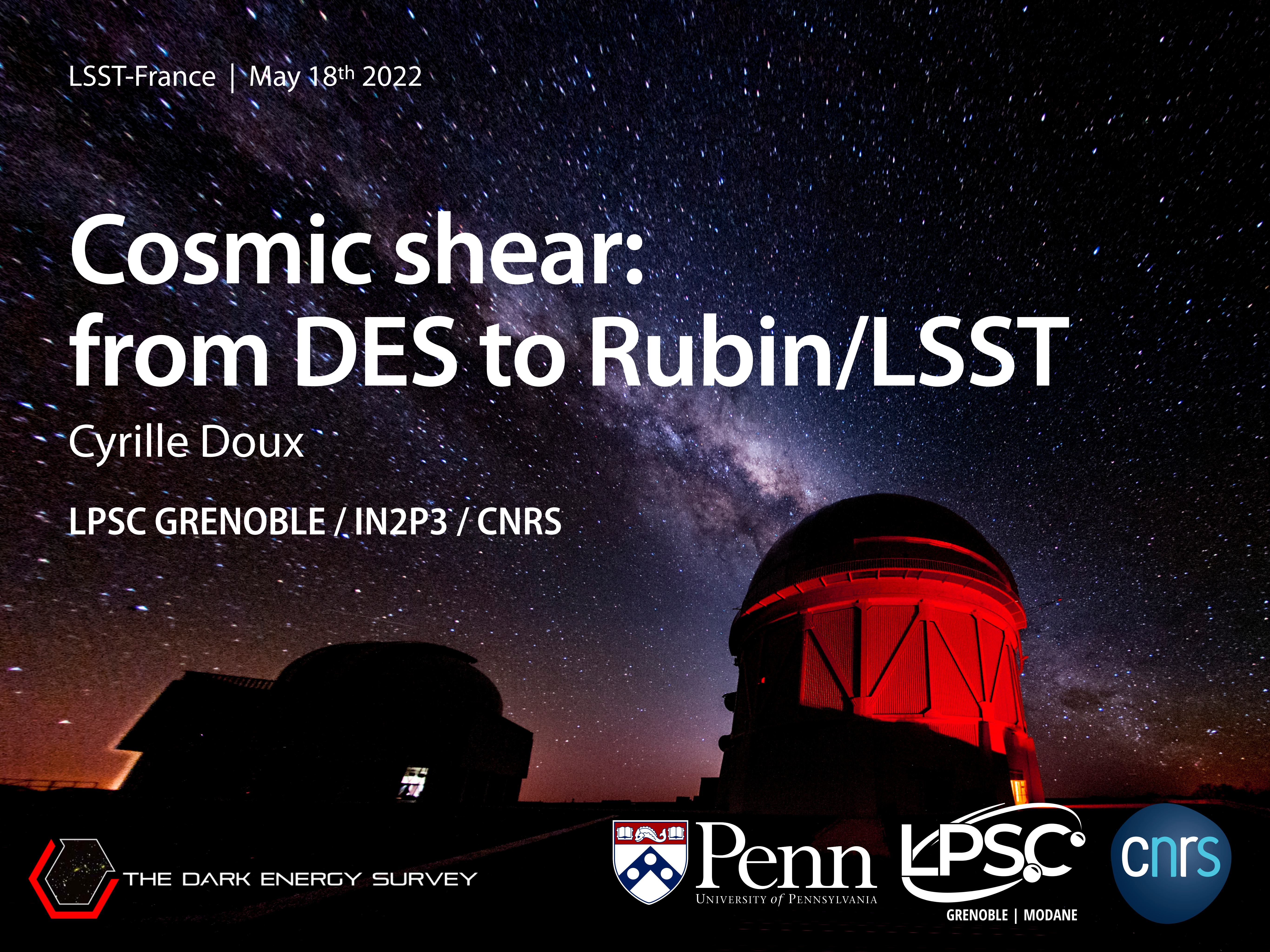
LSST-France | May 18th 2022

Cosmic shear: from DES to Rubin/LSST

Cyrille Doux

LPSC GRENOBLE / IN2P3 / CNRS



THE DARK ENERGY SURVEY

Penn UNIVERSITY of PENNSYLVANIA

LPSC GRENOBLE | MODANE

cnrs

- Cosmic shear 101
- Dark Energy Survey Year 3 analysis
  - Advances in shear/redshift calibration
  - Cosmological constraints
  - Outstanding issues
- Cosmic shear with LSST: new problems

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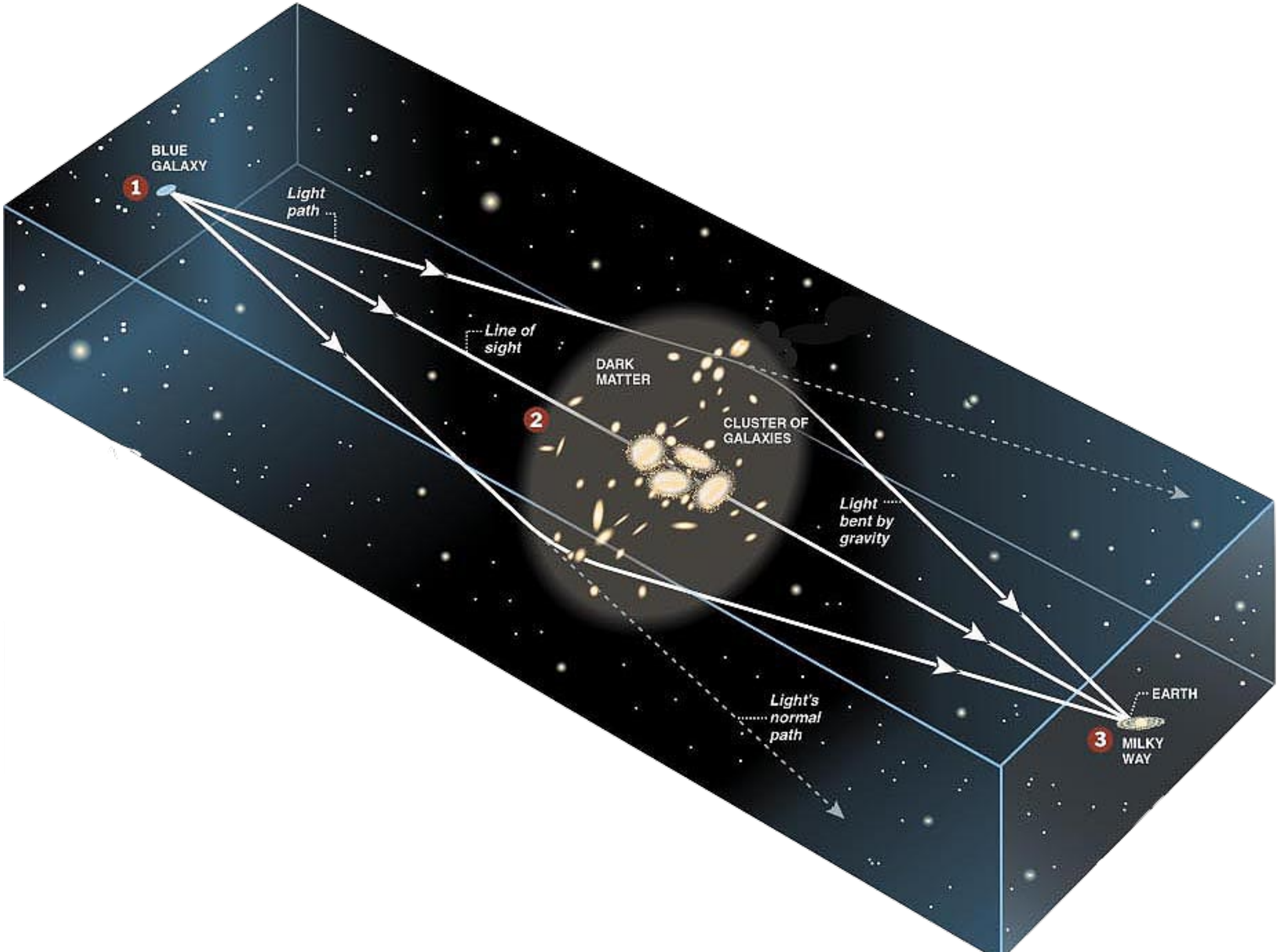
Weak gravitational lensing



Weak gravitational lensing

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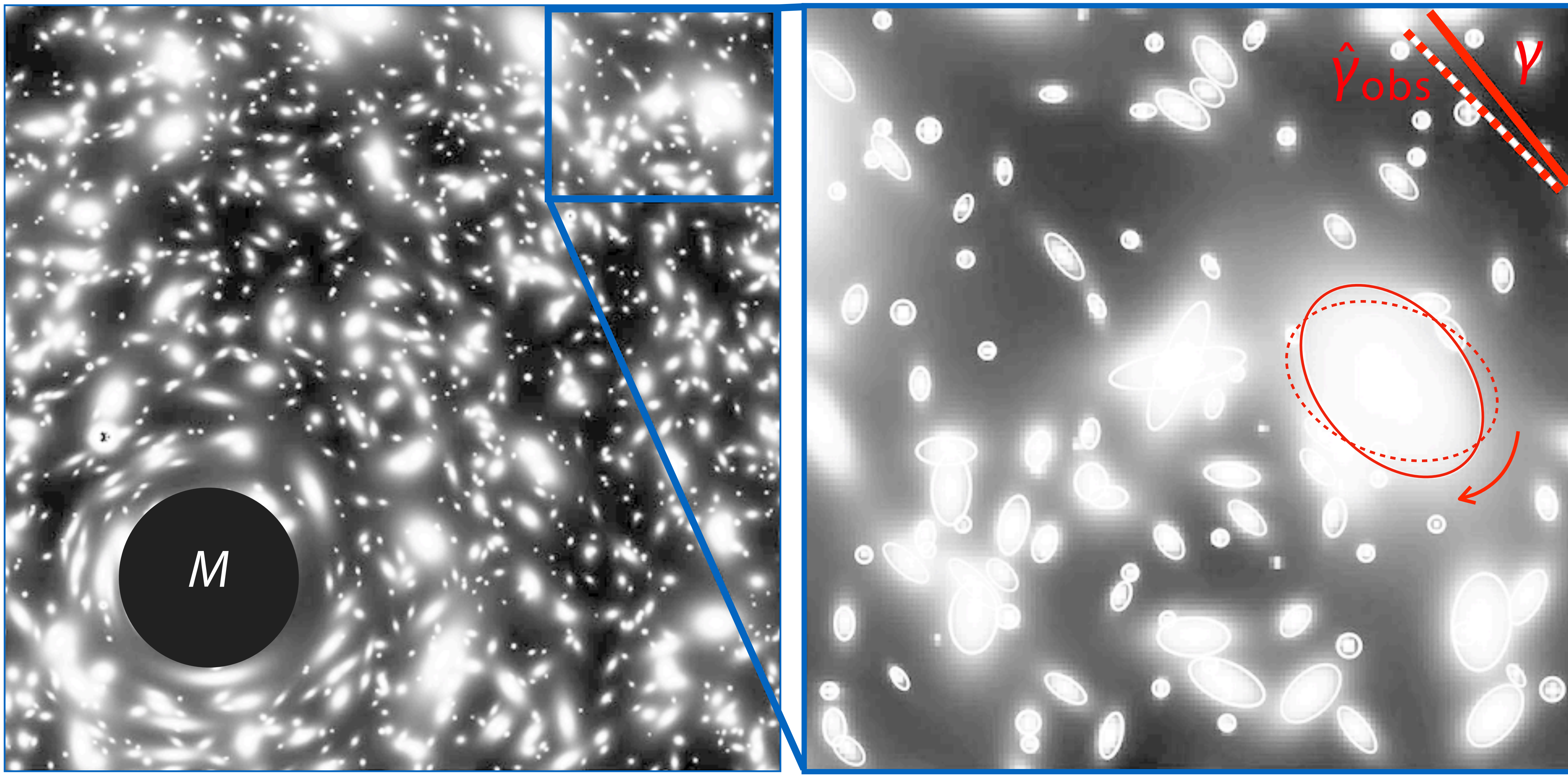
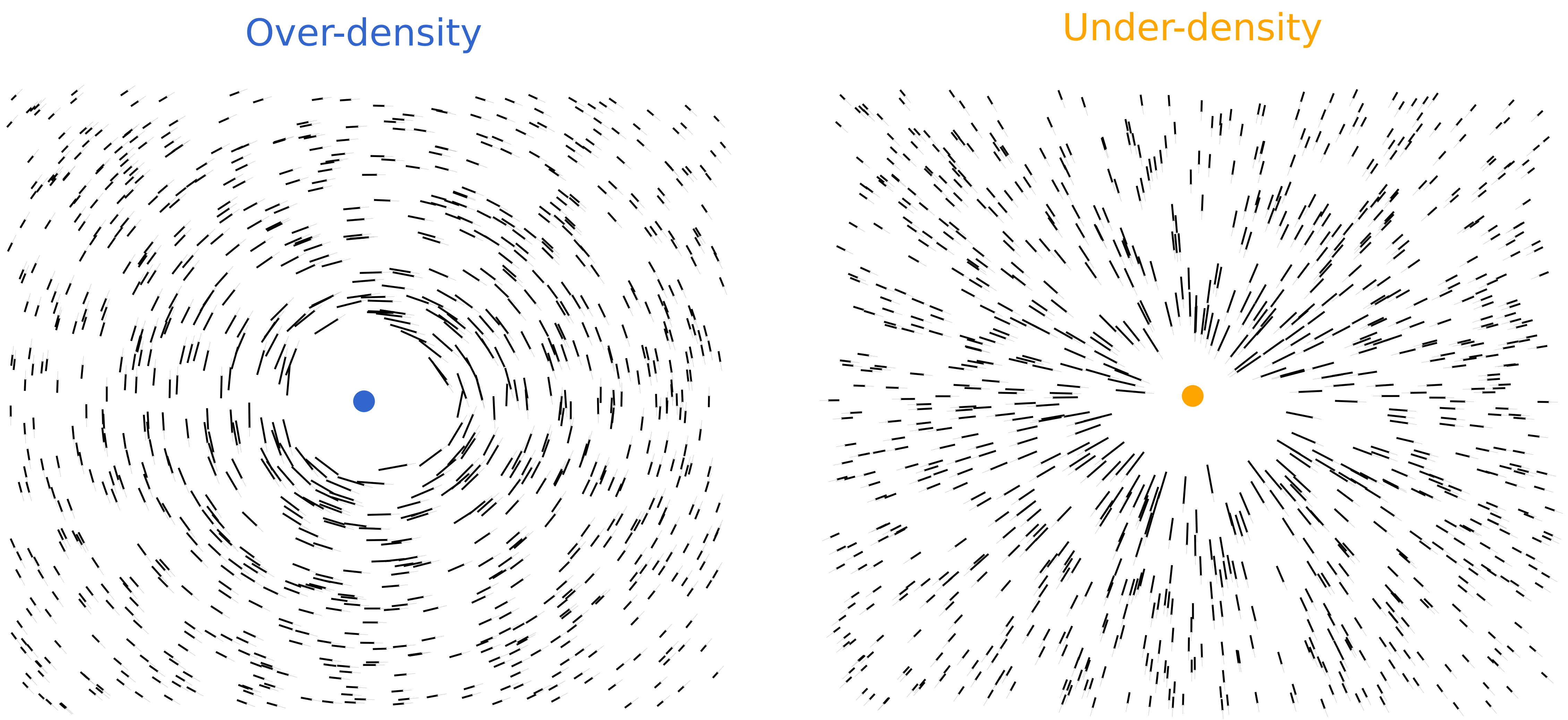


In practice, $|\gamma| \sim 0.01$ (in the field) to 0.1 (in clusters)

