Field-Level Inference for Joint Analysis of Galaxy Clustering and CMB Lensing

Jonathan Hawla, supervised by Arnaud De Mattia and Etienne Burtin, June 3, 2026

Field-Level Inference

Galaxy Clustering

CMB Lensing

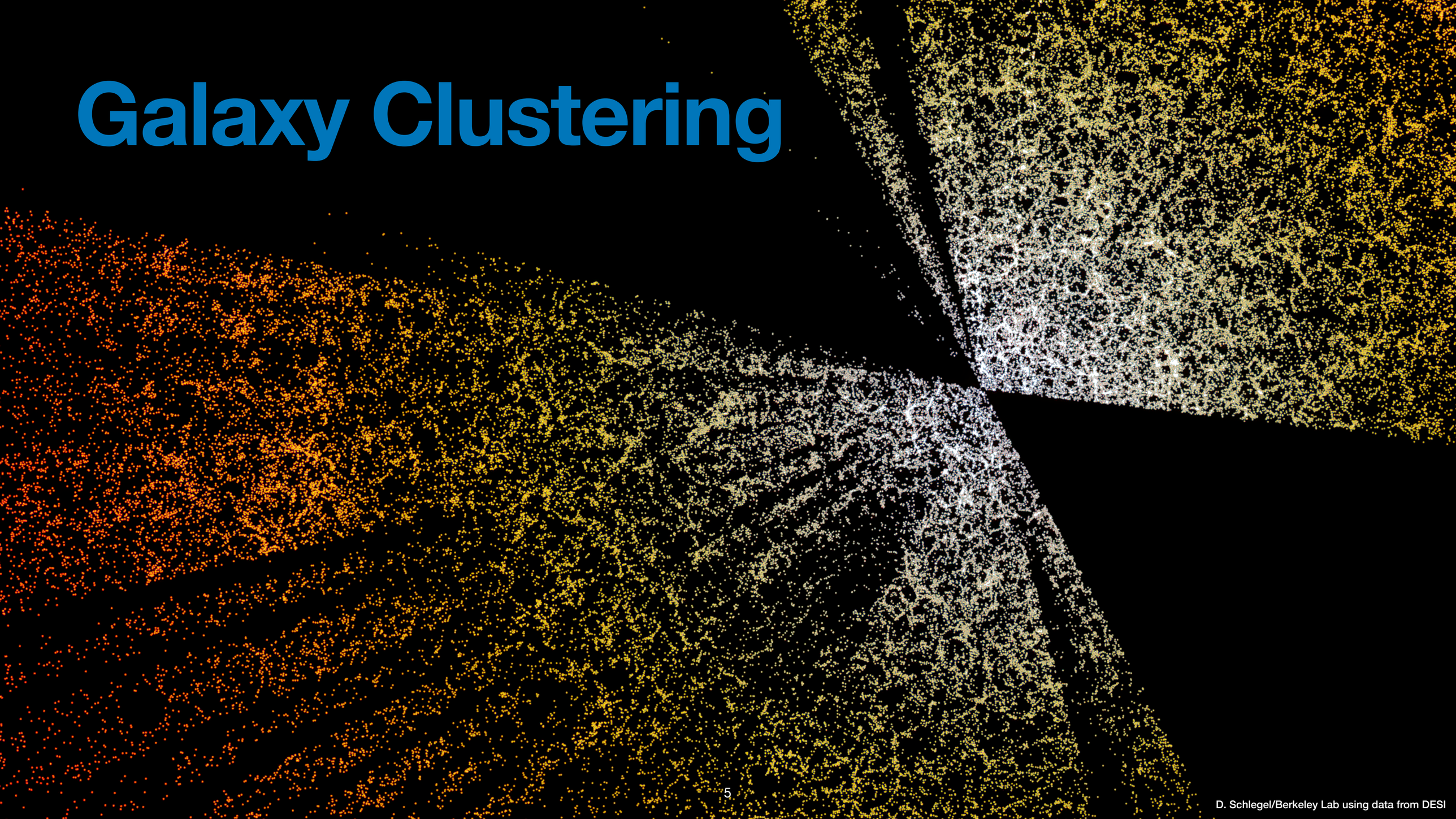
Field-Level Inference

Galaxy Clustering

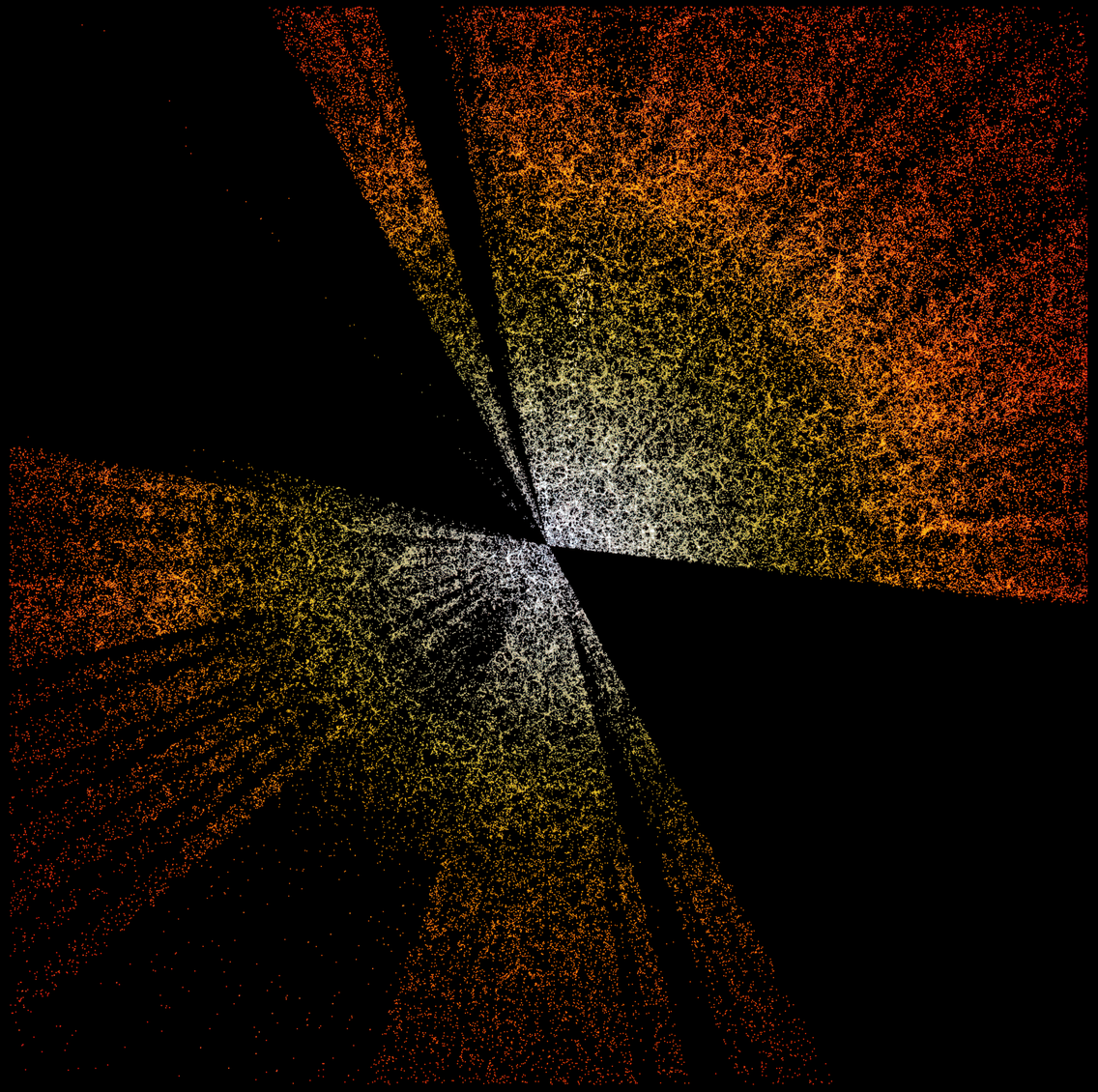
CMB Lensing

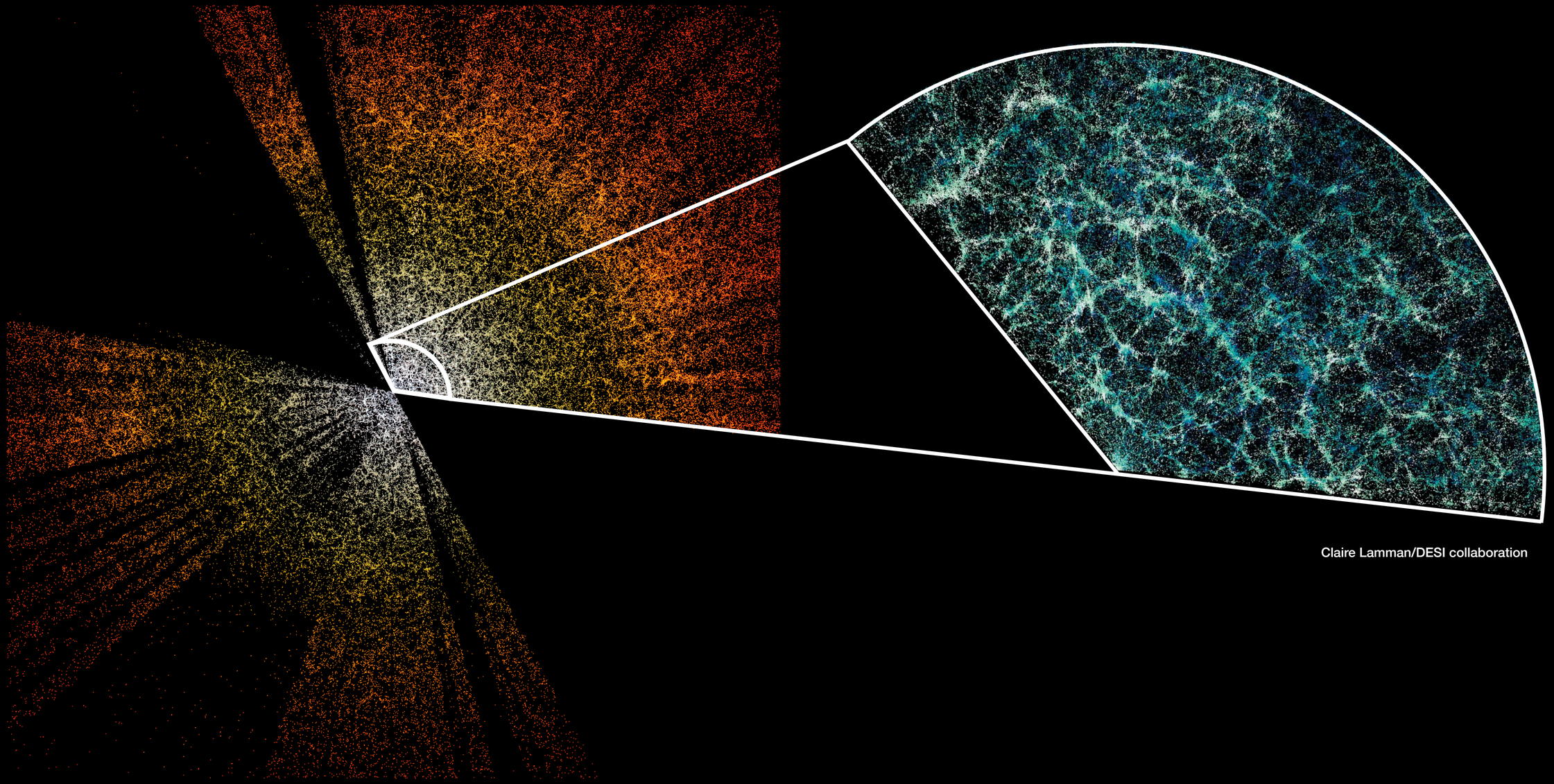
Galaxy Clustering

