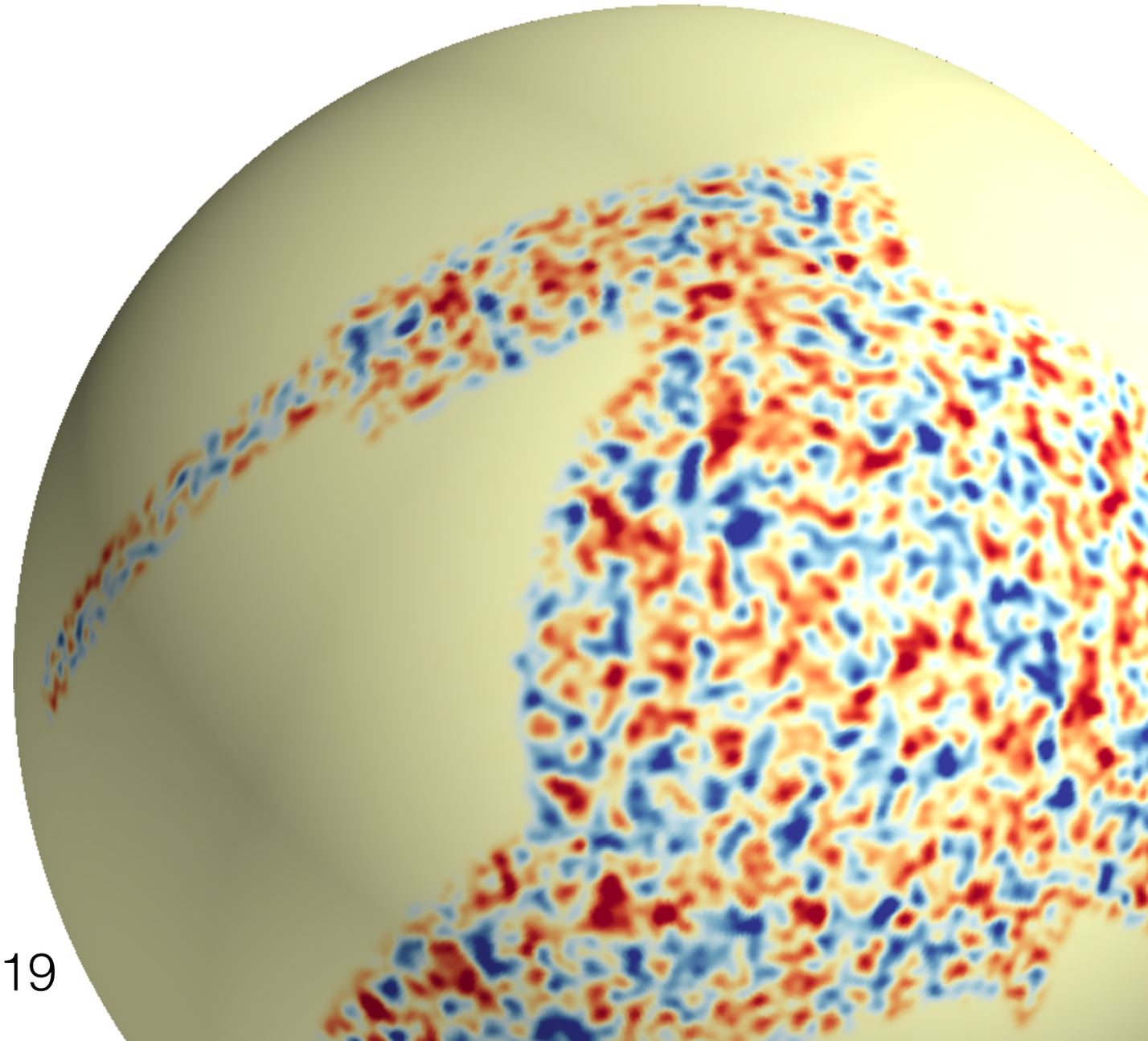
Cosmological Constraints from Moments of Weak Lensing Mass Maps

Marco Gatti
IFAE (Barcelona)

DARK ENERGY SURVEY



with Chihway Chang, Oliver Friedrich, Bhuvnesh Jain,
and the DES collaboration

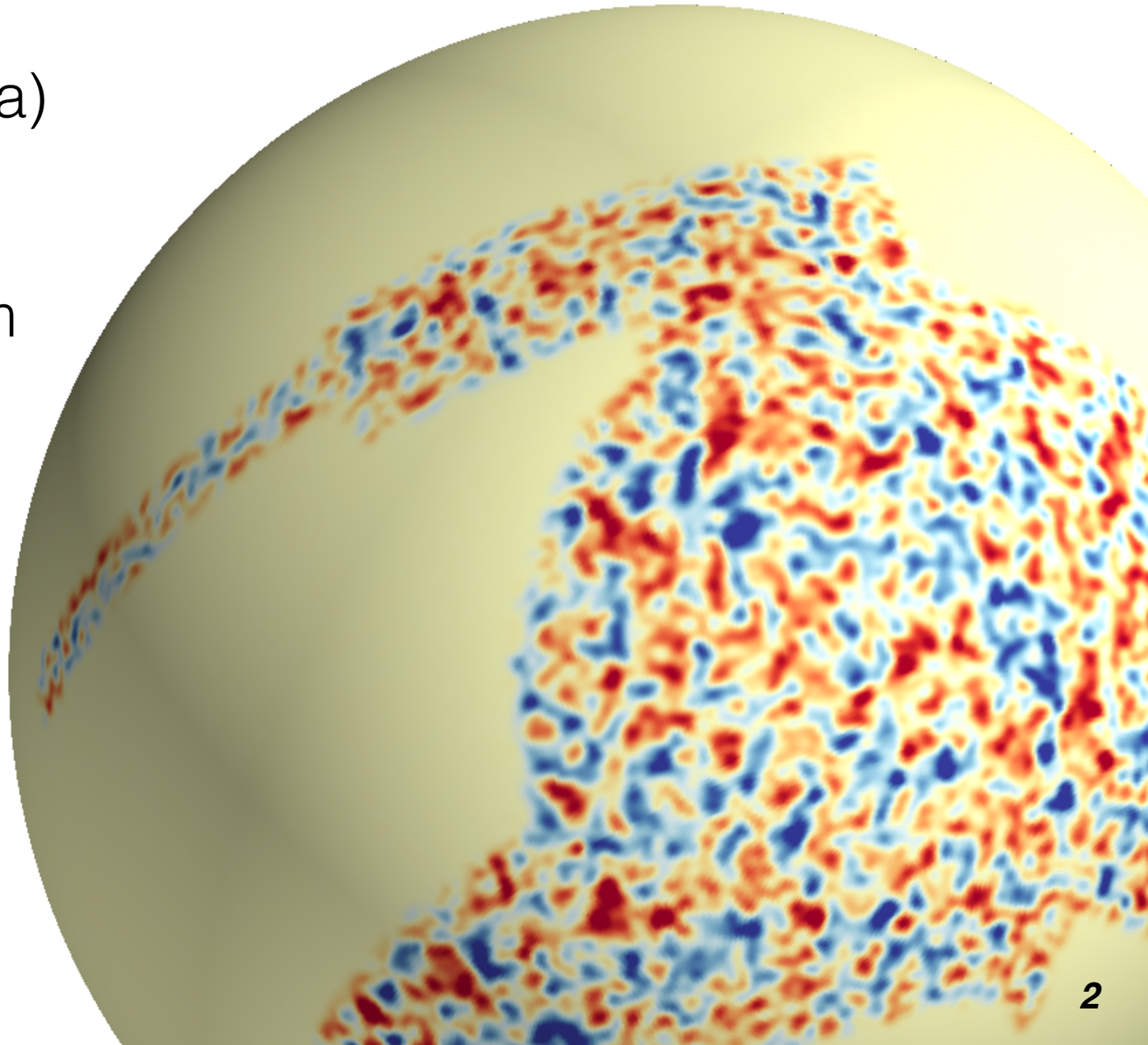
Cosmo19, Aachen, September 2nd 2019

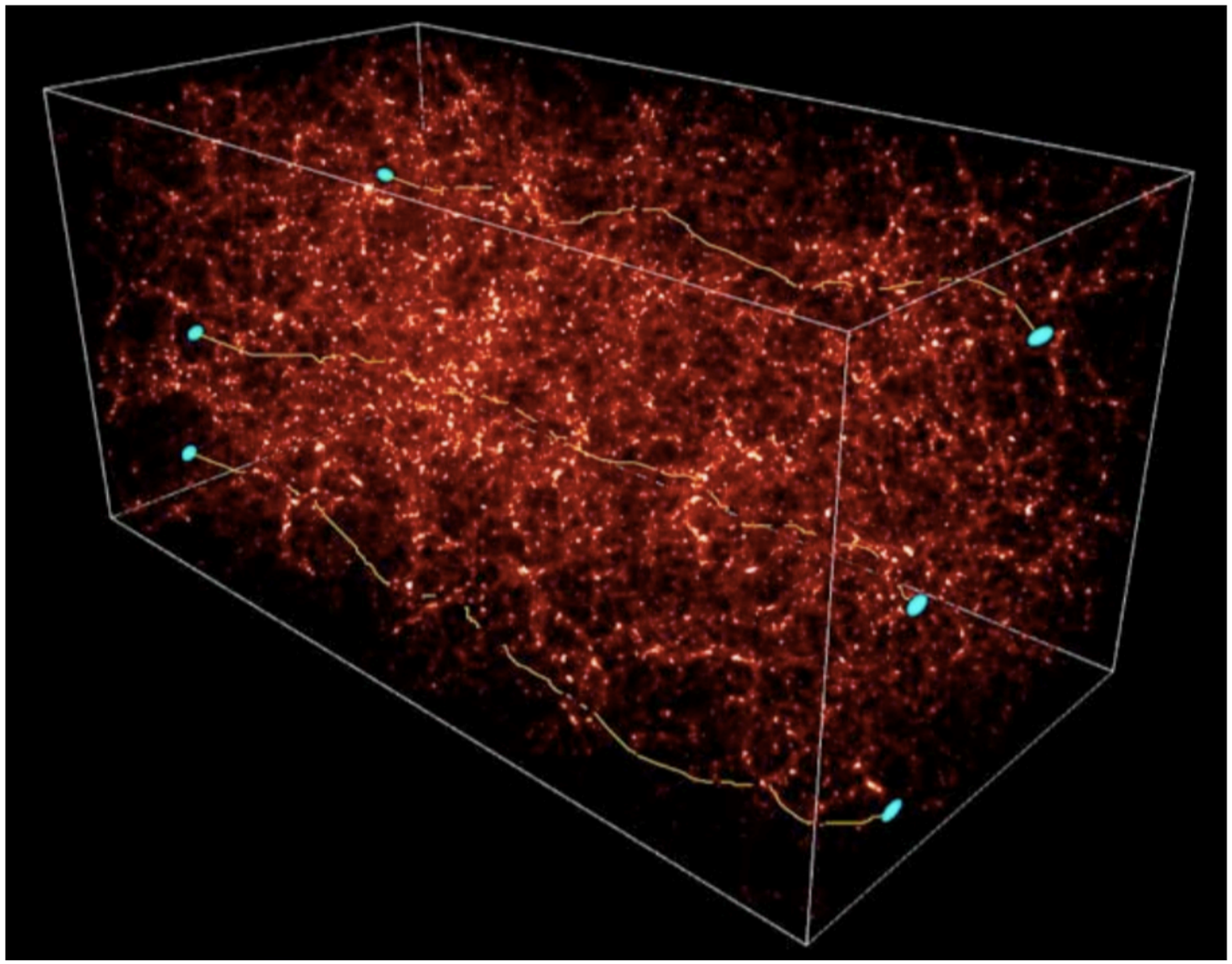
Outline

- Introduction to Weak Lensing Mass Maps

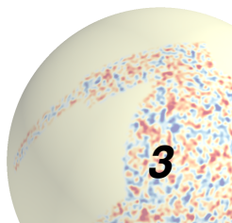
- Mass Maps from DES Y3 (data)

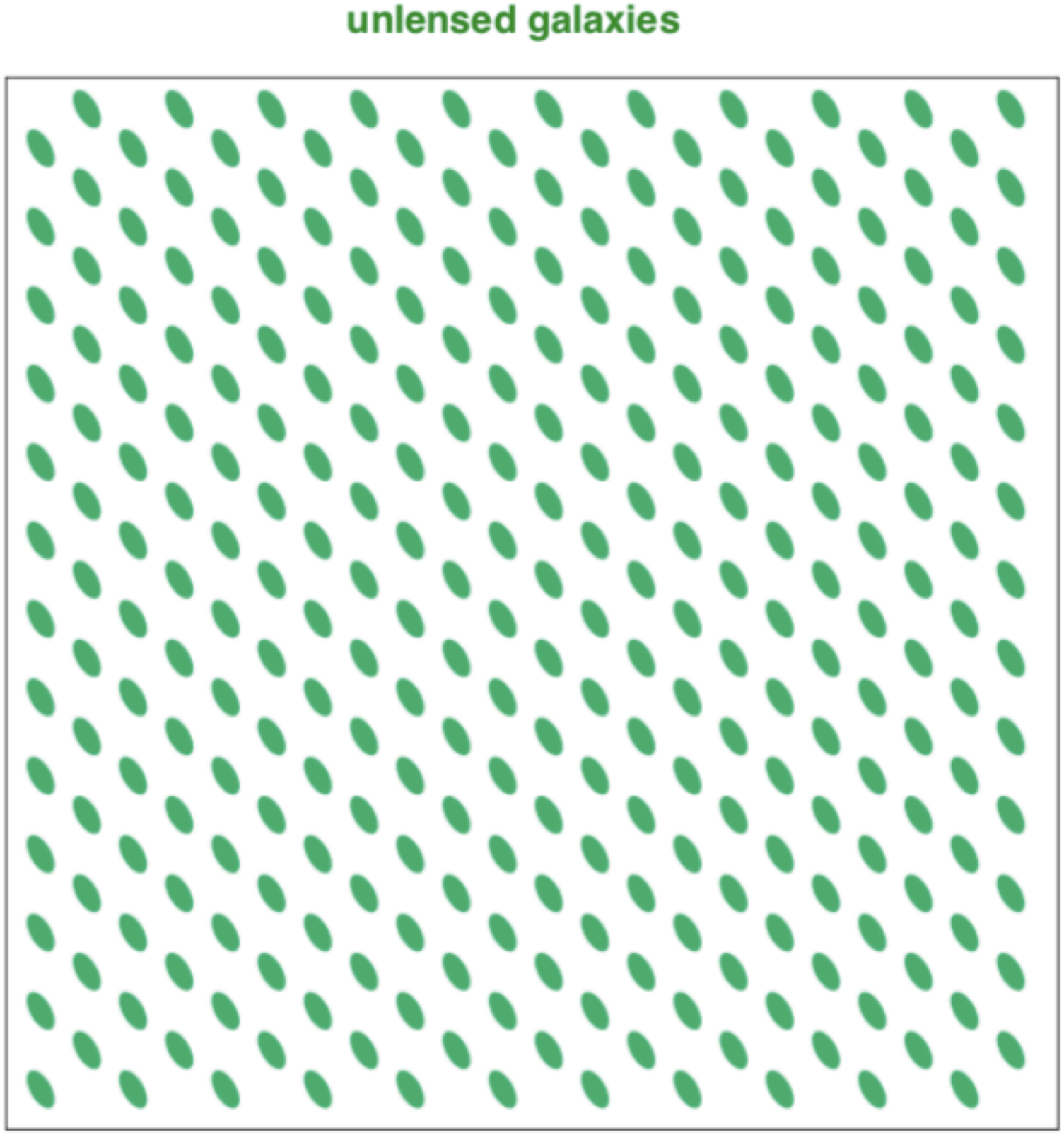
- Cosmological constraints from Mass Maps moments (sims)





