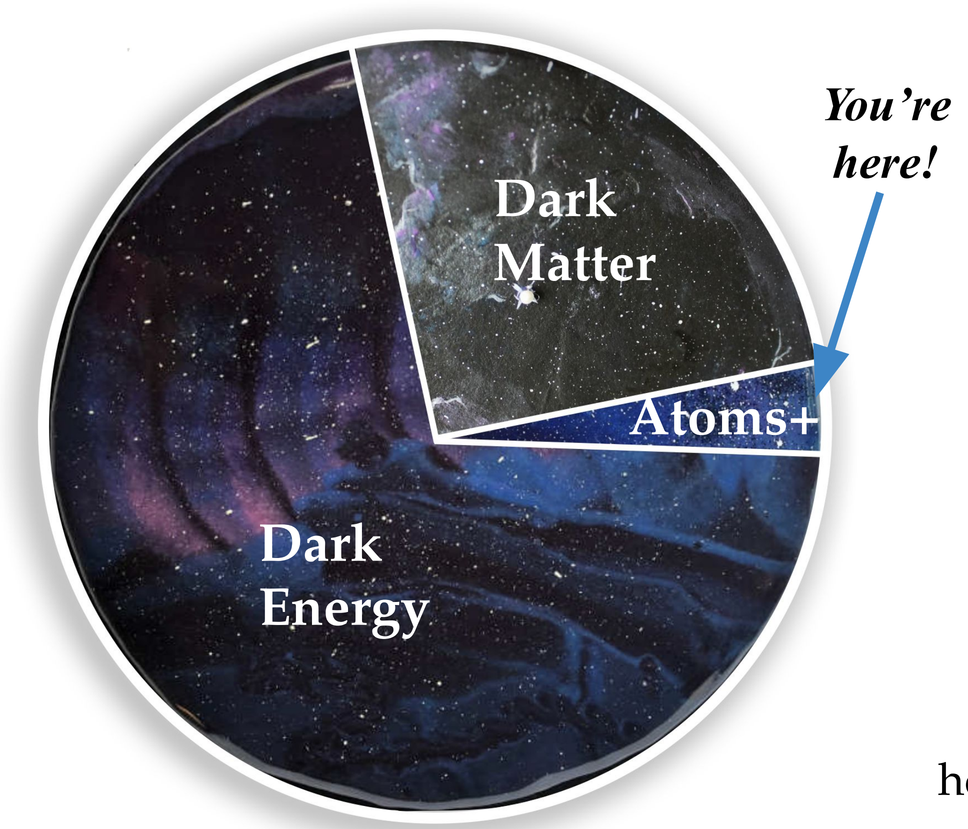
Legacy Cosmology Results from the Dark Energy Survey Year 6 Data

Martin Crocce, Institute of Space Science (ICE-CSIC)

Results from the Dark Energy Survey Collaboration

Standard Cosmological Model



ΛCDM

Cosmological Constant → accelerated expansion

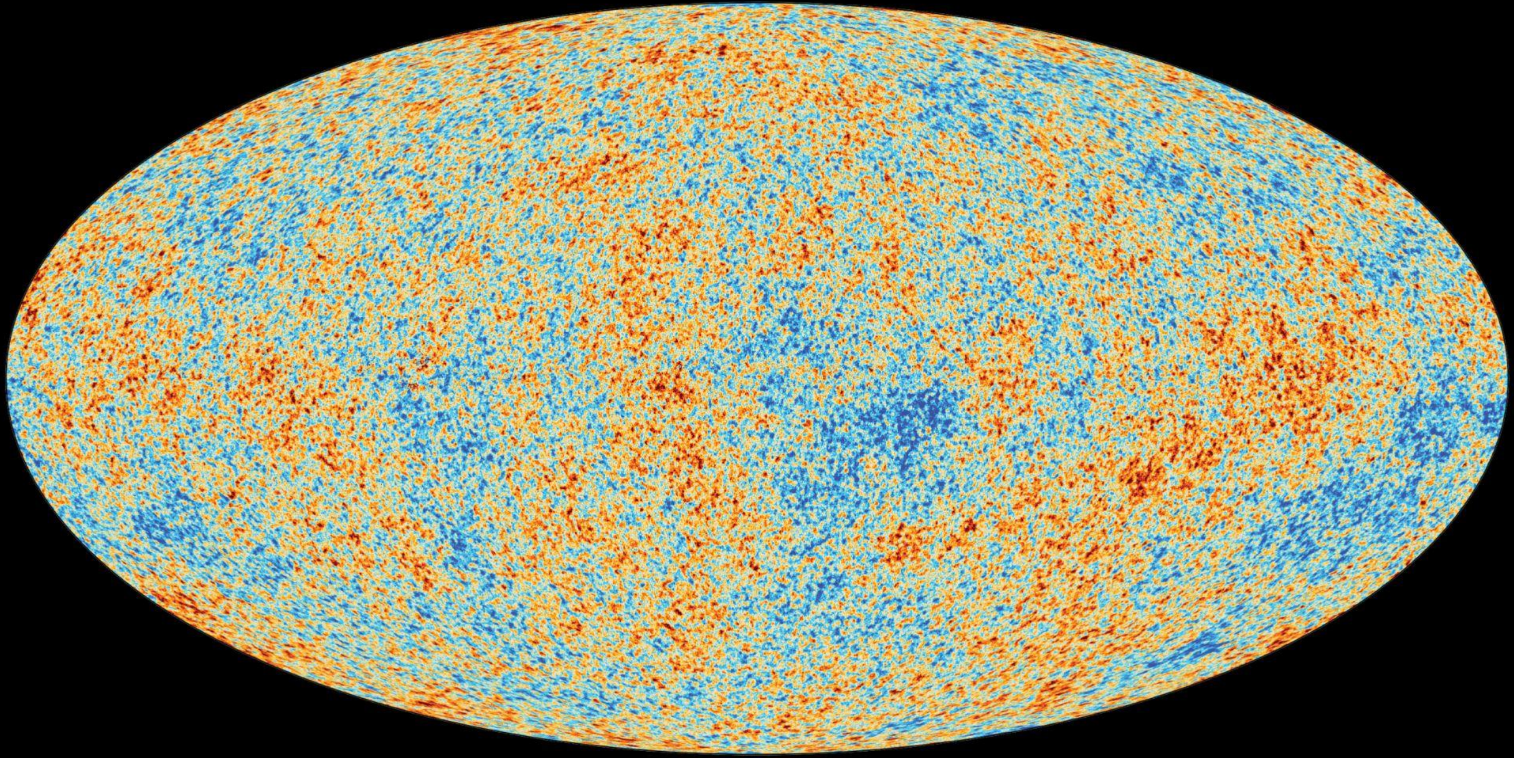
Cold Dark Matter → structure formation

Assumes General Relativity in a homogeneous, isotropic universe w/ Big Bang+inflationary ICs

Slide credit: G. Giannini

→ THE COSMIC MICROWAVE BACKGROUND

Planck Legacy Release 2018



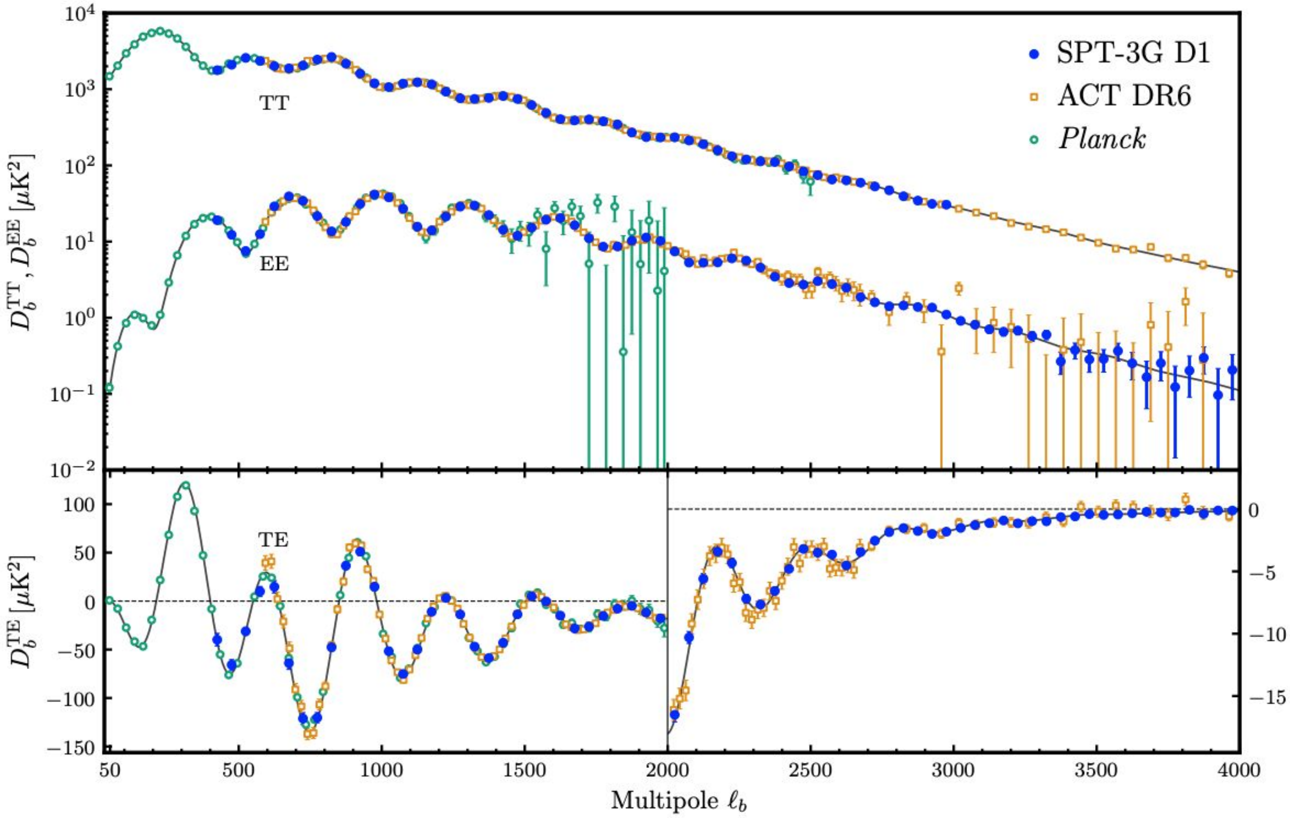
Credit: ESA/Planck Collaboration

www.esa.int

European Space Agency

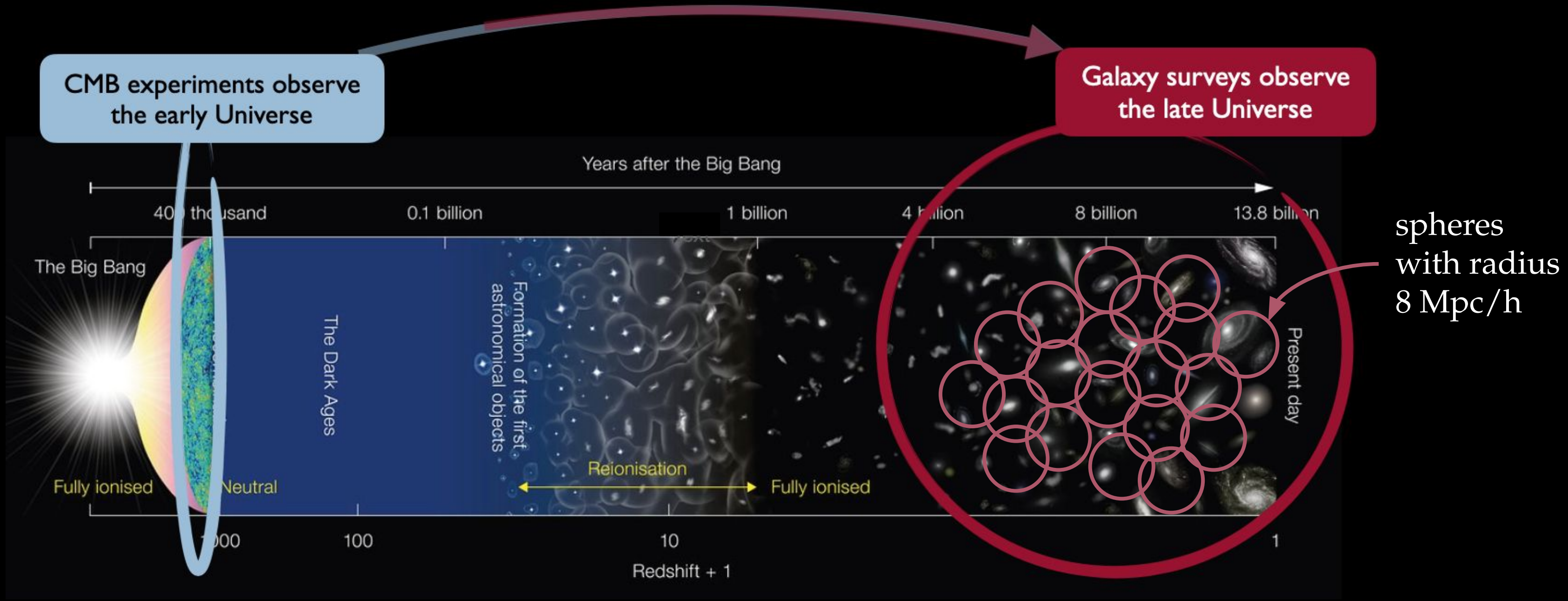
CMB power spectrum

All six LCDM parameters constrained to high precision



From SPT-3D D1 arxiv : 2506.20707

Can ΛCDM describe 13.8 billion years of cosmic history?



