DES-Y3 results and comparison with KiDS and HSC:

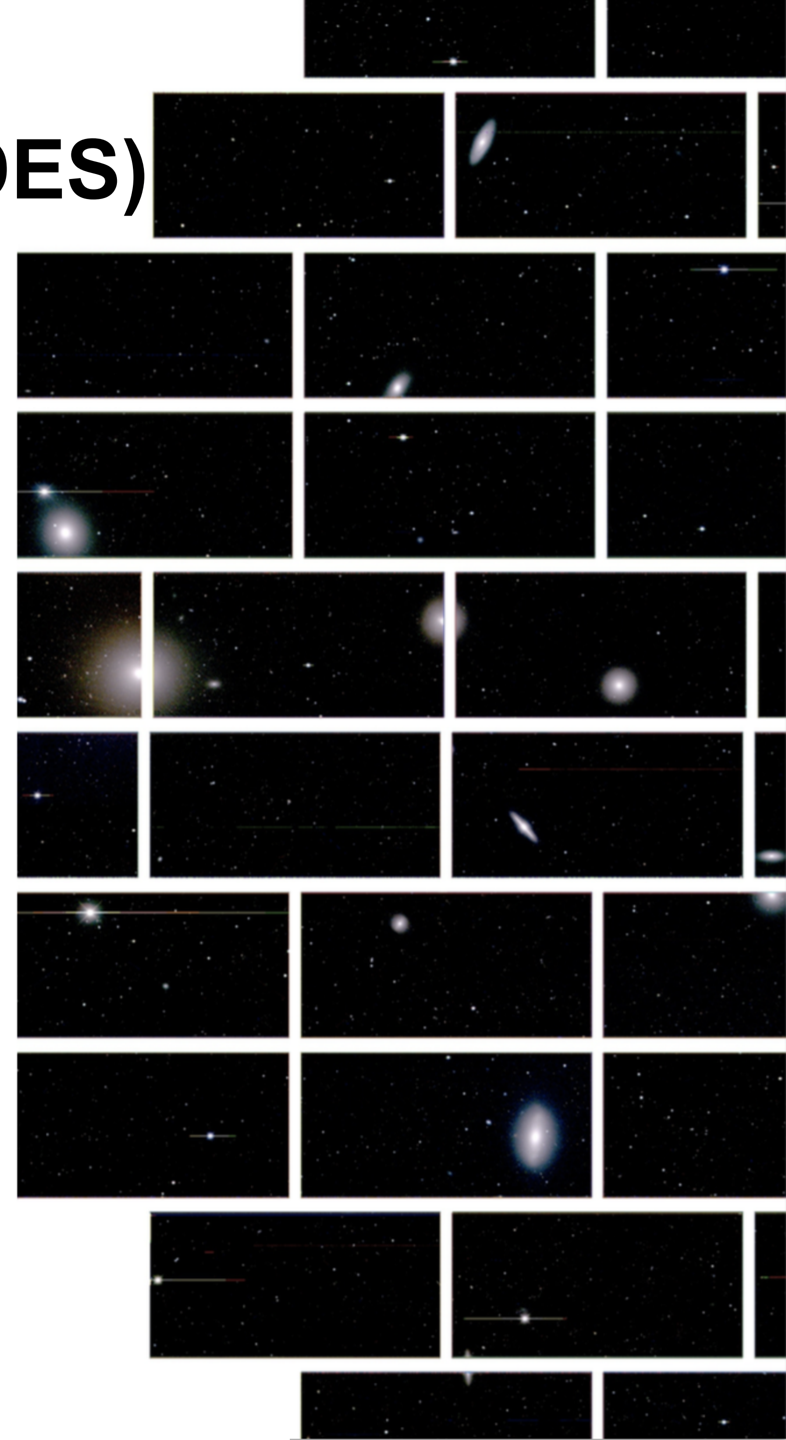
Is there a σ_8 tension?

Ramon Miquel
ICREA / IFAE Barcelona

DSU, Kigali, July 10th 2023

DARK ENERGY SURVEY

Dark Energy Survey (DES)

