Co-funded by
the European Union

Comunidad de Madrid

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

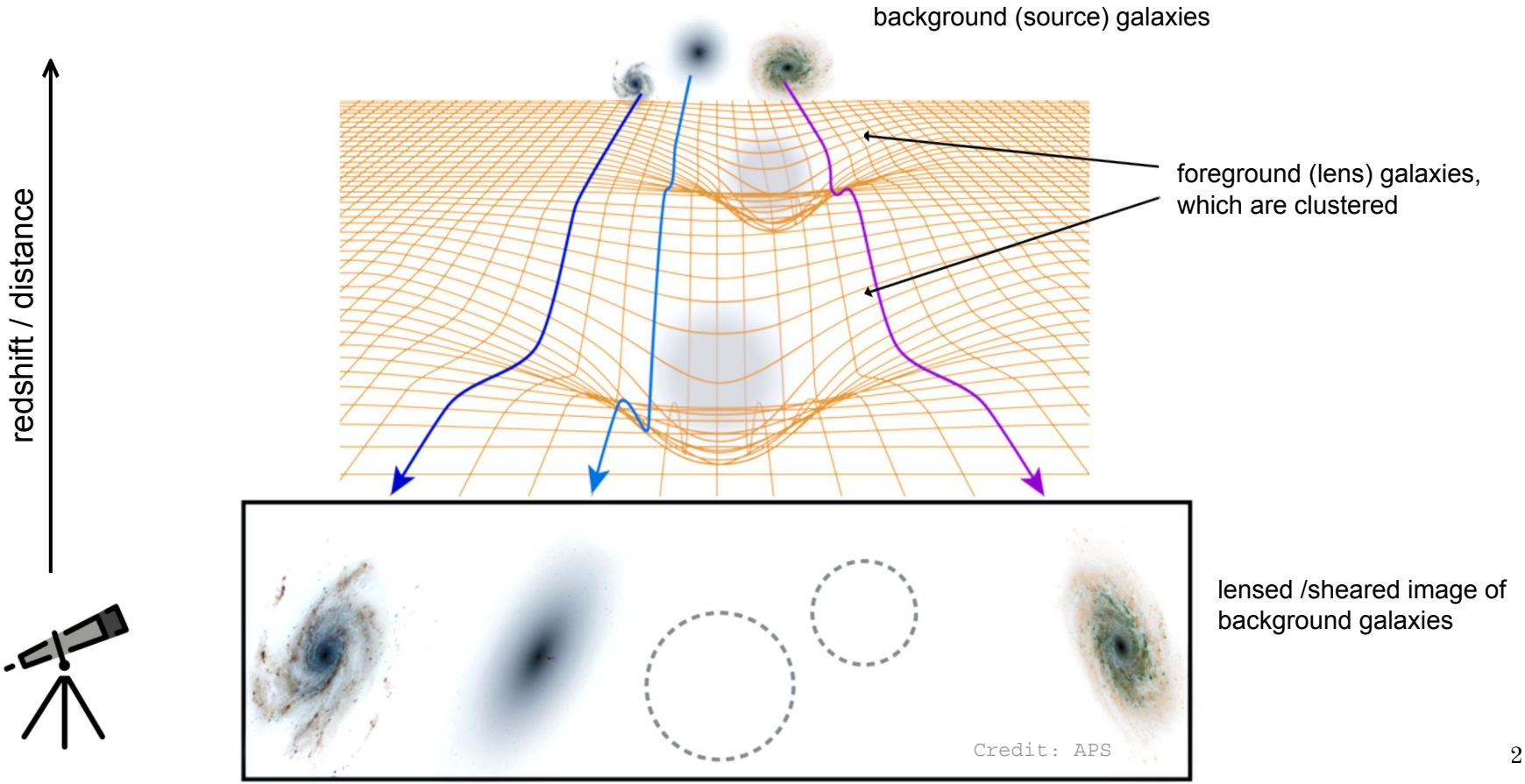
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Multi-survey cosmology from galaxy clustering and weak lensing

Anna Porredon
César Nombela Talent Attraction Fellow at CIEMAT, Madrid

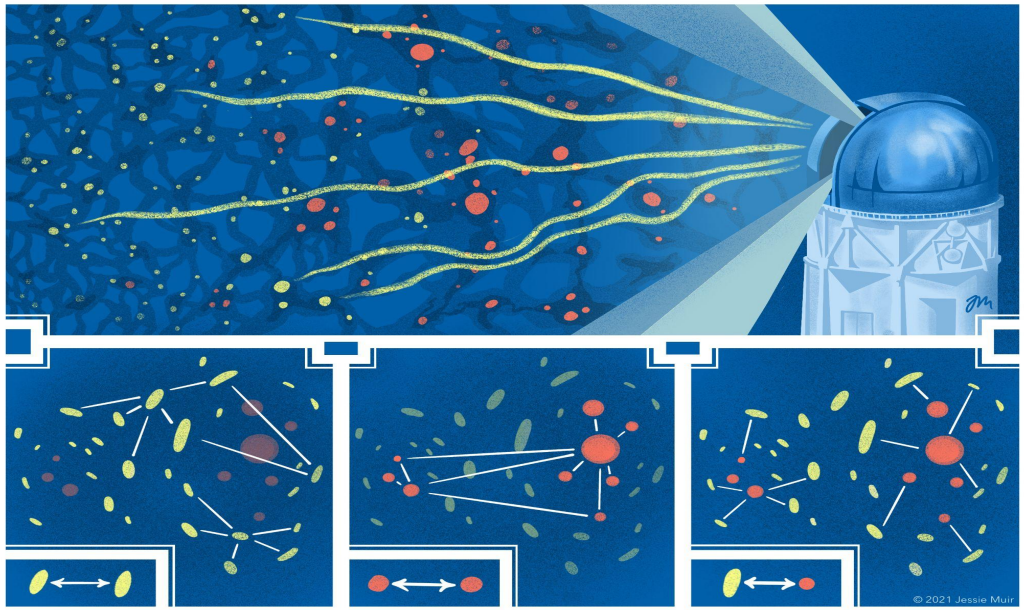
Synergistic Power of Combined Cosmological Observables, 28 October 2025, LPNHE Paris (France)

Weak gravitational lensing



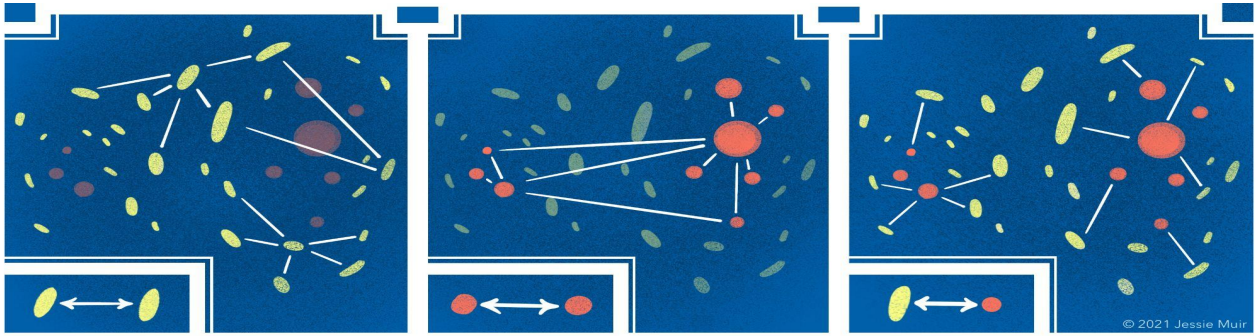
3x2pt cosmology

Jessie Muir



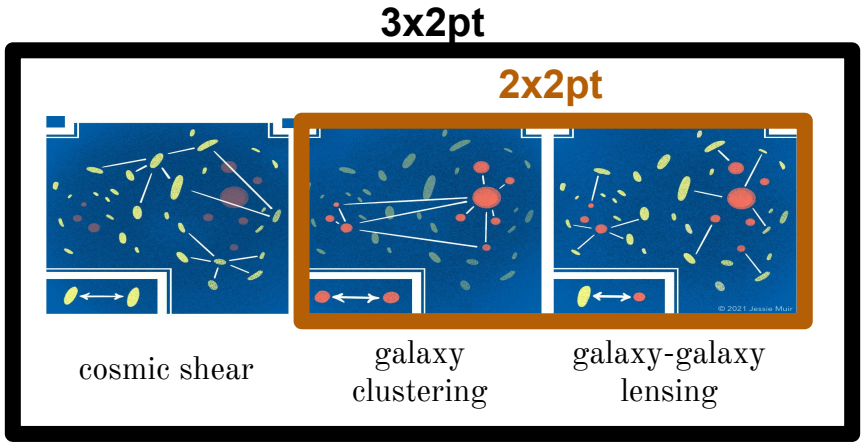
cosmic shear	galaxy clustering	galaxy-galaxy lensing
correlation in the shapes of (source) galaxies	correlation in the positions of (lens) galaxies	correlation between positions of the lenses and shapes of the sources

3x2pt

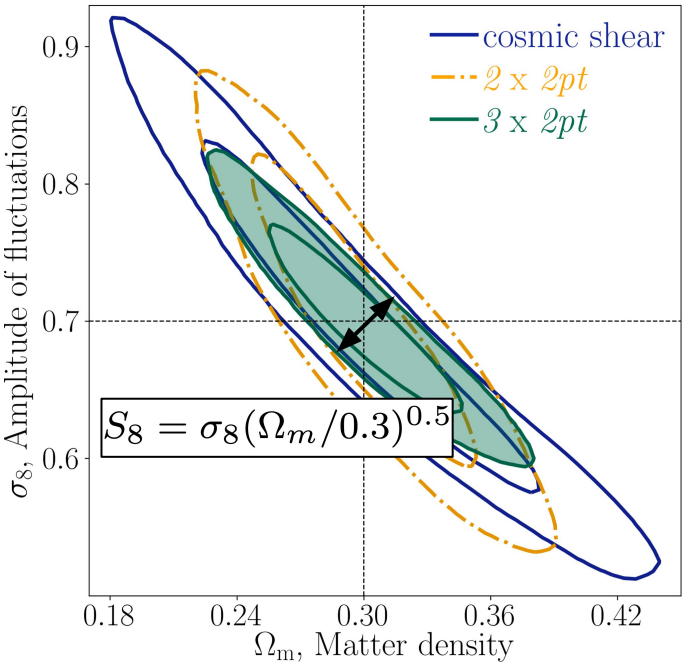


cosmic shear galaxy clustering galaxy-galaxy lensing

3x2pt cosmology

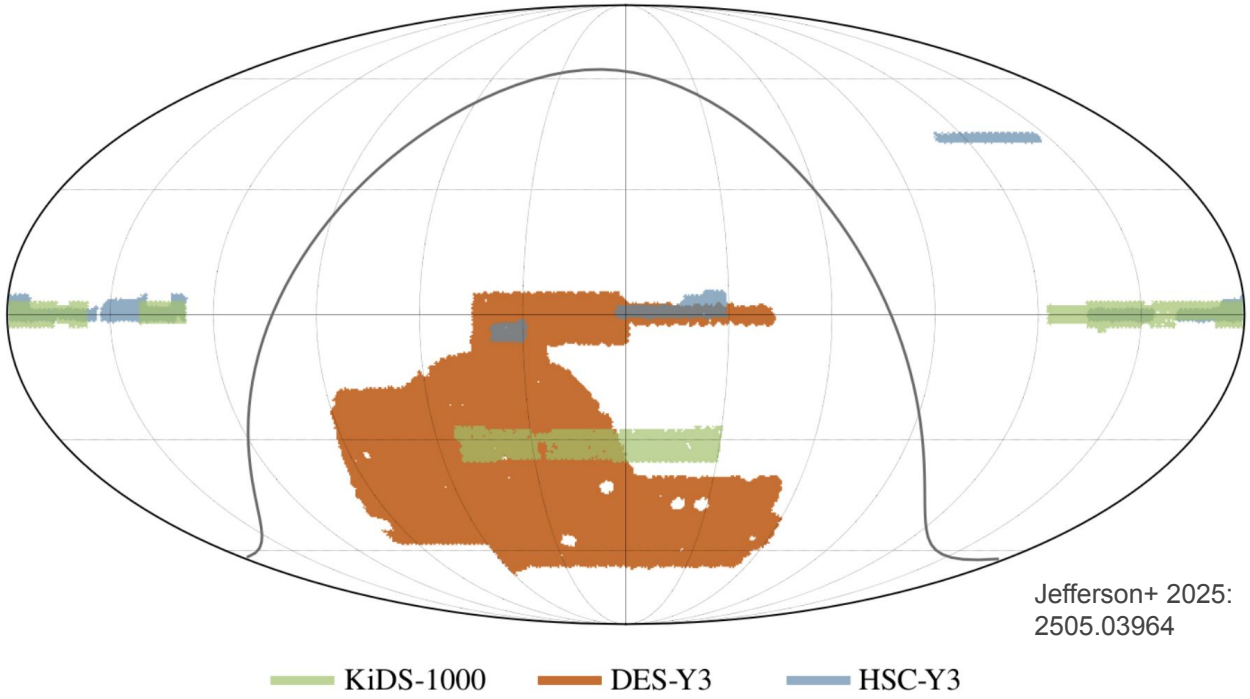


Credit image: DES Y3 3x2pt webinar



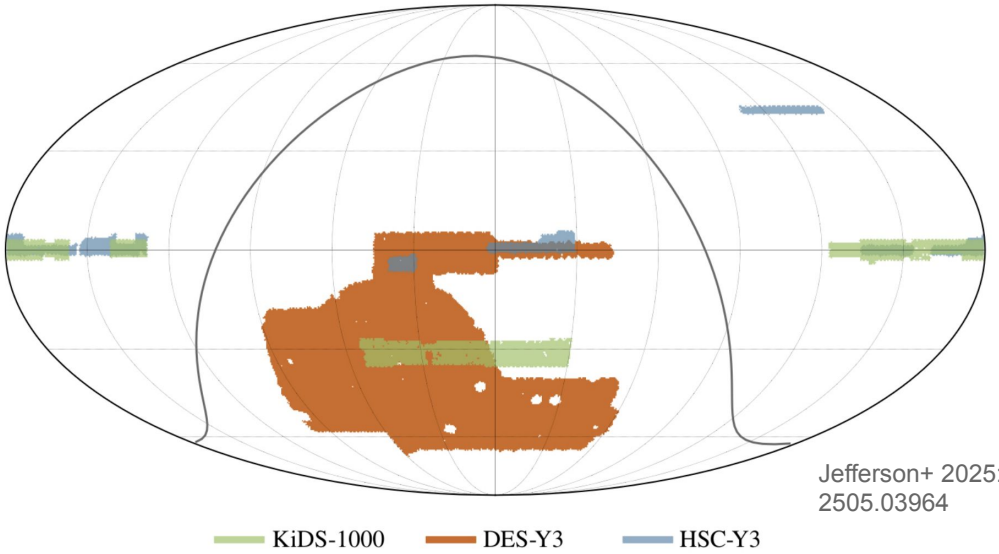
A joint analysis maximizes the cosmological information and robustly constrains astrophysical & observational systematics in the analysis!