Weak gravitational lensing

Cosmic shear

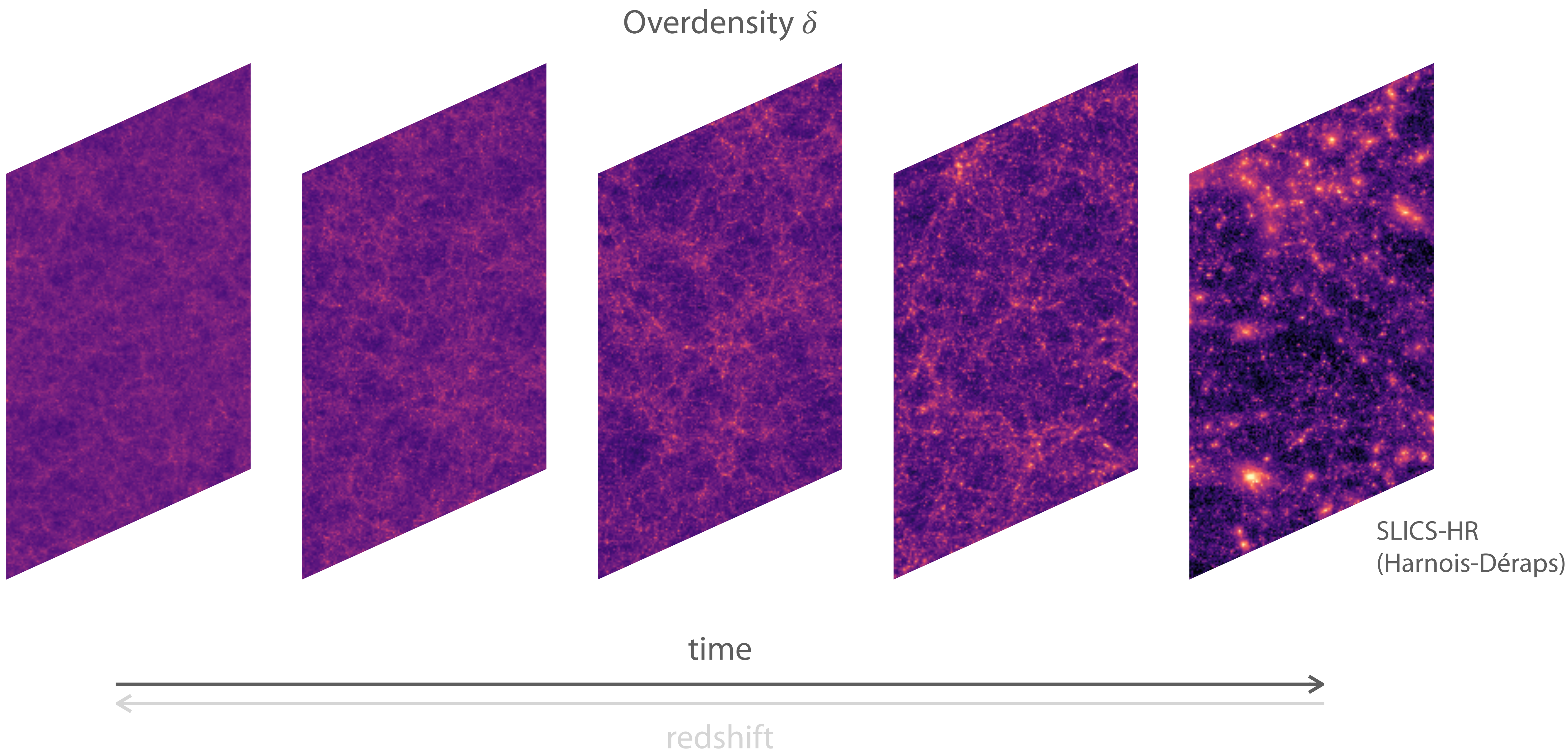


* Lengths do not scale

https://github.com/LSSTDESC/CLMM

Weak gravitational lensing

A large-scale structure probe



Weak gravitational lensing

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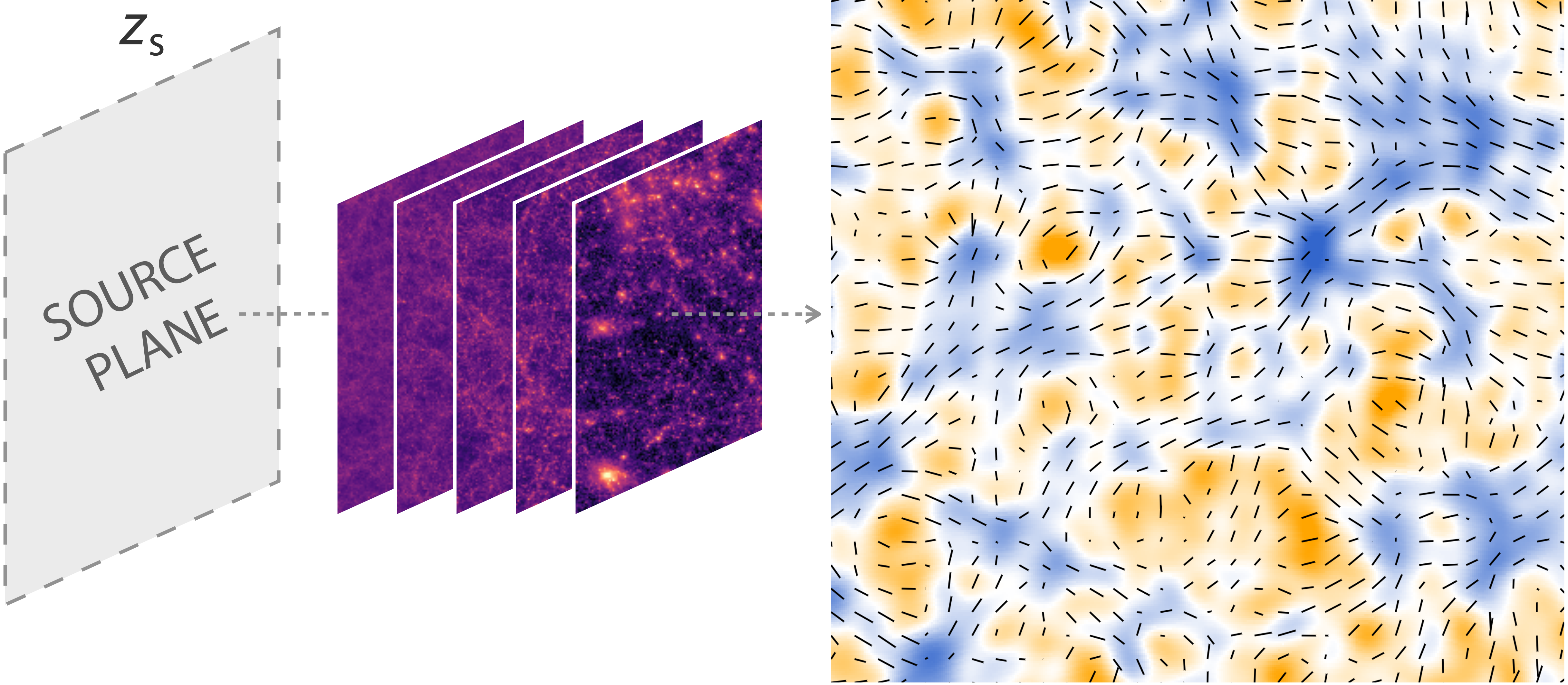
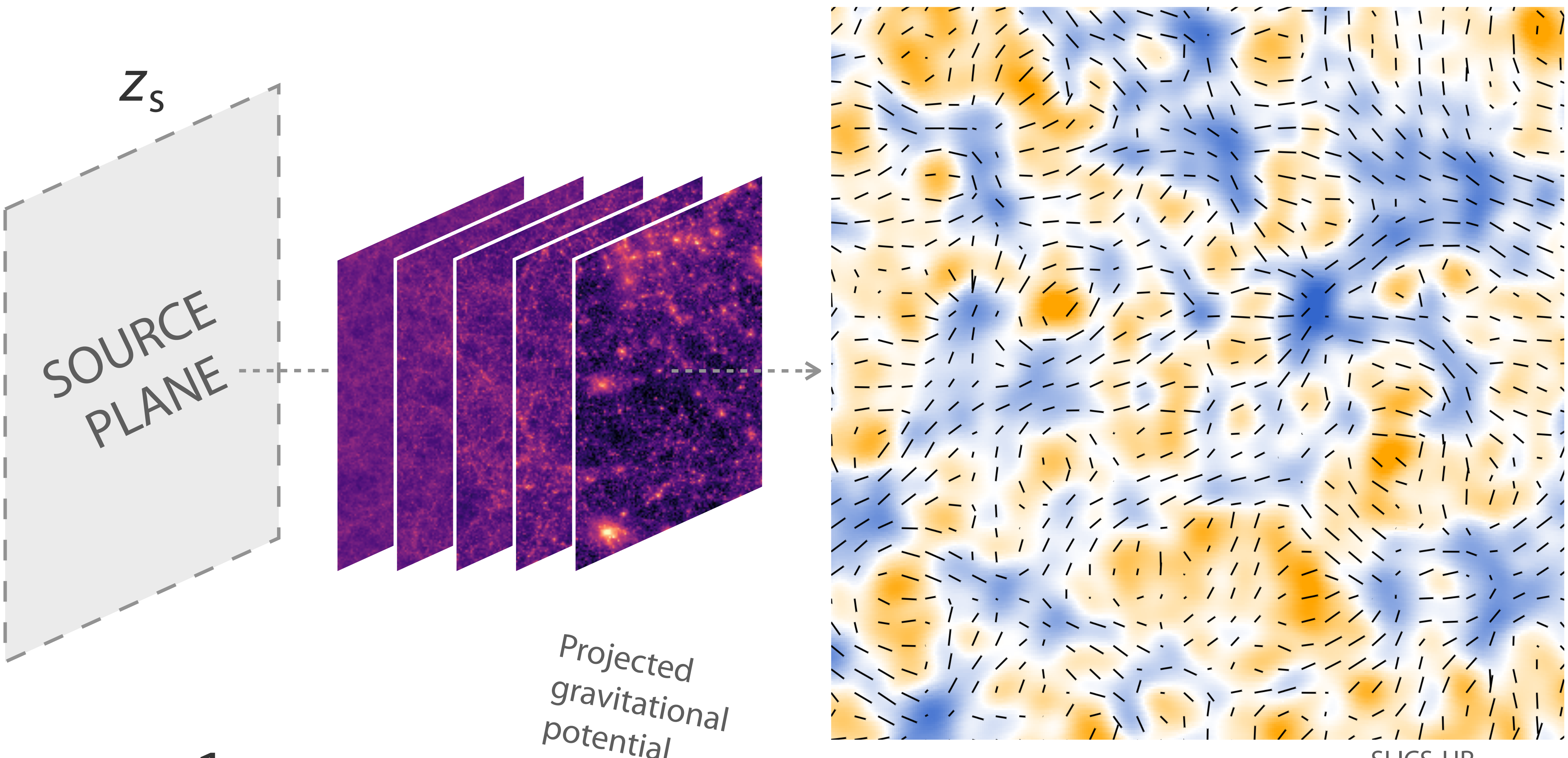


SLICS-HR
(Harnois-Déraps)

Weak gravitational lensing

A large-scale structure probe



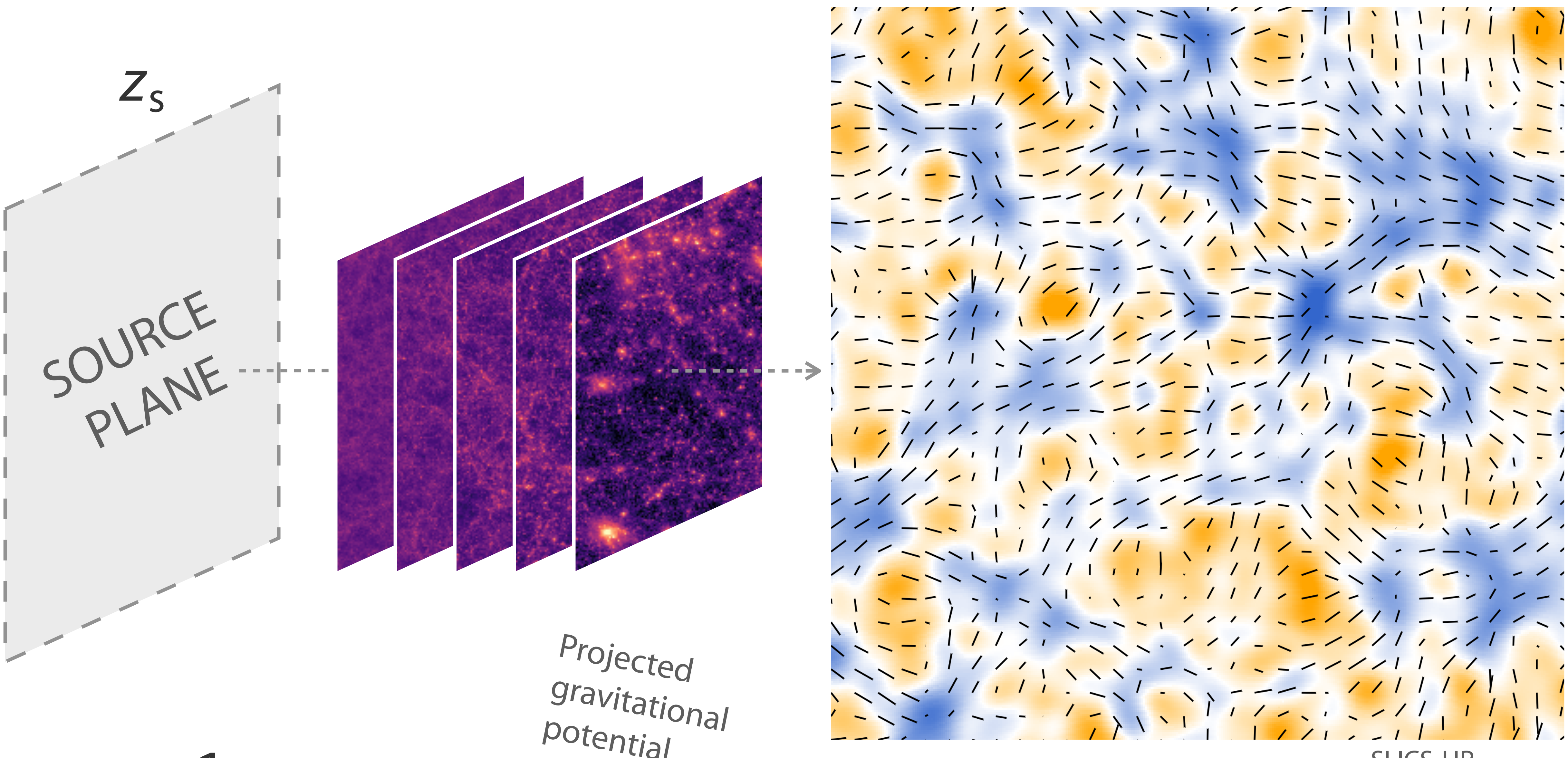
SLICS-HR
(Harnois-Déraps)

$$\kappa = \frac{1}{4}\left(\eth\bar{\eth} + \bar{\eth}\eth\right)\psi$$

$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}\eth\eth\psi$$

Weak gravitational lensing

A large-scale structure probe



SLICS-HR (Harnois-Déraps)

$$\kappa = \frac{1}{4}\left(\eth\bar{\eth} + \bar{\eth}\eth\right)\psi$$

$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}\eth\eth\psi$$

$$\kappa(\theta) = \int \mathrm{d}z\, W^{\kappa}(z, z_s)\,\delta(\theta, z)$$

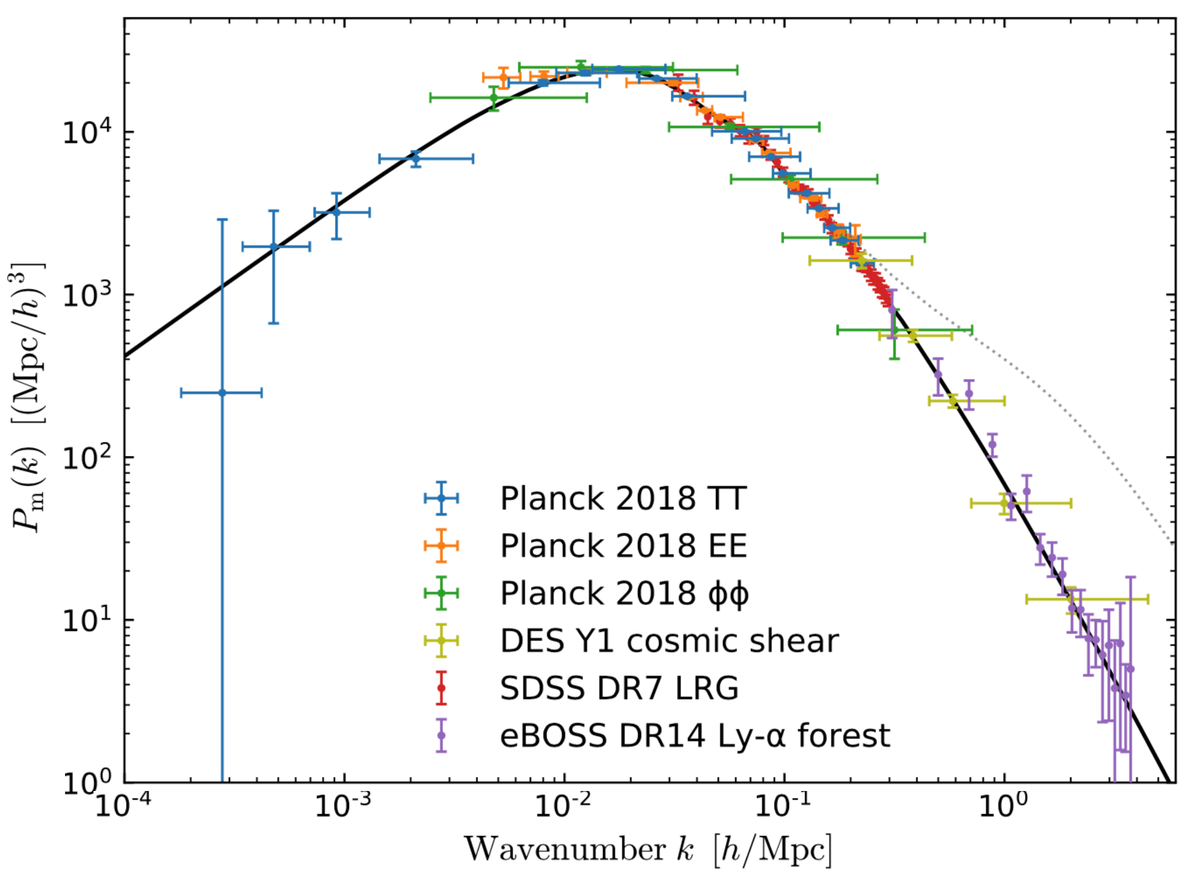
Cosmic shear power spectrum

$$C_\ell^{\gamma_a \gamma_b} = \int_0^{z_\star} \mathrm{d}z \, \frac{H(z)}{c\,\chi(z)} \, W^a(z) W^b(z) \, P_\mathrm{m}\left(k = \frac{\ell + 1/2}{\chi(z)}, z\right)$$