Galaxy Clustering

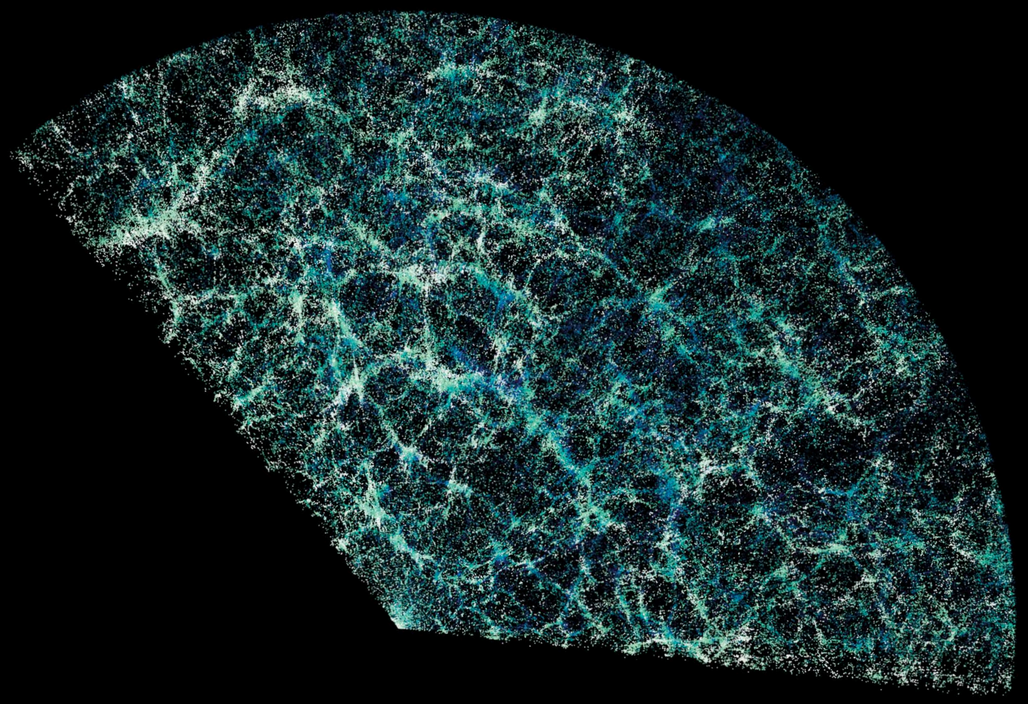


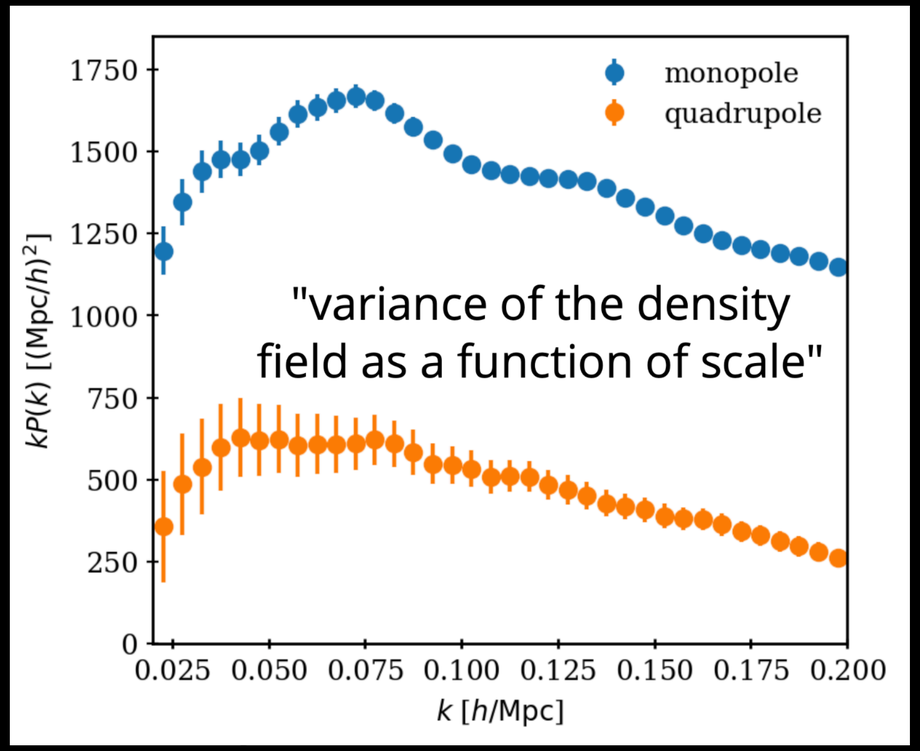
D. Schlegel/Berkeley Lab using data from DESI

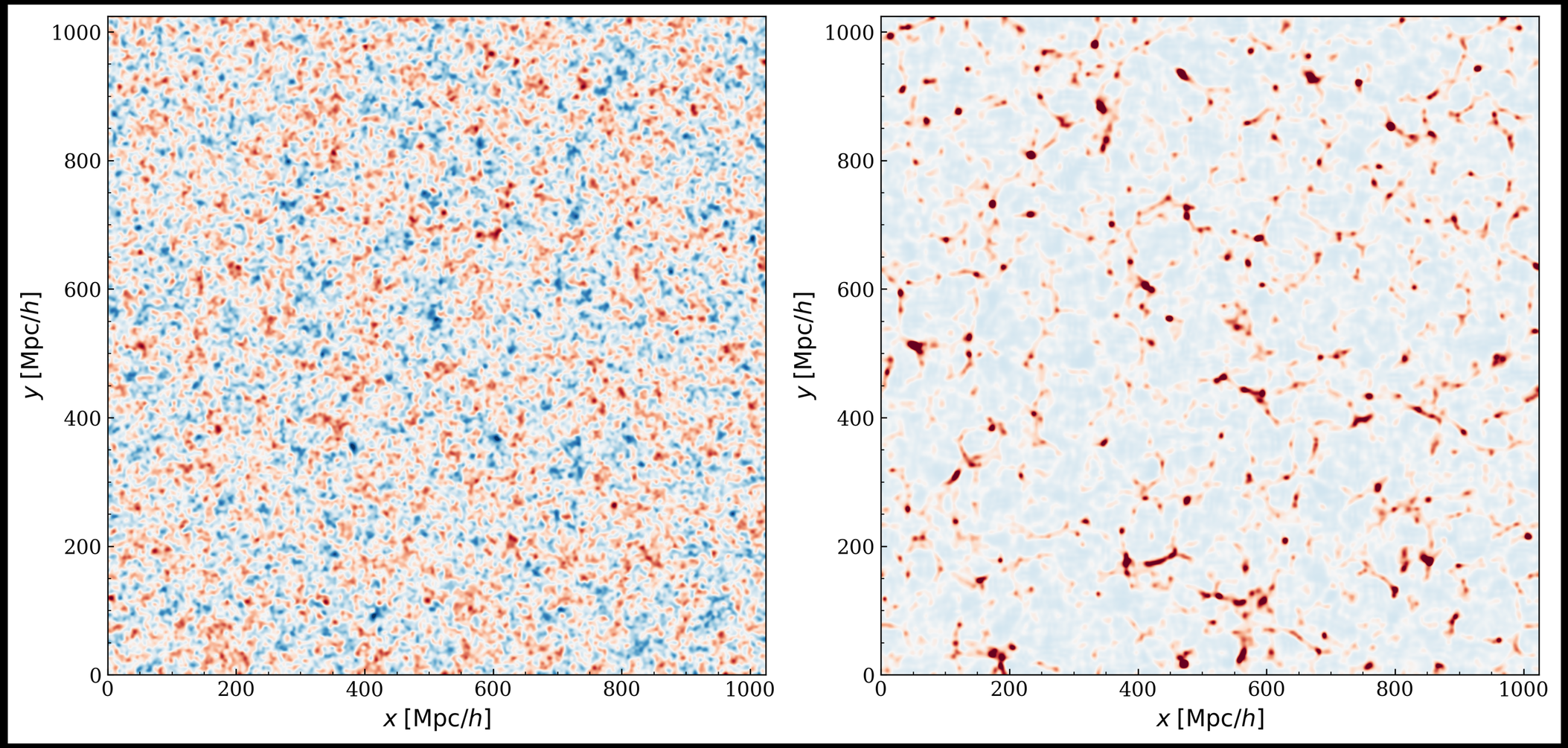




Claire Lamman/DESI collaboration




monopole
quadrupole
"variance of the density field as a function of scale"
$kP(k)$ [(Mpc/h)^2]
1750
1500
1250
1000
750
500
250
0
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
k [h/Mpc]



