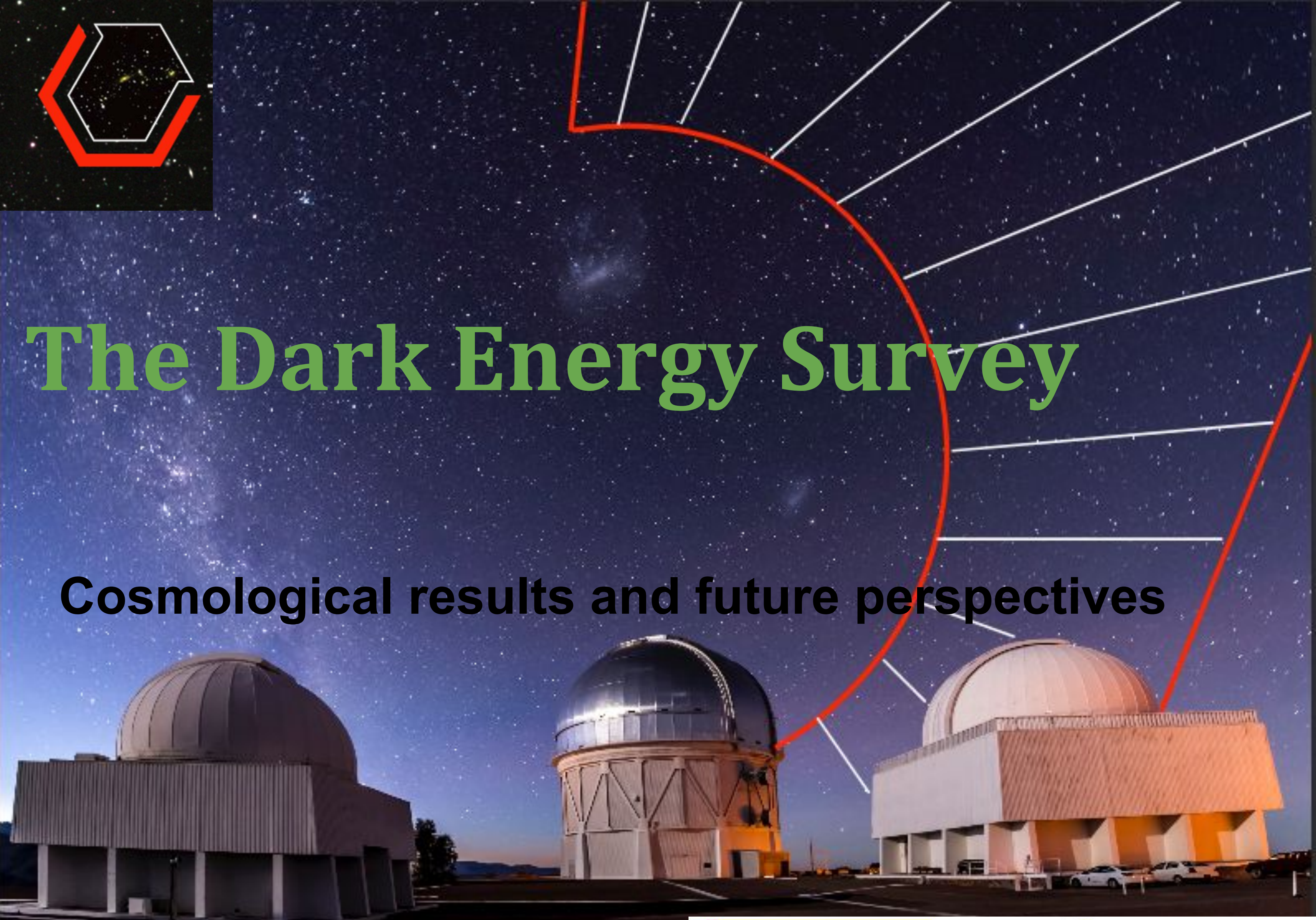
The Dark Energy Survey

Cosmological results and future perspectives



Aurelio Carnero Rosell on behalf of the DES Collaboration

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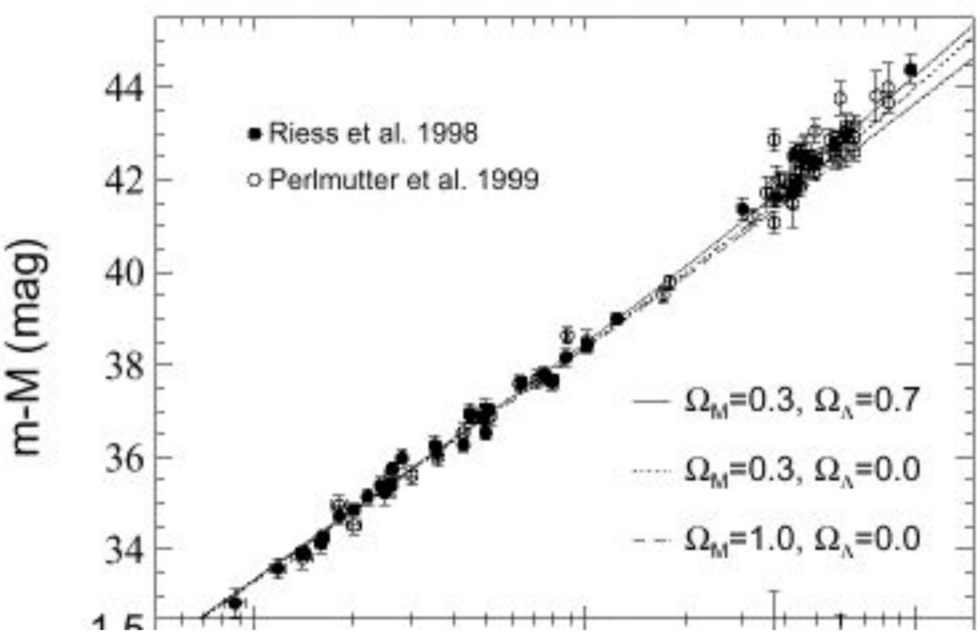
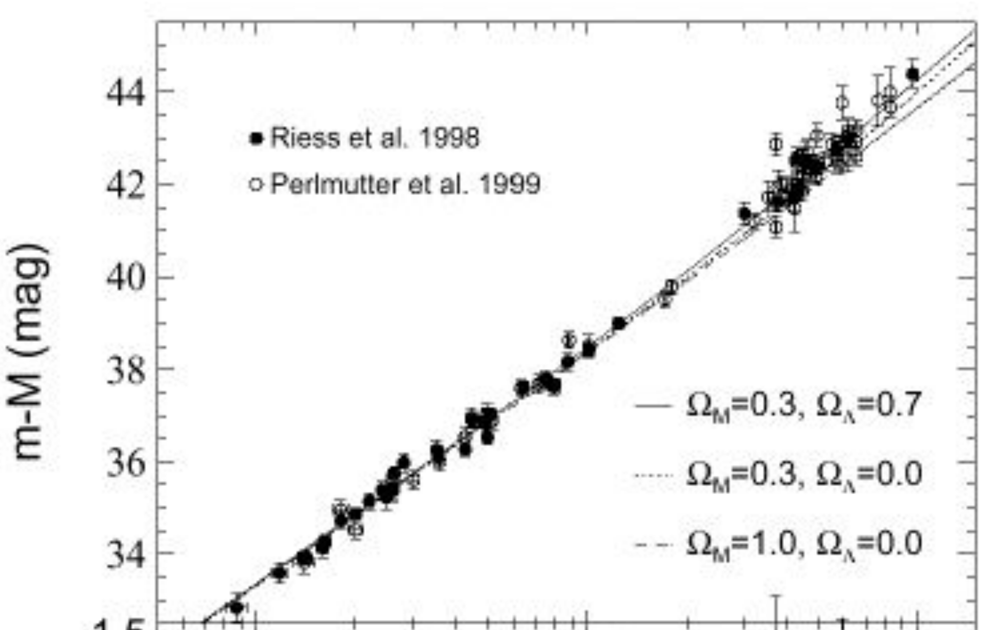
Dark Energy is one of the most intriguing issues in physics today



$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Is it the cosmological constant? Is it other type of DE?