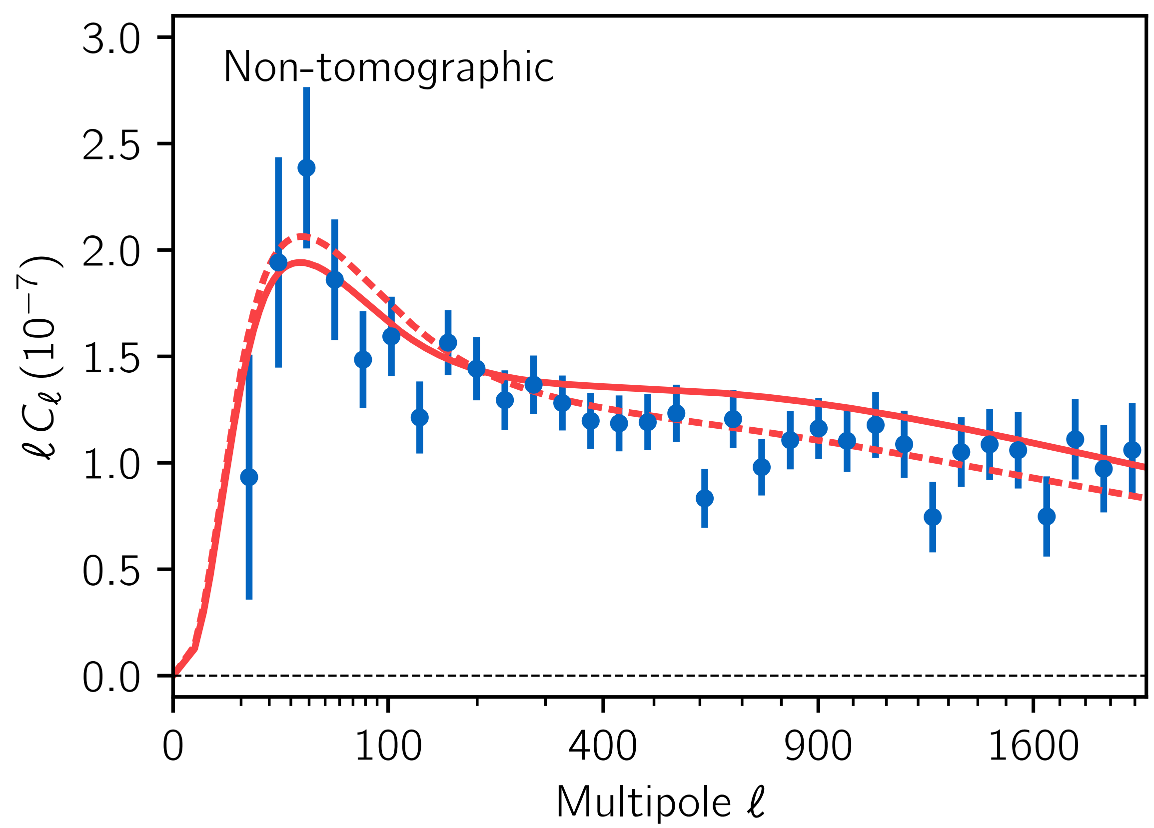
GEOMETRY

GROWTH

Matter power spectrum

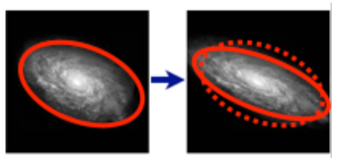


Cosmic shear power spectrum



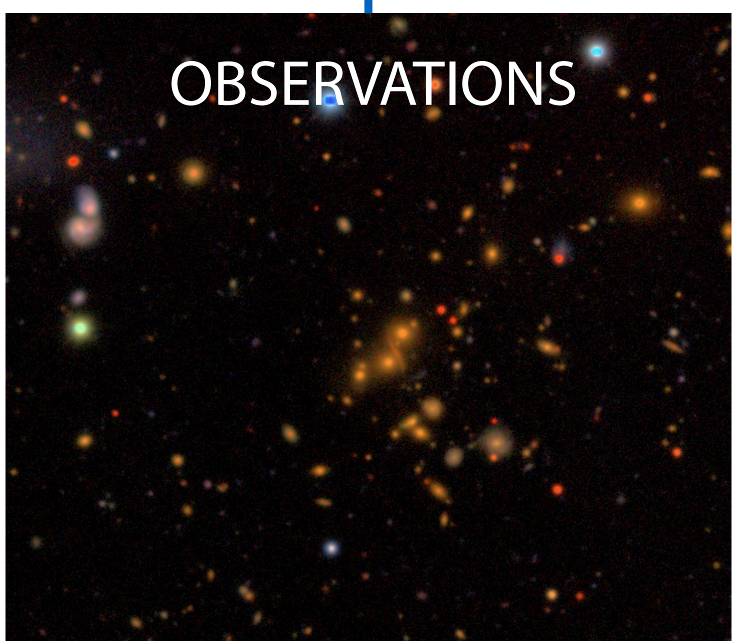
The cosmic shear power spectrum is a *projection* of the matter power spectrum !

Cosmic shear pipeline



ELLIPTICITIES

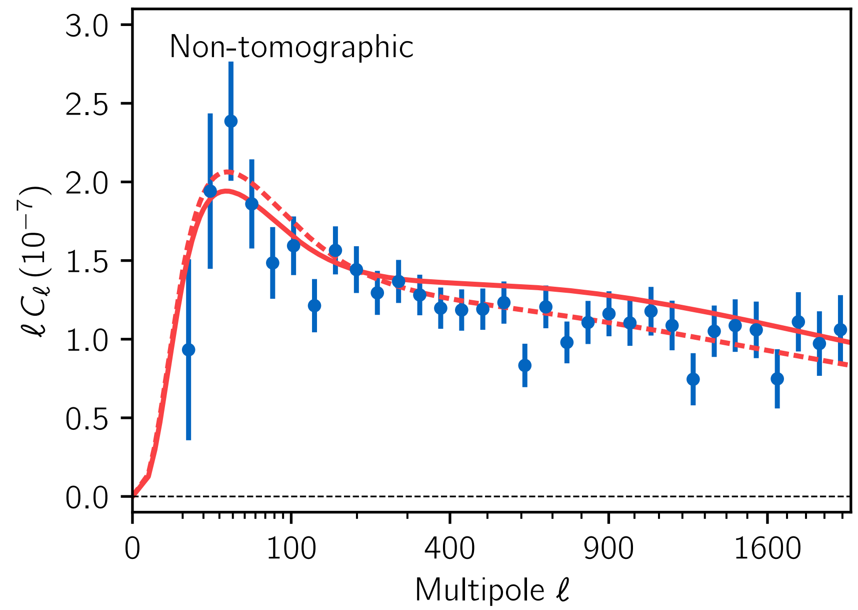
e_1/e_2



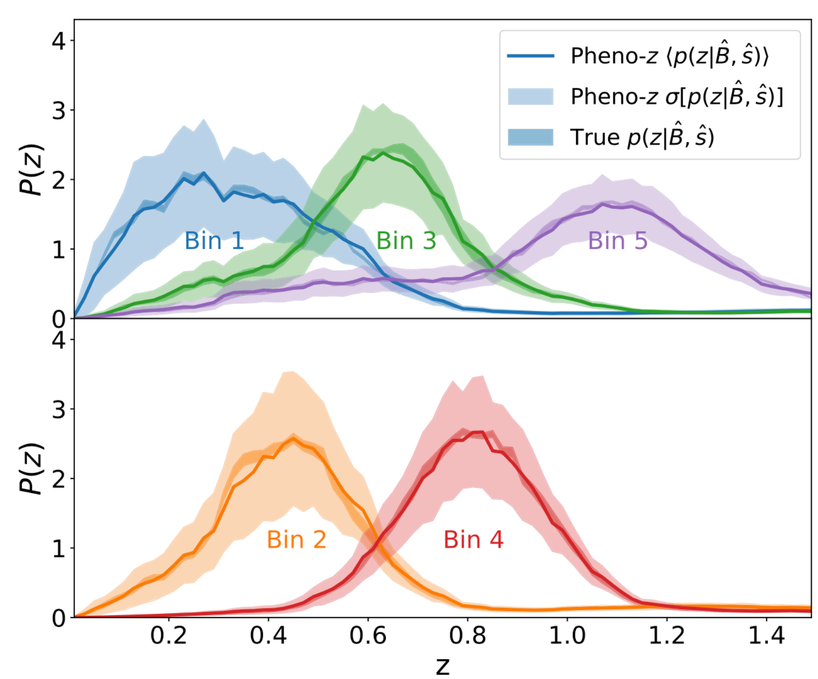
FLUXES

griz

- STATISTICS



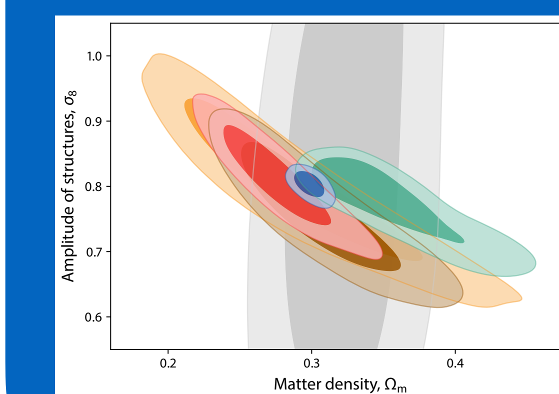
- REDSHIFT DISTRIBUTIONS



- COSMOLOGICAL SIGNAL
  - Matter power spectrum P_{NL}
  - Lensing window functions q^i

$$C_\ell^{ij} = \int_0^{\chi_H} \mathrm{d}\chi \, \frac{q^i(\chi)\, q^j(\chi)}{\chi^2} P_{\mathrm{NL}}\left(k = \frac{\ell + 1/2}{\chi}, \chi\right)$$

COSMOLOGICAL PARAMETERS



- SYSTEMATIC UNCERTAINTIES
  - Shear calibration m_i
  - Redshift uncertainties Δz_i
  - Intrinsic alignements model

- Cosmic shear 101
- Dark Energy Survey Year 3 analysis
    - Advances in shear/redshift calibration
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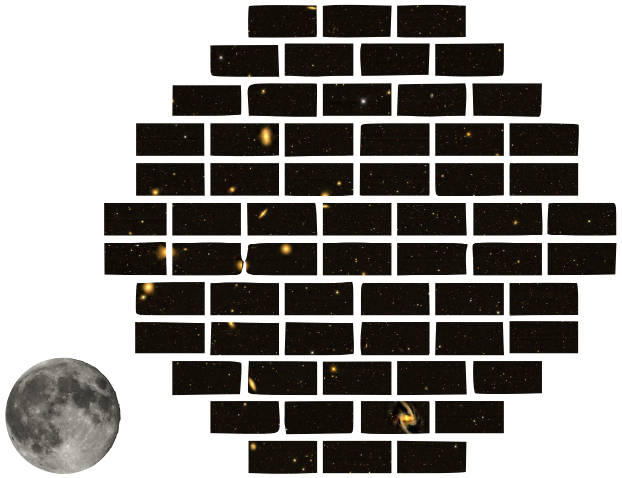
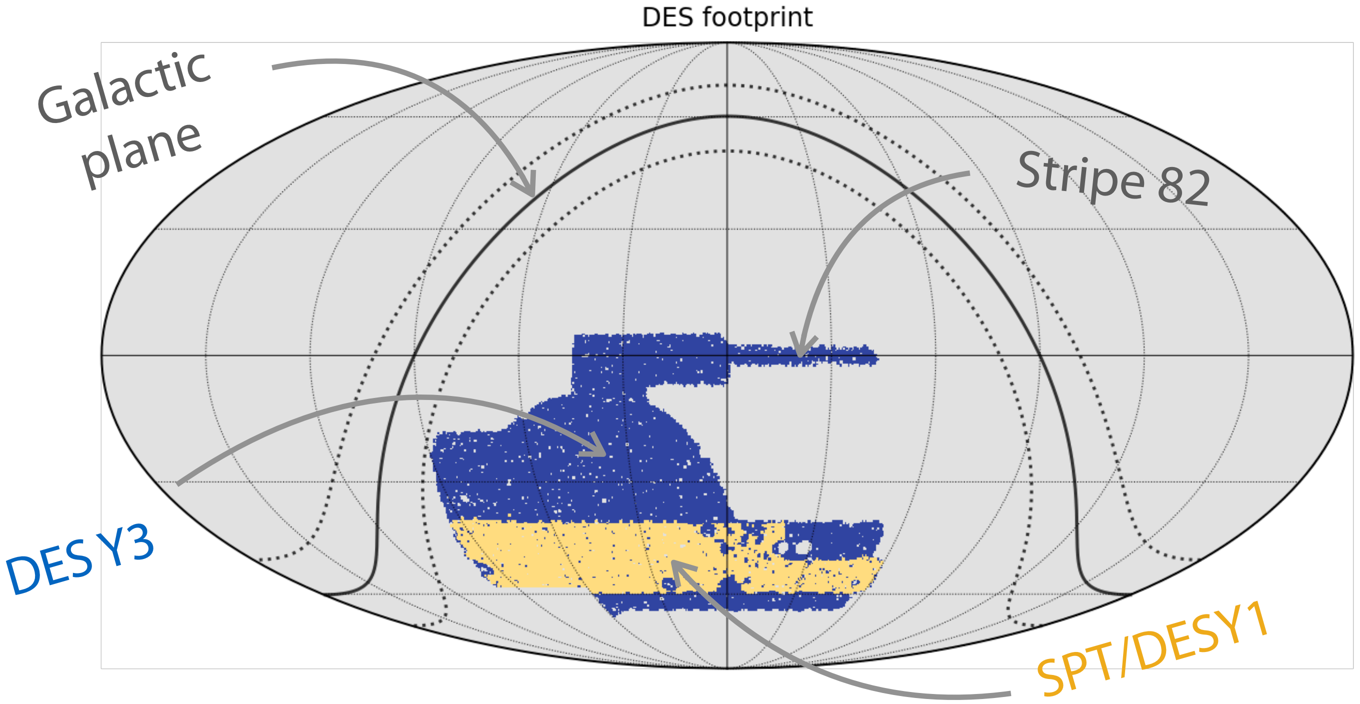
The Dark Energy Survey

- **Blanco 4-meter telescope** at Cerro Tololo (CTIO) in Chile
- **Dark Energy Camera** (DECam)
  - 3.0 deg² field-of-view, 70 CCD chips, 570 Mpix, *griz(Y)* filters
  - Seeing ~0.9′ in *r*-band, magnitude $i_{AB}<23.0$, $r<23.5$
- **Survey(s)**
  - 5000 deg² footprint + **deep fields**, observed 2013-2019
- **DES Year 3 in numbers**
  - ~100 people, ~100M galaxies, ~30 papers





DES Y3 METACALIBRATION shape catalogue

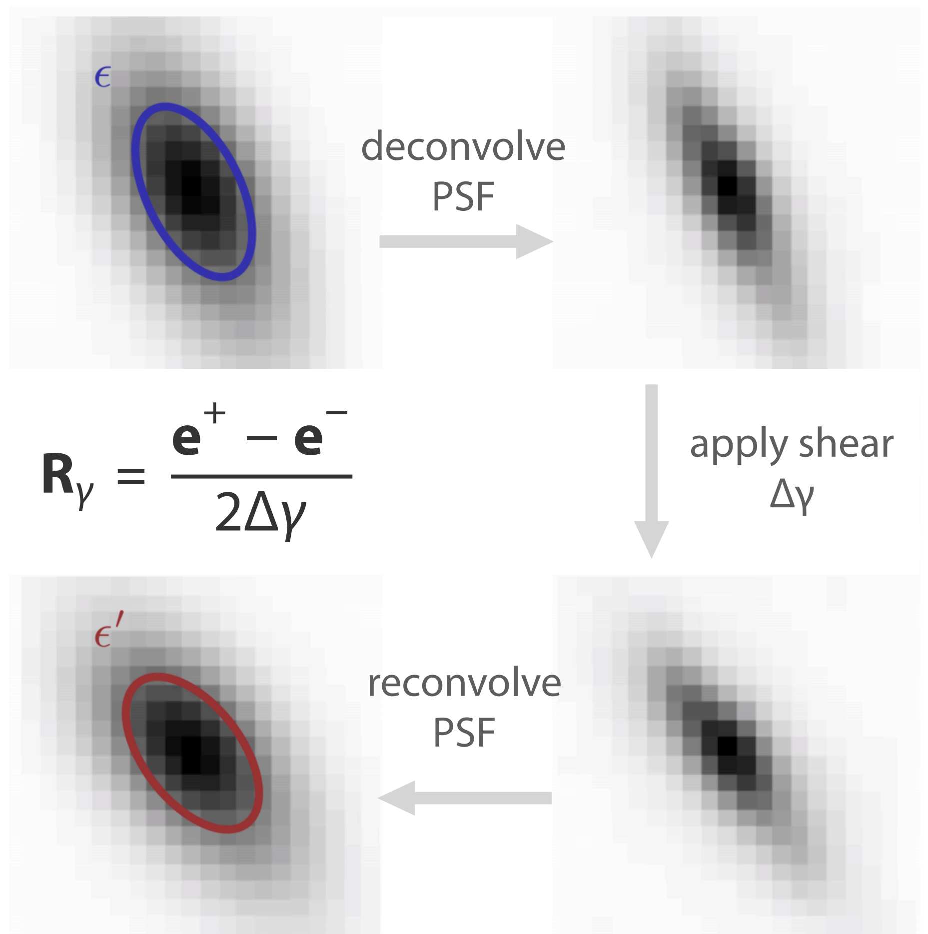
- **METACALIBRATION in a nutshell**
  - For any *biased* shear estimator **e**,

$$\mathbf{e} = \mathbf{e}|_{\gamma=0} + \gamma \cdot \underbrace{\left.\frac{\partial \mathbf{e}}{\partial \gamma}\right|_{\gamma=0}}_{\mathbf{R}_\gamma} + \mathcal{O}(\gamma^3)$$

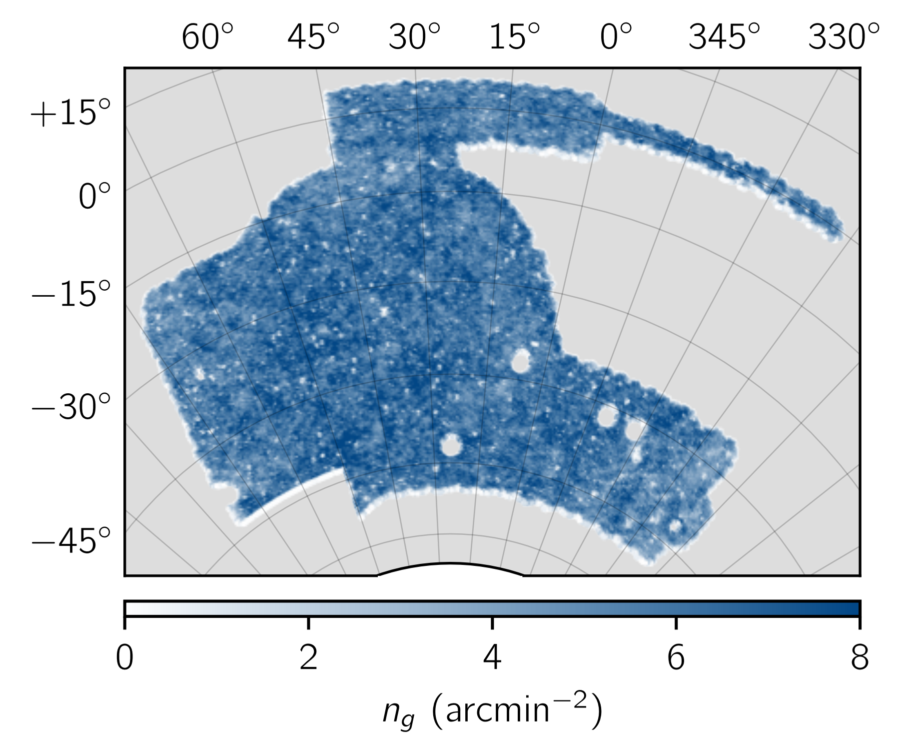
  such that $\langle \hat{\gamma} \rangle \approx \langle \mathbf{R}_\gamma \rangle^{-1} \langle \mathbf{e} \rangle$ is *unbiased* 👍