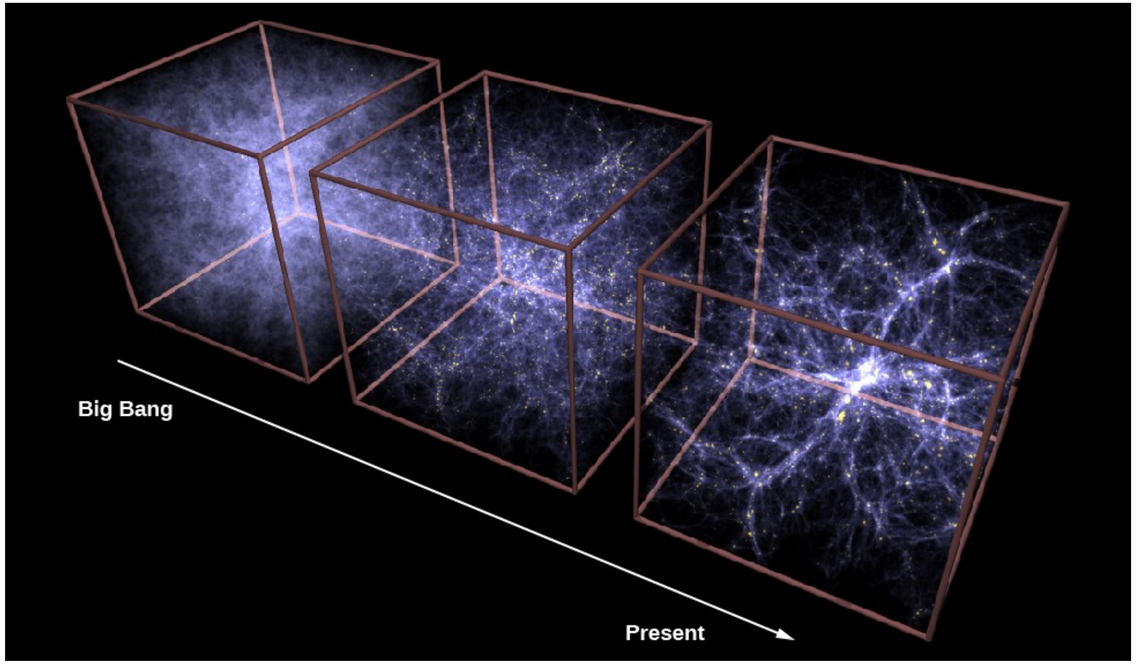
→ **Same power spectrum !**

Field-Level Inference

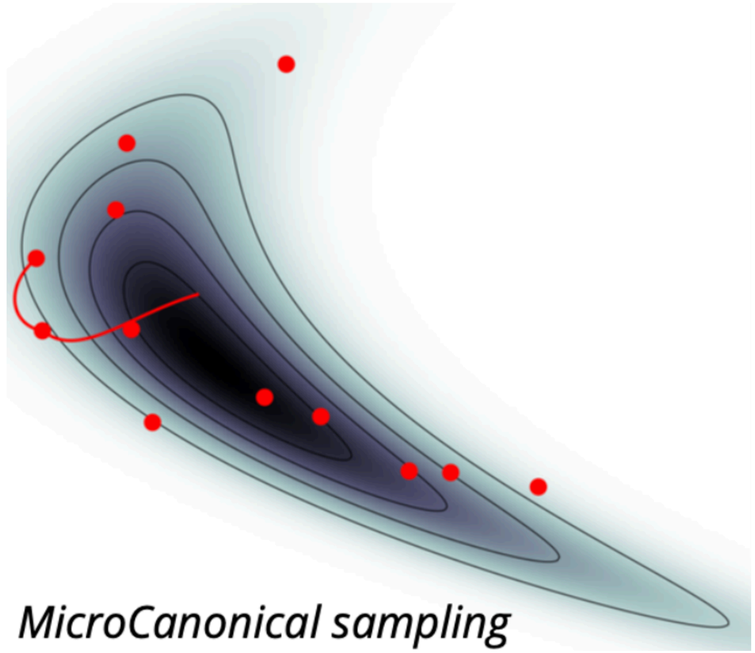
Galaxy Clustering

CMB Lensing

Field-Level Inference



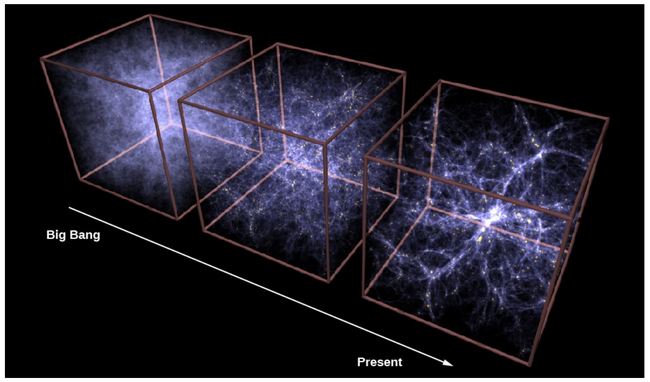
+

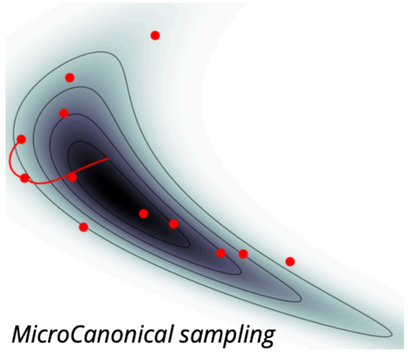


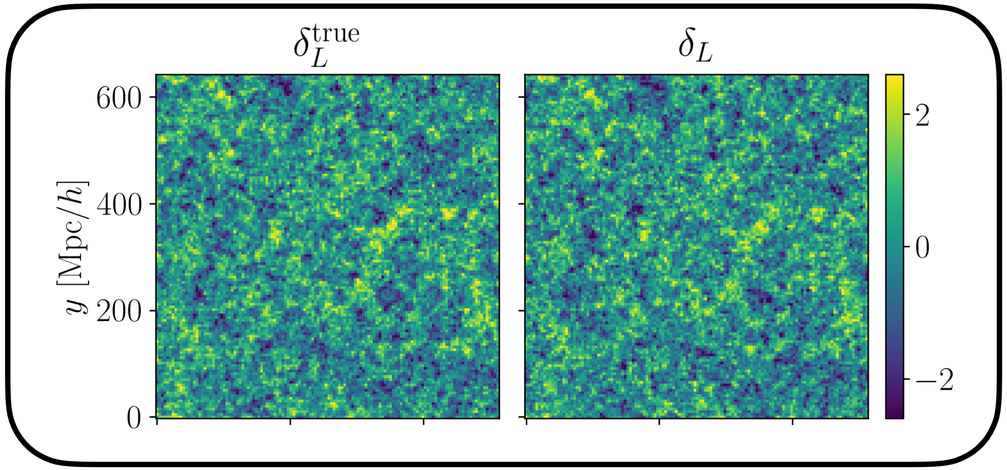
Simulator

Sampler

Field-Level Inference

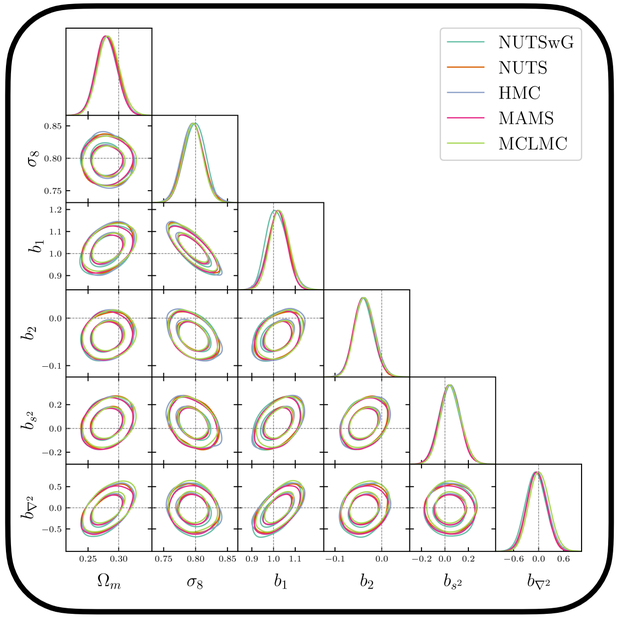






github.com/hsimonfroy/benchmark-field-level

128^3 complete analysis **in ~2h** on 4 GPUs



Hugo Simon et al. 2025

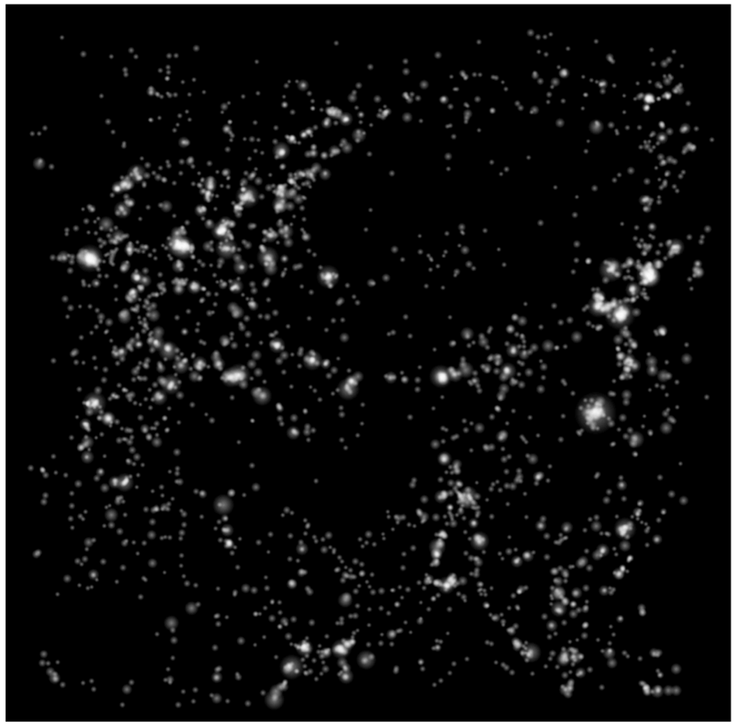
Field-Level Inference

Galaxy Clustering

CMB Lensing

CMB Lensing

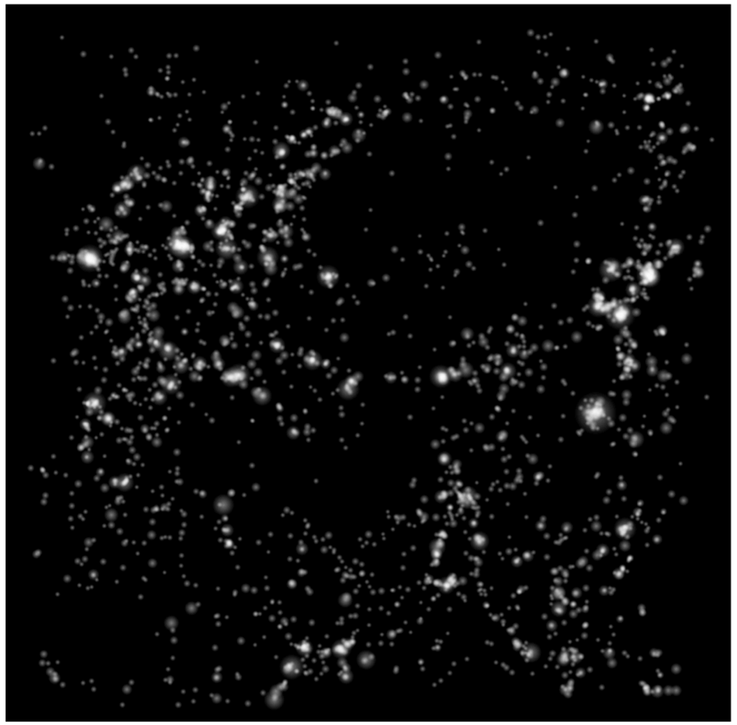
Why a joint analysis ?



