Cosmology from KiDS+DES peak count

Dr. Joachim Harnois-Déraps
STFC-ERF, Newcastle University

COSMO21
Chania

Science and Technology Facilities Council

Newcastle University

based on arXiv: 2405.10312

Thanks: KiDS and DES, Sven Heydenreich, Nicolas Martinet, Benjamin Giblin, Marika Asgari & Tilman Tröster

Dr. Joachim Harnois-Déraps
STFC-ERF, Newcastle University

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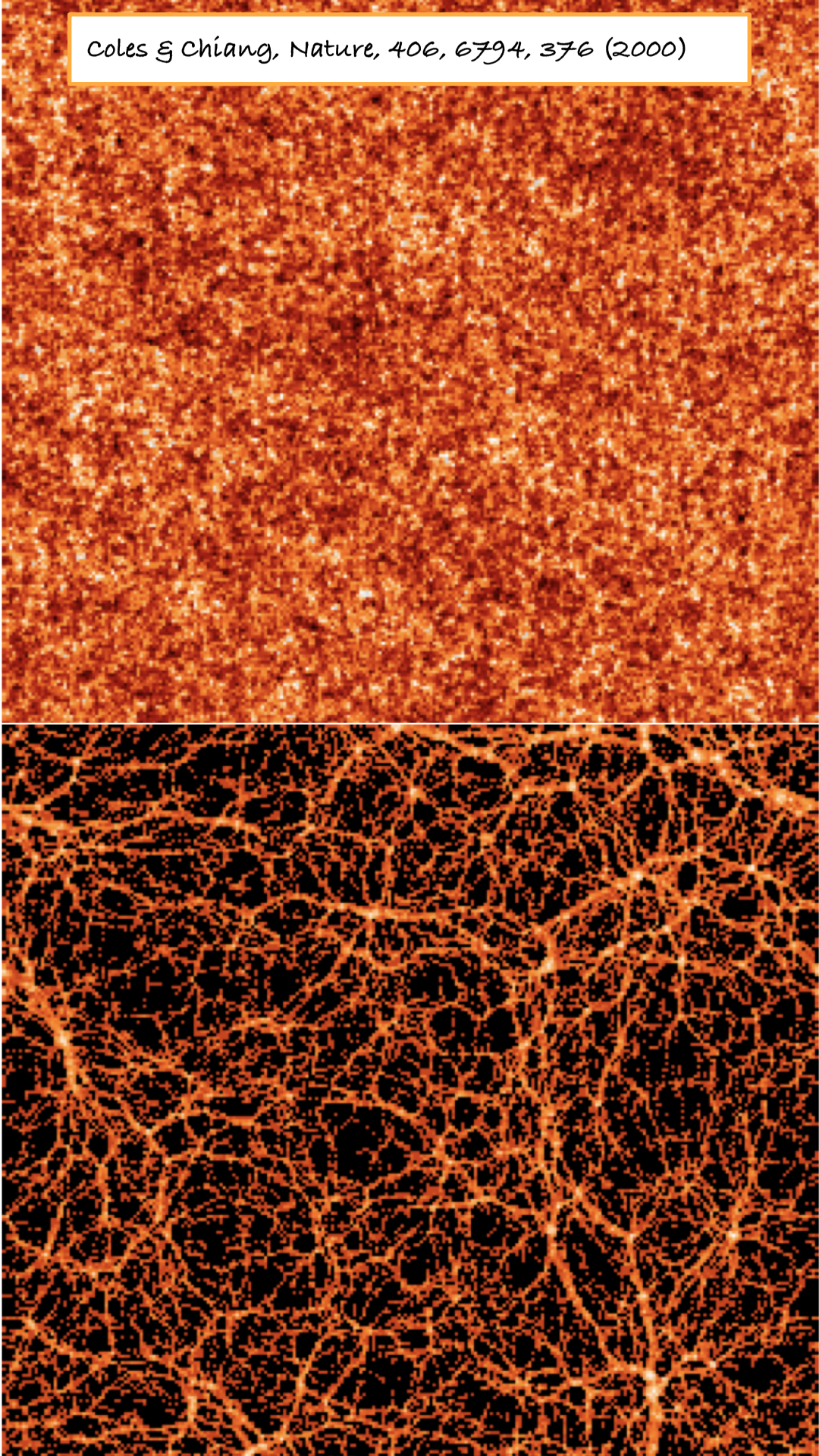
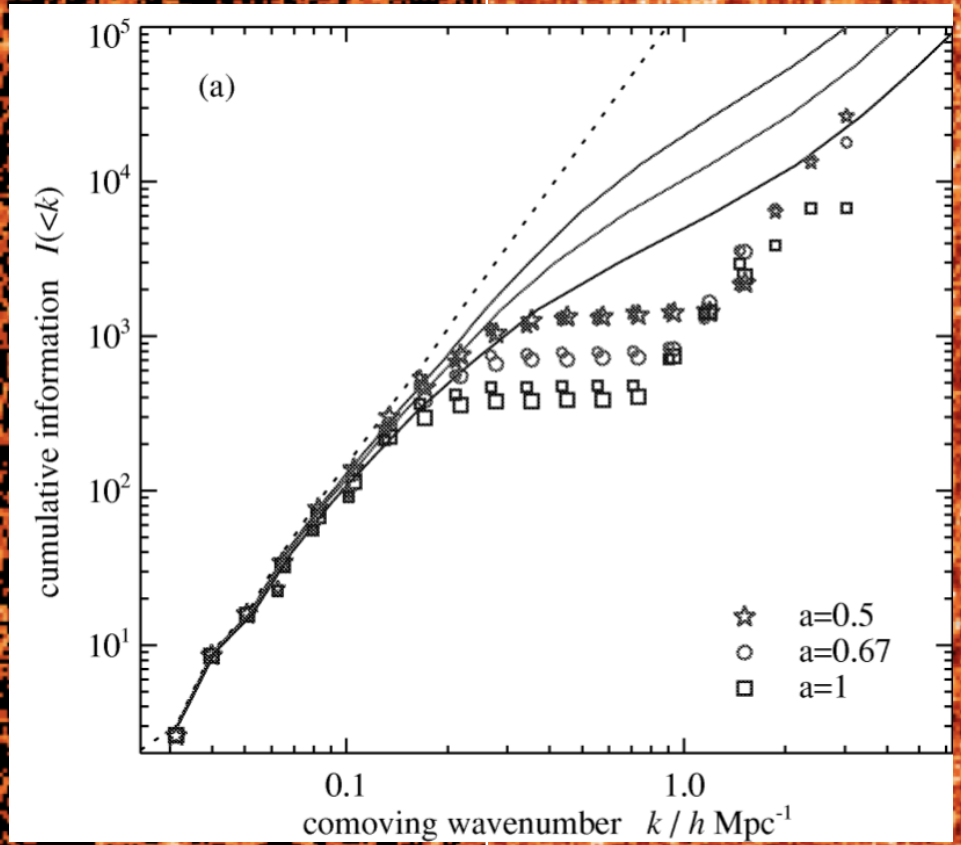

Coles & Chiang, Nature, 406, 6794, 376 (2000)



Information content of the non-linear matter power spectrum

Christopher D. Rimes[1]★ and Andrew J. S. Hamilton[1,2]★ (2005)

Coles & Chiang, Nature, 406, 6794, 376 (2000)

Cosmology inference with shear 2pt

$$\hat{\xi}^{ij}_{\pm}(\theta) = \frac{\sum_{ab} w_a w_b \left[\epsilon^i_t(\vec{x}_a)\epsilon^j_t(\vec{x}_b) \pm \epsilon^i_\times(\vec{x}_a)\epsilon^j_\times(\vec{x}_b)\right]}{\sum_{ab} w_a w_b}$$

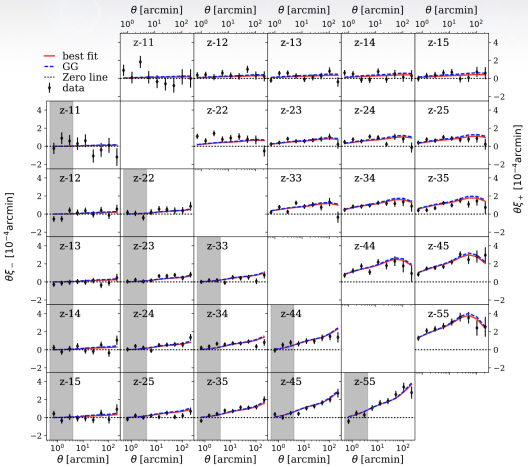
Observations

Ellipticities (ϵ_1, ϵ_2)

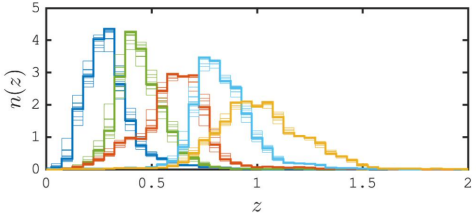
Redshifts (z)