  - Mitigates model+noise biases and *shear-dependent* selection

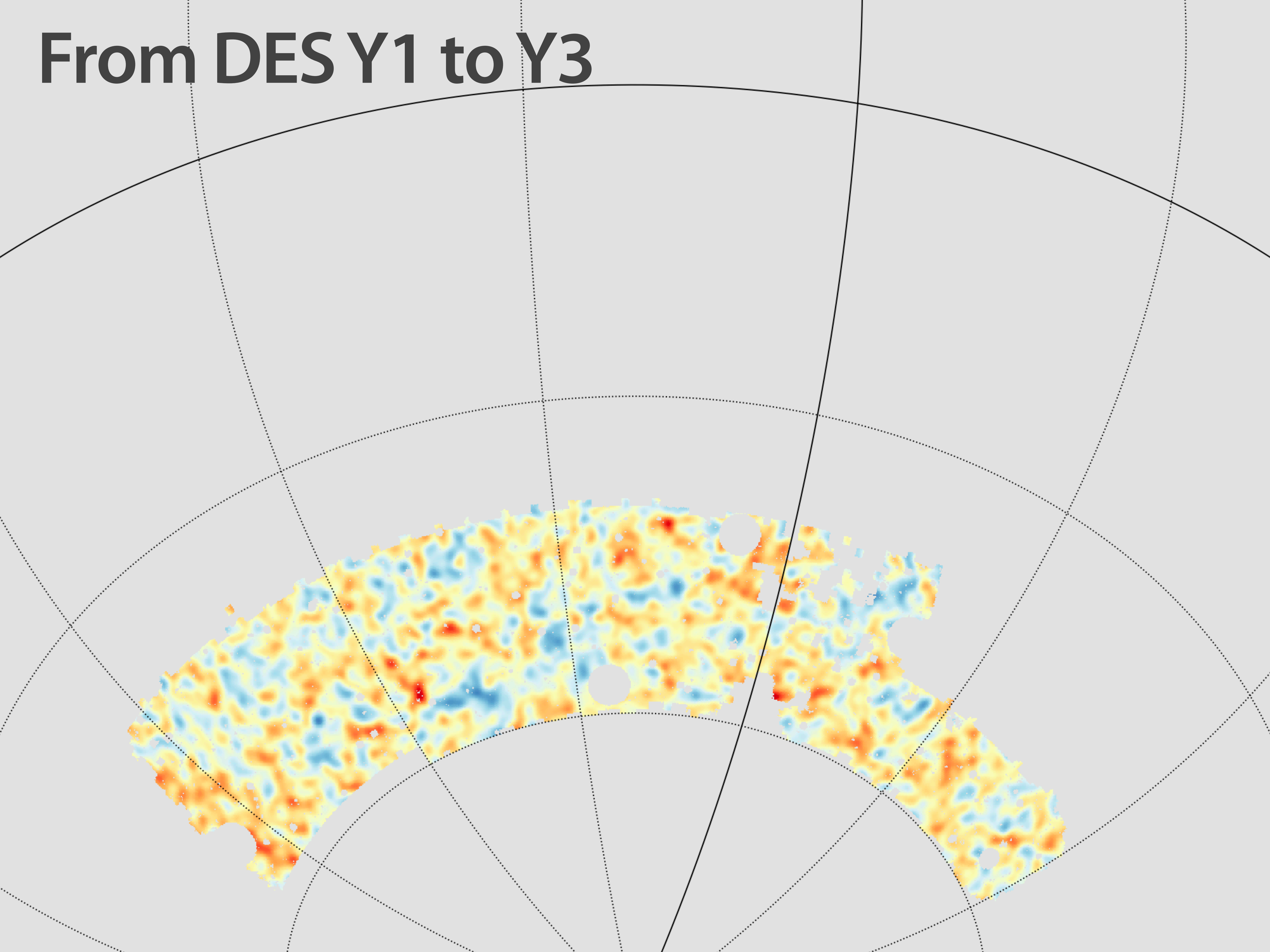
- **DES Y3 METACALIBRATION catalogue**
  - Cuts: 10<S/N<1000, T/TPSF>0.5 + color cuts
    - 100,204,026 galaxies from Y3 GOLD in *riz*
    - $\sigma_e = 0.261$ with inverse-variance weights($S/N, T/T_{PSF}$)
    - $n_{\rm eff} = 5.59$ gal/arcmin^2
  - Catalogue found to be very robust *Gatti…CD+20* [DES Y3]



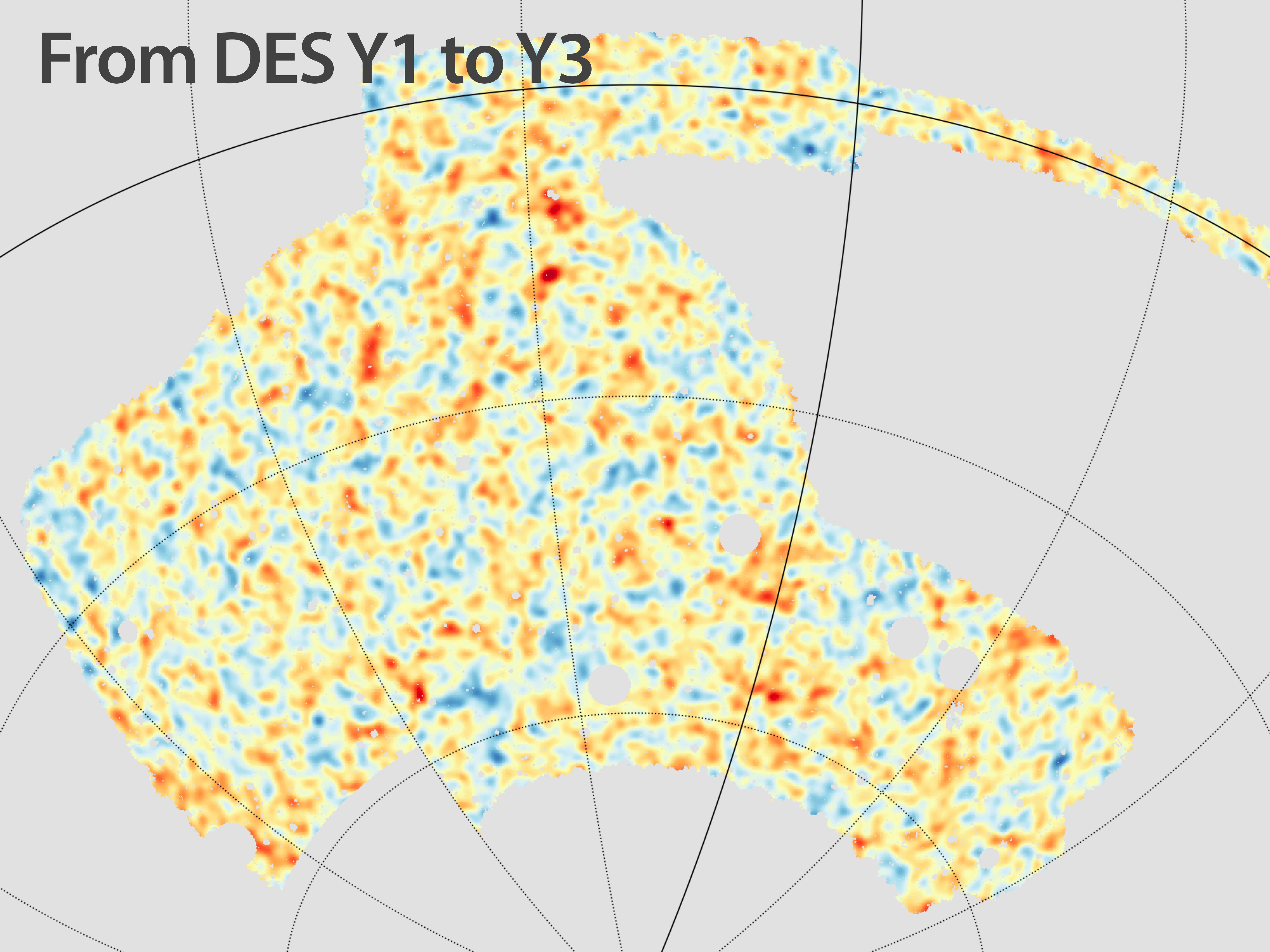
N. MacCrann



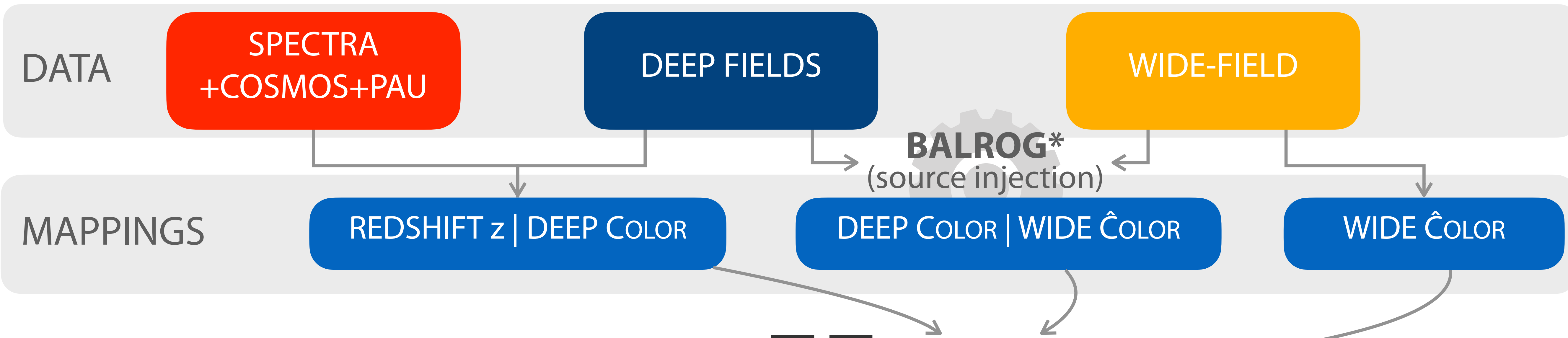
From DES Y1 to Y3



From DES Y1 to Y3



DES Y3 redshift distributions with SOMPZ

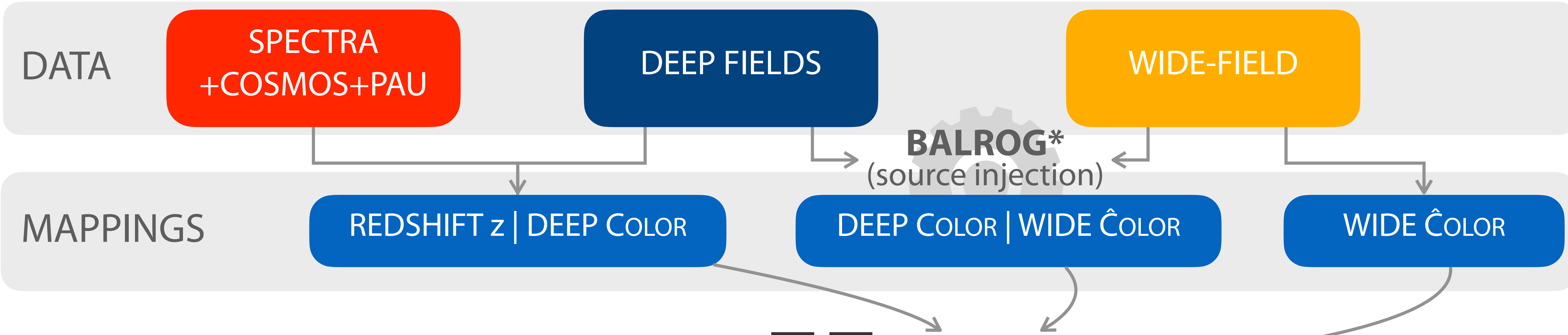


- Marginal photo-z for bin $\hat{b}$ is

$$p(z|b) = \sum_{\hat{c}\in b} \sum_{c} p(z|c)\, p(c|\hat{c})\, p(\hat{c})$$

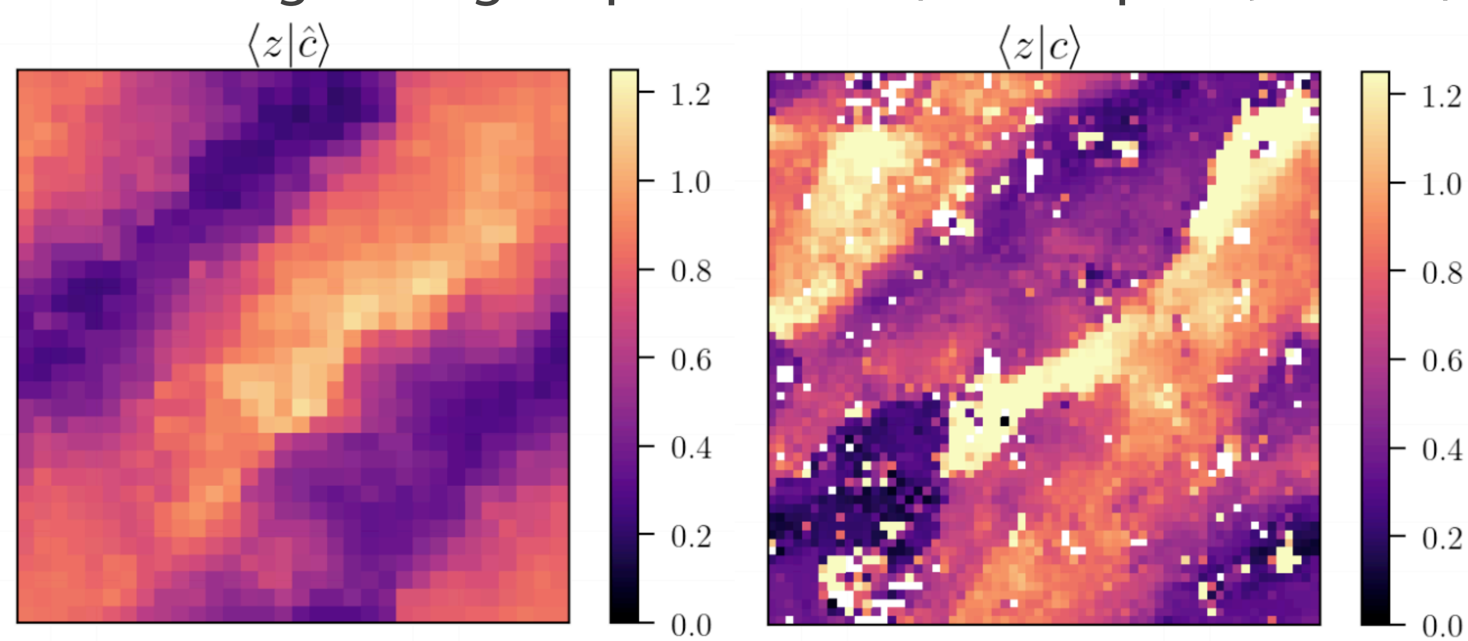
*Everett+20 [DES Y3]

DES Y3 redshift distributions with SOMPZ



- Marginal photo-z for bin $\hat{b}$ is $$p(z|b) = \sum_{\hat{c}\in b} \sum_{c} p(z|c)\, p(c|\hat{c})\, p(\hat{c})$$

- Bayesian mapping with self-organizing maps method (no template, no ML) from Buchs+19



Myles+20 [DES Y3]

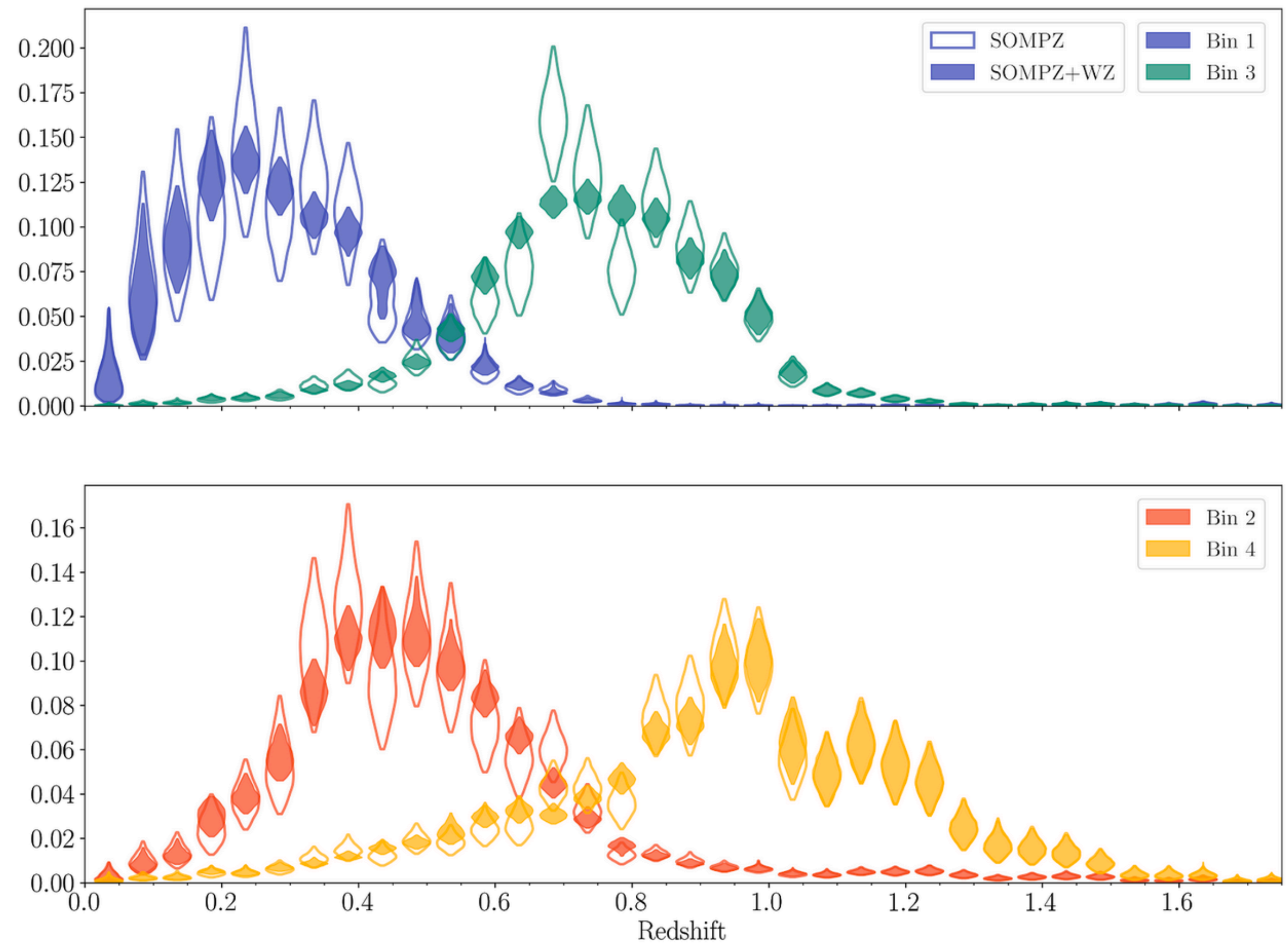
- **RESULT**: produces *posterior samples* of $n(z)$ for each redshift bin

