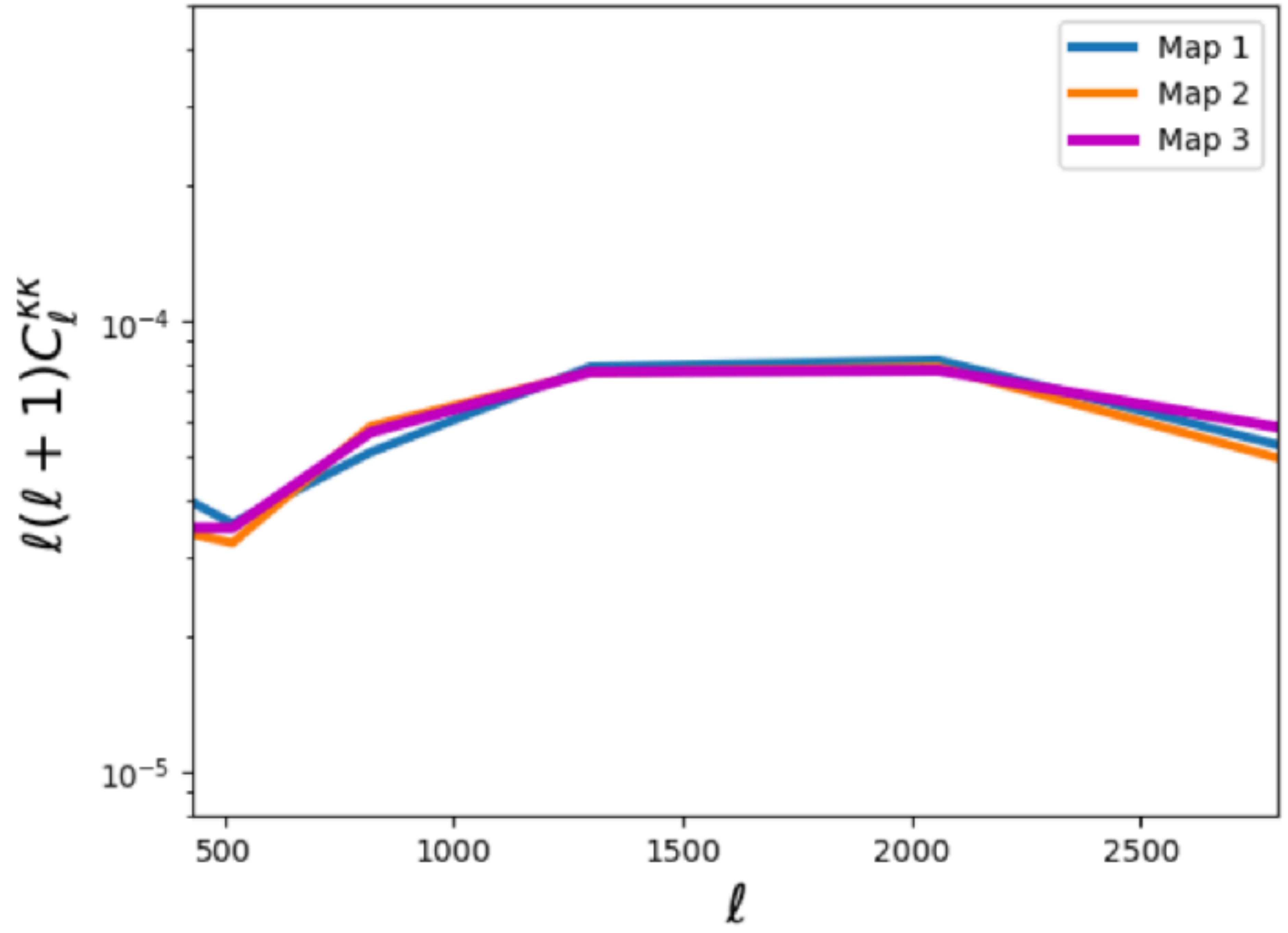


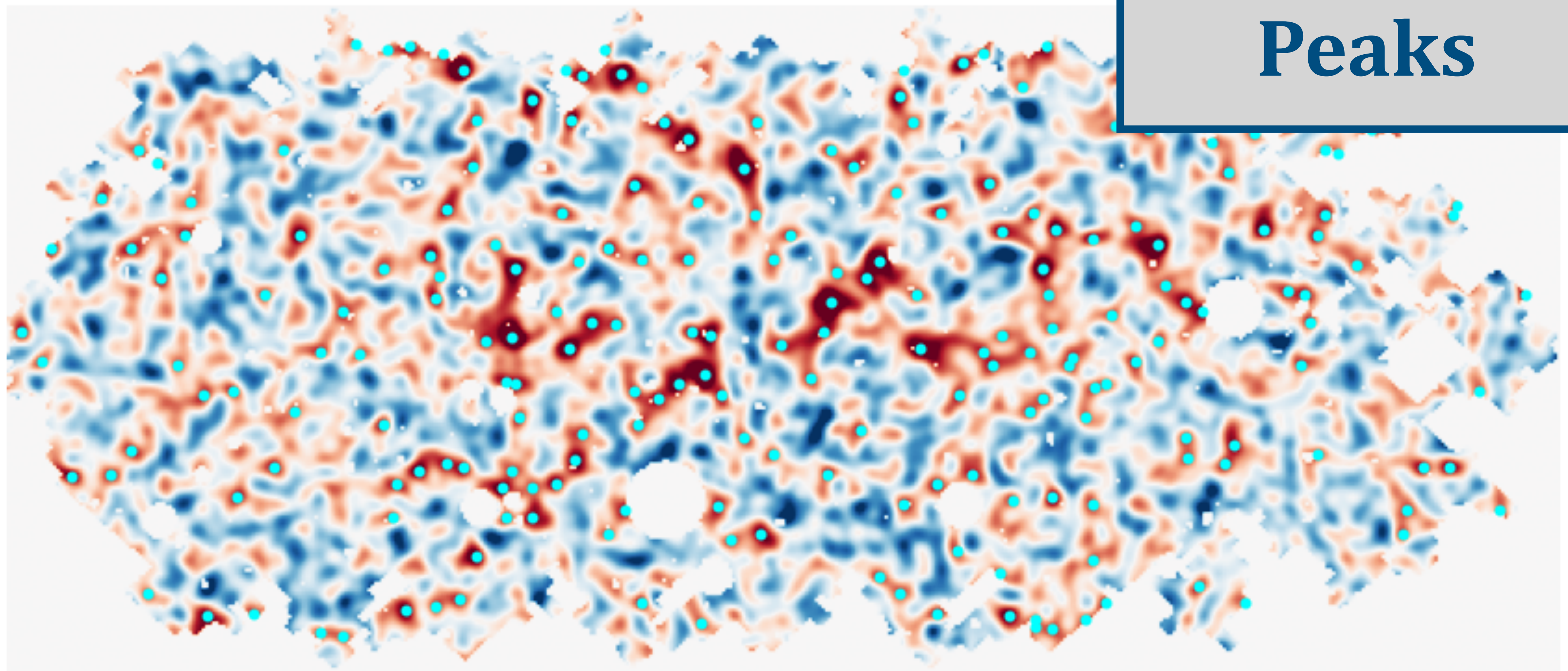
We need to go beyond 2point information!

➡ **Non-Gaussian, higher order statistics**

Non-Gaussian, higher-order statistics

Non-Gaussian statistics

- **Peak counts:**
  Probe overdense regions, massive clusters along the line of sight.

