Cosmology from Cross-Correlation of ACT-DR4 CMB Lensing and DES-Y3 Cosmic Shear

in preparation work…

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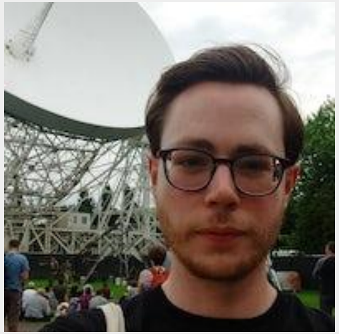

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(Cardiff)

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(ASU)

Gabriela Marques
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ACT & DES Collaboration

Weak Gravitational Lensing

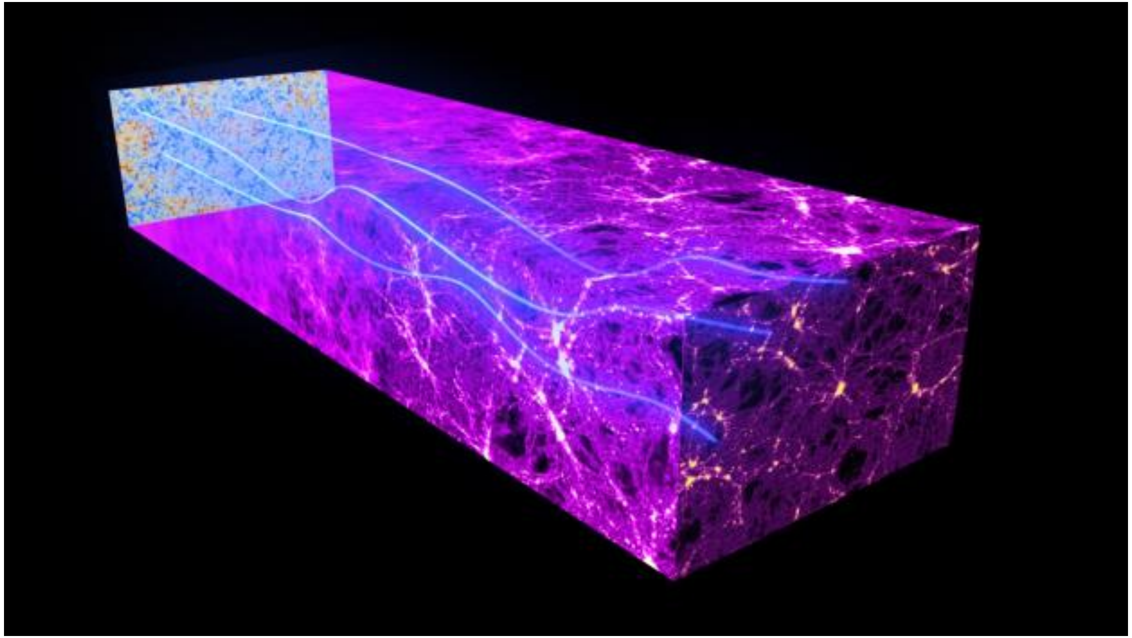


Image Credits: ESA and the Planck Collaboration

Radiation from cosmological sources such as galaxies and the CMB is gravitationally lensed by the intervening matter distribution.

For example, typical deflection of CMB photons is ~ 1 arcmin,
"Weak" gravitational lensing

Knowledge of the lensing deflection field allows the reconstruction of a measure of the projected mass distribution.