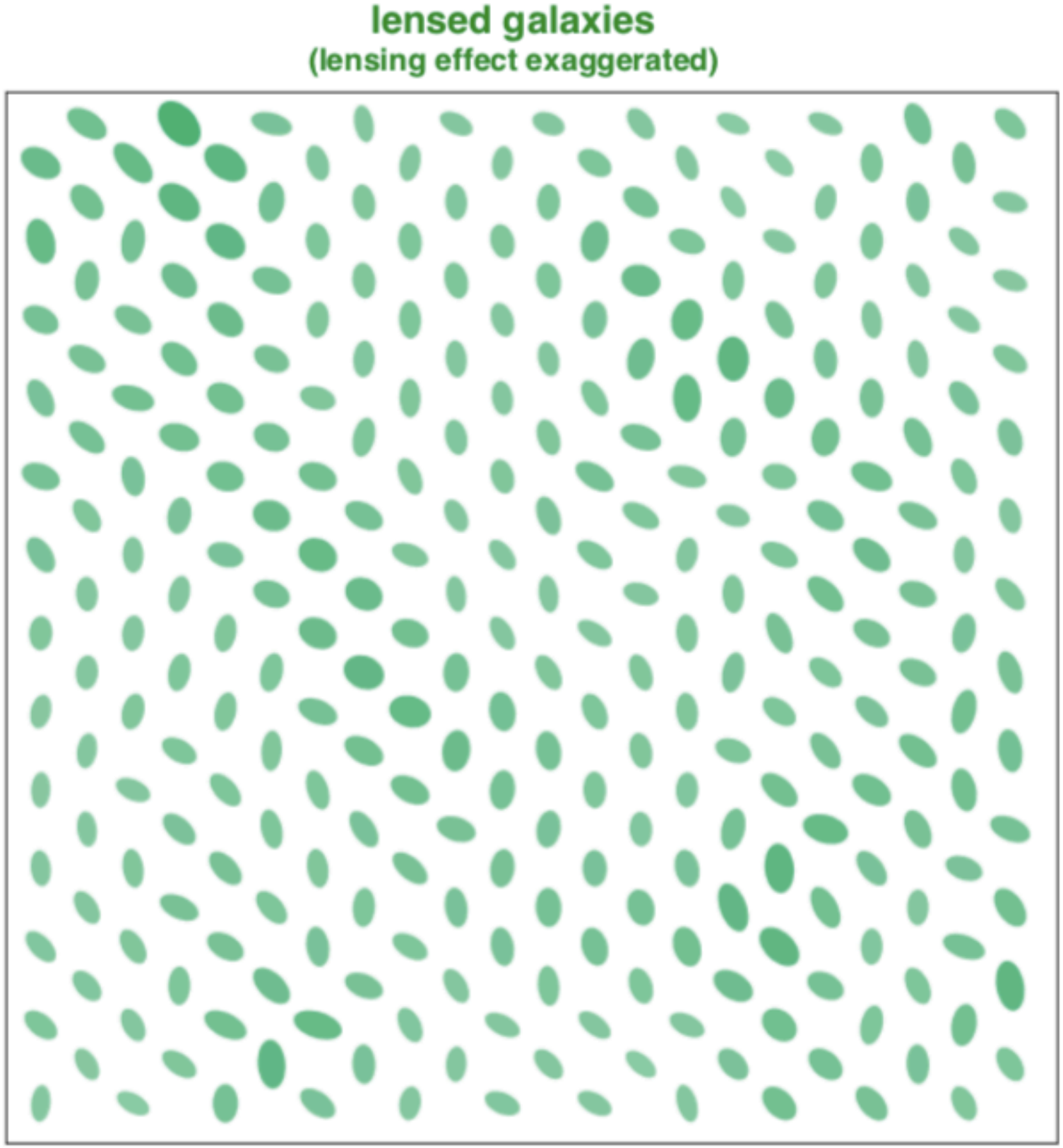
Due to the **Large Scale Structure** of the Universe, the path followed by the light emitted by distant galaxies will appear distorted





Ideal situation:

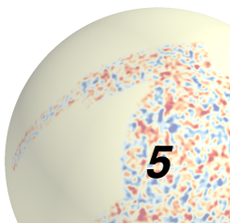
- Galaxies with same shape and orientation

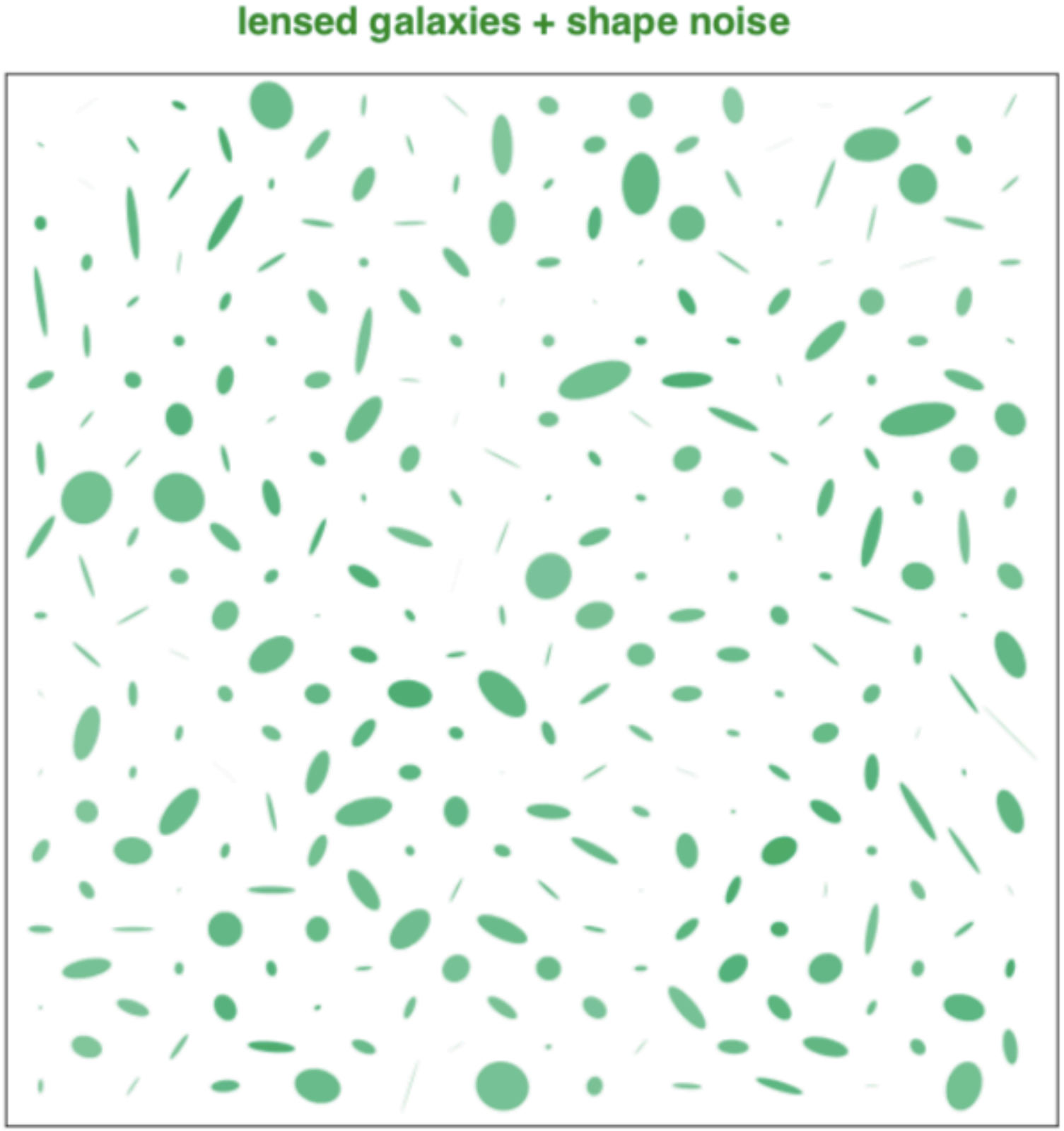


Source galaxies lensed by the Universe LSS are sheared and magnified

→ but the effect is small!

Shear due to LSS: **γ ~ 0.01**



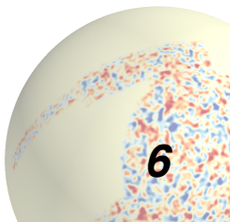


Real case:

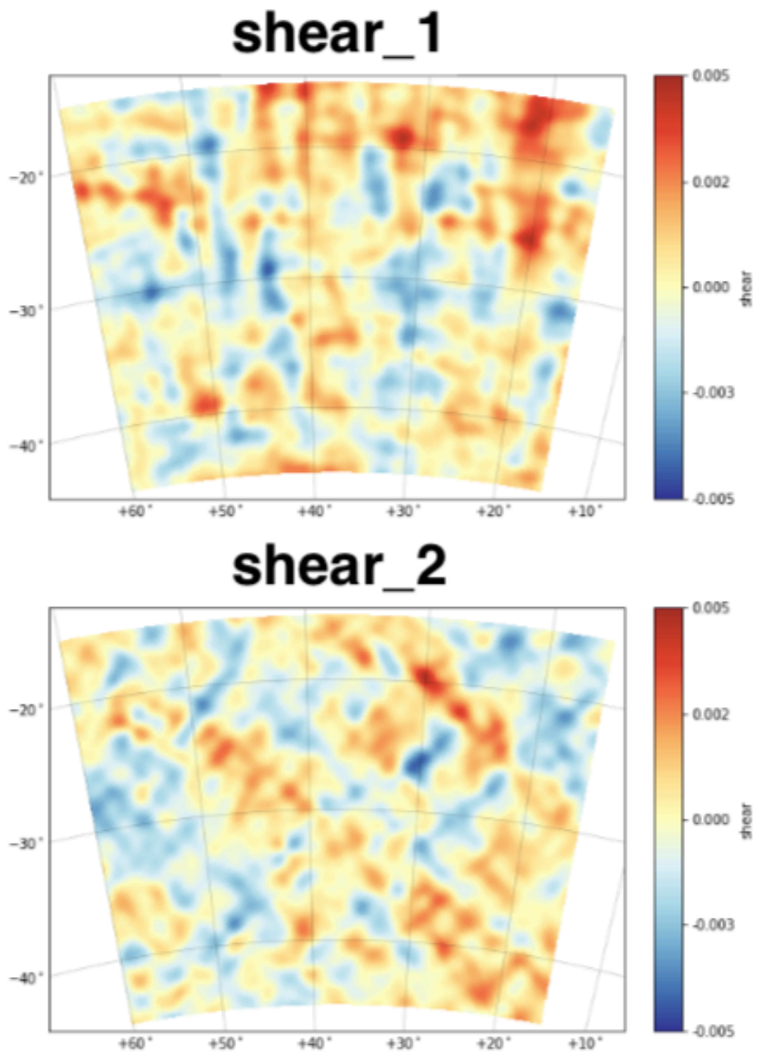
- Galaxies have random orientation and different intrinsic shape

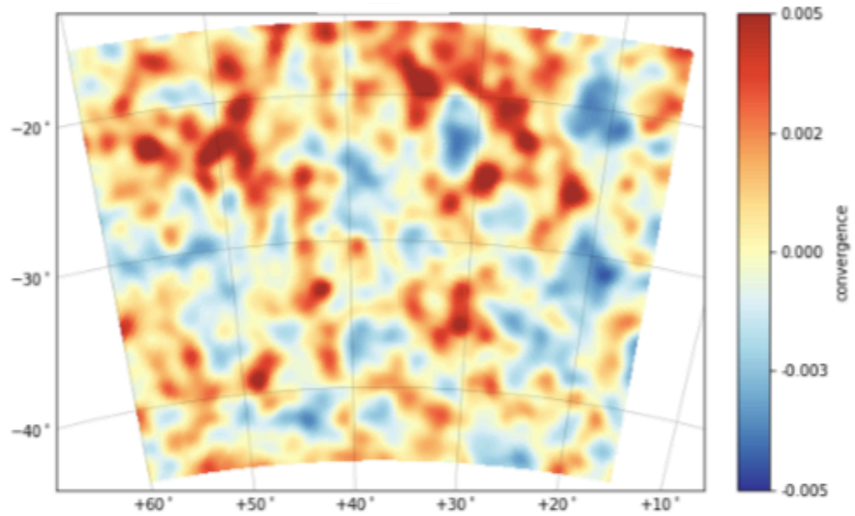
Typical galaxy shape: **$\gamma \sim 0.3$**