Spectroscopic calibration/SOM/ML

Tomography



Redshift distribution



Systematic biases

- Shear calibration (m, c)
- Mean redshift (Δz)
- Intrinsic alignment (A_{IA})
- Baryons (B)

Cosmological parameters (e.g. Ω_m, σ_8)

Theoretical predictions

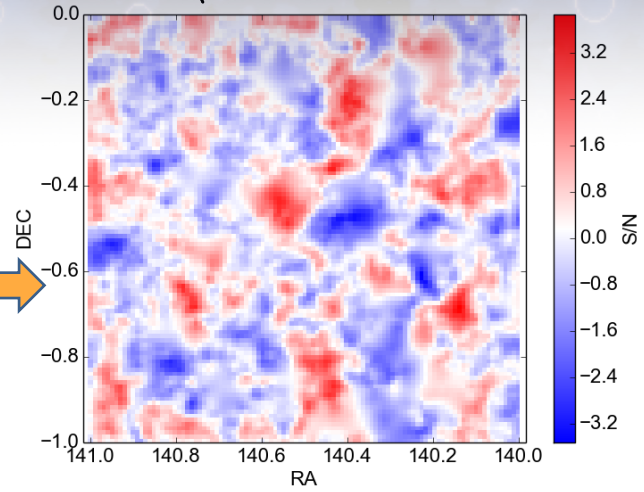
$$\xi^{ij}_{\pm}(\theta) = \frac{1}{2\pi}\int \mathrm{d}\ell\, \ell\, P^{ij}_\kappa(\ell)\, J_{0,4}(\ell\theta)$$

$$P^{ij}_\kappa(\ell) = \int_0^{\chi_H} \mathrm{d}\chi \frac{q_i(\chi) q_j(\chi)}{[f_K(\chi)]^2} P_\delta\left(\frac{\ell}{f_K(\chi)}, \chi\right)$$

$$q_i(\chi) = \frac{3H_0^2\Omega_m}{2c^2}\frac{f_K(\chi)}{a(\chi)}\int_\chi^{\chi_H} \mathrm{d}\chi'\, n_i(\chi')\frac{f_K(\chi'-\chi)}{f_K(\chi')}$$

Cosmology inference beyond 2pt

Non-Gaussian statistics



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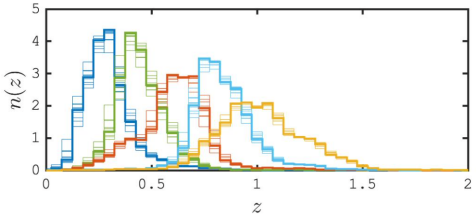
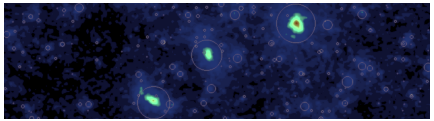


Cosmological parameters (e.g. Ω_m, σ_8)

~~Theoretical predictions~~

Simulation-based inference



Basic Pipeline

Create mock catalogues:

-Run N-body

-Light-cone mass maps (potentially many per N-body)

-Ray-trace: convergence, shear maps (+ 2D tidal fields for IA)

-Clone data: assign simulated lensing quantities to clone

-Repeat for every simulations

Measure non-Gaussian statistics:

Lensing peak statistics, lensing PDF, lensing voids, topological analysis (e.g. Minkowski functional, Betti numbers, persistent homology), scattering transform, CNN...

Infer cosmology:

Interpolate model

Model & Sample likelihood

Constrain parameters

Simulations

How many:

Cosmology: 50

Covariance matrix: 225

Intrinsic alignments: 10

Baryons: 2 (Hydro, so $£€!)

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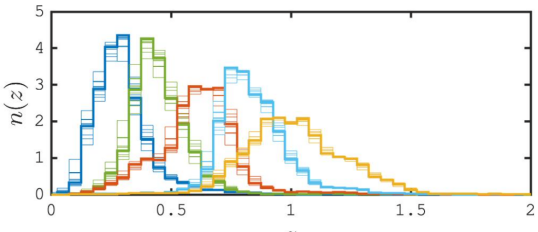
PDF: Castiblanco+ (2024) arXiv :2405.09651

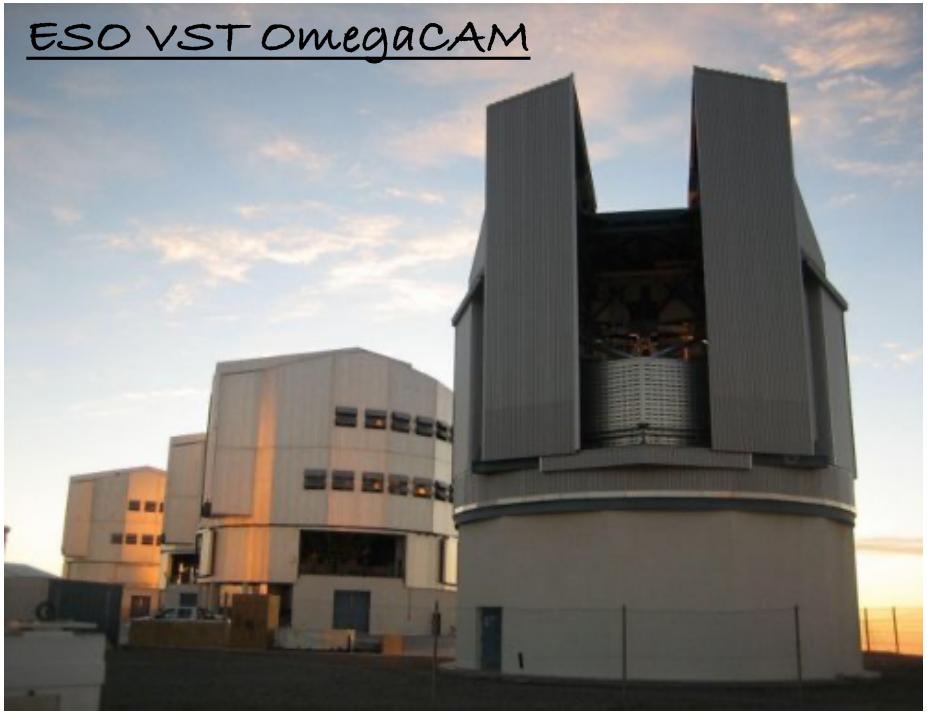
Comparison: Euclid Collaboration (2023) A&A, 675, 120

KiDS-1000 Survey:

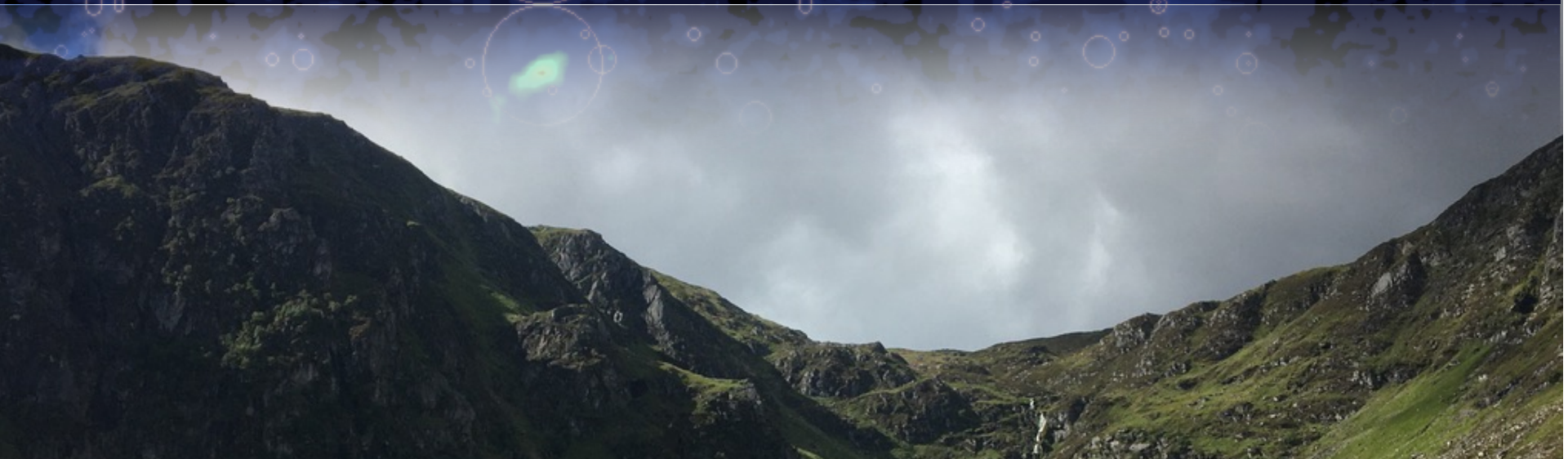
777 (unmasked) deg^2
6.2 gal/arcmin^2
9 photometric bands
5 tomographic bands
21 million galaxies