Gravitational lensing of CMB and galaxies

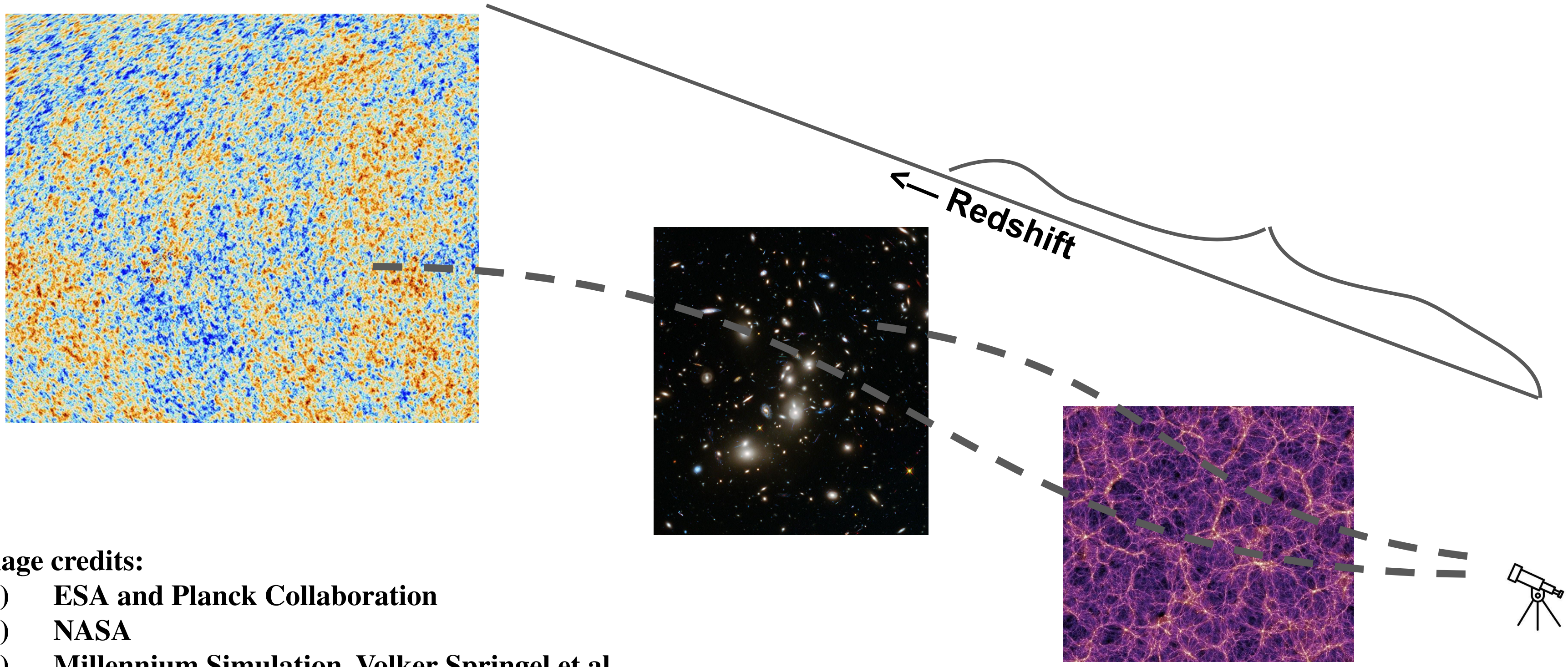


Image credits:

1) **ESA and Planck Collaboration**
2) **NASA**
3) **Millennium Simulation, Volker Springel et al.**

Weak Gravitational Lensing of CMB

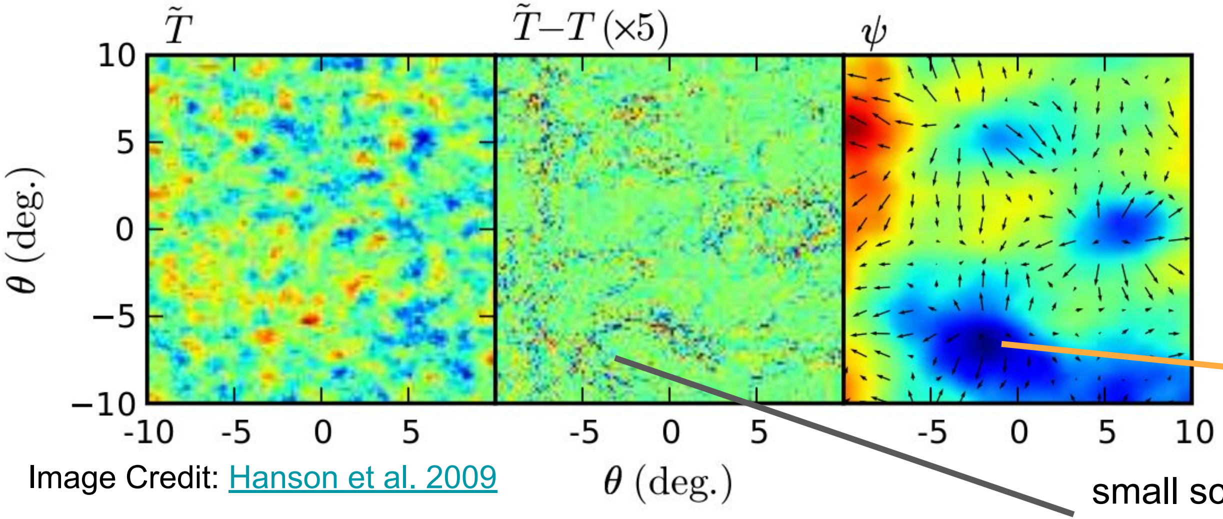


Image Credit: Hanson et al. 2009

Lensing induced correlation:

$$\langle \Delta T_{\boldsymbol{\ell}} \Delta T_{\mathbf{L}-\boldsymbol{\ell}} \rangle = f_{\boldsymbol{\ell},\mathbf{L}-\boldsymbol{\ell}} \kappa_{\mathbf{L}} + \dots$$

large scale lenses (**L**)

small scale temperature anisotropies (**l**)