Dark Energy is one of the most intriguing issues in physics today

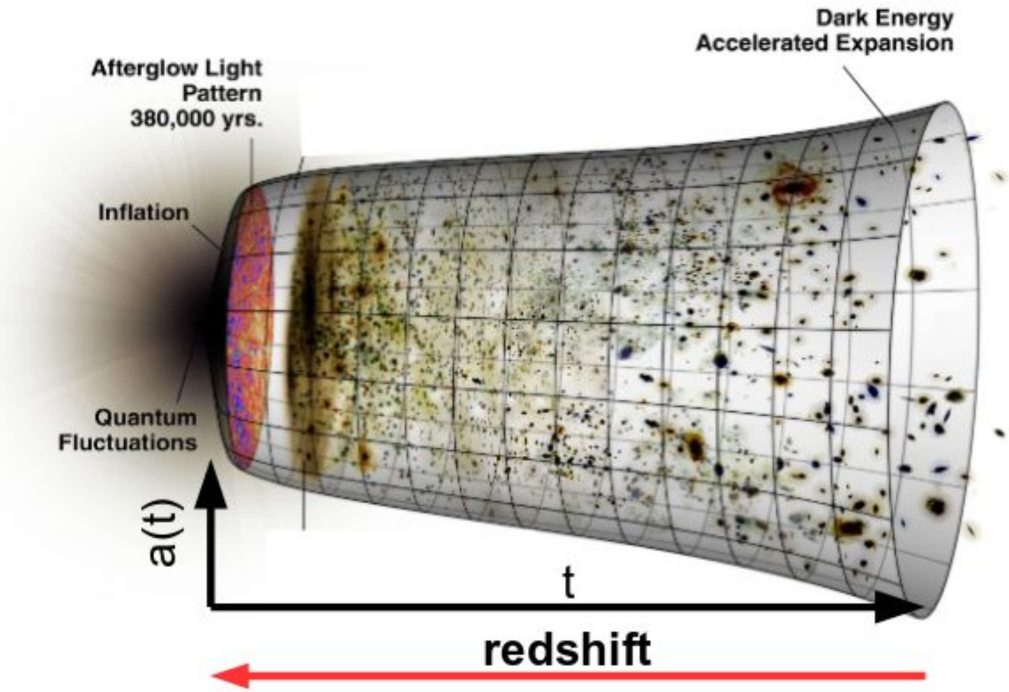


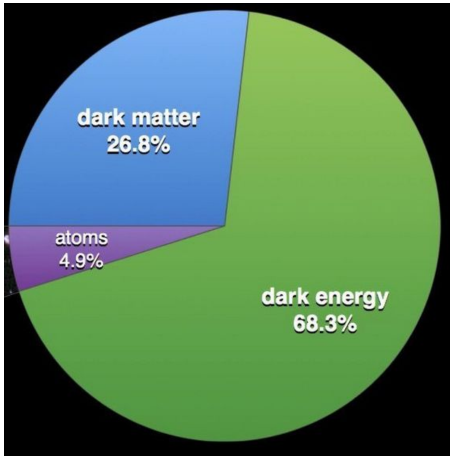
$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu}$$

Maybe we need to change the metric itself?

Modified Gravity, f(R) theories

LCDM model in a nutshell





On large scales, the Universe is described as a homogeneous fluid in a expanding space

$$H(a)^2 = H_0^2 \left(\Omega_{M,0} a^{-3} + \Omega_{\Lambda,0} + \Omega_{rad,0} a^{-4} + \Omega_{K,0} a^{-2} \right)$$

Age of the Universe ~ 14. Gyr

4 additional parameters:

σ_8 / S_8: amplitude of density fluctuations

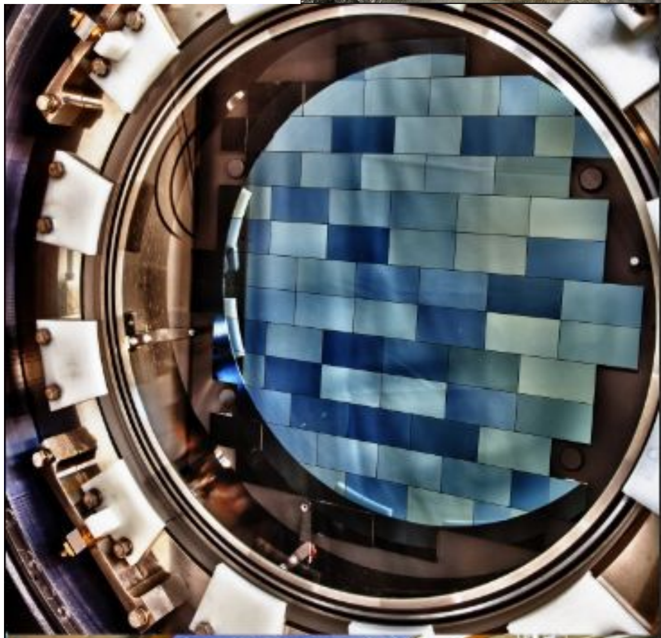
m_v / Ω_v: mass/density of neutrinos

h / H / $\left(\frac{\dot{a}}{a}\right)$: rate of expansion today

n_s: scale dependence of early density fluctuations

The Dark Energy Survey in a nutshell

A photometric galaxy survey aiming for 200 million galaxies in a 8th of the sky



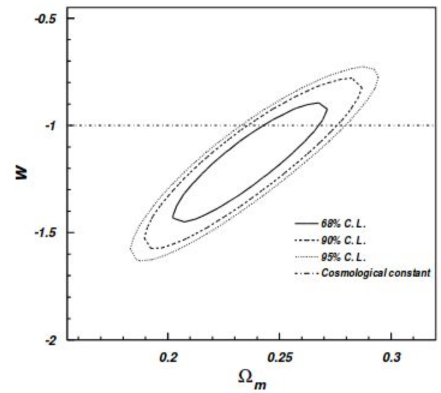
Reaching ~ 1% uncertainty in DE equation of state by the end of the analysis (in 2, 3 years)

Combination of various cosmological probes to give a single measurement: Galaxy clustering, weak lensing, standard candles, galaxy clusters.

Current Dark Energy precision, in combination with Planck, is 4%. **No hints of a crack in the model.**

Observe in 5 filters, from 4,000 A to 11,000 A, covering optical and near-infrared spectrum

Observations ended in January 2019, after 6 years.