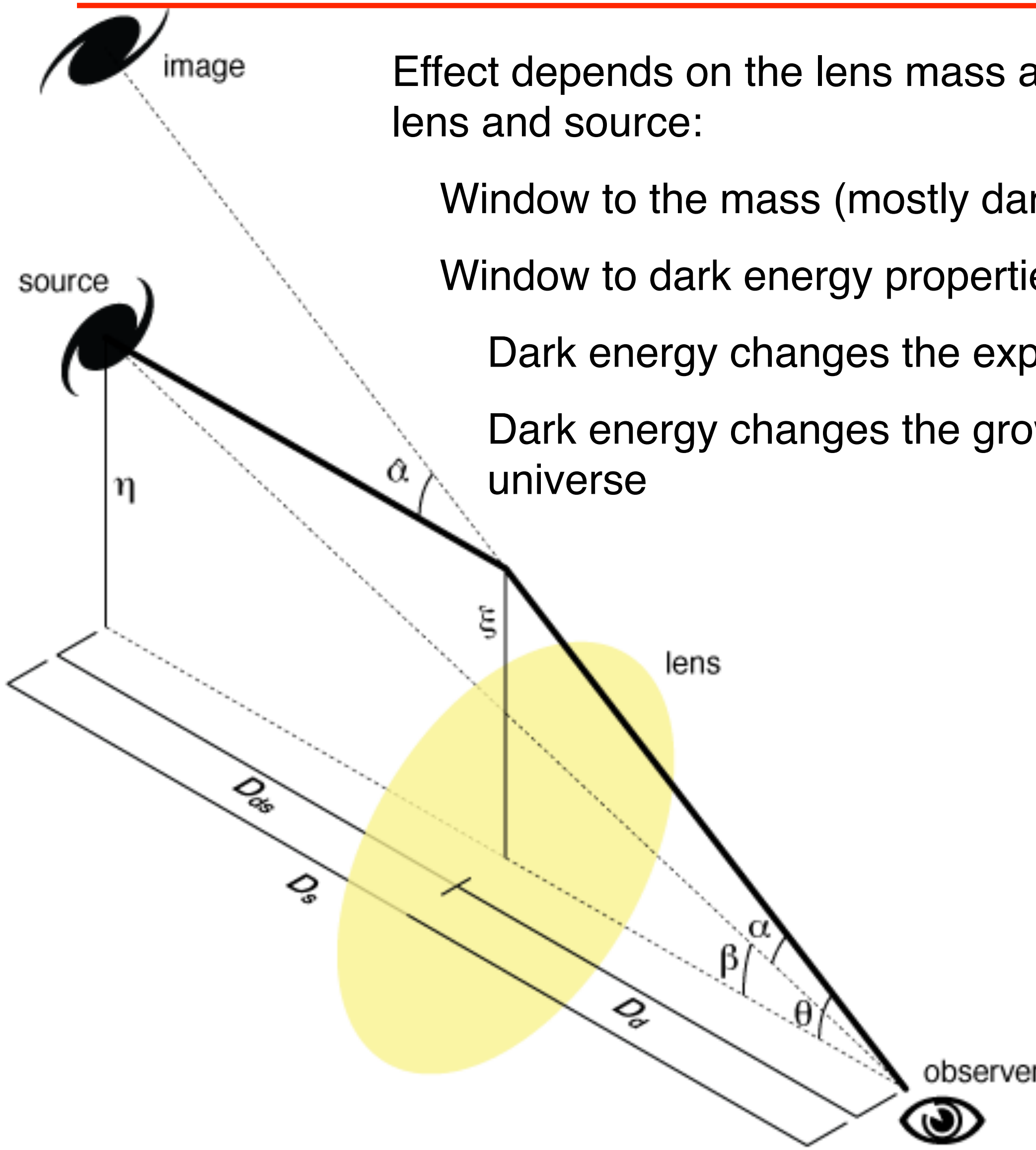


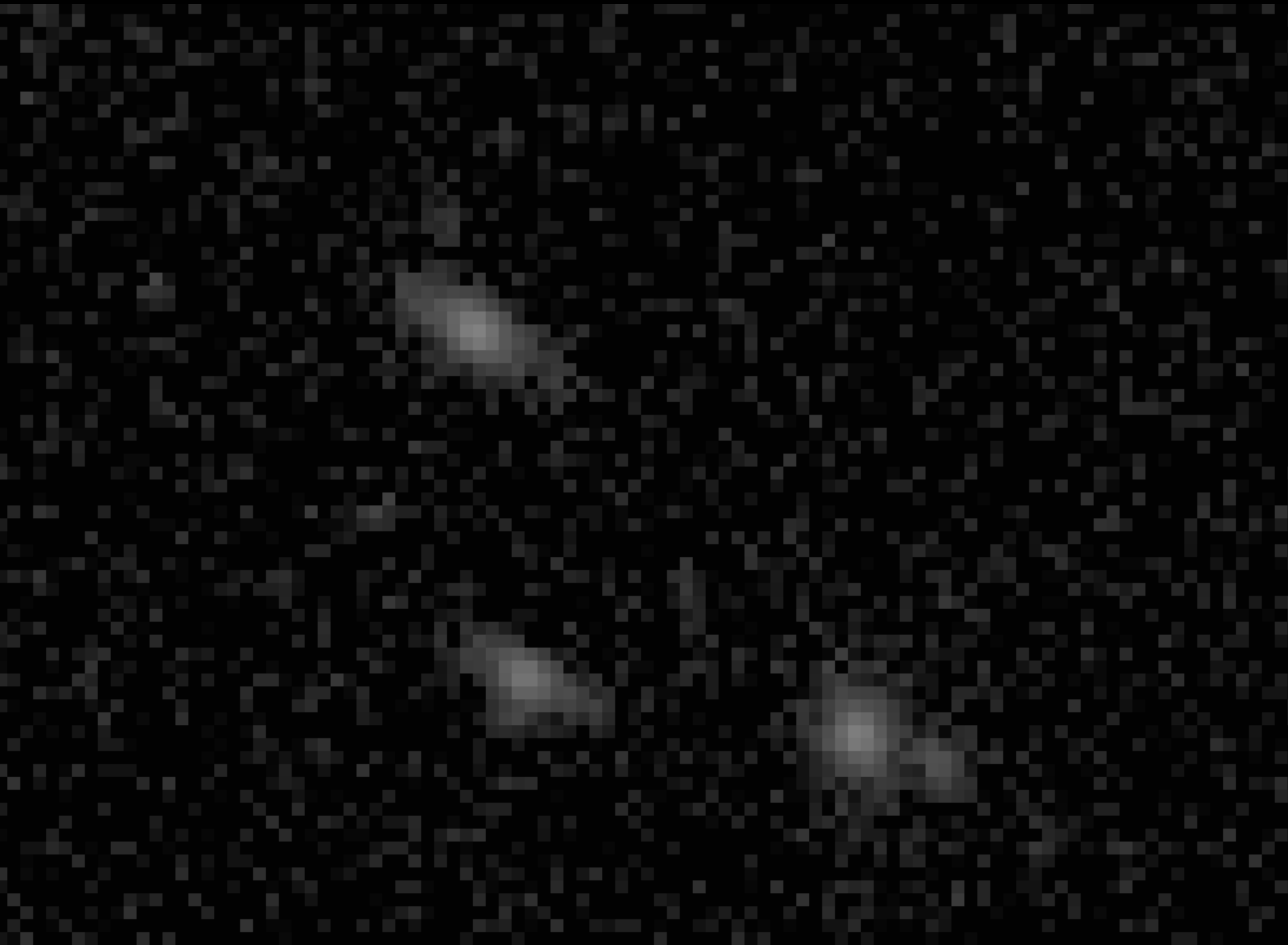
- Imaging galaxy survey on the 4-m Blanco telescope (Chile) to study Dark Energy
- 400 scientists in 28 institutions in USA, Spain, UK, Brazil, Switzerland, Germany, Australia
- Operated 2013-2019. 577 nights in 6 seasons
- Mapped 1/8 of sky (5000 deg^2) to z ~ 1.3 in 5 optical bands: 200+ million galaxies
- Four dark energy probes:
    - Galaxy cluster counting
    - Galaxy distribution (including BAO)
    - Type-Ia supernovae
    - **Weak gravitational lensing**

Weak gravitational lensing

Effect depends on the lens mass and the distances between observer, lens and source:

- Window to the mass (mostly dark matter) distribution in the universe
- Window to dark energy properties:
  - Dark energy changes the expansion rate: distances $\mathbf{D_d}$, $\mathbf{D_s}$, $\mathbf{D_{ds}}$
  - Dark energy changes the growth rate of mass structures in the universe

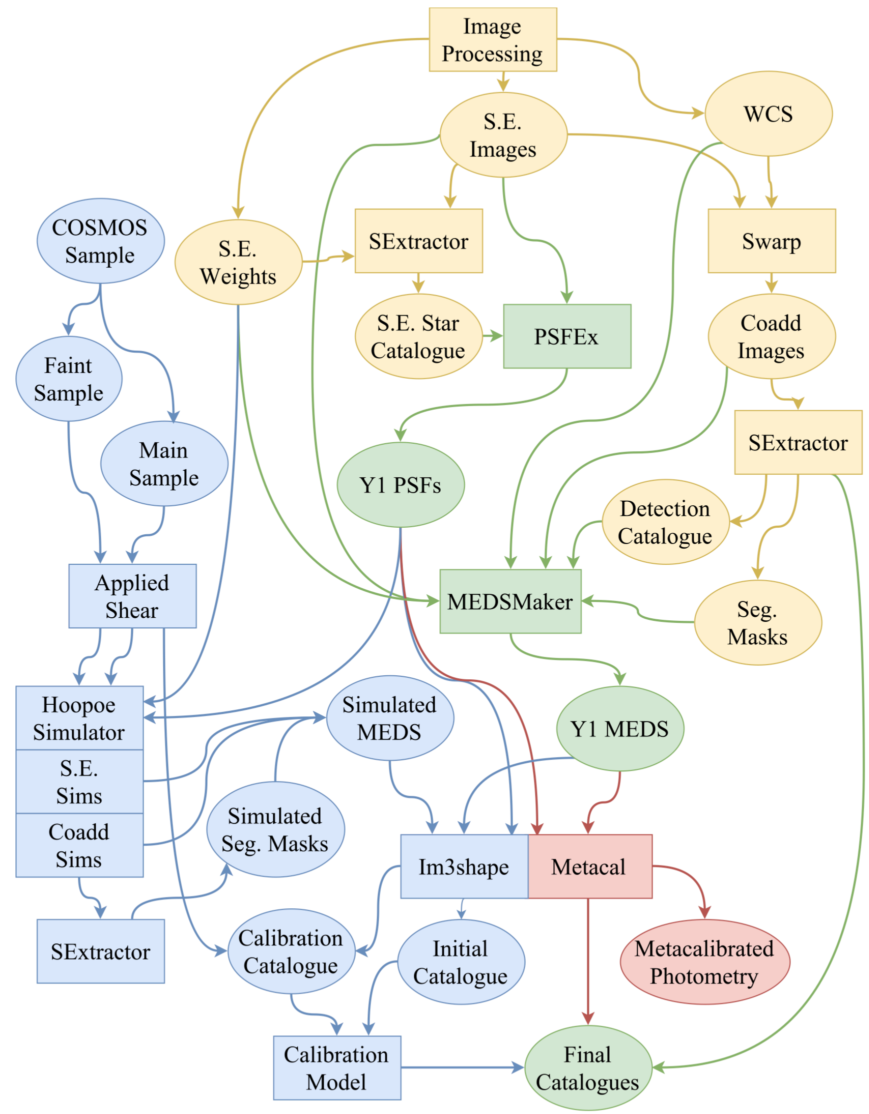




A huge effort!