Stage-III weak lensing surveys



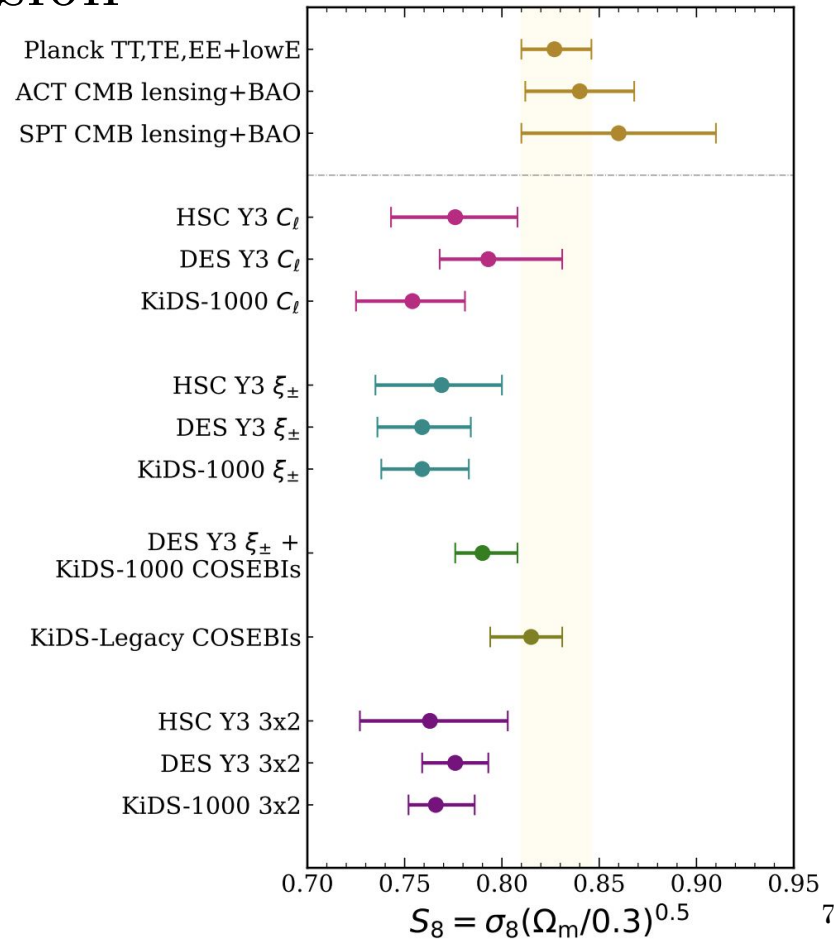
Jefferson+ 2025:
2505.03964

Stage-III WL surveys & S8 tension



Jefferson+ 2025: 2505.03964

The CosmoVerse Network 2025: 2504.01669



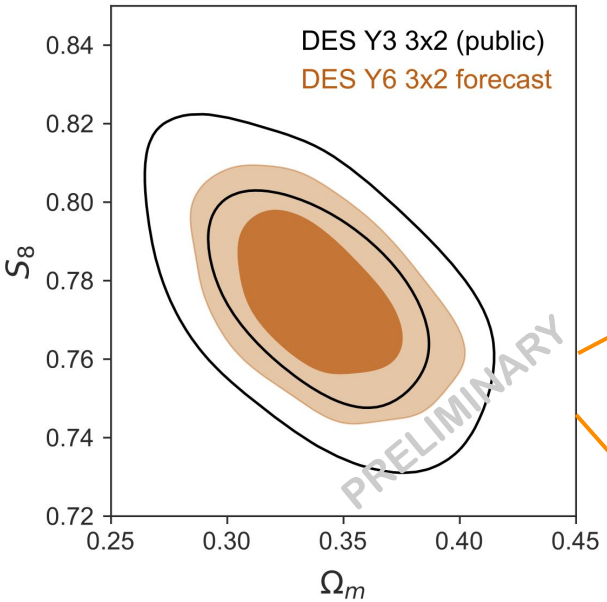
Stage-III WL surveys & S8 tension

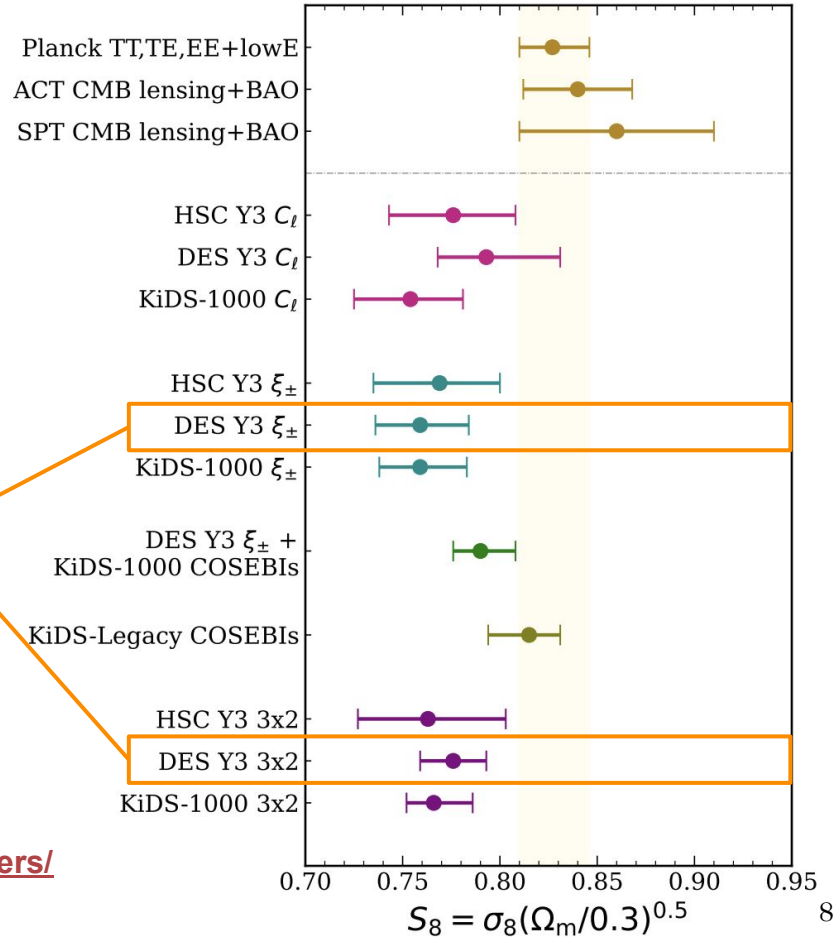
The CosmoVerse Network 2025: 2504.01669

DES Y6 3x2pt already unblinded!

Results will be public this ~December 🥁

Credit: DES Y6 forecast from David Sánchez Cid, figure from AP





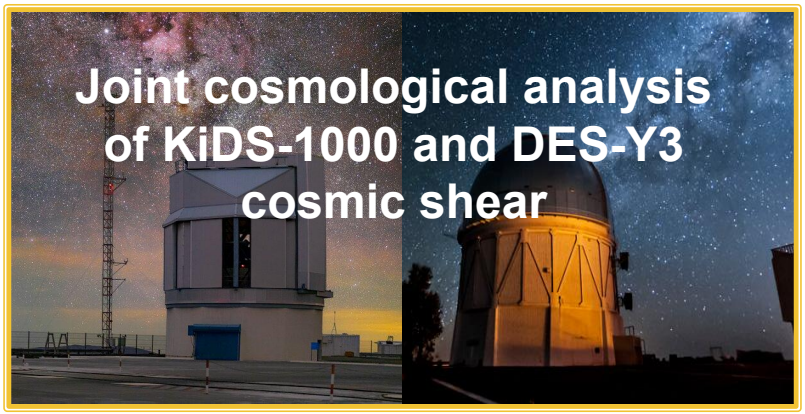
Some supporting papers are already out! Stay tuned in:
https://www.darkenergysurvey.org/des-y6-cosmology-results-papers/

Unified cosmological analyses across weak lensing surveys

- Stage-III WL surveys tend to favour lower S_8 compared to CMB observations.
- DES, KiDS and HSC differ in multiple aspects.
- **It is essential to analyse their datasets with a unified pipeline to assess the robustness and consistency of their cosmological constraints.**

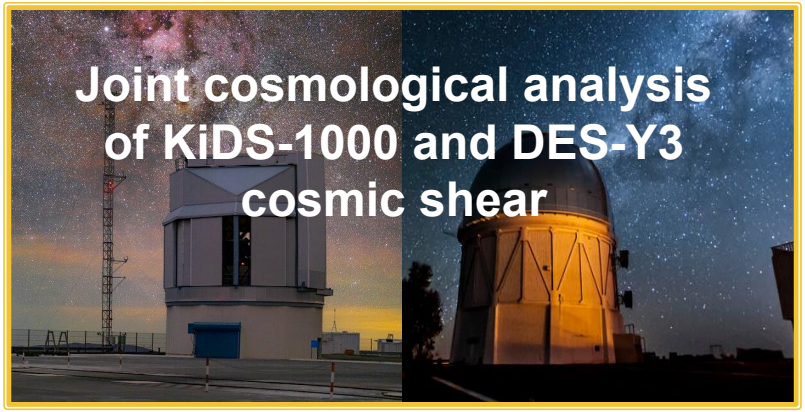
Unified cosmological analyses across weak lensing surveys

- Stage-III WL surveys tend to favour lower S_8 compared to CMB observations.
- DES, KiDS and HSC differ in multiple aspects.
- **It is essential to analyse their datasets with a unified pipeline to assess the robustness and consistency of their cosmological constraints.**



Unified cosmological analyses across weak lensing surveys

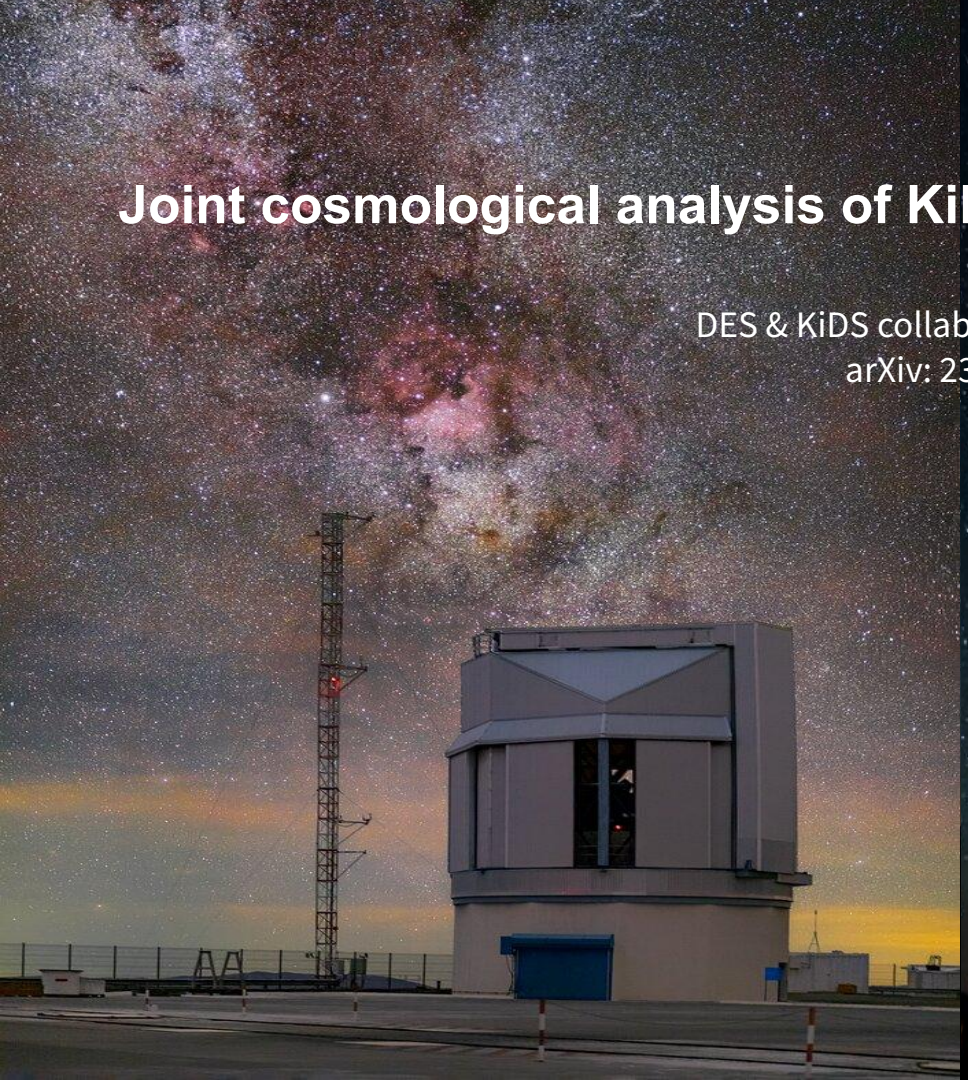
- Stage-III WL surveys tend to favour lower S_8 compared to CMB observations.
- DES, KiDS and HSC differ in multiple aspects.
- **It is essential to analyse their datasets with a unified pipeline to assess the robustness and consistency of their cosmological constraints.**

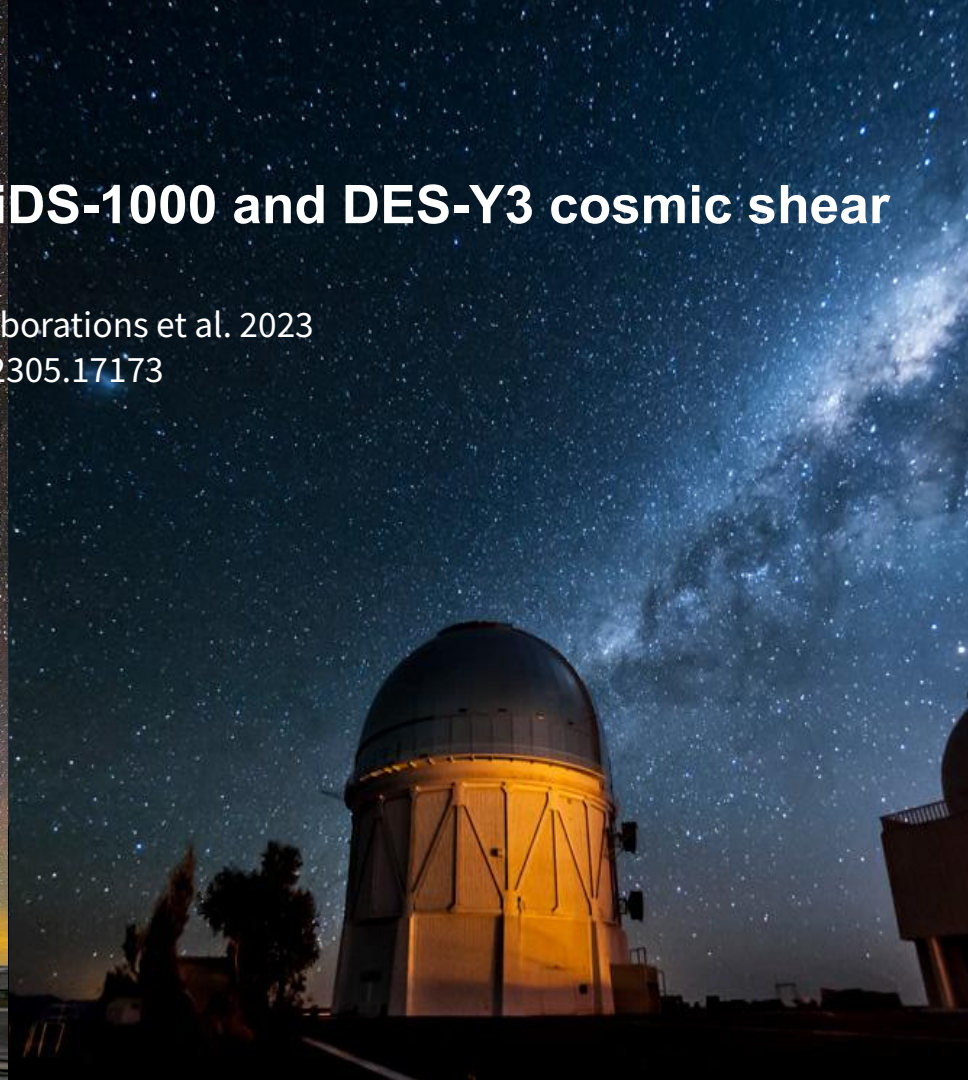


3x2pt cosmology from DESI DR1 spectroscopic galaxies and weak lensing from DES, KiDS and HSC