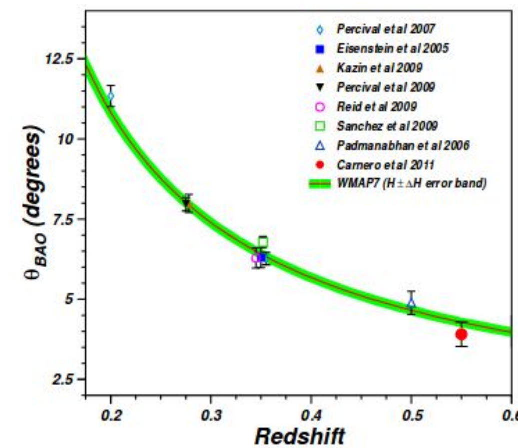
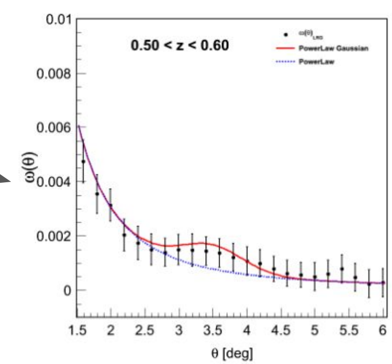
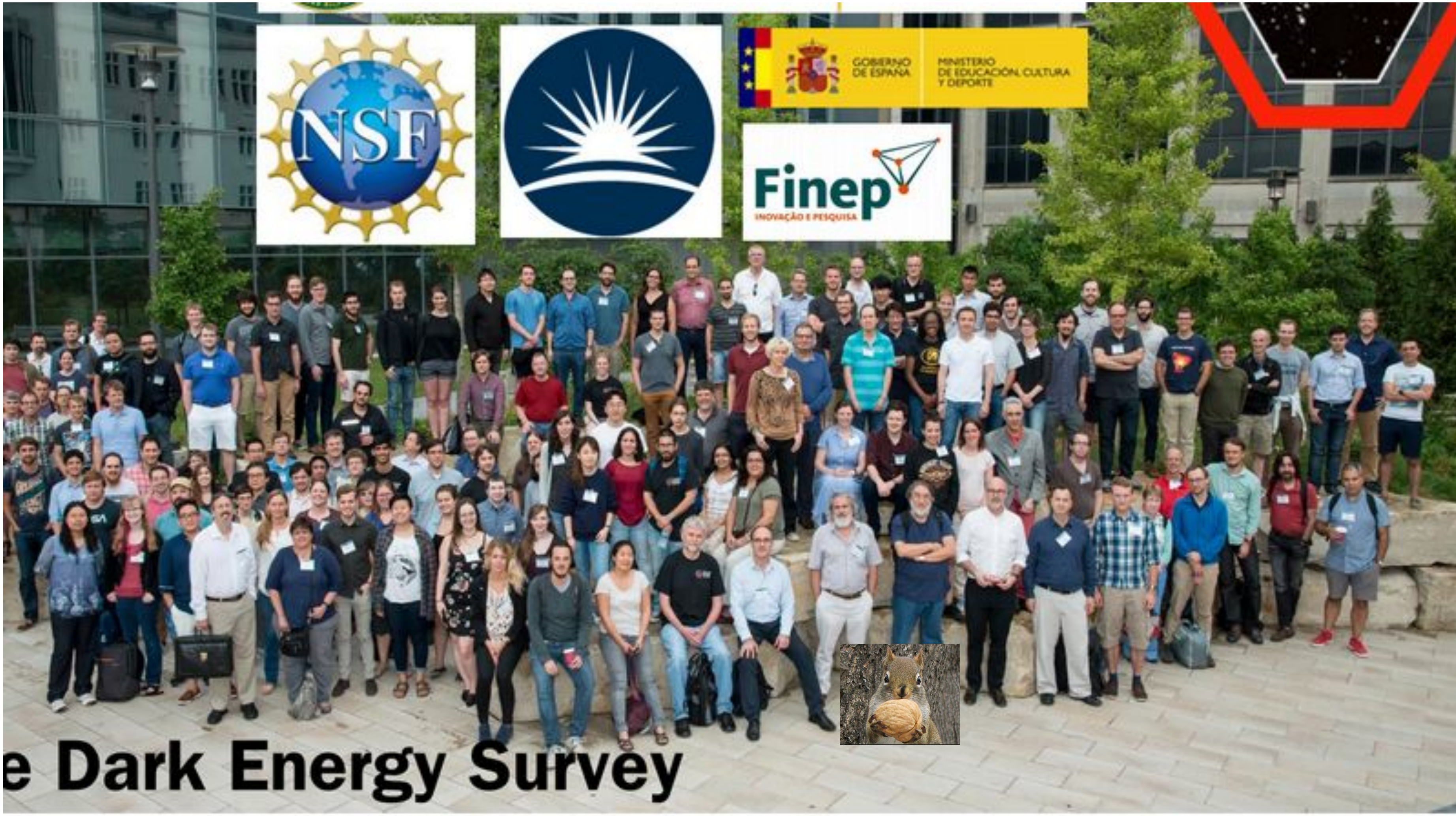


Table Browser for 1: DESY3_LTcatalog.fits

	COADD_OB...	RA	DEC	SPT_TYPE	NBANDS	XI2_CLASSIF	DISTANCE_...
1	302513036	18,38307	-51,73295	10,	5	5,94452	277,50127
2	71547410	330,93739	-57,23148	10,	7	3,9938	308,3687
3	288867161	14,2374	-56,99098	10,	5	1,5716	423,55642
4	383488977	58,13261	-49,18317	27,	8	36,21945	26,5464
5	356877876	50,33078	-60,19452	11,	5	1,75701	166,10141
6	94543045	34,49283	1,19037	10,	7	2,09446	375,59893
7	151675786	348,23559	-61,84114	10,	6	2,74458	299,22055
8	484157841	60,69891	-51,34498	10,	8	8,45061	163,54118
9	133695937	352,54567	-46,86276	10,	5	5,13862	392,19415
10	213746245	326,30041	-57,41039	10,	6	3,29331	355,29298
11	484349921	60,71999	-29,70896	10,	7	2,91982	238,09705
12	109390888	344,82671	-51,16338	10,	8	10,94459	197,38772





laborating
itutions:

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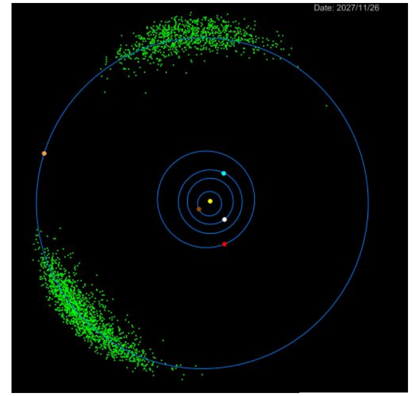
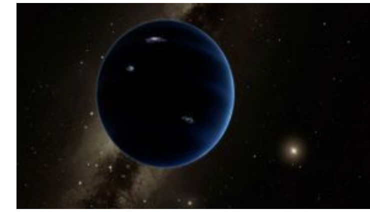
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

DES is not only cosmology!