Galaxies

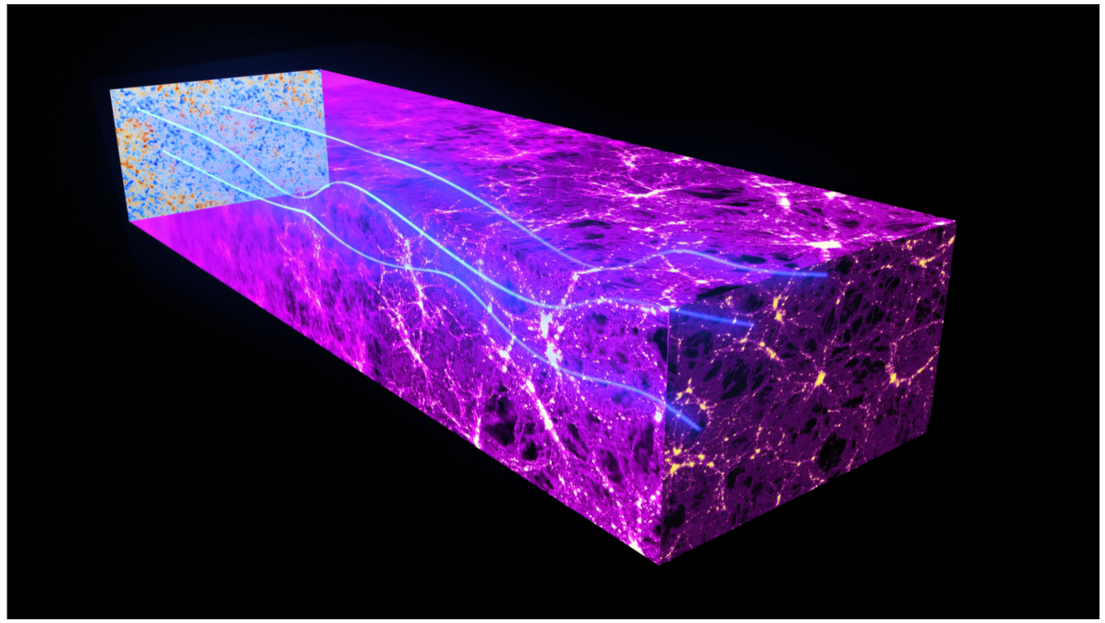
- **Biased** tracer $\delta_g = b_1 \delta_m + \mathcal{O}(\delta_m^2)$
- **Sensitive to** $b_1 \times \sigma_8$: degeneracy partially broken with Redshift Space Distortion sensitive to $f \times \sigma_8$

CMB Lensing



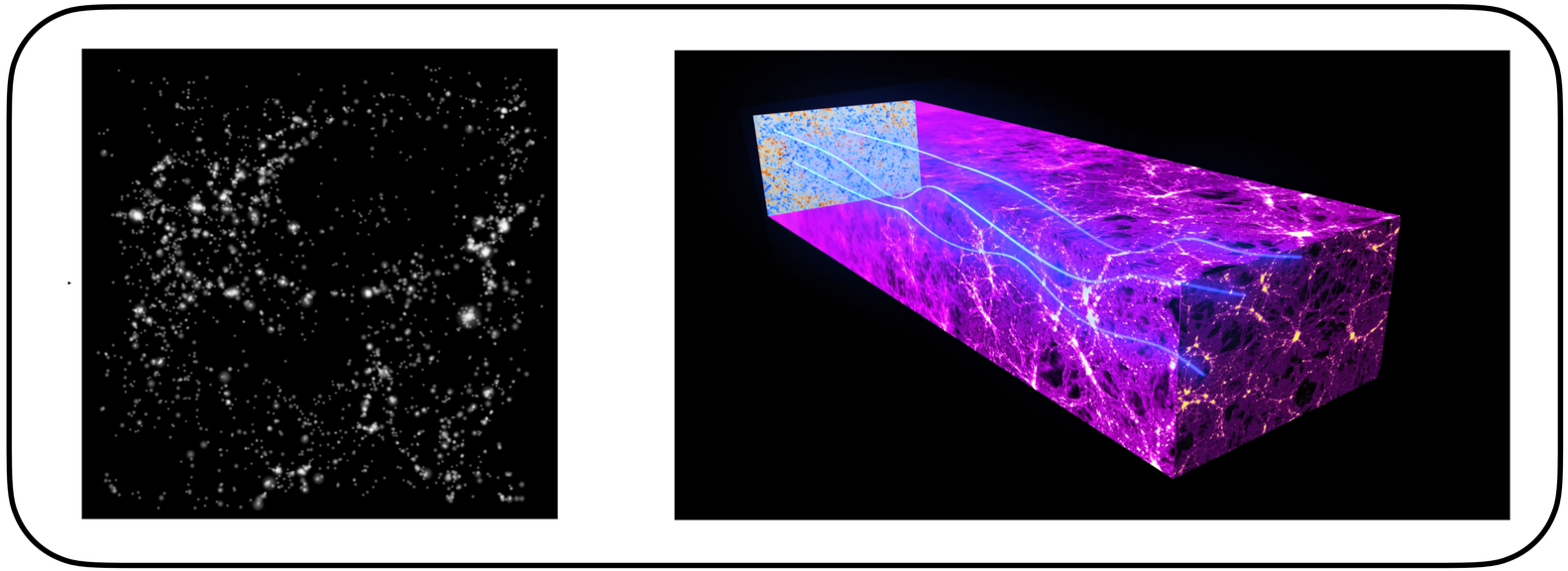
Galaxies

+



Unbiased projection of total matter, sensitive to $\sigma_8 \times \Omega_m^{0.25}$

CMB Lensing



Together : better constraints on Ω_m, σ_8

CMB Lensing

The standard analysis

M. Maus et al. 2025

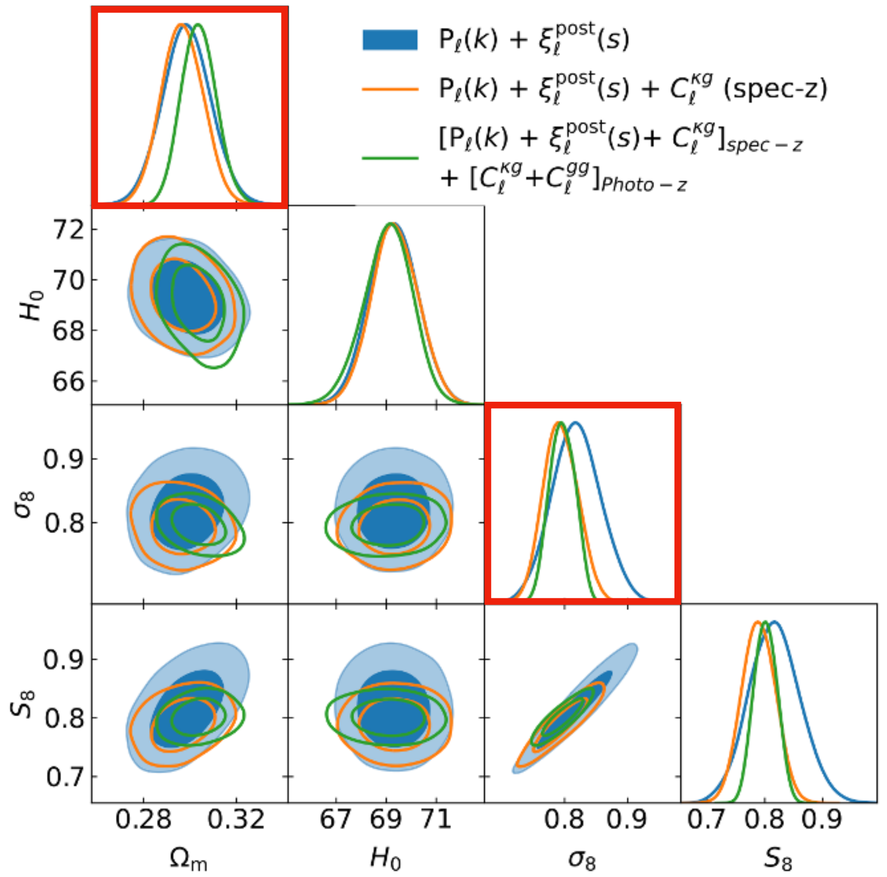
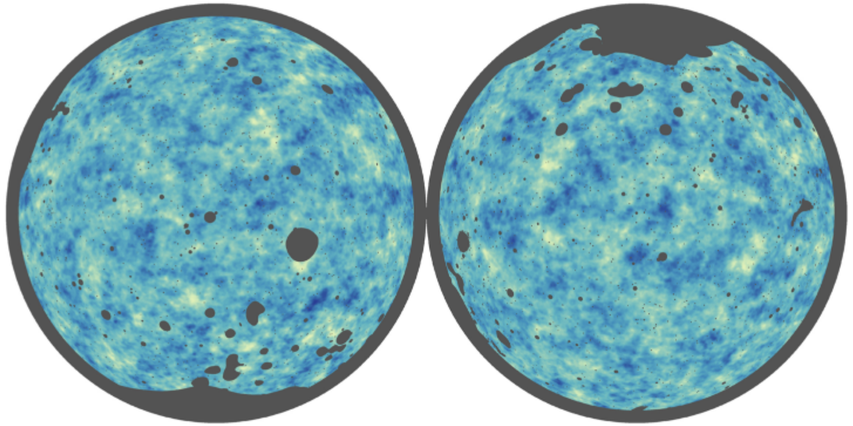