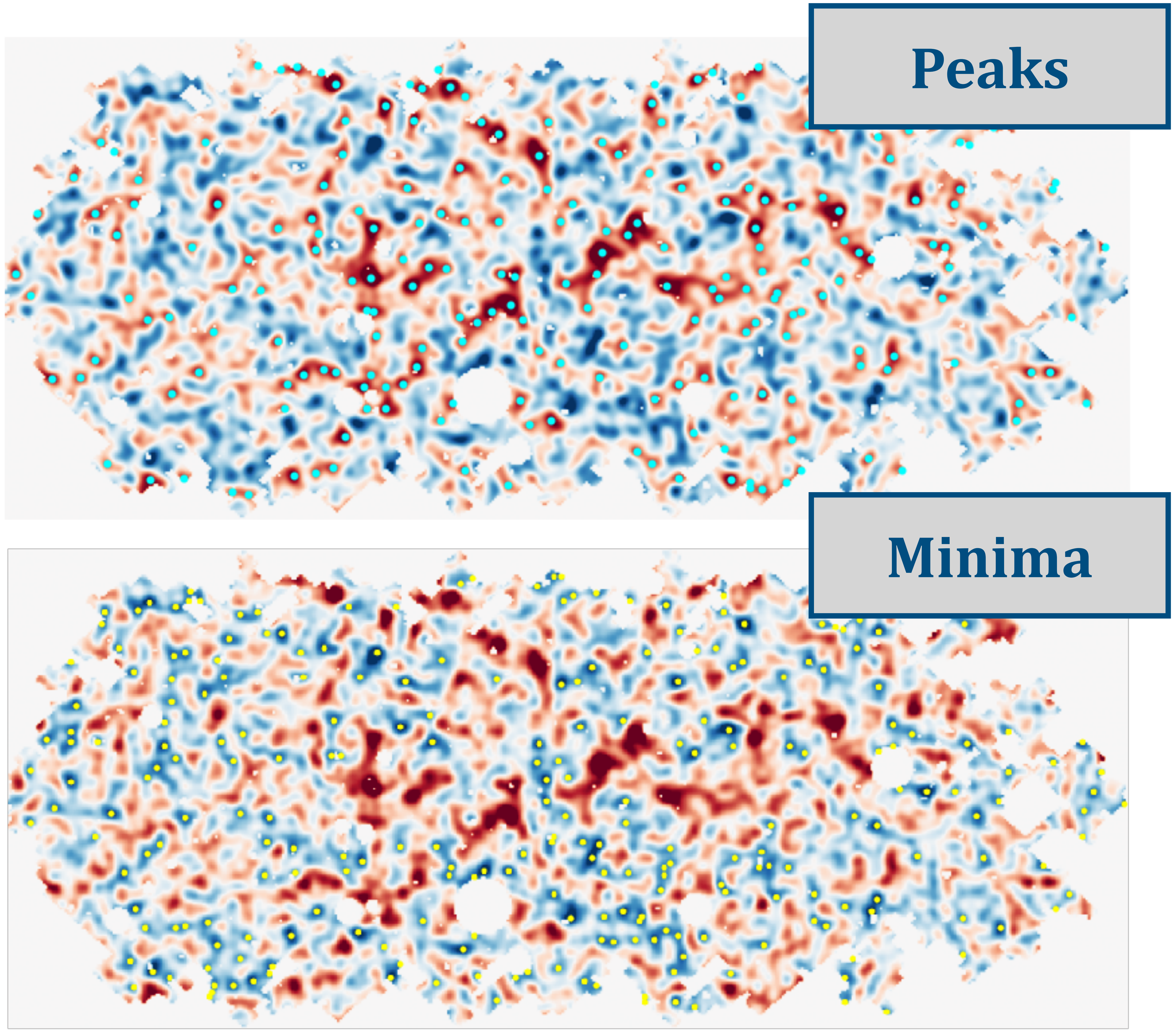


Peaks

Credit: Gabriela Marques

Non-Gaussian statistics

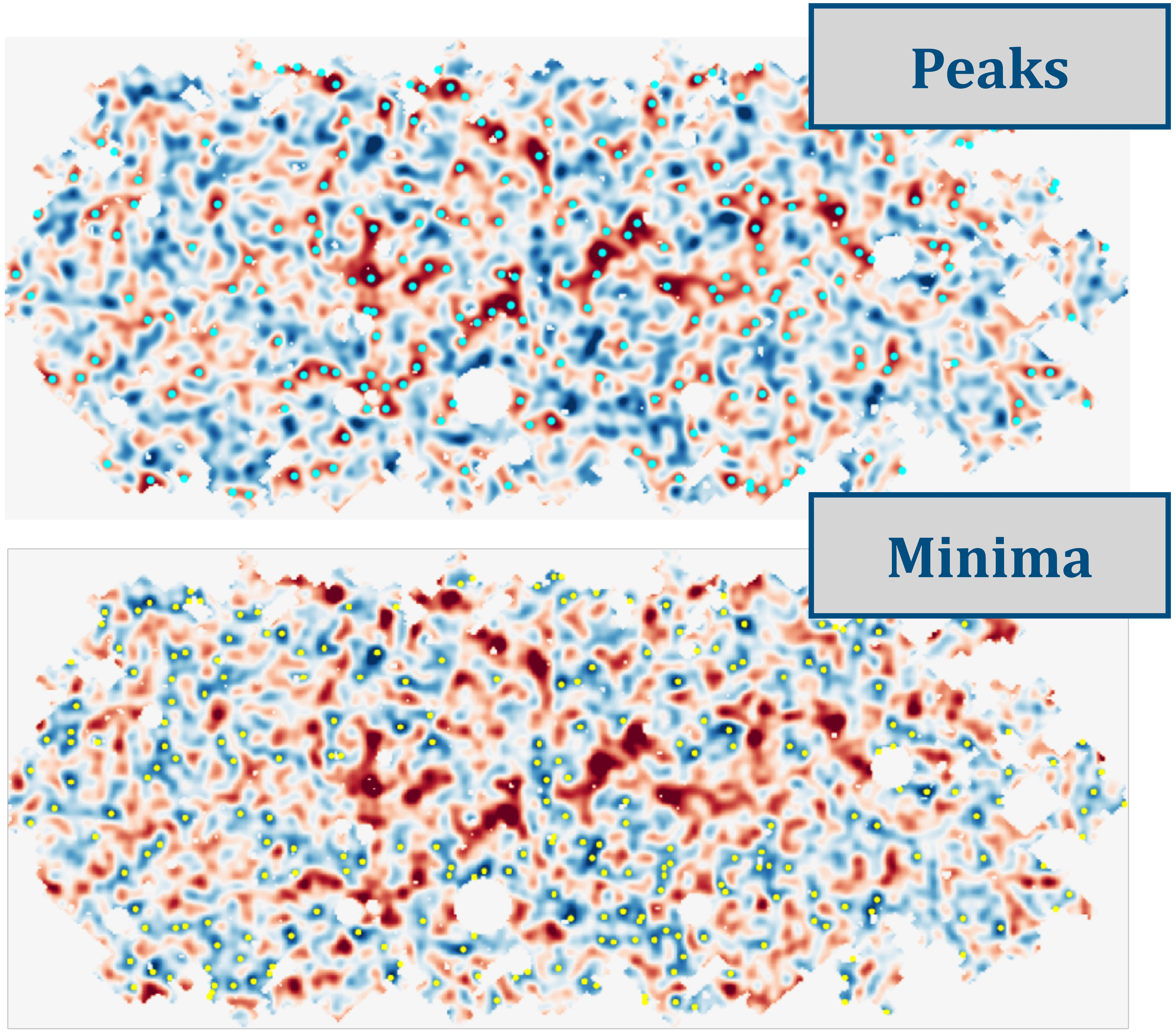
- **Peak counts:**
  Probe overdense regions, massive clusters along the line of sight.
- **Minimum counts:** Probe the emptiest/underdense regions.



Credit: Gabriela Marques

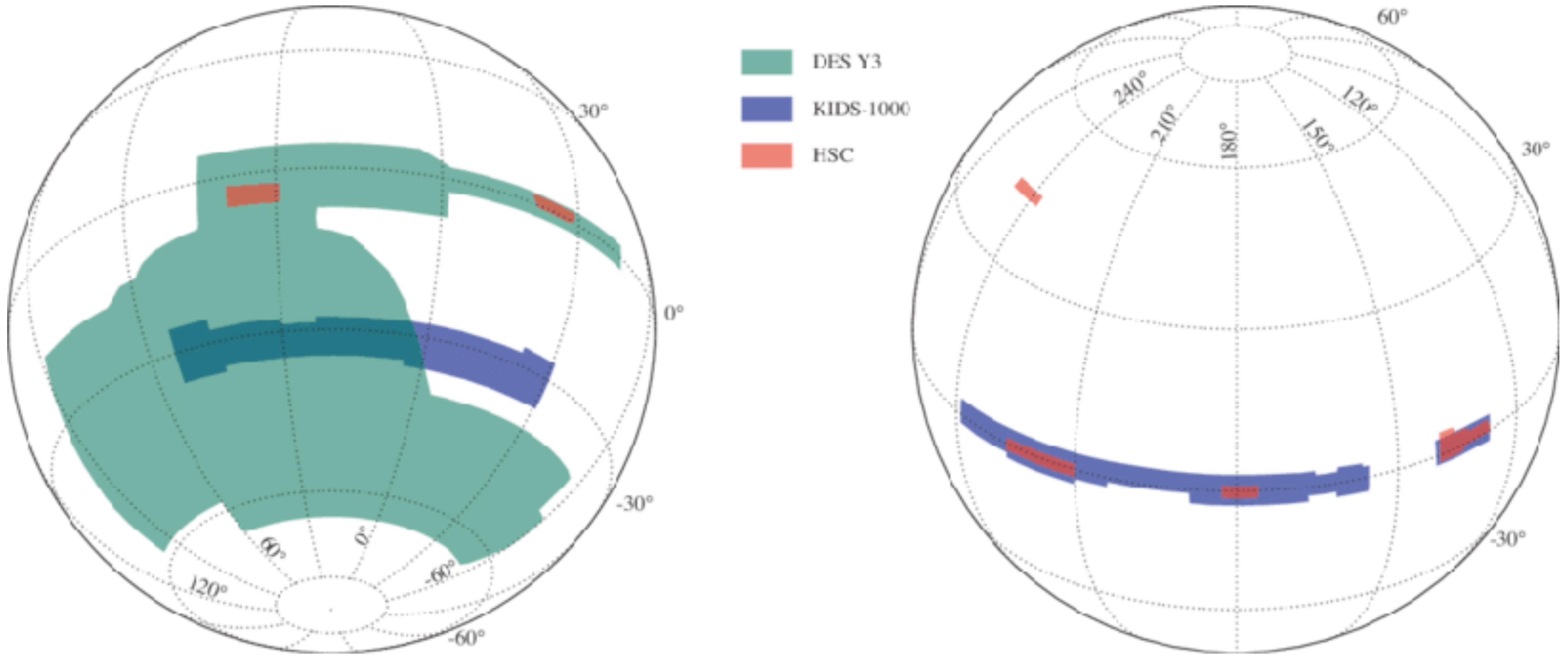
Non-Gaussian statistics

- **Peak counts:**
  Probe overdense regions, massive clusters along the line of sight.
- **Minimum counts:** Probe the emptiest/underdense regions.
- **PDF:** Histogram of convergence values.



Credit: Gabriela Marques

Stage III analysis: Subaru Hyper Suprime-Cam Y1 data

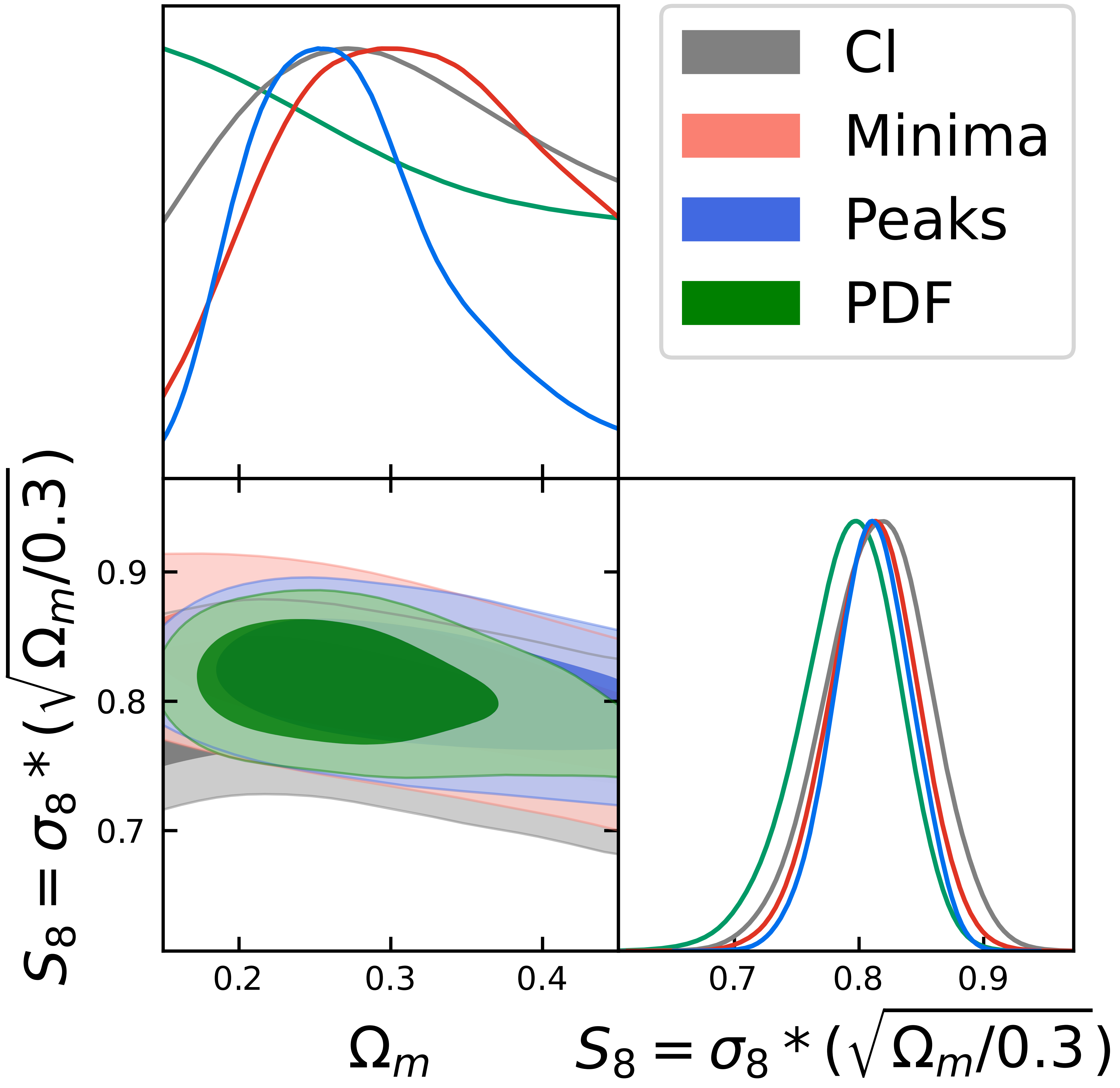


- ➡ Y1 data: 137 deg^2
- ➡ n_gal=17 arcmin^{-2}
- ➡ Likelihood based on N-body sims
- ➡ **Model the statistics with emulators.**

z-range	n_g^{eff} [arcmin^{-2}]
$0.3 < z < 0.6$	5.14
$0.6 < z < 0.9$	5.23
$0.9 < z < 1.2$	3.99
$1.2 < z < 1.5$	2.33

Marques et al. 2023, Grandón et al. 2024
Thiele et al. 2023, Cheng et al. 2024, Armijo et al. in prep 2024