Joint cosmological analysis of KiDS-1000 and DES-Y3 cosmic shear

DES & KiDS collaborations et al. 2023
arXiv: 2305.17173





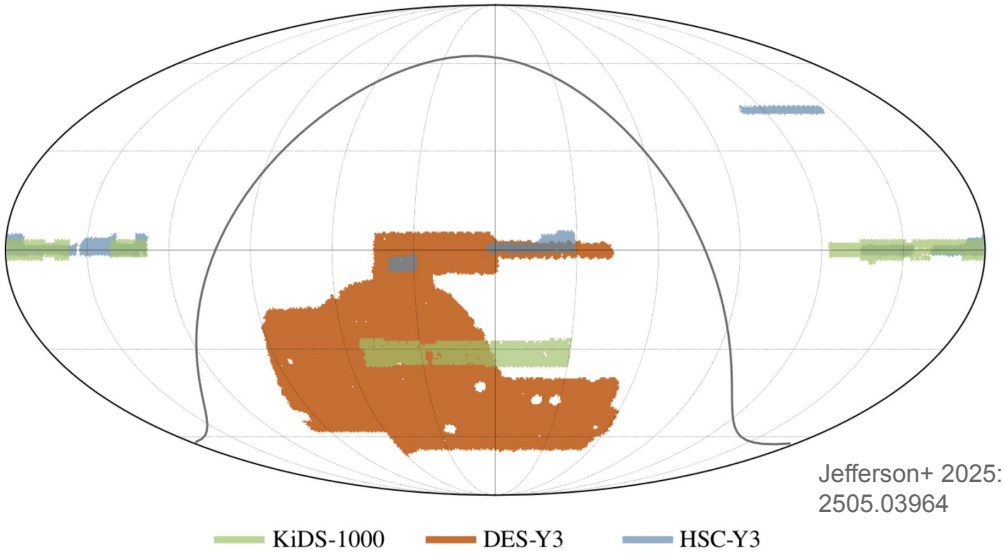
The DES+KiDS Cosmic Shear Team

Alex Amon, Marika Asgari, Ami Choi, Catherine Heymans, Anna Porredon, Simon Samuroff
and KiDS & DES Collaborations

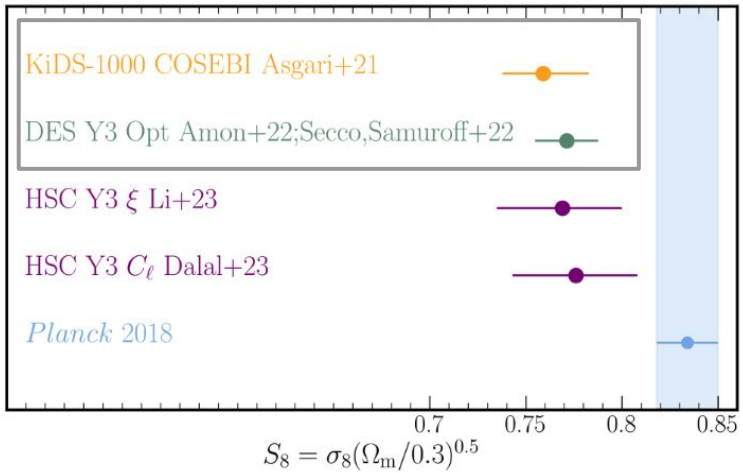
- **Analysis contributions**: *Felipe Andrade-Oliveira, Hugo Camacho, Konrad Kuijken, Jessie Muir, Joe Zuntz & Roohi Dalal and Xiangchong Li for HSC*
- **Internal reviewers**: *Hendrik Hildebrandt, Chihway Chang, Scott Dodelson, Michael Troxel; guidance from Gary Bernstein, Jonathan Blazek, Elisabeth Krause, Xiao Fang, Benjamin Joachimi, Angus Wright, Andrej Dvornik*
- **KiDS-1000** and **DES Y3** infrastructure contributors and builders

Incredibly valuable learning exercise sharing knowledge between the two collaborations

Current cosmic shear surveys

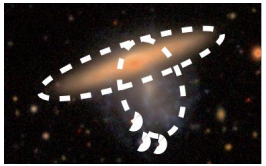


Jefferson+ 2025: 2505.03964



First joint DES+KiDS collaboration effort to combine this cosmic shear data and analyse it with a unified pipeline

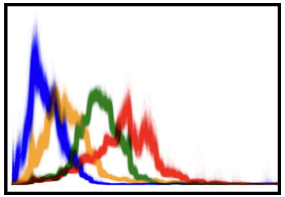
Weak lensing cosmology pipeline



Images

Calibrated shapes

Calibrated redshift distributions



Measurements & covariance

Scale selection
Nuisance parameter prior choices

$P(\mathbf{p}|\hat{\mathbf{D}}, M) \propto \mathcal{L}(\hat{\mathbf{D}}|\mathbf{p}, M)P(\mathbf{p}|M)$

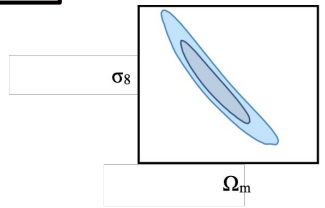
Model choices:
Non-linear P_k
Baryon feedback
Intrinsic alignments

Simulations

Analytic models

Likelihood analysis: Sampler

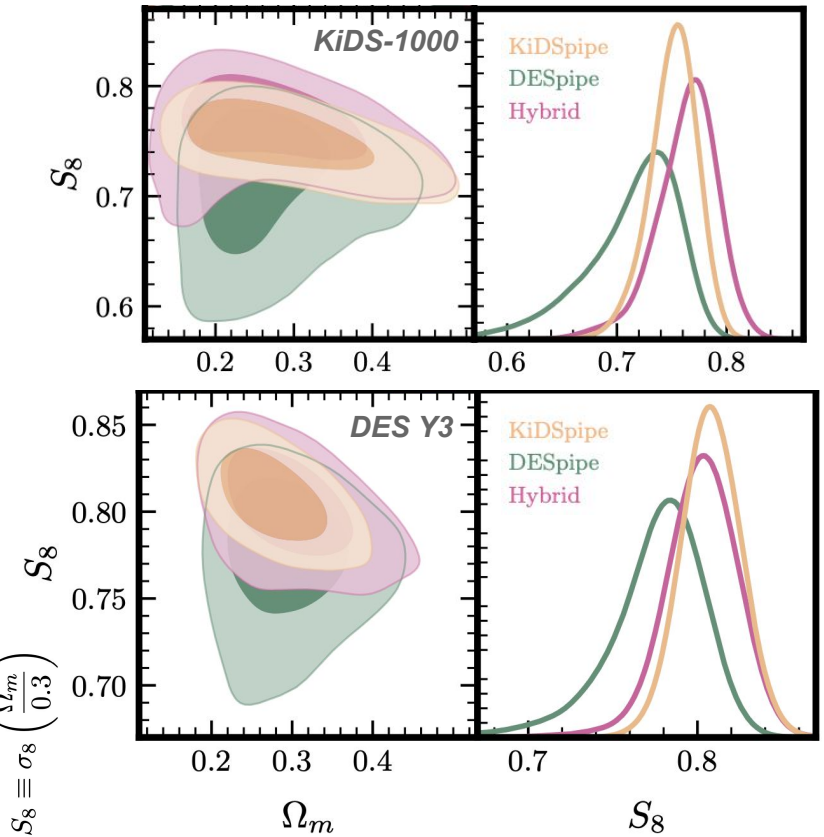
Cosmological inference



Re-analysis at the parameter estimation level

Original surveys' calibrated shapes and redshifts unchanged in our work

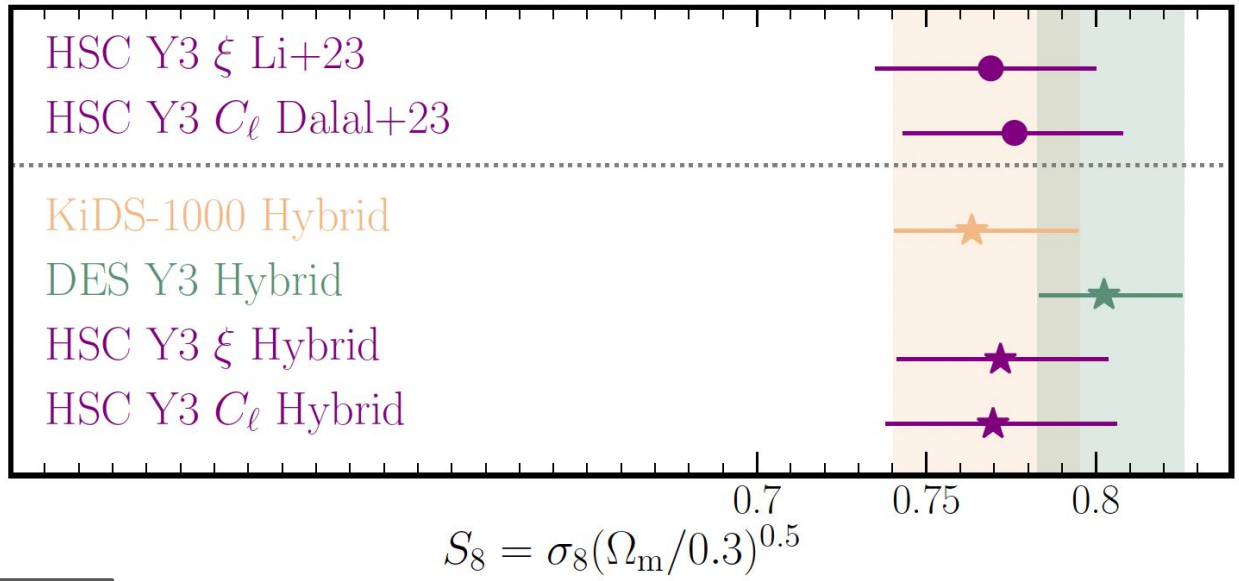
Re-analysis of KiDS-1000 and DES Y3



We use a ***Hybrid*** pipeline for the combined results with:

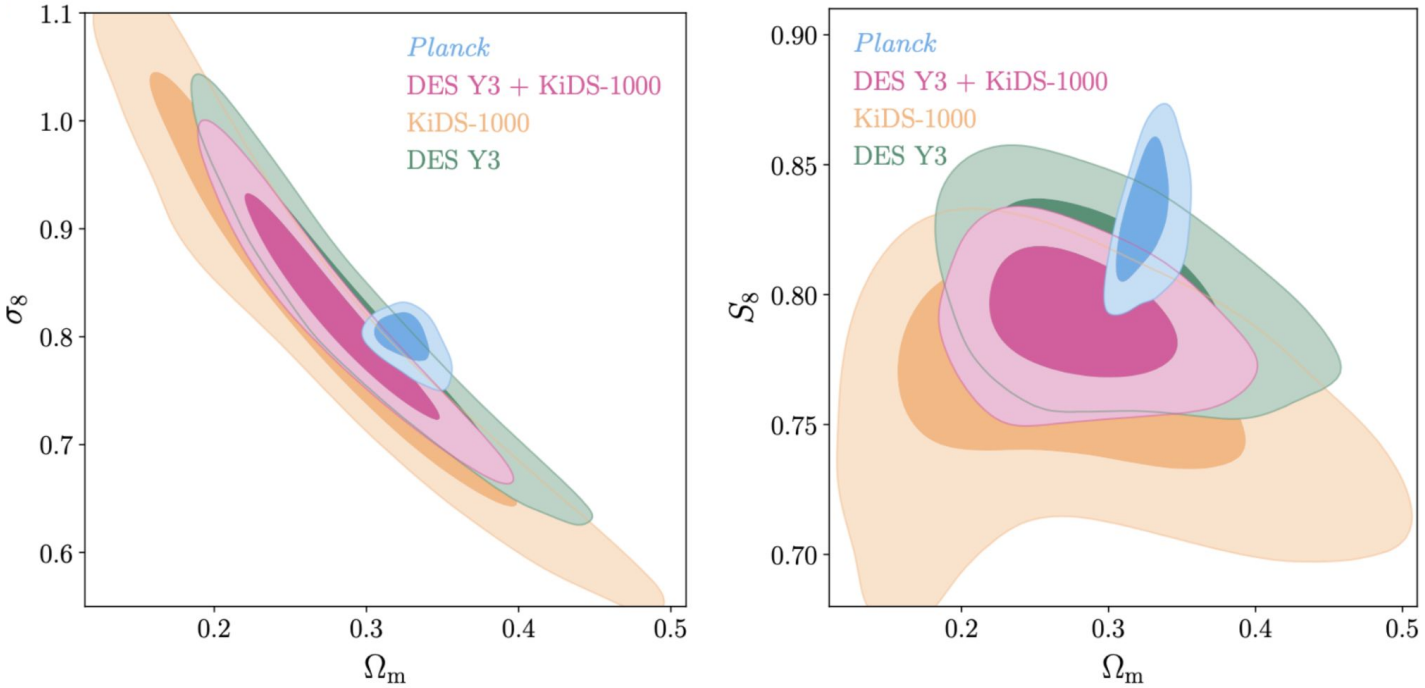
- Middle-ground configuration between KiDSpipe and DESpipe
- More accurate modelling of the matter power spectrum at small scales, using HMCode2020
- Double baryonic feedback mitigation

Re-analysis of HSC Y3



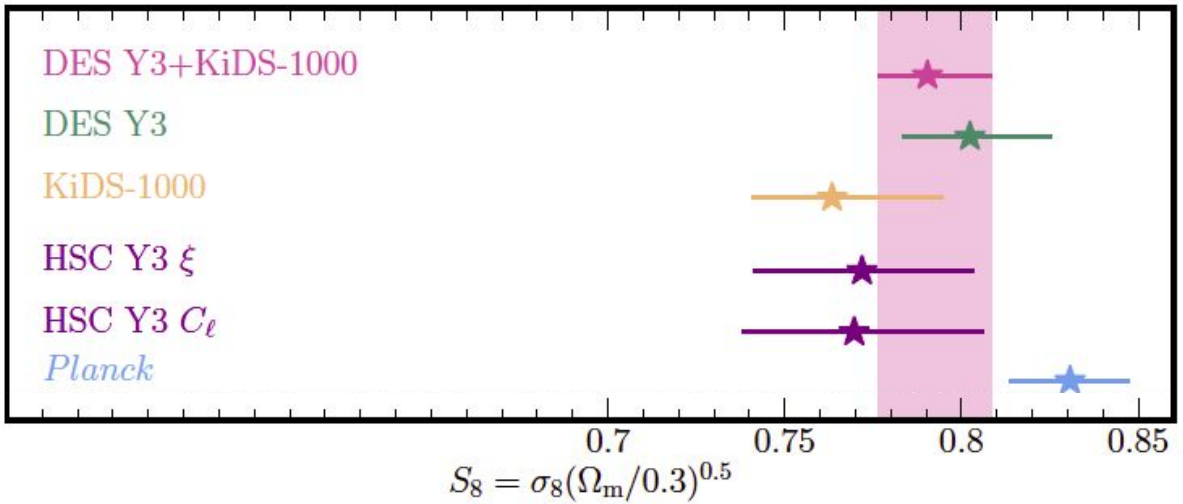
With thanks to Roohi Dalal & Xiangchong Li