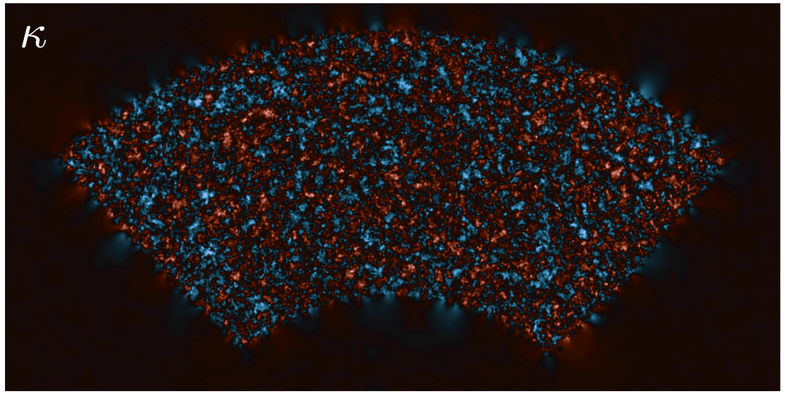
Figure 5. Comparison of FS+BAO only, FS+BAO combined with cross-correlations with lensing (*Planck* PR4 and ACT DR6), and the whole combination of 3D clustering and angular spectra from both spectroscopic and photometric BGS and LRG galaxies from DESI along with PR4 and DR6 lensing data sets.

CMB Lensing

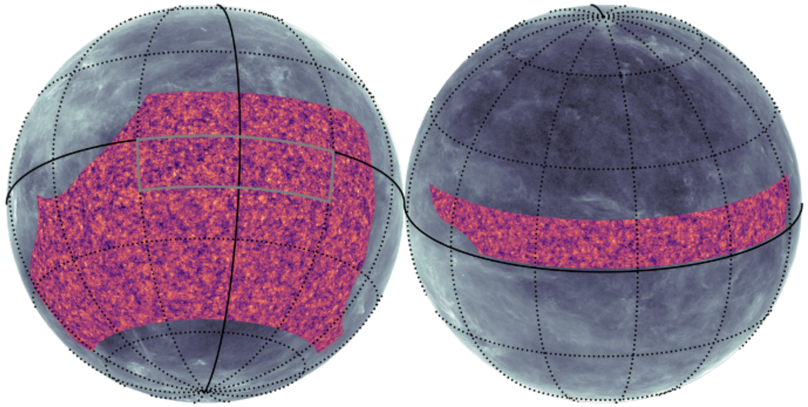
Current data



Planck PR4 (Planck Collaboration et al. 2020a)

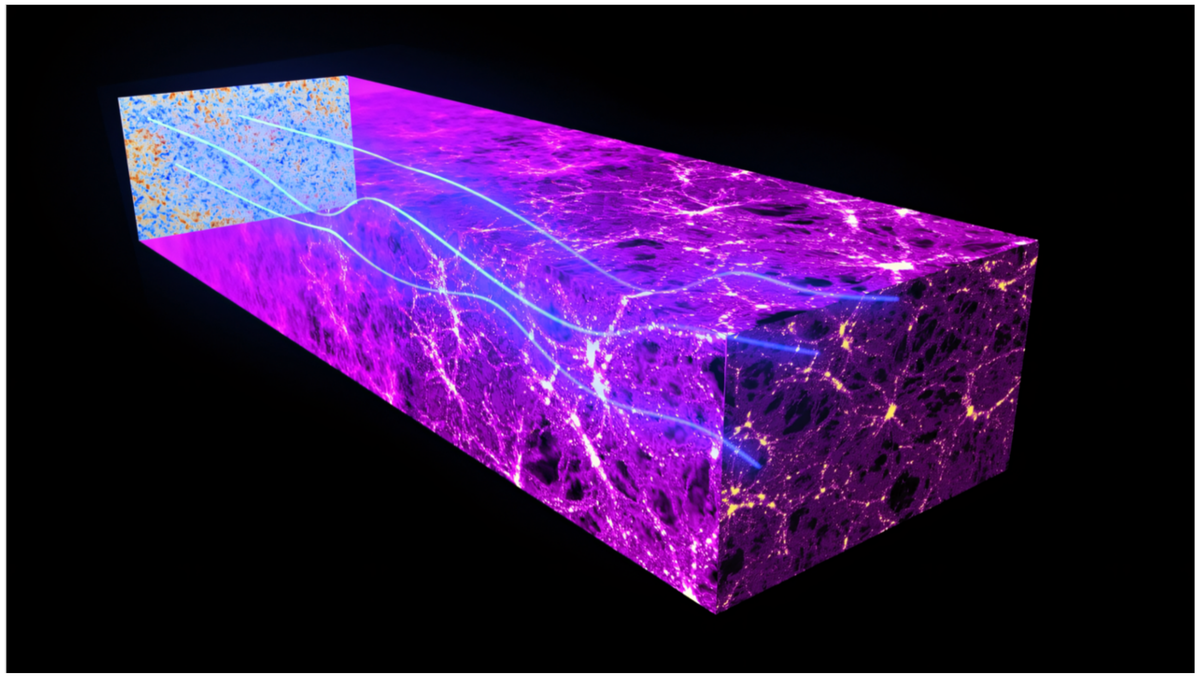


SPT-3G (F. Ge et al. 2025)



ACT DR6 (M. S. Madhavacheril et al. 2024)