Results Stage III: HSC Y1 Non-Gaussian statistics



Grandón et al. 2024 arXiv:2403.03807, Marques et al. 2023 arXiv:2308.10866

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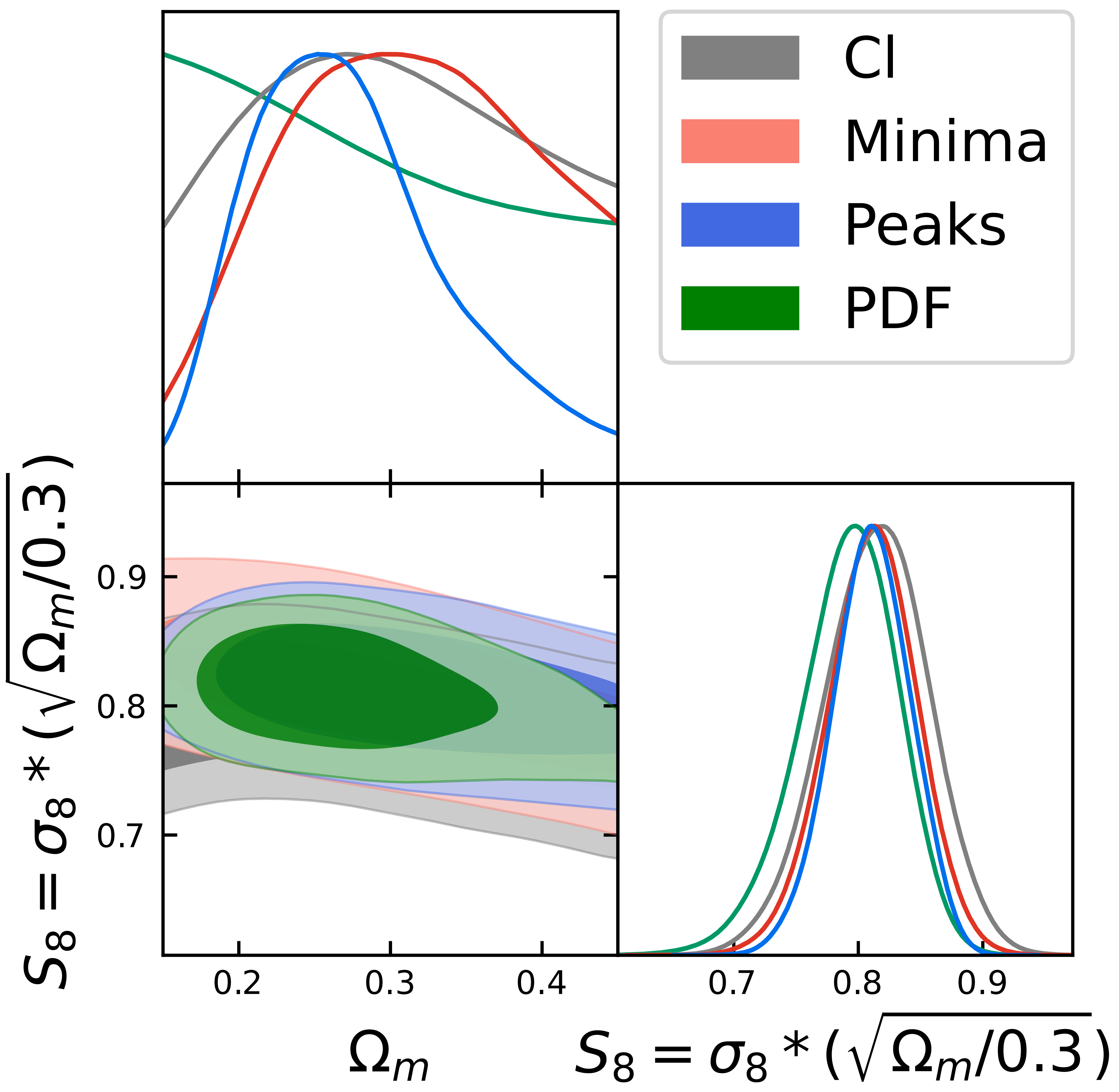


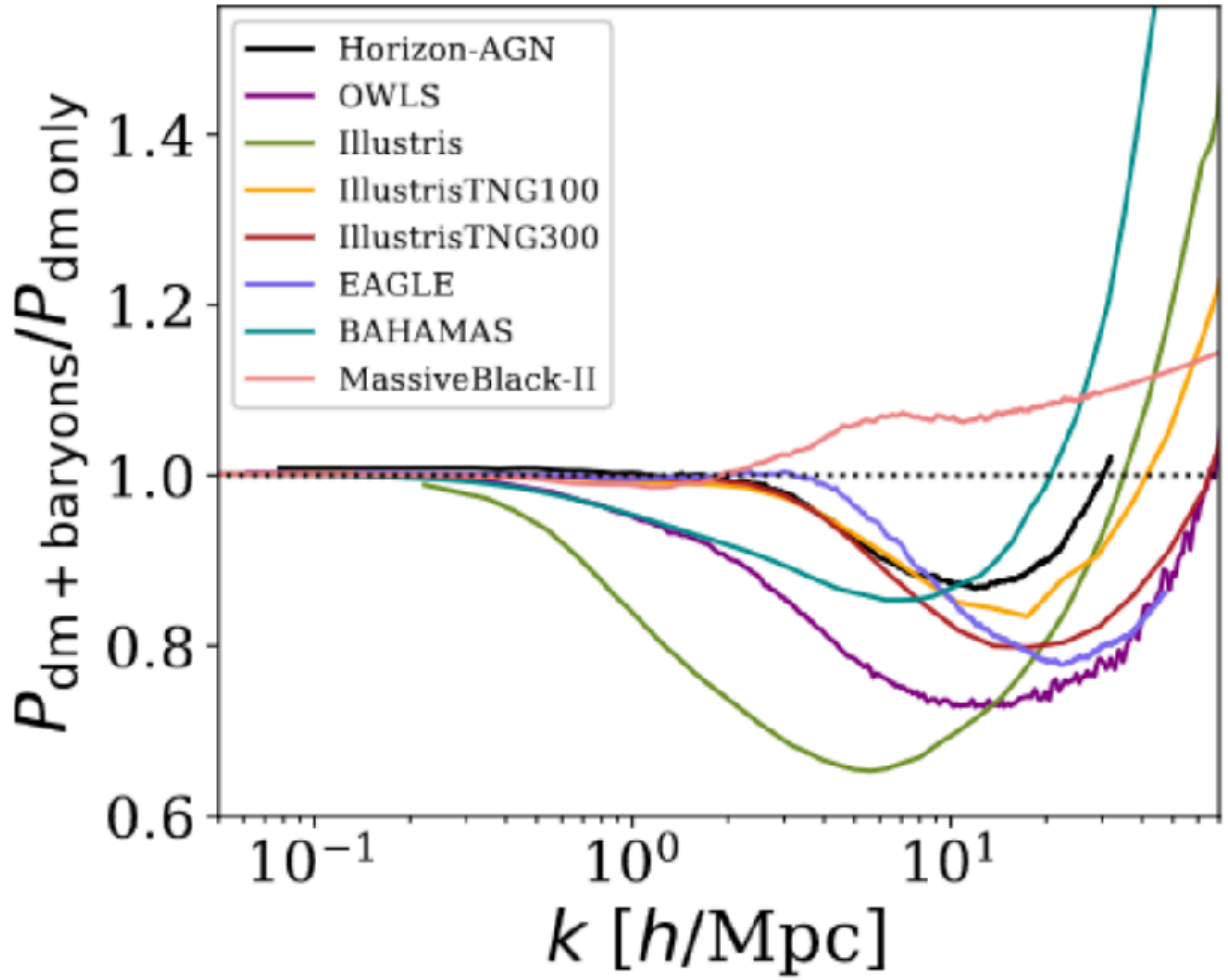
Improvement of ~21% compared to power spectrum only.
~35% when combined.

Grandón et al. 2024 arXiv:2403.03807, Marques et al. 2023 arXiv:2308.10866

Baryonic feedback

Baryonic feedback

Fractional impact of baryons on the matter power spectrum at z=0 for different simulations.



Chisari et al. 2019

HSC Y1 analysis: Impact of baryons

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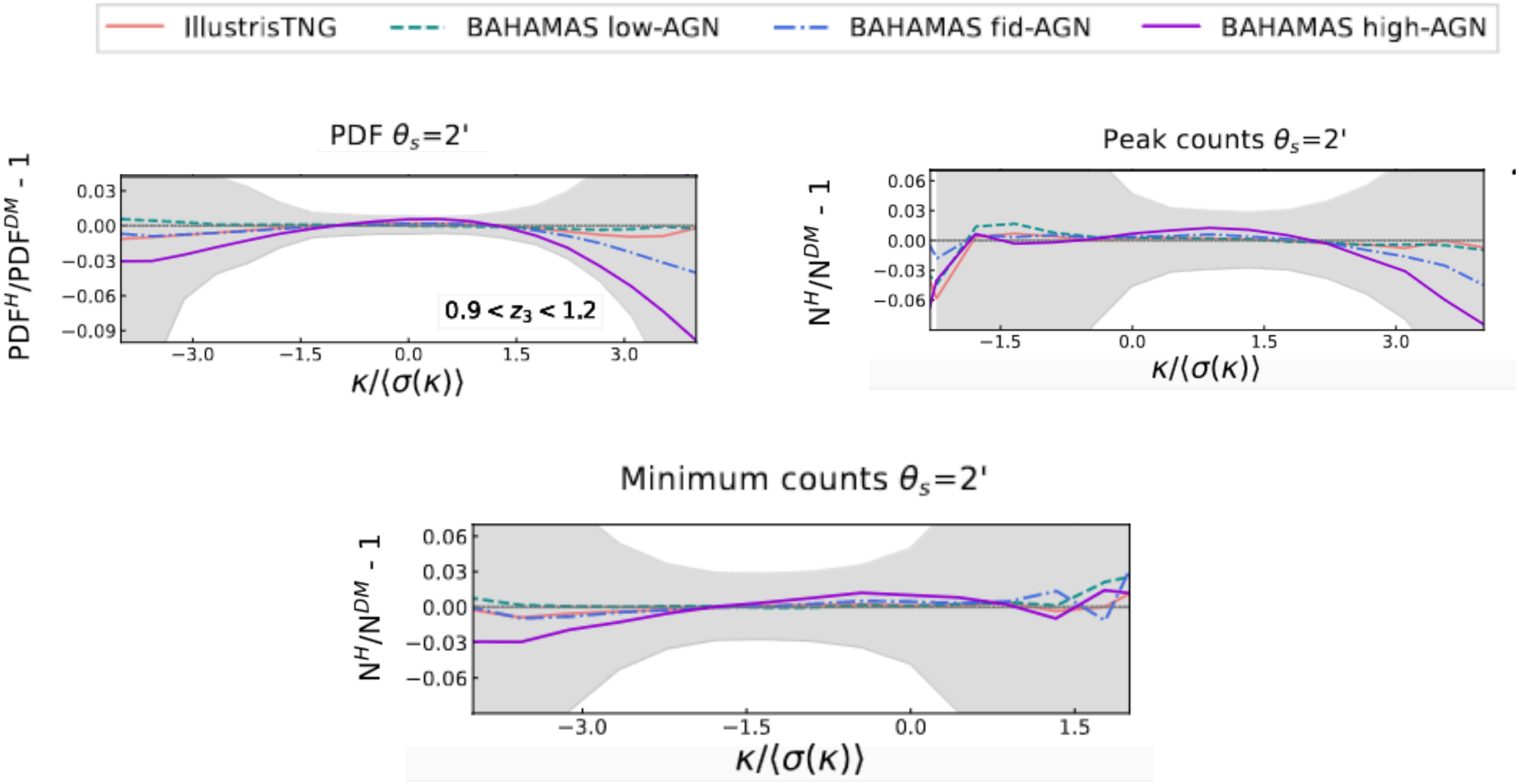
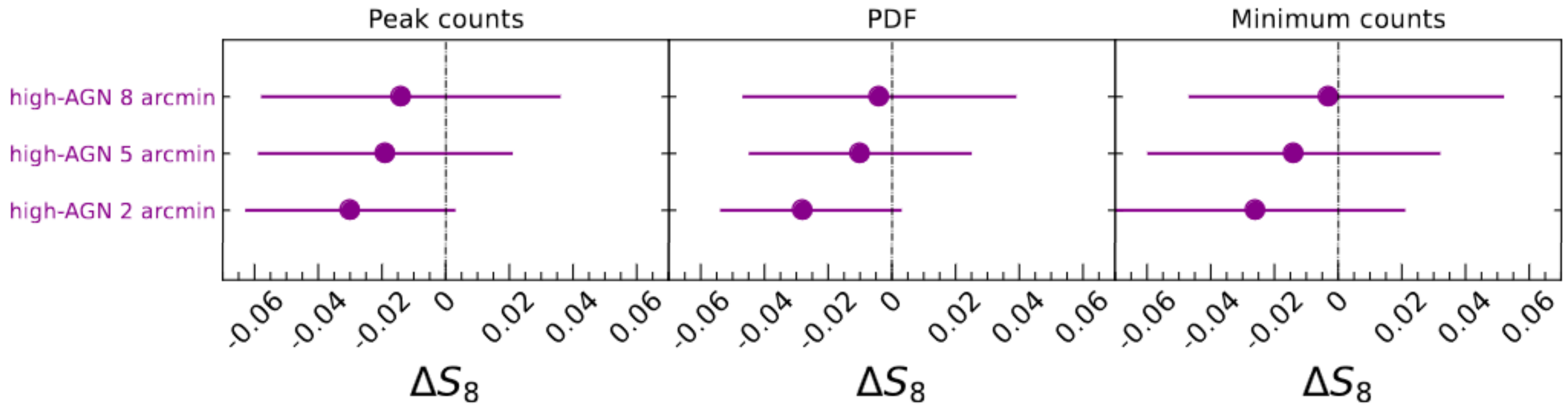