σ_8: the variance in density in spheres of 8 Mpc/h;

Ω_m: fraction of universe composed of matter

→ best constrained parameter

$S_8 = \sigma_8 (\Omega m / 0.3)^{0.5}$.

Slide credit: G. Giannini, **Image credit:** NAOJ

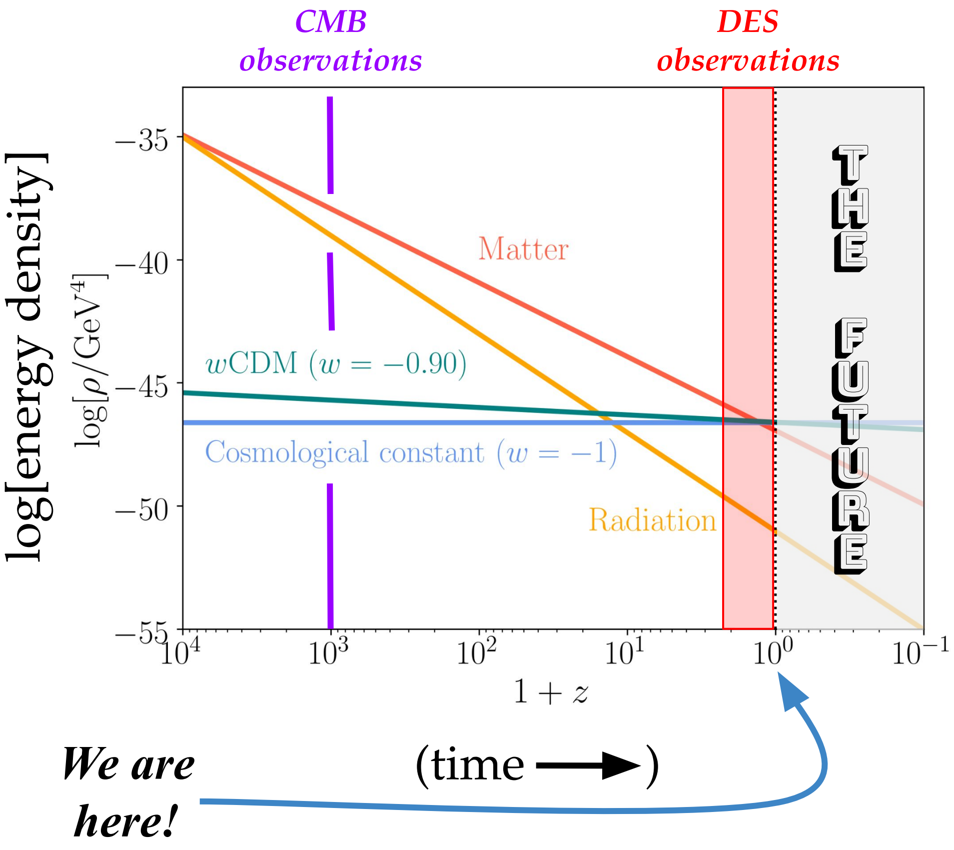
Alternatives to a cosmological constant: *w0waCDM model*

The dark energy component might not be a cosmological constant Λ!

$$w(z) \equiv \frac{\mathcal{P}}{\rho} = w_o + w_a \frac{z}{1+z}$$

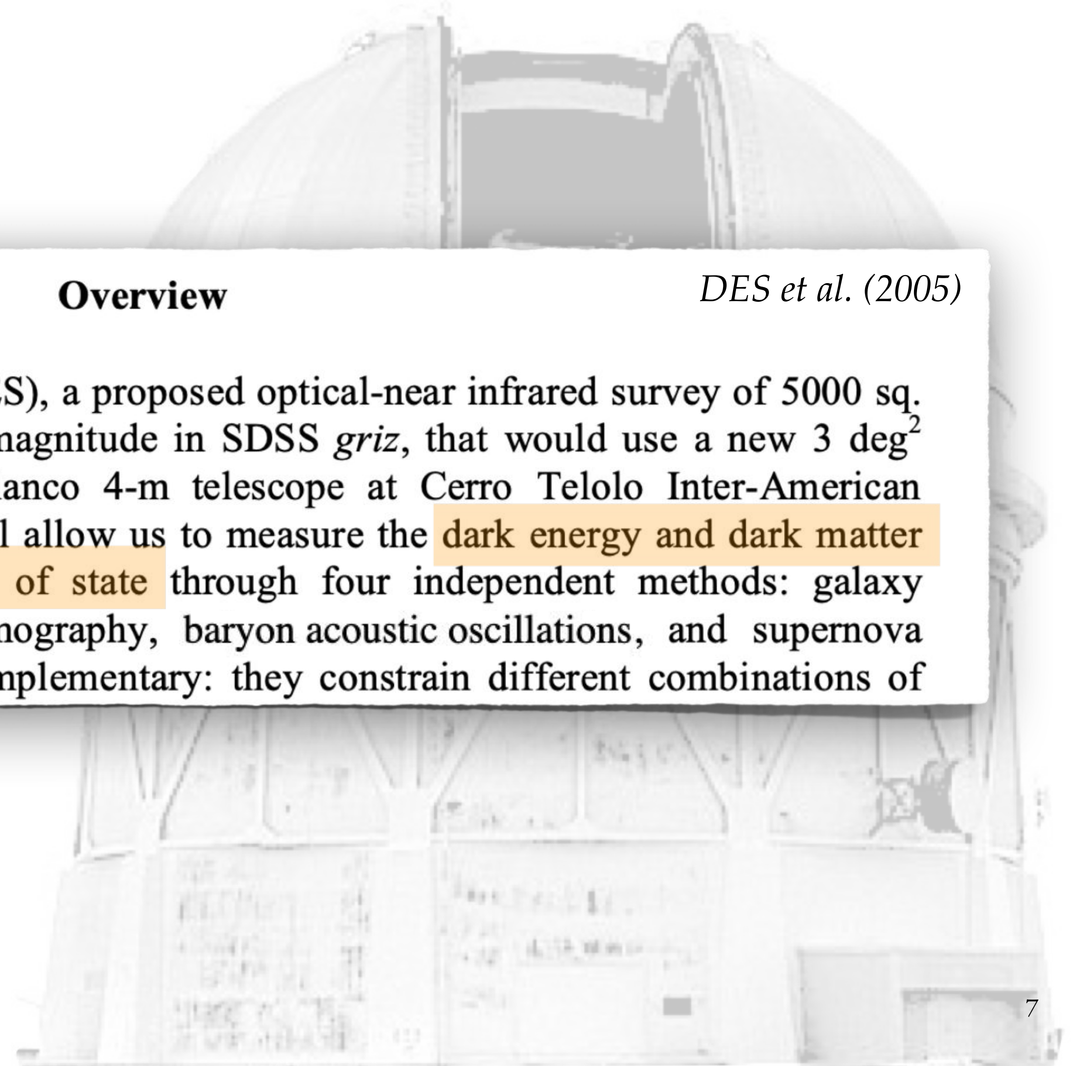
We can open up the parameter space to measure *w0-wa*, which defines the **equation of state** of dark energy (Chevallier & Polarski+01, Linder+02).

Λ is (w0, wa) = (-1, 0).



Slide credit: G. Giannini

The Core Mission of DES



Overview

DES et al. (2005)

We describe the Dark Energy Survey (DES), a proposed optical-near infrared survey of 5000 sq. deg of the South Galactic Cap to ~24th magnitude in SDSS *griz*, that would use a new 3 deg^2 CCD camera to be mounted on the Blanco 4-m telescope at Cerro Telolo Inter-American Observatory (CTIO). The survey data will allow us to measure the dark energy and dark matter densities and the dark energy equation of state through four independent methods: galaxy clusters, weak gravitational lensing tomography, baryon acoustic oscillations, and supernova distances. These methods are doubly complementary: they constrain different combinations of

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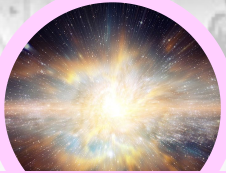
In Preparation

Completed in 2026 (Y6 3x2pt)

Completed in 2024 (Y6 BAO)



Completed in 2025 (Y5 SN)

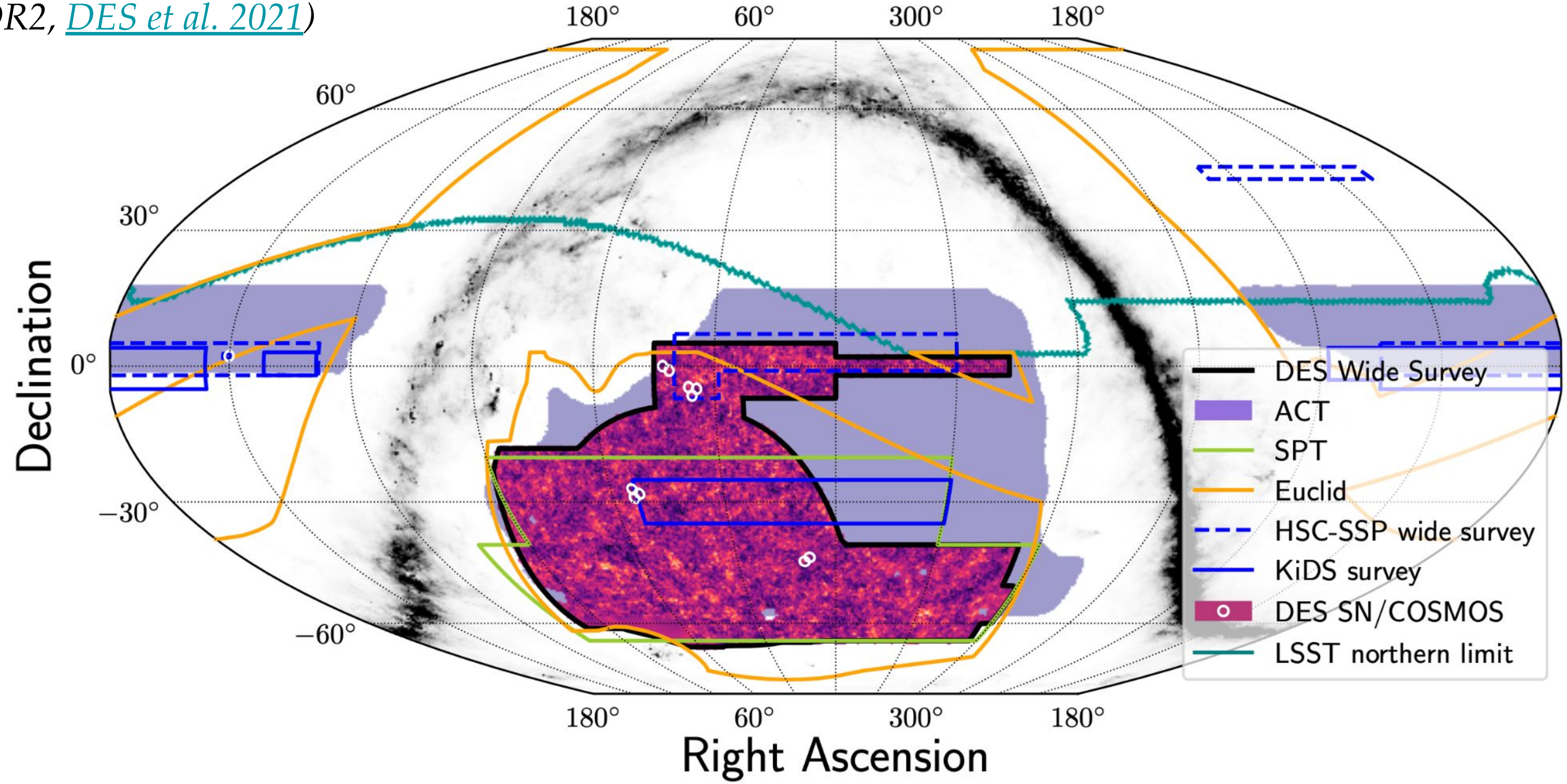
The Dark Energy Survey (DES)