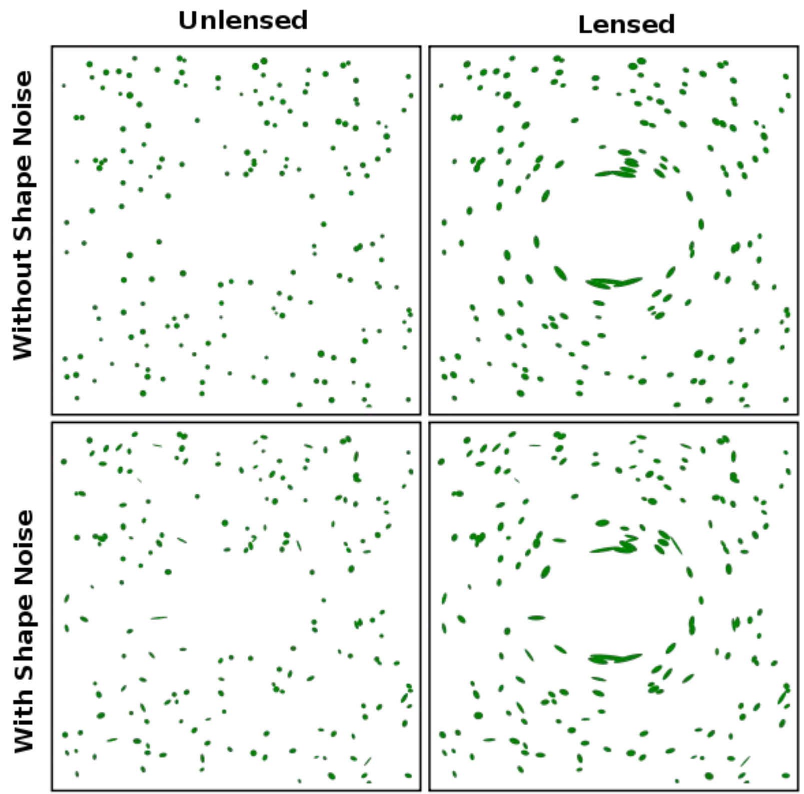
lensing weight

Convergence (κ):

$$\kappa(z_s, \hat{n}) = \int_0^{z_s} W(z, z_s)\,\delta(z, \hat{n})\,dz.$$

matter density contrast

Weak Gravitational Lensing of Galaxies



Shape of galaxies is a statistical measure of lensing induced shear (γ)

$$e = e_{\text{intrinsic}} + \gamma \Rightarrow \langle e \rangle = \langle \gamma \rangle$$

Shear and convergence are related:

E mode of shear: $\gamma_{\boldsymbol{L}} = f(\boldsymbol{L})\kappa_{\boldsymbol{L}}$

$$\kappa(z_s, \hat{n}) = \int_0^{z_s} W(z, z_s)\delta(z, \hat{n})dz.$$

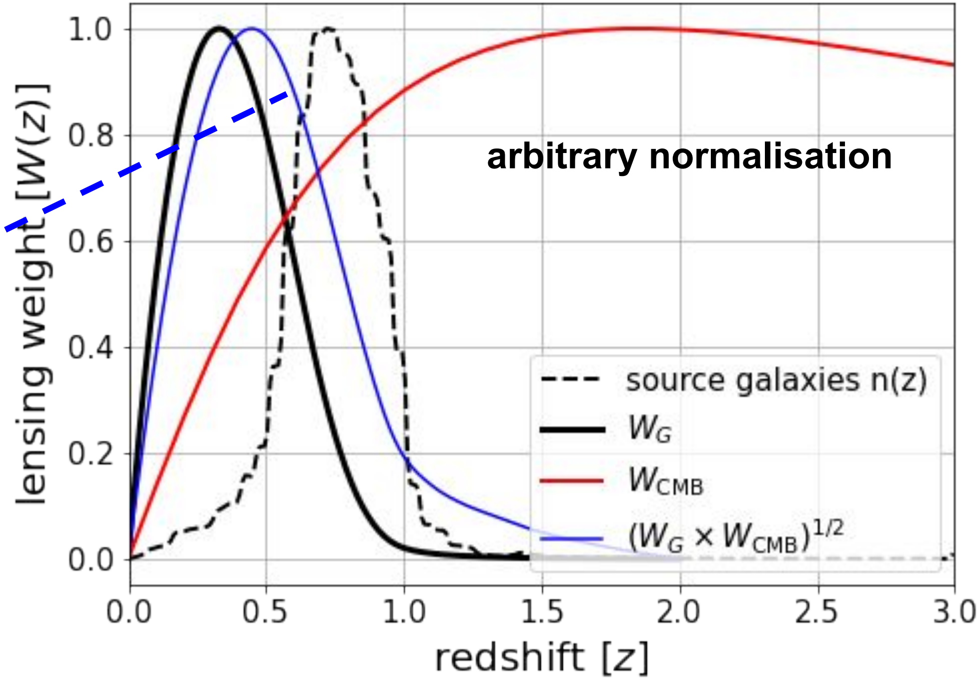
Image Credit

Weak Lensing
probe of matter distribution over wide range of redshift

Convergence (κ):