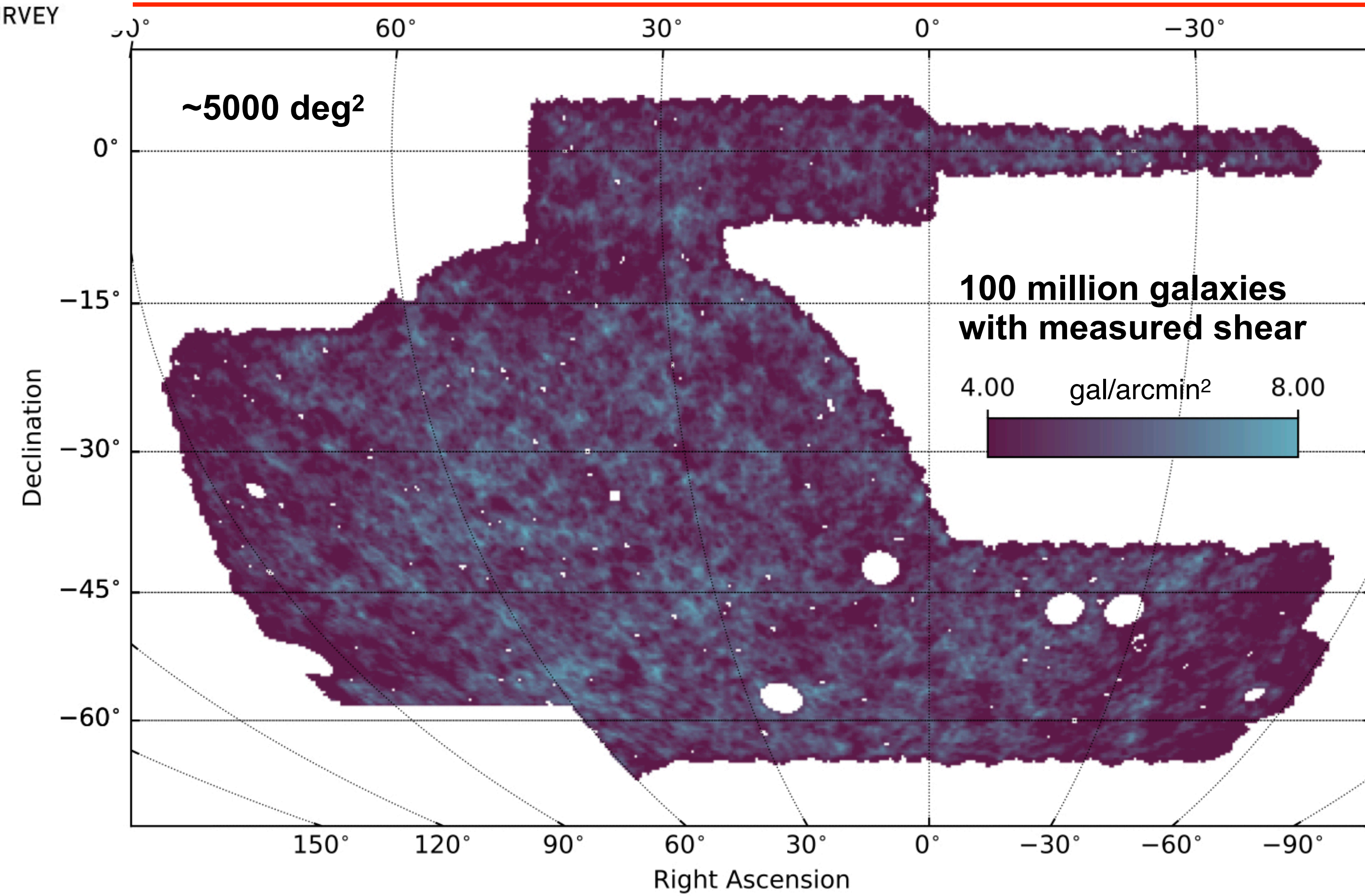
Reduction of single-epoch images
Astrometric solution
Photometric calibration
Co-addition into deep images
Object detection
Flux measurement
Star / galaxy separation
PSF extraction from stars
Shear measurement on galaxies

Each bubble can represent months of development and millions of CPU hours.



Credit: Michael Troxel (DES-Y1)