<u>6 years</u> of data: 2013 - 2019

(DR2, [DES et al. 2021](#))

Wide field: ~5000 deg^2 , i~24

Deep field: ~27 deg^2, ~7 day cadence



[DES et al. (2026)](#)

The Dark Energy Survey Datasets and Legacy Analysis

<u>6 years</u> of data: 2013 - 2019

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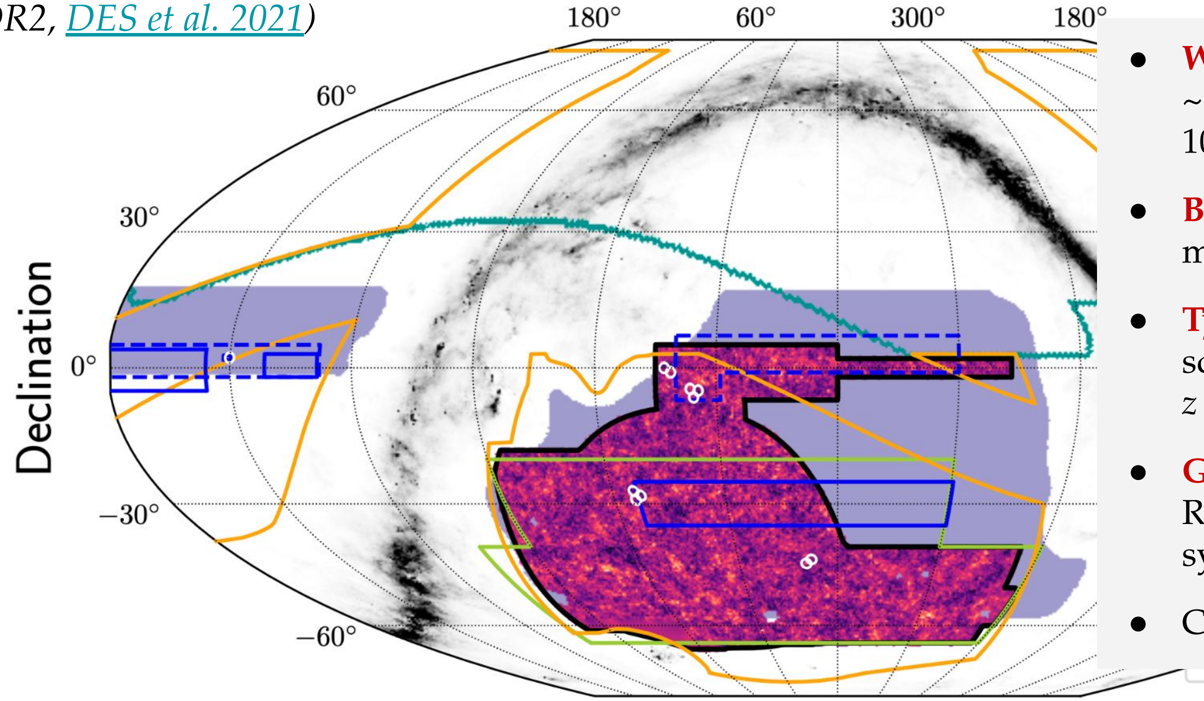

- **Weak lensing** calibrated shapes of ~ 140 millions galaxies up to $z < 2$ + 10 millions lenses for 3x2pt.
- **Baryonic acoustic oscillations** 16 millions red galaxies to $0.6 < z < 1.2$
- **Type Ia supernovae** (distance) 30 sq. deg. SN fields : 1650 SNIa up to $z \sim 1.13$
- **Galaxy clusters** ~ 20,000 RedMapper clusters (z ~ 0.7) synergies with WL, SZ, Xray
- Combined constraints

***DES BAO** 2024 : arxiv/2402.10696*   ***DES SN** 2025 : arxiv/2506.05471*   ***DES 3x2pt** 2026 : arxiv/2601.14559*

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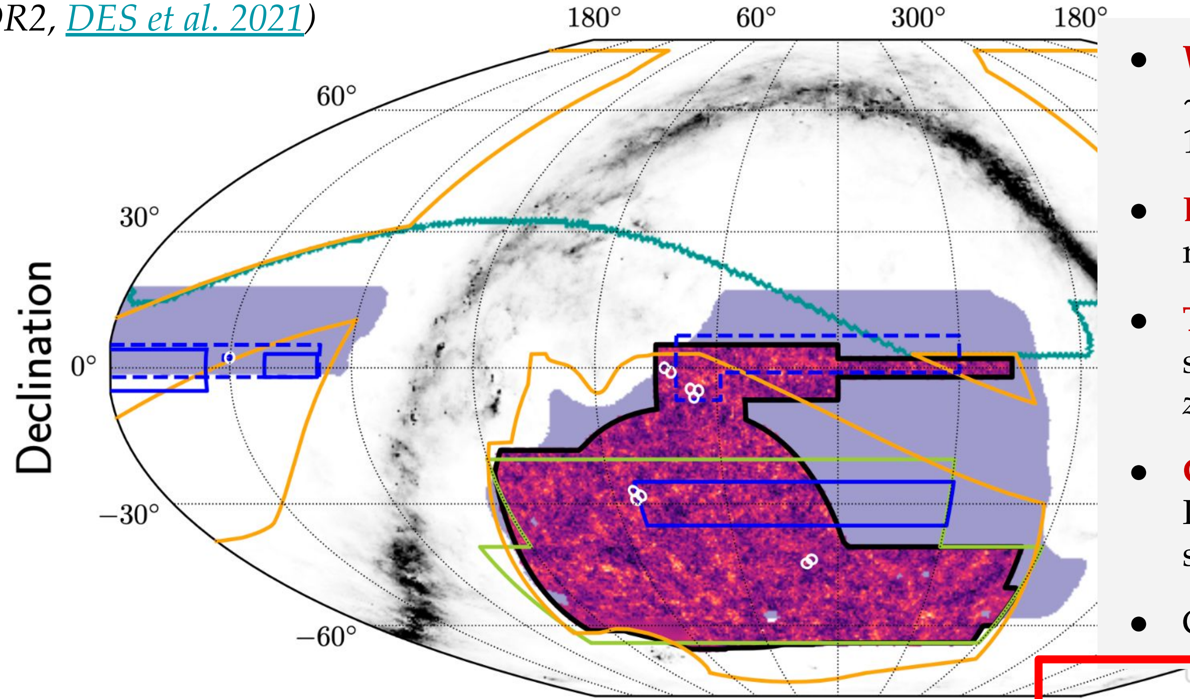

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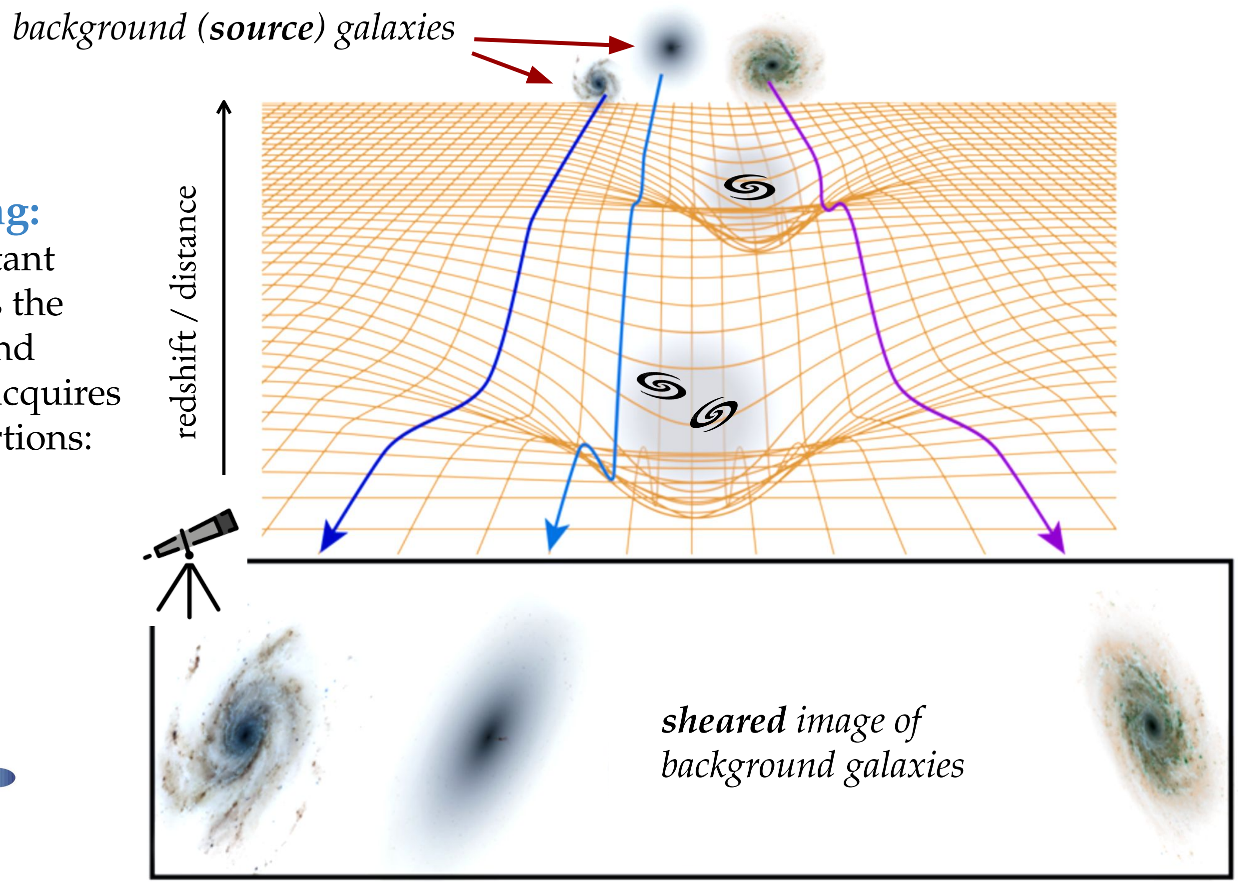
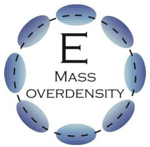
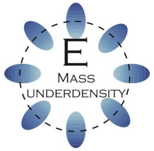
Weak Lensing and 3x2pt