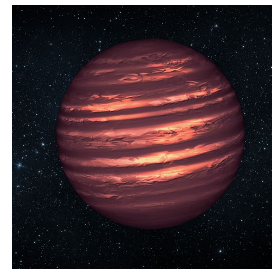




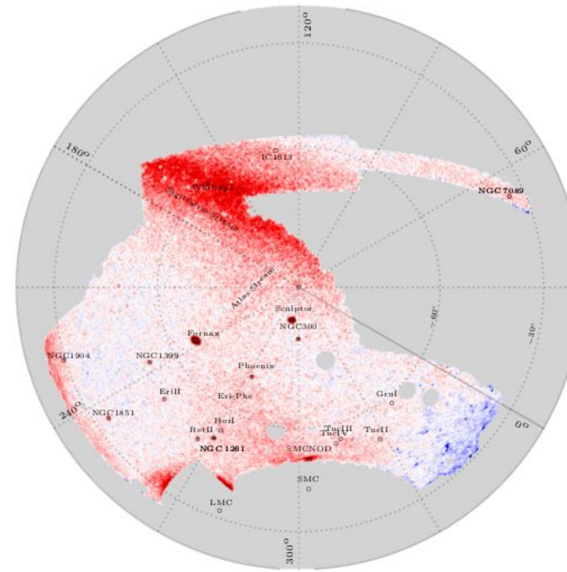
Solar system:

- TNO and Centaurs, Planet 9 search

Galactic searches:



- Brown dwarfs, RR lyrae

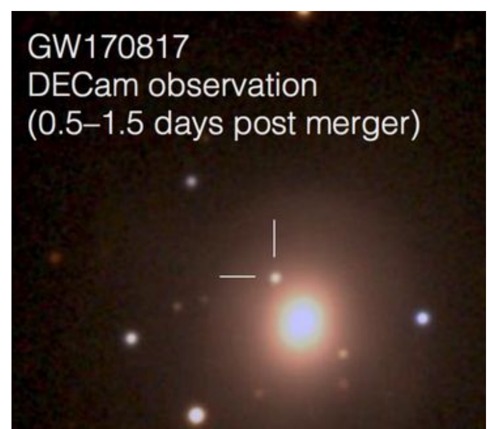


Milky Way formation:

- Large Scale Structure, Stellar streams discoveries

Local Universe:

- MW faint companions



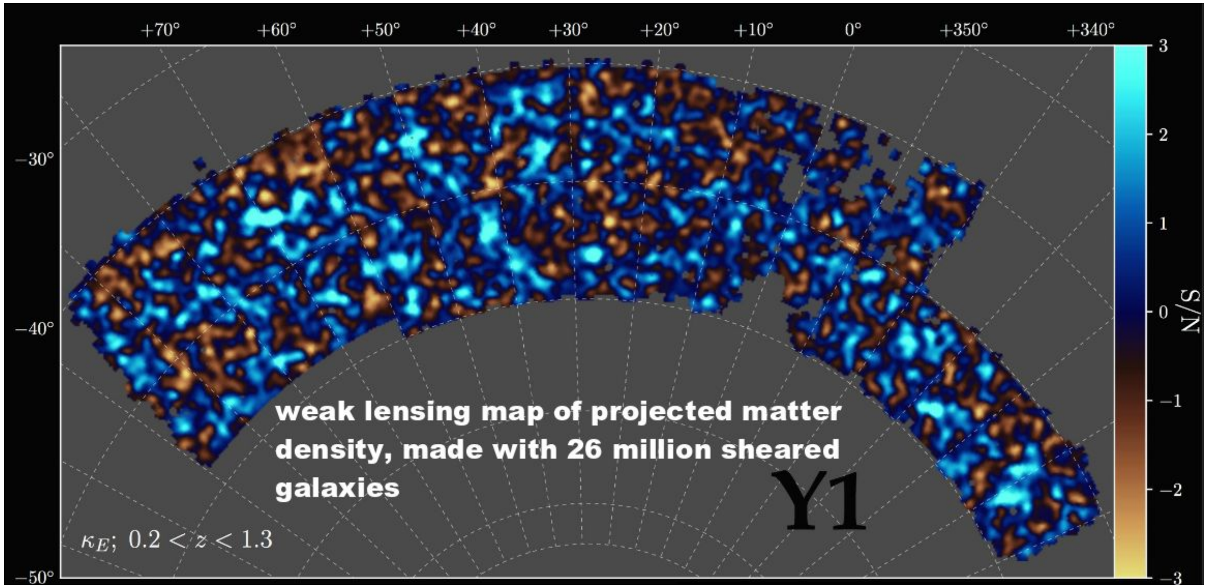
Galaxy evolution, Galaxy clusters

Gravitational waves events

DES data

Scientific results found here:

https://www.darkenergysurvey.org/des-year-1-cosmology-results-papers/



Catalog made from first year of observations (Y1 data): 50% coverage, 50% depth

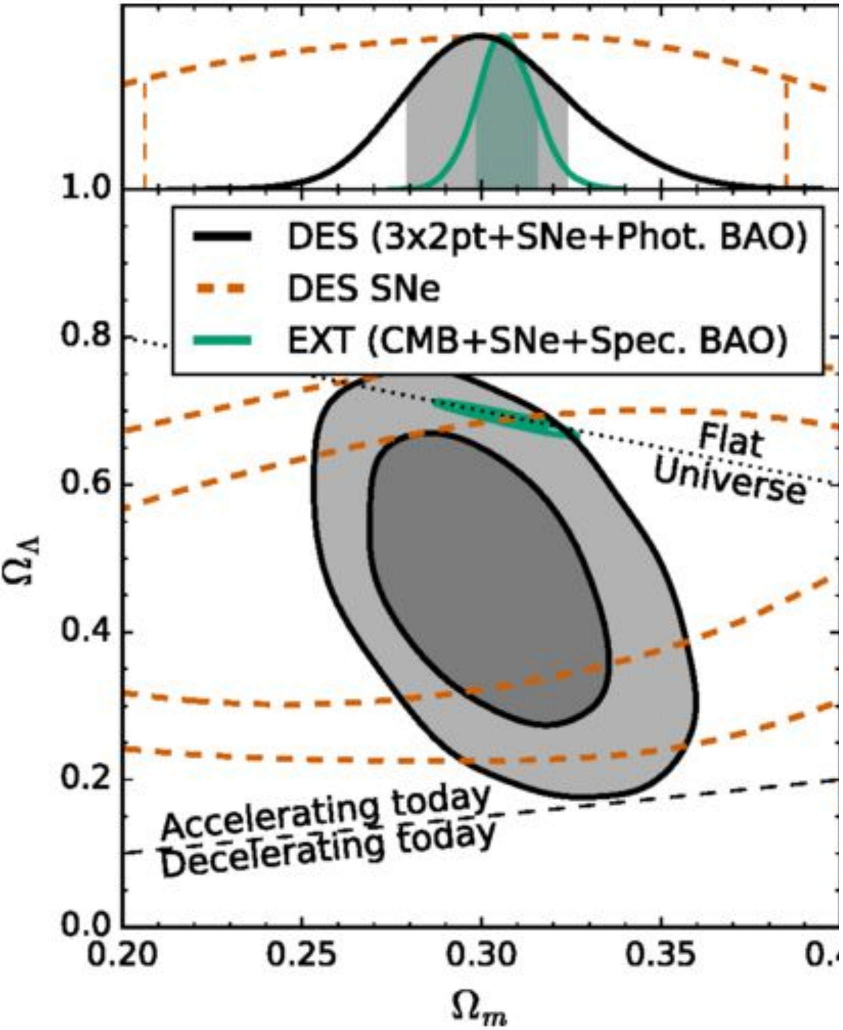
Current collaboration analysis, first 3 years of observations (Y3 data): 100% coverage, 50 depth%