→ Need for (very) large sample of galaxies and statistical tools



Map making



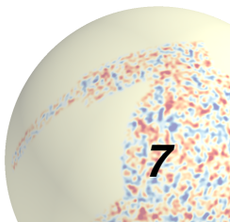


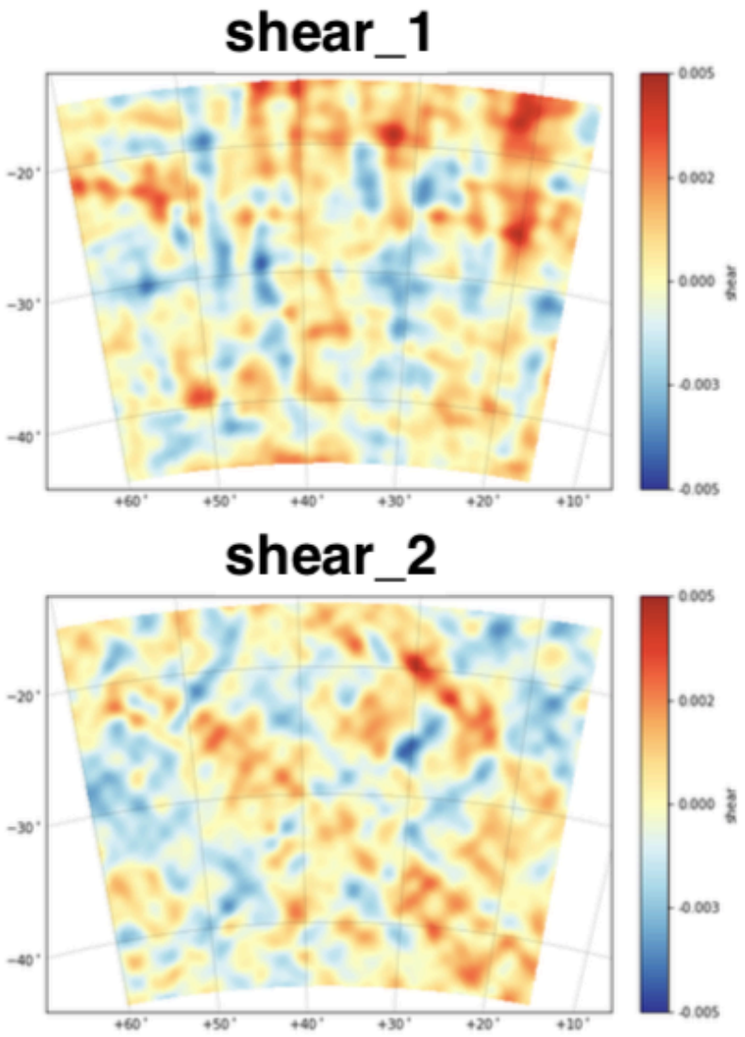
$$\gamma = \gamma^1 + i\gamma^2 = 2\sum_{lm} \hat{\gamma}_{lm\,2}Y_{lm}$$

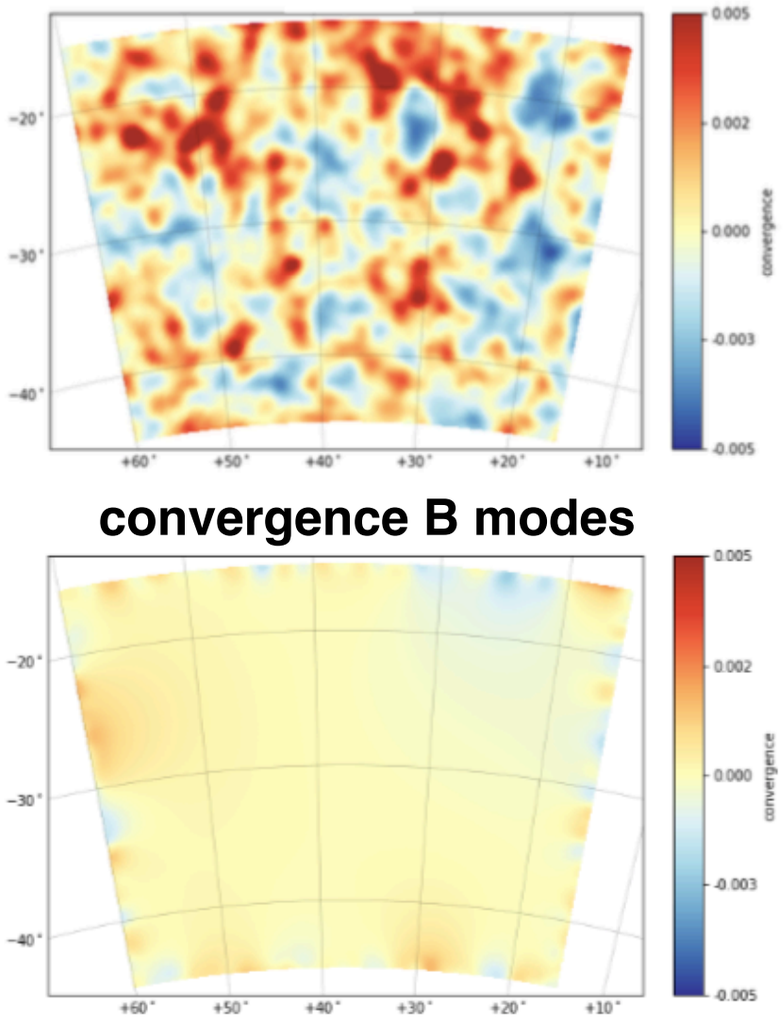
$$\hat{\gamma_{lm}} = \hat{\gamma}_{E,lm} + i\hat{\gamma}_{B,lm} = \frac{1}{4}[l(l+1)(l-1)(l+2)]^{1/2}\,\hat{\phi}_{lm}$$

$$= \frac{1}{2}\left[\frac{(l+2)(l-1)}{l(l+1)}\right]^{1/2}(\hat{\kappa}_{E,lm} + i\hat{\kappa}_{B,lm})$$

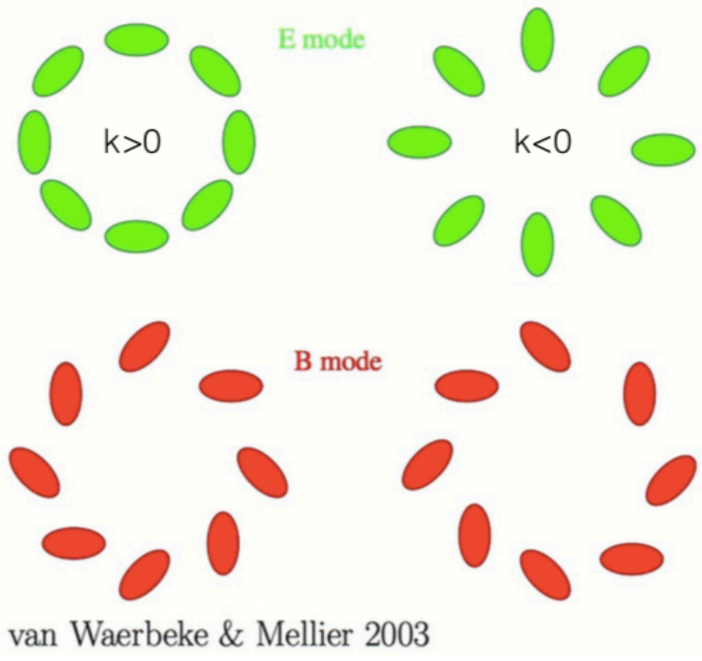
The mass map is obtained from the shear field using a full-sky, spherical harmonic Kaiser-Squires algorithm





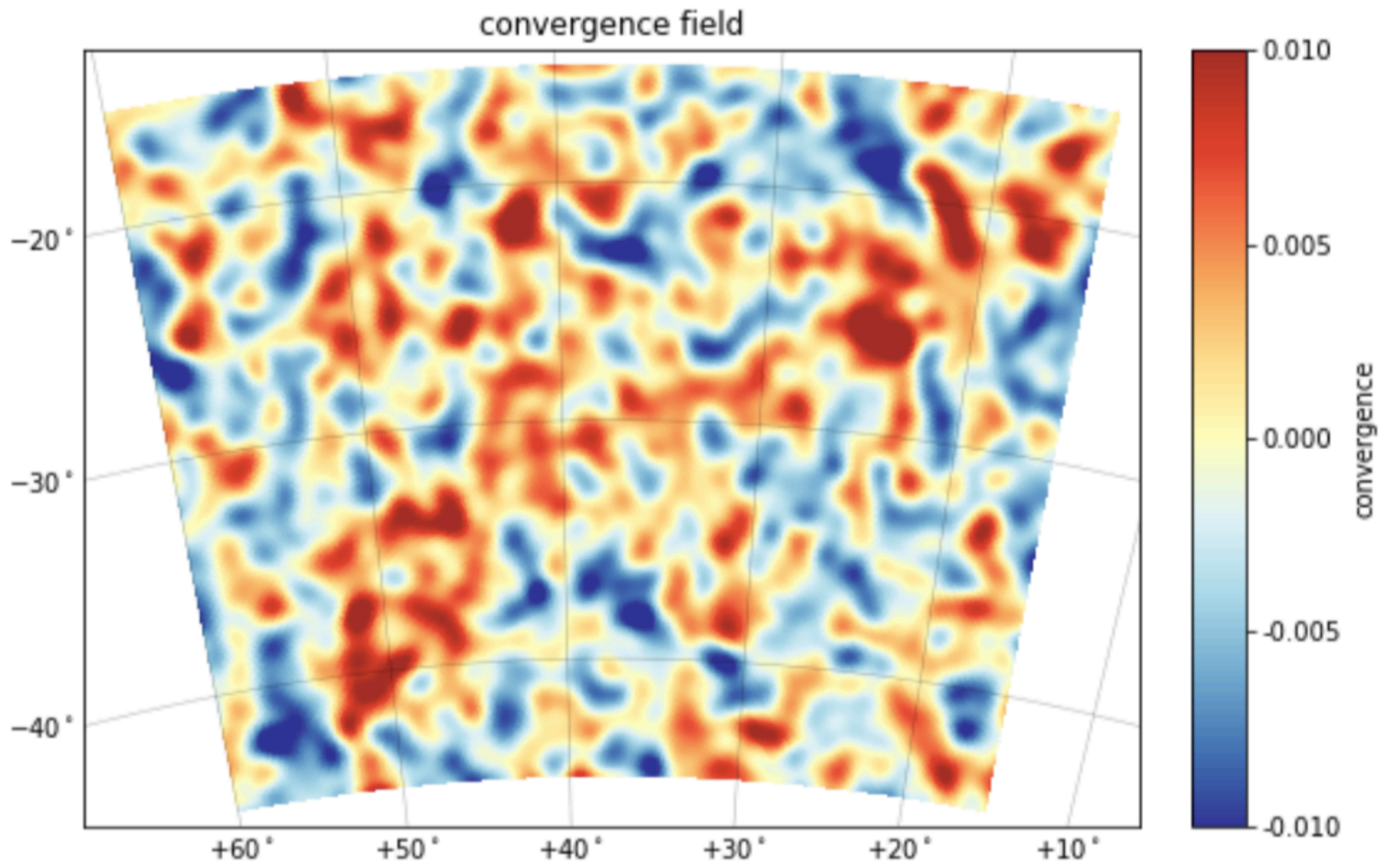


Mask effects: partial sky coverage generates spurious, unphysical **B-modes** at the edges of the footprint



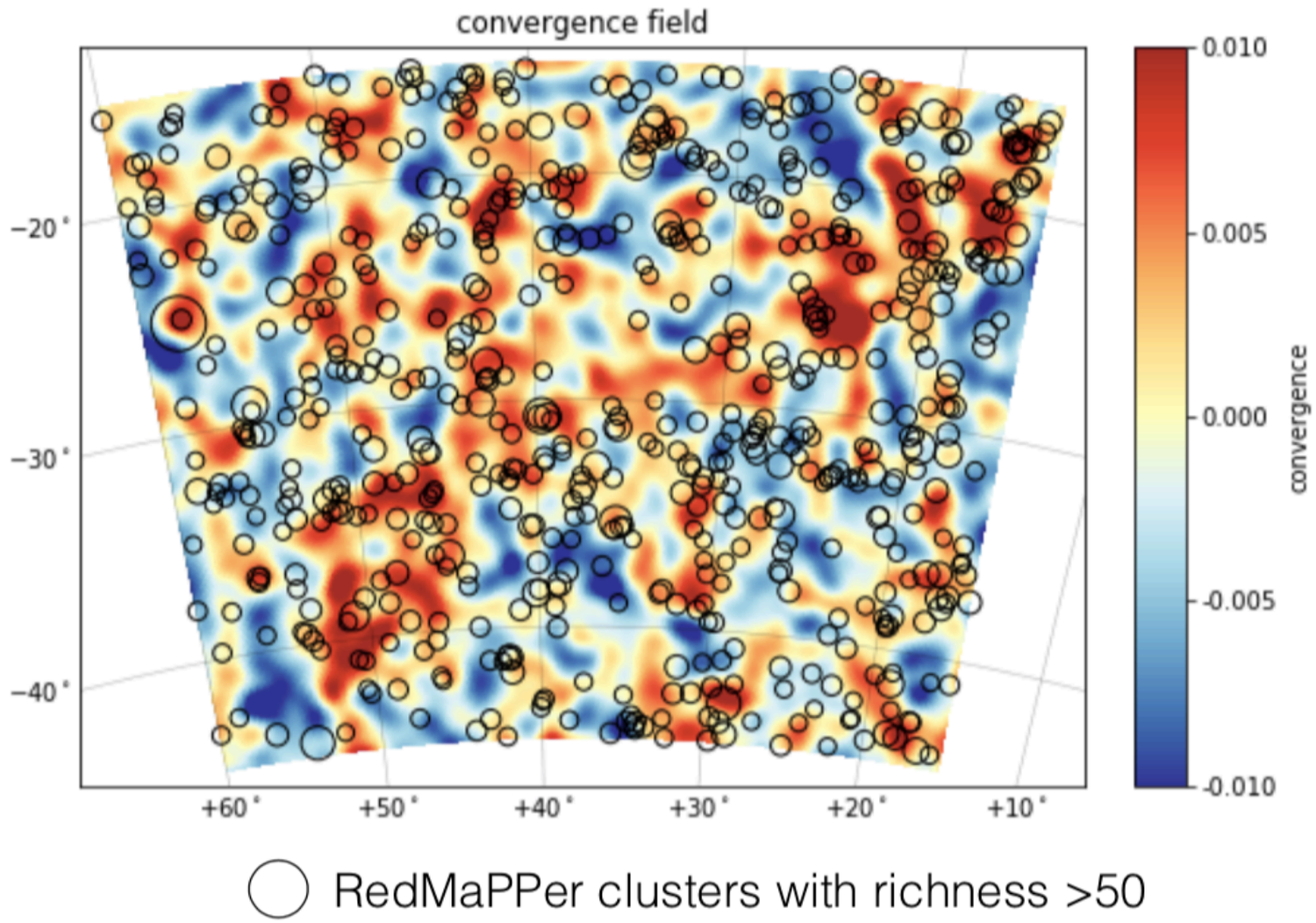
Mass maps = maps of the convergence field