Probing Large-Scale Structure : Weak Gravitational Lensing



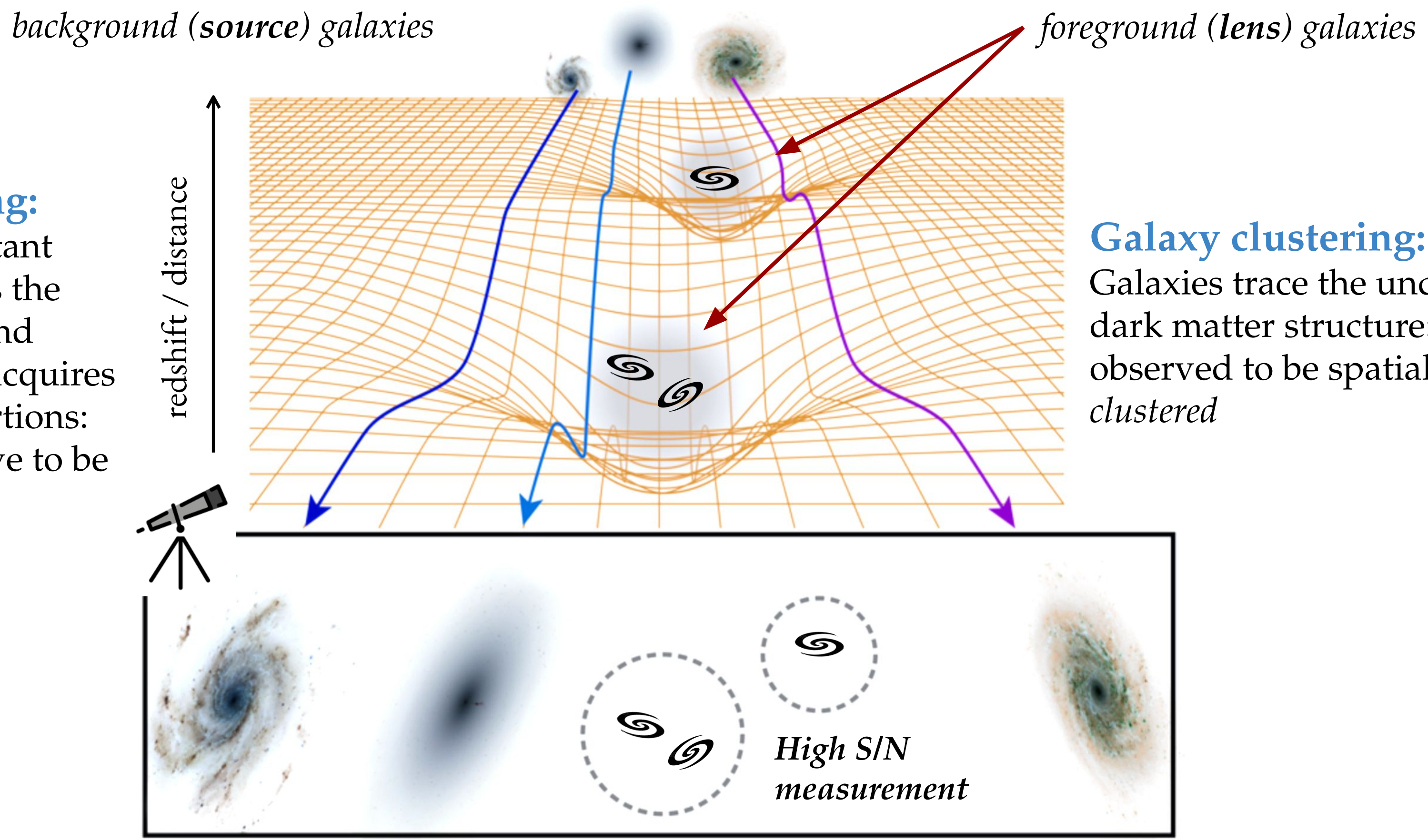
Weak Lensing:
Light from distant galaxies passes the same foreground structure and acquires coherent distortions:





WARNING: The signal is tiny (~1%) and there are a lot of other things that can look like WL!

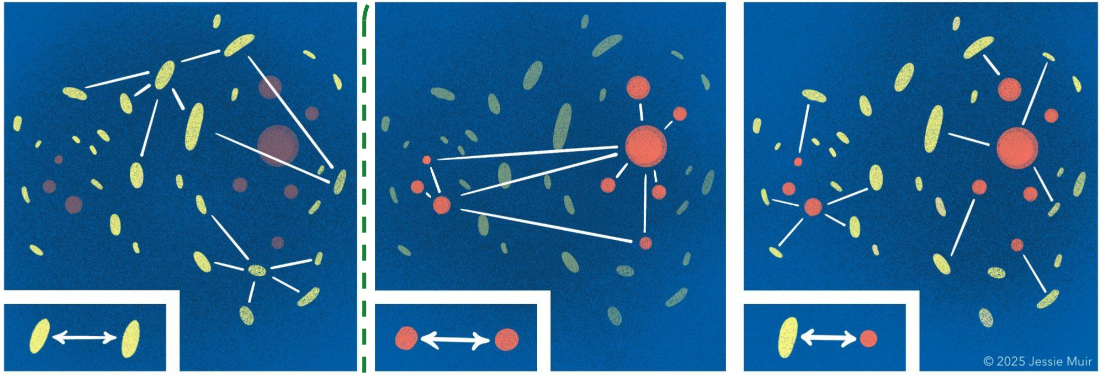
Probing Large-Scale Structure: Galaxy Clustering



Weak Lensing:
Light from distant galaxies passes the same foreground structure and acquires coherent distortions: they are observe to be *lensed*

Galaxy clustering:
Galaxies trace the underlying dark matter structure: they are observed to be spatially *clustered*

3x2pt cosmology



Cosmic Shear
shape-shape
1x2pt

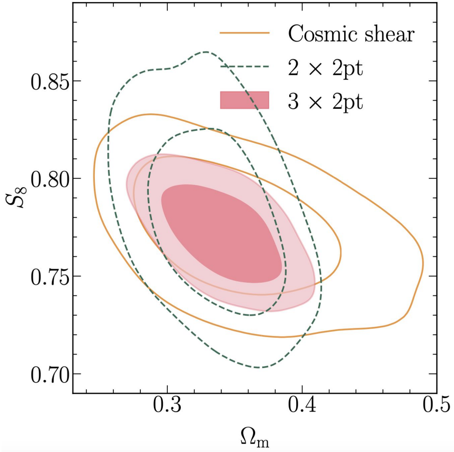
Galaxy Clustering
position-position

Gal-Gal Lensing
position-shape

2x2pt

3x2pt

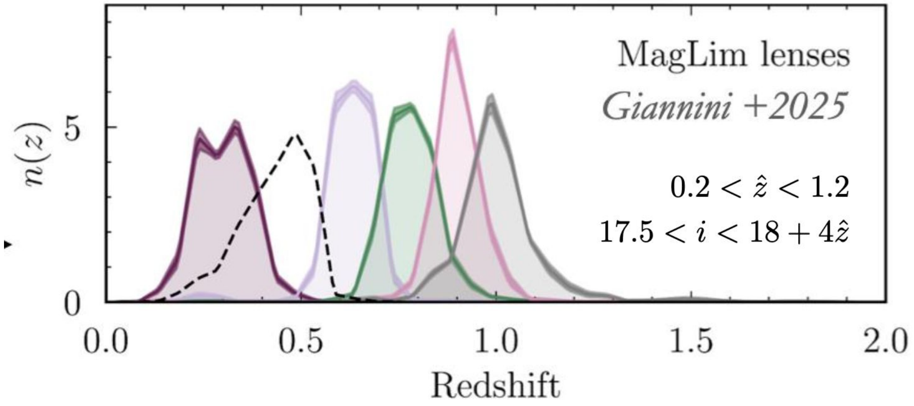
$\Omega_m - S_8$:
best-constrained parameter combination



$$\boxed{S_8 = \sigma_8(\Omega_m/0.3)^{0.5}}$$

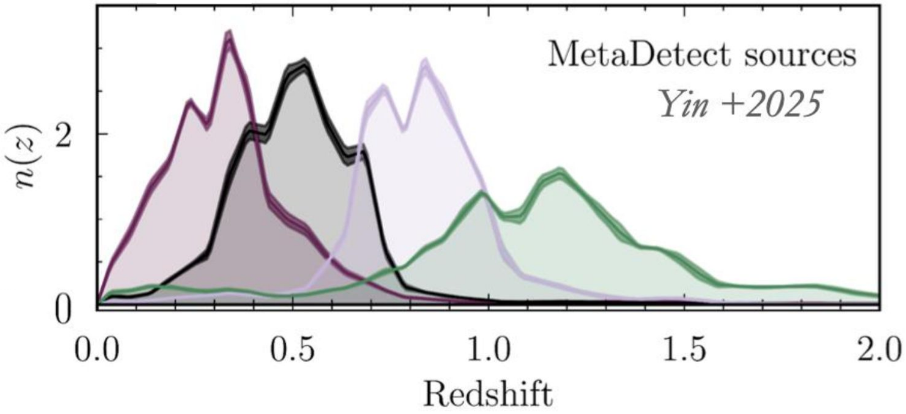
A joint analysis **maximises the cosmological information** and robustly **constrains astrophysical & observational systematics!**

DES Y6 tomography analysis



9,186,205 bright galaxies to z ~ 1

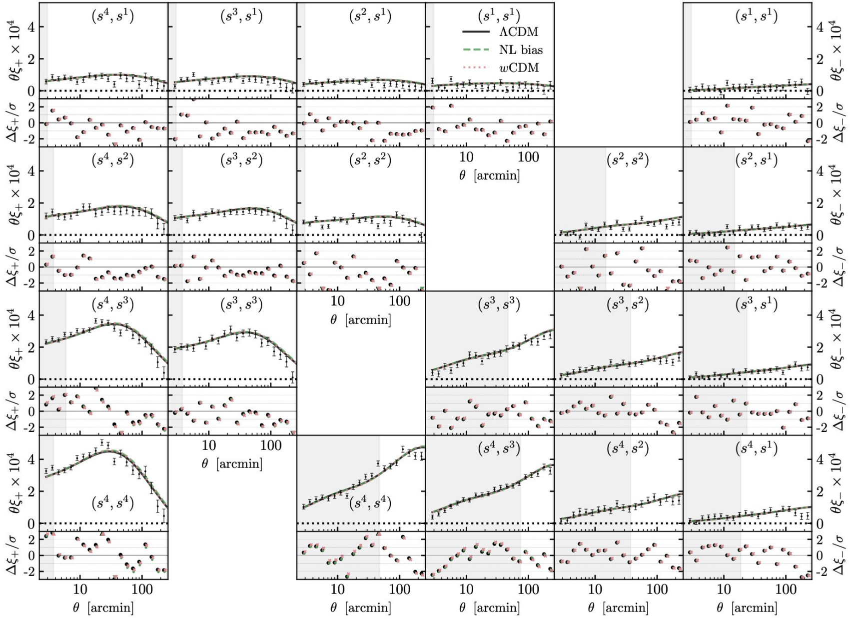
Balances density and redshift precision to optimize cosmological constraining power