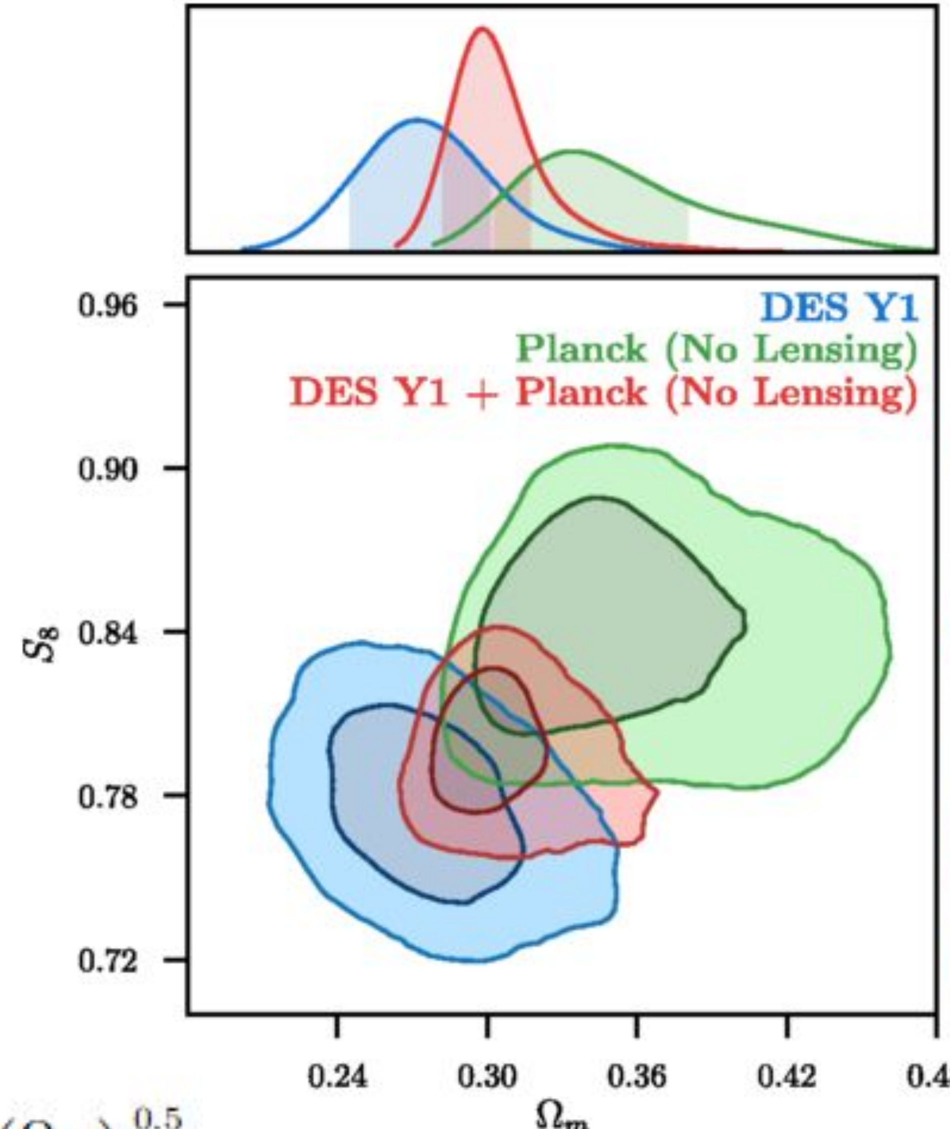
In the following months, the collaboration will have access to the last release (Y6 data): 100% coverage, 100% depth

Public data: https://des.ncsa.illinois.edu/releases/

- DR1 (coadded Y3 data)
- Y1 Gold (coadded Y1 data + value added information for cosmology)