**Everett+20* [DES Y3]

DES Y3 redshift distributions with SOMPZ

- **3 sources of information**

Myles+20 [DES Y3]



  1. **SOMPZ** method calibrated with Balrog
  2. **Constraints from clustering**
  3. **Shear-ratio**

- **DES Y3 *n*(*z*)'s**
  - Effective combined ⟨*z*⟩ uncertainties between 0.008 and 0.015
  - Error dominated by
    - photo-calibration at low *z*
    - sample variance at higher *z*

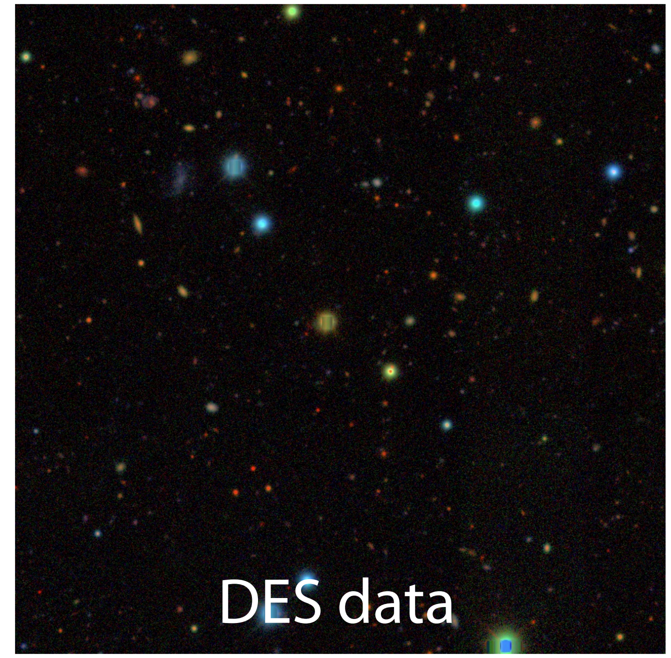
- **Marginalisation over n(z)'s with HYPERRANK** *Cordero+ 21* [DES Y3]
  - *Posterior samples* of *n*(*z*)*'s* instead of usual shift n'(z) = n(z+Δz)
  - HYPERRANK ranks *n*(*z*)'s to allow marginalisation over both ⟨*z*⟩ *and n*(*z*) *shape*

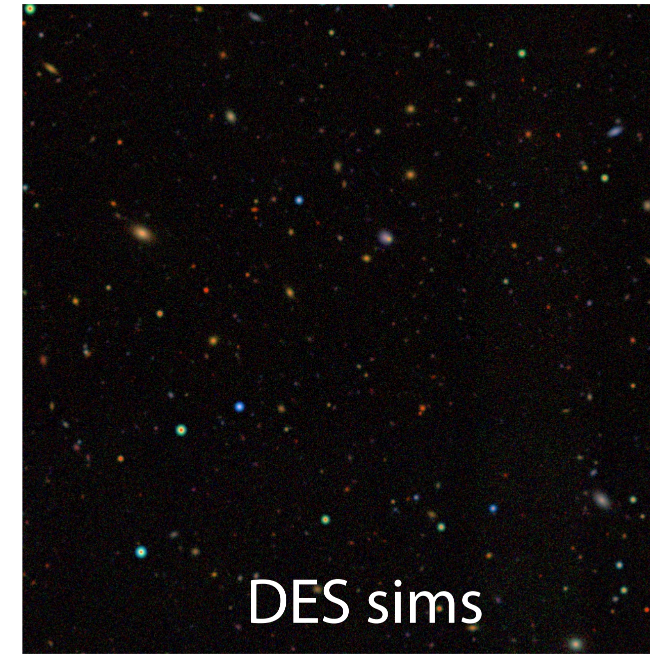
Joint calibration of shears and redshifts

- **Redshift distributions as *shear response***
  - Consider $n(z)$ as *response of data ensemble to shear* at redshift z

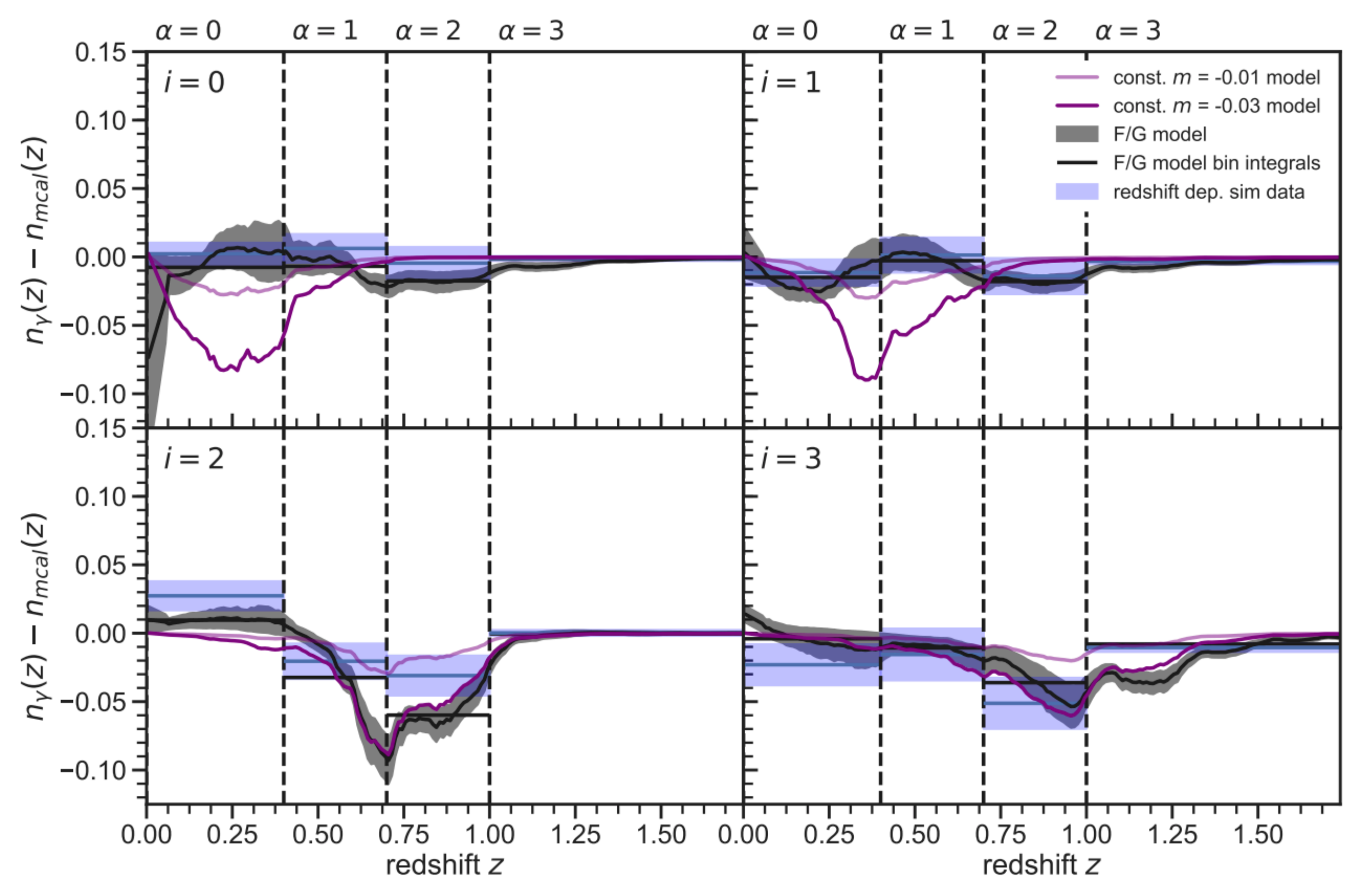
$$\langle \mathbf{e}_{\mathrm{obs}} \rangle = \int n_\gamma(z)\gamma_{\mathrm{true}}(z)\,\mathrm{d}z + c + \text{noise}$$

  - Distorsion $n(z) \to n_\gamma(z)$ measured by sims
    - $n_\gamma(z)$ has norm $1+m$
    - Very realistic simulations matching deep field colors and blending
- **DES Y3 results**
  - $m \sim -2\%$ dominated by blending
  - Distorted/calibrated SOMPZ $n_\gamma(z)$ samples to be used for cosmology





MacCrann+20 [DES Y3]



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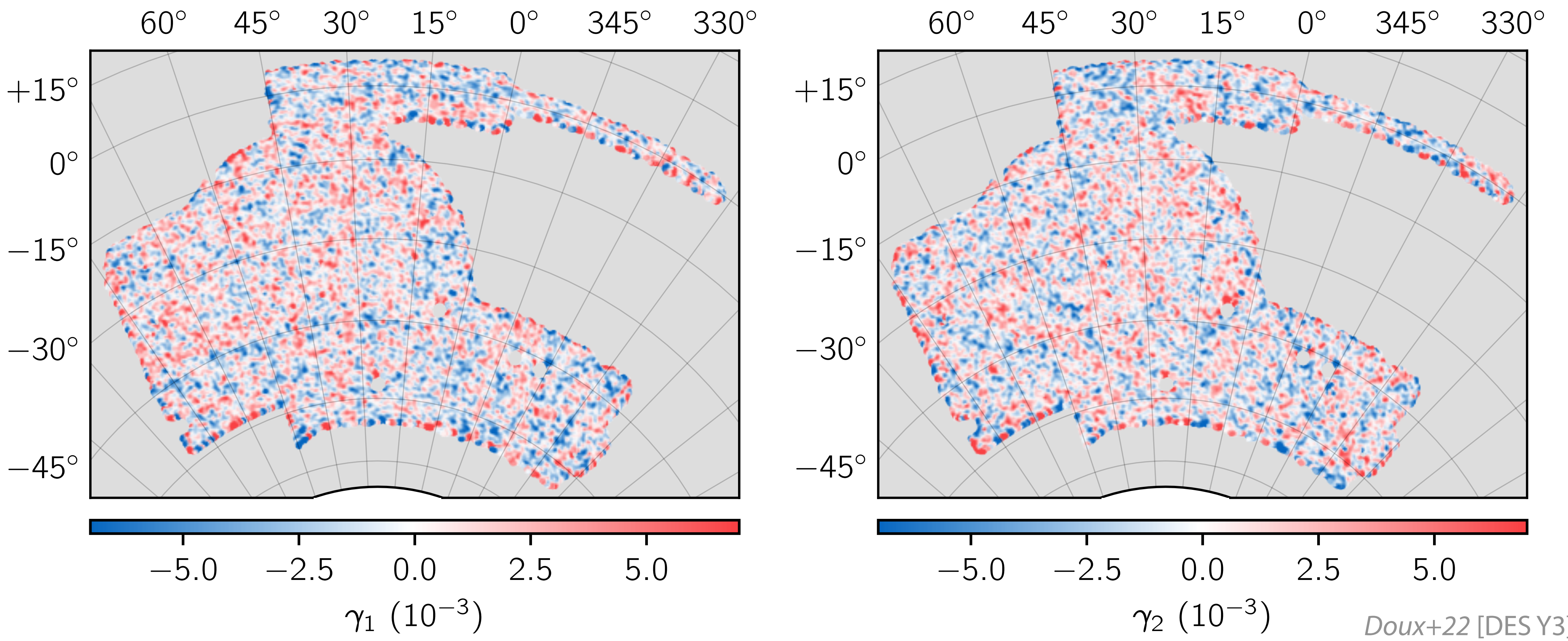
DES Y3 cosmic shear maps

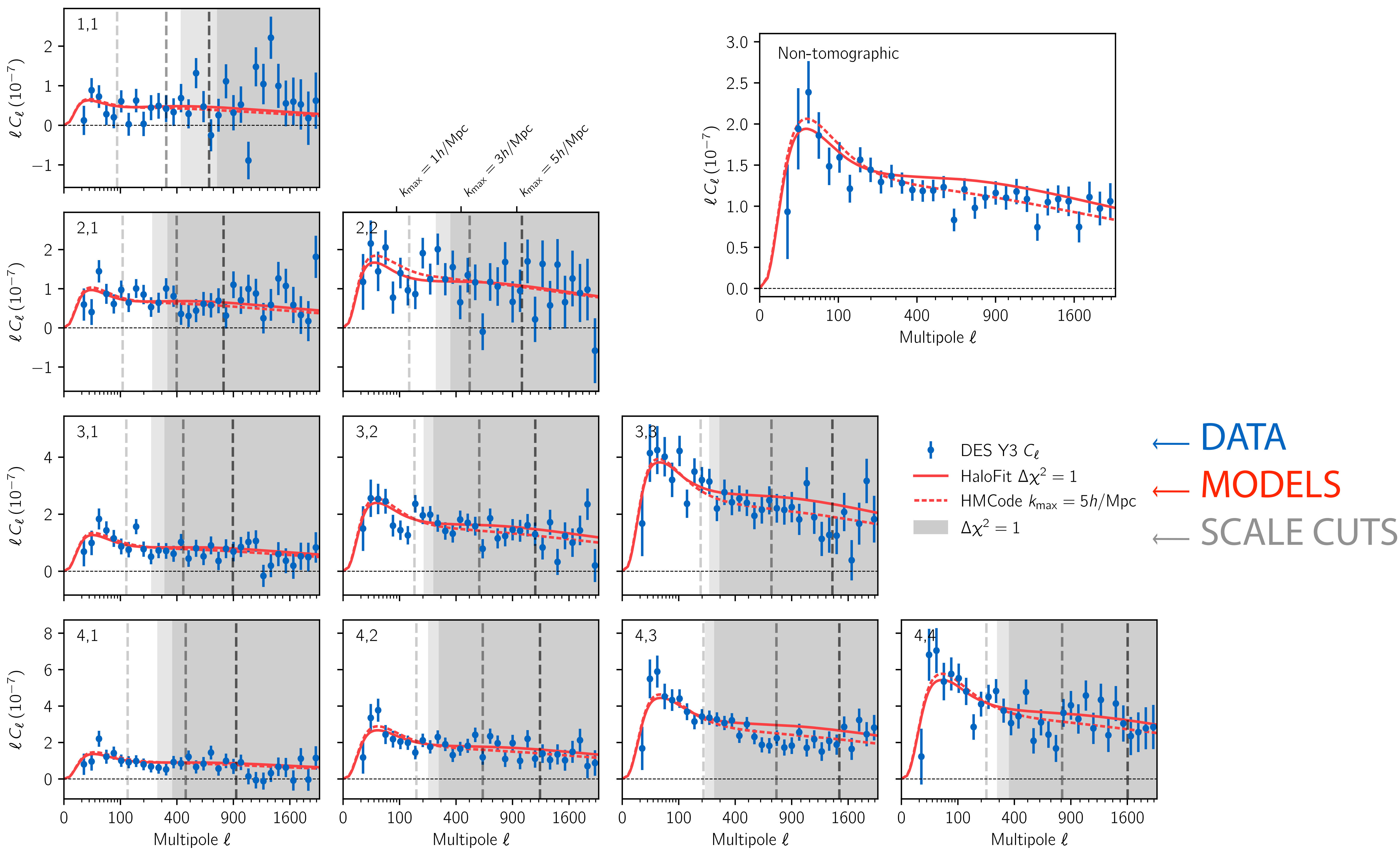
NON-TOMOGRAPHIC MAPS



Doux+22 [DES Y3]

- γ_1/γ_2 shear maps per redshift bin
- Auto- and cross two-point functions
  - Correlations functions $\xi_{\pm}(\theta)$: *Amon+21 and Secco+21 [DES Y3]*
  - Angular power spectra C_ℓ : *Doux+22 [DES Y3]*