- Projected matter along the line of sight



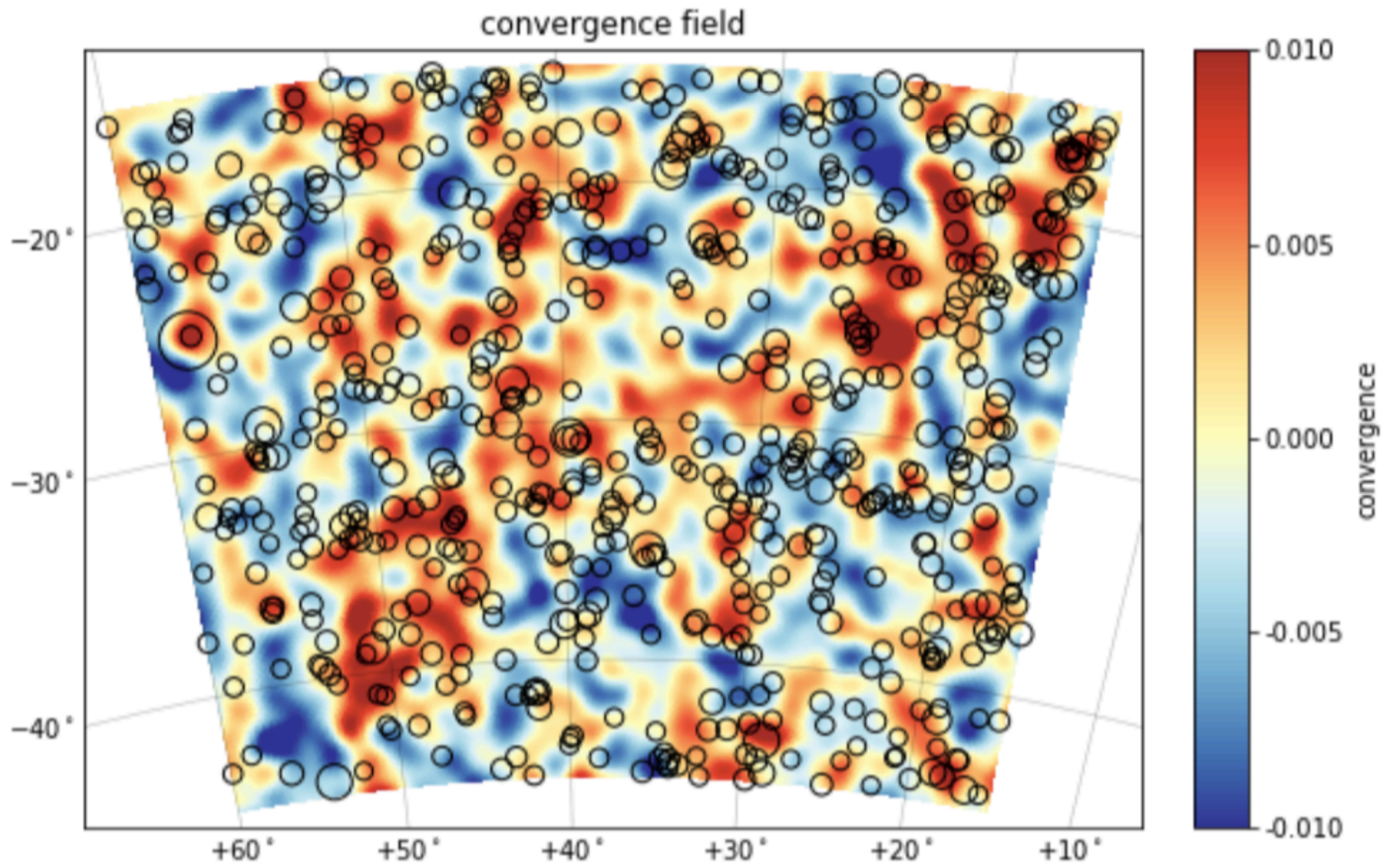
Mass maps = maps of the convergence field

- Projected matter along the line of sight
- Useful to identify imprints of the most massive structures

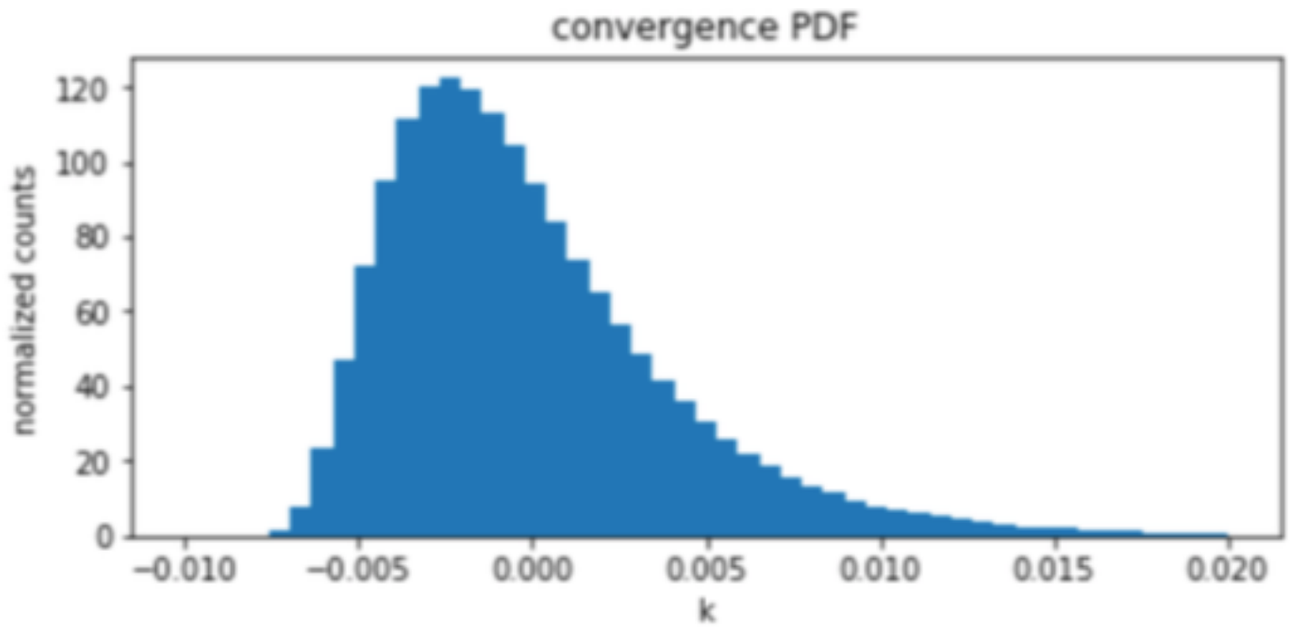


Mass maps = maps of the convergence field

- Projected matter along the line of sight
- Useful to identify imprints of the most massive structures
- Preserve the full non gaussian information

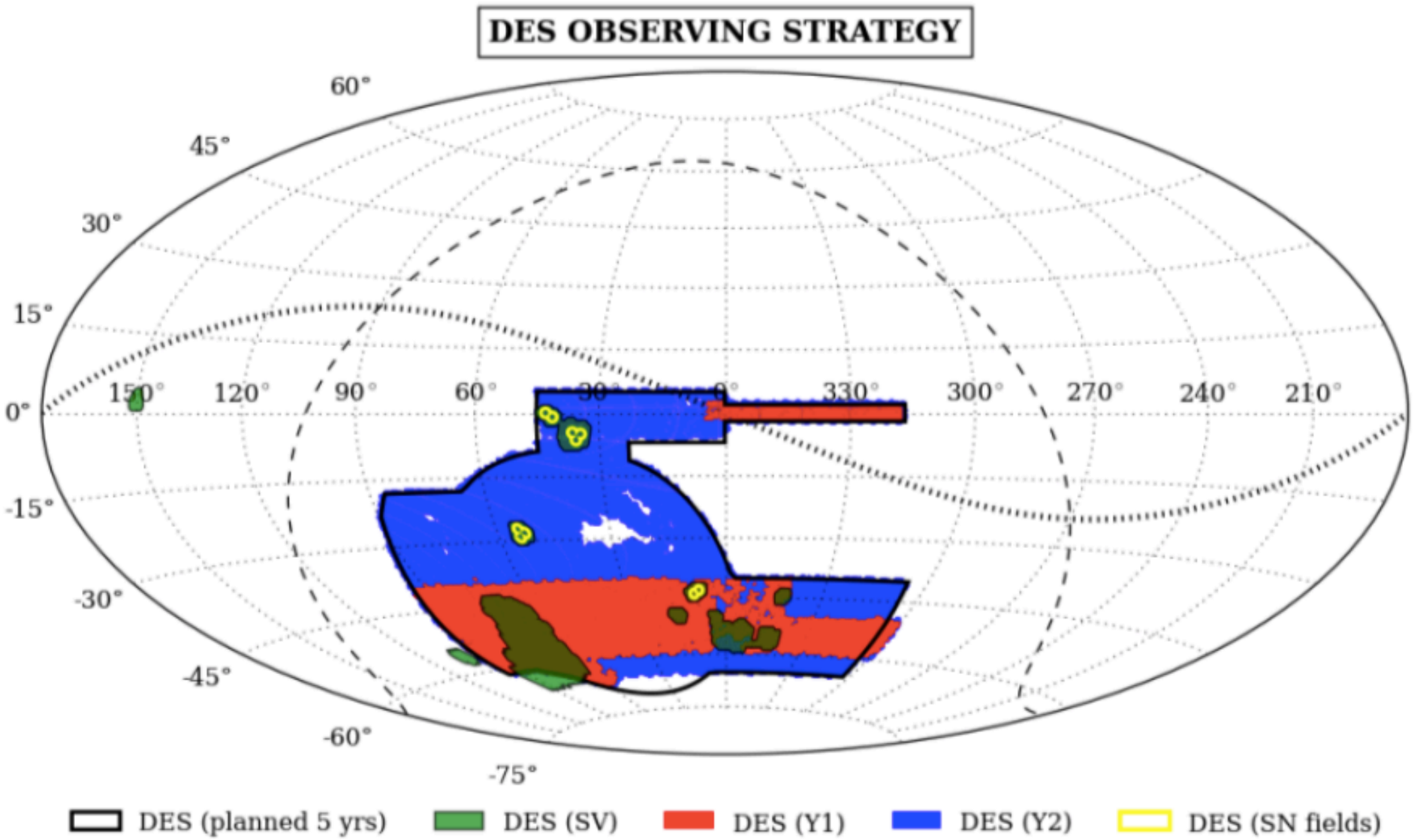


RedMaPPer clusters with richness >50

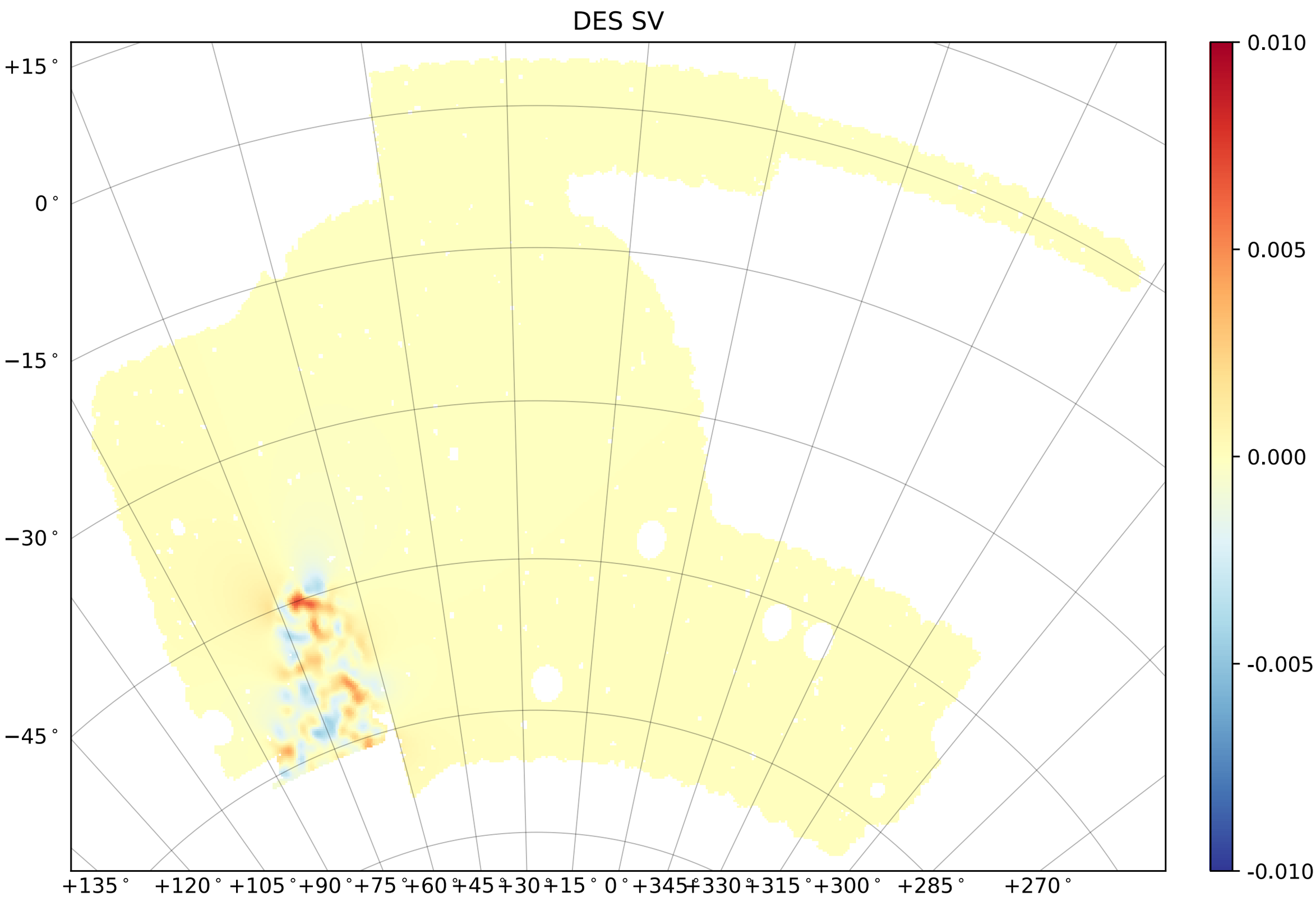


The Dark Energy Survey (DES)