Grandón et al. 2024 arXiv:2403.03807

Impact of baryons on the inferred S_8



$$\Delta S_8 = S_8^{\mathrm{H}} - S_8^{\mathrm{DM}}$$

Grandón et al. 2024 arXiv:2403.03807

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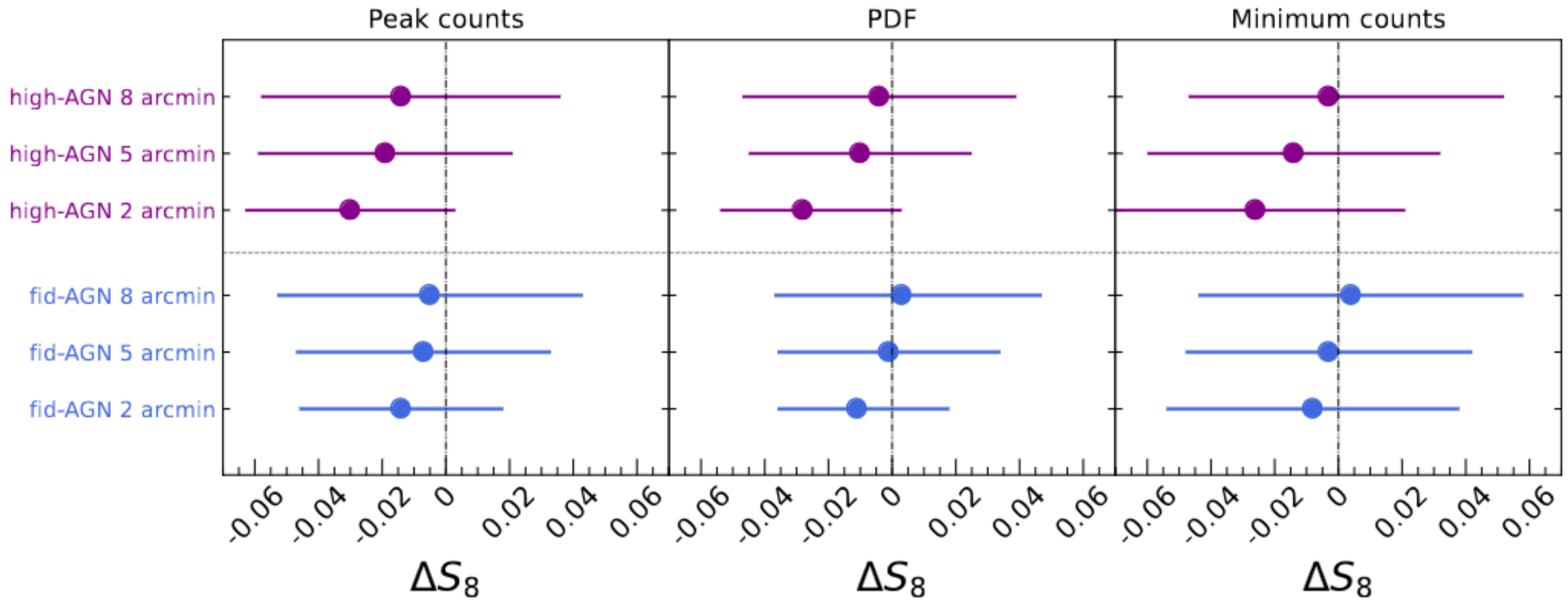

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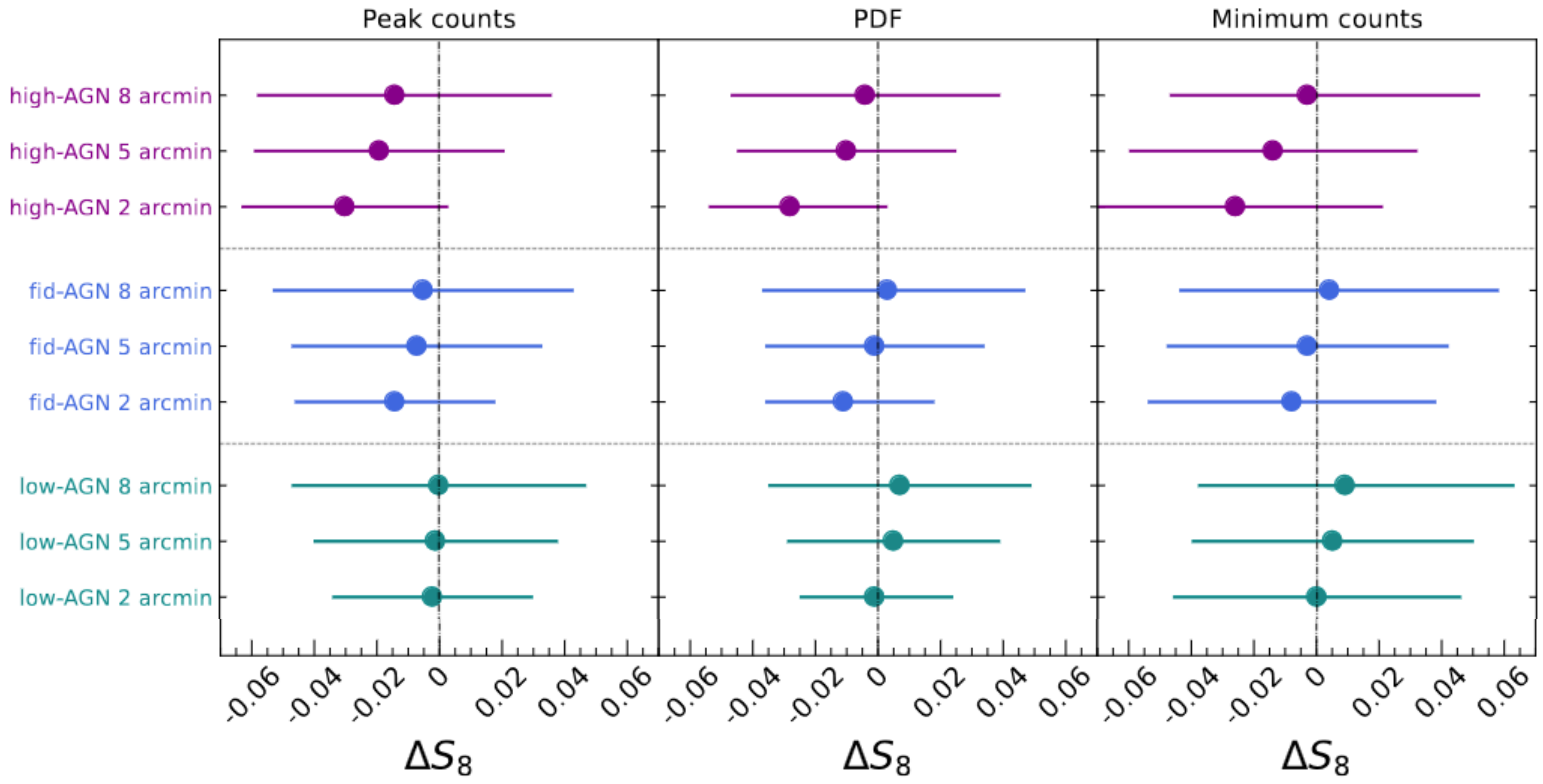

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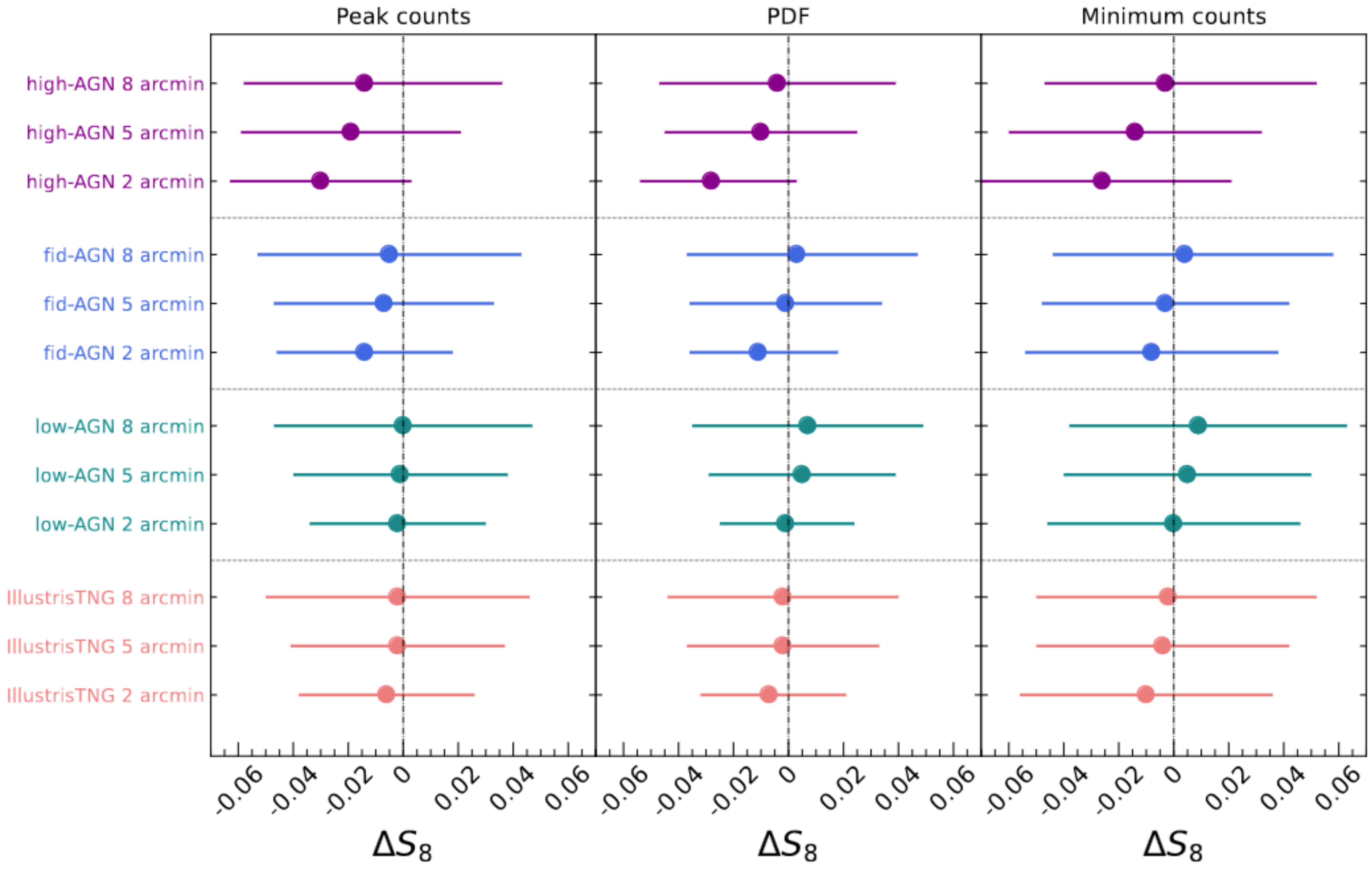