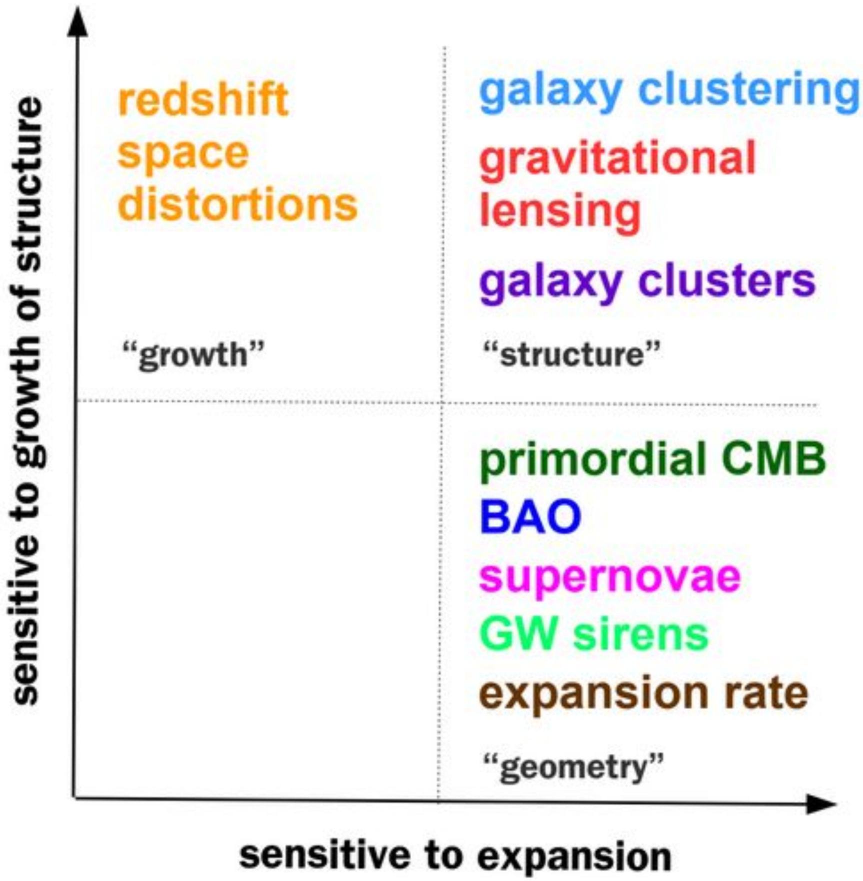
The Dark Energy Survey greatest hits





$$S_8 \equiv \sigma_8 \left(\frac{\Omega_m}{0.3} \right)^{0.5}$$

How to survey dark energy

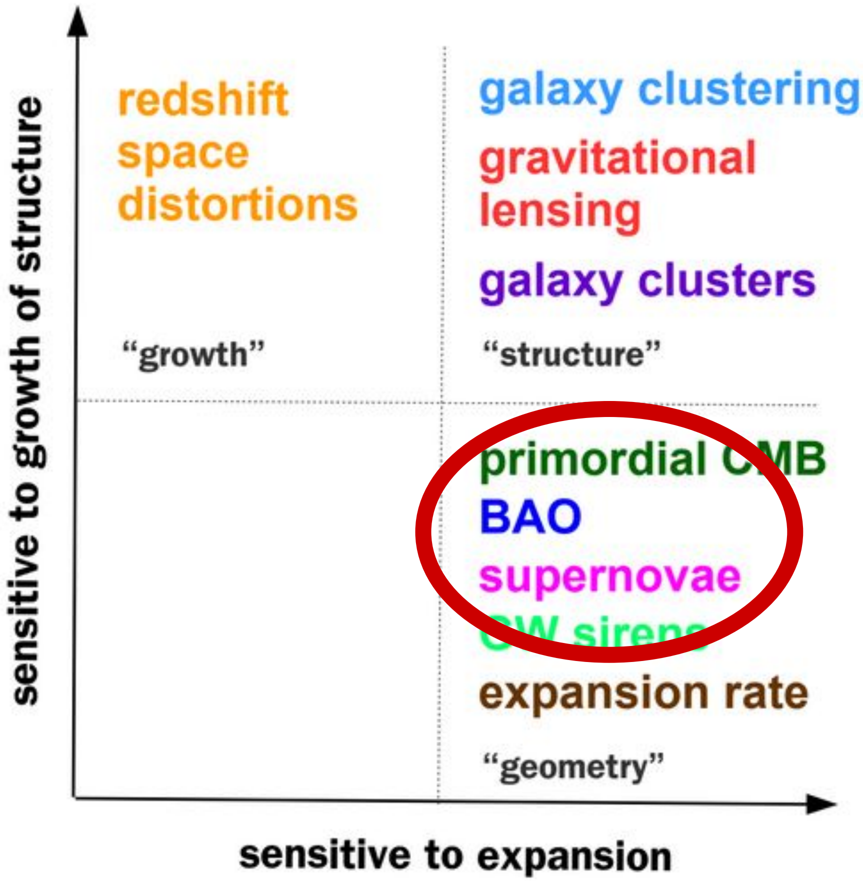


Q: Do all these measurements agree with predictions in the same, fiducial ΛCDM model?

Is cosmic geometry consistent with an expansion governed by general relativity with a cosmological constant?

Are the structures found in the evolved Universe explained by initial fluctuations growing under general relativity, dark matter and dark energy?

How to survey dark energy



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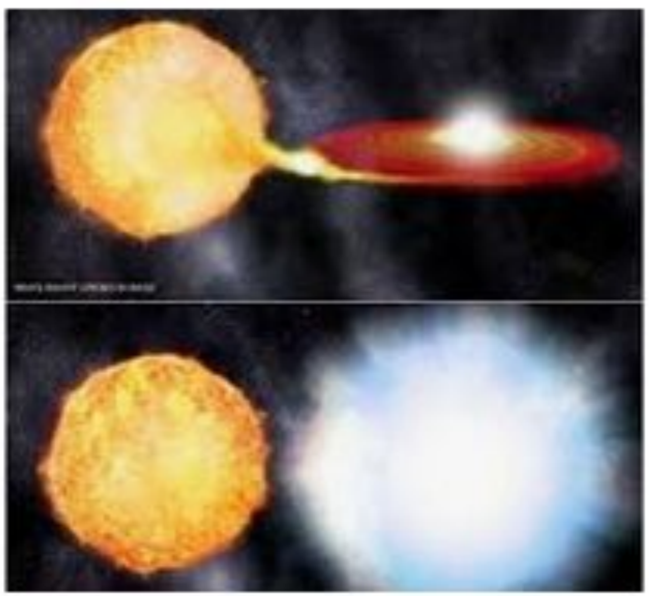
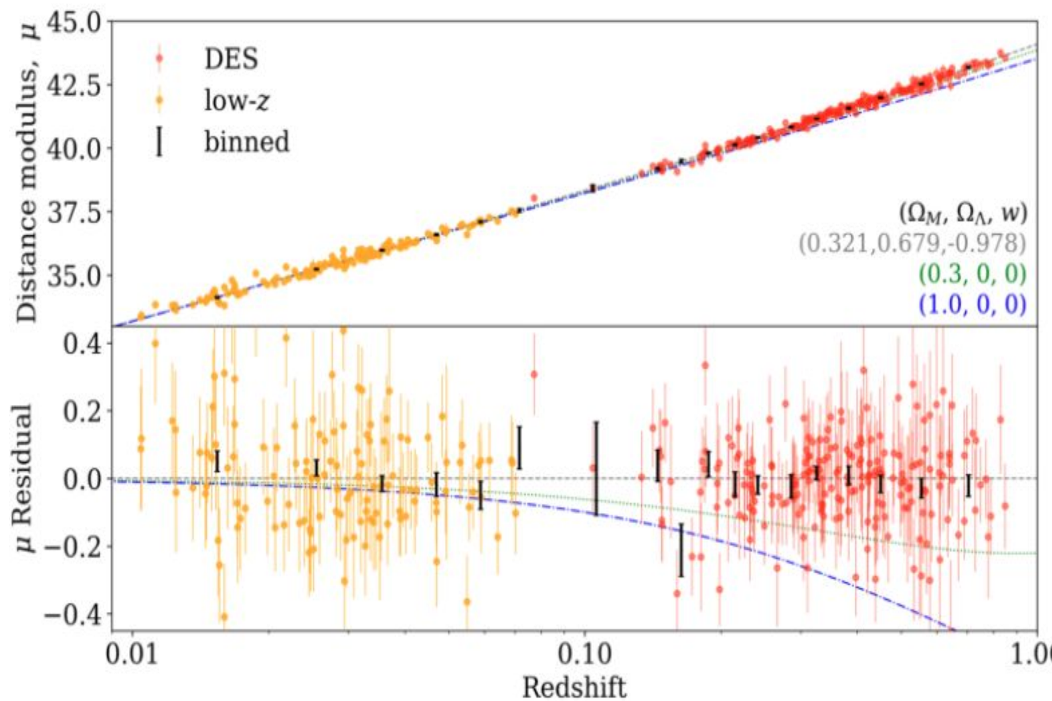
Measurements of expansion history with DES