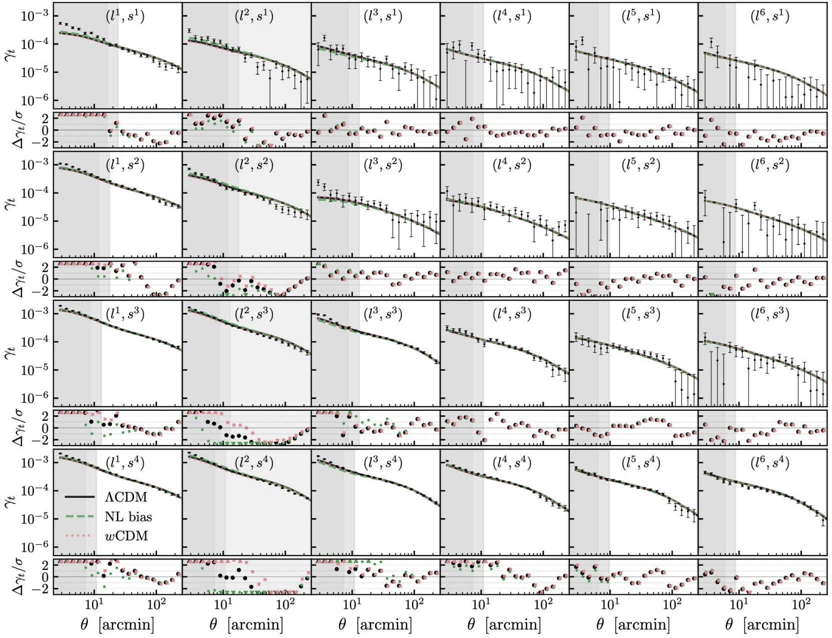
139,662,173 galaxies up to z < 2

Metacalibration shape measurement technique [new!]
Density [gals/arcmin^2]: 8.29

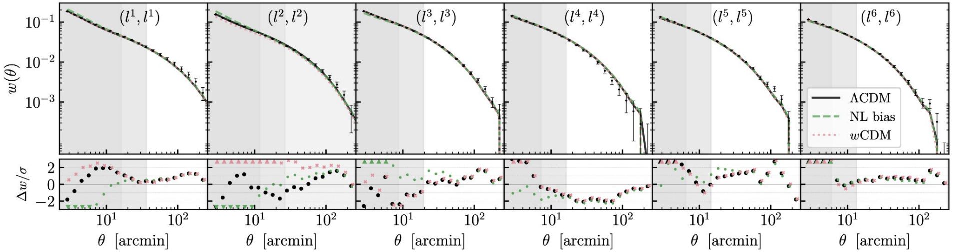
Cosmic Shear: S/N = 83 (Y3 ~ 40)



Galaxy-galaxy Lensing: S/N = 39 (Y3 ~ 28)



Galaxy Clustering: S/N = 90 (Y3 ~ 63)

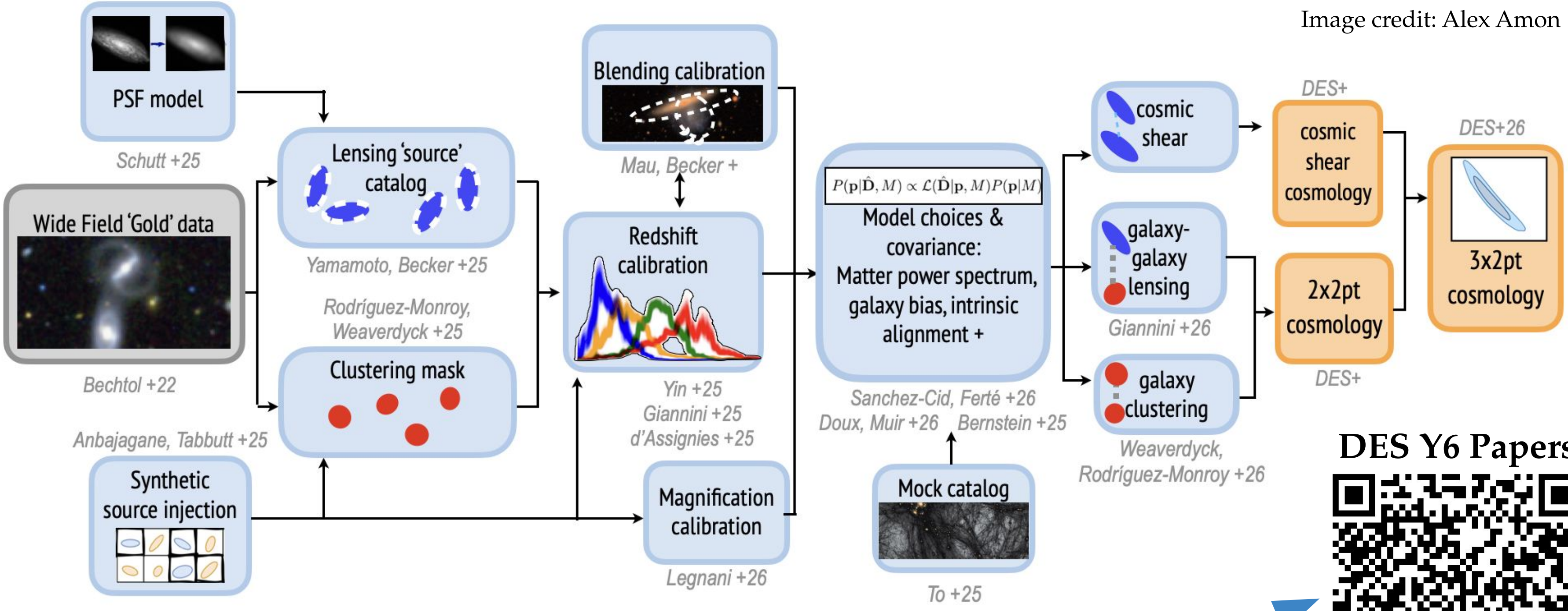


50 2-pt correlations across redshift and scale, and all correlated to some degree!

Our full model for the 3x2pt data has over 40 parameters, only 6 of which are cosmological.

Weak lensing and 3x2pt analysis is complex and difficult.

Image credit: Alex Amon



DES Y6 Papers

The analysis took us ~4 years, and we wrote 16+3 papers describing all of the inputs+results! Check them out!

…and now finally parameter constraints for some cosmological models! 🎉

DES Y6 3x2pt vs CMB in ΛCDM

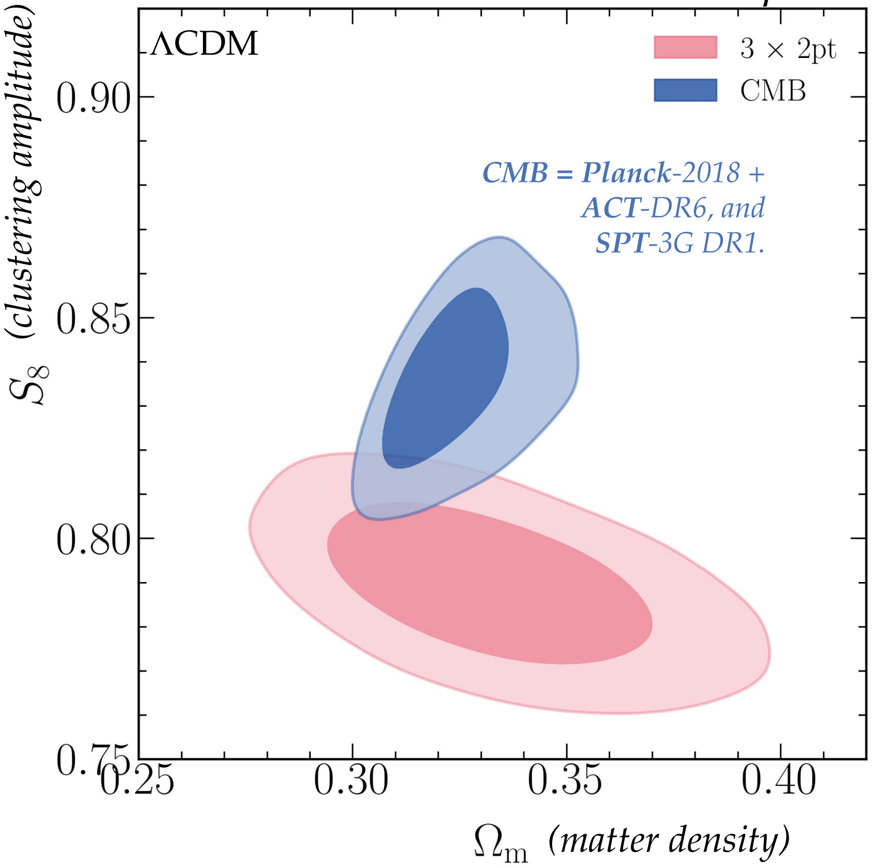
Y6 3x2pt yields similar constraining power as the CMB on the S_8 direction (clustering amplitude).

Full-parameter difference between 3×2pt and CMB is **1.8σ.**

In the **2D plane** of the clustering amplitude-matter density is **2.2σ**.

In **S_8, **it is **2.6σ**.

From DES Y6 3x2pt 2026



DES dark-energy probes combined: *3x2pt, BAO, SN, Clusters*

All four dark energy probes fully consistent,

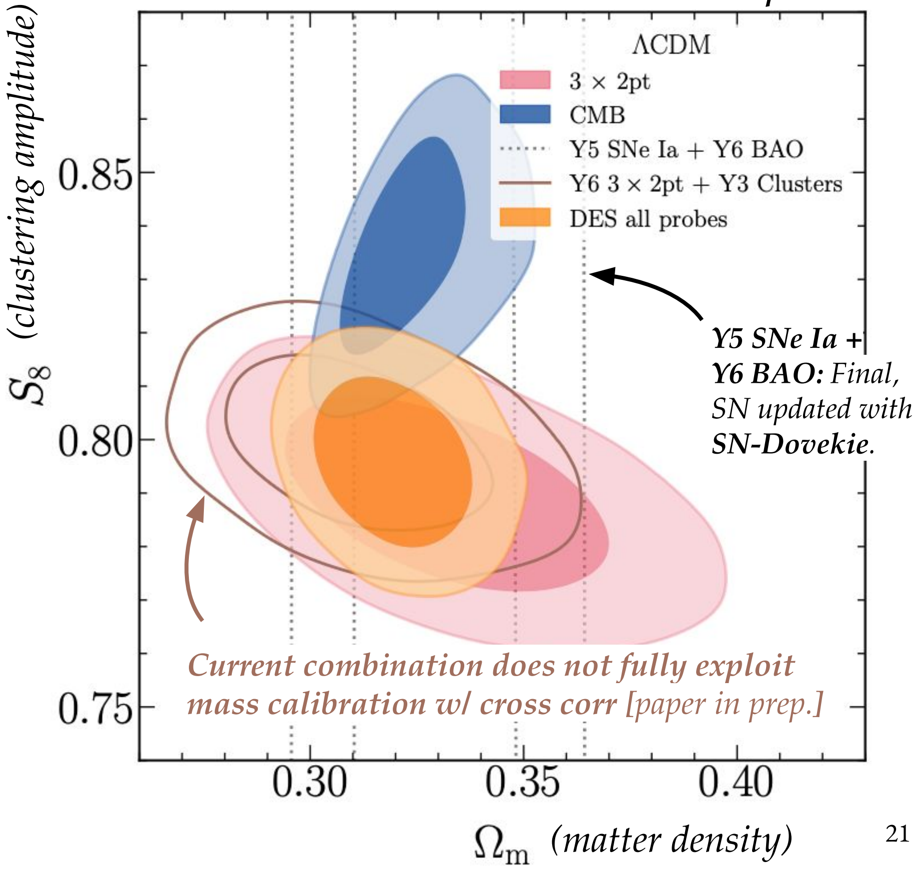
For the first time we combined all four as originally designed for DES,

First time this is done within a single survey.

DES all-probes has similar constraining power as CMB in both S_8 and Ω_m.

Full-parameter difference of 2.8σ with the CMB, with fully consistent Ω_m

From DES Y6 3x2pt 2026



Comparison of Stage III lensing missions and CMB

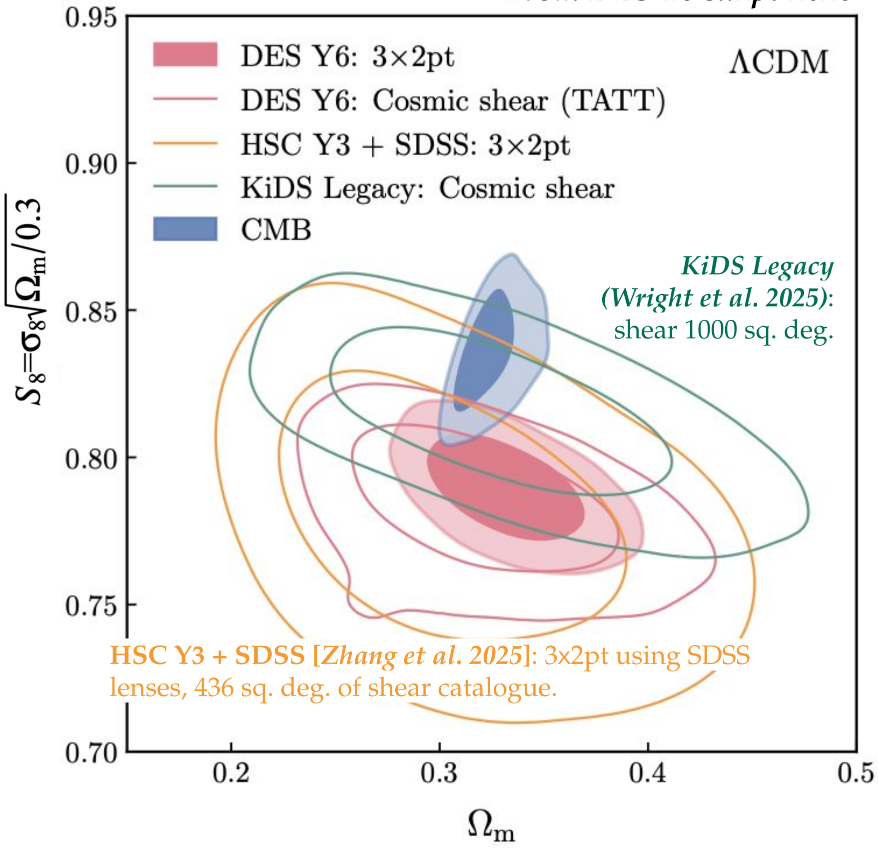
Final **DES Y6** 3×2pt, **KiDS Legacy** cosmic shear and **HSC Y3** + SDSS analyses are consistent among them and with the CMB.