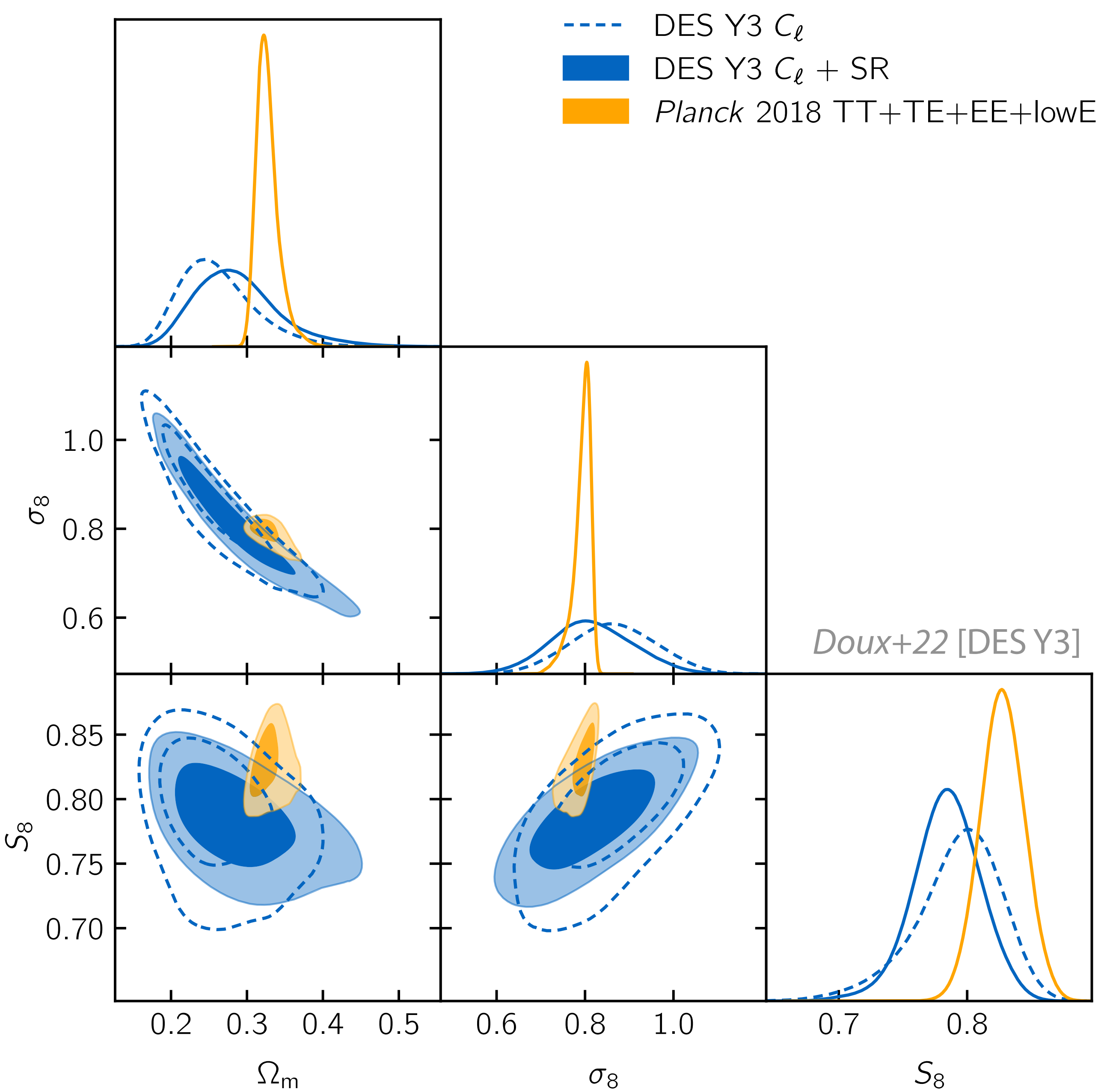
Cosmic shear power spectra



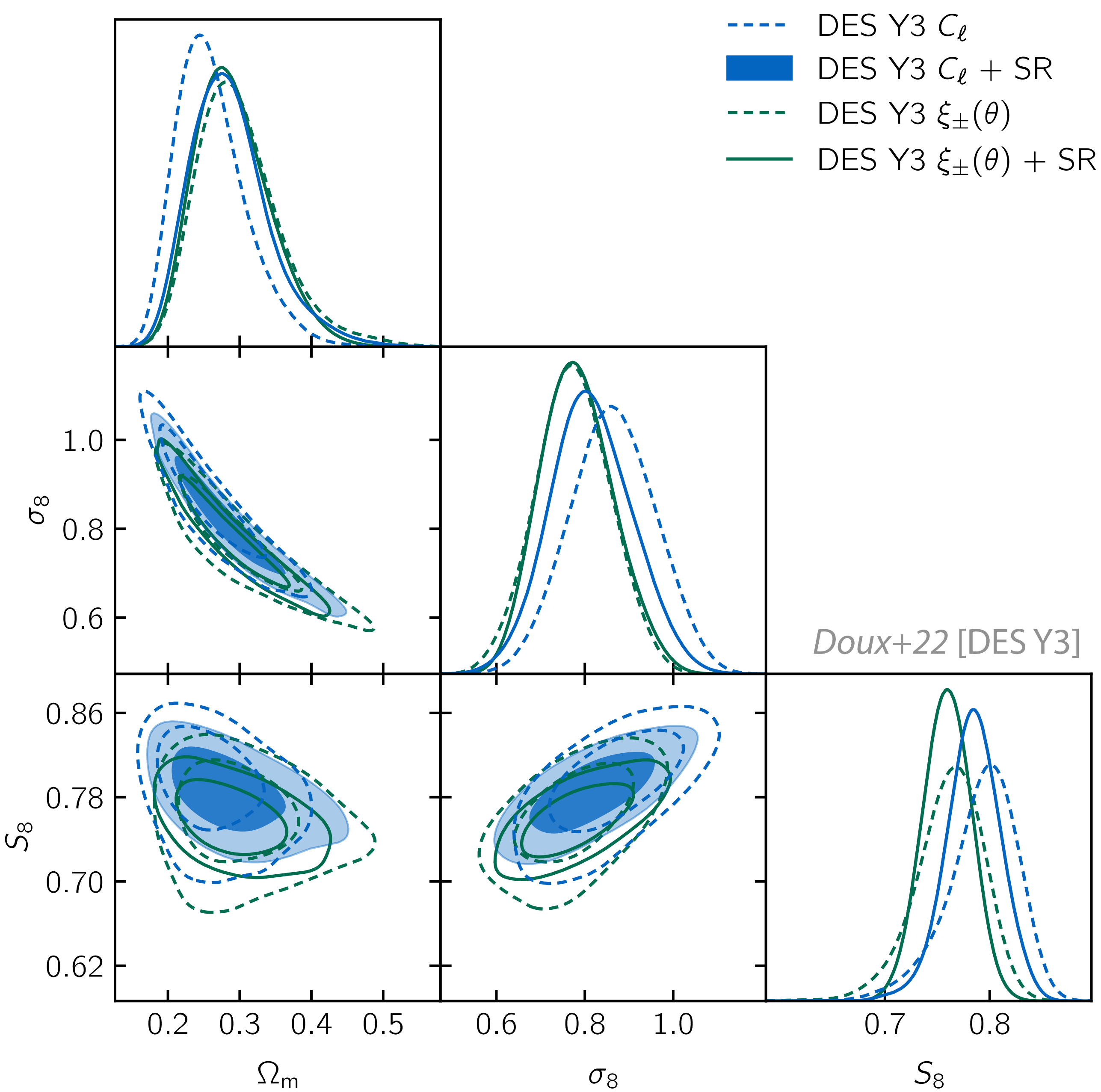
Doux+22 [DES Y3]

Cosmological constraints

DES Y3 cosmic shear power spectra *vs* Planck



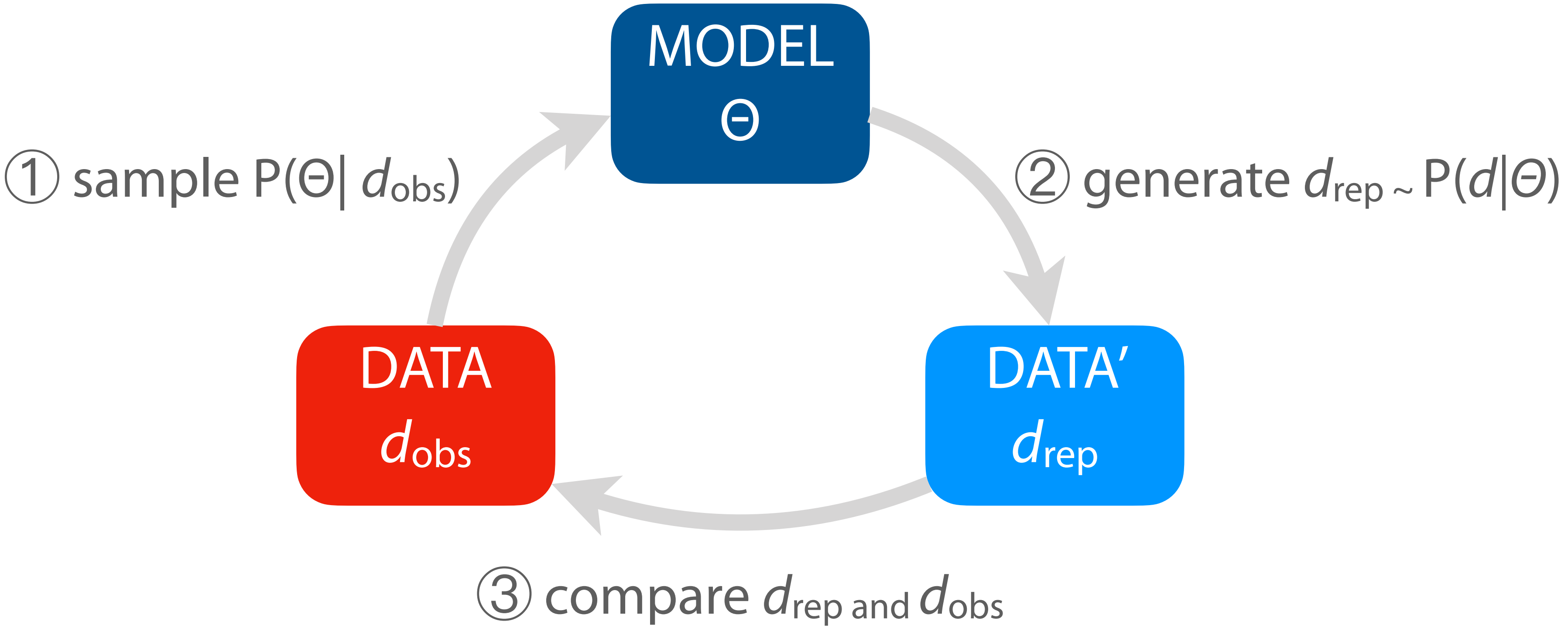
DES Y3 power spectra *vs* two-point functions

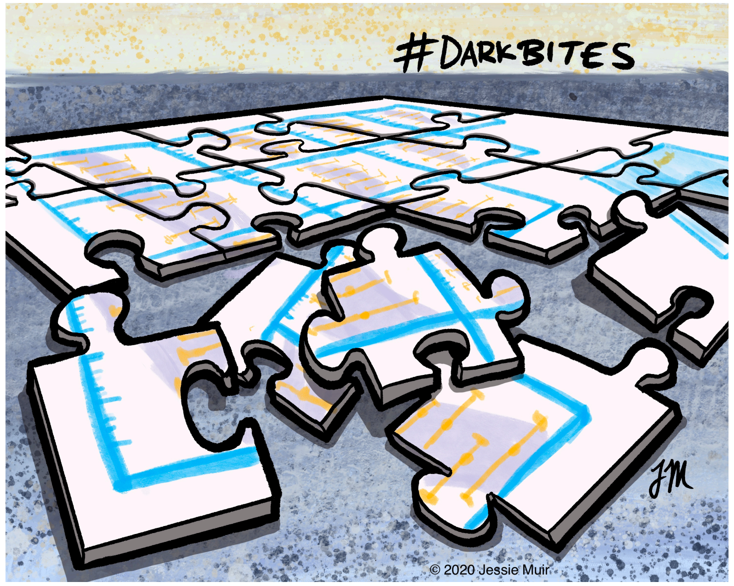


- S_8=0.784±0.026 at 1.6σ from Planck
- ΔS_8=0.002 from two-point function analysis (expected)

Internal consistency

- **Consistency in *data* space**
  - Posterior predictive distribution (PPD) method *Doux+21* [DES Y3]

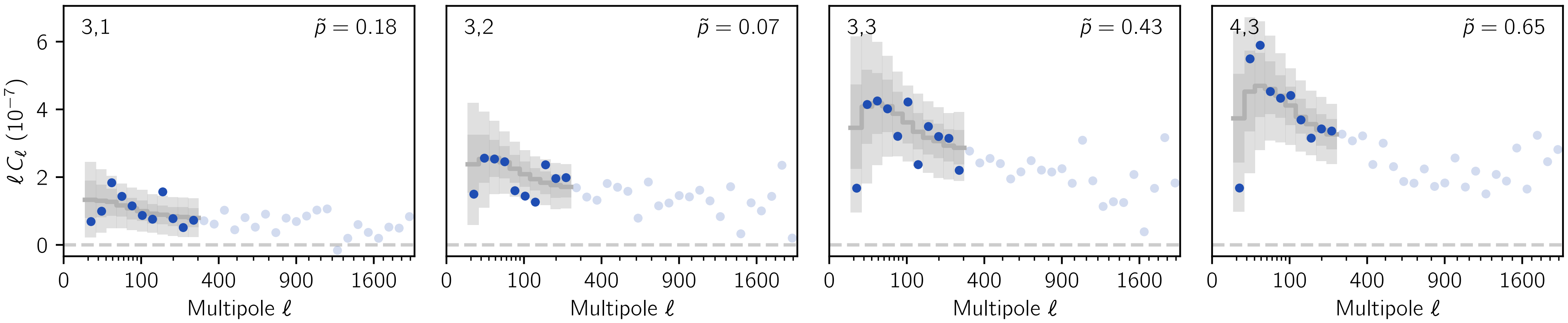




Jessie Muir | #darkbites

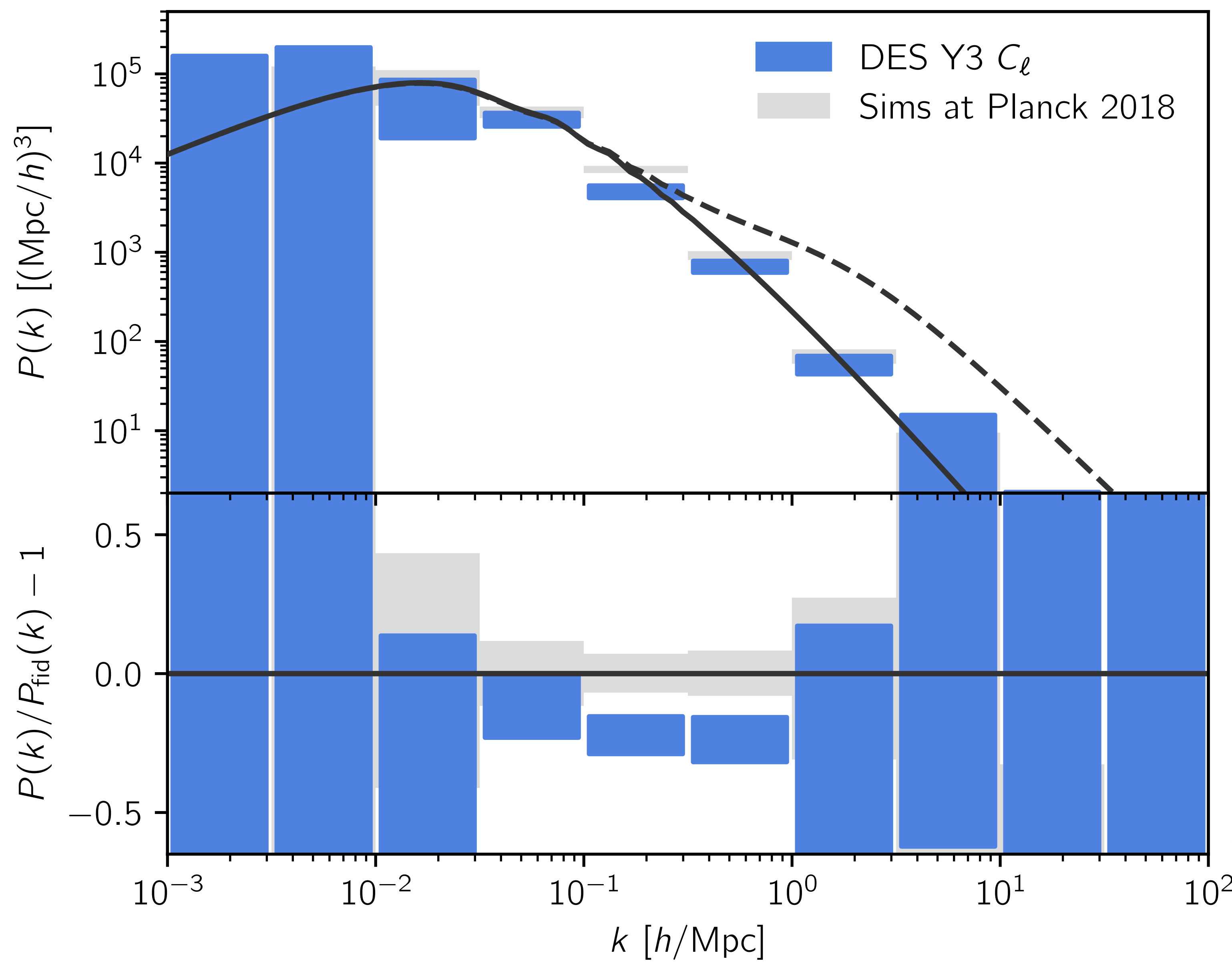
  - Test *goodness-of-fit* and *internal consistency* : splitting data according to redshift, scales, etc