KiDS + DES cosmic shear results

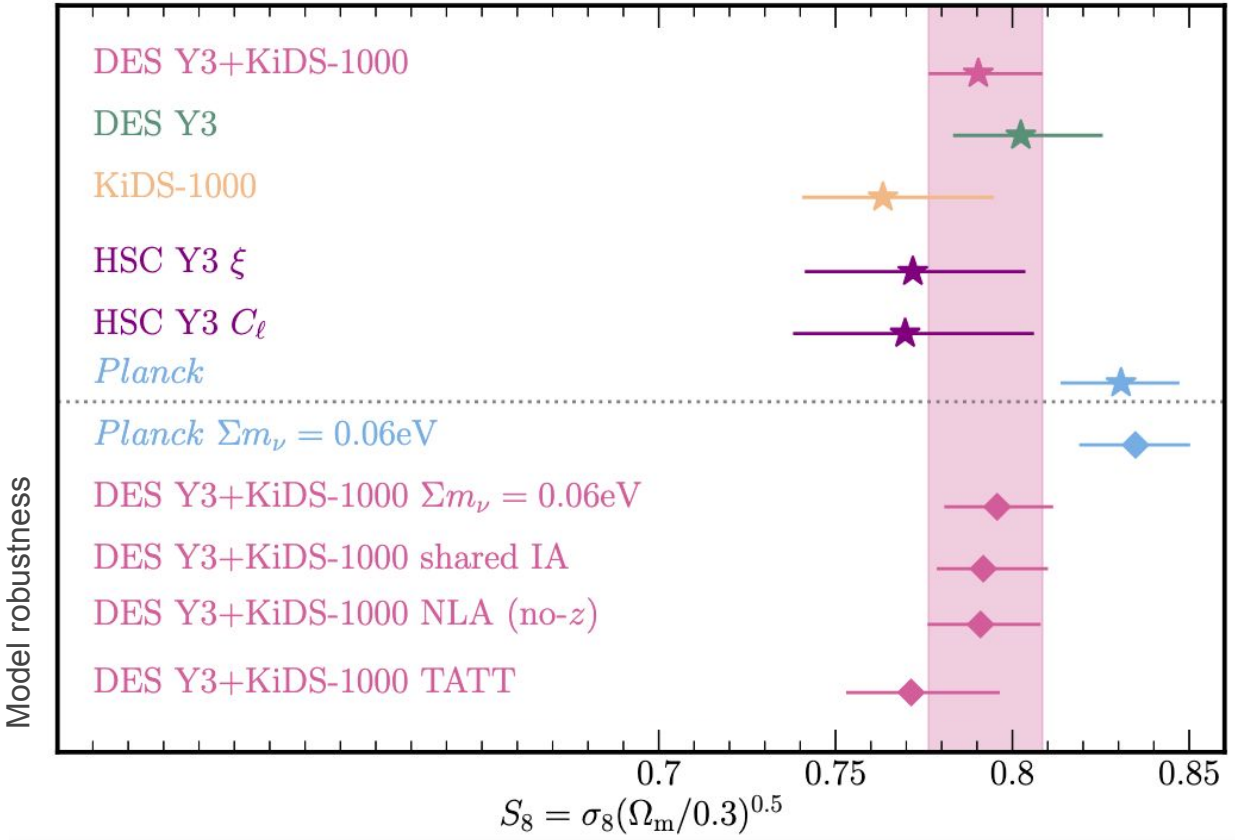


DES Y3 + KiDS-1000: S_8 1.7σ lower than *Planck*

The S_8 tension



The S_8 tension



DESI and weak lensing surveys

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Focus on combined-probe analyses of DESI spectroscopic samples with KiDS, DES and HSC public weak lensing data

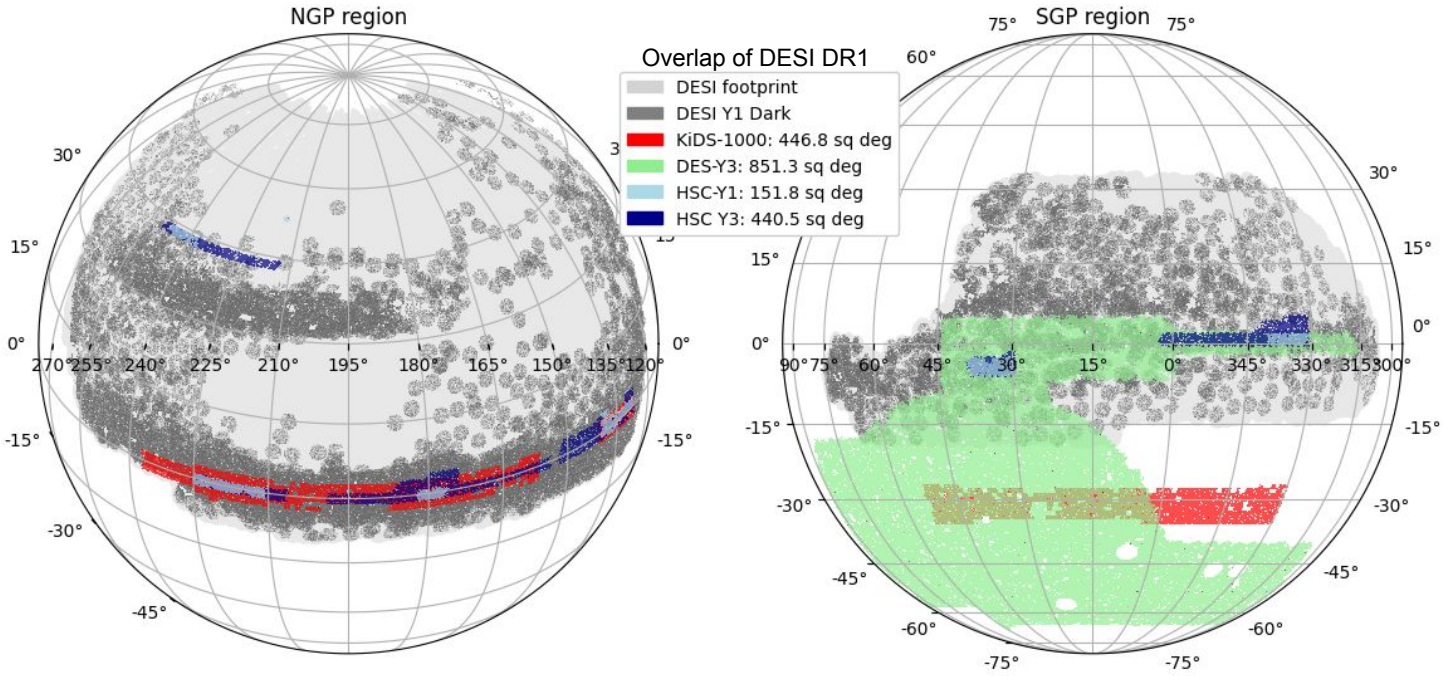
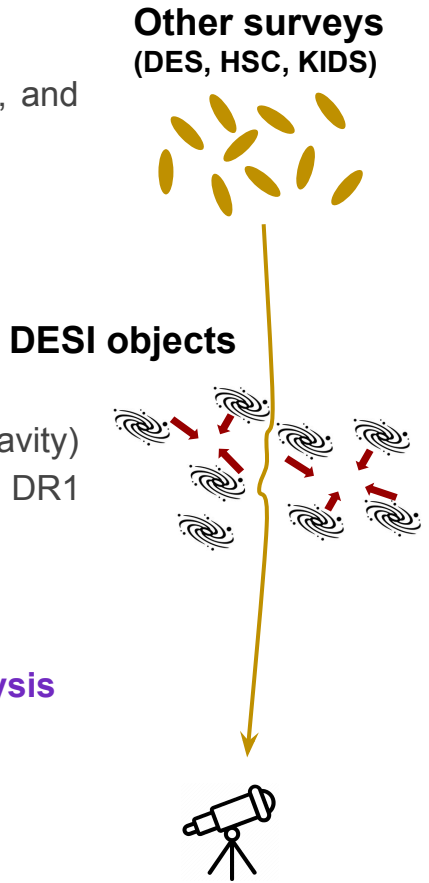


Figure credit: Chris Blake

DESI DR1 x weak lensing analyses:

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

- **Measurements of galaxy-galaxy lensing** from DESI lenses and KiDS, DES, and HSC sources using a **common pipeline**
- **Joint analysis of KiDS, DES and HSC** weak lensing data using:
  - a common modeling and analysis pipeline
  - a common set of cosmological priors
- **Cosmological constraints** on LCDM and extended models (e.g. modified gravity) from the combination of KiDS, DES, and HSC weak lensing data with DESI DR1 galaxy clustering using:
  - projected galaxy clustering (w_p) → **3x2pt analysis**
  - galaxy clustering multipoles → **shear + redshift space distortions analysis**
  - **emulators**, to allow the inclusion of **small scales** in the analysis



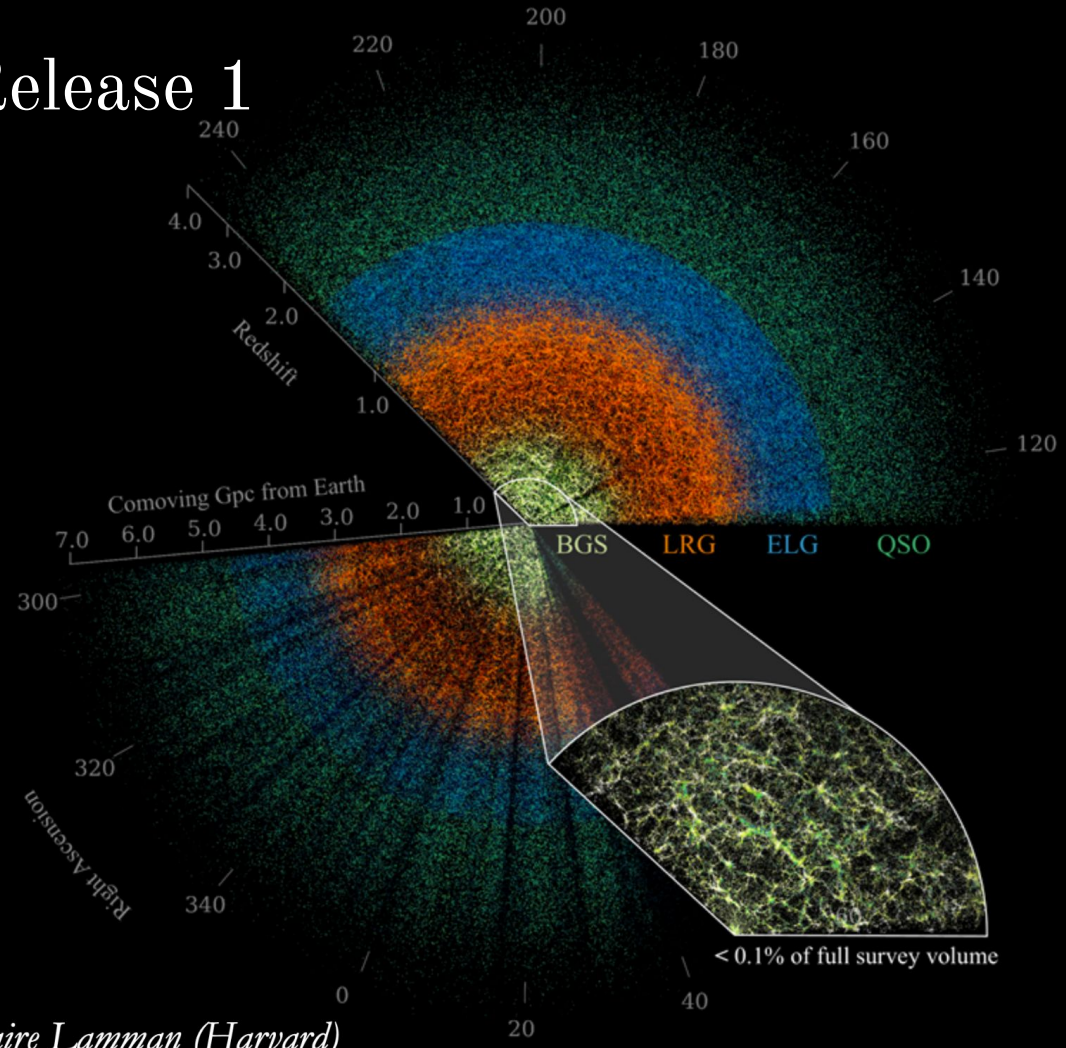
DESI Data Release 1

DESI collaboration 2025

https://arxiv.org/abs/2503.14745

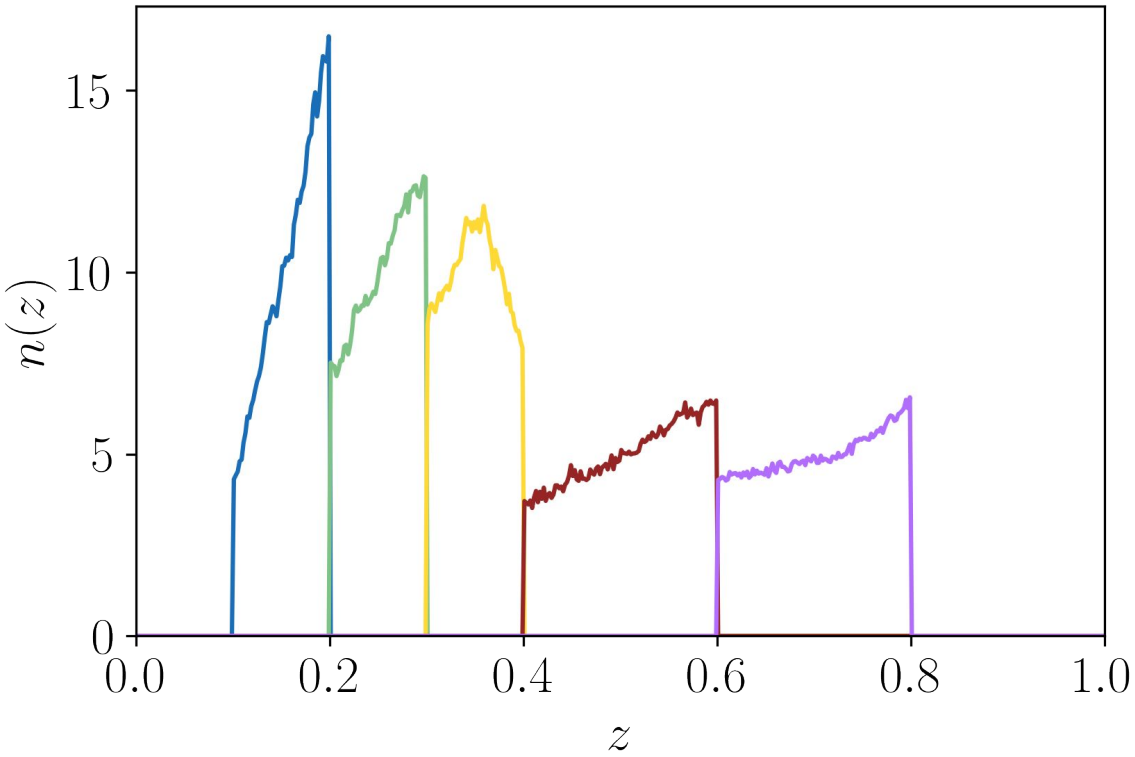
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science