(Giblin+2021, Hildebrandt+2021, Joachimi+2021, Asgari+2021)





KiDS-1000: Cosmology from Peak count



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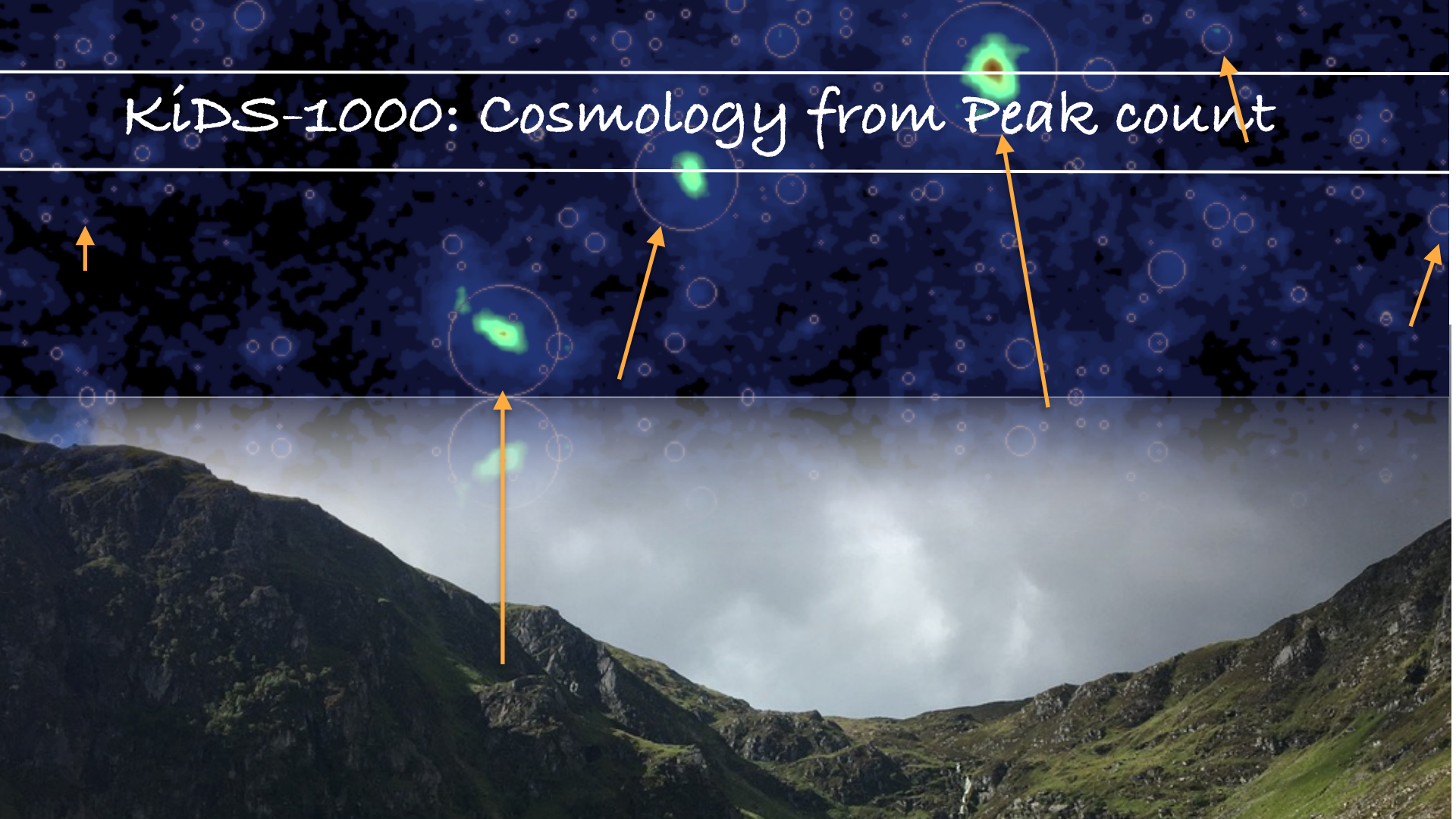

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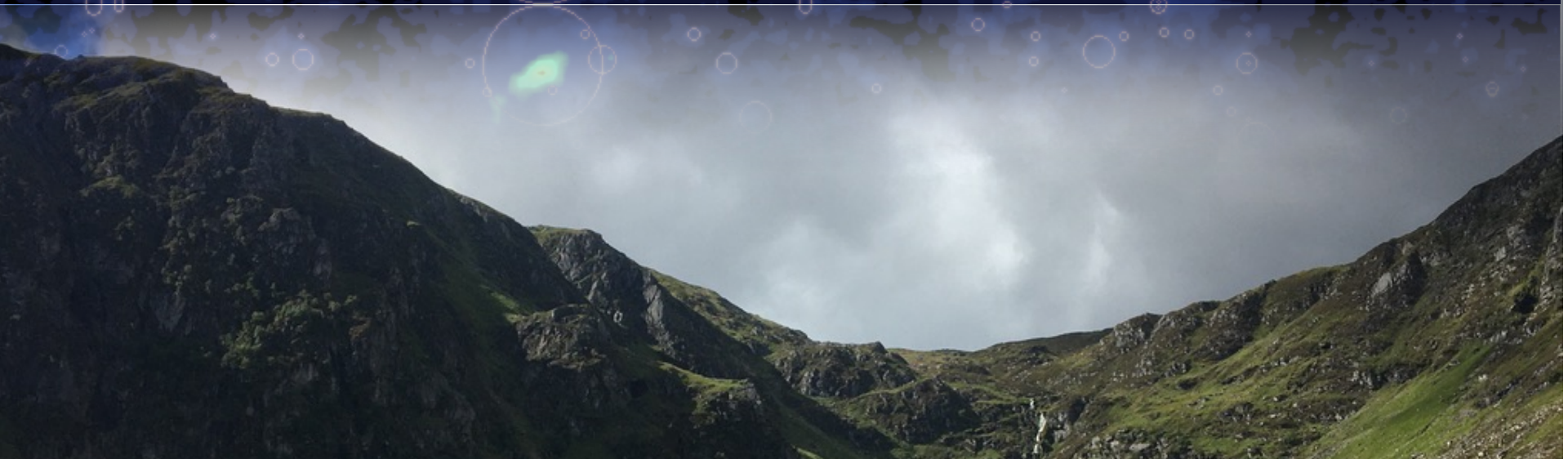