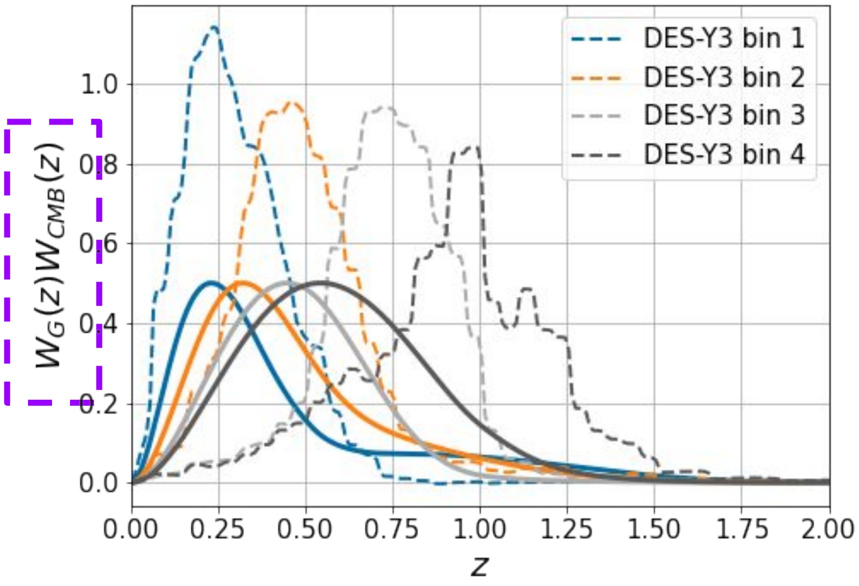
$$\kappa(z_s, \hat{n}) = \int_0^{z_s} \boxed{W(z, z_s)} \delta(z, \hat{n}) dz.$$

Combination probes a different effective redshift range.



Convergence x Shear Angular Power Spectrum

$$C_l^{\kappa\gamma_E} = \int_0^{z_H} dz \frac{H(z)}{c\chi^2(z)} W_G(z) W_{CMB}(z) P_{\delta\delta}\left(k = \frac{l+0.5}{\chi(z)}, z\right)$$



This measurement allows constraints on clustering of matter, through $\boldsymbol{\sigma_8}$ or $\mathbf{S_8}$

$$S_8 \equiv \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{1/2}$$

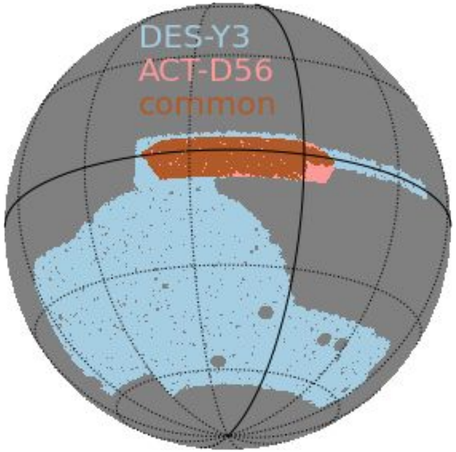
$\mathbf{S_8}$ inferred from CMB and galaxies ("*lower redshift*") observations are in somewhat disagreement.

Convergence x Shear: increasing precision

Over the last decade, CMB convergence X galaxies shear measurements have increased in precision.

ACT DR4 x DES-Y3 SNR ~ 7

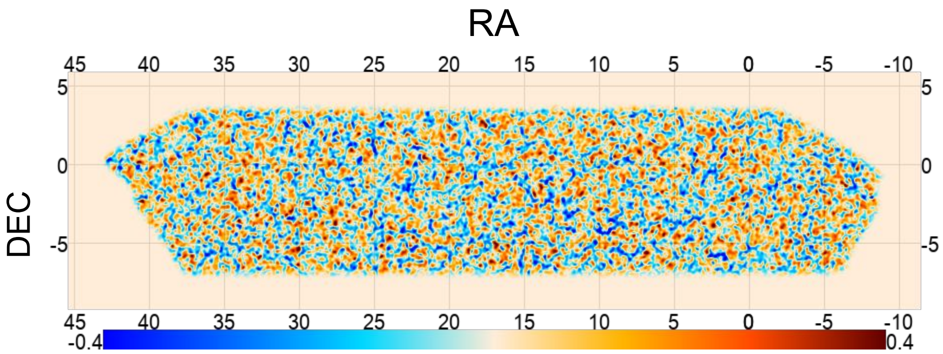
CMB and cosmic shear survey	Reference	Overlap area	Precision
ACT DR1 × CFHT Stripe 82	Hand et al. 2013	121 sq. deg.	24%
Planck × CFHTLenS	Liu et al. 2015	154 sq. deg.	22%
SPT, *Planck* × DES-SV	Kirk et al. 2015	139 sq. deg.	30%, 39%
Planck × SDSS	Singh et al. 2016	8000 sq. deg.	23%
Planck × CFHTLenS, RCSLenS	Harnois-Deraps et al. 2016	147, 601 sq. deg.	31%, 33%
Planck × KiDS-450	Harnois-Deraps et al. 2017	450 sq. deg.	19%
SPT + *Planck* × DES-Y1	Omori et al. 2018	1289 sq. deg.	17%
POLARBEAR × HSC	Namikawa et al. 2019	11 sq. deg.	48%
Planck × HSC	Marques et al. 2020	131 sq. deg.	25%
Planck, ACTPol × KiDS-1000	Robertson et al. 2020	450, 275 sq. deg.	14%, 15%
SPT + *Planck* × DES-Y3	Chang et al. 2023	3920 sq. deg.	5.5%
ACT DR4 × DES-Y3	**This work**	**450 sq. deg.**	**14%**
ACT DR6 × DES-Y3	approximate forecast	~ **4000 sq. deg.**	~ **4%**