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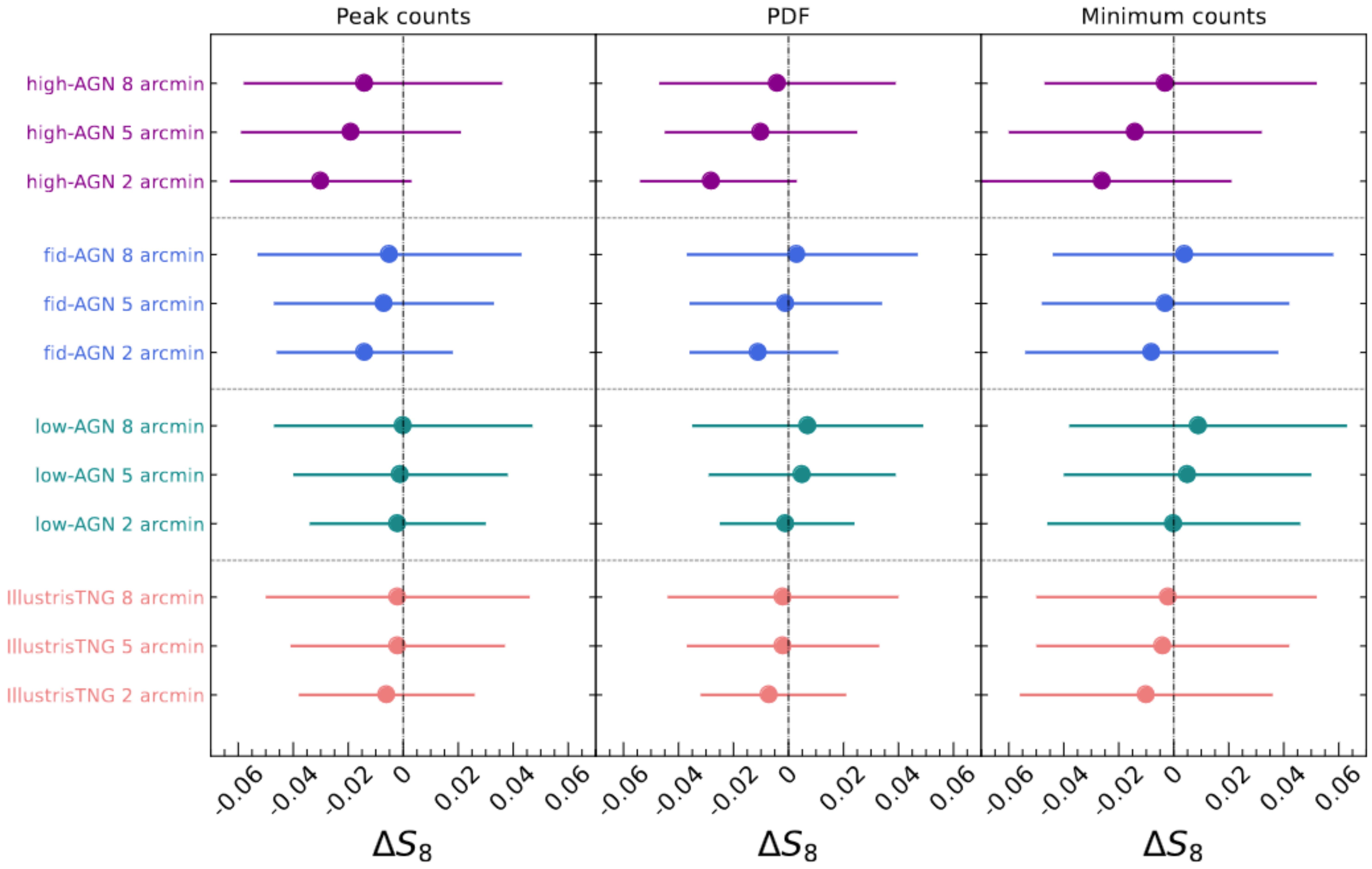

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<1σ bias in S_8.

Grandón et al. 2024 arXiv:2403.03807

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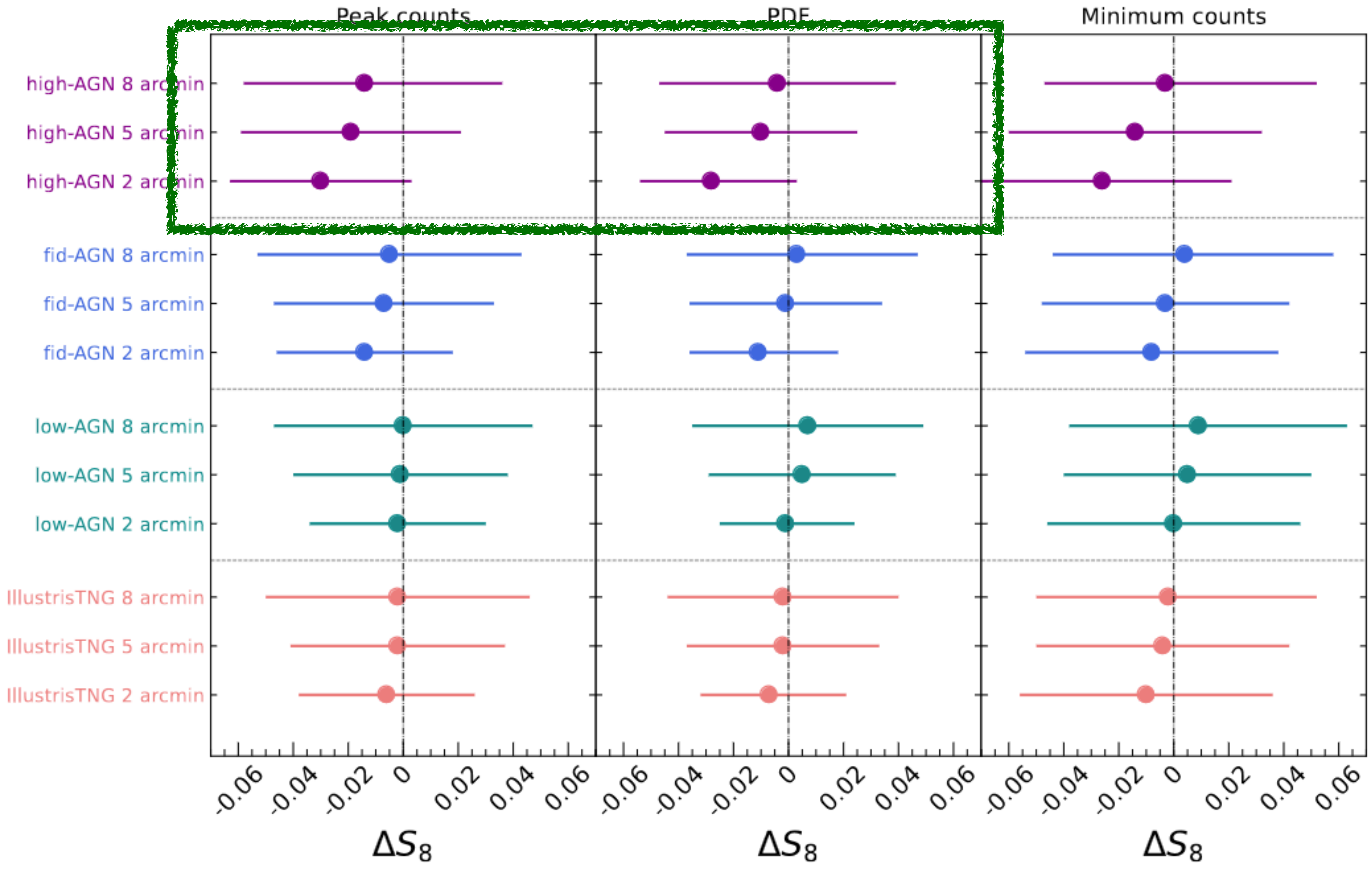

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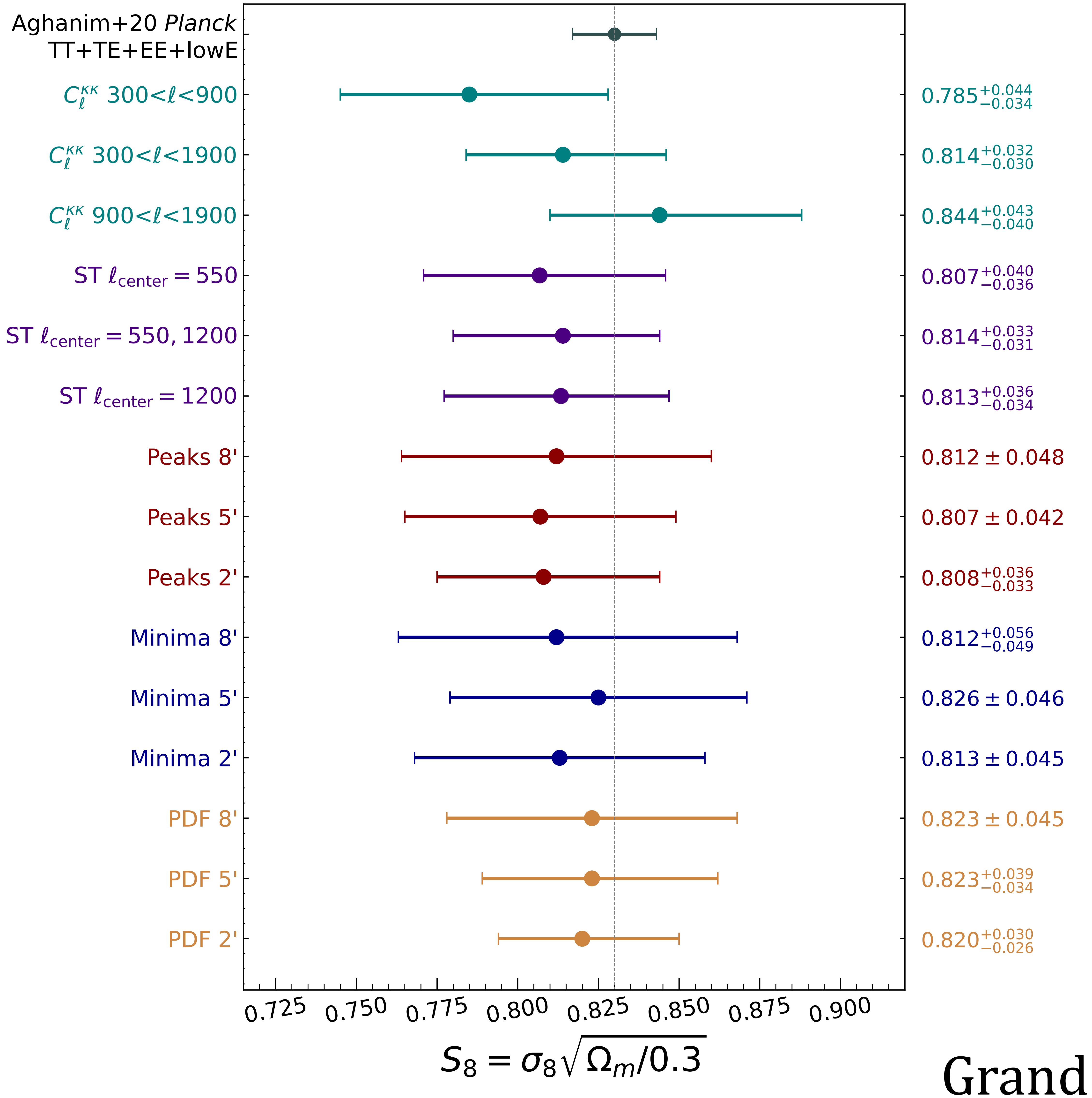
Results: HSC Y1 real data