Credit: Claire Lamman (Harvard)

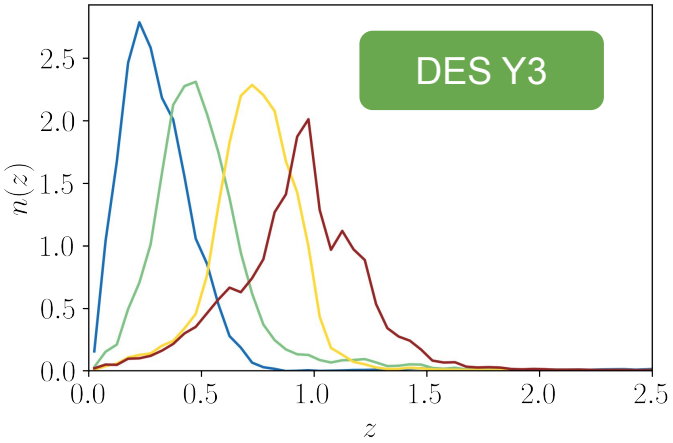
DESI DR1 3x2pt analysis: lenses

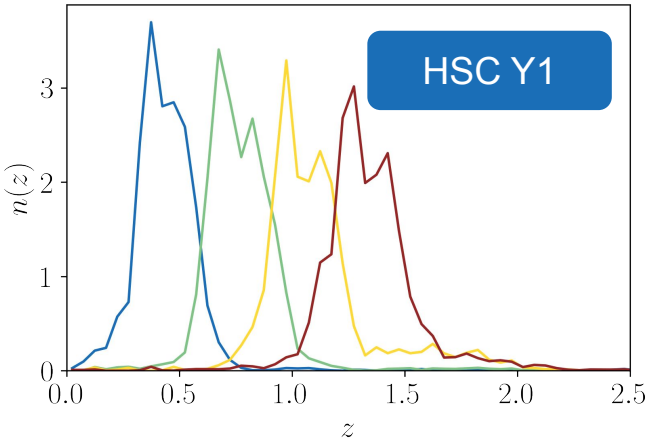


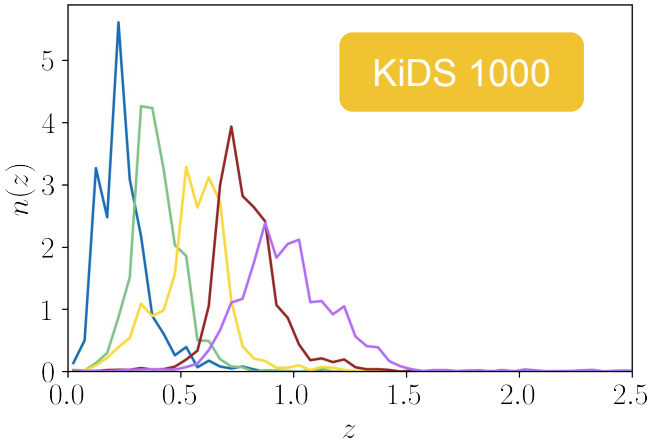
BGS 0.1 < z < 0.2
BGS 0.2 < z < 0.3
BGS 0.3 < z < 0.4
LRG 0.4 < z < 0.6
LRG 0.6 < z < 0.8

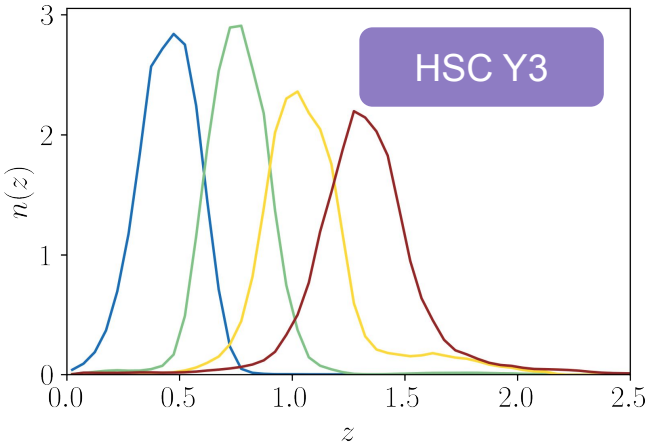
Bright Galaxy Sample Luminous Red Galaxies

DESI DR1 3x2pt analysis: sources









DESI DR1 3x2pt mock challenge

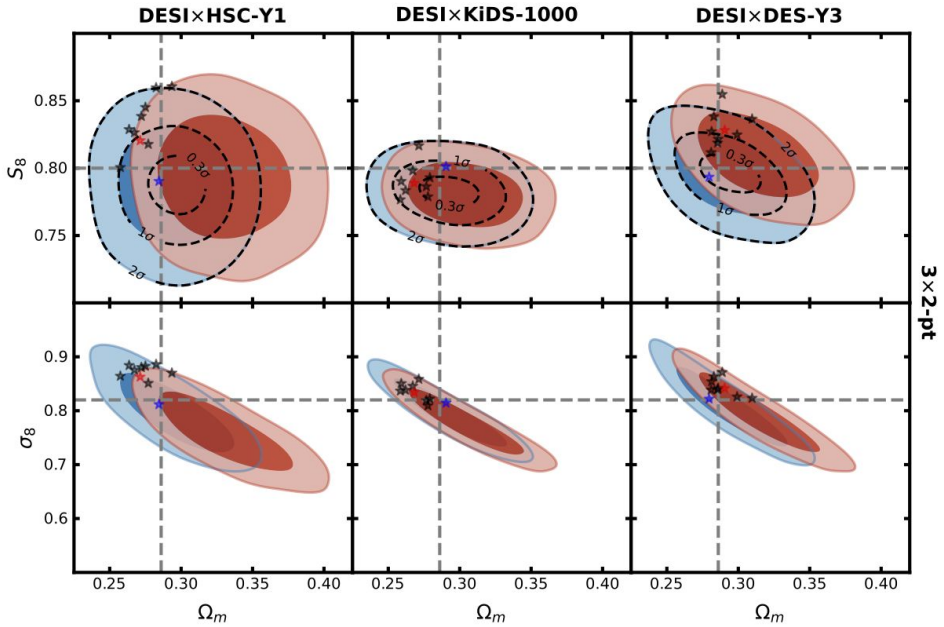
Chris Blake, Cristhian Garcia-Quintero, et al. 2024

https://arxiv.org/abs/2412.12548

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

- Use of Buzzard N-body catalogues to build realistic mocks to validate the DESI DR1 3x2pt analyses, including:
  - Realistic DESI DR1 galaxy populations (BGS, LRG)
  - Match to photo-z, weights, calibration corrections for KiDS-1000, DES-Y3, HSC-Y1 weak lensing samples
  - Mocks for each survey tuned to match footprint overlap
  - Several mock realizations for each WL survey



Parameter fits to the 3x2-pt correlations for DESI Y1 combined with KiDS, DES, HSC

Red = fit to mock mean

Blue = fit to fiducial model vector

DESI DR1 3x2pt mock challenge

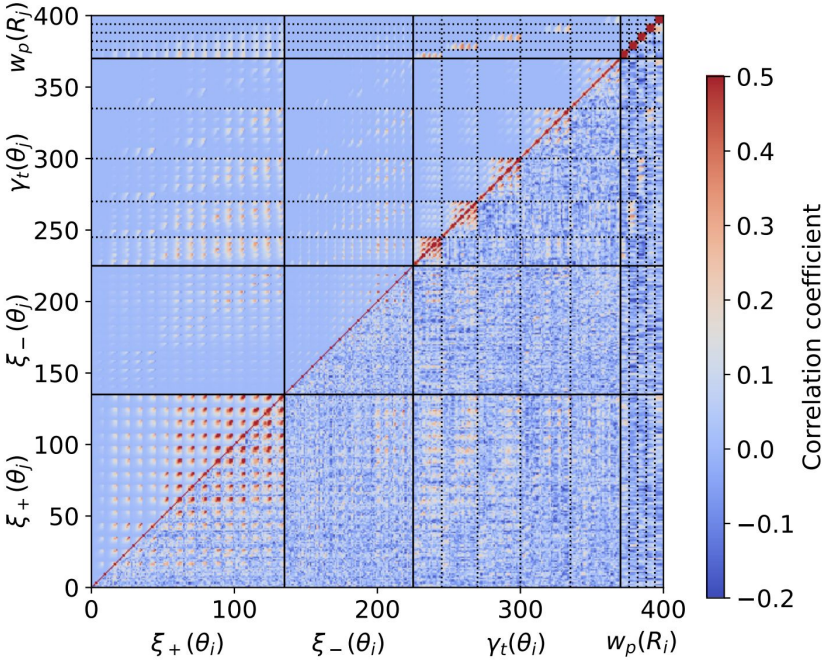
Chris Blake, Cristhian Garcia-Quintero, et al. 2024

https://arxiv.org/abs/2412.12548

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

- Use of Buzzard N-body catalogues to build realistic mocks to validate the DESI DR1 3x2pt analyses, including:
  - Realistic DESI DR1 galaxy populations (BGS, LRG)
  - Match to photo-z, weights, calibration corrections for KiDS-1000, DES-Y3, HSC-Y1 weak lensing samples
  - Mocks for each survey tuned to match footprint overlap
  - Several mock realizations for each WL survey



Validation of the analytical covariance (fiducial, upper left triangle) with 160 realizations (lower right triangle)

DESI DR1 3x2pt analysis: observables & pipeline

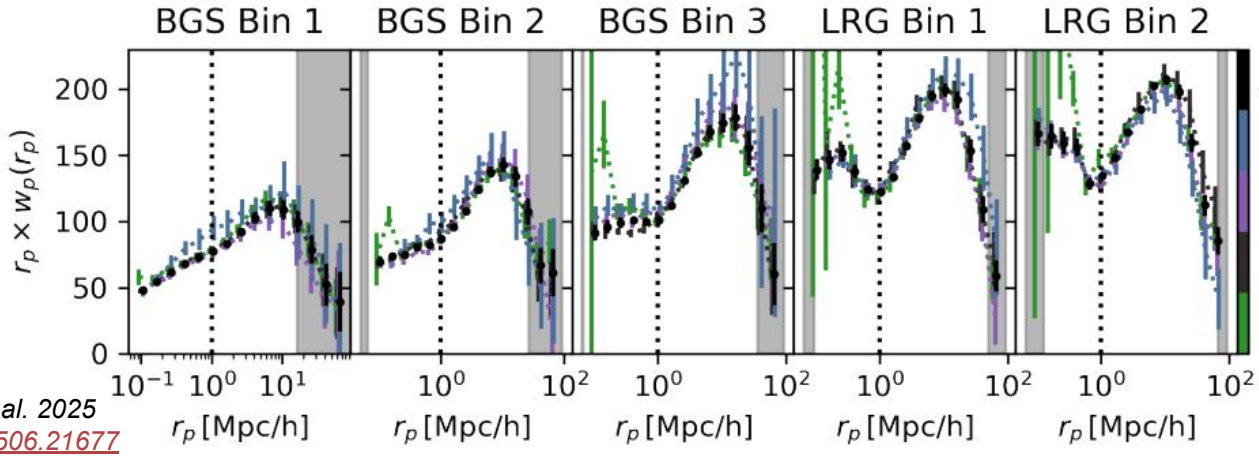
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Observables:

- cosmic shear: xi+/xi- (publicly released by each WL survey)
- galaxy-galaxy lensing: γ_t
- galaxy clustering: w_p

Pipeline: CosmoSIS (already used in DES, KiDS, and HSC), validated against 3 other pipelines using Cobaya and CosmoMC

Modelling choices: Following DES-Y3 fiducial and DES+KiDS hybrid pipeline



Sven Heydenreich et al. 2025
https://arxiv.org/pdf/2506.21677

DESI DR1 3x2pt analysis: scale cuts

Ni Emas, Anna Porredon, Chris Blake, Joe DeRose et al. 2025

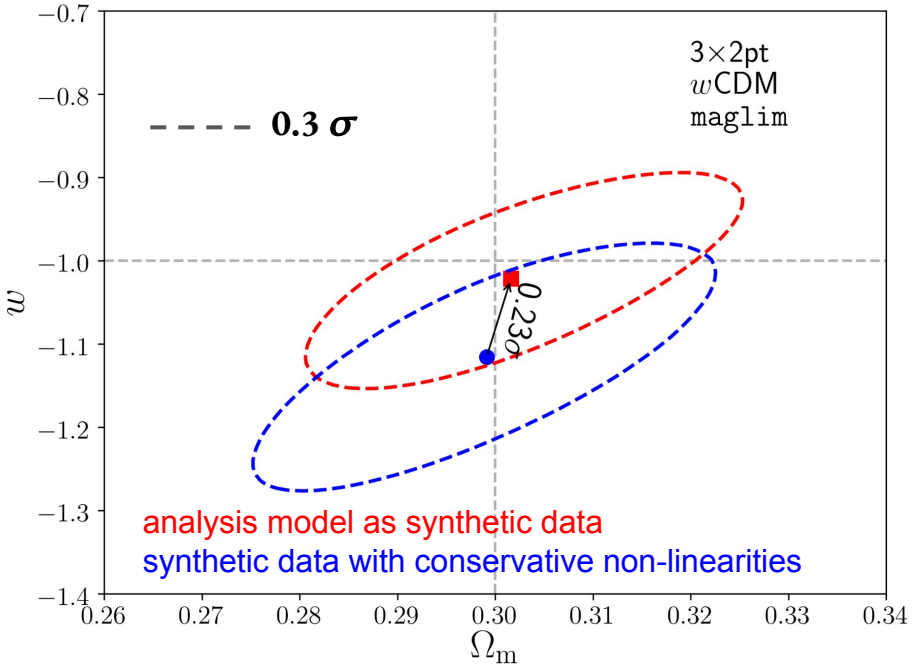
https://arxiv.org/abs/2510.05539

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Analysis restricted to scales such that non-linear modeling uncertainties bias cosmology constraints by < 0.3σ in 2D or < 0.5σ in 1D constraints

DES Y3 3x2pt methods: E. Krause++ 2021



DESI DR1 3x2pt analysis: scale cuts

Ni Emas, Anna Porredon, Chris Blake, Joe DeRose et al. 2025

https://arxiv.org/abs/2510.05539

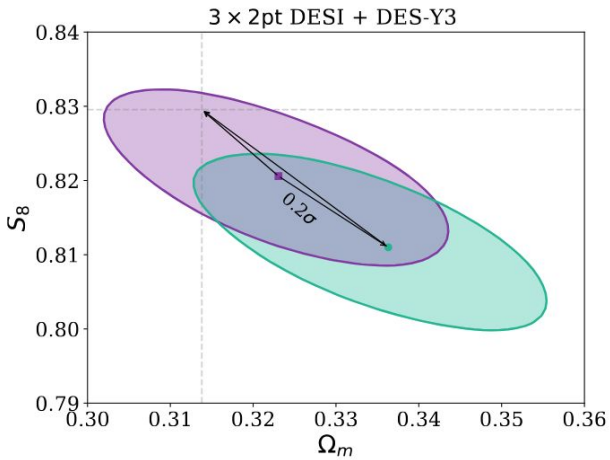
DARK ENERGY SPECTROSCOPIC INSTRUMENT

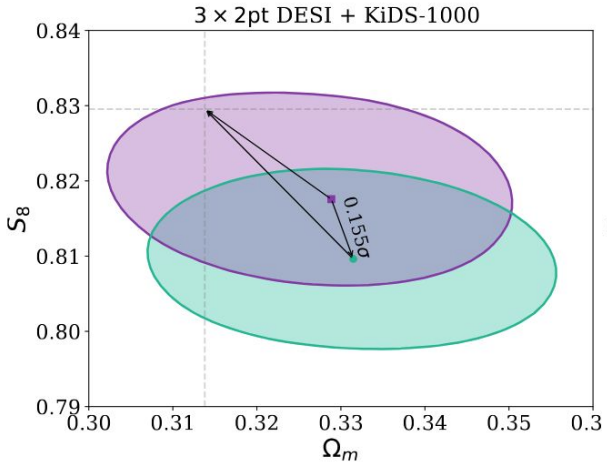
U.S. Department of Energy Office of Science

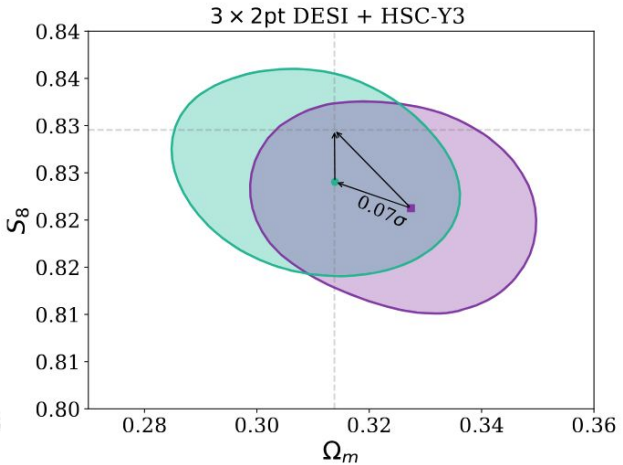
Scale cuts validated for all survey combinations: DES-Y3, KiDS-1000, HSC-Y1, HSC-Y3.