Comparison of distance and redshift

Standard candle: brightness of source with known luminosity

- SNe: luminosity can be determined by color/duration



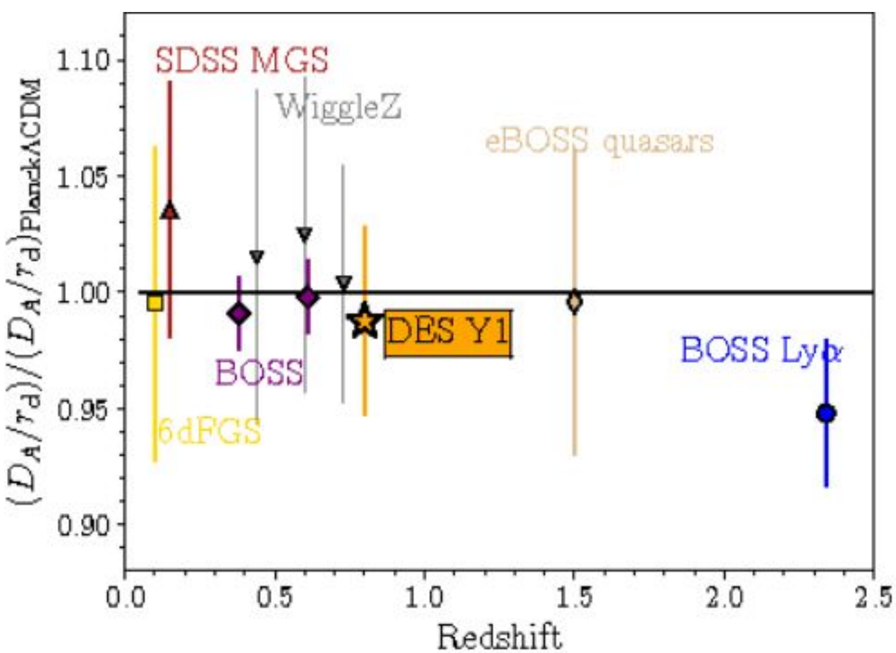


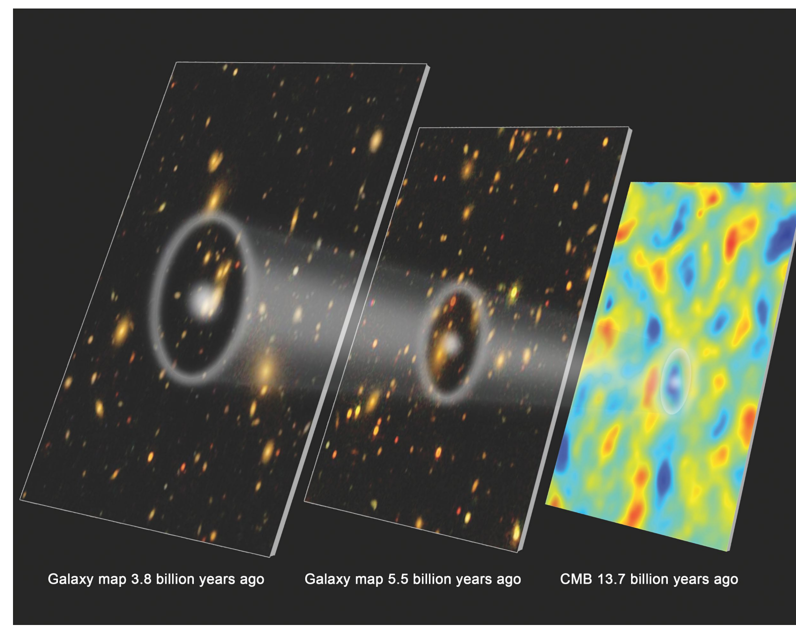
Measurements of expansion history with DES

Comparison of distance and redshift

Standard ruler: angle subtended by known scale

- CMB: sound horizon in early Universe (380,000 years)
- BAO: same scale, but expanded at later times (billions of years)





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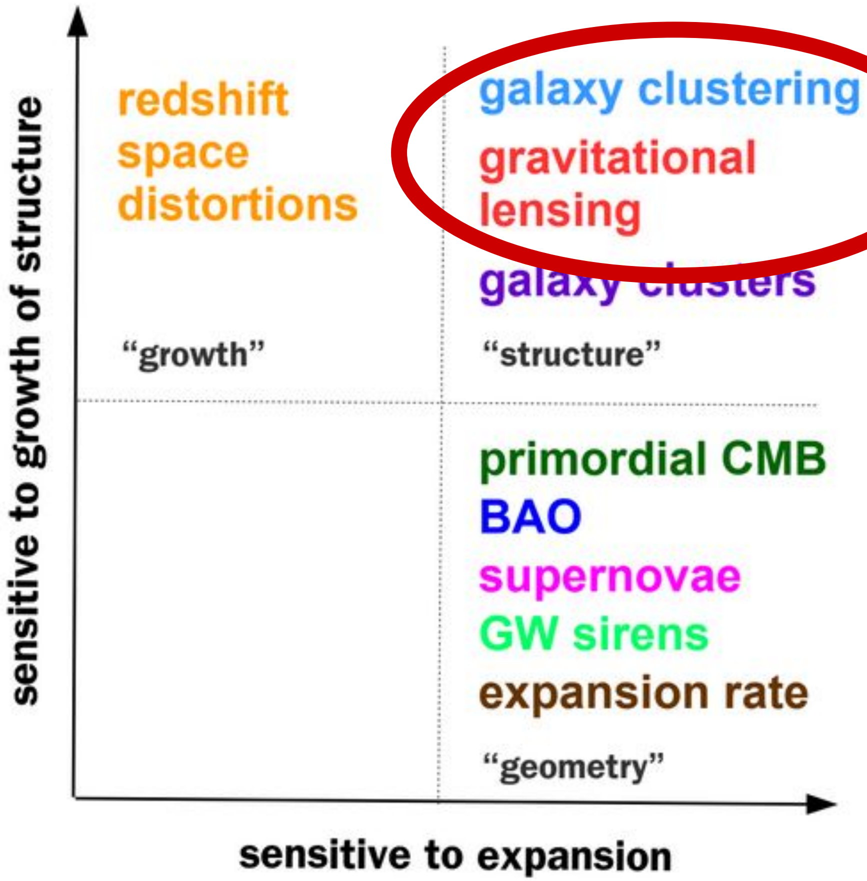

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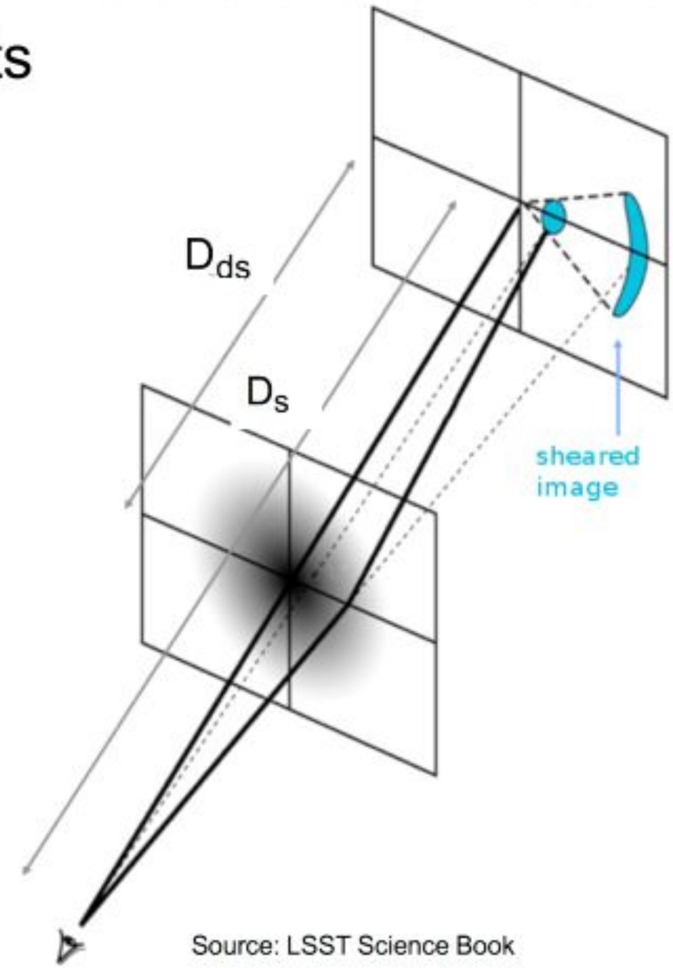
Gravitational lensing

- When light passes massive structures, it feels gravity and its path gets bent
- This causes shifting, and magnification, and <u>shearing</u> of the galaxy image

$$\gamma_t(\theta) = \langle\kappa(\theta')\rangle_{\theta'<\theta} - \kappa(\theta)$$

$$\kappa = \Sigma / \left[\frac{c^2}{4\pi G}\frac{D_{\rm s}}{D_{\rm d}D_{\rm ds}}\right]$$