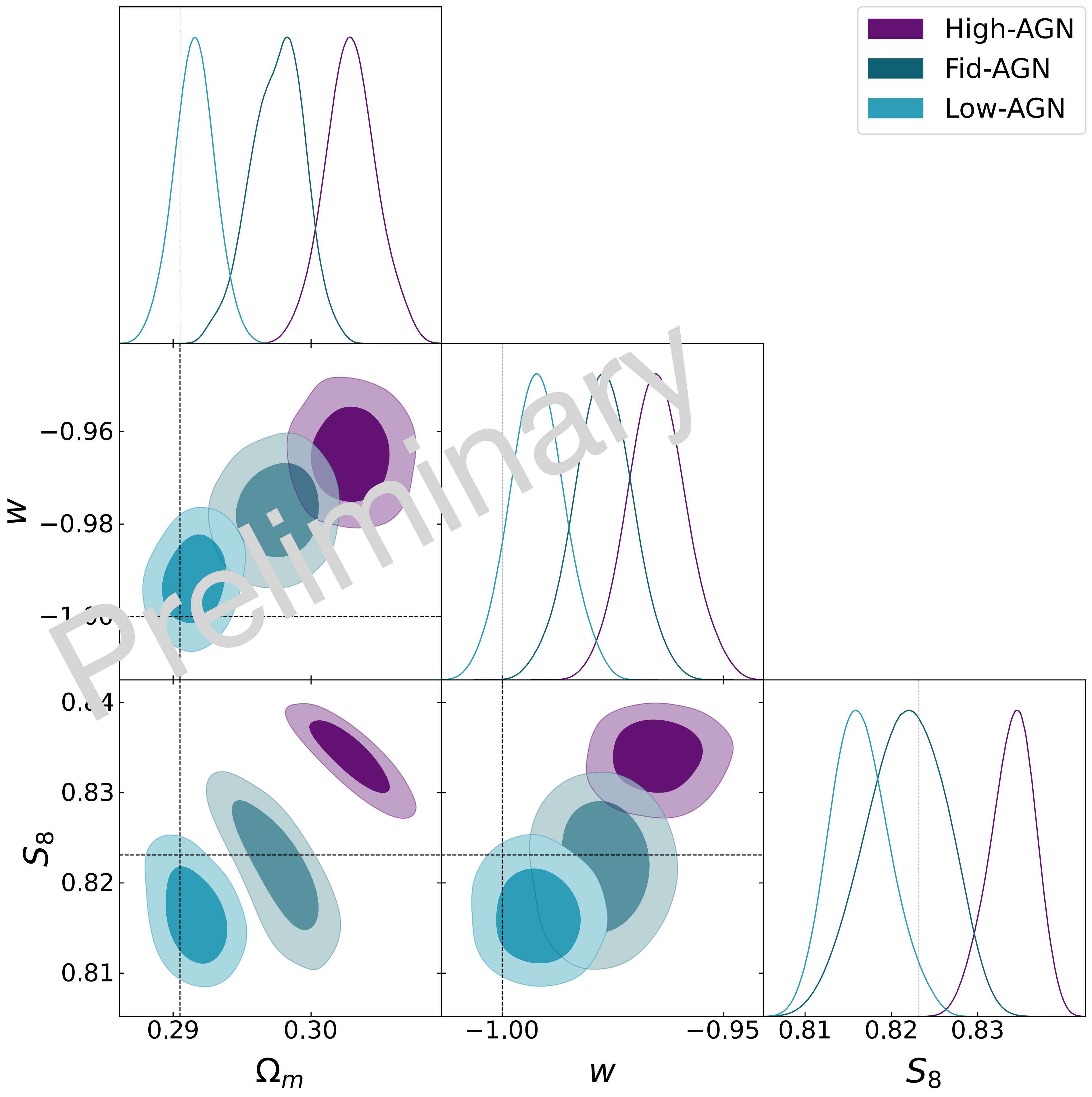


Grandón et al. 2024 arXiv:2403.03807

Baryonic feedback and Stage IV analysis

Impact of baryons for Stage IV: Peak counts

Peak counts 2 arcmin



Grandón et al. in prep 2024 LSST-DESC

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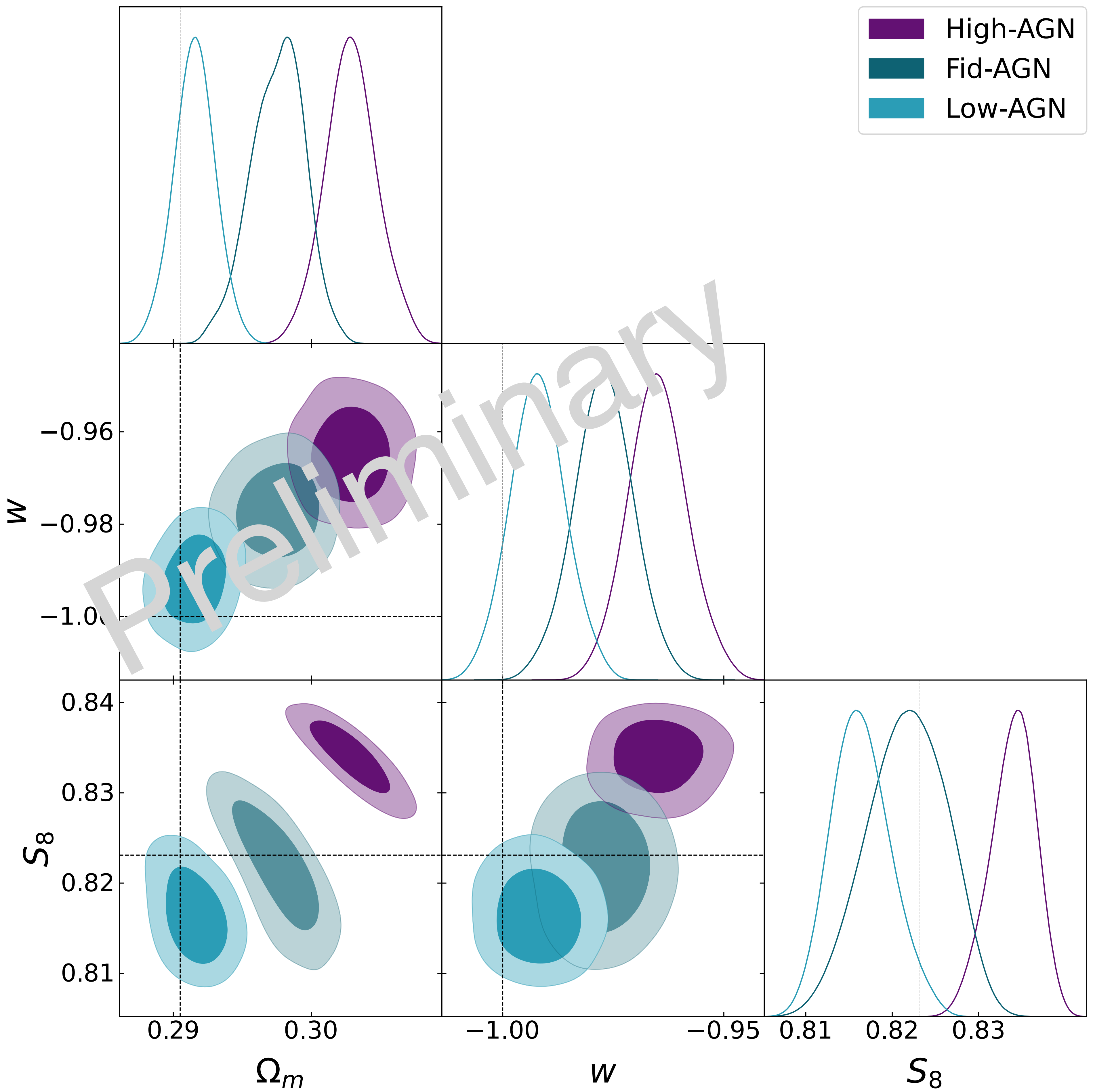
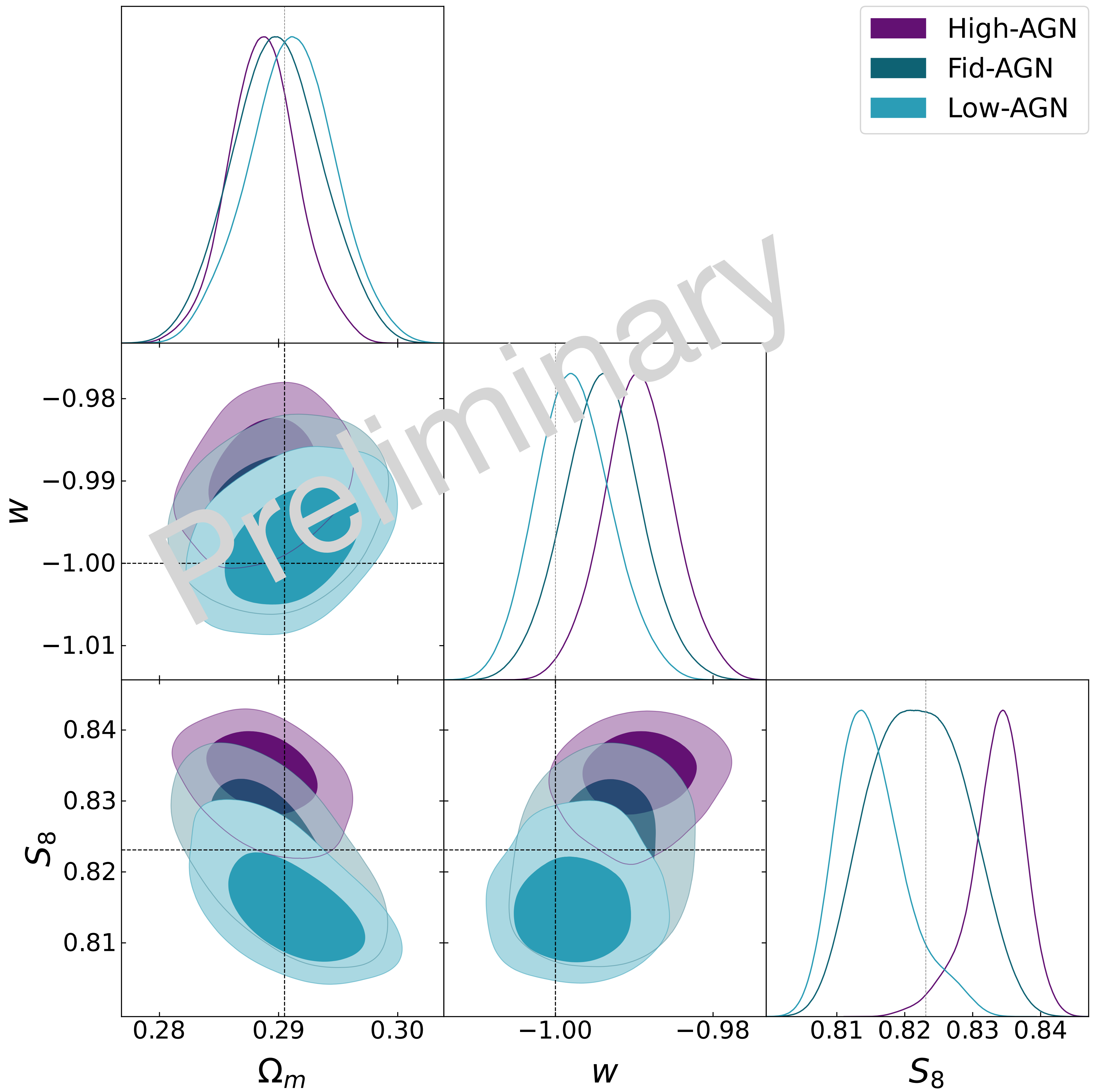


Peak counts 5 arcmin



Grandón et al. in prep 2024 LSST-DESC

Baryons and Stage-IV surveys: Bayesian Model Averaging

Our goal is to establish a Bayesian framework that enables trustworthy parameter inference from non-Gaussian statistics, applied to real data.

Bayesian Model Averaging (BMA)

Weighted average of multiple models (baryonic feedback models). Weights determined by the Bayesian evidence.

$$\mathcal{P}(\boldsymbol{\theta}|\boldsymbol{x}) = \frac{\sum_k \mathcal{P}(\boldsymbol{\theta}|\boldsymbol{x}, M_k)\mathcal{P}(M_k|\boldsymbol{x})}{\sum_k \mathcal{P}(M_k|\boldsymbol{x})}$$

The models M_k: BAHAMAS low-AGN, fid-AGN, high-AGN.

Baryons and Stage-IV surveys: Bayesian Model Averaging

Bayesian Model Averaging for Baryonic feedback.