Robust against modelling of the non-linear matter power spectrum, non-linear galaxy bias and baryonic feedback effects

- Cosmic shear: fiducial scale cuts from each survey, with minor change for KiDS-1000
- Galaxy-galaxy lensing and projected galaxy clustering: 6 Mpc/h for γ_t and 8 Mpc/h for w_p







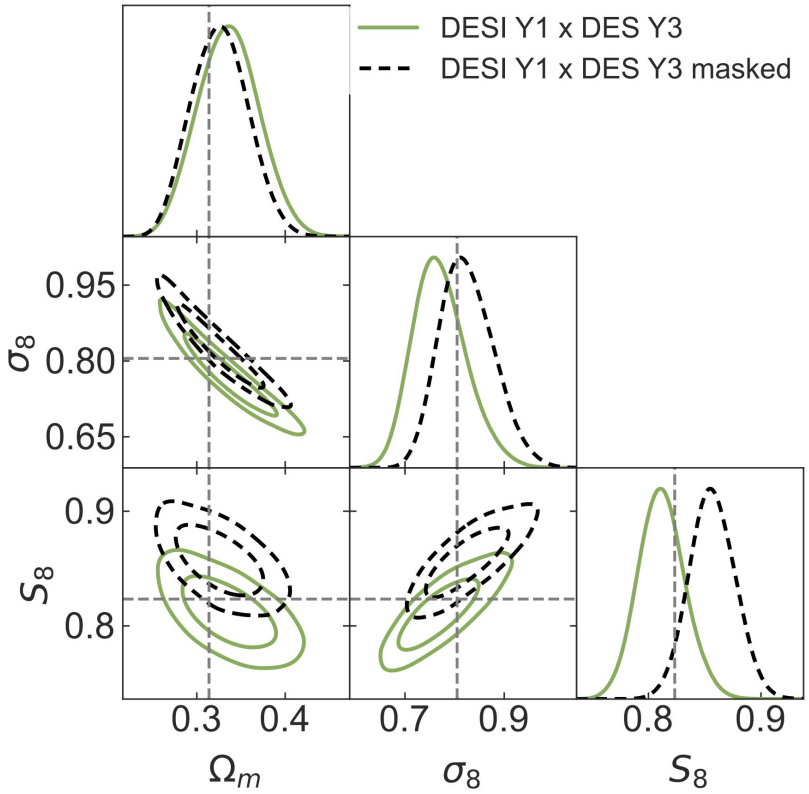
DESI DR1 3x2pt analysis: blinding

Anna Porredon++ (in prep.)

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

In order to avoid confirmation biases, we validate the whole analysis in a blind way, and we first run the pipeline on data vectors with a shifted value of S_8

The blinding methodology has been developed by Johannes Lange following the DES 3x2pt approach (Jessie Muir et al. 2020)

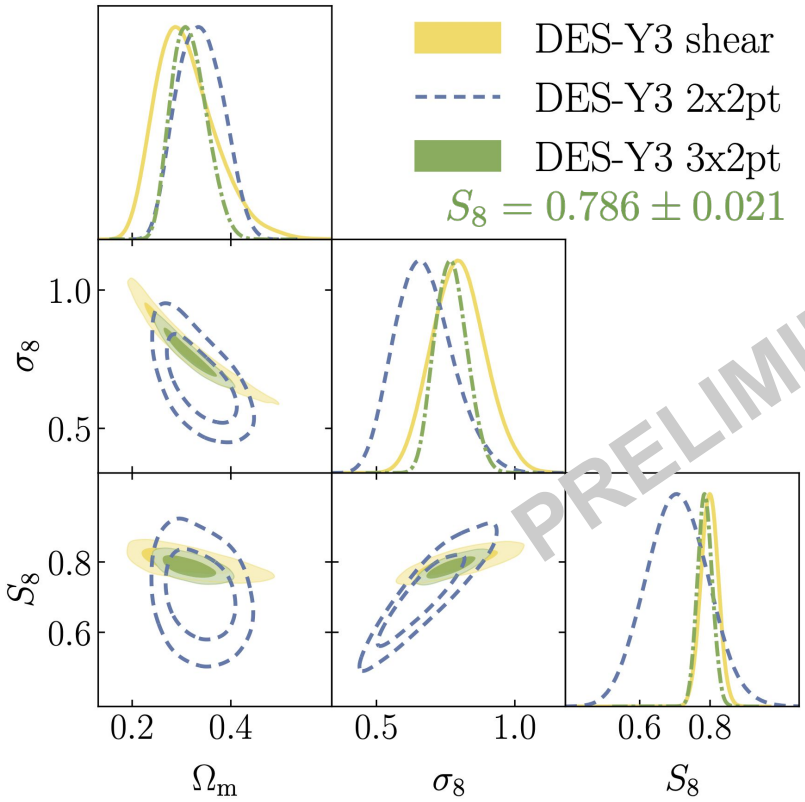


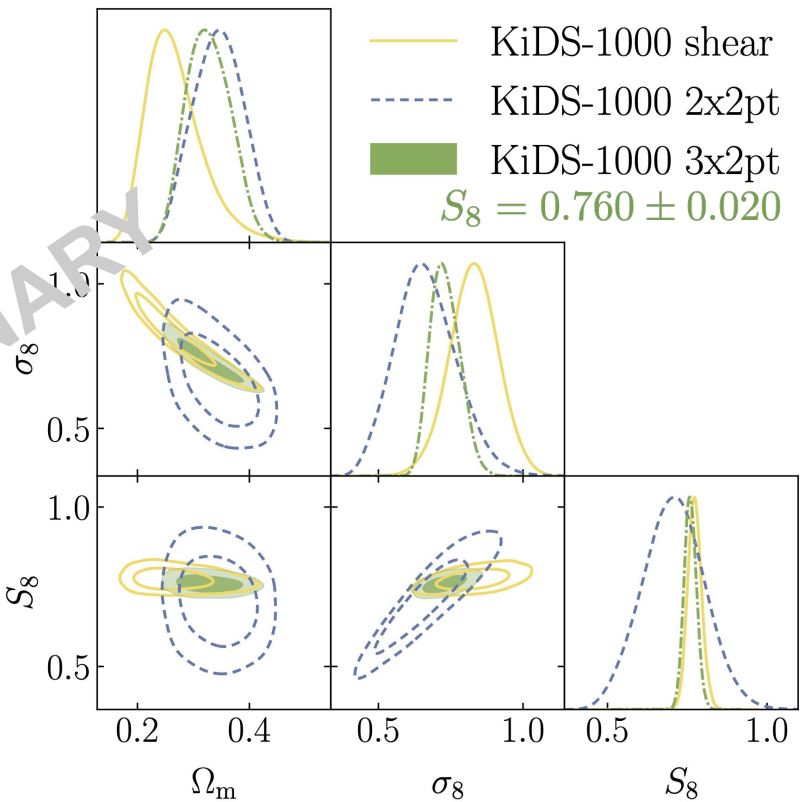
Similar results for the other surveys

DESI DR1 3x2pt analysis: results on data

Anna Porredon++ (in prep.)

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

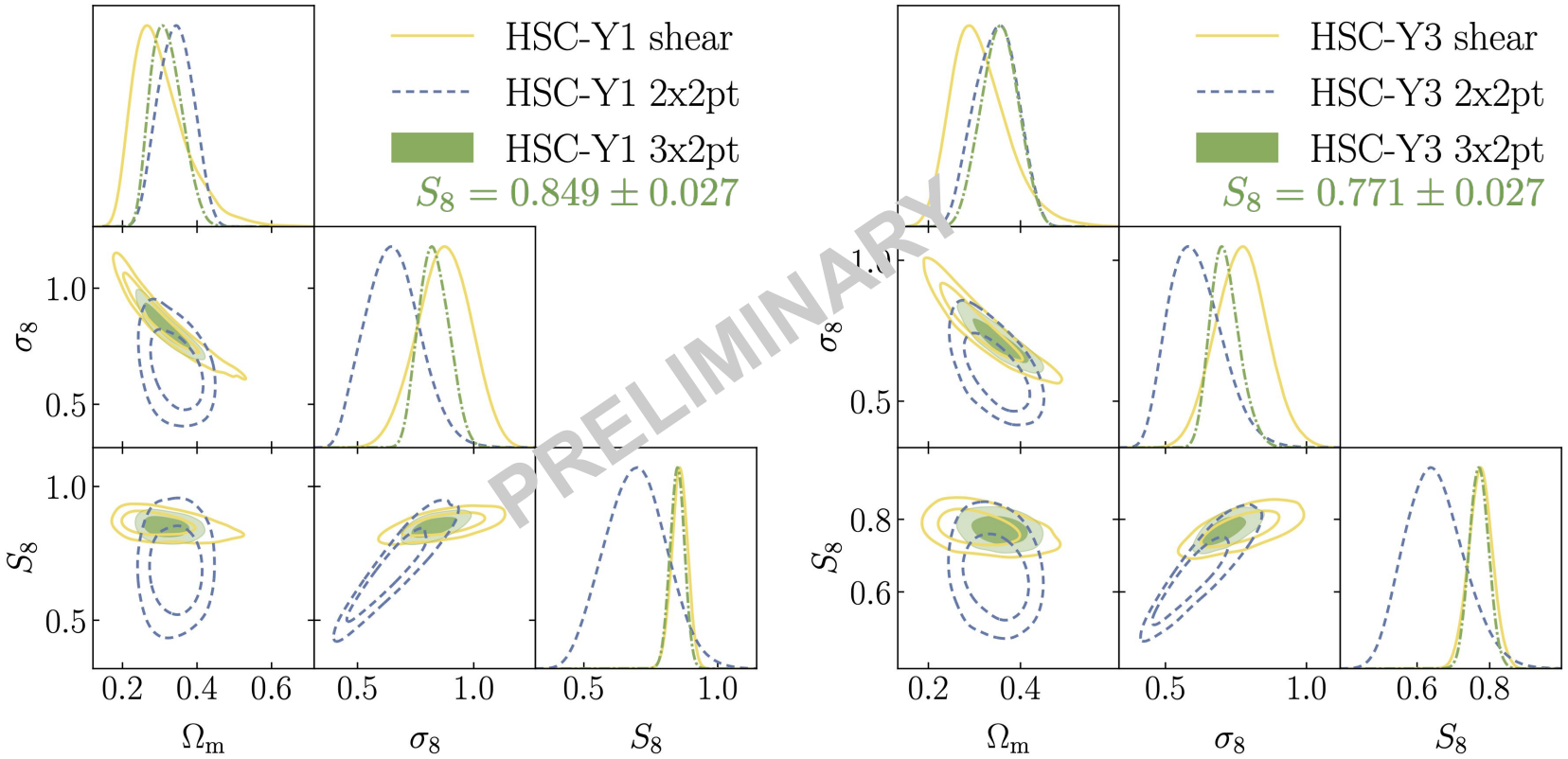




DESI DR1 3x2pt analysis: results on data

Anna Porredon++ (in prep.)

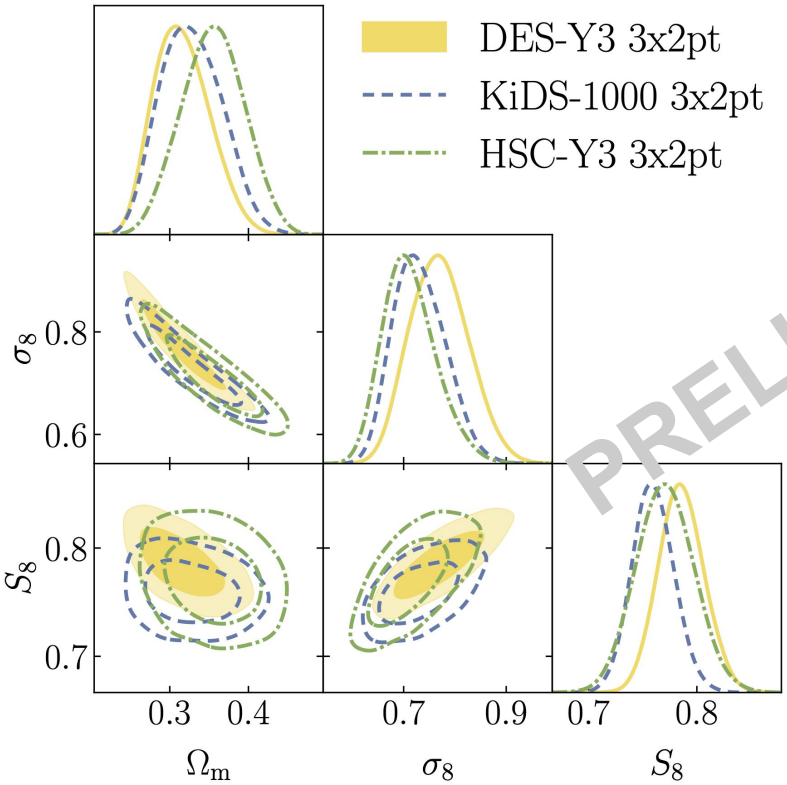
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science



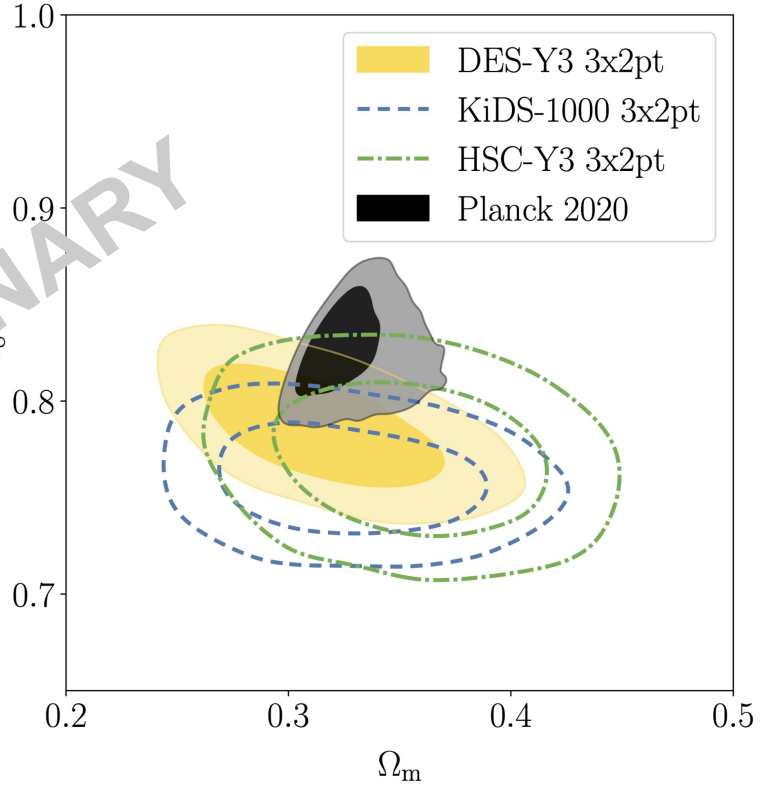
DESI DR1 3x2pt analysis: survey comparison

Anna Porredon++ (in prep.)