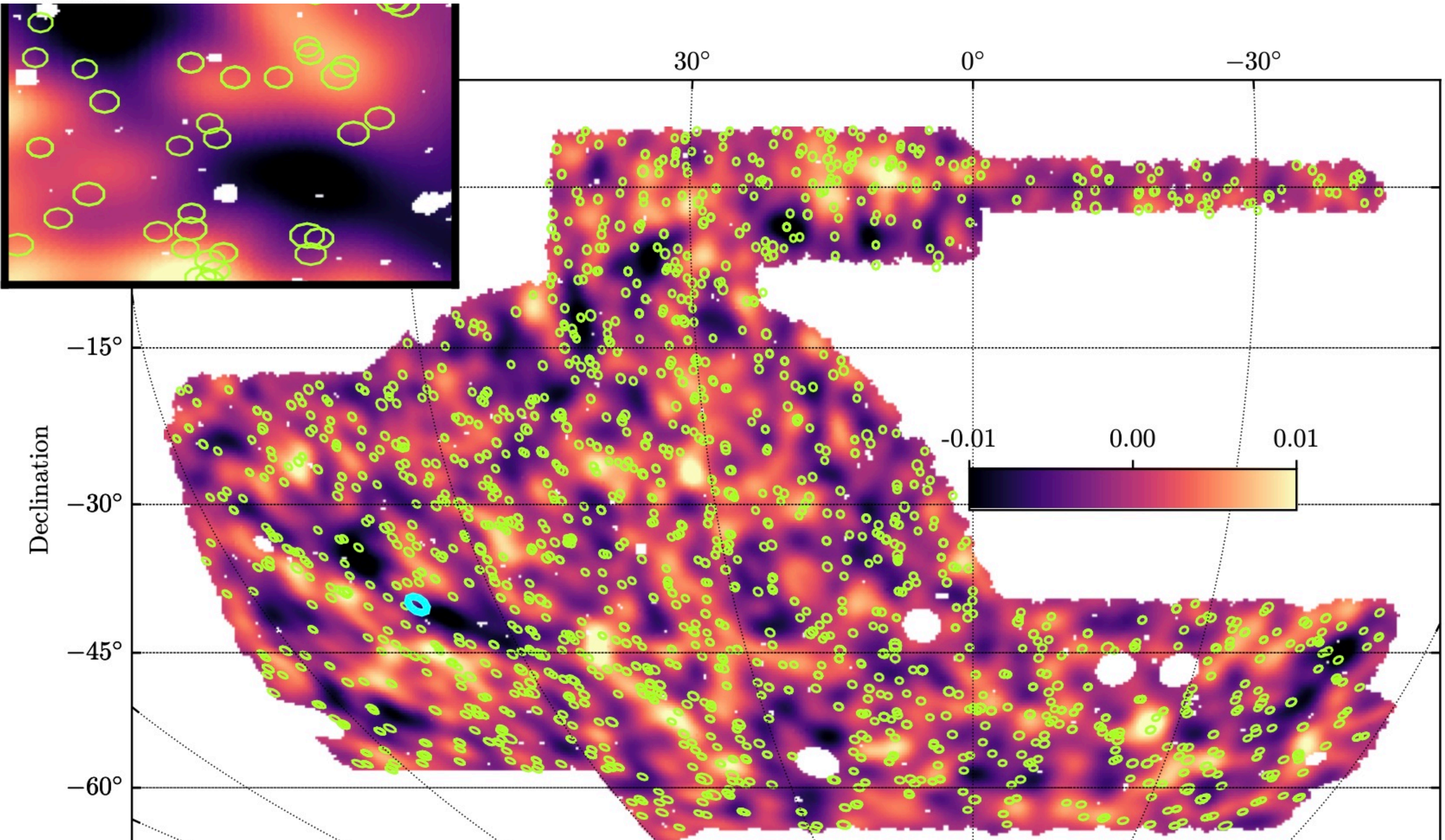
DES Year-3 weak lensing sample



Gatti, Sheldon et al., MNRAS 504 (2021) 4312, arXiv:2011.03408

DES Year-3 mass map

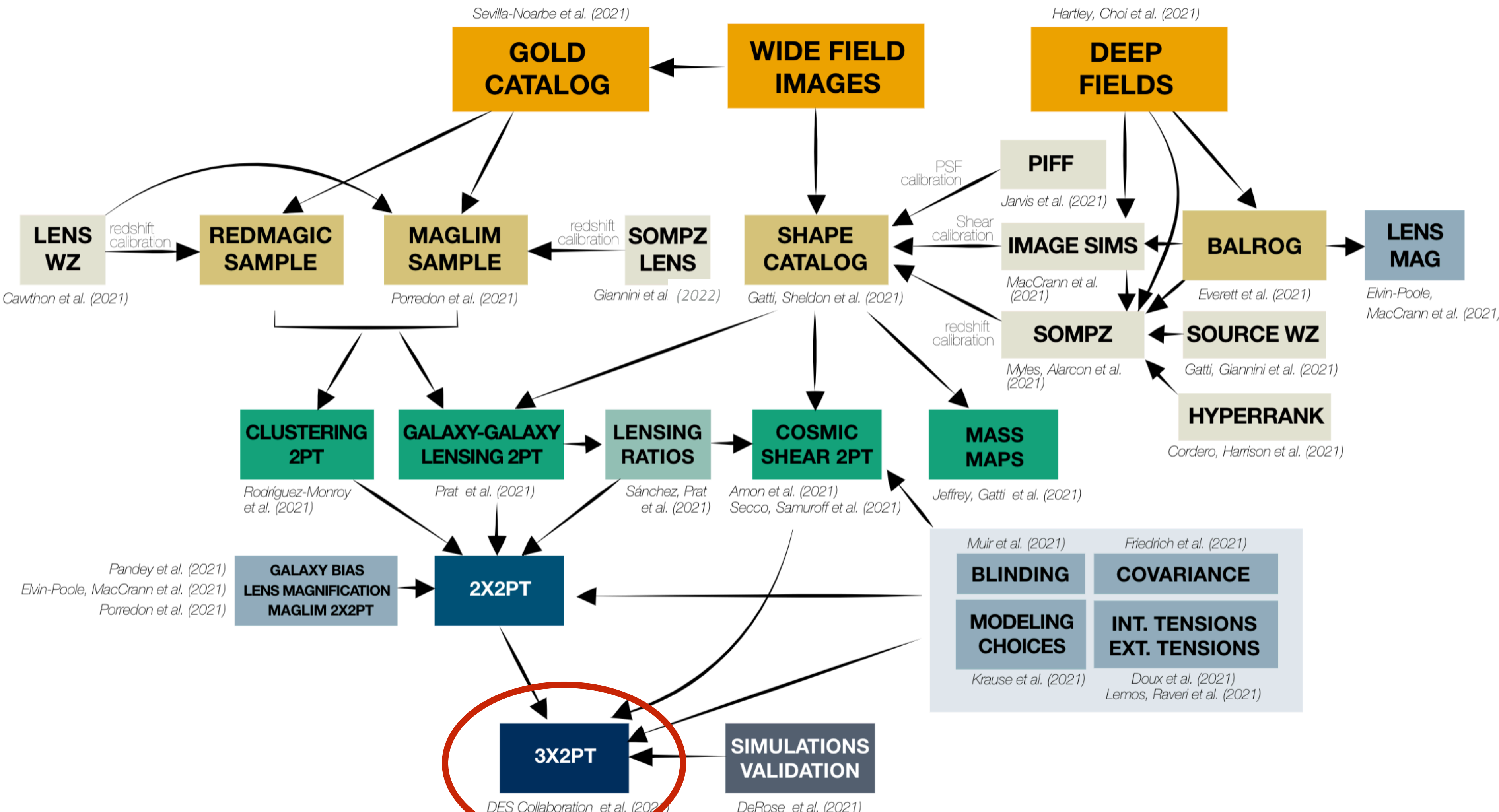
DARK ENERGY SURVEY



Jeffrey, Gatti et al., MNRAS 505 (2021) 4626, arXiv:2105.13539

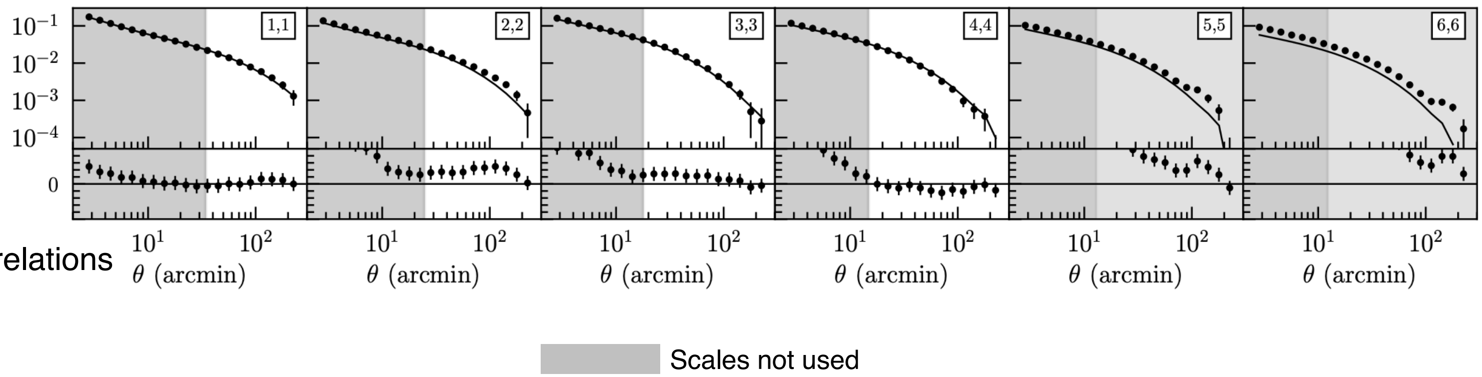
DES Year-3 cosmological analysis

DARK ENERGY SURVEY

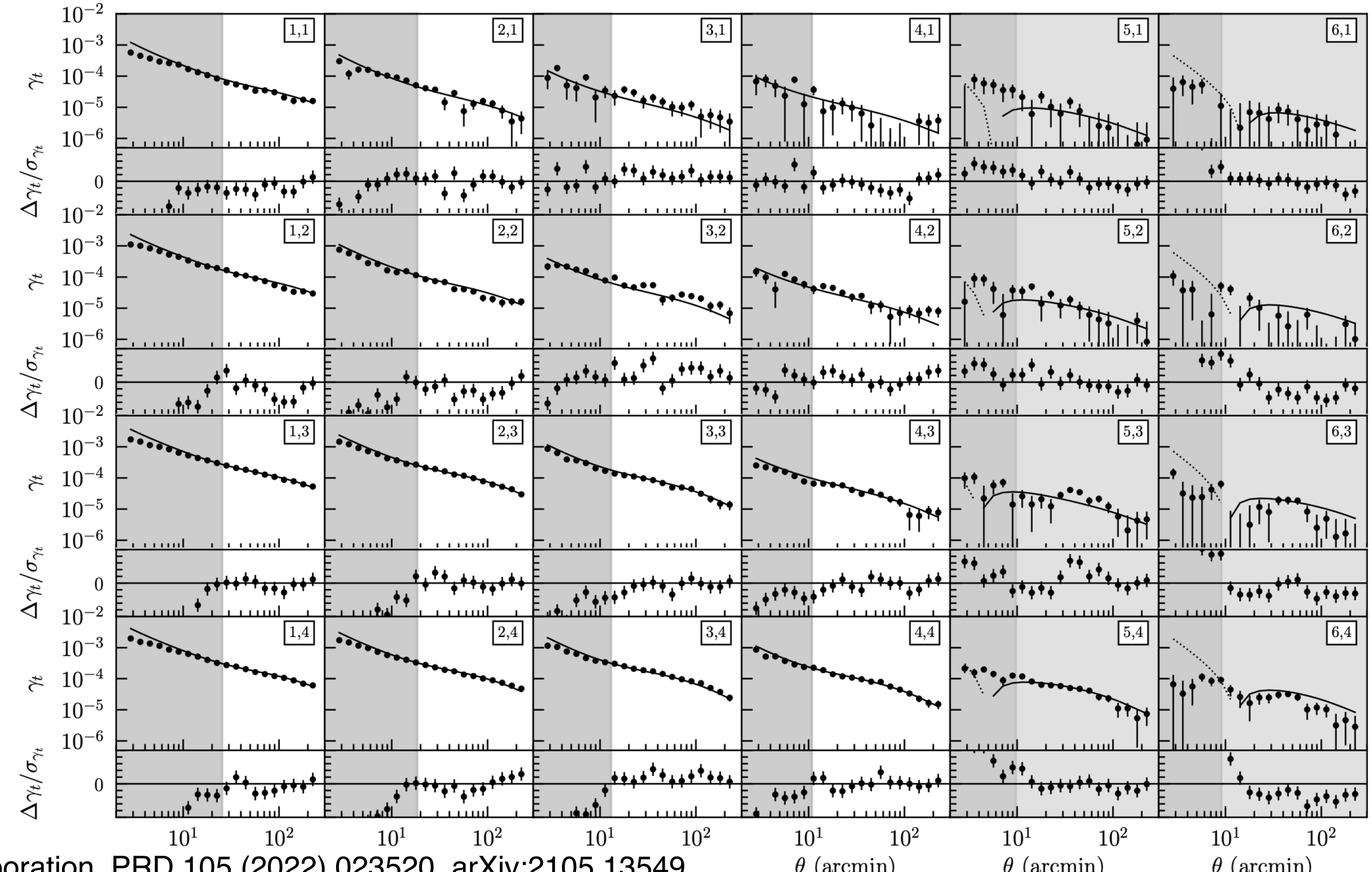


Credit: Judit Prat

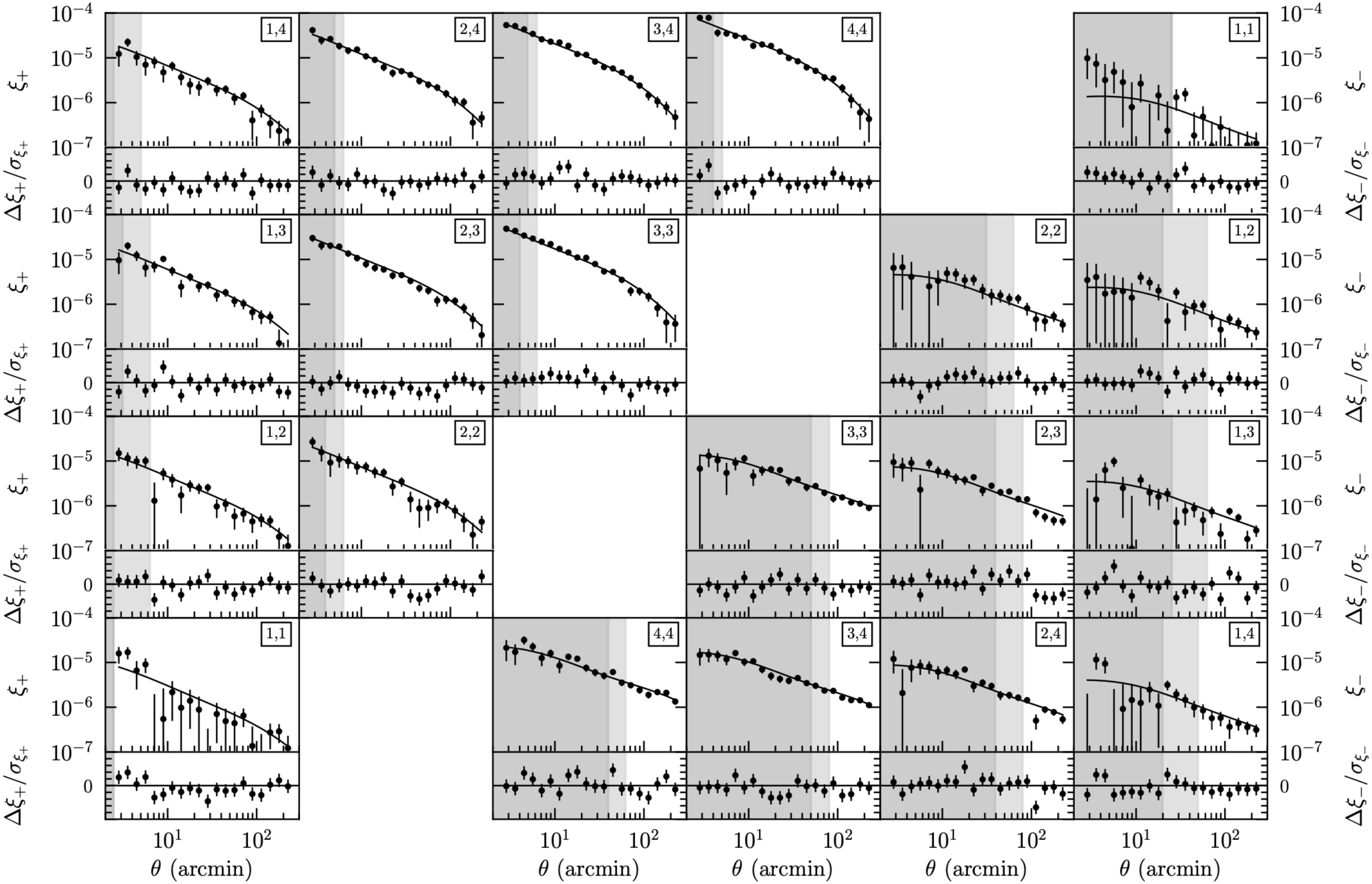
galaxy-galaxy correlations
(lens-lens)



galaxy-shear correlations
(lens-source)



DES Collaboration, PRD 105 (2022) 023520, arXiv:2105.13549



shear-shear correlations
(source-source)

DES Collaboration, PRD 105 (2022) 023520, arXiv:2105.13549

Modeling

DARK ENERGY SURVEY

Parameter	Prior	
Cosmology		
$\Omega_{\rm m}$	Flat	(0.1, 0.9)
$10^9 A_{\rm s}$	Flat	(0.5, 5.0)
$n_{\rm s}$	Flat	(0.87, 1.07)
$\Omega_{\rm b}$	Flat	(0.03, 0.07)
h	Flat	(0.55, 0.91)
$10^3 \Omega_\nu h^2$	Flat	(0.60, 6.44)
w	Flat	(−2.0, −0.33)
Lens Galaxy Bias		
$b_i (i \in [1,4])$	Flat	(0.8, 3.0)
Lens magnification		