Y6 3x2pt **full-parameter** difference between 3×2pt and CMB is **1.8σ,** and **2.6σ** along **S8.**

Status of **"S8 (no?-) tension"**: Various estimates of tension metrics across WL experiments with the CMB still range from **~ 1σ to ≲ 3σ.**

CMB → Planck + ACT + SPT (no-lensing)

From DES Y6 3x2pt 2026



Comparison of all-low-redshift probes vs. CMB

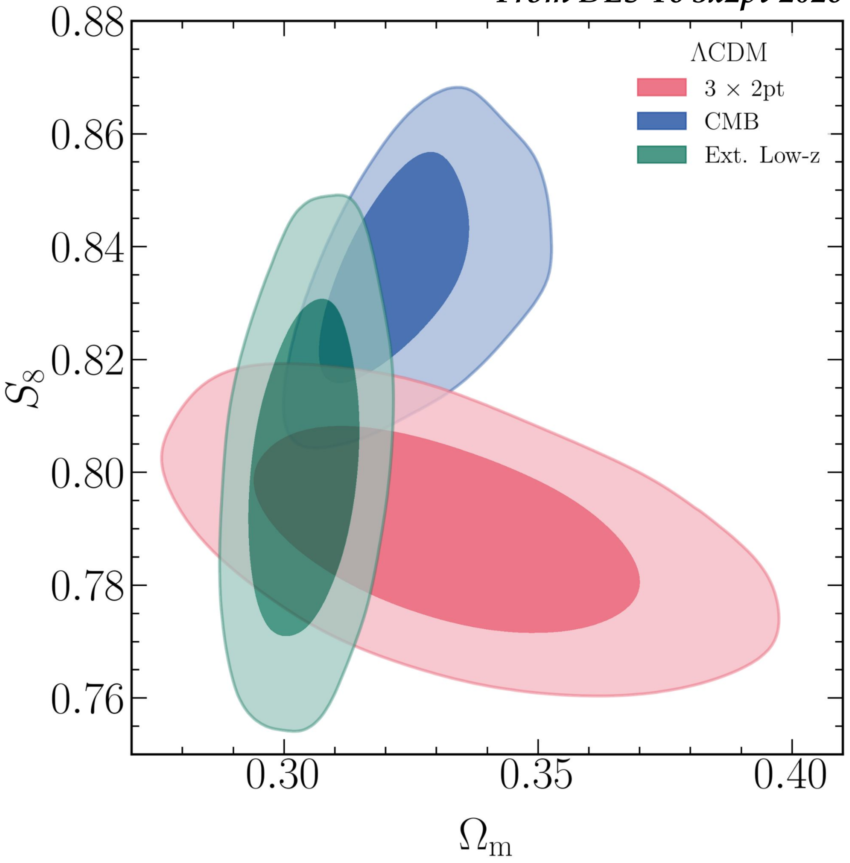
We constructed three independent data sets:

1. Weak lensing and clustering from DES Y6 (3x2pt)
2. SNIa from DES Y5 [Dovekie] + BAO from DESI DR2 & DES Y6(*) + Clusters abundance from SPT → **Ext. Low-*z***
3. **CMB**

These are highly complementary.

(*) DES BAO excludes overlap between DES and DESI

From DES Y6 3x2pt 2026



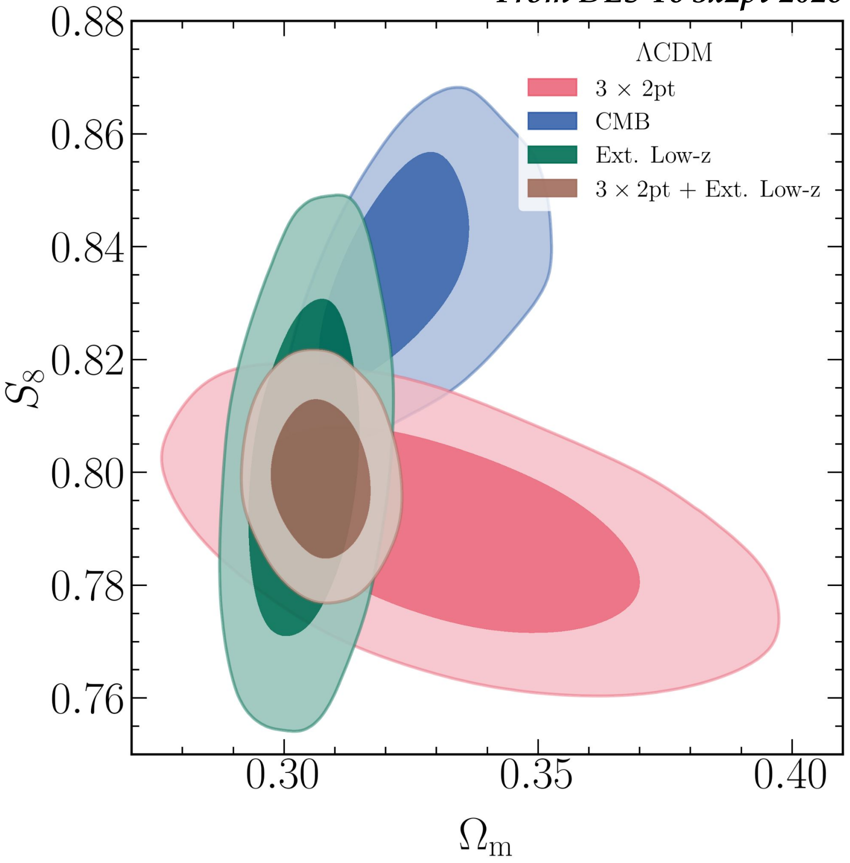
Comparison of all-low-redshift probes vs. CMB

DES Y6 3x2pt + Ext. Low-*z* has a parameter difference with respect to CMB of **2.3σ** in **ΛCDM and 2.4σ** in **wCDM** in full space.

Mostly along **S8**

This represents our best understanding of the two models from the late and early universe.

From DES Y6 3x2pt 2026

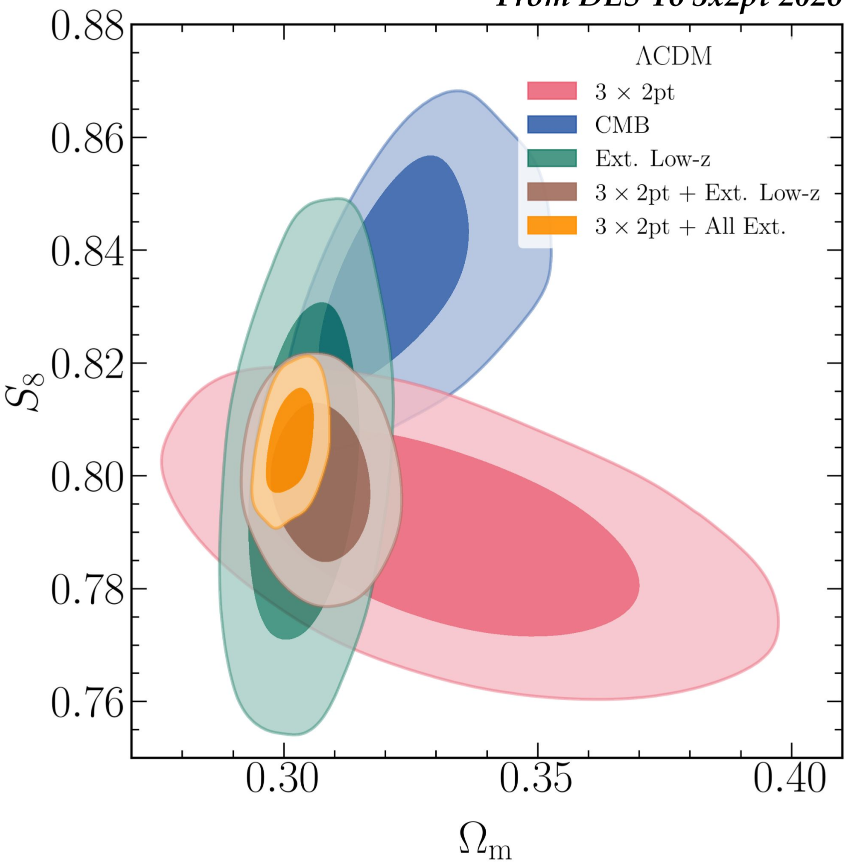


Joint cosmological constraints in ΛCDM

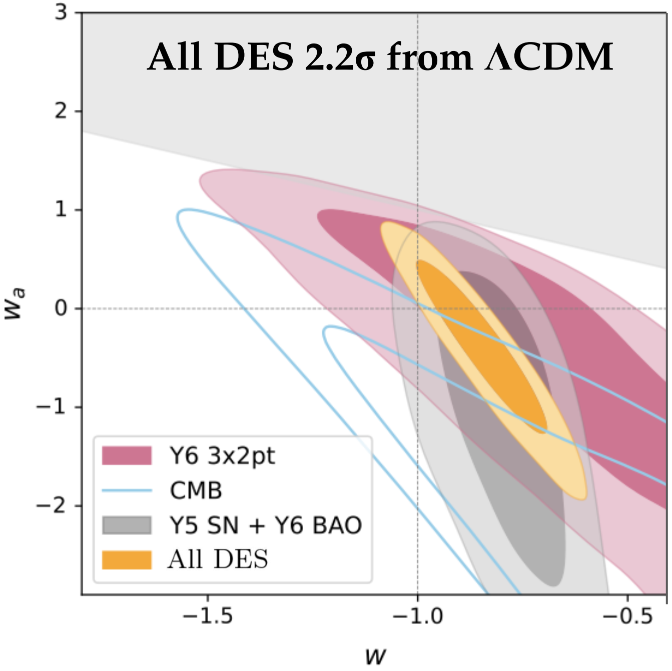
DES Y6 3×2pt + Ext. Low-*z* + CMB yield the **tightest joint constraint** from major cosmic surveys **on ΛCDM to date**.

$$S_8 = 0.806^{+0.006}_{-0.007}$$
$$\Omega_{\rm m} = 0.302^{+0.003}_{-0.003}$$
$$\sigma_8 = 0.804^{+0.007}_{-0.006}$$
$$h = 0.683^{+0.003}_{-0.002}$$
$$\Omega_{\rm b} \times 10^2 = 4.83^{+0.03}_{-0.04}$$
$$\sum m_\nu < 0.14\,\mathrm{eV}\,(95\%\ \mathrm{CL})$$

From DES Y6 3x2pt 2026



What about evolving w0-wa dark energy models?



Λ is (w0, wa) = (-1, 0).