CMB Lensing



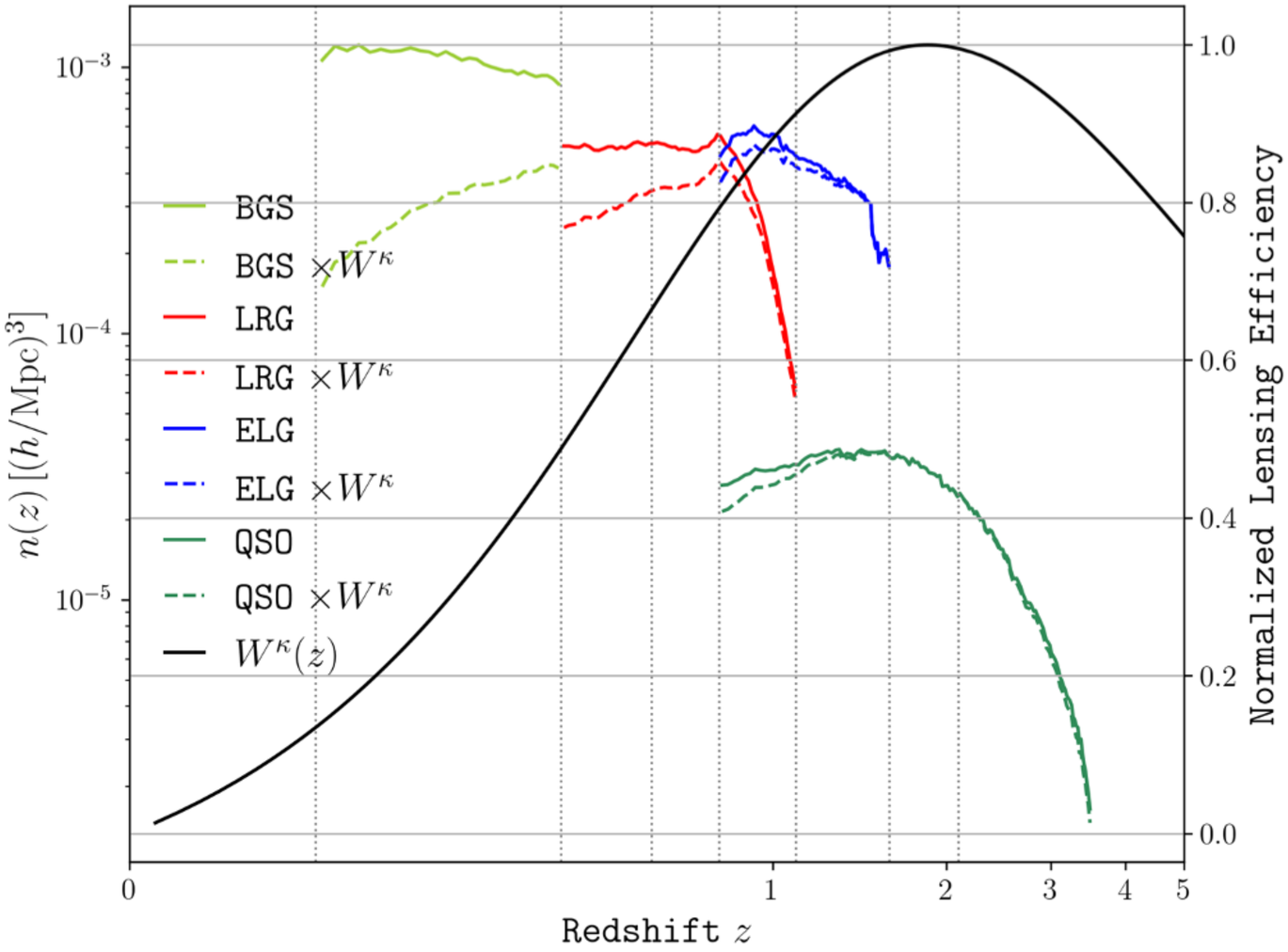
Born Approximation

$$\kappa(\theta) = \int d\chi W_\kappa(\chi)\delta_m(\chi,\theta)$$

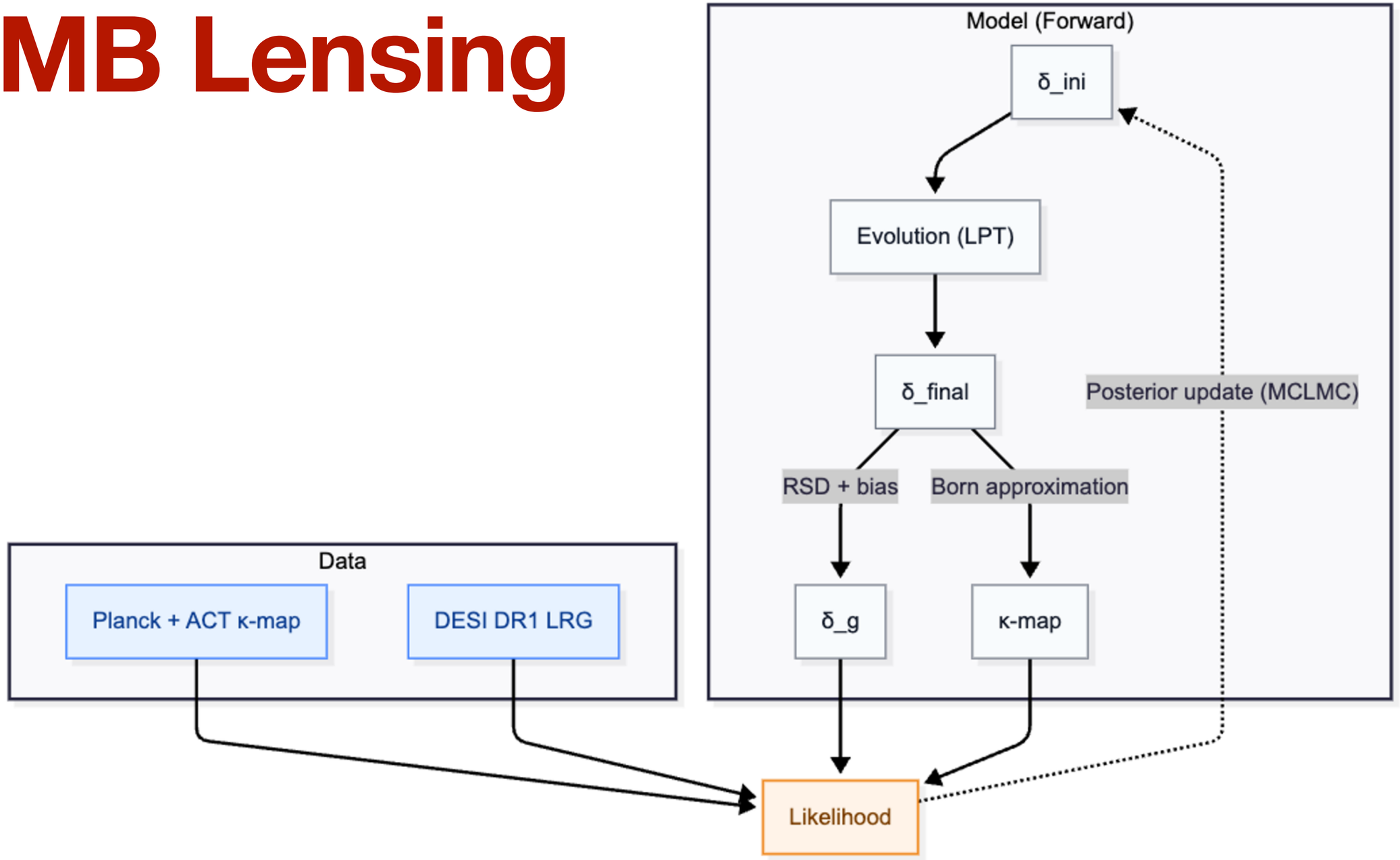
$$W_\kappa(\chi) = \frac{3}{2}\Omega_\mathrm{m}\left(\frac{H_0}{c}\right)^2 \frac{\chi}{a}\frac{\chi_s-\chi}{\chi_s}$$

Differentiable curved-sky implementation : https://github.com/DifferentiableUniverseInitiative/JaxPM by **Wassim Kabalan (JaxPM)**

CMB Lensing

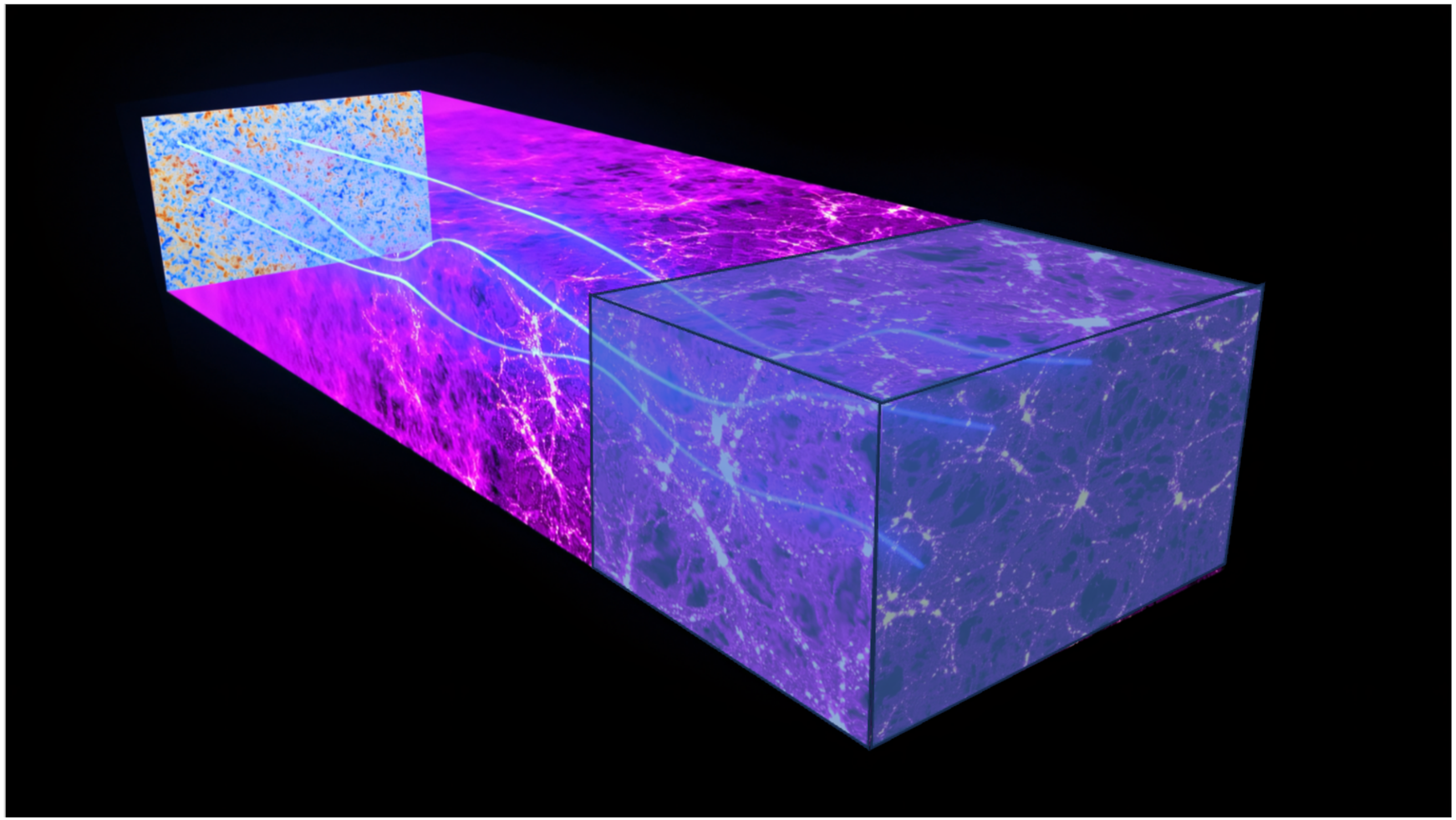

BGS
BGS $\times W^\kappa$
LRG
LRG $\times W^\kappa$
ELG
ELG $\times W^\kappa$
QSO
QSO $\times W^\kappa$
$W^\kappa(z)$
$n(z)\,[(h/\mathrm{Mpc})^3]$
10^{-3}
10^{-4}
10^{-5}
Redshift z
0
1
2
3
4
5
Normalized Lensing Efficiency
0.0
0.2
0.4
0.6
0.8
1.0

CMB Lensing


Model (Forward)
δ_ini
Evolution (LPT)
δ_final
Posterior update (MCLMC)
RSD + bias
Born approximation
δ_g
κ-map
Data
Planck + ACT κ-map
DESI DR1 LRG
Likelihood