$C_{\rm l}^1$	Fixed	0.42
$C_{\rm l}^2$	Fixed	0.30
$C_{\rm l}^3$	Fixed	1.76
$C_{\rm l}^4$	Fixed	1.94
Lens photo-z		
$\Delta z_{\rm l}^1 \times 10^2$	Gaussian	$(-0.9, 0.7)$
$\Delta z_{\rm l}^2 \times 10^2$	Gaussian	$(-3.5, 1.1)$
$\Delta z_{\rm l}^3 \times 10^2$	Gaussian	$(-0.5, 0.6)$
$\Delta z_{\rm l}^4 \times 10^2$	Gaussian	$(-0.7, 0.6)$
$\sigma_{z,{\rm l}}^1$	Gaussian	$(0.98, 0.06)$
$\sigma_{z,{\rm l}}^2$	Gaussian	$(1.31, 0.09)$
$\sigma_{z,{\rm l}}^3$	Gaussian	$(0.87, 0.05)$
$\sigma_{z,{\rm l}}^4$	Gaussian	$(0.92, 0.05)$
Intrinsic Alignment		
$a_i \ (i \in [1,2])$	Flat	$(-5, 5)$
$\eta_i \ (i \in [1,2])$	Flat	$(-5, 5)$
$b_{\rm TA}$	Flat	$(0, 2)$
z_0	Fixed	0.62
Source photo-z		
$\Delta z_{\rm s}^1 \times 10^2$	Gaussian	$(0.0, 1.8)$
$\Delta z_{\rm s}^2 \times 10^2$	Gaussian	$(0.0, 1.5)$
$\Delta z_{\rm s}^3 \times 10^2$	Gaussian	$(0.0, 1.1)$
$\Delta z_{\rm s}^4 \times 10^2$	Gaussian	$(0.0, 1.7)$
Shear calibration		
$m^1 \times 10^2$	Gaussian	$(-0.6, 0.9)$
$m^2 \times 10^2$	Gaussian	$(-2.0, 0.8)$
$m^3 \times 10^2$	Gaussian	$(-2.4, 0.8)$
$m^4 \times 10^2$	Gaussian	$(-3.7, 0.8)$