We can open up the parameter space to measure *w0-wa*, which defines time evolving **equation of state** of dark energy, ***Λ is (w0, wa) = (-1, 0).***

$$w(z) \equiv \frac{\mathcal{P}}{\rho} = w_o + w_a \frac{z}{1+z}$$

First time evolving DE constrained using a single mission only [!]. **All DES** is **2.2σ from ΛCDM**

Last week on arXiv
DES dynamical DE constrains *(2026) : arxiv/2605.27221*

What about evolving $w0$-wa dark energy models?

All DES (SN+BAO+3x2) : 2.2σ from ΛCDM

First time from a single mission

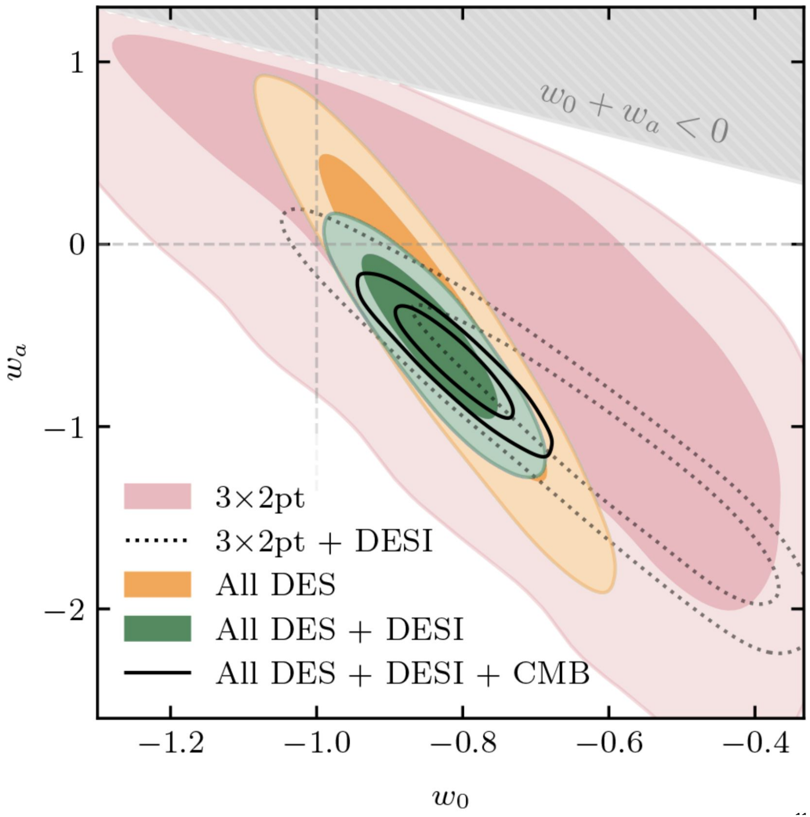
All DES + DESI BAO (no CMB) : 2.3σ from ΛCDM

Low-z only : adding 3x2 doubles constraining power

All Data (DES+DESI+CMB) : 3.0σ from ΛCDM

Largest most constraining departure (x 2 low-z only)

$$\left.\begin{aligned} w_0 &= -0.82 \pm 0.05 \\ w_a &= -0.63^{+0.21}_{-0.18} \end{aligned}\right\} \text{All data (68\% C.L.)}$$



Summary

Novel methods and data leading to legacy cosmological results from the DES Y6.

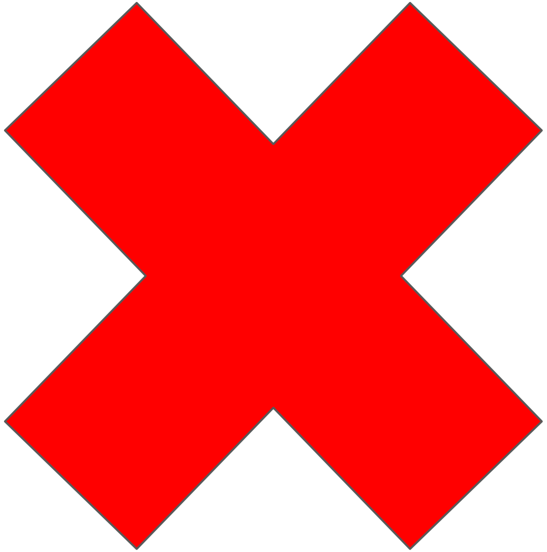
First time **we combine all four DE probes** proposed at the DES inception: 3×2pt, BAO, SNIa and Clusters. Similar constraining power as CMB *in both* Ω_m and S_8.

[1] In ΛCDM, DES all-probes is 2.8σ from the CMB.

[2] In Λ**CDM: no significant evidence for inconsistency** between DES and CMB, or between DES + other complementary low-redshift probes and CMB, although we find *systematically lower values* of the $\mathbf{S_8}$ parameter.

[3] In *w0wa*CDM, first time single mission constraints evolving dark energy, leading to a 2.2σ from ΛCDM

[4] In *w0wa*CDM, DES+CMB+DESI is 3.0σ from ΛCDM. **No significant evidence from departure from a cosmological constant**



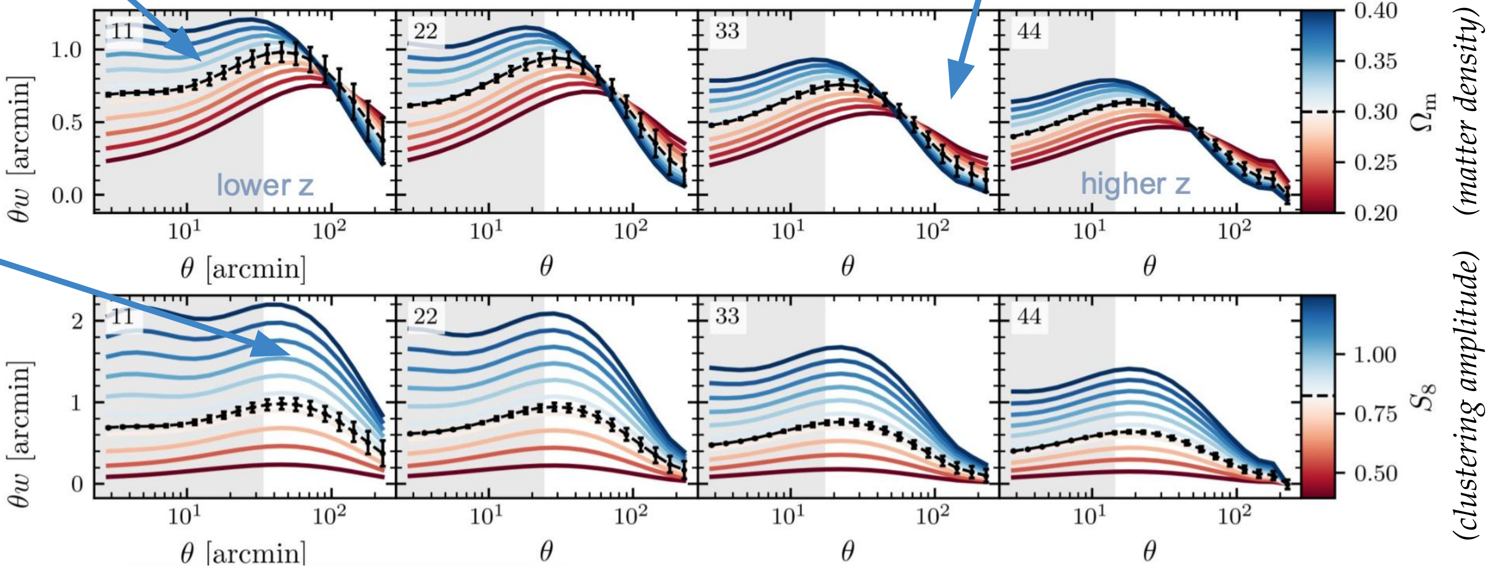
Example: Galaxy Clustering

Our full model for the 3x2pt data has over 50 parameters, only 6 of which are cosmological.

We ignore small-scale measurements in the gray regions because we cannot make accurate predictions for them.

The effects of Ωm are approximately orthogonal to S_8 (i.e., tilting the signal vs. changing the amplitude).

The parameter combination $S_8=\sigma_8(\Omega m/0.3)^{0.5}$ approximately sets the overall amplitude of the signal, and so is the best constrained parameter.



Slide credit: J. Muir

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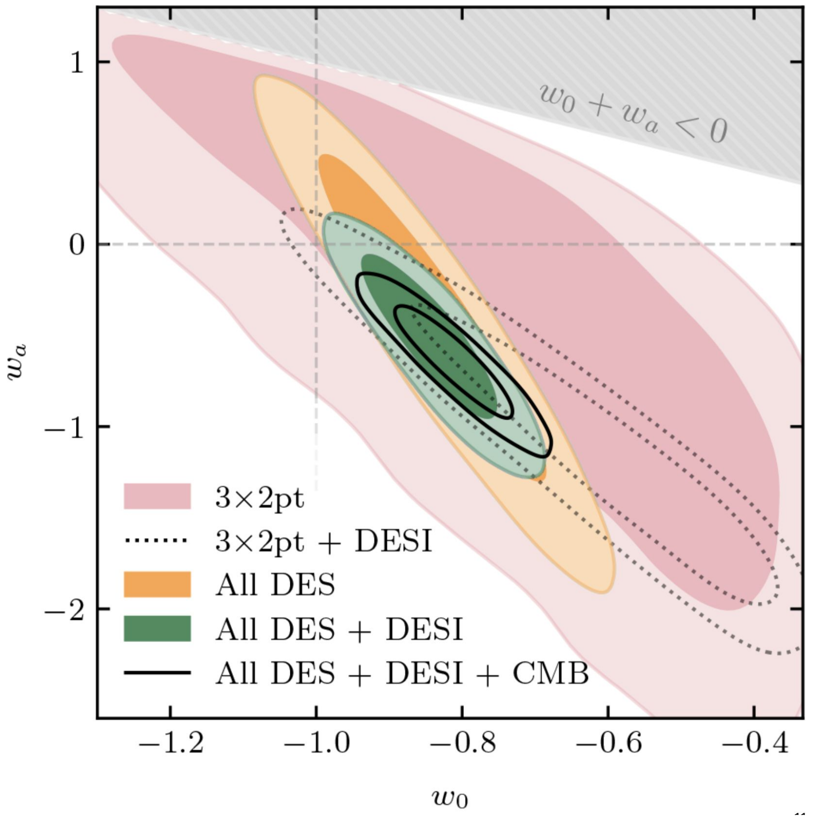
Low-*z* only : adding 3x2 doubles constraining power

All Data (DES+DESI+CMB) : 3.0σ from ΛCDM
Largest most constraining departure (x 2 low-*z* only)

All DES + CMB (no DESI BAO) : 2.8σ from ΛCDM

3x2 + BAO + CMB (no DES SN) : 2.6σ from ΛCDM



Cosmology constraints with 3x2pt

Parameter inference based on Bayes' theorem $\mathcal{P}\left(\mathbf{p}|\mathbf{D}\right) \propto \mathcal{L}(\mathbf{D}|\mathbf{p}) \cdot \Pi\left(\mathbf{p}\right)$

$$\mathcal{L}(\mathbf{D}|\mathbf{p}) \propto \exp\left(-\frac{1}{2}\left[\mathbf{D}-\mathbf{M}(\mathbf{p})\right]^T \mathbf{Cov}^{-1}\left[\mathbf{D}-\mathbf{M}(\mathbf{p})\right]\right)$$

assuming a Gaussian likelihood, analytical covariance, and a model **M(p).**

Model **M(p)**

Cosmology (6/7)
- ΛCDM/wCDM with massive neutrinos.

Astrophysics (23)
- galaxy bias, IA, baryons & lens magnification.

Data calibration (29)
- redshift distributions and shear calibration.