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science



PRELIMINARY

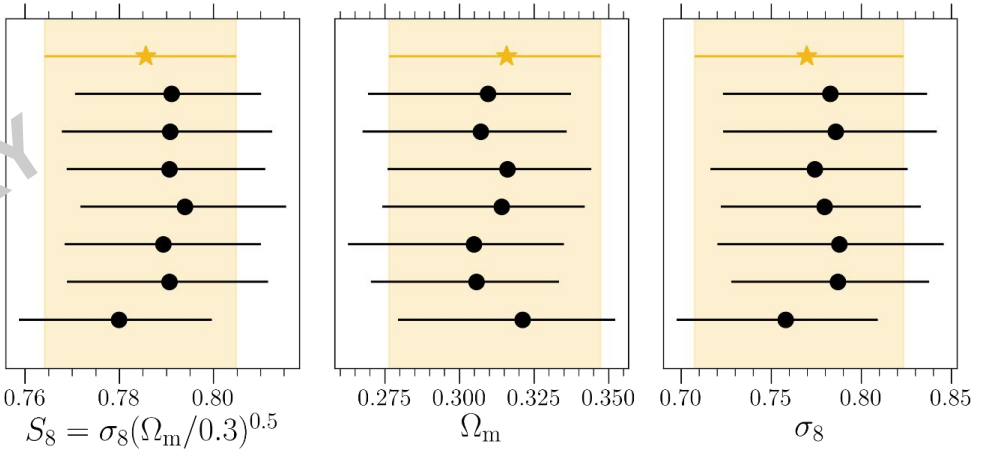


DESI DR1 3x2pt analysis: robustness

Anna Porredon++ (in prep.)

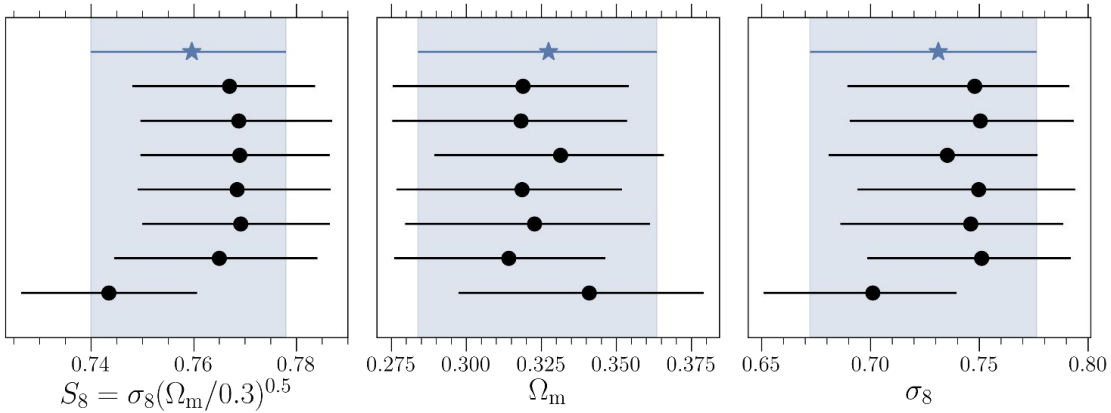
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

DESI DR1 x DES-Y3 3x2pt
No lens bin 1
No lens bin 2
No lens bin 3
No lens bin 4
No lens bin 5
Fix neutrinos
Dark-matter only



PRELIMINARY

DESI DR1 x KiDS-1000 3x2pt
No lens bin 1
No lens bin 2
No lens bin 3
No lens bin 4
No lens bin 5
Fix neutrinos
Dark-matter only



Conclusions and looking ahead

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

- It is essential to analyse data from multiple surveys with a unified pipeline to assess the robustness and consistency of their cosmological constraints.
- We have obtained cosmological constraints from the 3x2pt combination of DESI DR1 with weak lensing from DES Y3, KiDS-1000, HSC-Y1, and HSC-Y3, finding in general consistent results between surveys and with each survey's fiducial results.

Constraining power will improve significantly by using 3D clustering and DESI-DR2 data

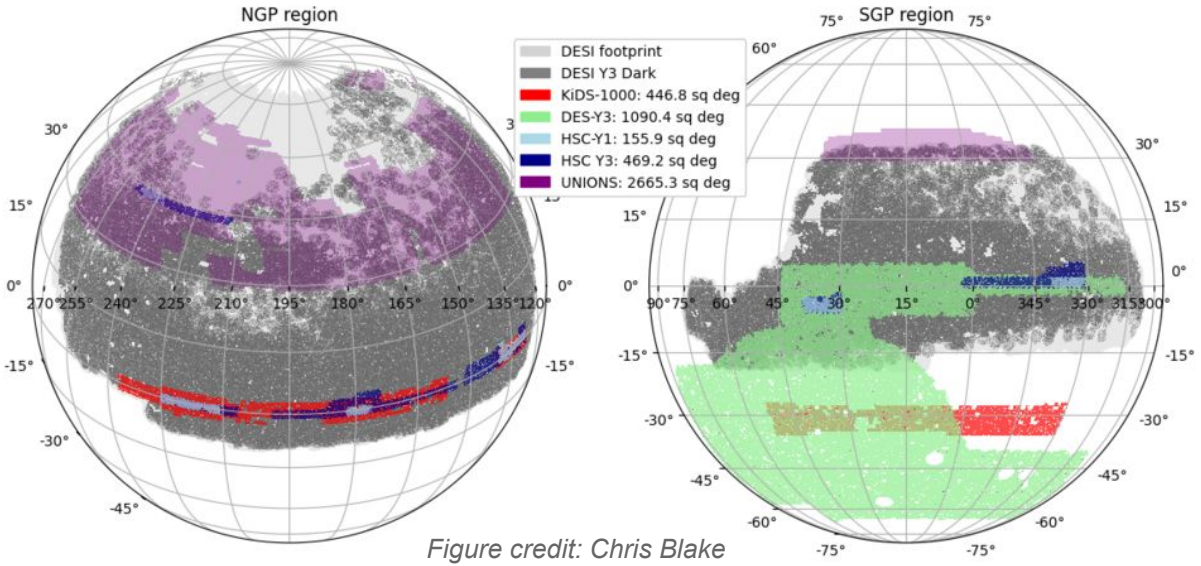


Figure credit: Chris Blake

Looking ahead: Euclid x DESI

About ~200 sq. deg. of overlap, which will increase significantly with further Euclid and DESI data releases

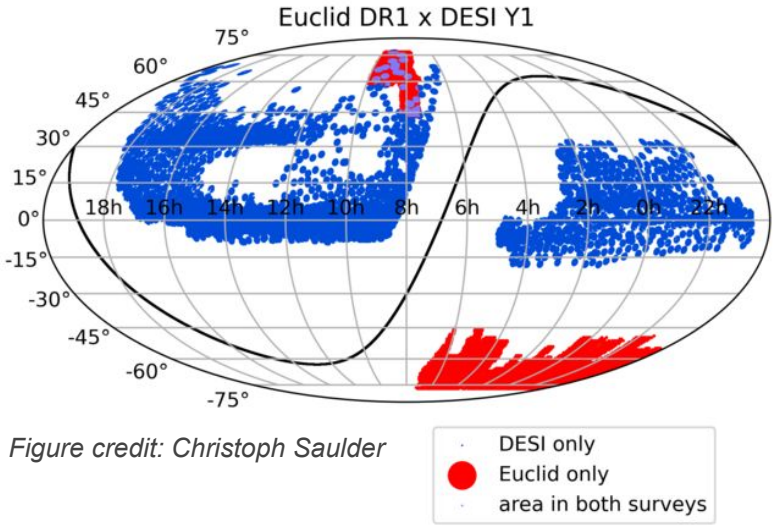
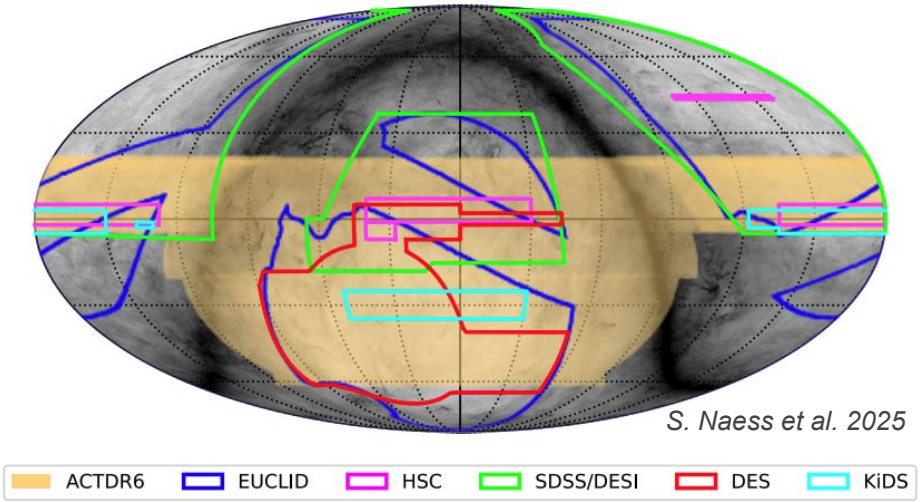
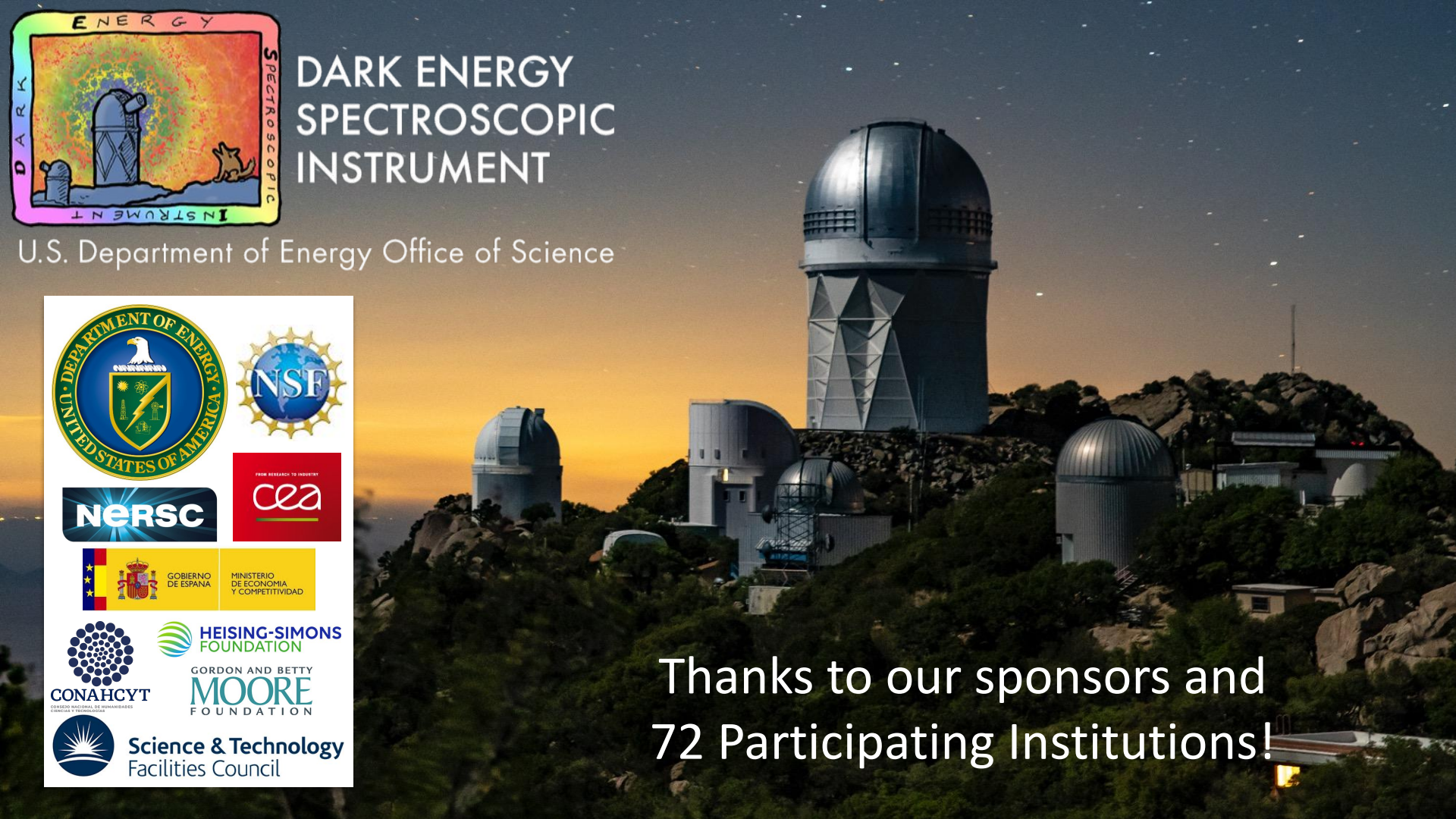


Figure credit: Christoph Saulder



S. Naess et al. 2025


DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science
NERSC
GOBIERNO DE ESPANA
MINISTERIO DE ECONOMIA Y COMPETITIVIDAD
HEISING-SIMONS FOUNDATION
CONAHCYT
GORDON AND BETTY MOORE FOUNDATION
Science & Technology Facilities Council
Thanks to our sponsors and
72 Participating Institutions!