First step: Parameter inference for each model individually.
Likelihood (Sellentin & Heavens 2016):

$$P(\boldsymbol{x}_\mathrm{o}|\boldsymbol{\mu}_B, \mathsf{C}, N_r) = \frac{\bar{c}_p |\mathsf{C}|^{-1/2}}{\left[1 + \frac{(\boldsymbol{x}_\mathrm{o} - \boldsymbol{\mu}_B)^T \mathsf{C}^{-1} (\boldsymbol{x}_\mathrm{o} - \boldsymbol{\mu}_B)}{N_r - 1}\right]^{\frac{N_r}{2}}}$$

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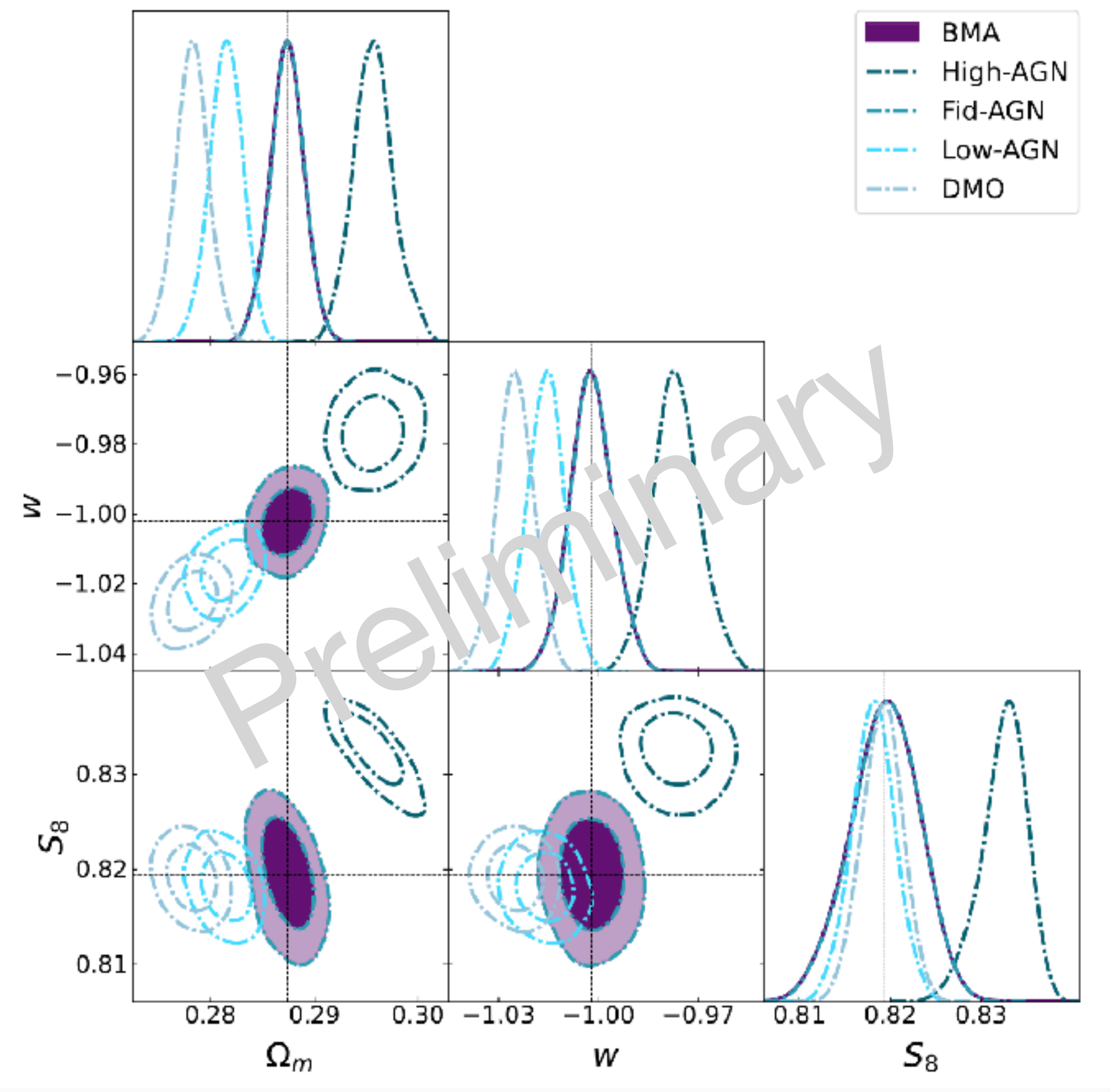
Baryonic feedback correction factor

$$B_i = \frac{\langle x_i^{\mathrm{B}} \rangle}{\langle x_i^{\mathrm{DMO}} \rangle}$$

$$\mu_i^B = \mu_i(\boldsymbol{\theta}) B_i$$

Baryons and Stage-IV surveys: Bayesian Model Averaging

Case 1: Data vector with Fid-AGN contamination



Peak counts 2 arcmin

Grandón & Sellentin in prep. 2024

Baryons and Stage-IV surveys: Bayesian Model Averaging

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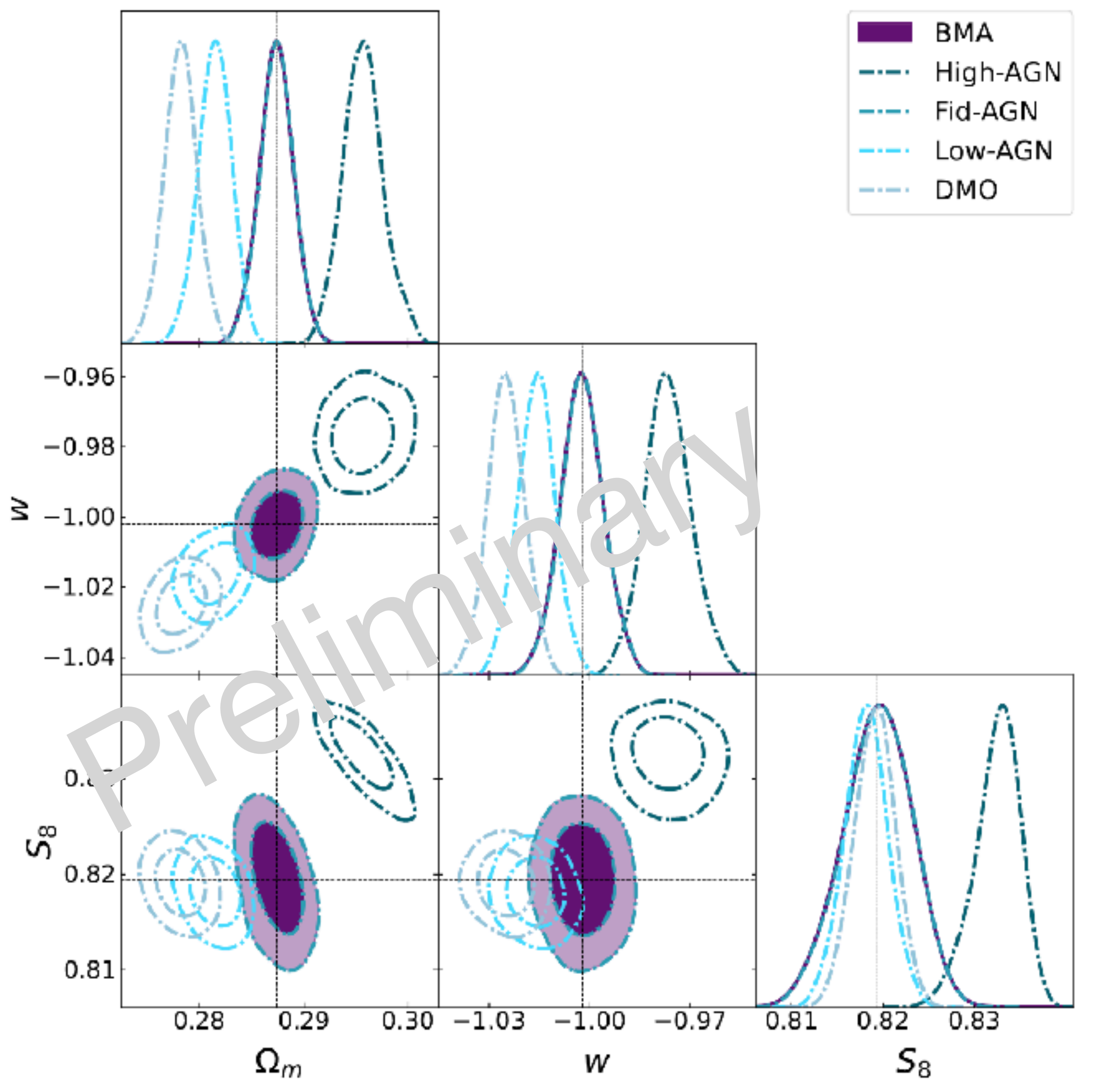
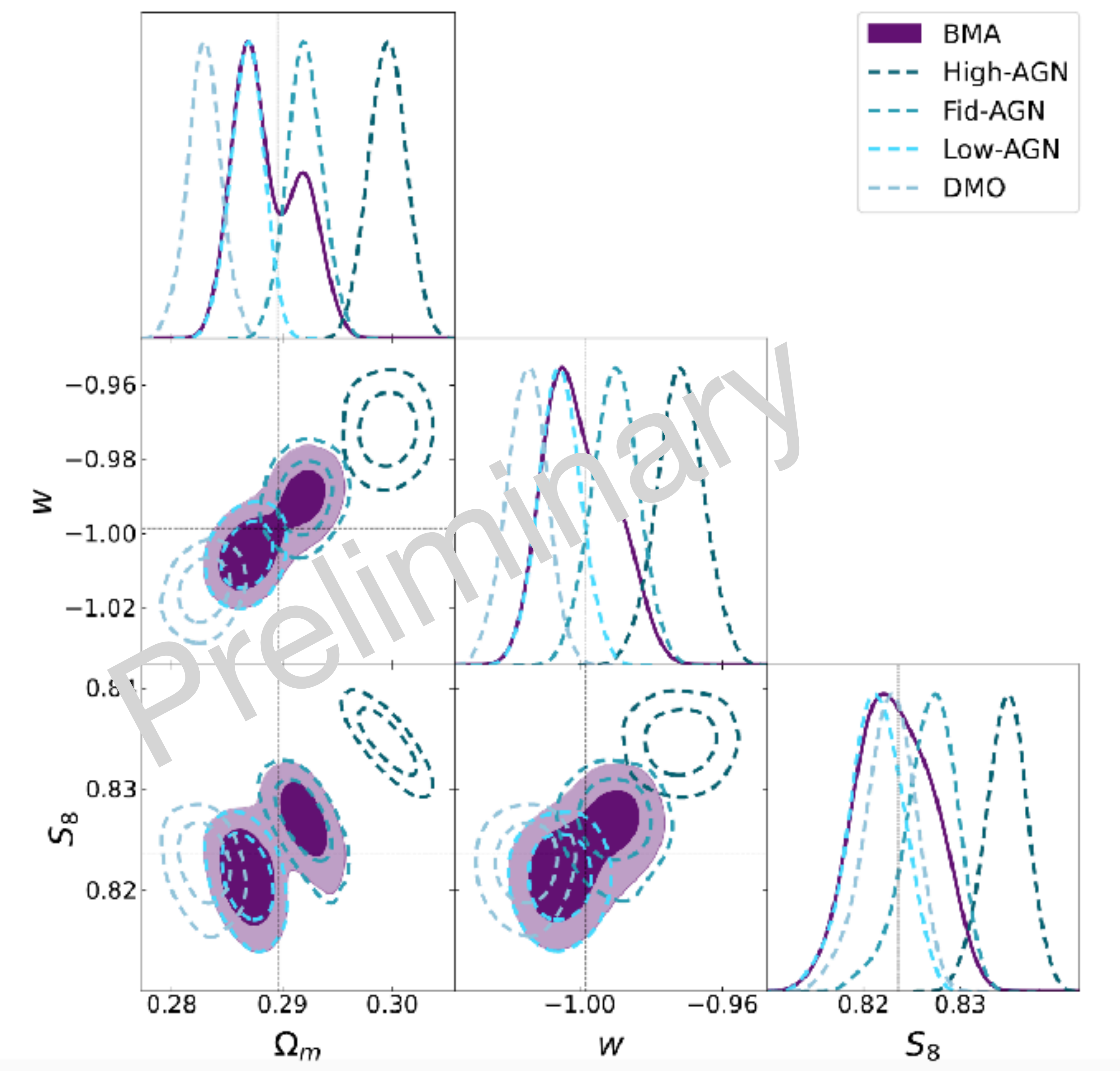