~ 450 sq. deg.
common area

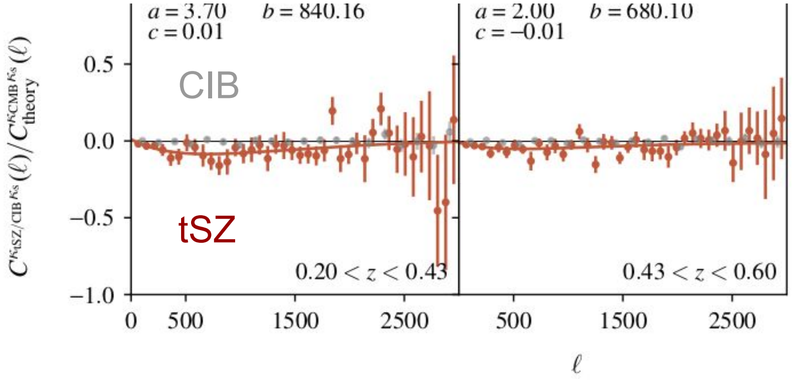
ACT DR4 κ maps

- ACT observations in 98 and 150 GHz
- Data from 2014 and 2015 observations
- Quadratic Estimator, two maps
  - ACT only
  - **ACT + Planck (thermal SZ signal is deprojected)**



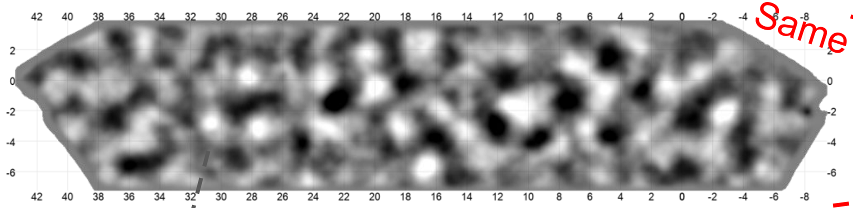
tSZ and CIB bias in CMB lensing and galaxy leaning cross-correlation

Baxter et al. 2019 (DES Y1 x SPT+Planck)