- 5 filter bands grizY , 3 sq. deg FOV, **5 years, 5000 sq. degrees**, i ~ 24
- currently analyzing Y3 data: full footprint, 10^8 shapes, but not full depth yet



Weak Lensing Mass Map from DES data



credit: the Dark Energy Survey collaboration

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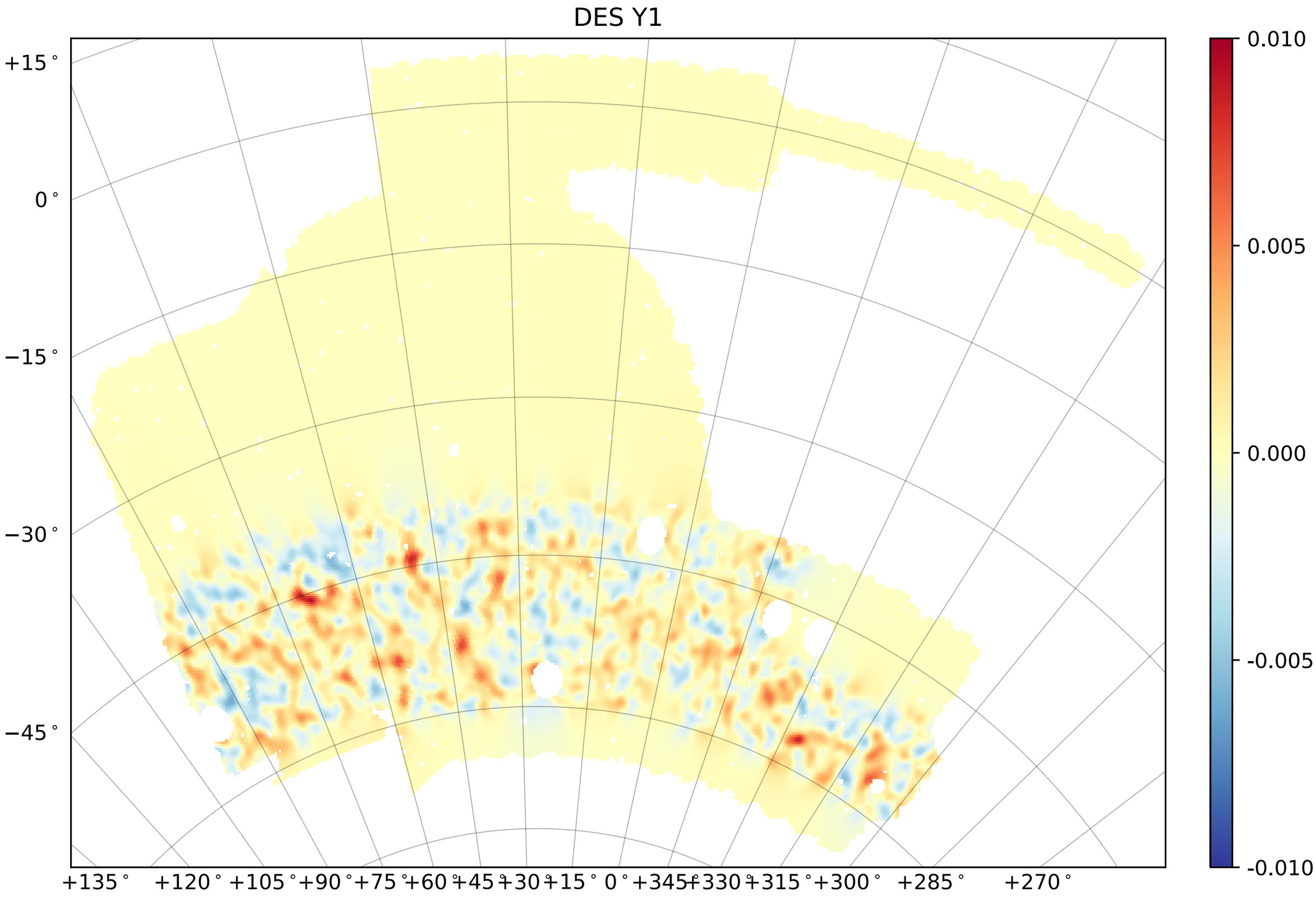

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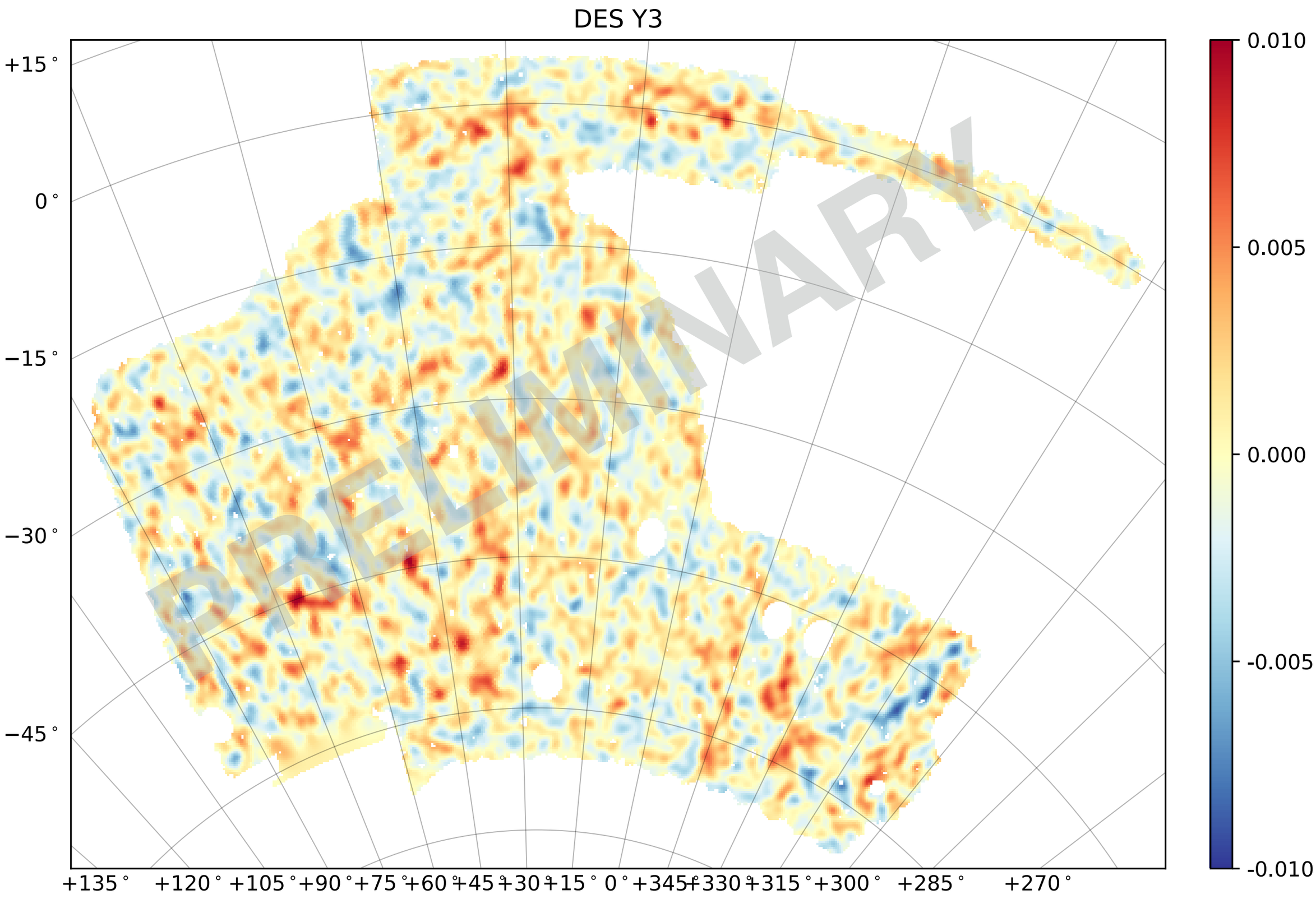

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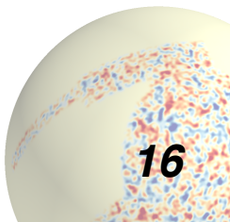
Mass Map application: cosmology with convergence moments

Goal: Constrain cosmological parameters from 2nd and 3rd moments of the convergence field



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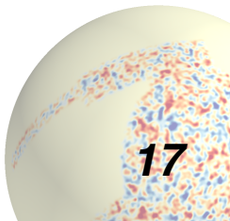

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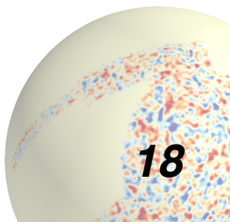

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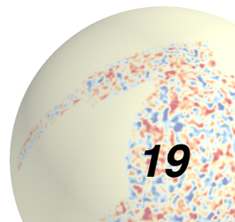
- N-body mocks (for 2nd and 3rd moments theory validation)



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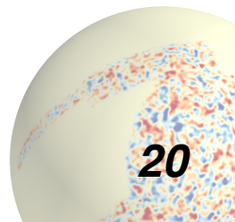
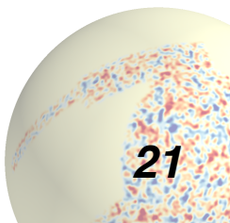
Systematic uncertainties :	Photo-z bias, IA, multiplicative shear biases



Modeling of the second and third moments:

$$\langle \kappa^2_{E/B} \rangle_{\theta_0} = \frac{1}{4\pi} \sum_l (2l+1) W_l^2(\theta_0) \sum_{l'} M^{E/B}_{ll'} C^{\kappa}_{l'} F^2_{l'}$$

$$\langle \kappa^3_{E/B} \rangle_{\theta_0} \approx S_3 \langle \kappa^2_{E/B} \rangle^2_{\theta_0}$$



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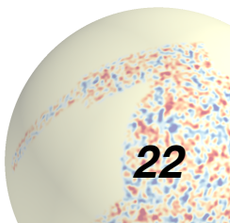
smoothing function (top-hat filter)



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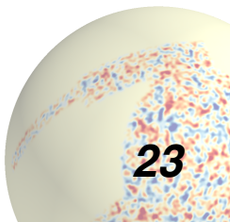
mixing matrix (mask effects)



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cosmology

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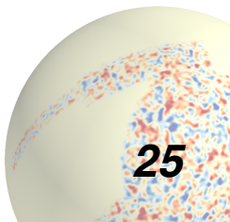
pixel window function



Is the modelling of the masking effects accurate? test with FLASK

FLASK sims are log-normal realisations of the convergence and shear fields.

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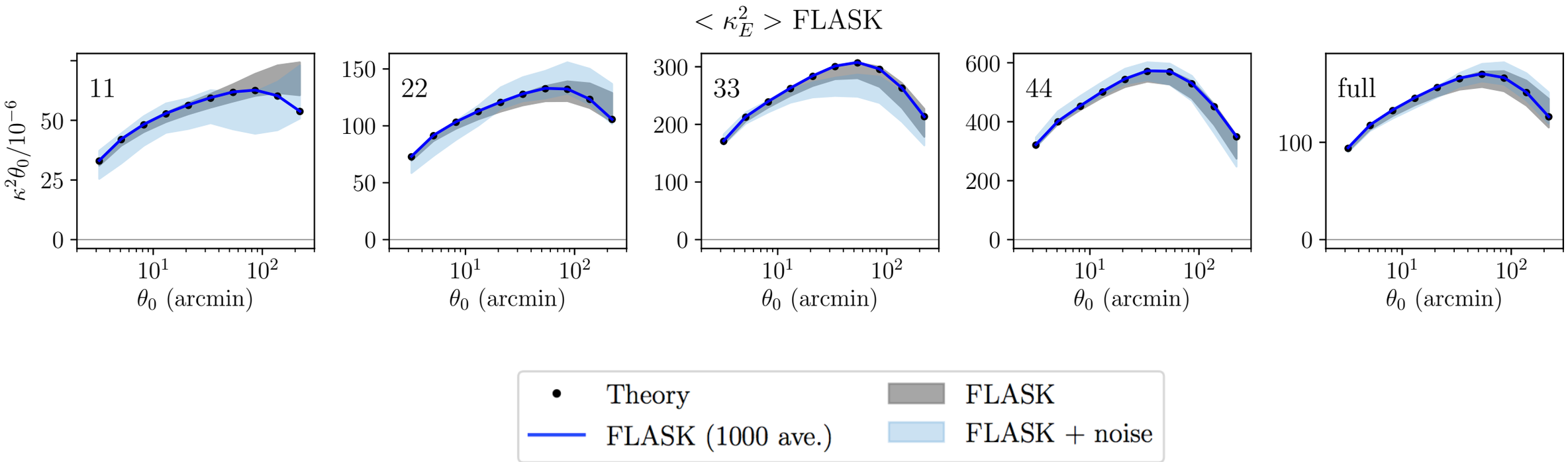
2 moments



average 1000 FLASK DES Y3 footprint (solid blue line) in agreement with theory (black points) <0.5%