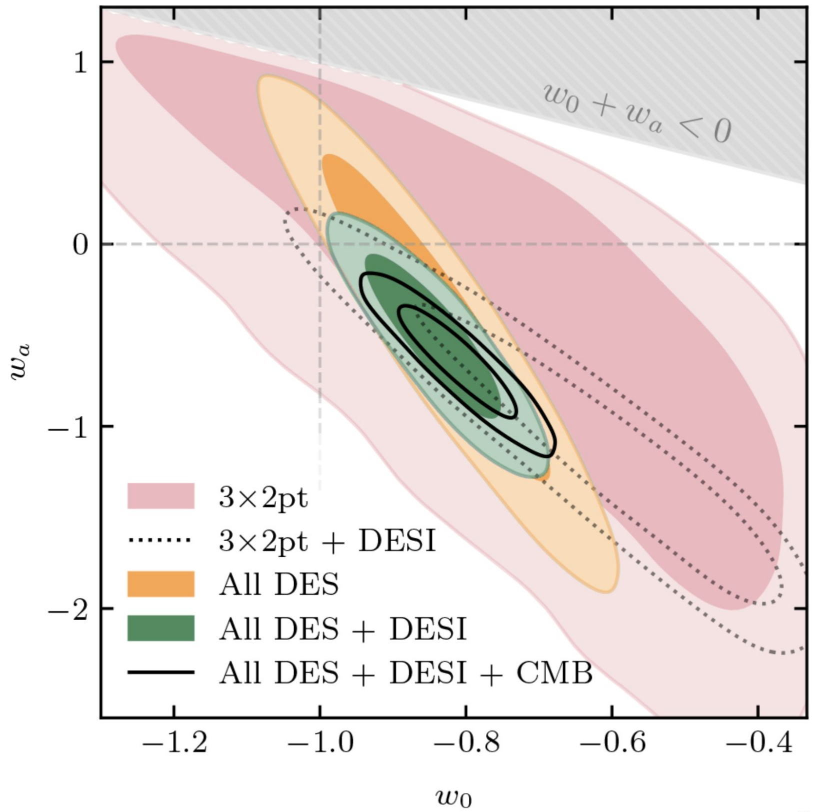
Analysis is validated on simulations and ***blinded !***

Priors Π(p) based on image simulations and other experiments.
[Sanchez-Cid+ 2026, Legnani+ 2026, Anbajagane+ 2025]

Bringing DES all probes and 3x2 into the picture

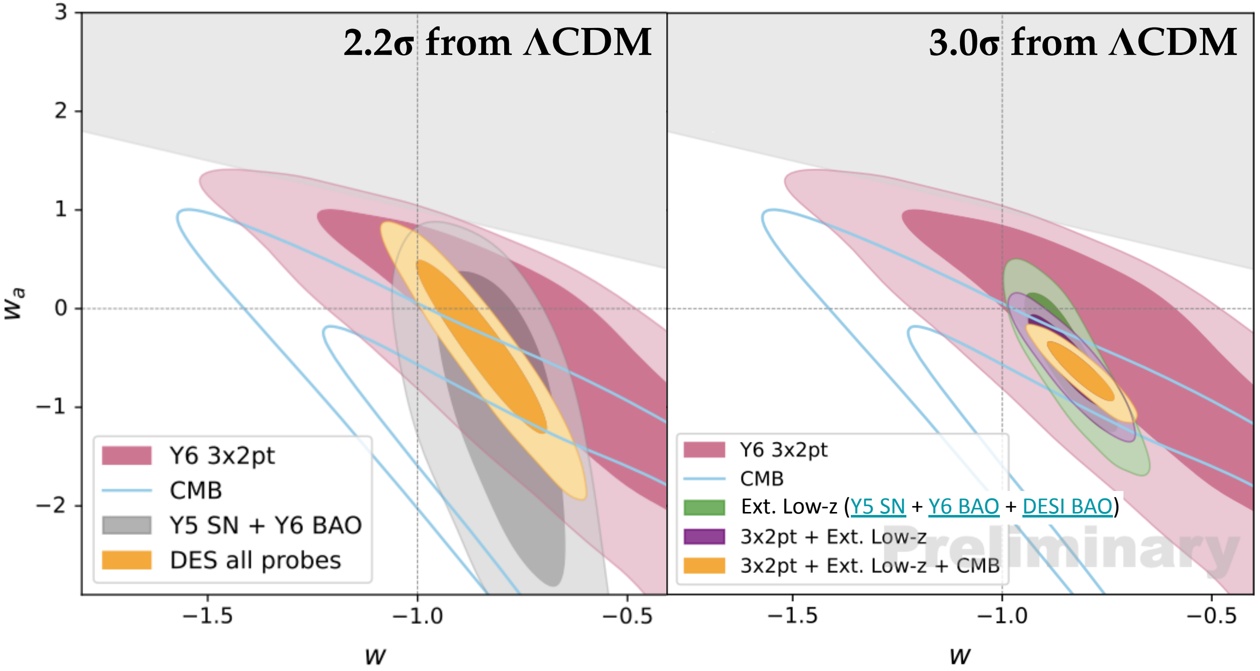
Preview from DES letter tomorrow

Datasets	Distance to ΛCDM (σ)	$\Delta\chi^2$ (σ)	FoM
3×2pt	1.0	1.0	6
SN + DES BAO	1.5	1.6	11
All DES (3×2pt + SN + DES BAO)	2.2	2.0	48
All data (All DES + DESI BAO + CMB)	3.0	3.0	222
SN + BAO	2.4	2.3	61
3×2pt + DESI BAO	1.7	1.5	32
CMB + DESI BAO	2.9	2.9	61
All DES + DESI BAO (All except CMB)	2.3	2.2	110
SN + BAO + CMB (All except 3×2pt)	3.2	3.3	202
3×2pt + BAO + CMB (All except SN)	2.6	2.5	66
3×2pt + SN + CMB (All except BAO)	2.4	2.4	96
All DES + CMB (All except DESI BAO)	2.8	2.8	102



If not real, we will have to find systematics in more than one probe

What about evolving w0-wa dark energy models?



Most constraining dataset:
DES 3x2pt + DES SN + DES BAO + DESI DR2 + CMB

$$\left.\begin{aligned} w_0 &= -0.82 \pm 0.05 \\ w_a &= -0.63^{+0.21}_{-0.18} \end{aligned}\right\} \text{All data (68\% C.L.)}$$

Alternatives to a cosmological constant: w0waCDM model

The dark energy component might not be a cosmological constant Λ

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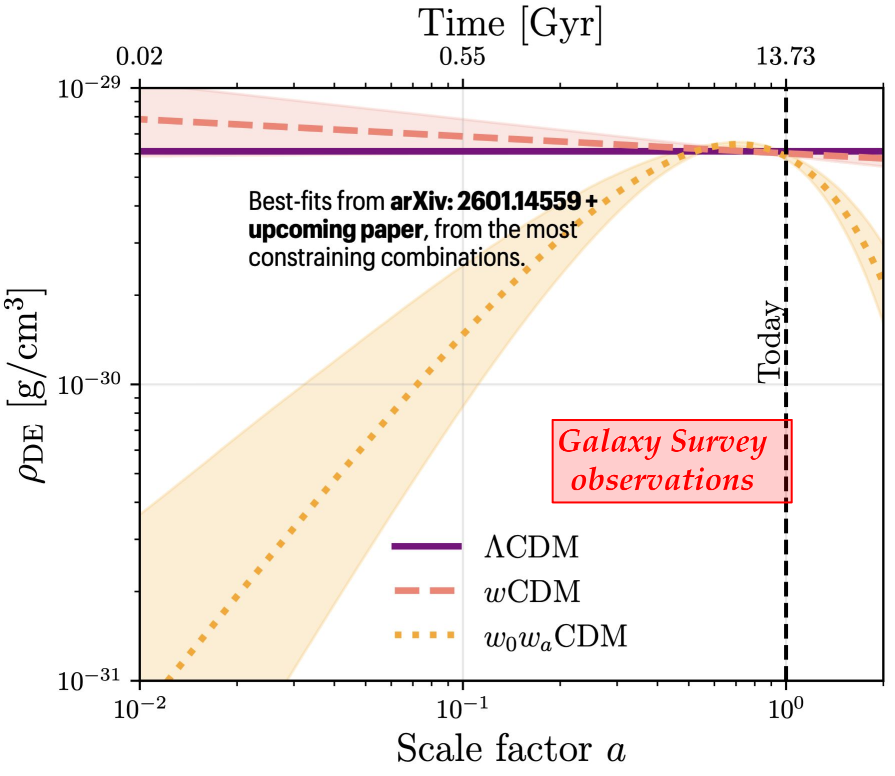


(time ⟶)

Fig credit: J. Prat

DES Y6 3×2pt cosmology

A factor of 2 improvement in FoM in this plane from DES Year 3.

In ΛCDM:

$S_8 = 0.789^{+0.012}_{-0.012}$

$\Omega_{\mathrm{m}} = 0.333^{+0.023}_{-0.028}$

$\sigma_8 = 0.751^{+0.034}_{-0.036}$

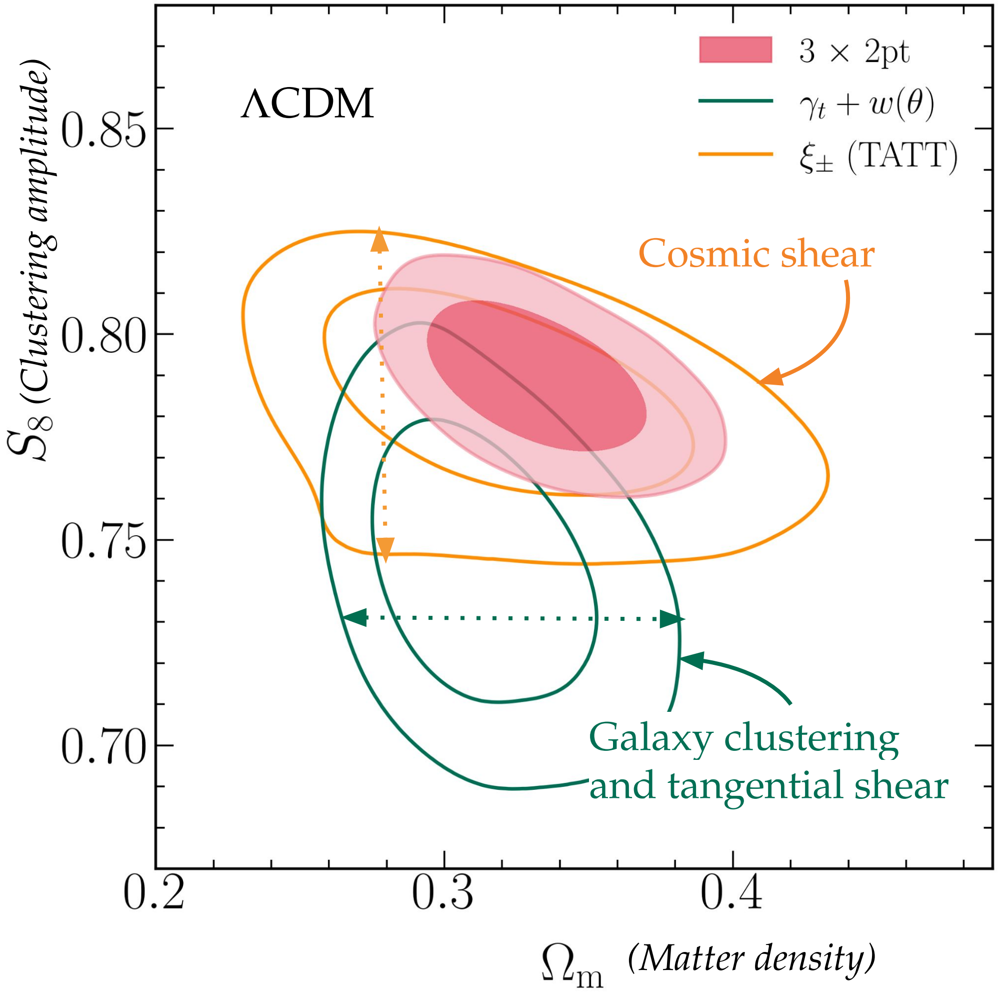
In *w*CDM:

$w = -1.12^{+0.26}_{-0.20}$

$\Omega_{\mathrm{m}} = 0.325^{+0.032}_{-0.035}$

$S_8 = 0.781^{+0.021}_{-0.020}$

We find w consistent with -1 and we don't find a significant preference (0.9σ) for wCDM over ΛCDM.



Robustness of 3x2pt results