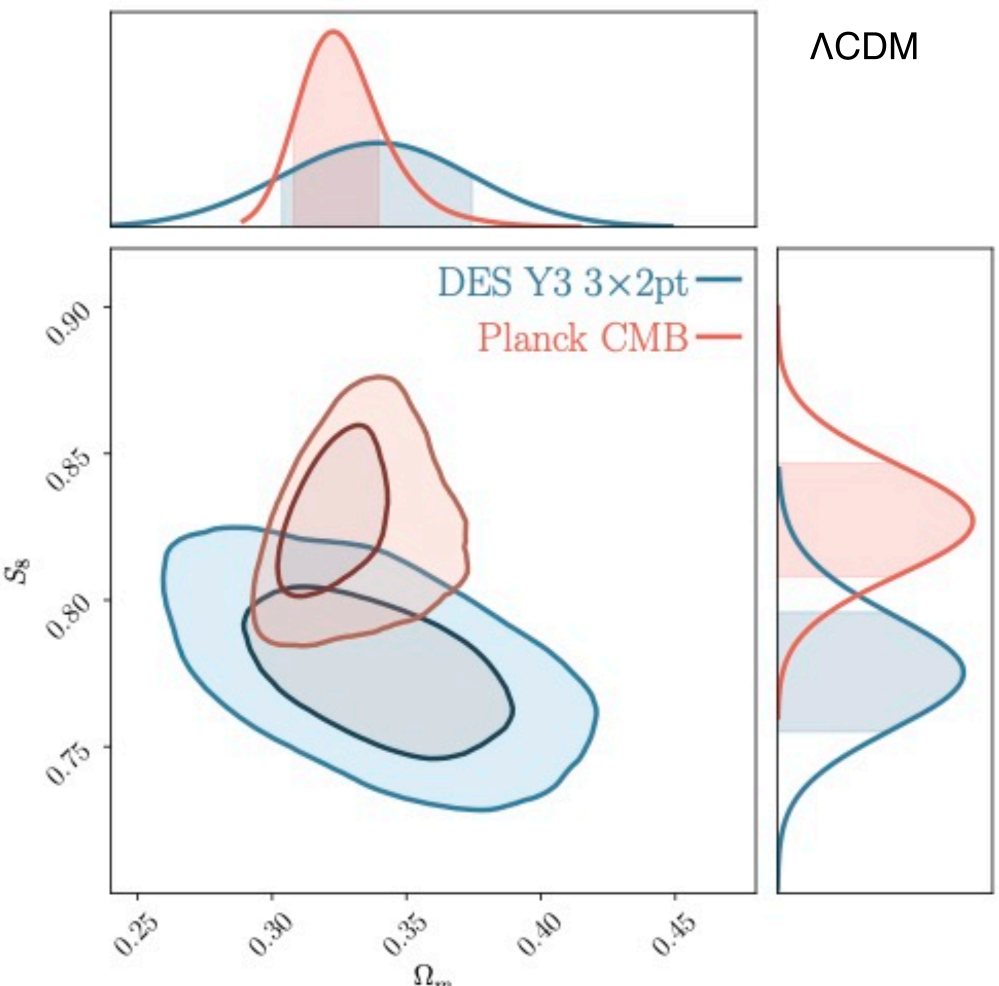
DES Collaboration, PRD 105 (2022) 023520, arXiv:2105.13549

DES-Y3 cosmological results

DARK ENERGY SURVEY

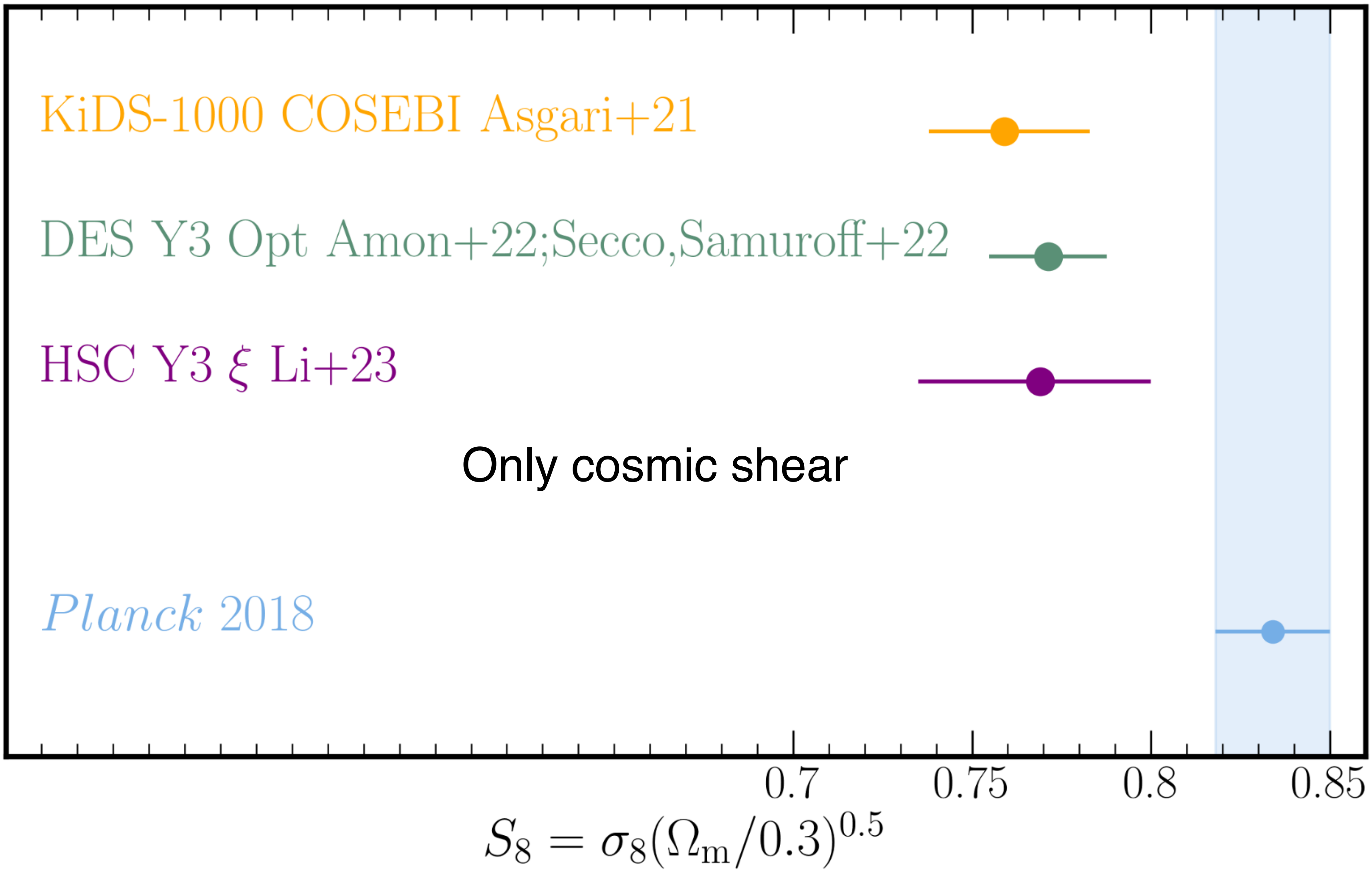
- Ω_m : fraction of matter in the total matter-energy of the universe now.
- $\boldsymbol{S_8} = \sigma_8\, (\Omega_m / 0.3)^{0.5}$ describes the **inhomogeneity of the matter distribution now**:
  σ_8 is the standard deviation of the matter-density distribution in spheres of radius 8 Mpc/h.
- About 2σ (dis)agreement in the measurement of S_8.