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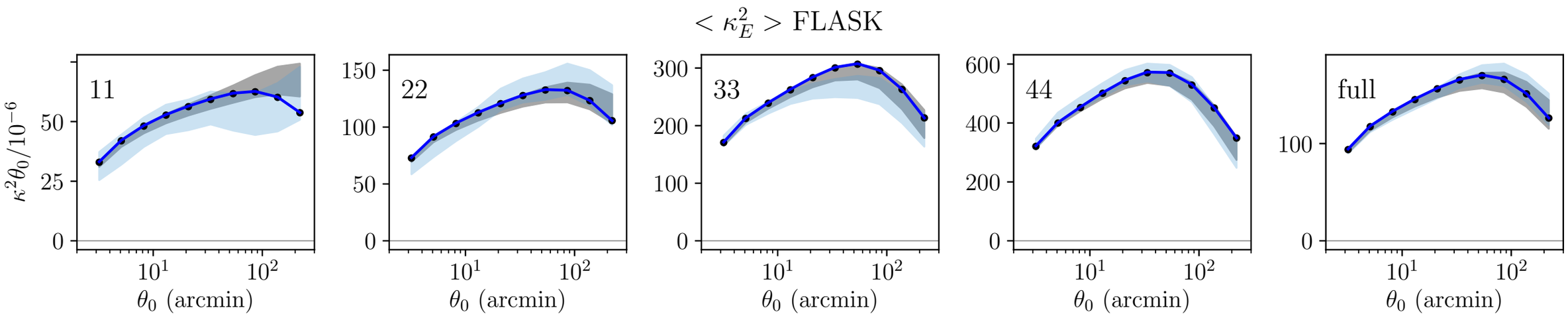
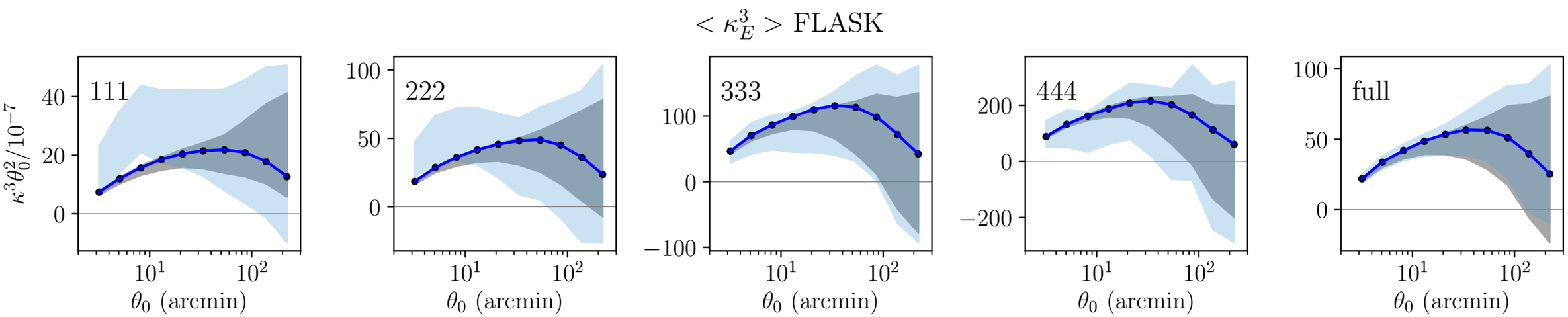
2 moments



3 moments



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T17 mocks are convergence and shear maps from full N-body sims and ray-tracing

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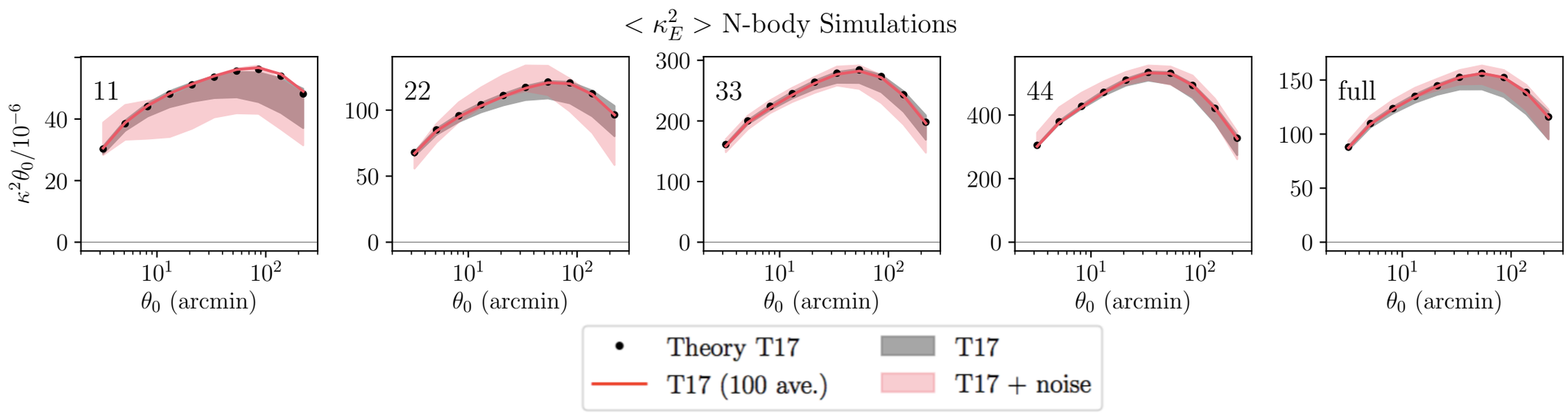

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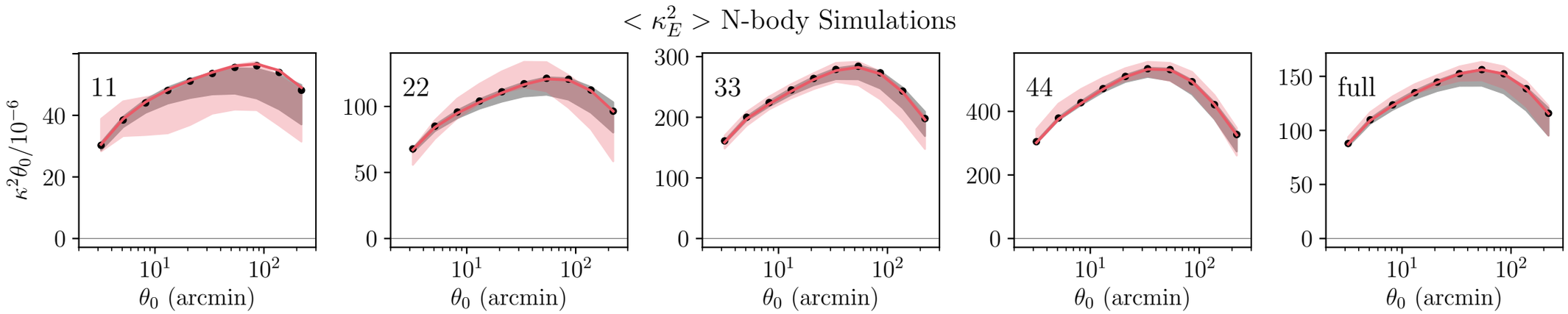

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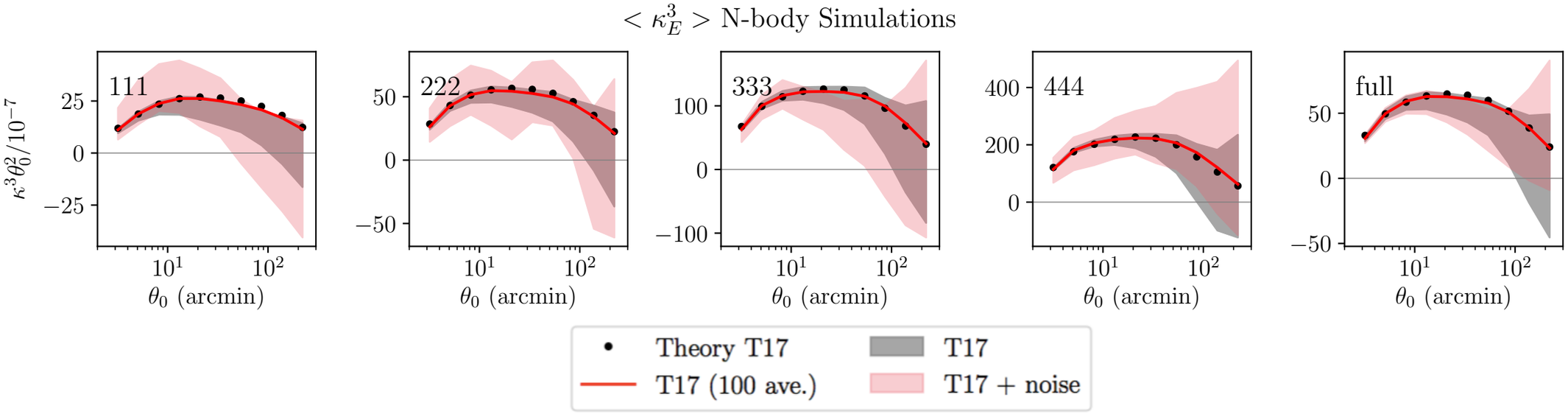
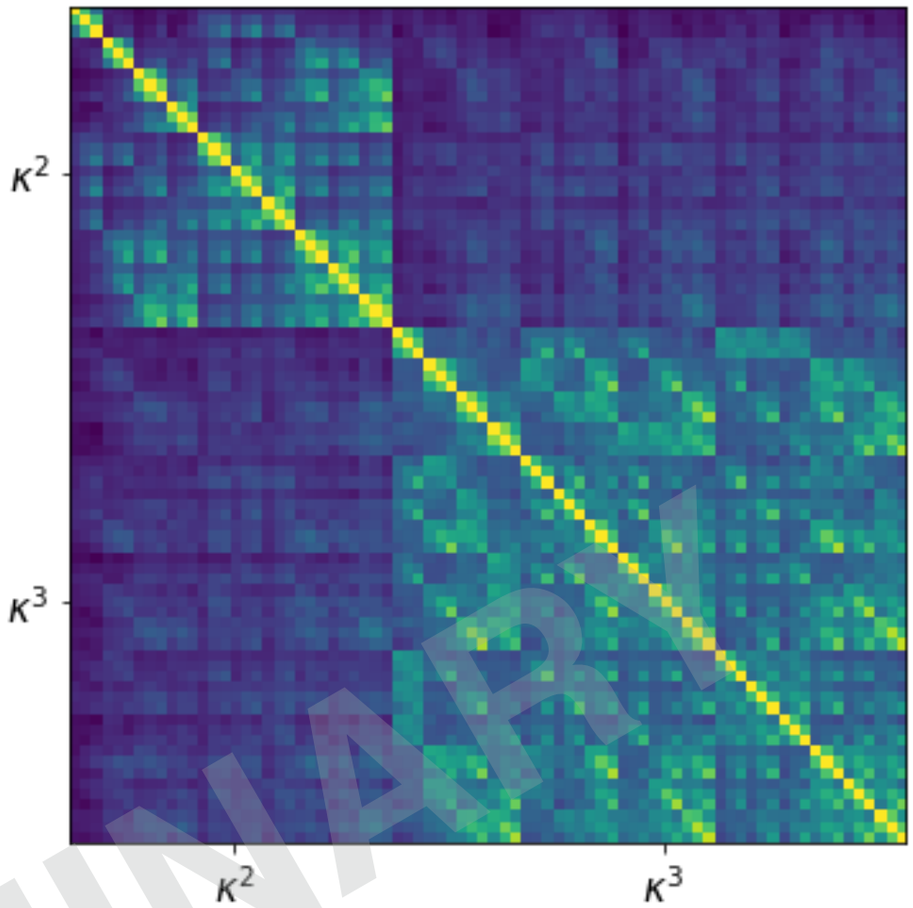
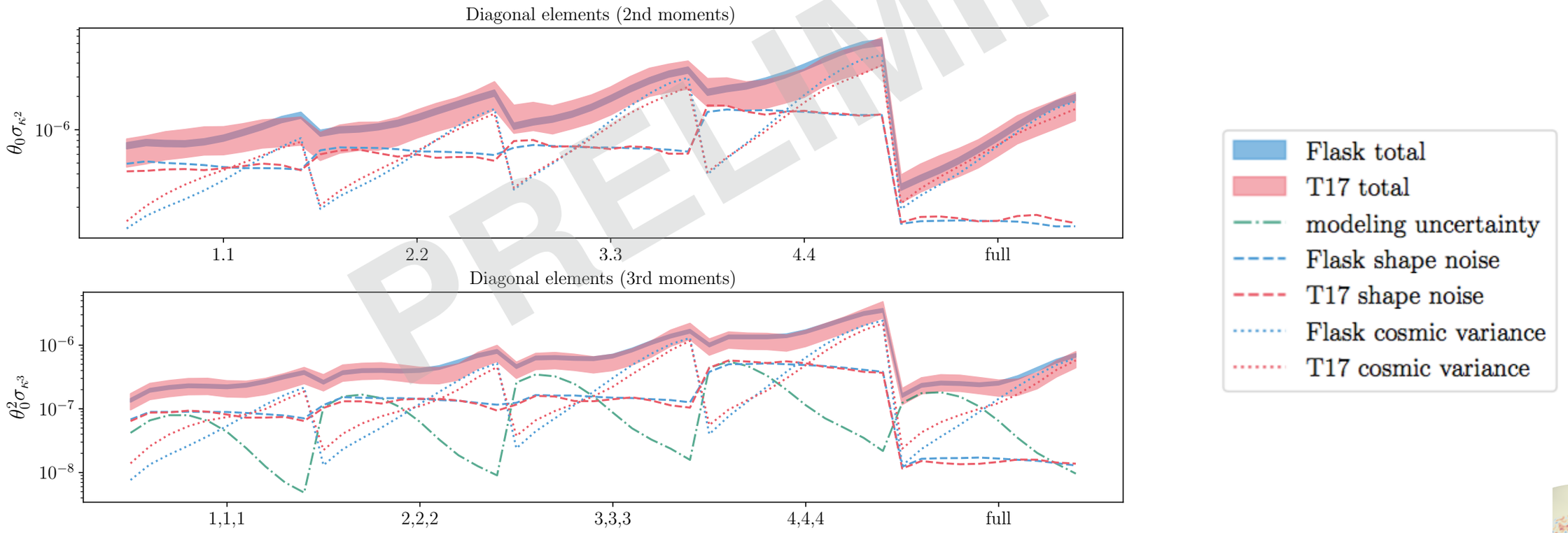