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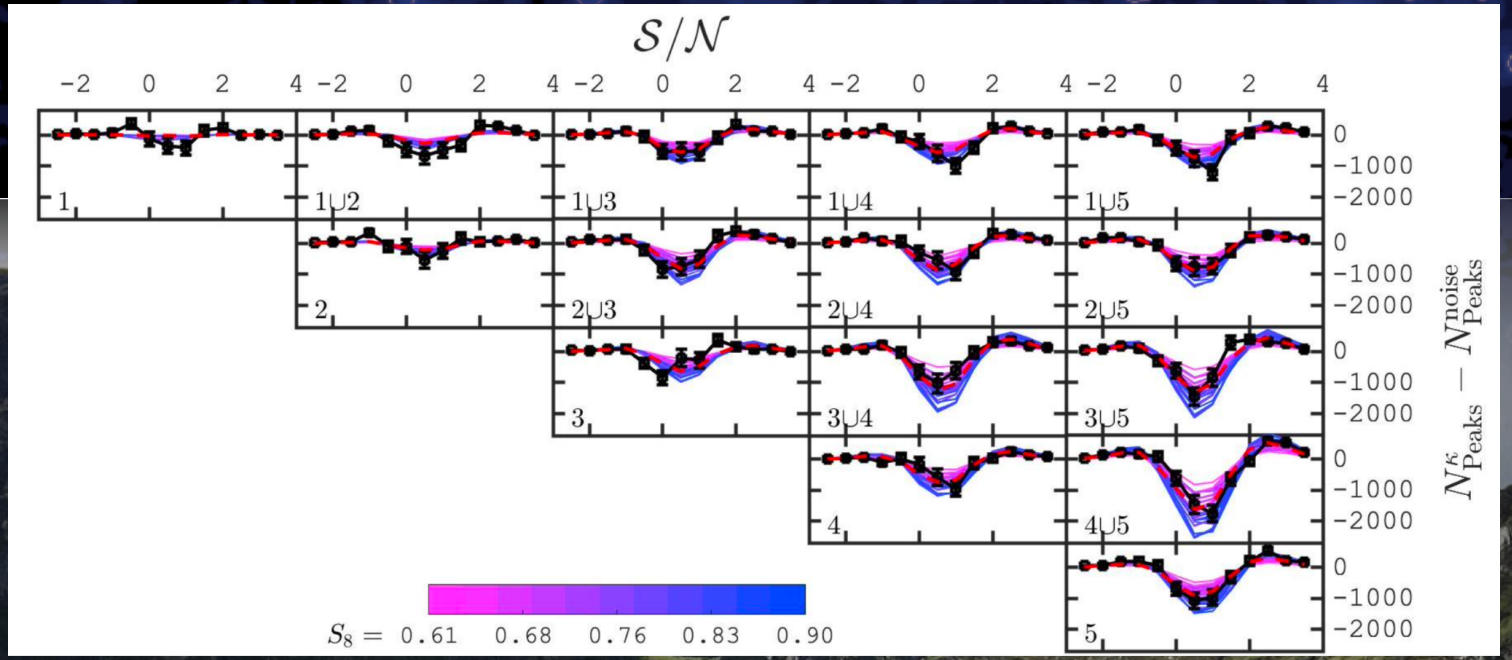
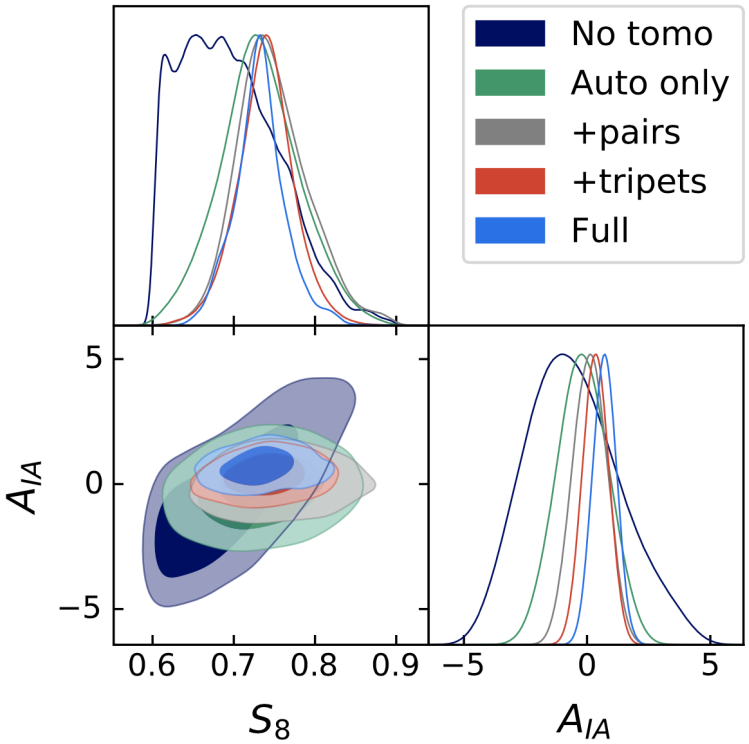
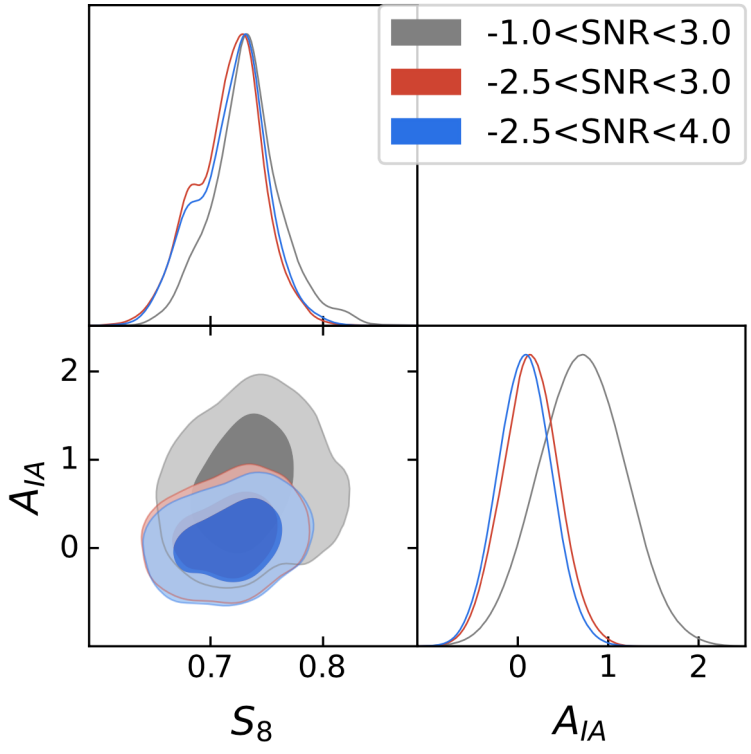


Tomography:



Cuts in SNR



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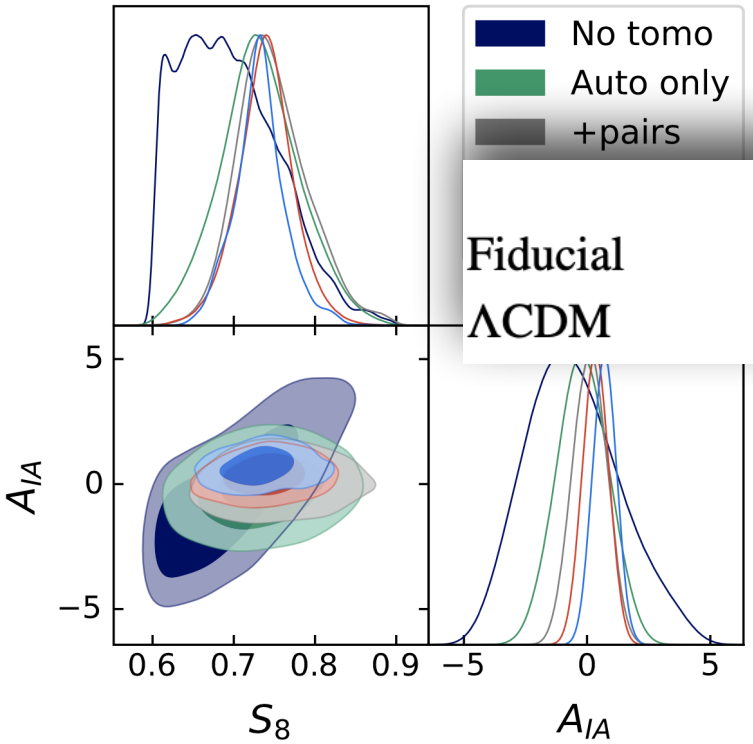
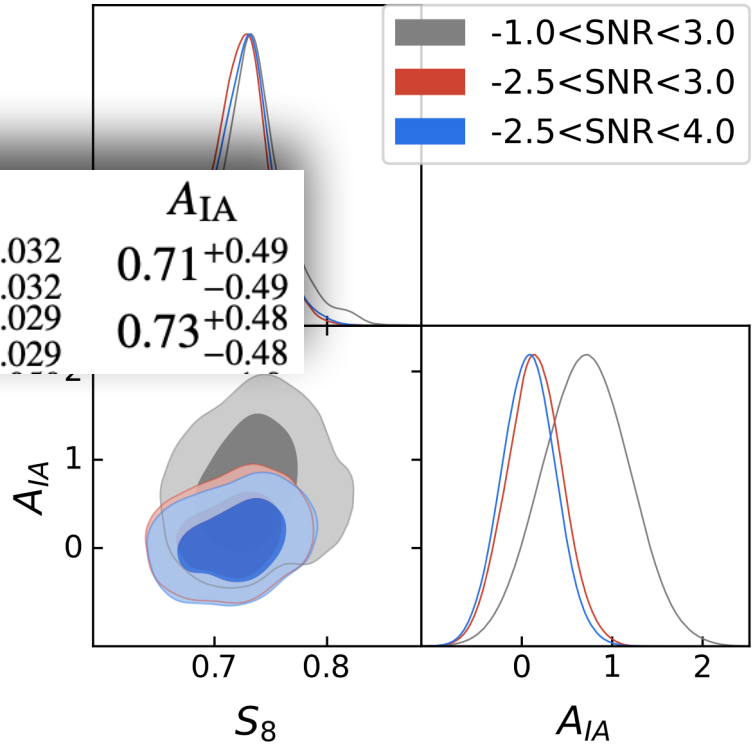
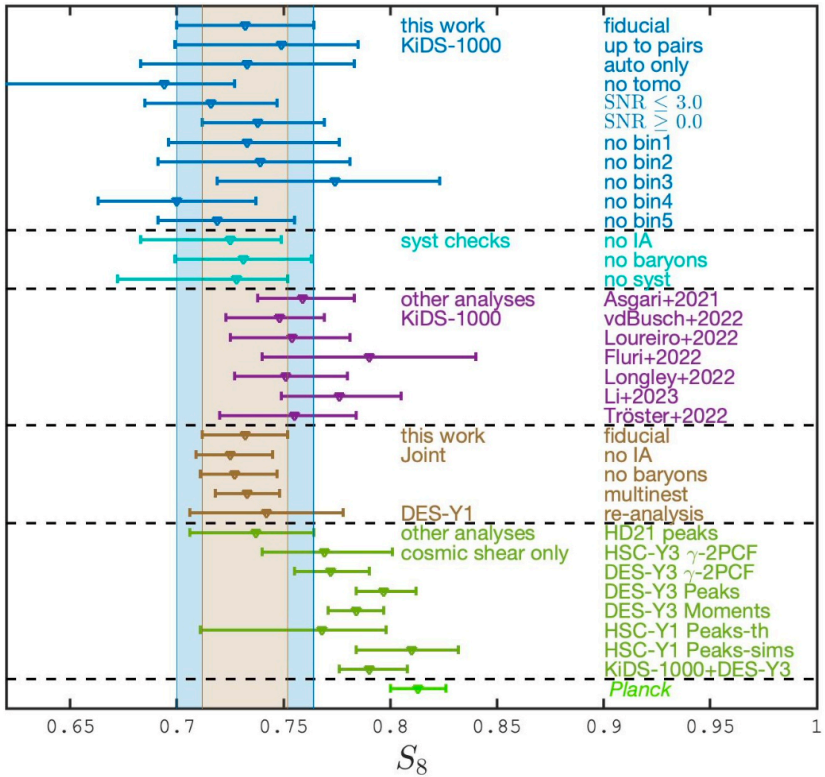