Weak gravitational lensing of CMB and galaxies
ACT DR4 and DES-Y3

Lensing potential (ϕ) map from CMB observations

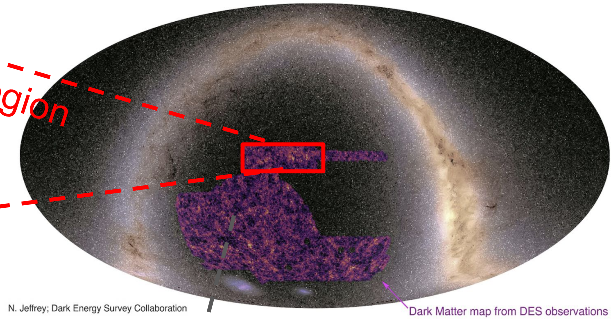


ACT collaboration, Darwish et al. 2020

Filtered map showing only large scale lenses

Same sky region

Mass map (κ) from galaxy observations



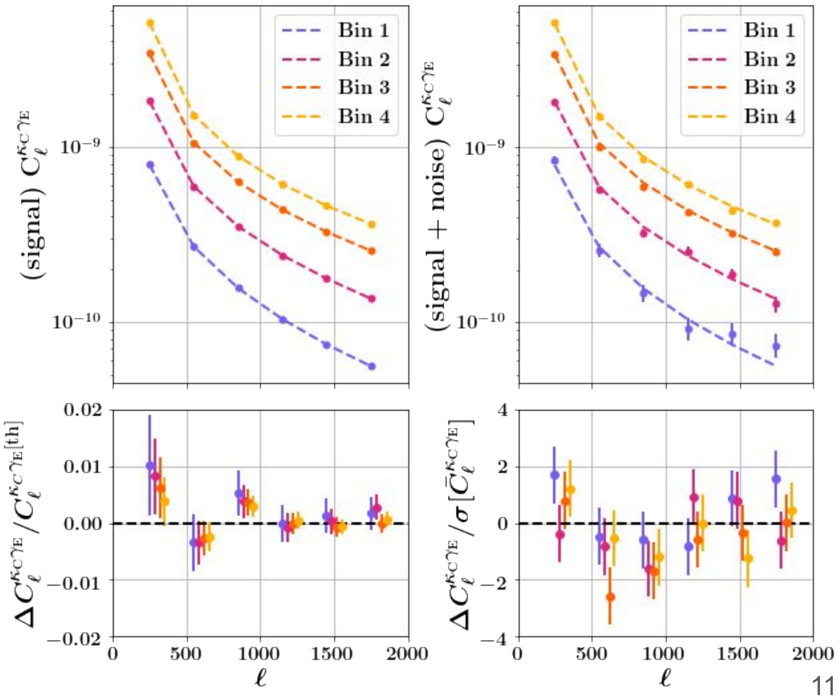
DES collaboration Jeffrey et al. 2021

κ map reconstructed from galaxies shear in Jeffrey et al. 2021. However, in this analysis, we use shear map directly.

Simulations and Covariance

- **Theory** (Halofit matter power spectrum)
- Correlated lognormal signal maps of κ and γ
- **CMB κ noise**: lensing reconstruction simulations (lensing noise is non-gaussian)
- **Galaxies γ noise:** random rotation of DES Y3 galaxy ellipticities
- **Power spectrum computation**
- **Covariance matrix** using 511 S+N simulations
- **Scale Cuts:**
  - **L_{min} = 100** (avoid *mean field bias* in CMB lensing reconstruction)
  - **L_{max} = 1900** (baryonic effects less than 1% of errorbar at L < 1900)