Covariance estimation

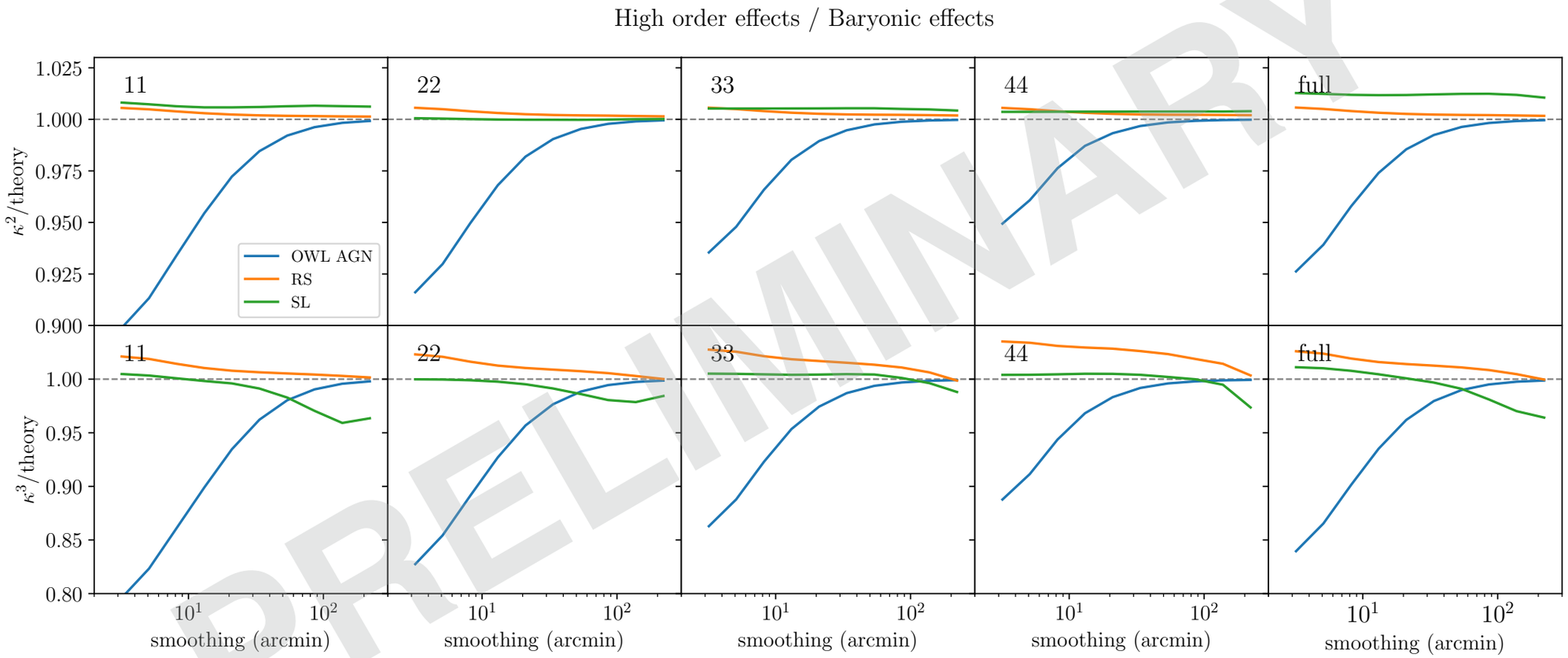
- Covariance estimated from 1000 Flask mocks
- Noise properties matched to DES Y3 catalog
- Data compression algorithm implemented to reduce dimensionality
- We assume a Gaussian Likelihood





Baryons & High Order effects

Contaminated data vector:



We measured the effect of:

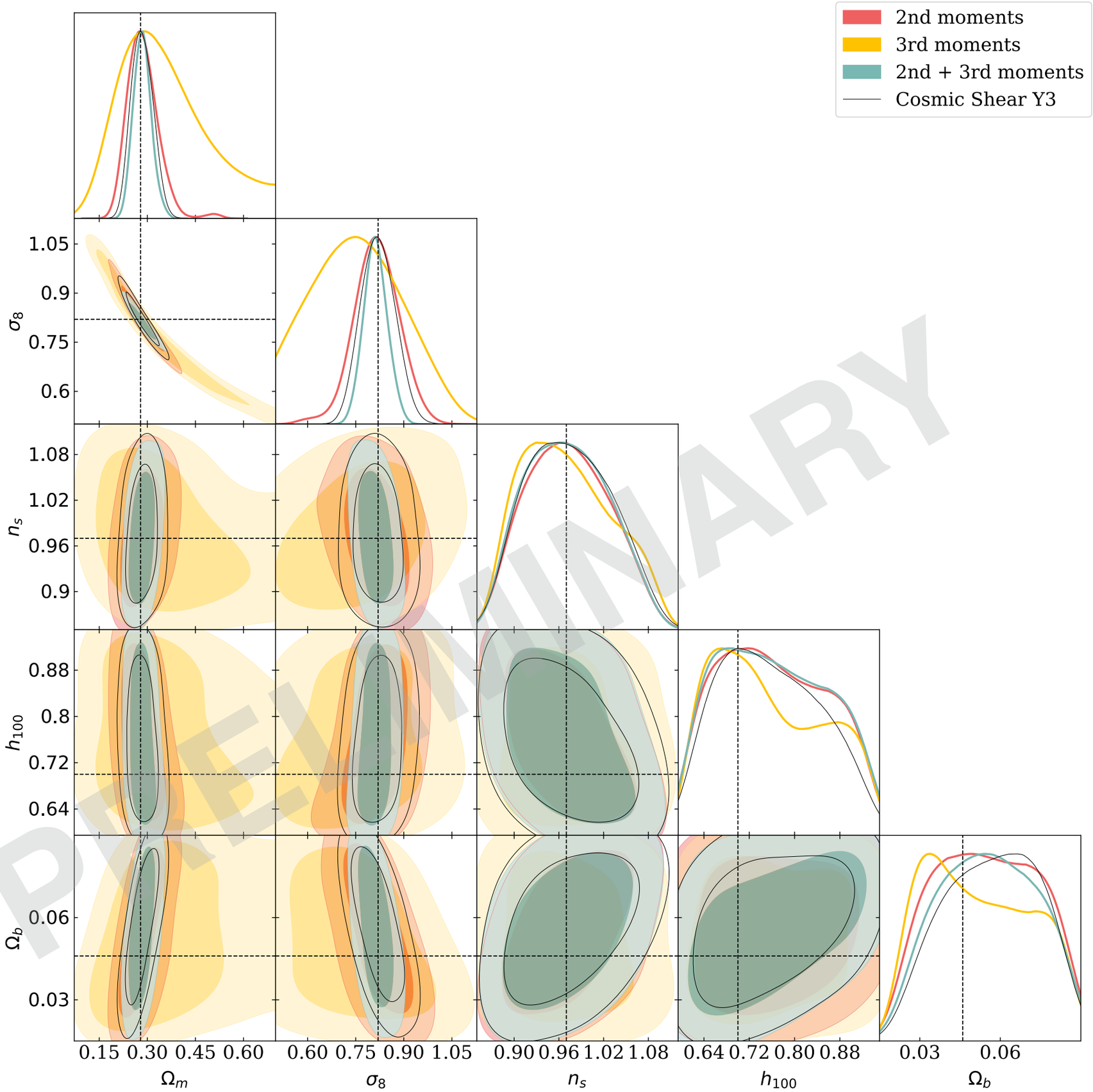
1) **Baryons (from the OWLS AGN sims)**
2) **Reduced Shear correction (RS)**
3) **Source-Lens clustering (SL)**

AGN feedback is the dominant effect and drives the scale cuts at small scales.

Y3 Forecast

3rd moments have different degeneration axis with respect to 2nd moments, they help improving constraints when combined

2nd + 3rd moments more constraining than cosmic shear alone



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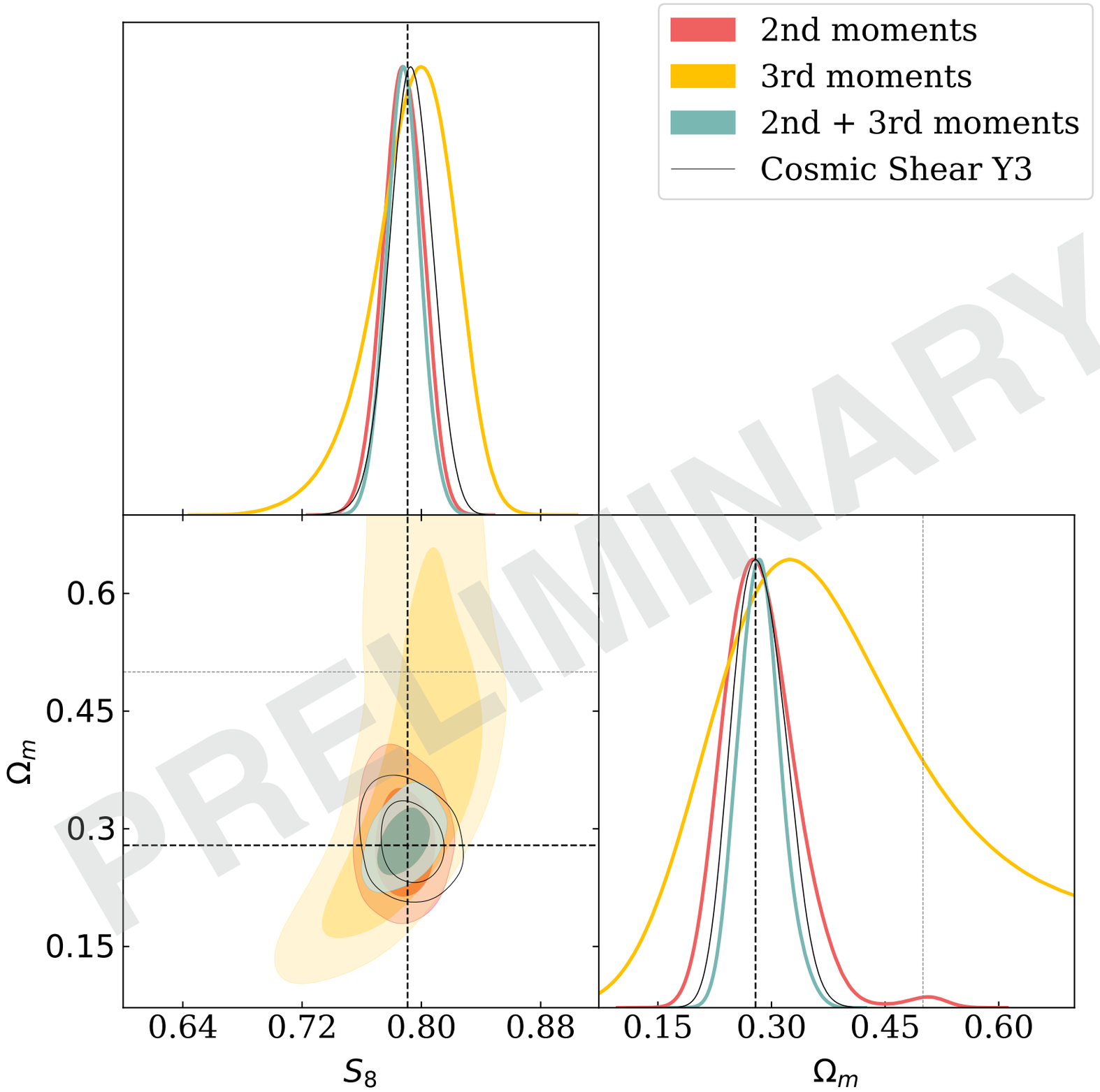
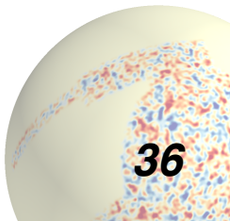


Conclusions

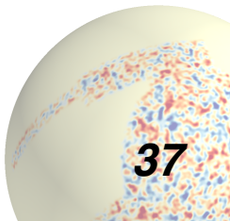
Weak Lensing Mass Maps provide complimentary information to 2pt correlation functions

DES Y3 delivers the biggest WL Mass Map up-to-date!
120M objects and 5000 sq degree

Combining 2nd and 3rd moments of WL Mass Maps delivers tighter constraints than cosmic shear only