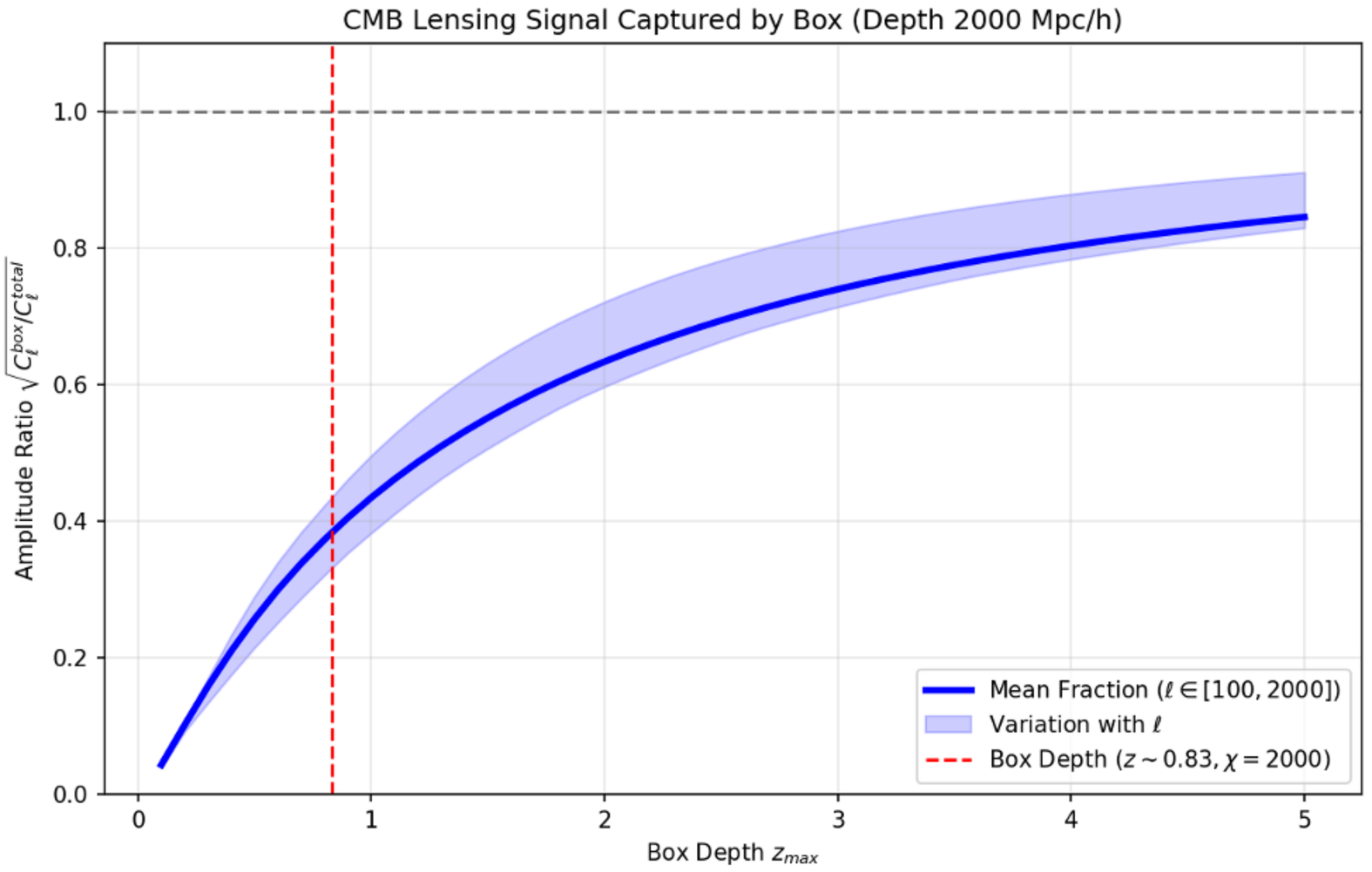
CMB Lensing

The finite box problem



CMB Lensing

The finite box problem



CMB Lensing

The finite box problem

$$\ln(\mathcal{L}) = \ln(\mathcal{L}_g) + \ln(\mathcal{L}_\kappa)$$

$$\ln(\mathcal{L}_\kappa) = -\frac{1}{2}\sum_\ell \left[\frac{|\Delta\kappa_\ell|^2}{C_\ell} + \ln(C_\ell)\right]$$

$$C_\ell = N_\ell + C_\ell^{\mathrm{high-z}}$$

Instrumental noise

Background noise

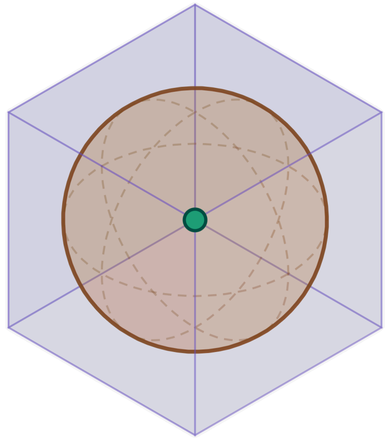
CMB Lensing

The finite box problem

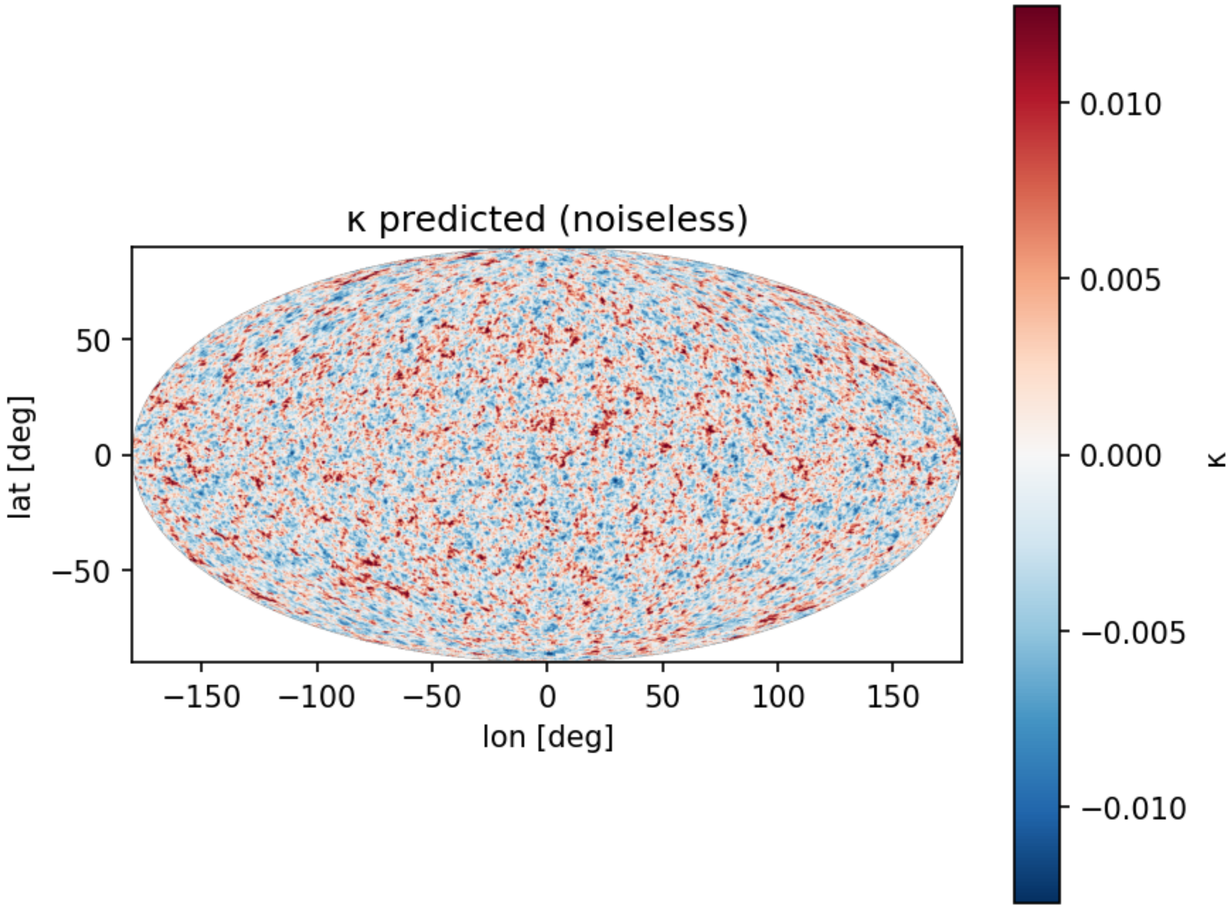
$$C_\ell^{\mathrm{high-z}}(\theta) = \int_{\chi_{\mathrm{end\_box}}}^{\chi_{\mathrm{CMB}}} \frac{W_\kappa^2(\chi)}{\chi^2} \times P(k,\chi) d\chi$$

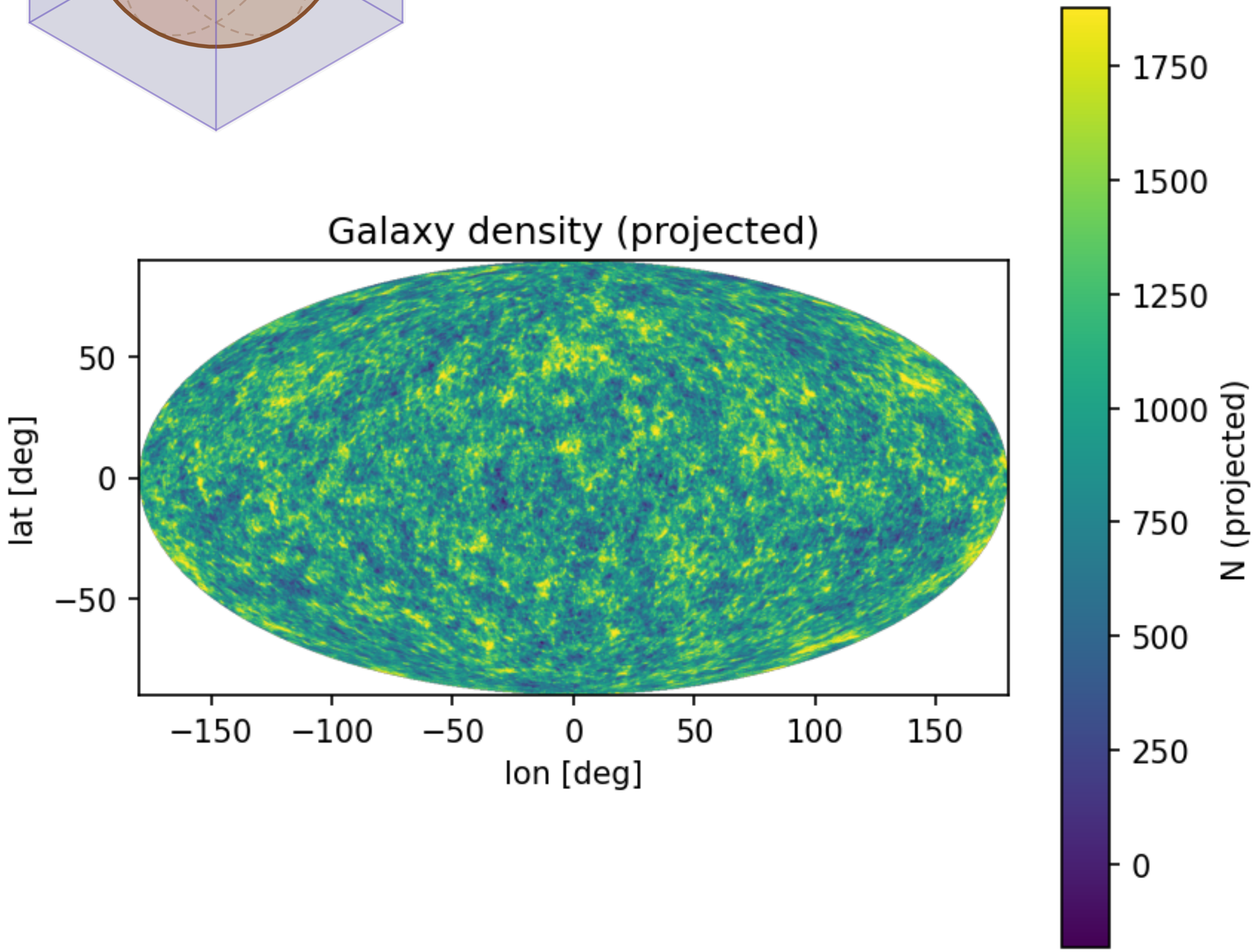
- **High z** : more linear regime
- Equivalent to a **standard analysis outside** of the simulation box