Example: redshift bin 3 *vs* bins 1,2,4



  - We found strong level of consistency between *all* data and the model

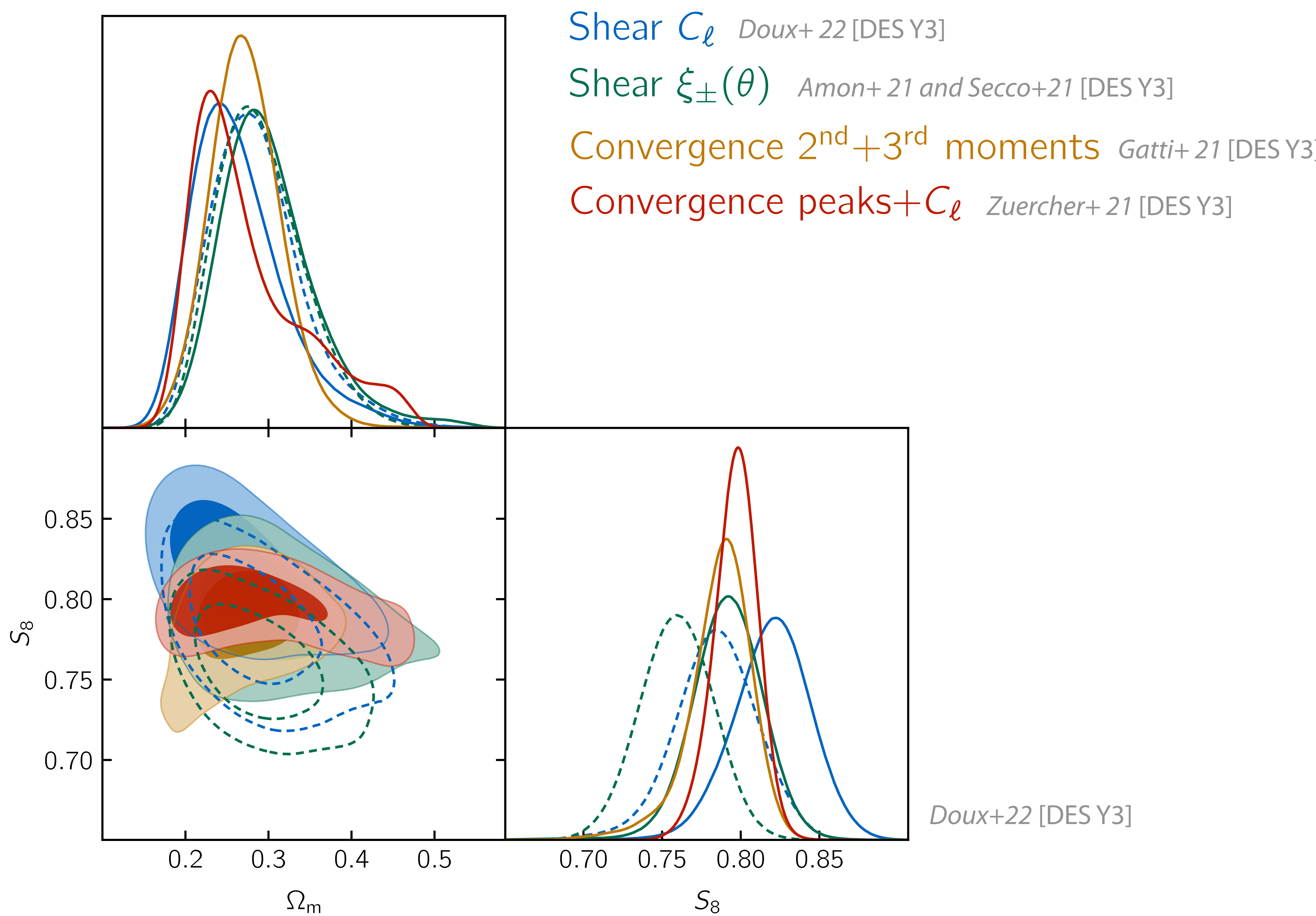
Reconstructing the power spectrum



Doux+22 [DES Y3]

- **IDEA** : *approximate* reconstruction by inverting $C_\ell = \mathrm{F}[\,P(k)\,]$
- **RESULT** : $P(k)$ found ~20% lower than Planck in 0.03 to1 h/Mpc

Gaussian *vs* non-Gaussian statistics



Doux+22 [DES Y3]

(CAVEAT: this comparison requires fixing the total neutrino mass and using a simpler IA model)

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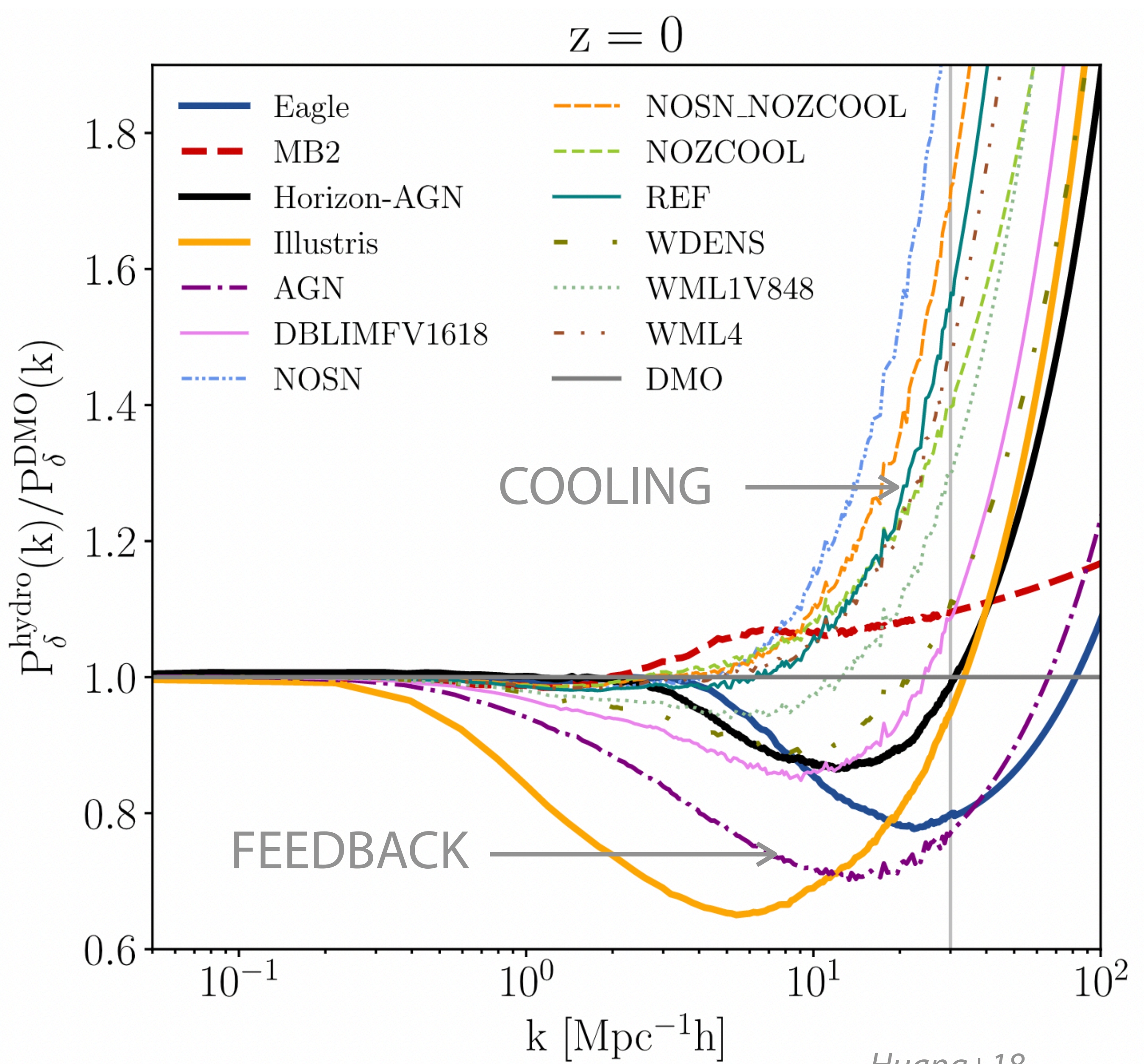
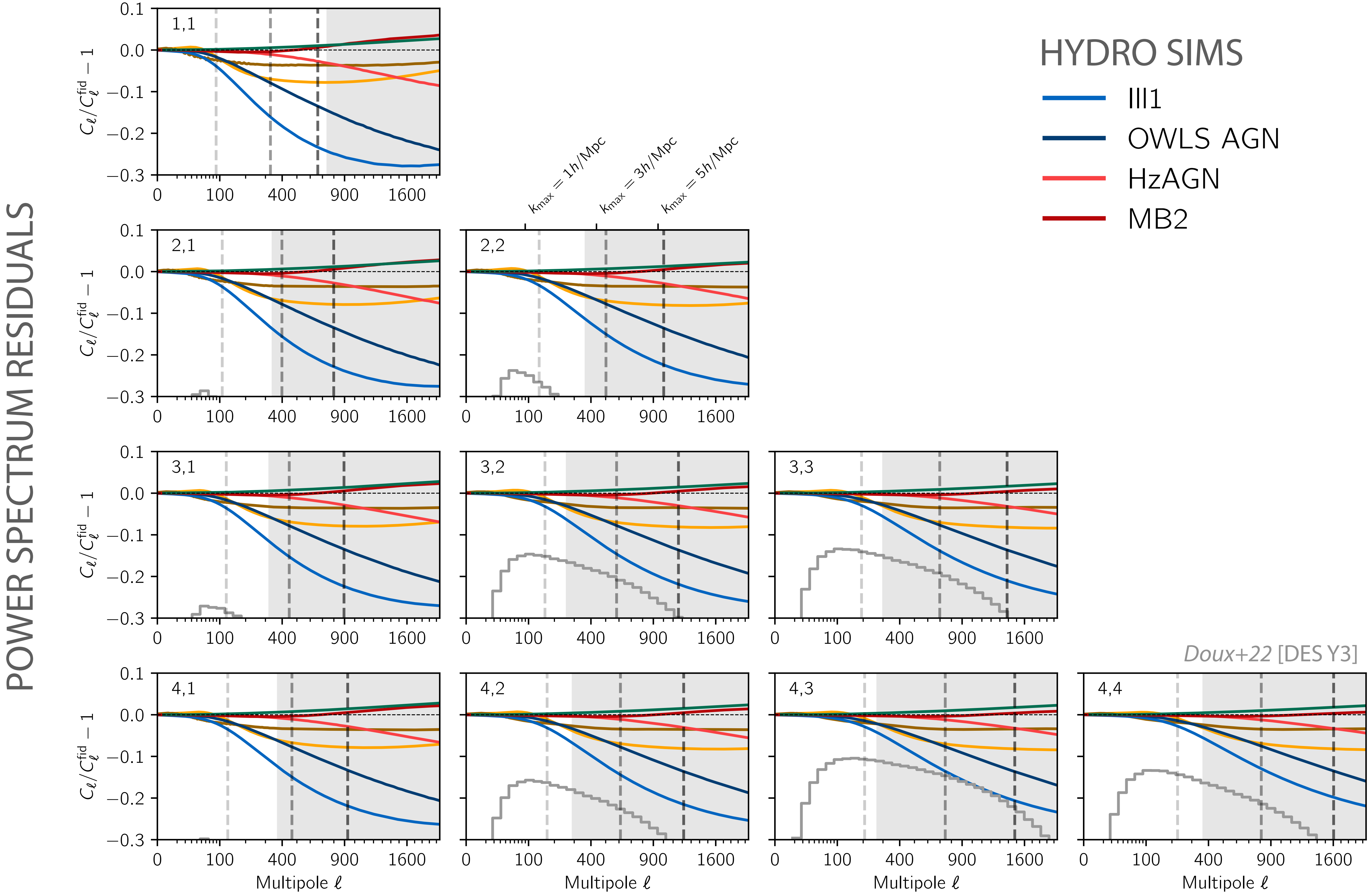
Impact of baryons

- **Impact of baryons**
  - Baryons redistribute matter
  - Suppression of power up to 30% at $k \sim 1\ h$/Mpc
  - Broooooaaaad variations across hydrodynamical simulations…
- **DES Y3 fiducial approach**
  - Discards these scales !



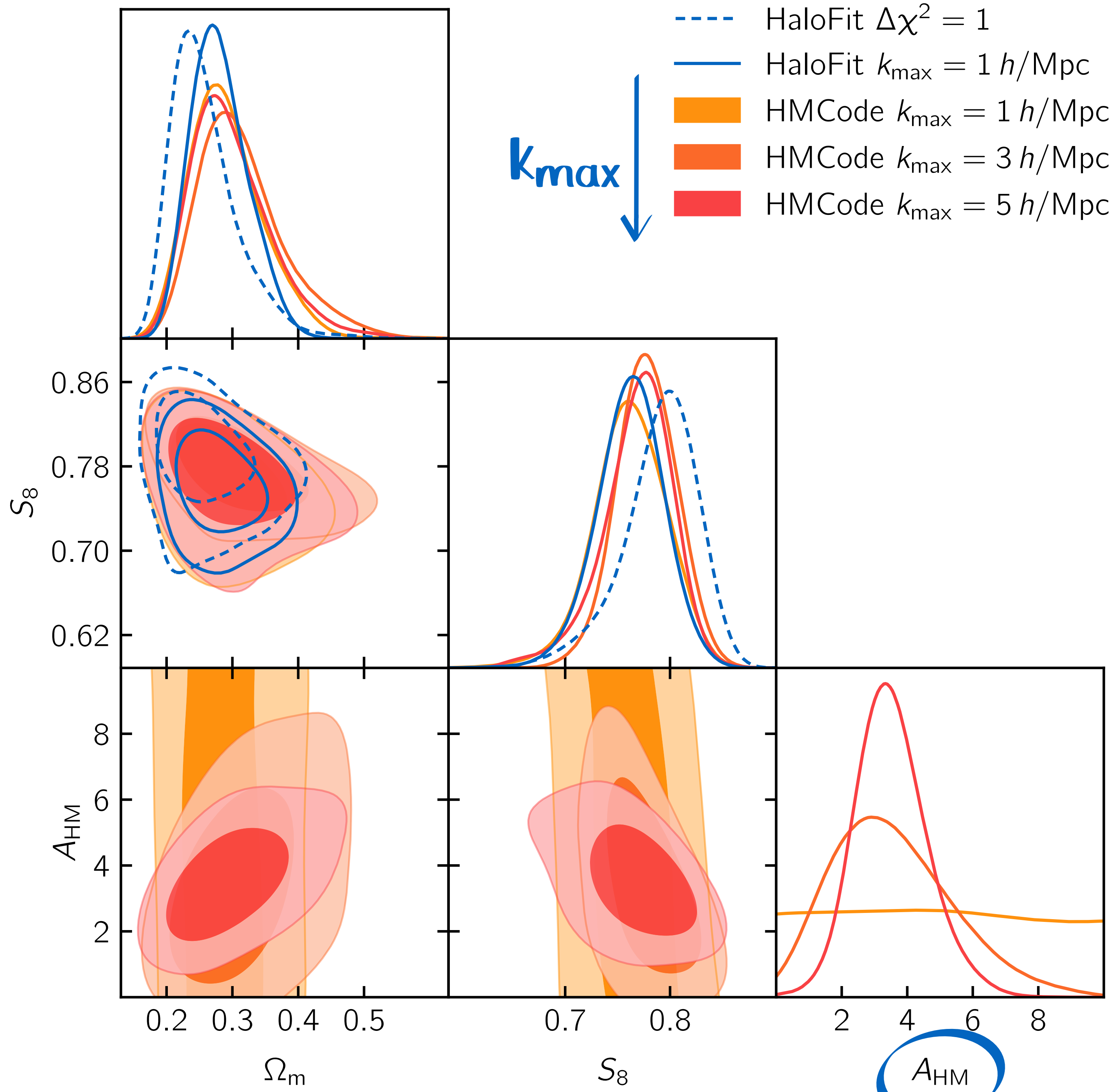
Huang+18

Baryons *vs* scale cuts



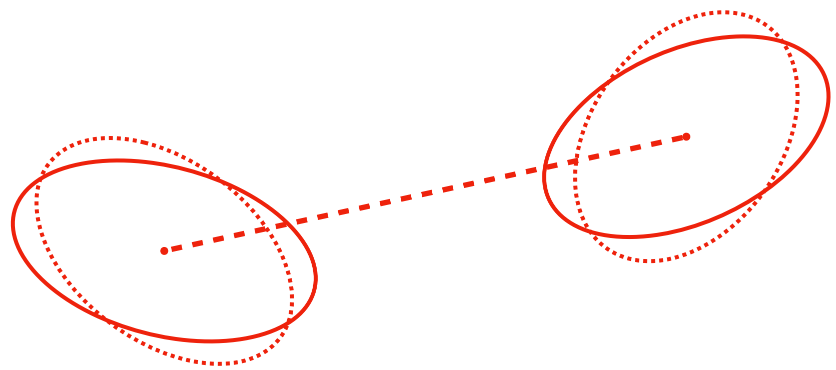
Baryons *vs* scale cuts

- **Alternative approach**
  - Model baryonic feedback with HMCode
    - A_{HM} parameter
  - Alternative scale cuts with *approximate 3D Fourier mode cut* k_{max}
    - k_{max} from 1 to 5 h^{-1}Mpc
    - ℓ_{max} from ~200 to ~1600
- **DES Y3 results**
  - HMCode shown to recover various models on simulations
  - Extra constraining power goes to baryonic feedback parameter !