Backup slides



Scale cuts

We contaminated a data vector with baryonic effects from the OWLS AGN simulation

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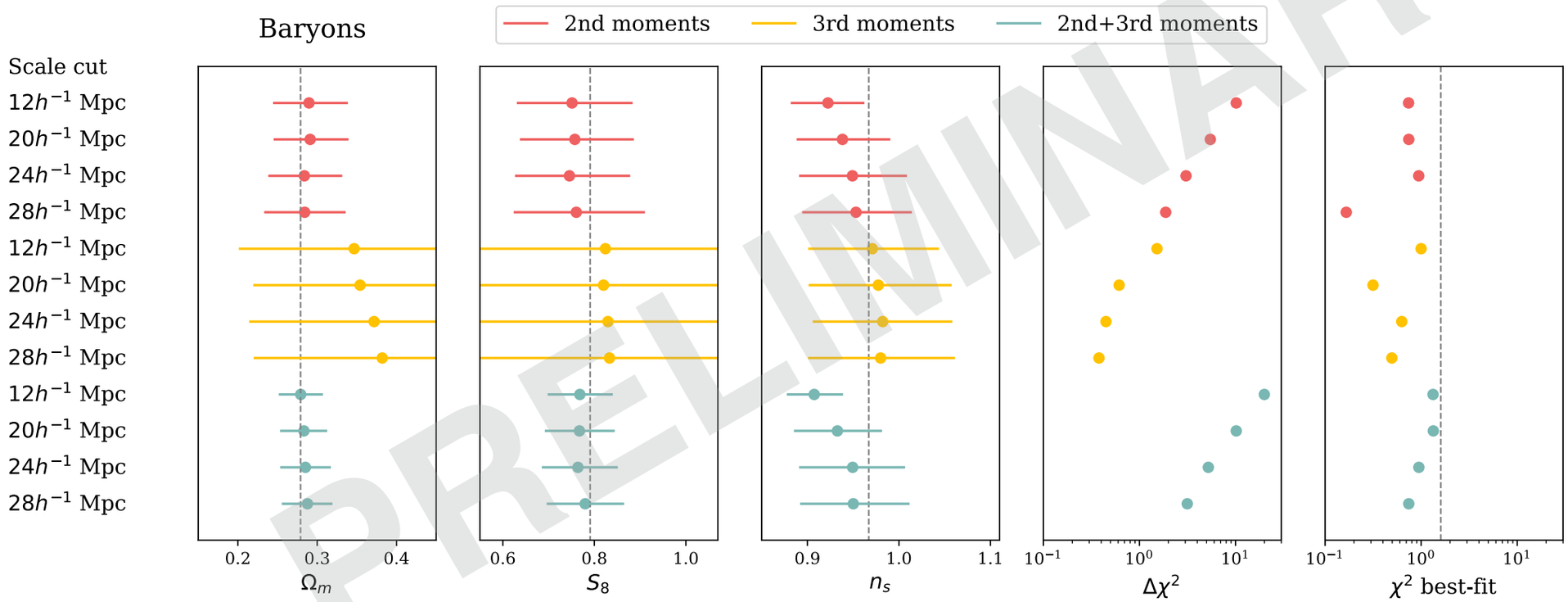
criteria 1) < 0.3 σ shift in the $\Omega_{\rm m}$ and S_8 posteriors, <0.5 σ in n_s posterior

criteria 2) best-fit χ2 smaller than 0.3 σ of the χ2 distribution

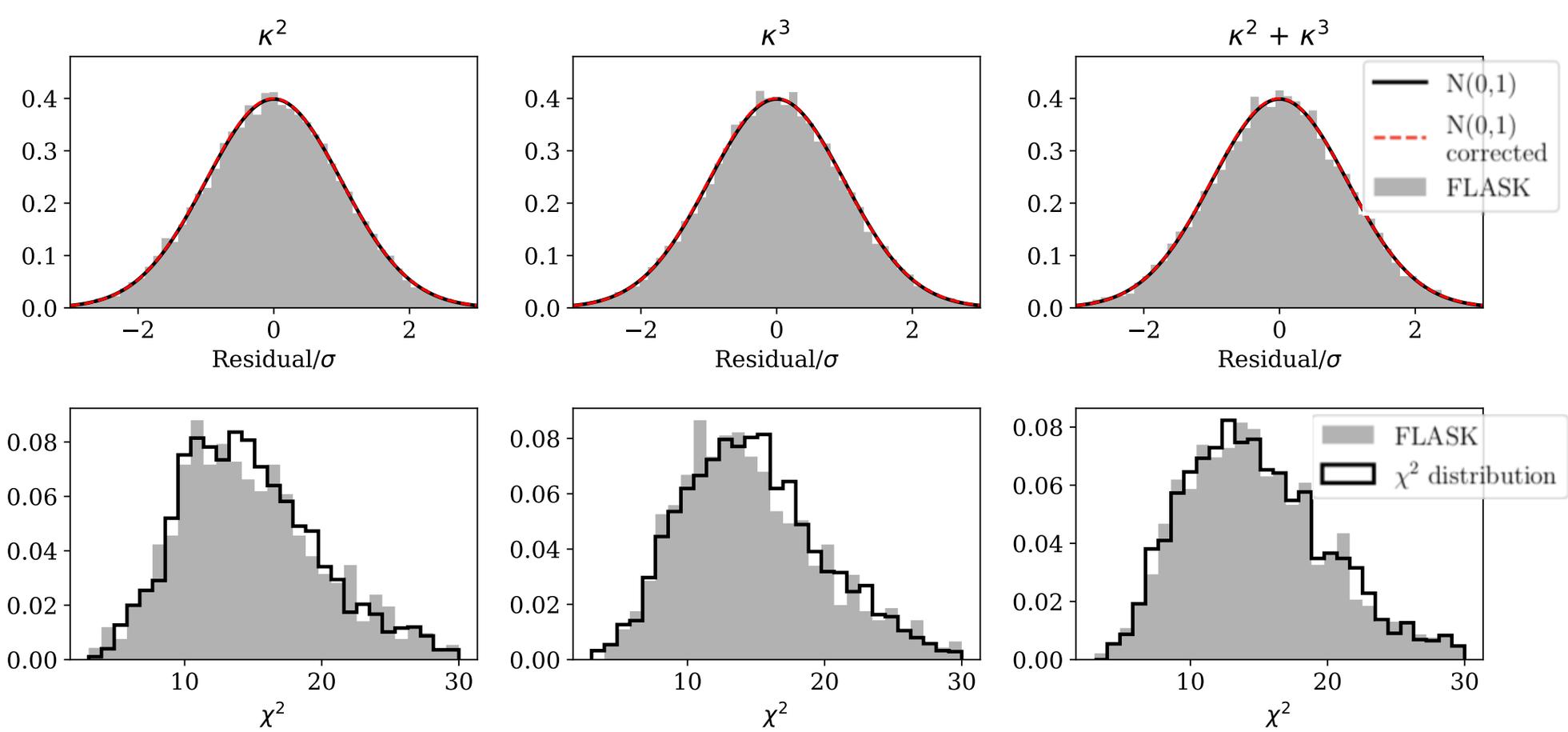


Gaussian Likelihood & Data compression

We use of a data compression scheme from Gualdi+18 based on the Karhuned and Loeve algorithm. This reduces the dimensionality of the data vector down to the number of parameters we want to estimate (15)

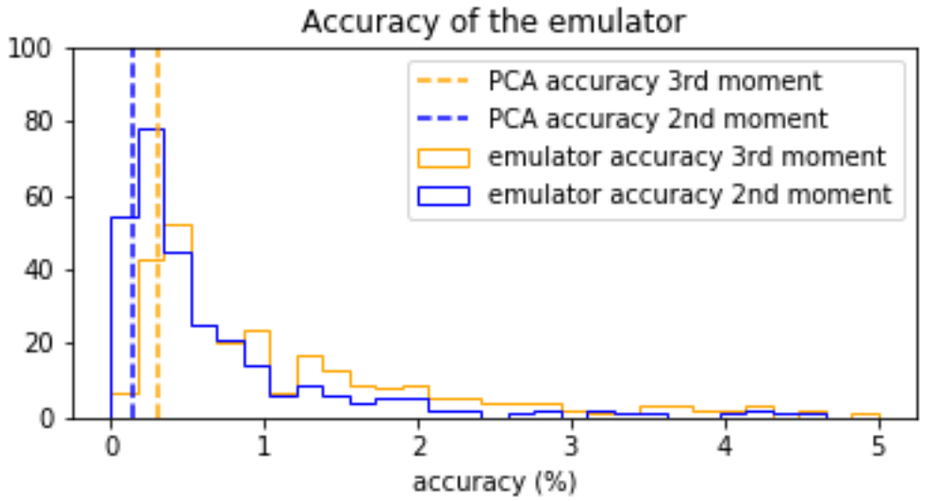
$$y_i = \langle x \rangle_{,i}^T Cov_x^{-1} x \equiv b_i x,$$

The compressed data-vector shows a Gaussian behaviour, justifying the use of a Gaussian Likelihood



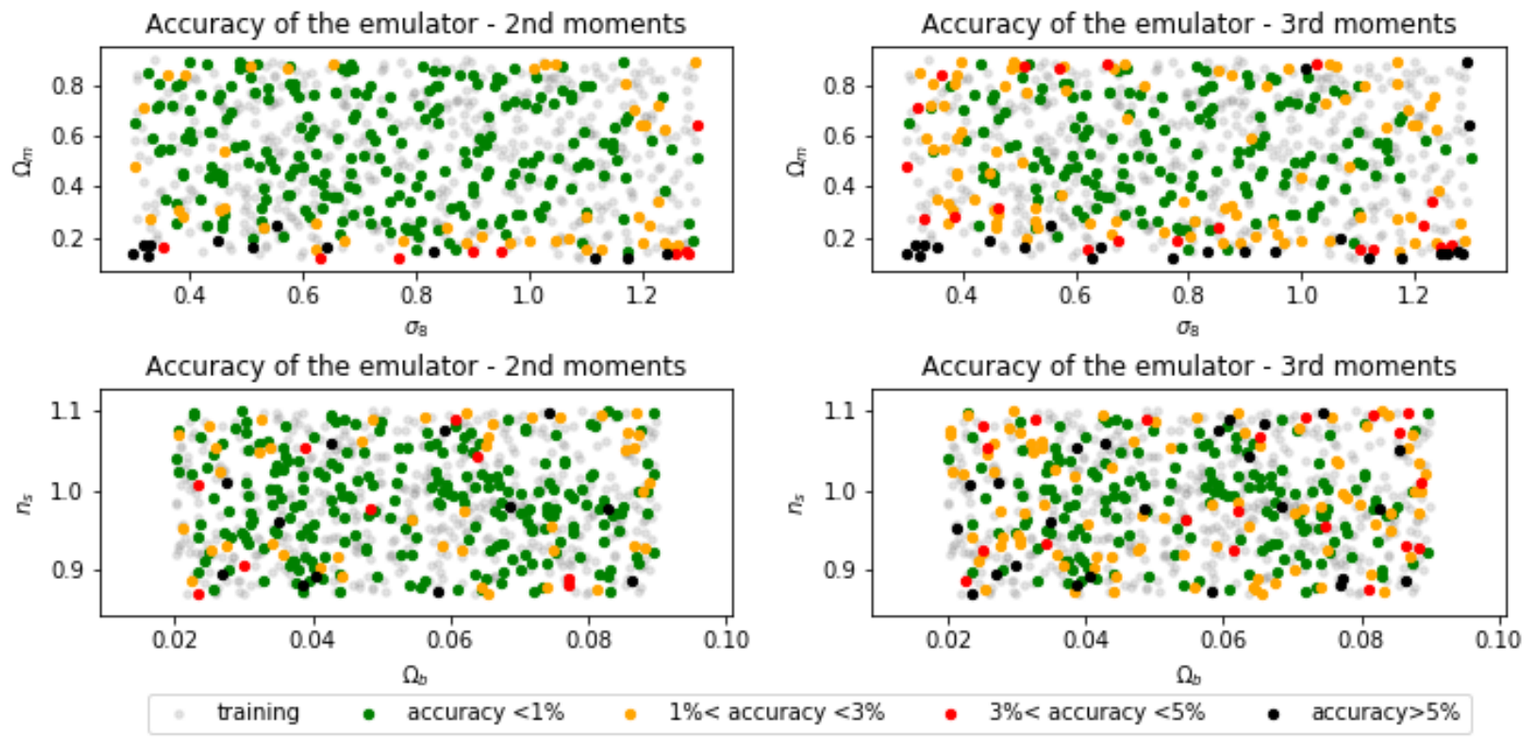
Fast theoretical predictions: moments Emulator

1) second and third moments of the masked density field predicted for 1000 combinations of the 5 cosmological parameters with a .01 redshift resolution (we used a latin hypercube)
2) SVD decomposition to reduce dimensionality
3) Gaussian Processes to interpolate between models



$$\langle \delta^2_{\theta_0,NL} \rangle^{EE/BB}(\chi(z), \Omega_m, \Omega_b, \sigma_8, n_s, h_{100}) =$$
$$\sum_{i=0}^{p} \omega_i^{\delta^2,\theta_0}(\Omega_m, \Omega_b, \sigma_8, n_s, h_{100}) \Phi_i^{\delta^2,\theta_0}(\chi(z)),$$

$$\langle \delta^3_{\theta_0,NL} \rangle^{EE/BB}(\chi(z), \Omega_m, \Omega_b, \sigma_8, n_s, h_{100}) =$$
$$\sum_{i=0}^{p} \omega_i^{\delta^3,\theta_0}(\Omega_m, \Omega_b, \sigma_8, n_s, h_{100}) \Phi_i^{\delta^3,\theta_0}(\chi(z)),$$



chains speeded up by a factor of 100..

Measuring moments from a map:

Estimator:

$$(\kappa^2_{\theta_0})^{i,j} = \frac{1}{N_{tot}} \sum_{ptx}^{N_{tot}} k^i_{\theta_0,ptx} k^j_{\theta_0,ptx},$$

$$(\kappa^3_{\theta_0})^{i,j,k} = \frac{1}{N_{tot}} \sum_{ptx}^{N_{tot}} k^i_{\theta_0,ptx} k^j_{\theta_0,ptx} k^k_{\theta_0,ptx},$$

De-noising:

$$\langle \kappa^2_{\theta_0,\mathrm{de-noised}} \rangle^{i,j} = \langle \kappa^2_{\theta_0} \rangle^{i,j} - \langle \kappa_{\theta_0} \kappa_{\theta_0,\mathrm{rand}} \rangle^{i,j} - \langle \kappa_{\theta_0,\mathrm{rand}} \kappa_{\theta_0} \rangle^{i,j} - \langle \kappa^2_{\theta_0,\mathrm{rand}} \rangle^{i,j},$$

$$\langle \kappa^3_{\theta_0,\mathrm{de-noised}} \rangle^{i,j,k} = \langle \kappa^3_{\theta_0} \rangle^{i,j,k} - \langle \kappa^3_{\theta_0,\mathrm{rand}} \rangle^{i,j,k} - \left[\langle \kappa^2_{\theta_0,\mathrm{rand}} \kappa_{\theta_0} \rangle^{i,j,k} - \langle \kappa_{\theta_0} \kappa^2_{\theta_0,\mathrm{rand}} \rangle^{i,j,k} + cycl. \right],$$