	S_8	$A_{\rm IA}$
Fiducial	$0.733^{+0.032}_{-0.032}$	$0.71^{+0.49}_{-0.49}$
ΛCDM	$0.732^{+0.029}_{-0.029}$	$0.73^{+0.48}_{-0.48}$

Cuts in SNR



Multiple analysis verifications



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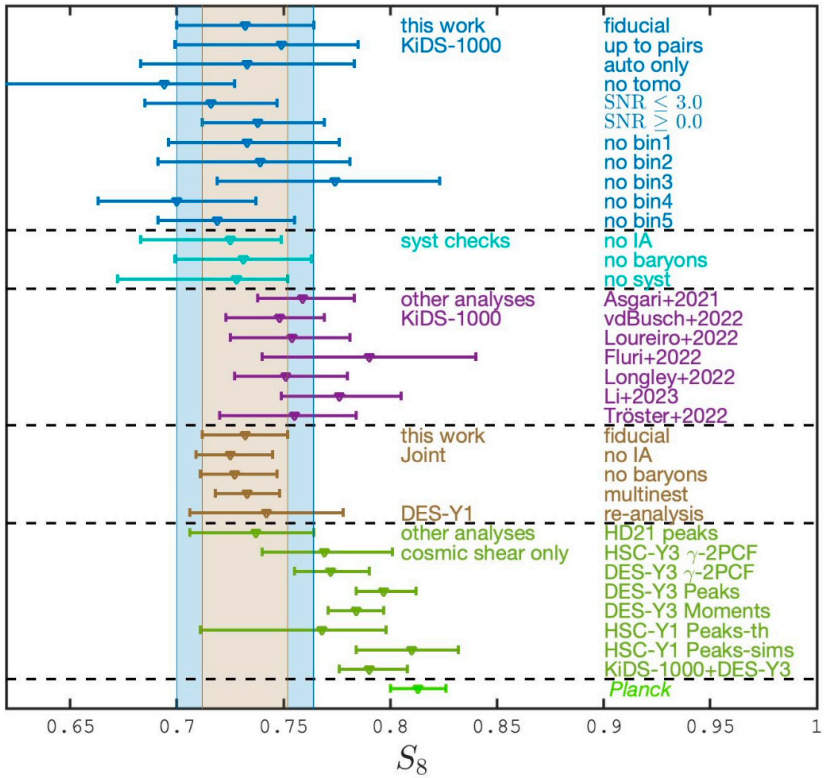
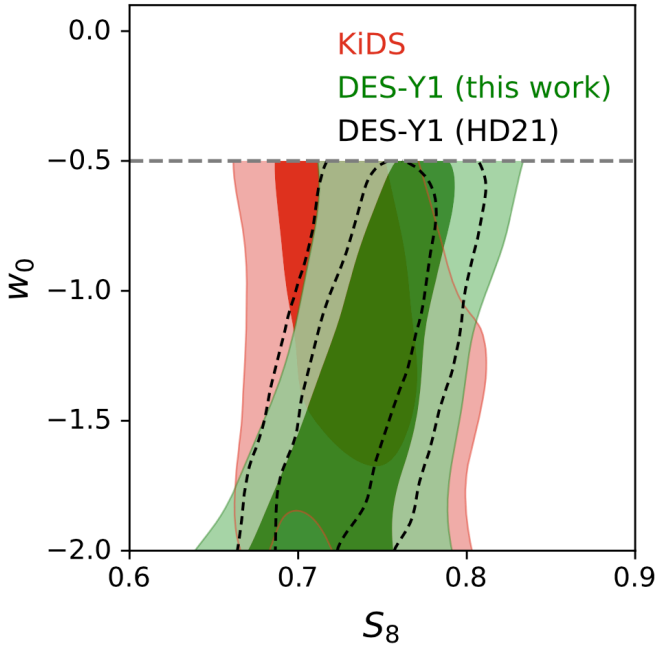


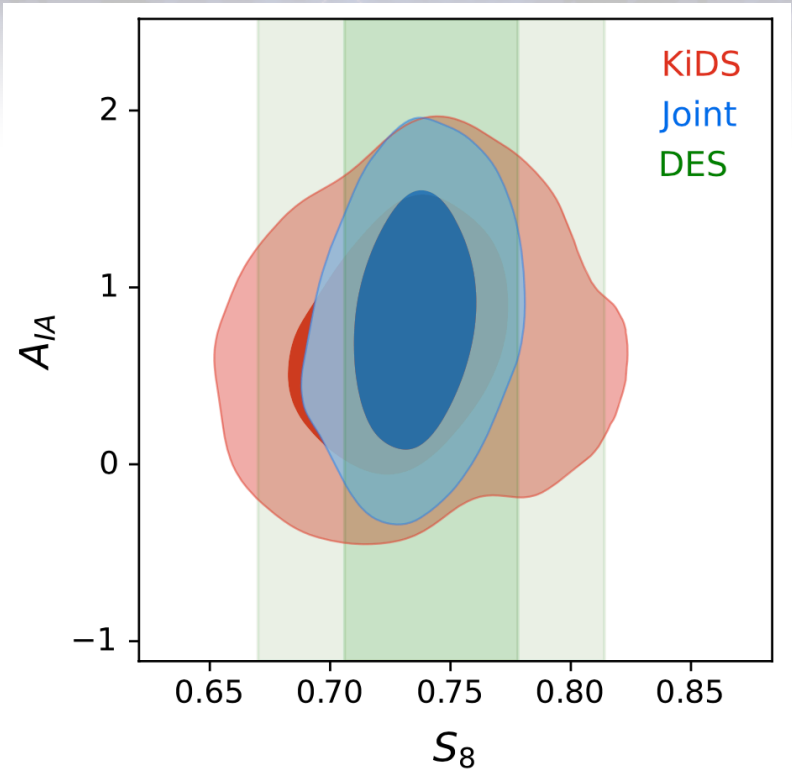
Posterior distribution fully consistent with the DES-Y1 peak count analysis (HD+2021)...