ΛCDM



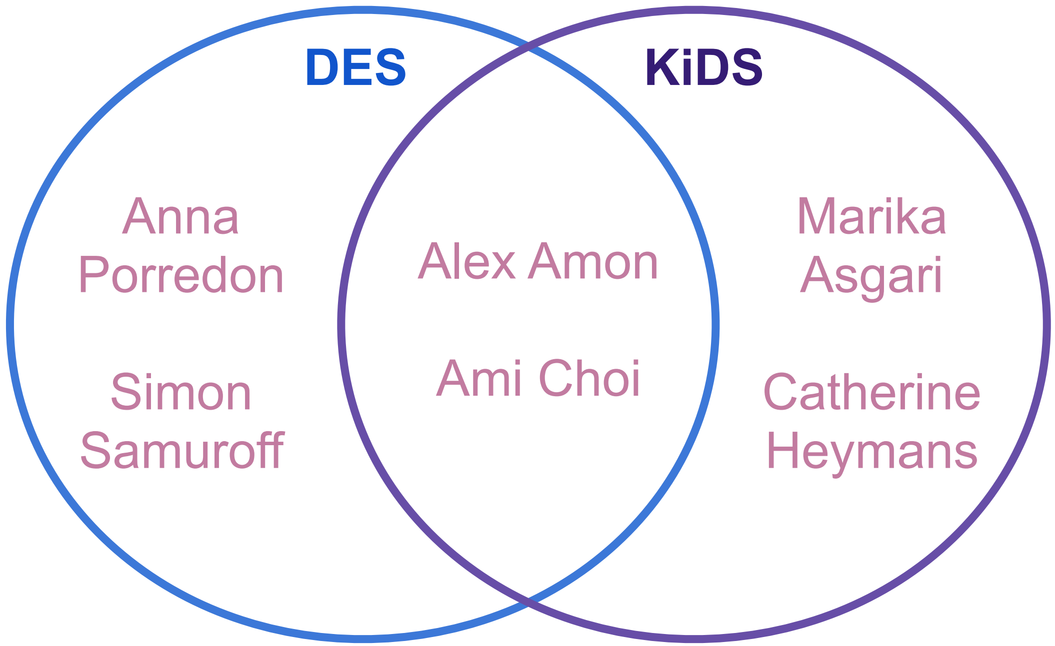
DES Collaboration, PRD 105 (2022) 023520, arXiv:2105.13549

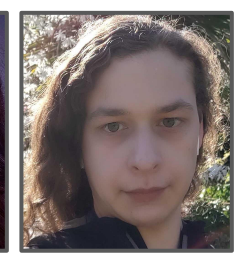
An S_8 (or σ_8) tension?



DES and KiDS Collaborations, arXiv:2305.17173

DES+KiDS: comparison & combination



DES and KiDS Collaborations, arXiv:2305.17173

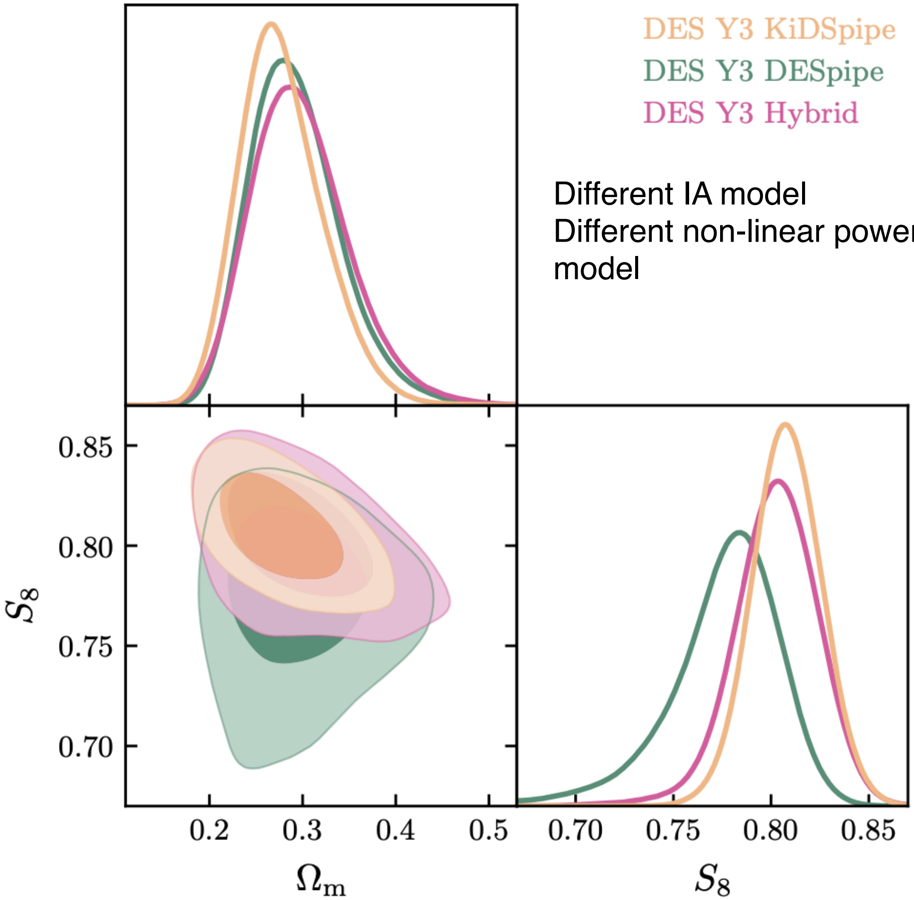
Significant differences in modeling

	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	Ω_m : [0.1, 0.9]	ω_c : [0.051, 0.255]
Baryon density	Ω_b : [0.03, 0.07]	ω_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, η_1, η_2 : [−5, 5]	NLA: A_{IA} : [−6, 6]
Non-linear Model	Halofit	HMCode2016
Baryon Feedback	Scale cuts	A_{bary} : [2, 3.13]
Neutrino Model	Bird et al. (2012)	HMCode2016
Sampling Algorithm:		
	PolyChord	MultiNest

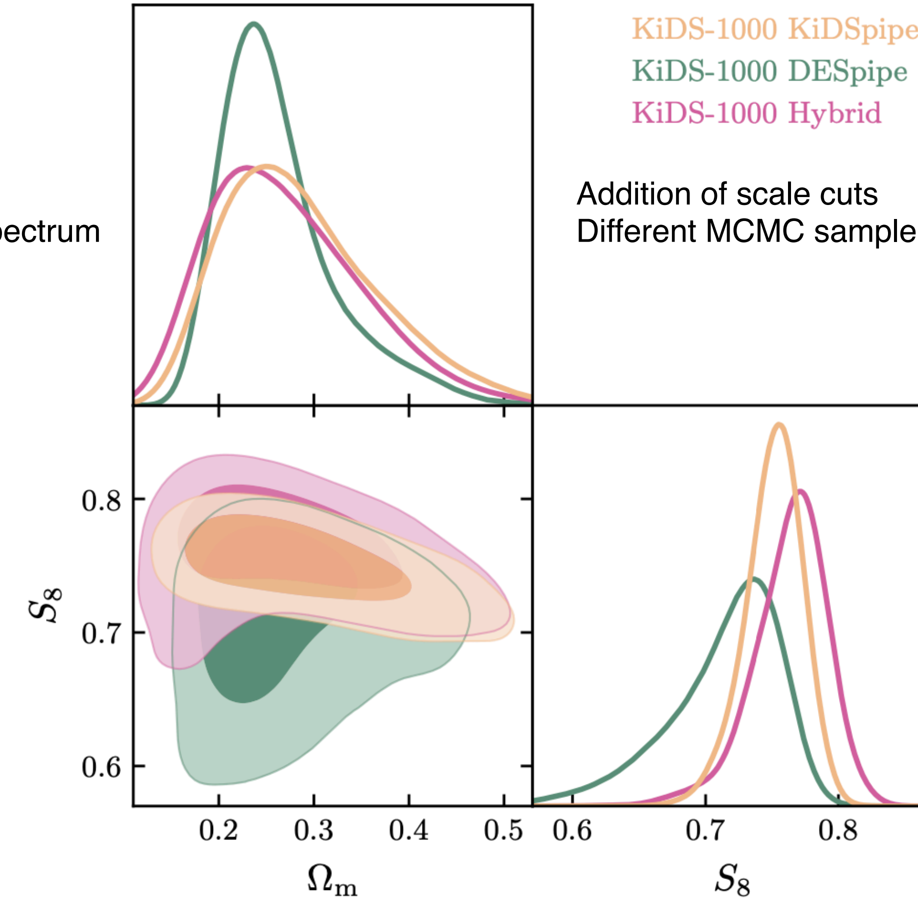
Significant differences in modeling

	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 & $\log_{10}(T_{AGN}/K) : [7.3, 8.0]$
Neutrino Model	Bird et al. (2012)	HMCODE2016	HMCODE2020
Sampling Algorithm:			
	POLYCHORD	MULTINEST	POLYCHORD