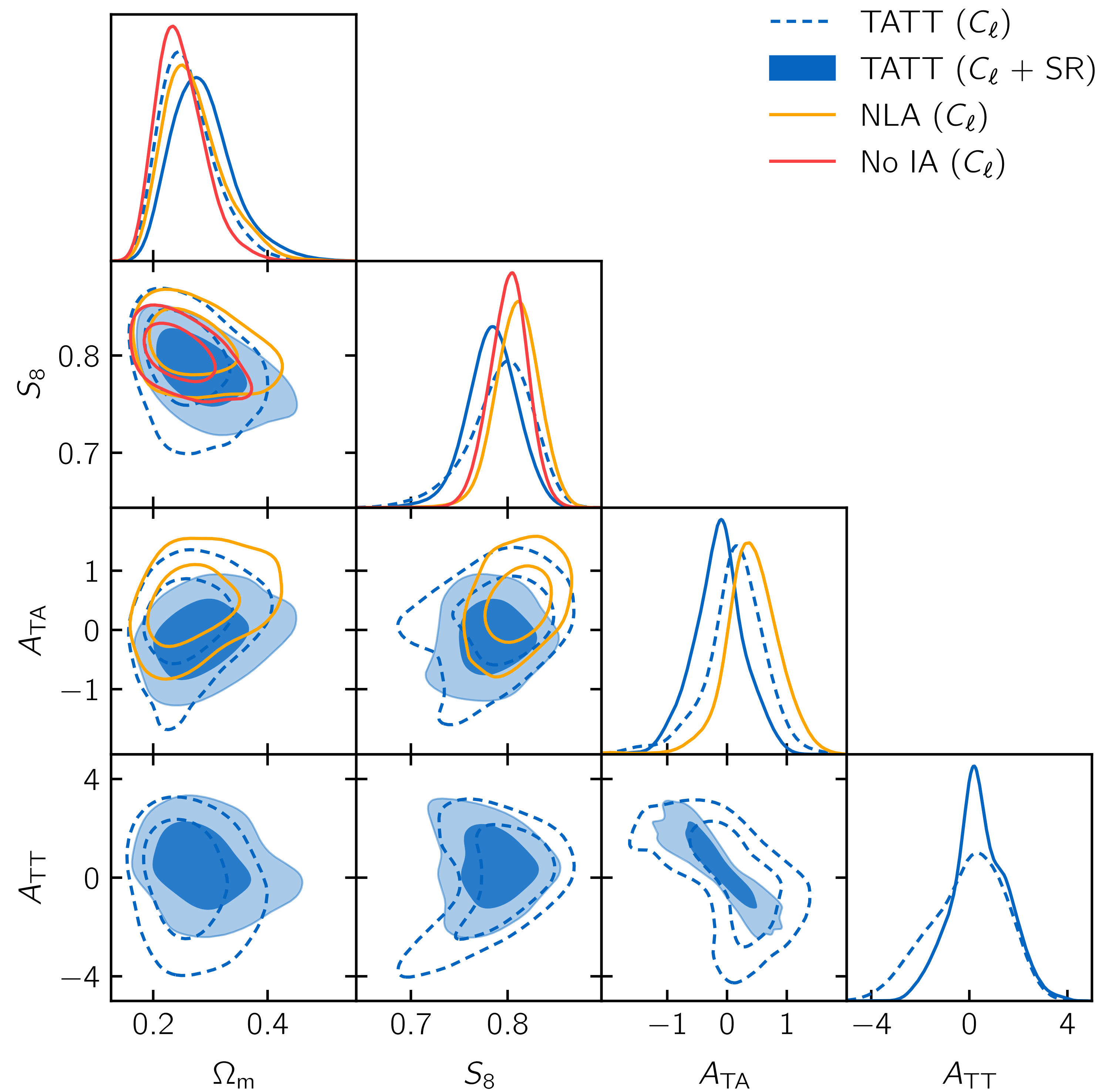


Doux+22 [DES Y3]

Intrinsic alignments



- **IA modelling**
  - Tidal alignment (TA) $\propto A_{\mathrm{TA}}$
  - Tidal torquing (TT) $\propto A_{\mathrm{TT}}$
- **DES Y3 results**
  - Degeneracy partially broken by *shear ratios*
  - More complex model (TATT) not favored by data over simpler one (NLA)



Doux+22 [DES Y3]

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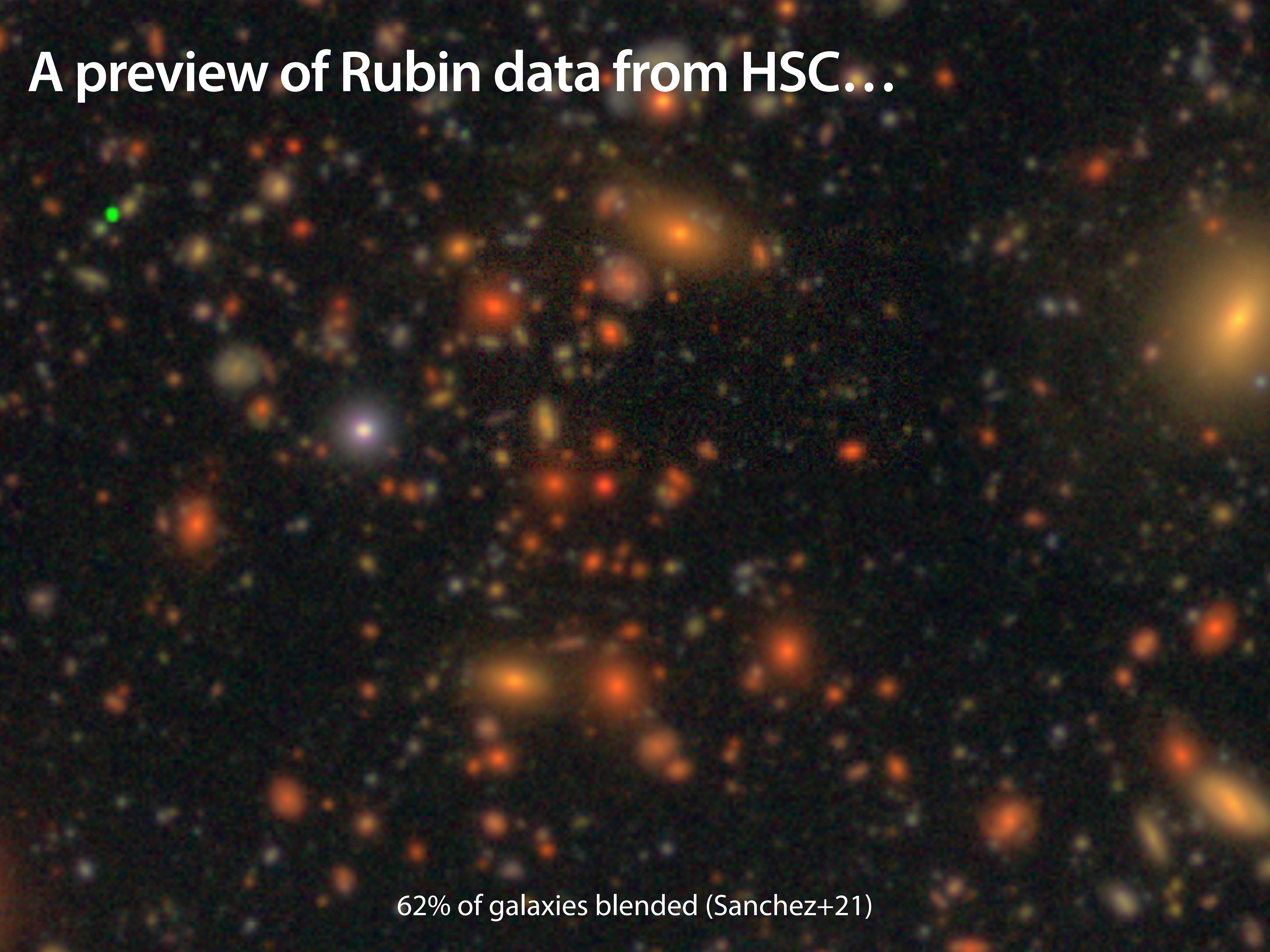
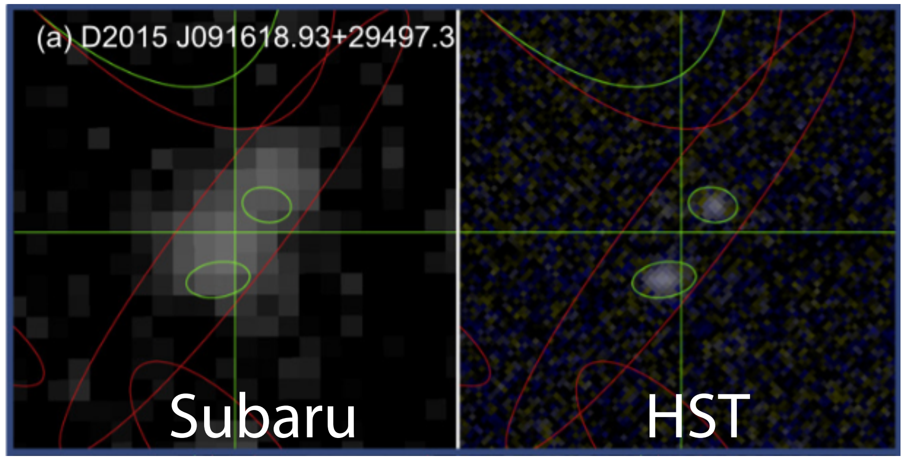
A preview of Rubin data from HSC…



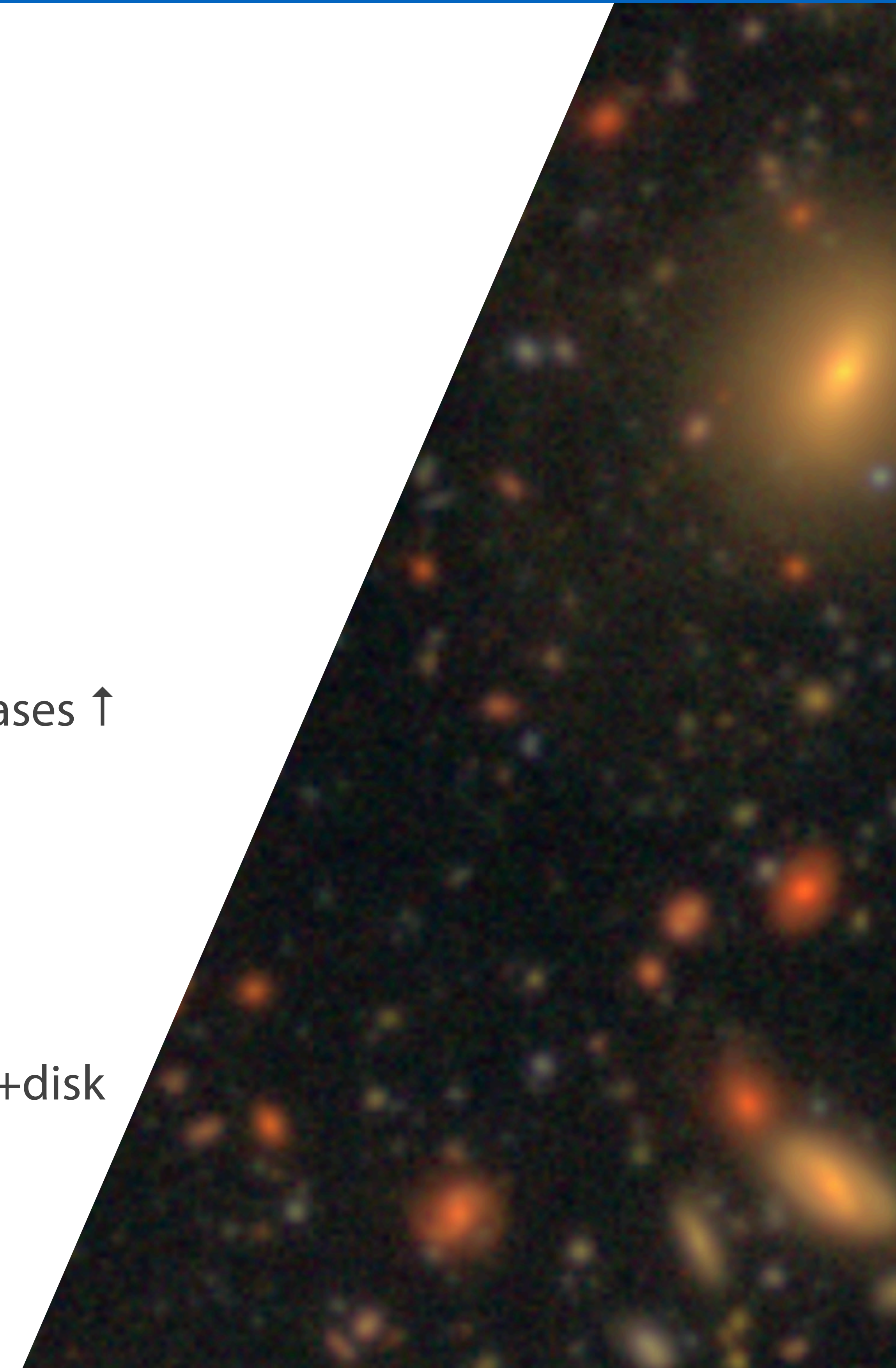
62% of galaxies blended (Sanchez+21)

Blending



Dawson+15

- **Why is it an issue?**
  - 62% galaxies are blended at LSST's depth
  - Discarding them? Statistical power ↓ and selection biases ↑
  - Impacts detection and shape/flux measurements, *ie* all weak lensing science!
- **Why is it difficult?**
  - Morphology of galaxies: Sérsic/de Vaucouleurs, bulge+disk profiles sufficient?
  - Strongly tied to detection algorithm, eg *unrecognised* blends (see Manon's talk)

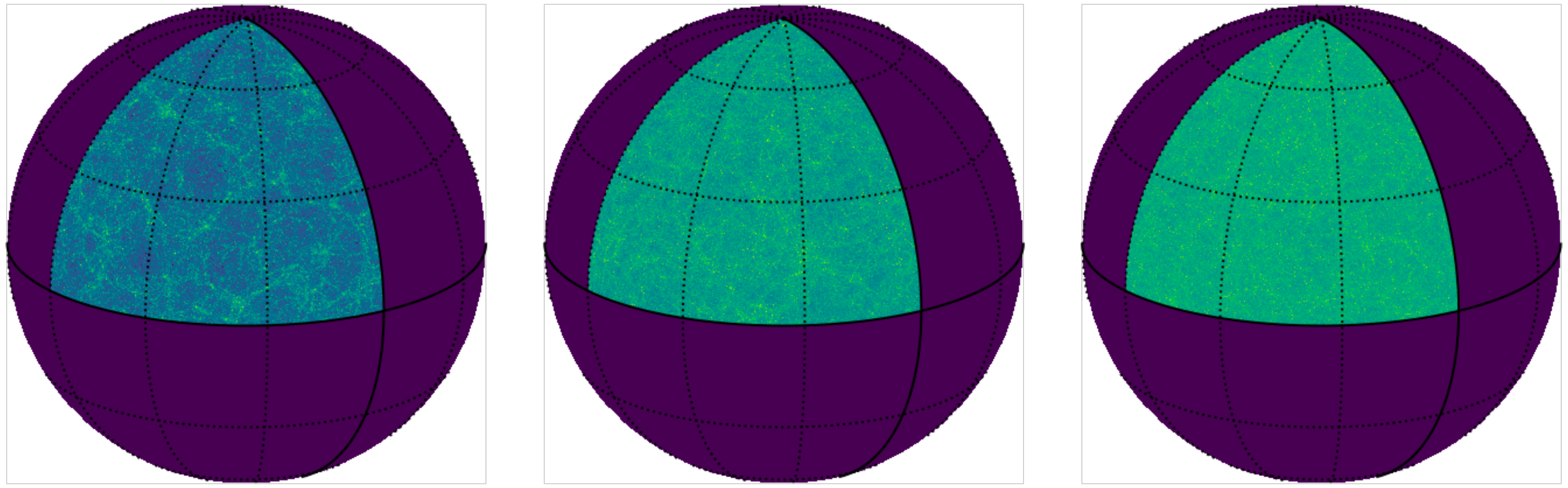


Blending WG

- **Communication**
  - Conveners: James Buchanan and myself
  - #desc-blending
- **Current approaches coordinated with DM**
  - SCARLET: multi-band deblender using constrained optimisation *Melchior, Moolekamp++*
  - METADETECT: corrects shear-dependent detection *Sheldon, Becker++*
  - Synthetic source injection (SSI): pipeline being integrated to DM stack *Meyers++*
- **DESC projects**
  - BLENDING TOOLKIT: simulation of blended images *Mendoza, Biswas, Boucaud++*
  - +++
- **Cross WG discussions**
  - #desc-blxpz : impact of blending on photometric redshift distributions
  - #desc-blxcl : impact of blending on cluster cosmology

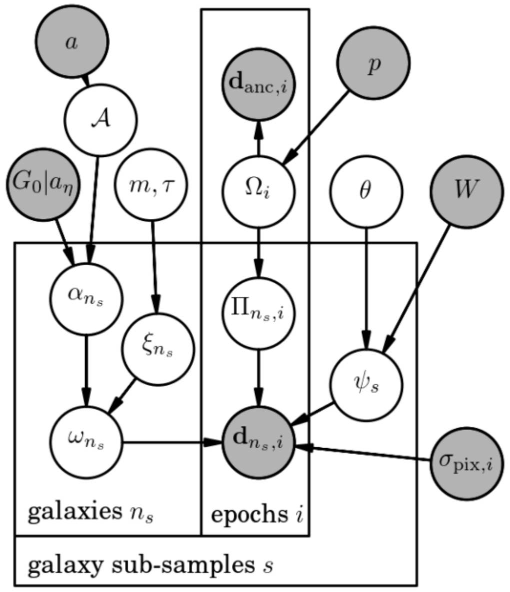
Beyond two-point functions

- **Higher-order statistics topical team**
  - Modelling of HOS: peaks, voids, 1D PDF, topological features, etc.
  - Robustness to systematics

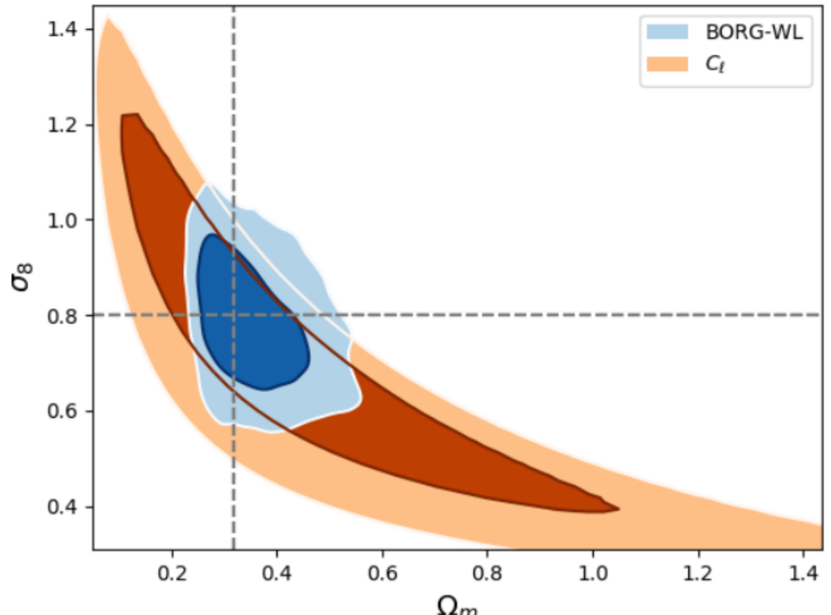


Computed rom SLICS-HR (Harnois-Déraps)

- **Bayesian pipelines topical team**
  - Cosmology to field to images forward-modelling
  - Requires fast simulations/sampling techniques (eg differentiable sims)



Schneider+15



Porqueres+21

Take-away messages

- Many algorithmic developments from DES Y3
  - PSF, deep-fields, joint redshift and shear calibration, internal consistency
- Modelling uncertainties
  - Intrinsic alignments
  - Small-scale matter power spectrum
    - Non-linearities and <u>baryonic feedback</u>
    - More data > more stringent scale cuts > constraints ??
- Weak lensing with Rubin
  - Blending impact on detection/measurement
  - Capturing more information with higher-order statistics and Bayesian pipelines, if modelling available…


Thanks!