Extra slides

Modelling choices for 3x2pt large-scale data analysis

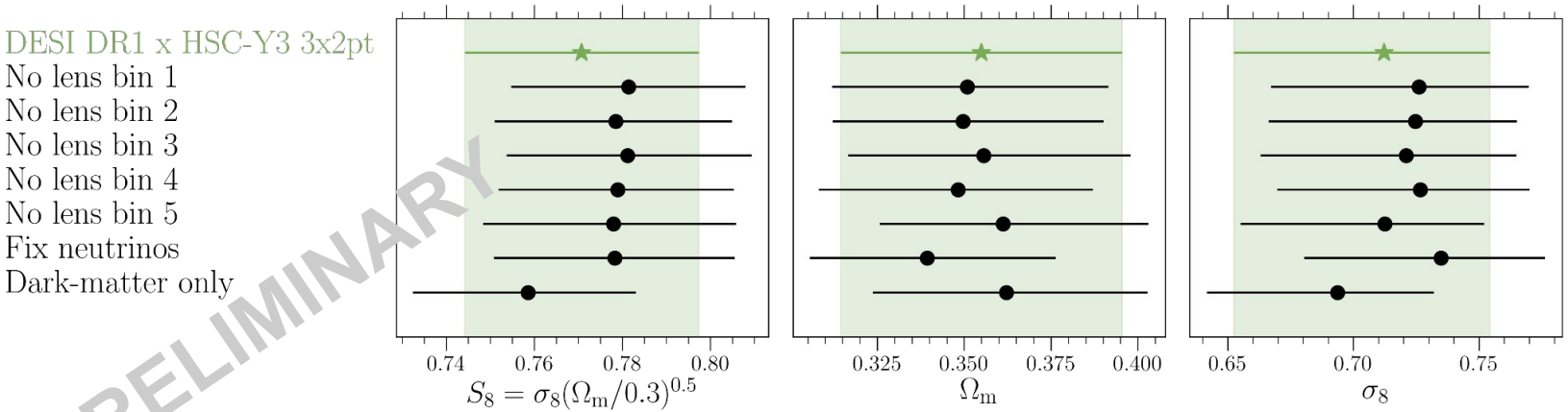
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Following DES-Y3 fiducial and DES+KiDS hybrid pipeline

- **Cosmological parameters and priors:** DESY3-like, sampling A_s and with free neutrinos
- **Non-linear Pk model + neutrino model:** HMcode2020 in CAMB
- **Baryonic feedback:** scale cuts and flat prior on T_agn parameter
- **Intrinsic alignments:** NLA with redshift dependence (2 parameters)
- **Lens magnification:** Gaussian priors using the measurements and uncertainty estimates from Sven Heydenreich et al. 2025
- **Point-mass marginalization:** included for γ_t
- **Galaxy bias**: linear model with one amplitude parameter per z-bin
- **Nuisance parameters:** shear calibration and source photo-z parameters as used in fiducial analyses of the WL surveys
- **Sampler:** Nautilus
- **Fiducial cosmology**: DESI fiducial (matches Abacus and Planck 2018)

DESI DR1 3x2pt analysis: robustness

Anna Porredon++ (in prep.)



D+K: The Hybrid Pipeline

	DES Y3	KiDS-1000	Hybrid
Cosmological parameter priors:			
Amplitude	$A_s : [0.5, 5.0]$	$S_8 : [0.1, 1.3]$	$S_8 : [0.1, 1.3]$
Hubble constant	$h : [0.55, 0.91]$	$h : [0.64, 0.82]$	$h : [0.64, 0.82]$
Matter density	$\Omega_m : [0.1, 0.9]$	$\omega_c : [0.051, 0.255]$	$\omega_c : [0.051, 0.255]$
Baryon density	$\Omega_b : [0.03, 0.07]$	$\omega_b : [0.019, 0.026]$	$\omega_b : [0.019, 0.026]$
Spectral index	$n_s : [0.87, 1.07]$	$n_s : [0.84, 1.1]$	$n_s : [0.84, 1.1]$
Neutrinos	$1000\,\Omega_\nu h^2 : [0.6, 6.44]$	$\Sigma m_\nu = 0.06$eV	$\Sigma m_\nu = [0.055, 0.6]$ eV
Astrophysical systematic models and priors:			
Intrinsic Alignments	TATT: $b_{TA} : [0, 2]$; $a_1, a_2, \eta_1, \eta_2 : [-5, 5]$	NLA: $A_{IA} : [-6, 6]$	NLA-z: $A_{IA}, \eta_{IA} : [-5, 5]$
Non-linear Model	HALOFIT	HMCODE2016	HMCODE2020
Baryon Feedback	Scale cuts	$A_{bary} : [2, 3.13]$	Scale cuts & $\log_{10}(T_{AGN}/\mathrm{K}) : [7.3, 8.0]$
Sampling Algorithm:			
	POLYCHORD	MULTINEST	POLYCHORD

Cosmological parameters: Our mock tests told us that these choices have minimal impact. We keep the neutrino mass free, and marginalise over S8.

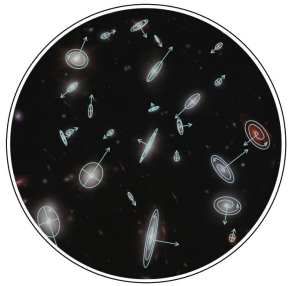
Intrinsic alignments: We opted for middle-ground with the IA model choice. IA have a redshift-dependence and we didn't find sufficient evidence to justify using TATT.

Non-linear Pk model: Testing against Euclid Emulator2, HMCode2020 was found to be the most accurate of the three choices.

Baryon feedback: We doubled down on mitigation methods against baryonic effects, using both scale cuts and the free HMcode2020 parameter.

Sampler: Testing against Emcee, Polychord produced more accurate constraints, with Multinest underestimating the uncertainty by 10-30%.

DES and KiDS analysis choices



	DES Y3	KiDS-1000
Cosmological parameter priors:		
Amplitude	$A_s : [0.5, 5.0]$	$S_8 : [0.1, 1.3]$
Hubble constant	$h : [0.55, 0.91]$	$h : [0.64, 0.82]$
Matter density	$\Omega_m : [0.1, 0.9]$	$\omega_c : [0.051, 0.255]$
Baryon density	$\Omega_b : [0.03, 0.07]$	$\omega_b : [0.019, 0.026]$
Spectral index	$n_s : [0.87, 1.07]$	$n_s : [0.84, 1.1]$
Neutrinos	$1000\,\Omega_\nu h^2 : [0.6, 6.44]$	$\Sigma m_\nu = 0.06$eV
Astrophysical systematic models and priors:		
Intrinsic Alignments	TATT: $b_{TA} : [0, 2]$; $a_1, a_2, \eta_1, \eta_2 : [-5, 5]$	NLA: $A_{IA} : [-6, 6]$
Non-linear Model	HALOFIT	HMCODE2016
Baryon Feedback	Scale cuts	$A_{bary} : [2, 3.13]$

Intrinsic alignments: KiDS uses the Non-Linear Alignment (NLA) model. DES uses the Tidal Alignment and Tidal Torquing (TATT) model, which includes extra higher order terms, and so has more flexibility in scale and redshift dependence.

In D+K, we opted for middle-ground with the IA model choice. IA have a redshift-dependence and we didn't find sufficient evidence to justify using TATT.

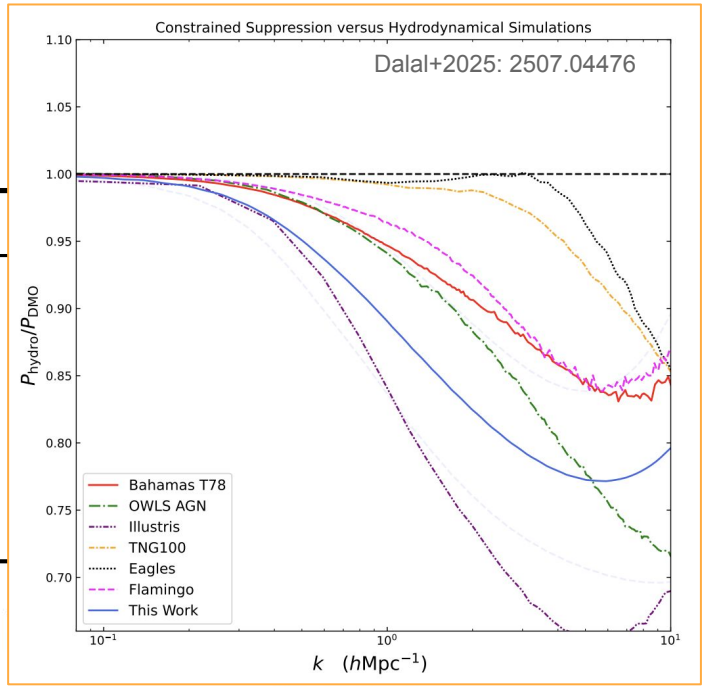
DES and KiDS analysis choices

	DES Y3	KiDS-1000
Cosmological parameter priors:		
Amplitude	$A_s : [0.5, 5.0]$	$S_8 : [0.1, 1.3]$
Hubble constant	$h : [0.55, 0.91]$	$h : [0.64, 0.82]$
Matter density	$\Omega_m : [0.1, 0.9]$	$\omega_c : [0.051, 0.255]$
Baryon density	$\Omega_b : [0.03, 0.07]$	$\omega_b : [0.019, 0.026]$
Spectral index	$n_s : [0.87, 1.07]$	$n_s : [0.84, 1.1]$
Neutrinos	$1000\,\Omega_\nu h^2 : [0.6, 6.44]$	$\Sigma m_\nu = 0.06$eV
Astrophysical systematic models and priors:		
Intrinsic Alignments	TATT: $b_{TA} : [0, 2]$; $a_1, a_2, \eta_1, \eta_2 : [-5, 5]$	NLA: $A_{IA} : [-6, 6]$
Non-linear Model	HALOFIT	HMCODE2016
Baryon Feedback	Scale cuts	$A_{bary} : [2, 3.13]$

Testing against Euclid Emulator2, HMCode2020 was found to be the most accurate of the three choices. So we used that for the DES+KiDS analysis.

DES and KiDS analysis choices

	DES Y3
Cosmological parameter priors:	
Amplitude	$A_s : [0.5, 5.0]$
Hubble constant	$h : [0.55, 0.91]$
Matter density	$\Omega_m : [0.1, 0.9]$
Baryon density	$\Omega_b : [0.03, 0.07]$
Spectral index	$n_s : [0.87, 1.07]$
Neutrinos	$1000\,\Omega_\nu h^2 : [0.6, 6.44]$
Astrophysical systematic models and priors:	
Intrinsic Alignments	TATT: $b_{TA} : [0, 2]; a_1, a_2, \eta_1, \eta_2 :$
Non-linear Model	HALOFIT
Baryon Feedback	Scale cuts $A_{bary} : [2, 3.13]$



Baryon feedback:

Large scatter in the predicted amplitude and extent of baryonic effects from simulations. Can either:

1. Discard the measurements on scales sensitive to these effects
2. Model the feedback with a parameter and prior range that captures the uncertainty

Cosmological-fitting pipelines: code comparison

Anna Porredon, Cristhian Garcia-Quintero, Joe DeRose, Shahab Joudaki

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Agreement between codes at the level of $\Delta\chi^2 < 1$ after scale cuts

Observables:

- cosmic shear: xi+/xi-
- galaxy-galaxy lensing: gamma_t
- galaxy clustering: w_p

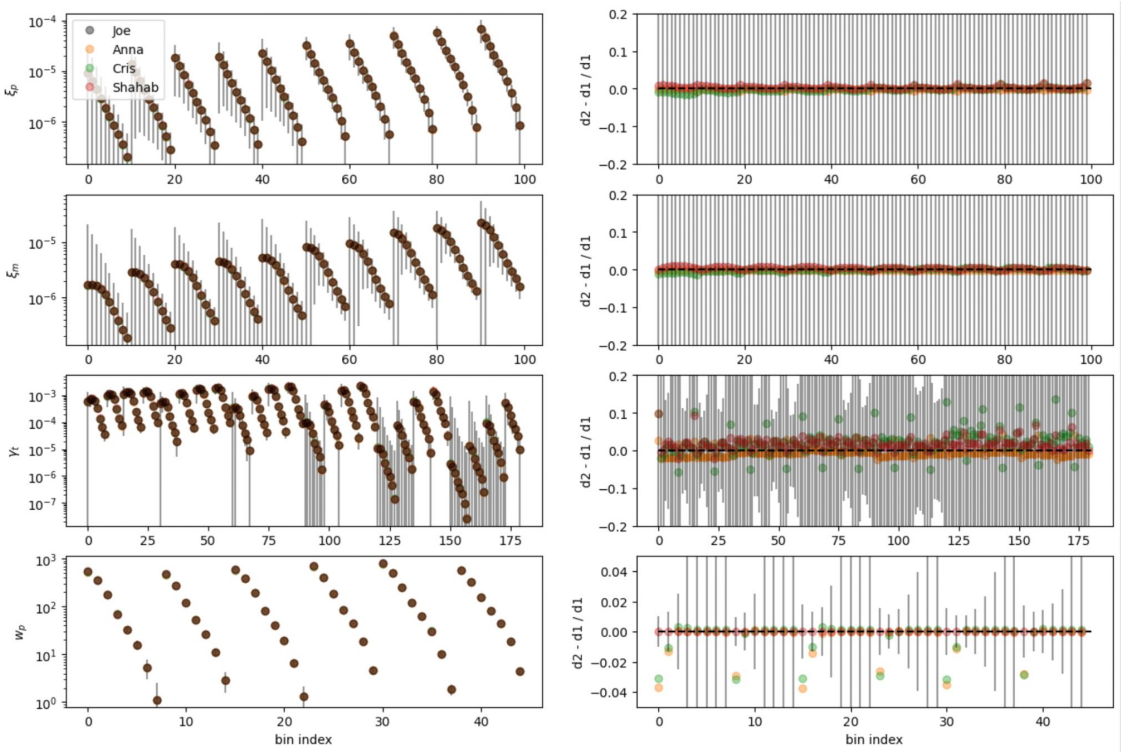


Figure credit: Joe DeRose

BGS for DESI DR1 weak lensing cross-correlations

Sven Heydenreich, Alexie Leauthaud ++

https://arxiv.org/pdf/2506.21677

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

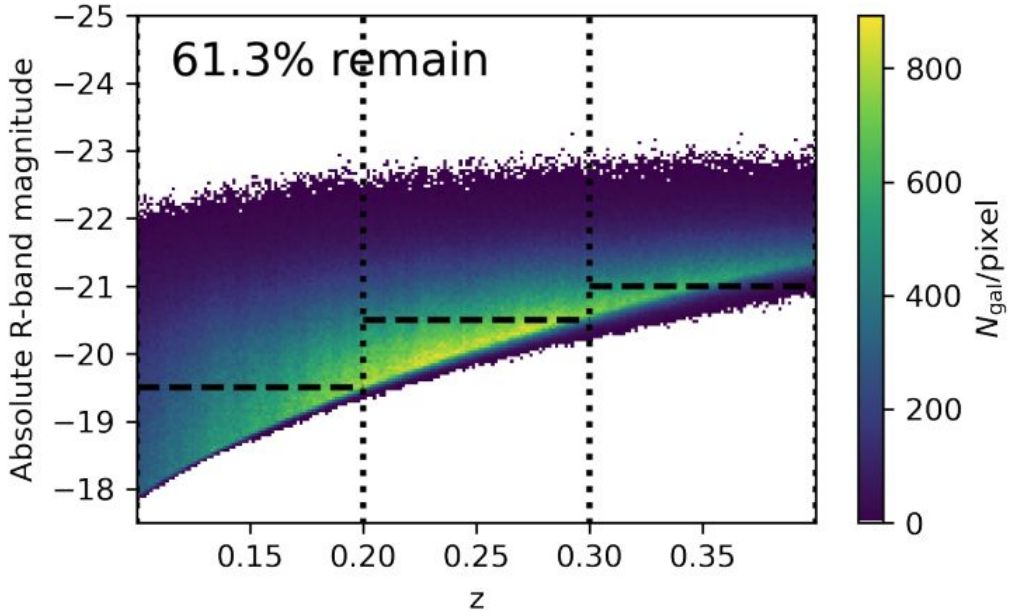


Figure 2. Absolute magnitudes of DESI DR1 BGS as a function of redshift. The galaxies that pass the magnitude cut described in Sect. 2.1 are the ones above the dashed lines. In total, 61% of all galaxies pass the magnitude cut.

CosmoSIS (3x2pt pipeline) vs CosmoMC comparison