KiDS1000+DES-Y1

DES-Y1 reanalysis:

-Nautilus sampler (vs Multinest)
-Updated baryon model



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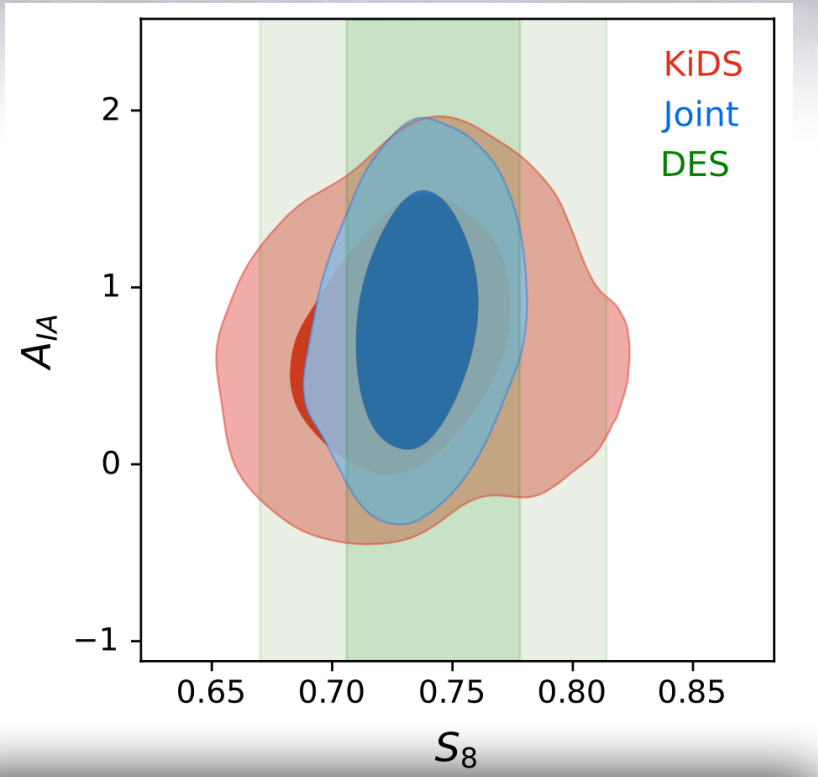


Fiducial	$0.732^{+0.020}_{-0.020}$	$0.82^{+0.47}_{-0.47}$
ΛCDM	$0.736^{+0.016}_{-0.018}$	$0.81^{+0.46}_{-0.46}$

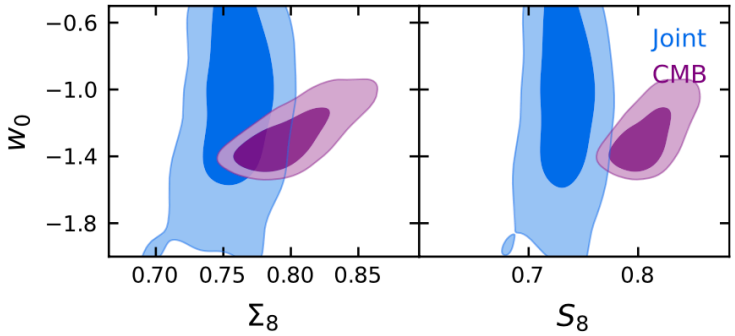
Tension with Planck

$$\tau = \frac{S_8^{Planck} - S_8^{\text{peaks}}}{\sqrt{\text{var}[S_8]^{Planck} + \text{var}[S_8]^{\text{peaks}}}}$$

$$\Sigma_8^{\alpha} \equiv \sigma_8[\Omega_m/0.3]^{\alpha}$$

$$\alpha = 0.58$$

Tension with Planck



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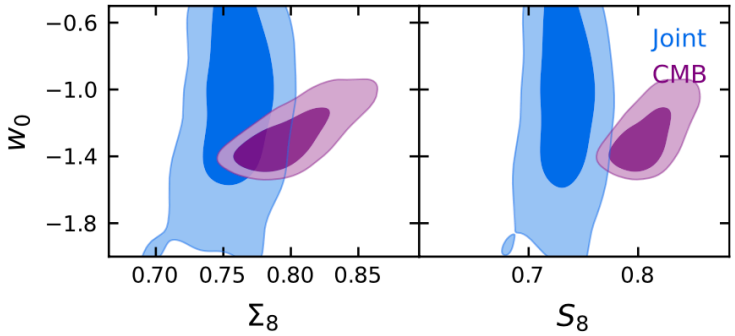

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	S_8		Σ_8	
	wCDM	ΛCDM	wCDM	ΛCDM
KiDS-1000	2.0	3.0	0.72	2.3
Joint	2.7	4.1	1.33	3.1

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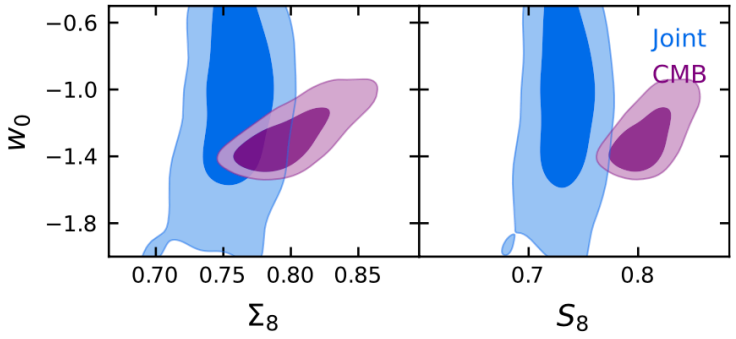

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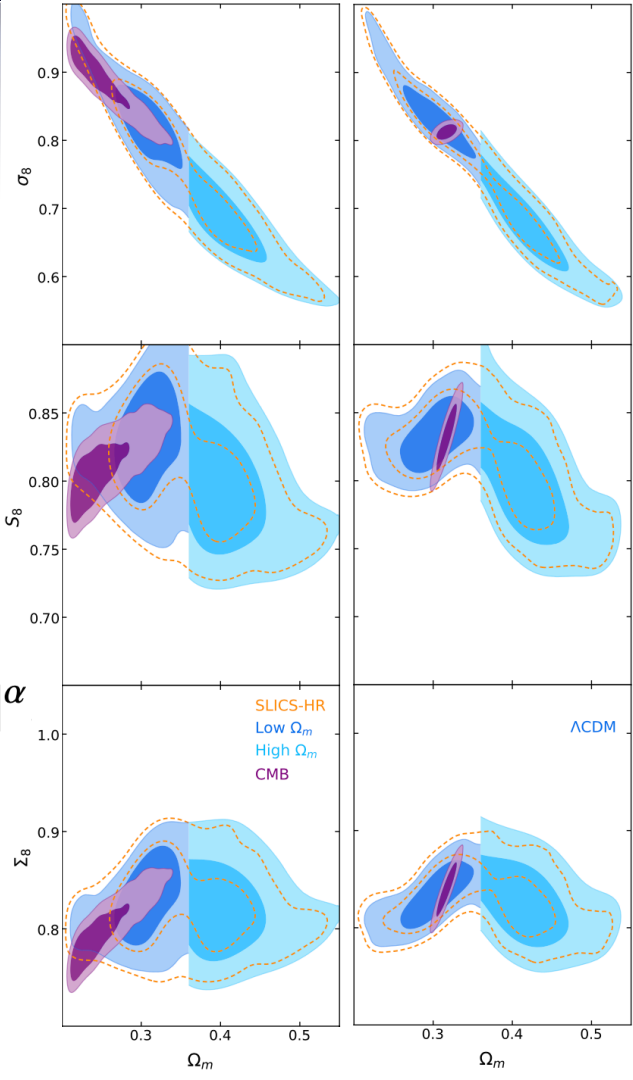


Caveats

Tension measured in 1D

Cosmology sampling is 4D

IA model is NLA

Ignored source clustering

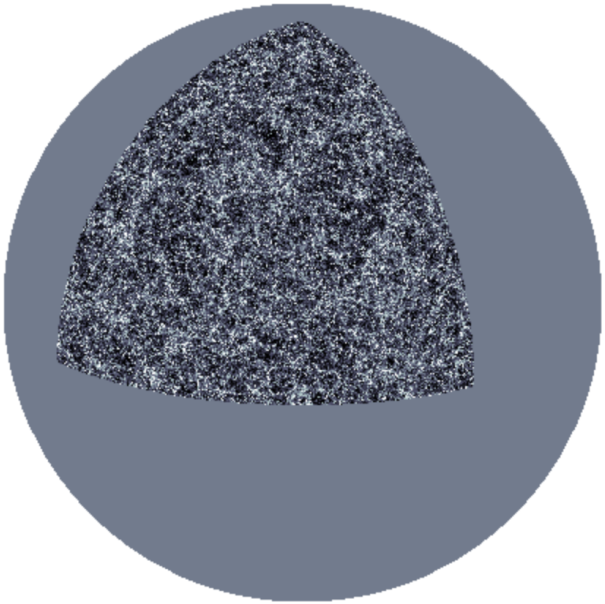
Baryon model has only 1 parameter

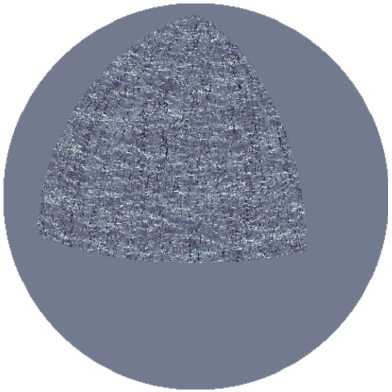
Assumed multivariate Gaussian likelihood