Case 2: Data vector with model misspecification



Peak counts 2 arcmin

Grandón & Sellentin in prep. 2024

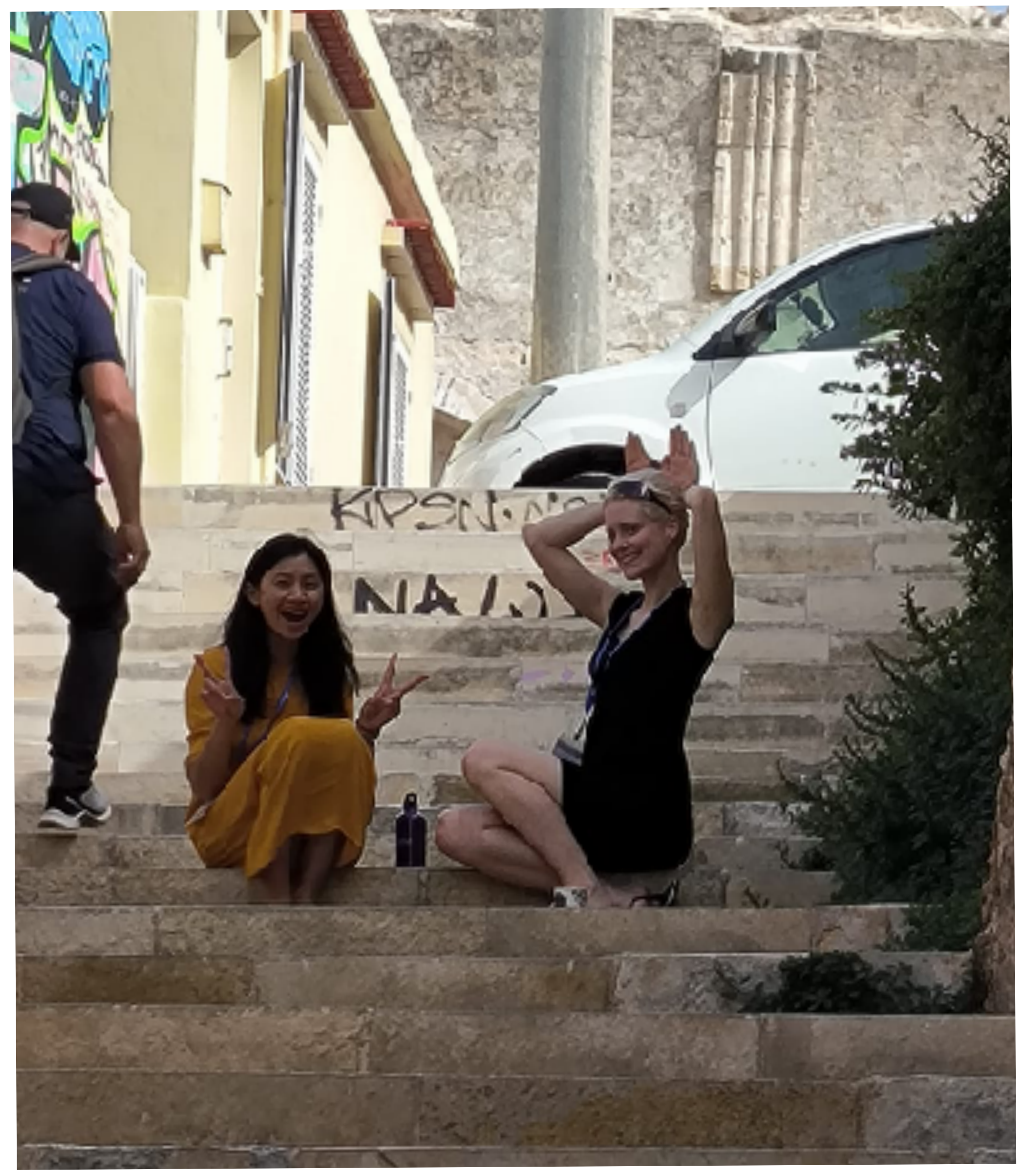
Summary

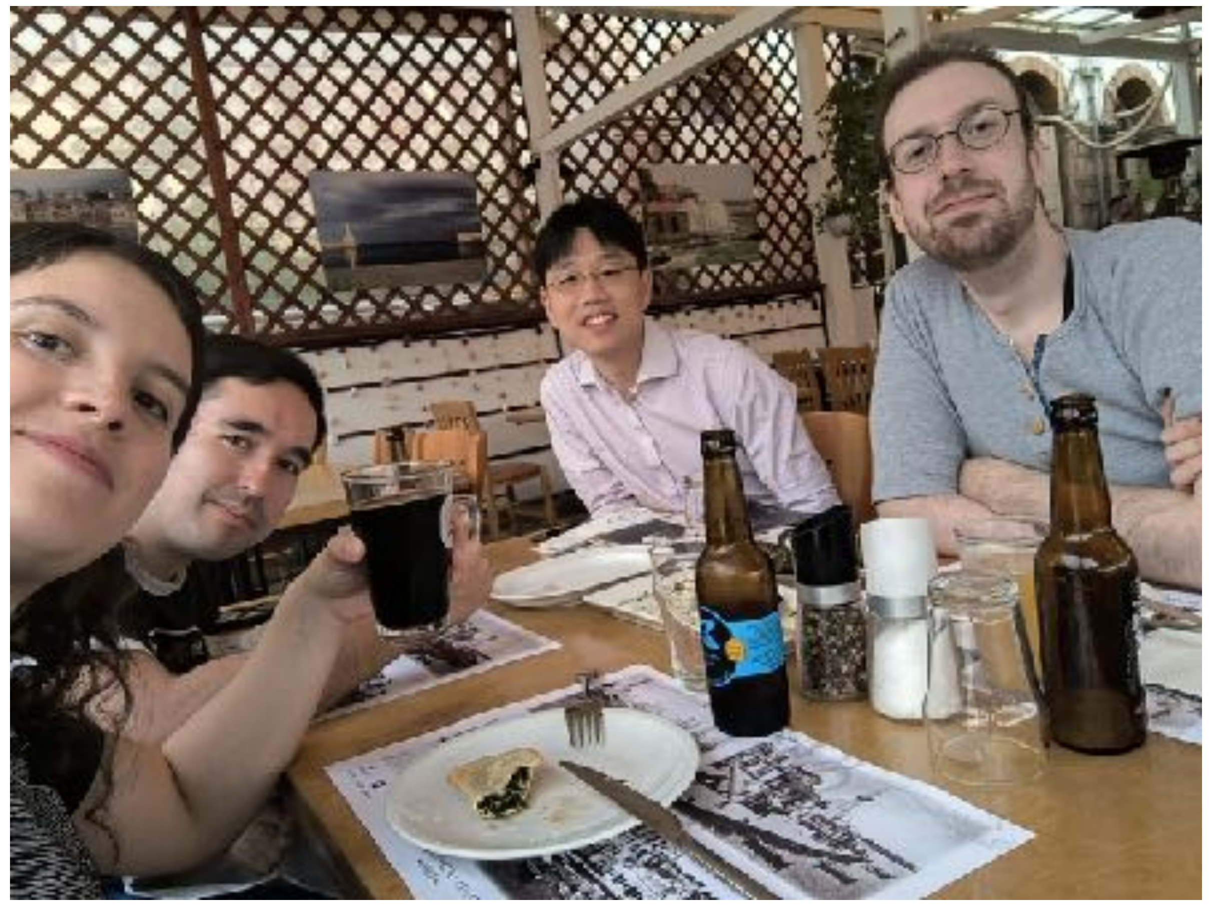
Non-Gaussian statistics can provide precise cosmological constraints for Stage-III and Stage-IV surveys.

We expect severe biases in cosmological parameters for weak lensing Stage-IV analysis. For peak counts, we need to smooth the map >>>5arcmin in order to debias parameter inference.

Fitting a multitude of baryon models to the data, and having the data select the best model, is a solid technique to inference from non-Gaussian estimators.

Thank you!



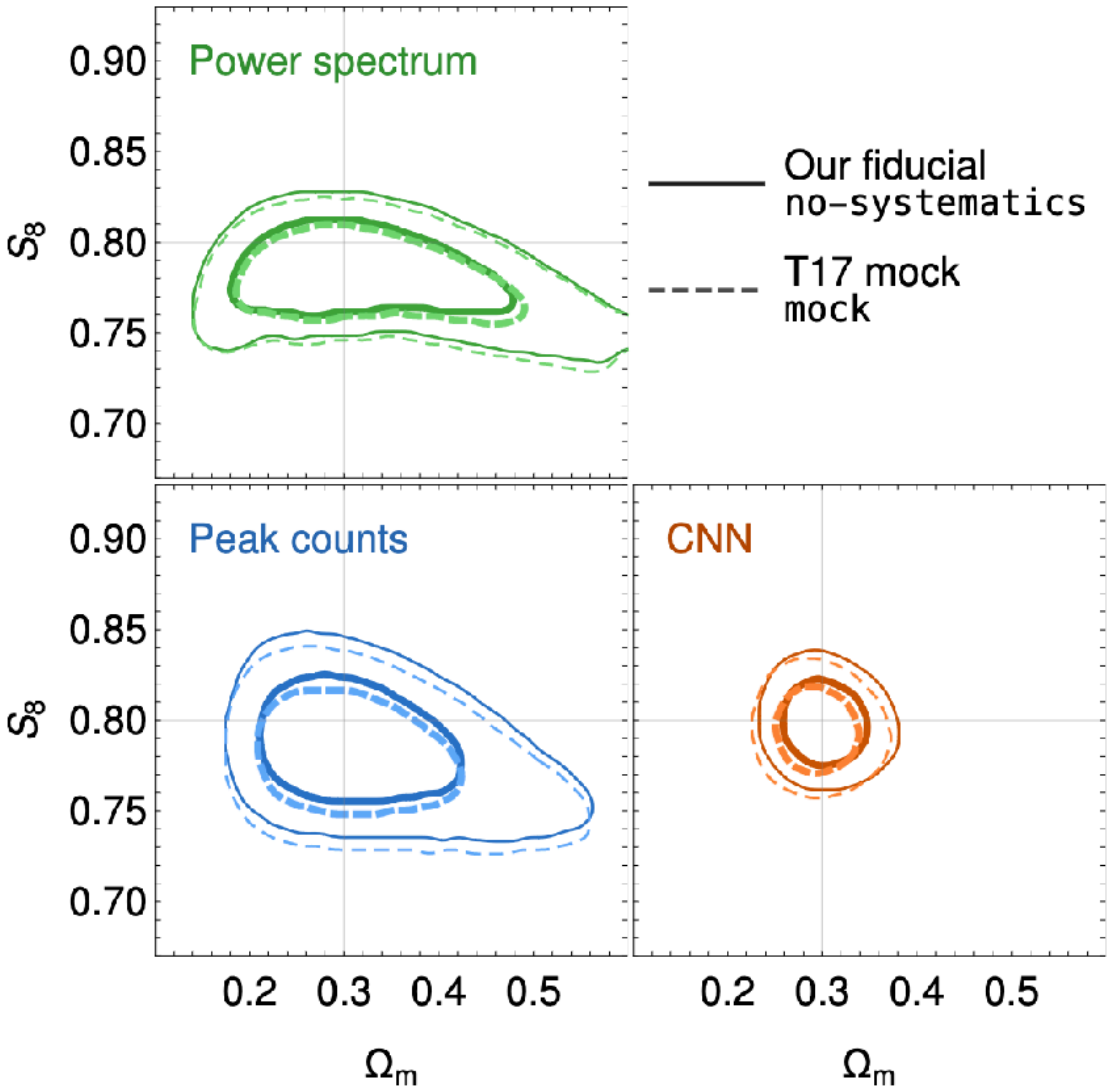


Stage III analysis:

Cosmology from weak lensing non-Gaussian stats with Subaru Hyper Suprime-Cam Y1

Marques et al. 2023 arXiv:2308.10866
Grandón et al. 2024 arXiv:2403.03807
Thiele et al. 2023 arXiv:2304.05928
Cheng et al. 2024 arXiv:2404.16085

HSC Y1 CNN, Lu et al. 2023



HSC Y1 ST, Cheng et al. 2023