Simulation mean bandpowers: comparison with theory input

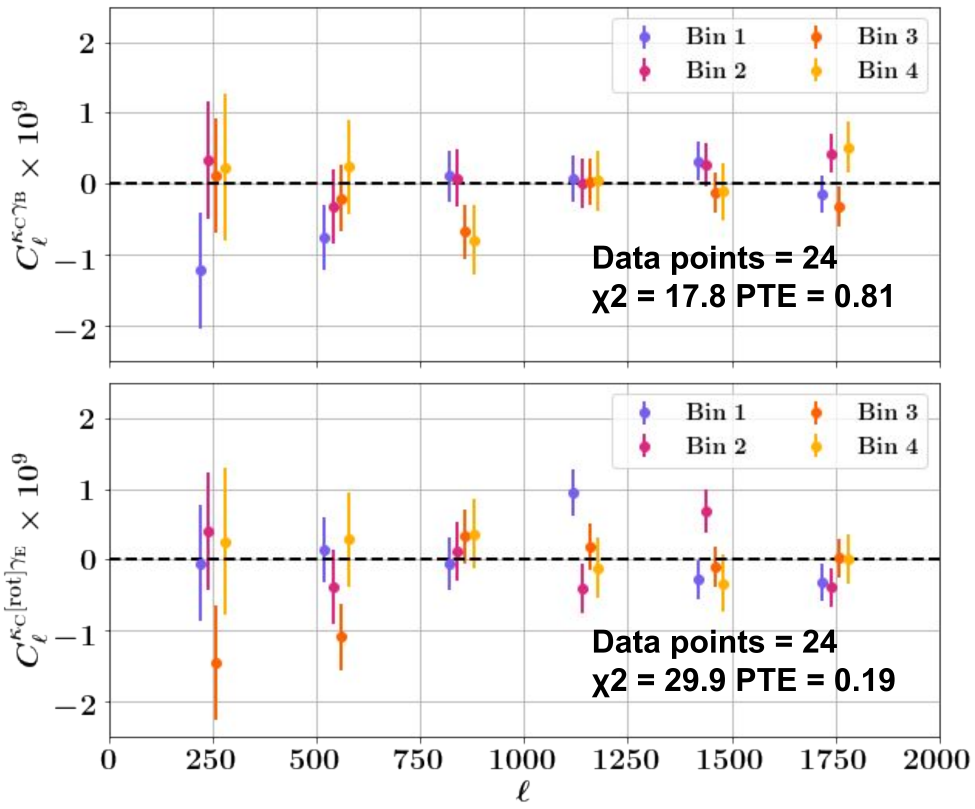


Null Tests: check data for non-idealities

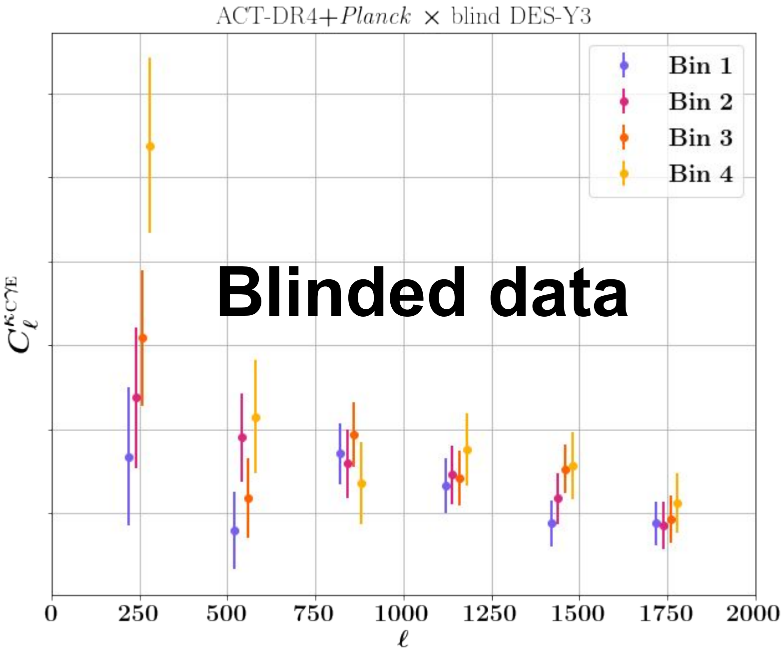
B-mode null test

Tests for the spurious B-modes in the shear maps

Rotation null test

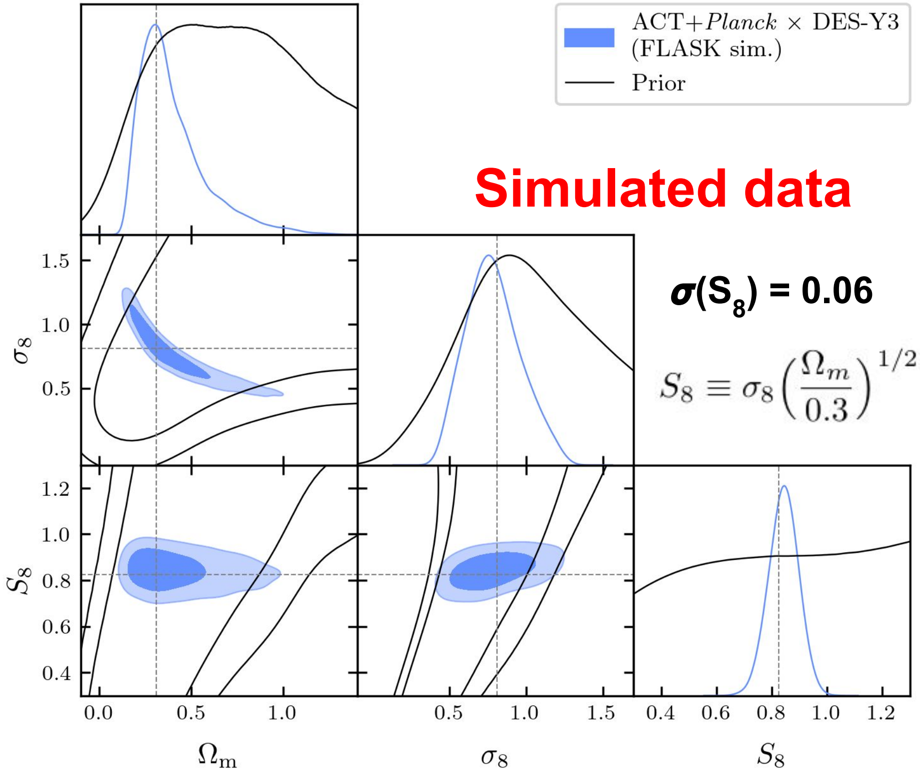


ACT+Planck (tSZ deprojected) data bandpowers



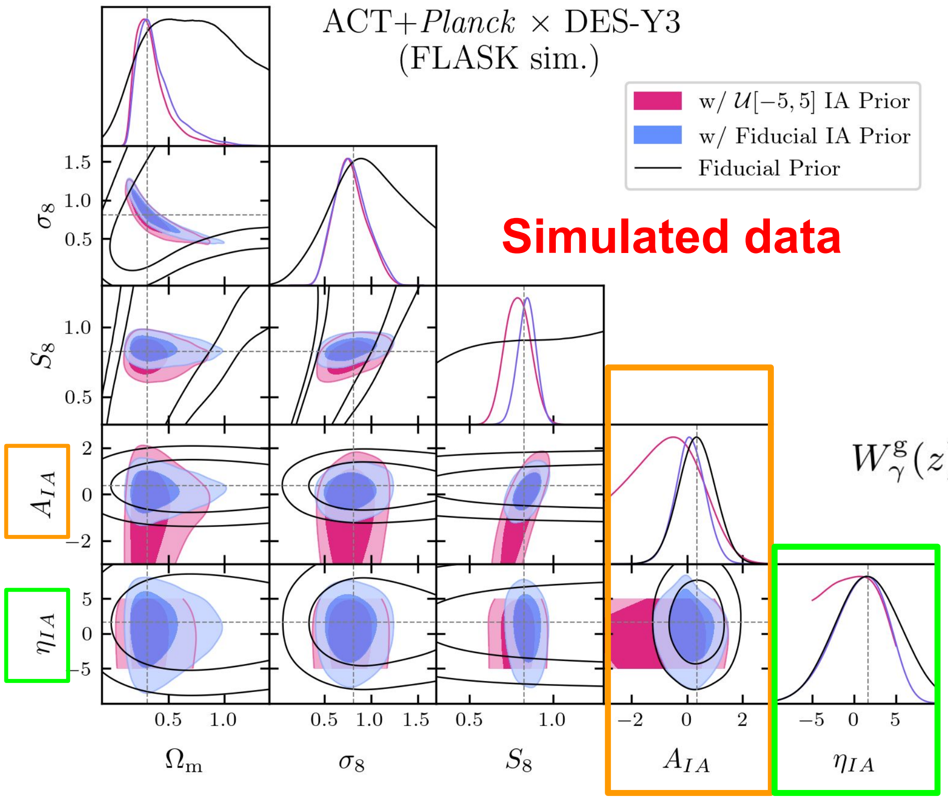
Blinding policy: catalog level blinding that results in rescaling of the power spectrum by an unknown factor.