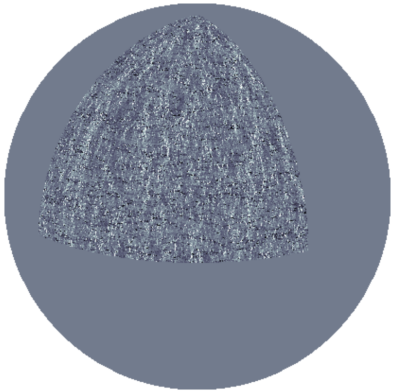
"Small" training set

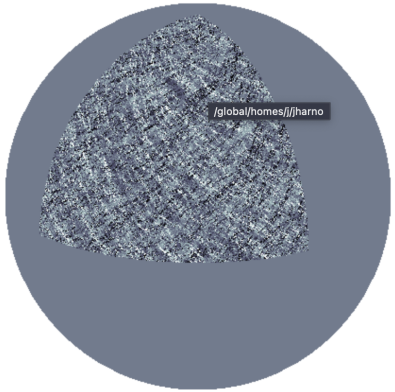
New IA simulations (in prep)

$$\gamma_{ij}^{I} = \underbrace{C_1 s_{ij}}_{\text{Tidal Alignment}} + \underbrace{C_{1\delta}(\delta \times s_{ij})}_{\text{Density Weighting}} + \underbrace{C_2 \left[\sum_{k=0}^{2} s_{ik} s_{kj} - \frac{1}{3} \delta_{ij} s^2 \right]}_{\text{Tidal Torquing}} + \ldots,$$









Conclusions:

Probes beyond 2pt rely heavily on numerical simulations

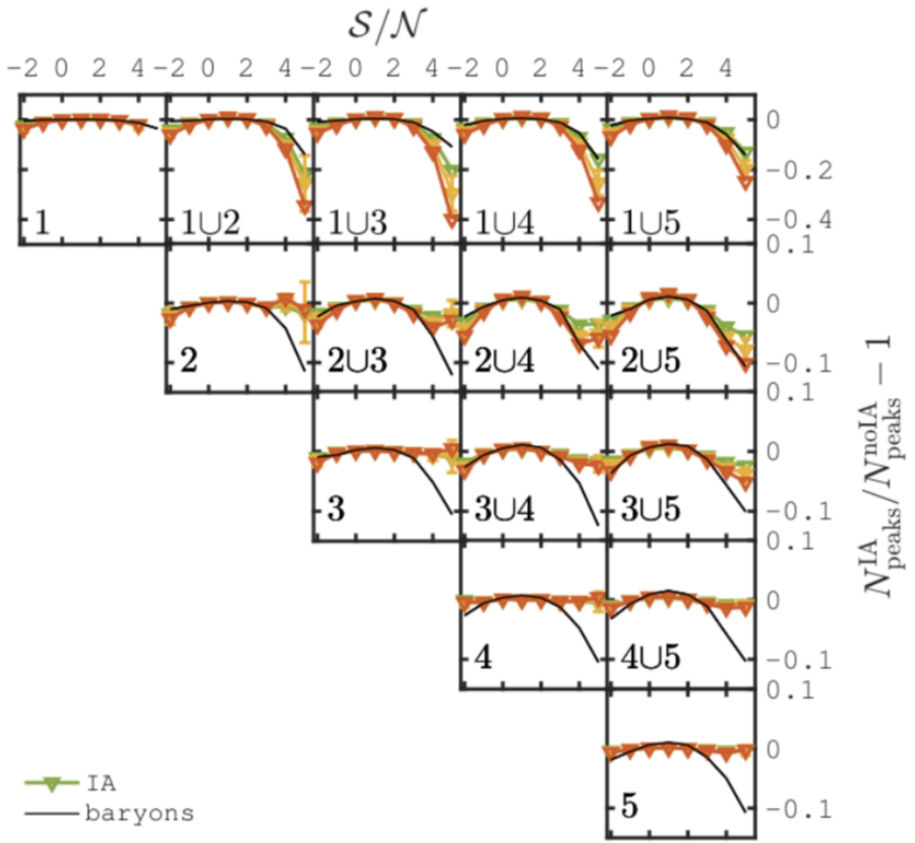
We Combine Surveys with unified analysis pipeline

Current analyses are mature and precise (2% on S8)

Measured a 3-4sigma tension on S8 with Planck in LCDM, with caveats

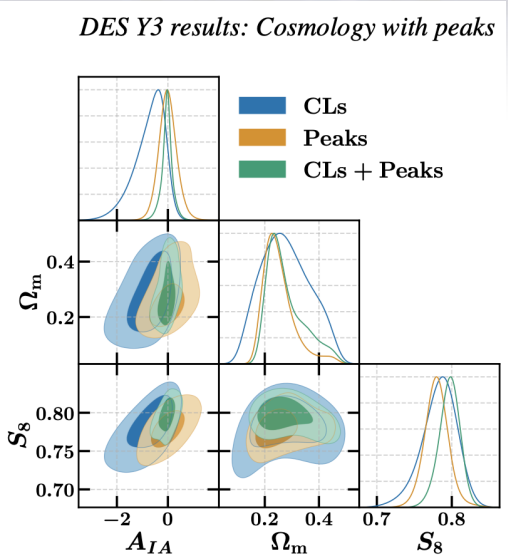
Effort on the way to improve everything

Aperture mass statistics: baryons vs. IA (JHD+2022)

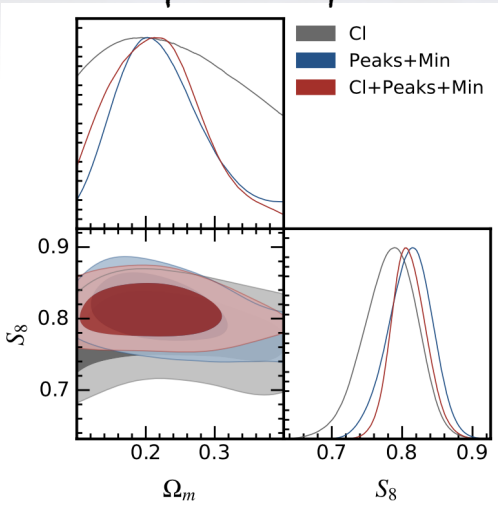


Everything
must be
improved

Zuercher+2022



Marques+2023
HSC-Y1 with peaks



Other non-Gaussian probes:
lensing PDF (Gatti+2020),
Persistent Homology (Heydenreich+2022)
Clipping (Giblin+2018)
CNN (Fluri+2022)
Scattering transform (Cheng+2024)

Additional Slides

The stakes are high!

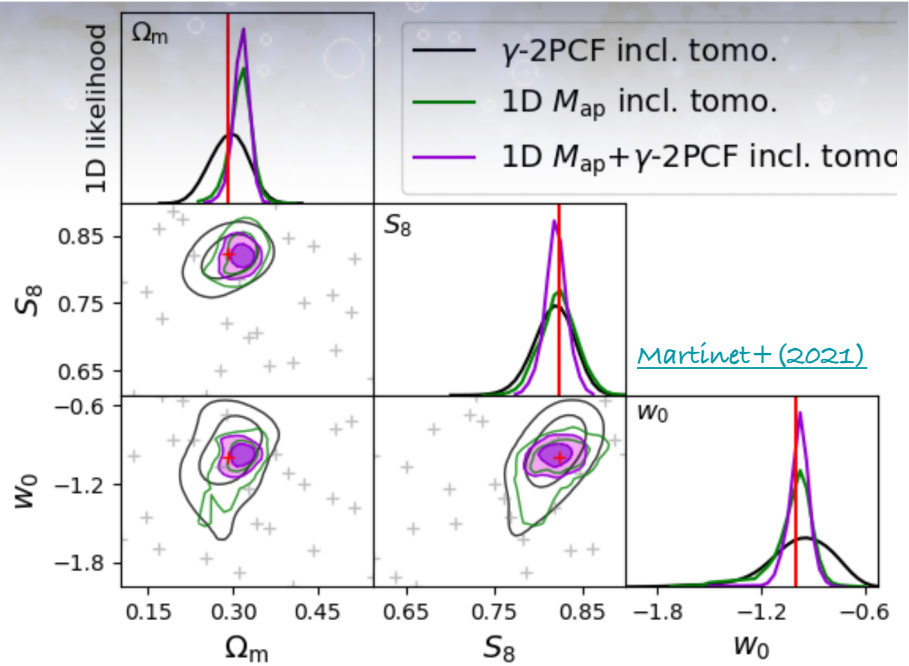
Ex: Weak Lensing "peak statistics"

1.5x improvement on $\sum m_\nu$

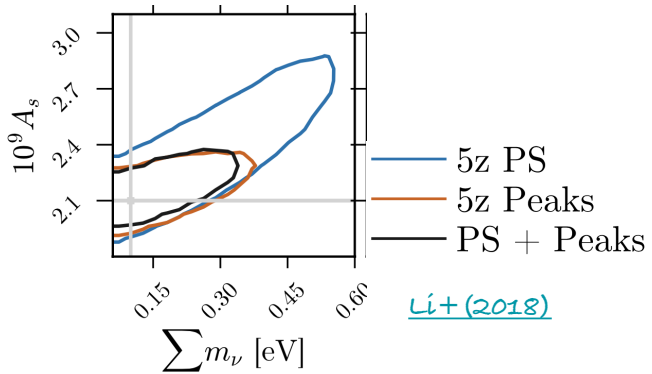
2x improvement on S_8

3x improvement on w_o

"No waste!
Get more from the same data!"