Significant differences in results

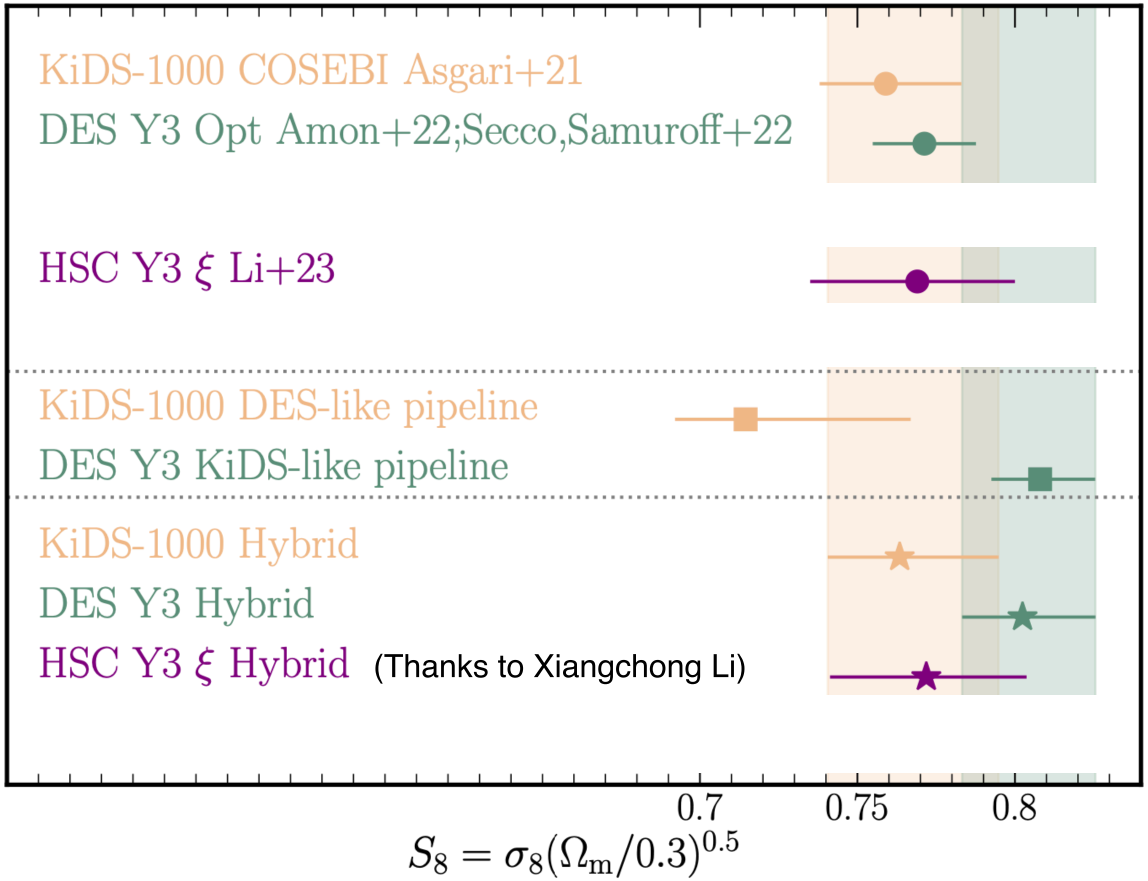


Different IA model
Different non-linear power-spectrum model



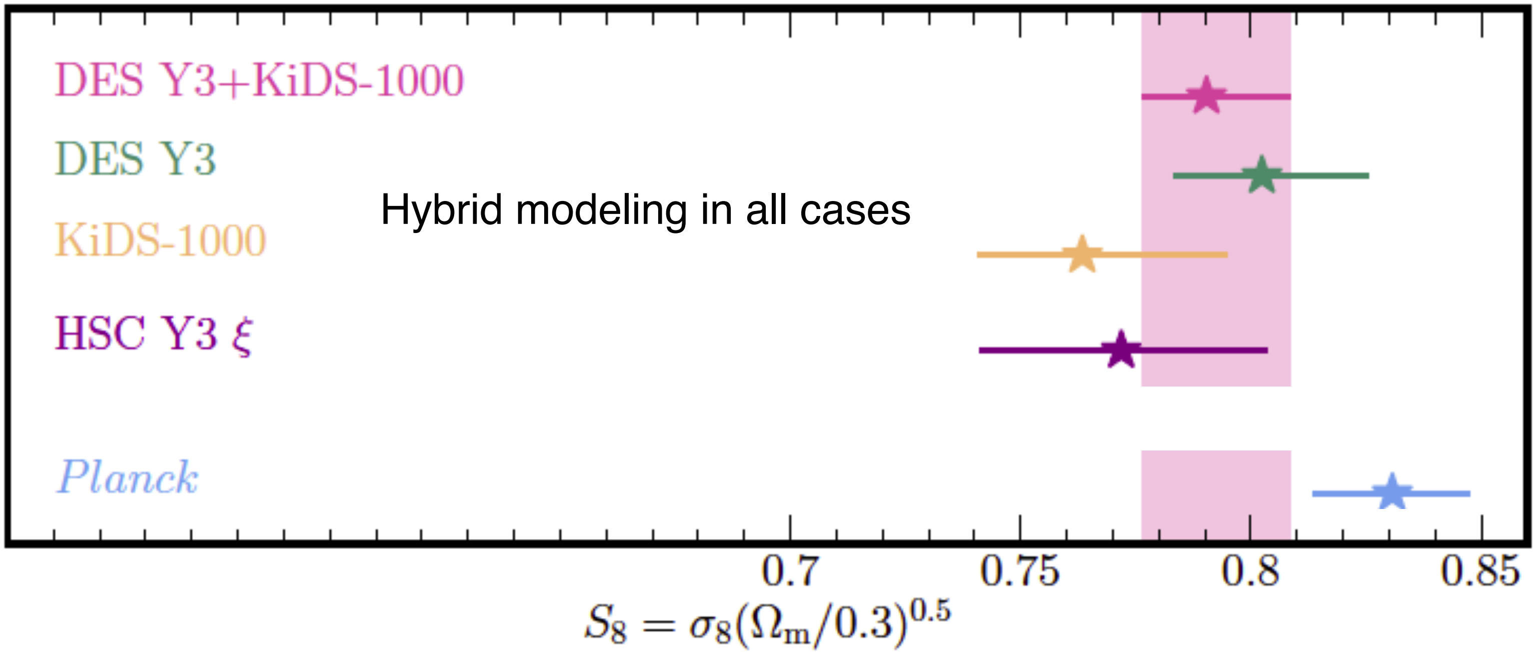
Addition of scale cuts
Different MCMC sampler

Significant differences in results



- On the same data, DES and KiDS modeling choices change the S_8 result by ~1-2 σ and its uncertainty by almost a factor 2.
- With the same modeling choices, DES, KiDS, and HSC results agree within 1σ.
- Hybrid analysis shifts DES fiducial result by ~1σ, KiDS and HSC results by less.

Is there a σ_8 tension?



- DES + KiDS combination after reanalysis results in S_8 1.7σ lower than Planck.
- Combining also HSC would bring the discrepancy up to ~2σ.
- Large sensitivity to modeling choices points to the need for further understanding:
  - Large hydrodynamical simulations can help (Chaves-Montero et al. 2022).
  - Better measurements of intrinsic alignments (Johnston et al. 2020, Samuroff et al. 2022).

Summary

- Analyzing its first three years of data, DES has measured the anisotropies in the matter distribution using weak lensing, with precision comparable to that of Planck and in ~2σ (dis)agreement.
- A similar pattern is found in KiDS and HSC ("σ_8 tension").
- When attempting to combine DES and KiDS results, significant differences in modeling have been found, which lead to significant differences in results (1-2σ).
- When using the same modeling, all data sets agree within 1σ.
- Before the possible "σ_8 tension" can be made more quantitative, more effort is needed in understanding the systematic errors coming from the necessary approximations in modeling, even more so in view of the upcoming, more precise, Euclid, Rubin/LSST and Roman surveys.

Thank you

Credit: SpaceX/ESA