Parameter Constraints Based on Simulations
Cosmological Parameters



Parameter inference with SOLikeT: parameter inference package being developed by SO collaboration which uses Cobaya Monte Carlo sampling framework.

Intrinsic Alignment of galaxies



Tidal forces by the surrounding large scale structure causes the galaxies to align with the surrounding matter distribution and nearby galaxies.

We use Nonlinear Linear Alignment (NLA) model.
(Hirata et al. 2007; Bridle & King 2007)

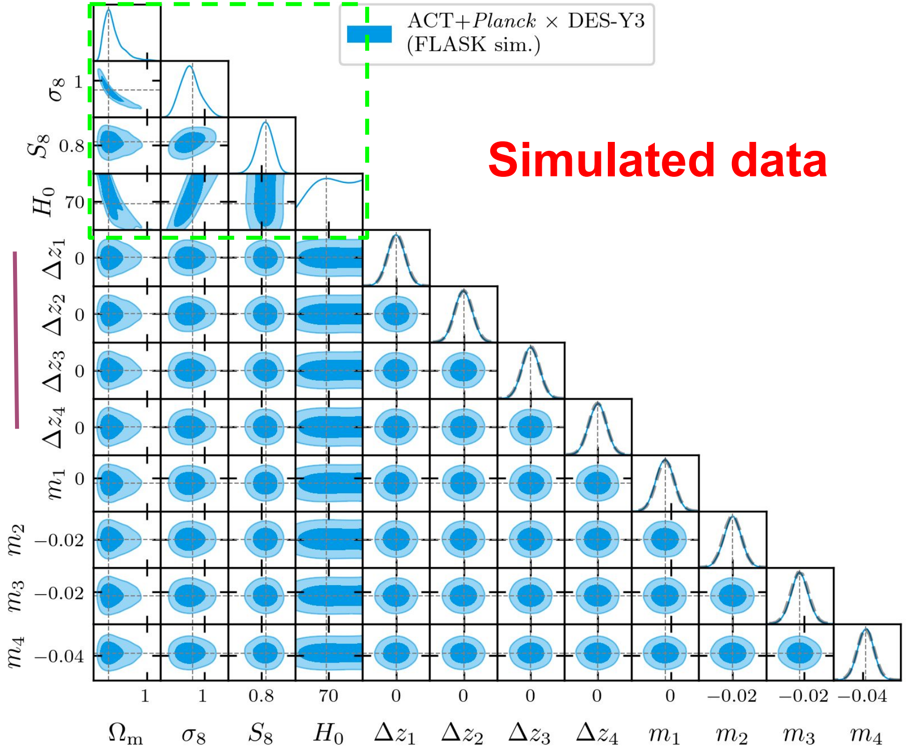
$$W^{g}_{\gamma}(z) \rightarrow W^{g}_{\gamma}(z) - A_{\rm IA} C_1 \rho_{\rm cr} \frac{\Omega_{\rm m}}{G(z)} n(z) \left(\frac{1+z}{1+z_0}\right)^{\eta_{\rm IA}}$$

Parameter Constraints Based on Simulations
Systematics Parameters

Cosmological parameters

Photometric redshift bias

Multiplicative shear bias



Simulated data

Cosmological parameter constraints are obtained after marginalisation over systematic parameters.

However, no significant constraining power for systematic parameters with ACT DR4 x DES Y3 when the DES-Y3 priors are assumed.

Summary

- Cross-correlations offer a way to constrain cosmological parameters robust to some of the systematics affecting individual probes.
- Combining different probes alleviates some of the parameter degeneracies.
- Combining galaxy weak lensing with CMB weak lensing probes effectively higher redshift range not accessible by the galaxy survey on its own.
- ACT DR4 $\boldsymbol{\kappa}$ x DESY3 $\boldsymbol{\gamma}$ is SNR ~ 7 measurement with $\boldsymbol{\sigma(S_8) = 0.06}$, with expected approximately three times more SNR with ACT DR6.