Martinet+ (2021)

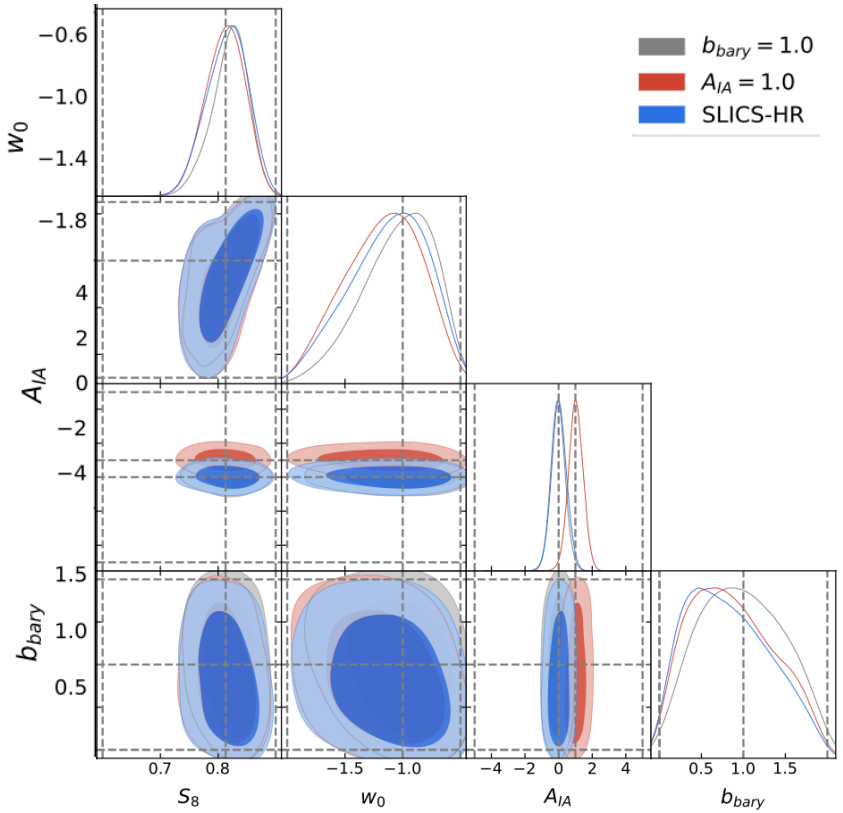


Li+ (2018)

Systematics:

Photo-z
Shear calibration
Baryon feedback
Intrinsic alignment
Modelling (gravity code)
Modelling (cosmology)

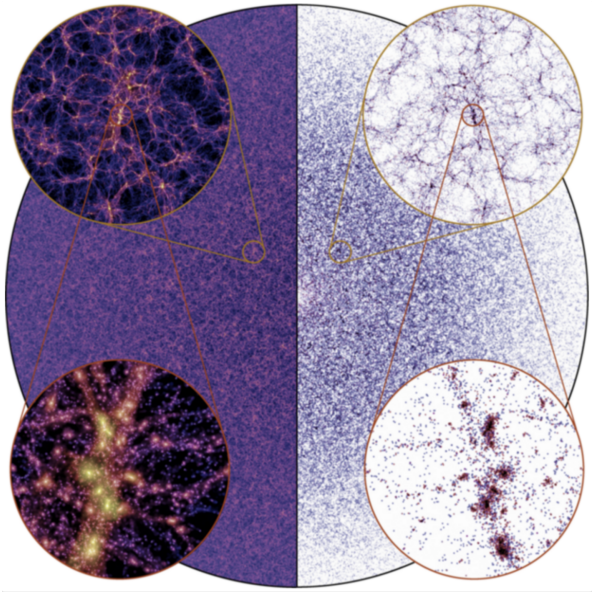
Validated on N-body simulations independent of the training set, contaminated with IA and baryons



$$N^{\rm syst}_{\rm peaks}(\boldsymbol{\pi}, \Delta m_a, \Delta z_a, A_{\rm IA}, b_{\rm bary}) =$$
$$N^{\rm GPR}_{\rm peaks}(\boldsymbol{\pi}) + \left[\partial N_{\rm peaks}/\partial \Delta m_a\right] \Delta m_a + \left[\partial N_{\rm peaks}/\partial \Delta z_a\right] \Delta z_a$$
$$+ \left[\partial N_{\rm peaks}/\partial A_{\rm IA}\right] A_{\rm IA} + \left[\partial N_{\rm peaks}/\partial b_{\rm bary}\right] \Delta b_{\rm bary}\,,$$

New hydro simulations

(Millennium TNG, Flamingo...)

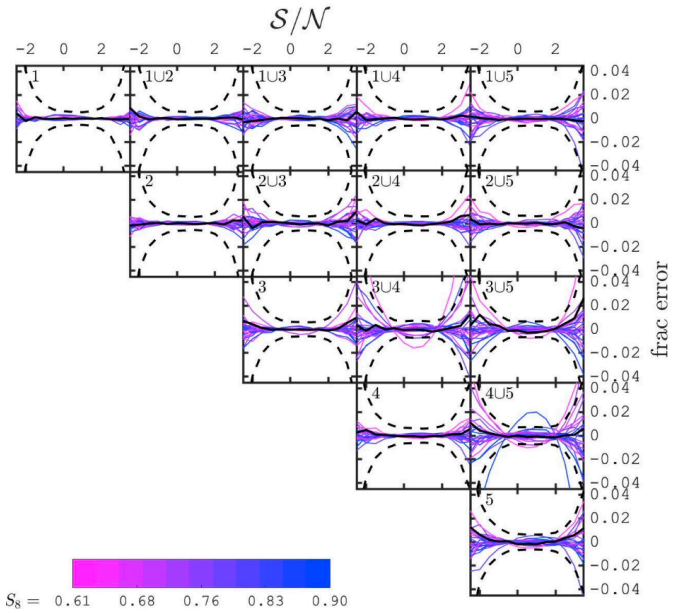


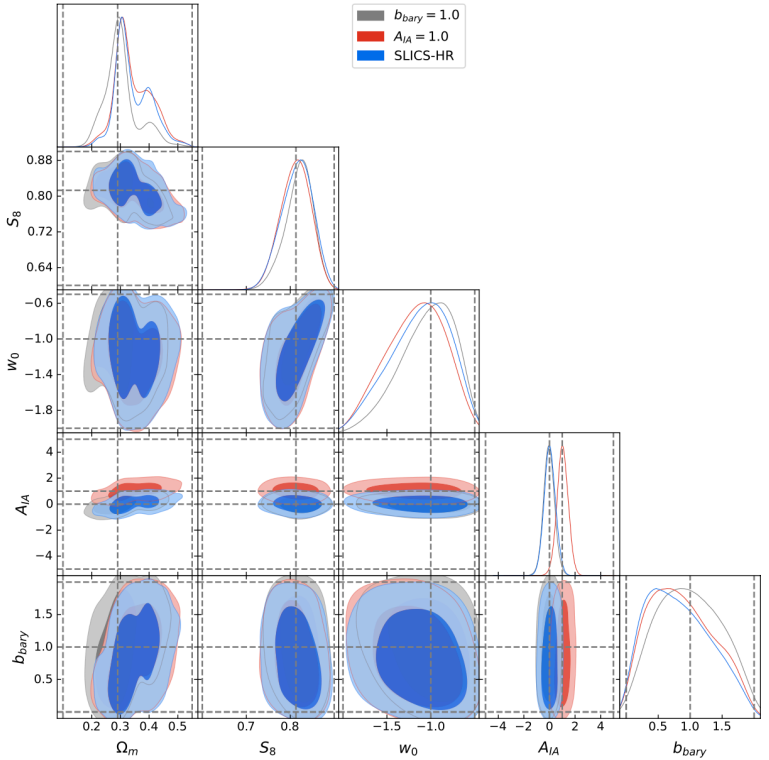
https://www.mtng-project.org/

New covariance simulations

TBD

Systematics: GPR





Requirement for Simulations-based approach

Signal modelling:
ΛCDM simulations (cosmo-SLICS, see right plot)
νΛCDM simulations (MassiveNuS, Liu+2018)
…

Covariance Matrix:
Scinet Light-Cone Simulations (900+ independent light-cones, public, see https://slics.roe.ac.uk)

Systematics:
Photometric uncertainty, shape calibration, Baryonic feedback, intrinsic alignment of galaxies, non-linear modelling…

cosmo-SLICS parameter space (26 nodes)