CMB Lensing



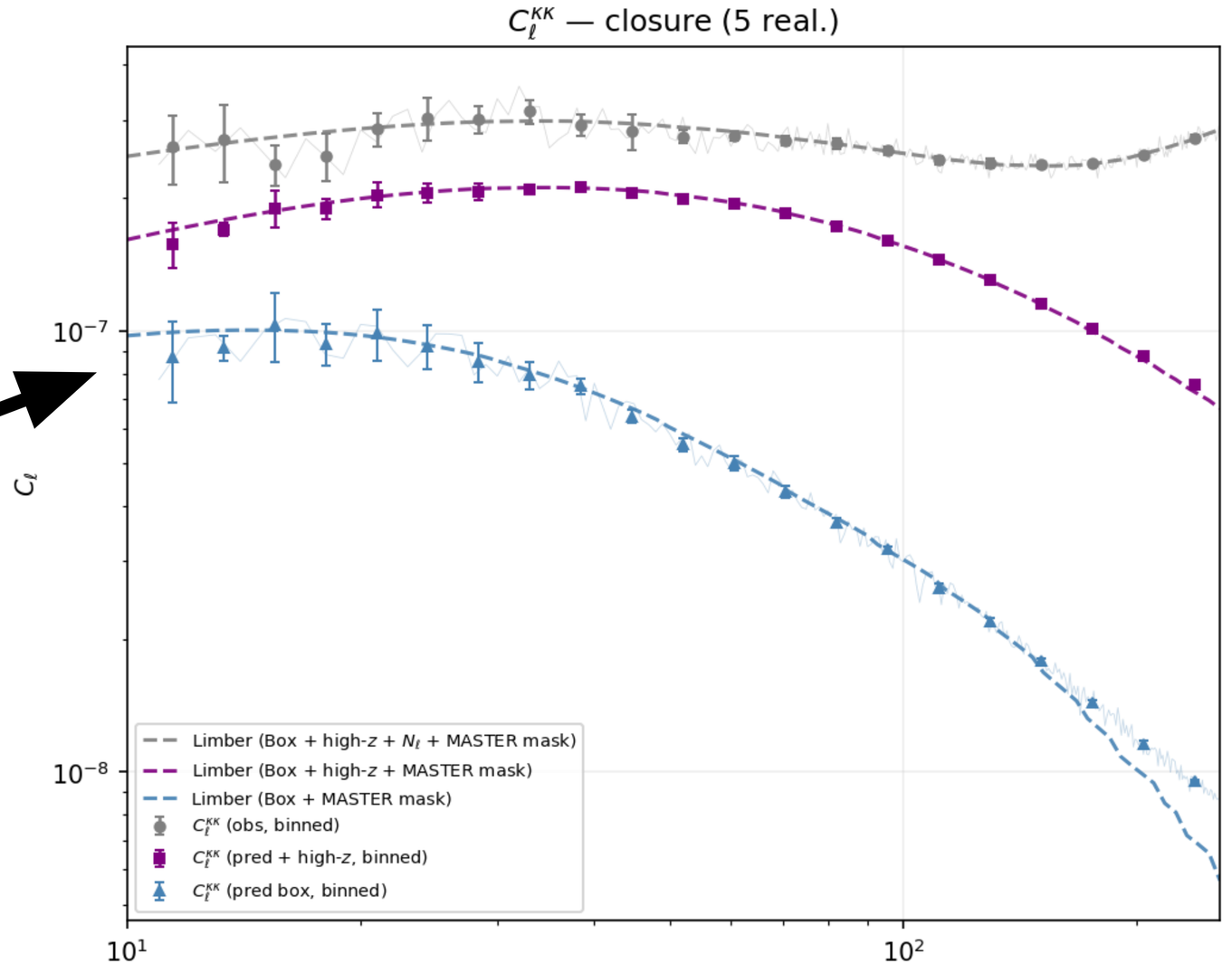
Full-sky setup





CMB Lensing

Validation



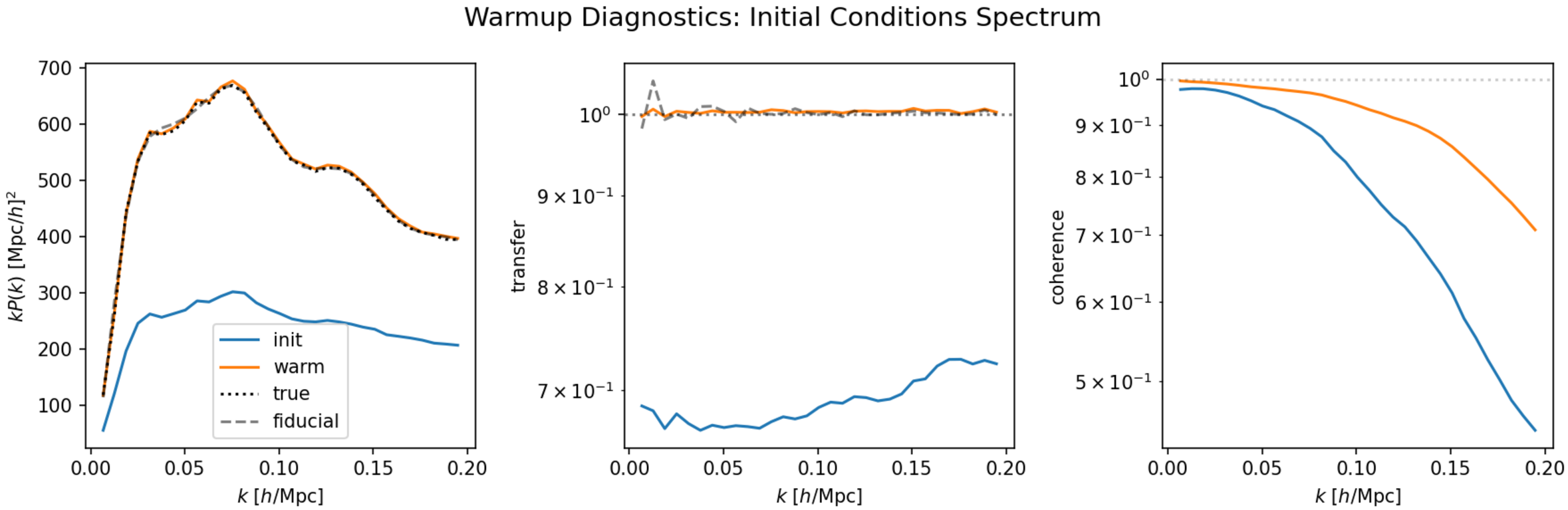
Inside the simulation box

$+ N_\ell$

$+ C_\ell^{\mathrm{high-z}}$

CMB Lensing

Validation

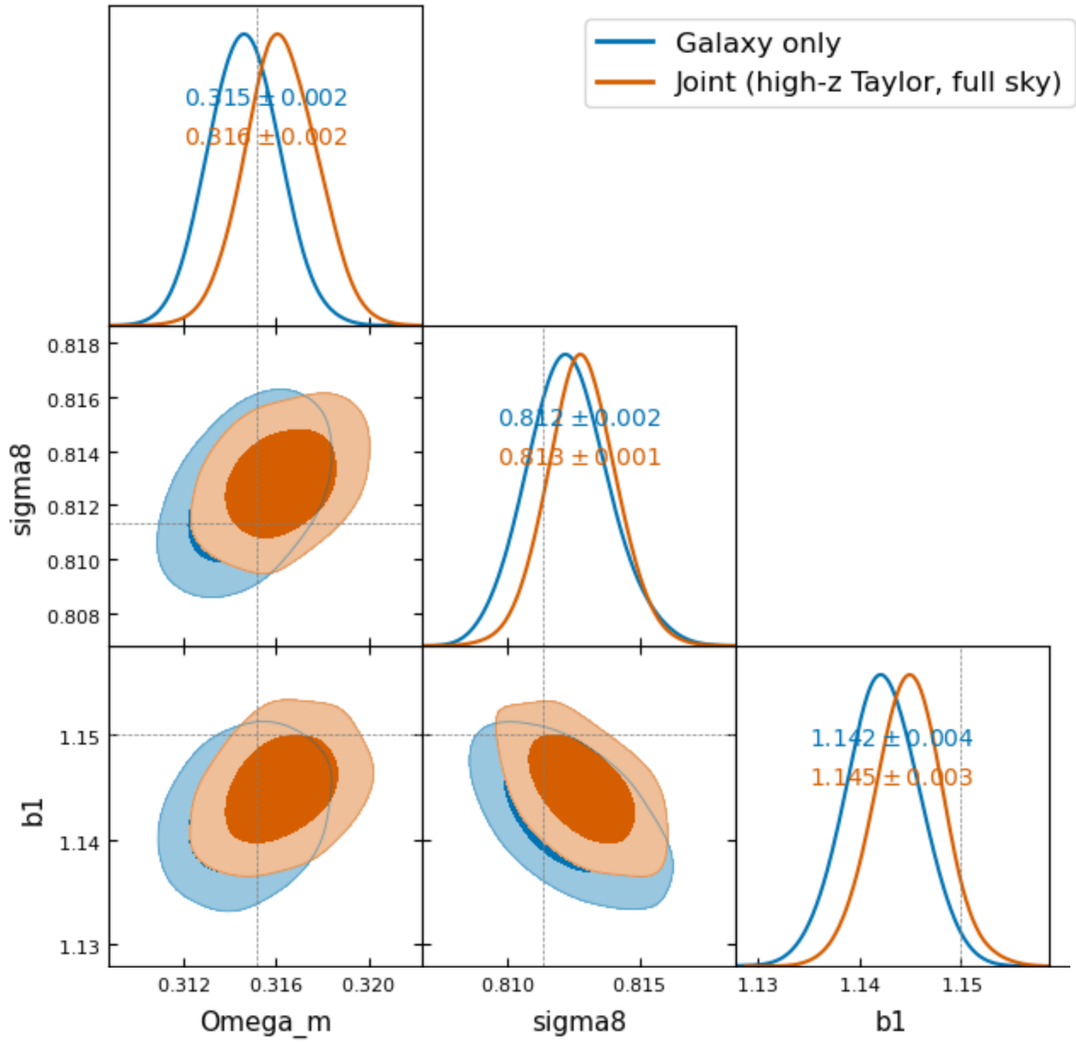


CMB Lensing

Results

Box : $(2\ \mathrm{Gpc/h})^3$

Cell size : $15\ \mathrm{Mpc/h}$



on synthetic data (closure test)

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Ongoing…

- **Validating the pipeline on external simulations** (ABACUS, B. Hadzhiyska et al. 2023)
- **Constraint** f_{NL} (Primordial Non Gaussianities)
- Work towards **more realism** and **real data analysis**

Thank you !