Need to measure galaxy shapes
and redshift distributions

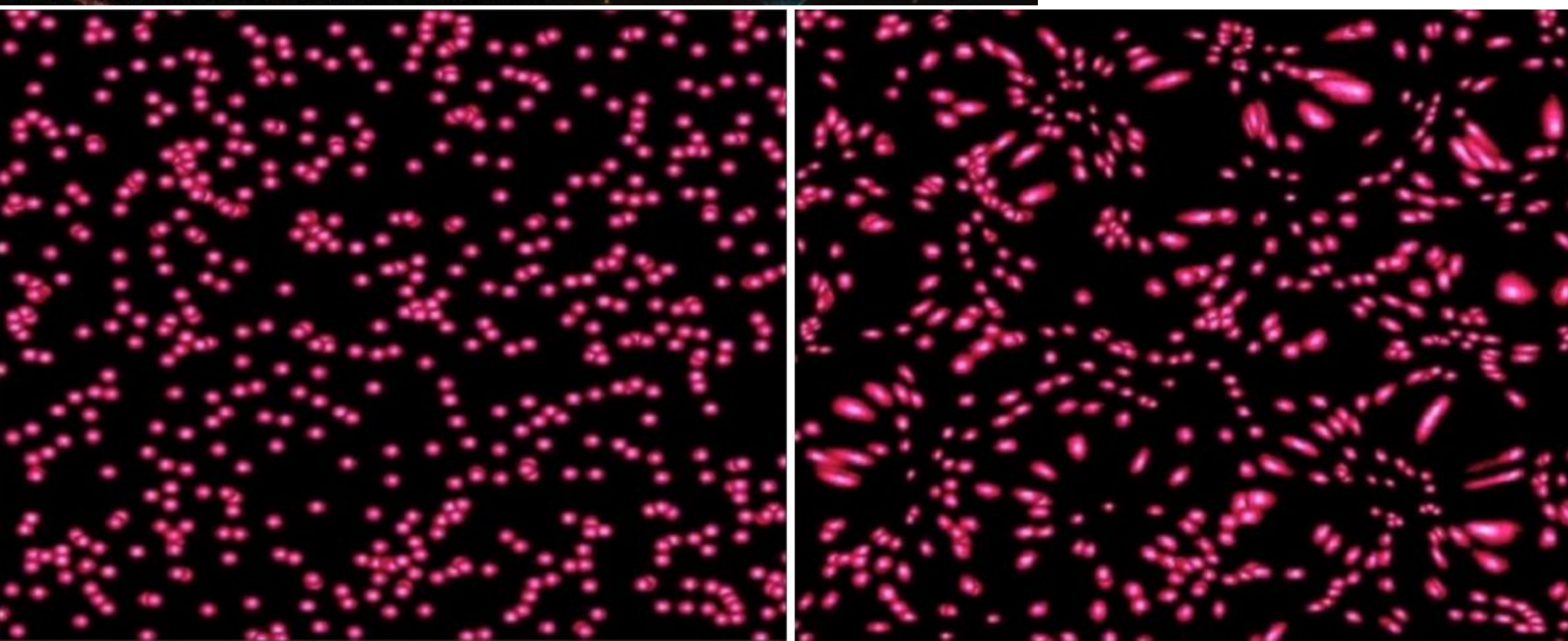


Source: LSST Science Book

Gravitational lensing

Strong lensing

Weak lensing



Cosmological results with weak lensing and galaxy clustering

Novel technique:

- Combined analysis of galaxy clustering and weak lensing.
- + likelihood join with DES Supernova and BAO
- + likelihood join with Planck (CMB)

Robust systematic analysis:

- Use of independent photo-z and shape catalogs.
- Full, validated treatment of covariance and nuisance parameters.
- Theory and simulated tested with 2 independent codes, CosmoLike and CosmoSis.

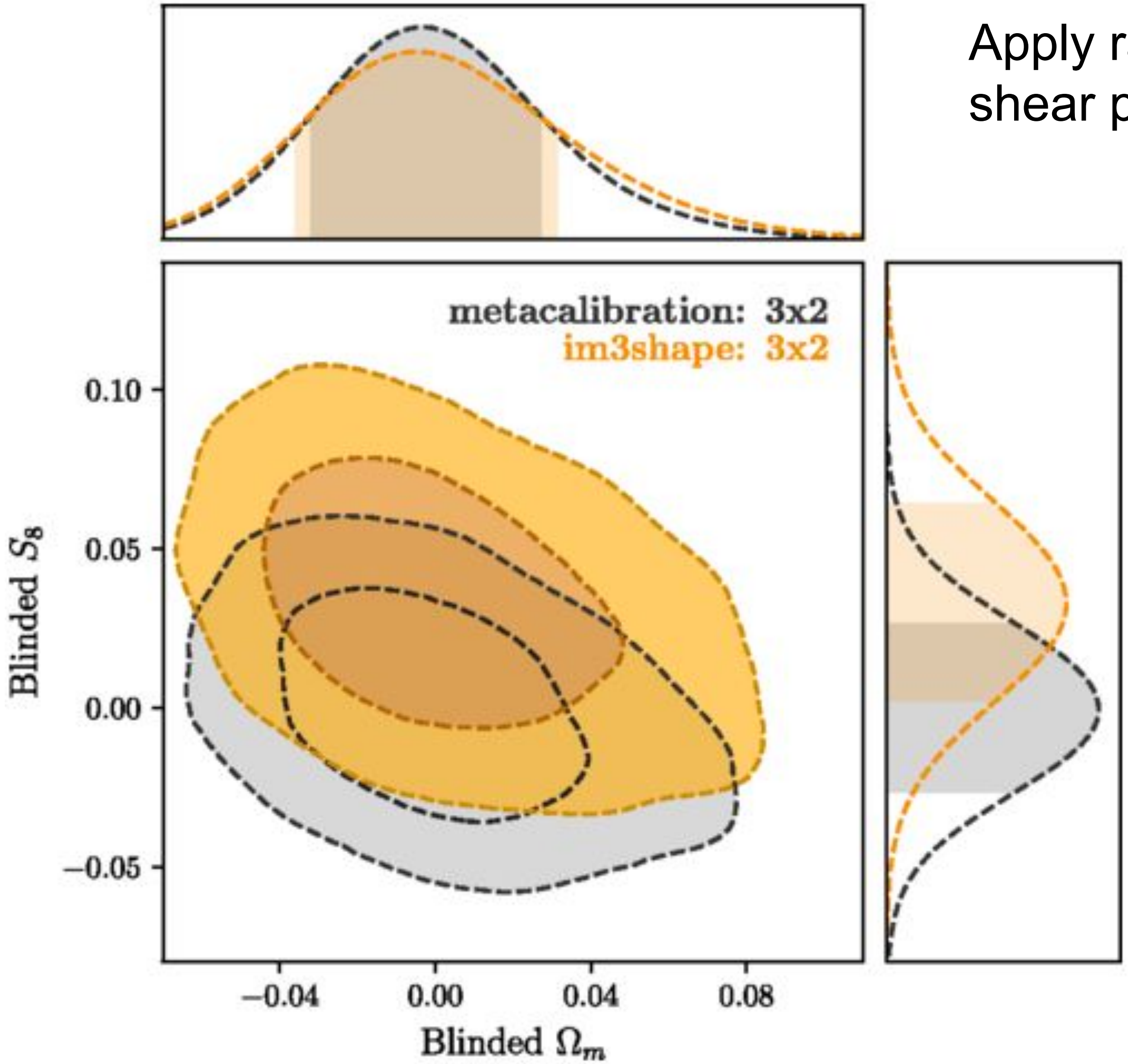
Blind analysis to avoid confirmation bias:

- Over-correct your data until you get the expected result (LCDM).

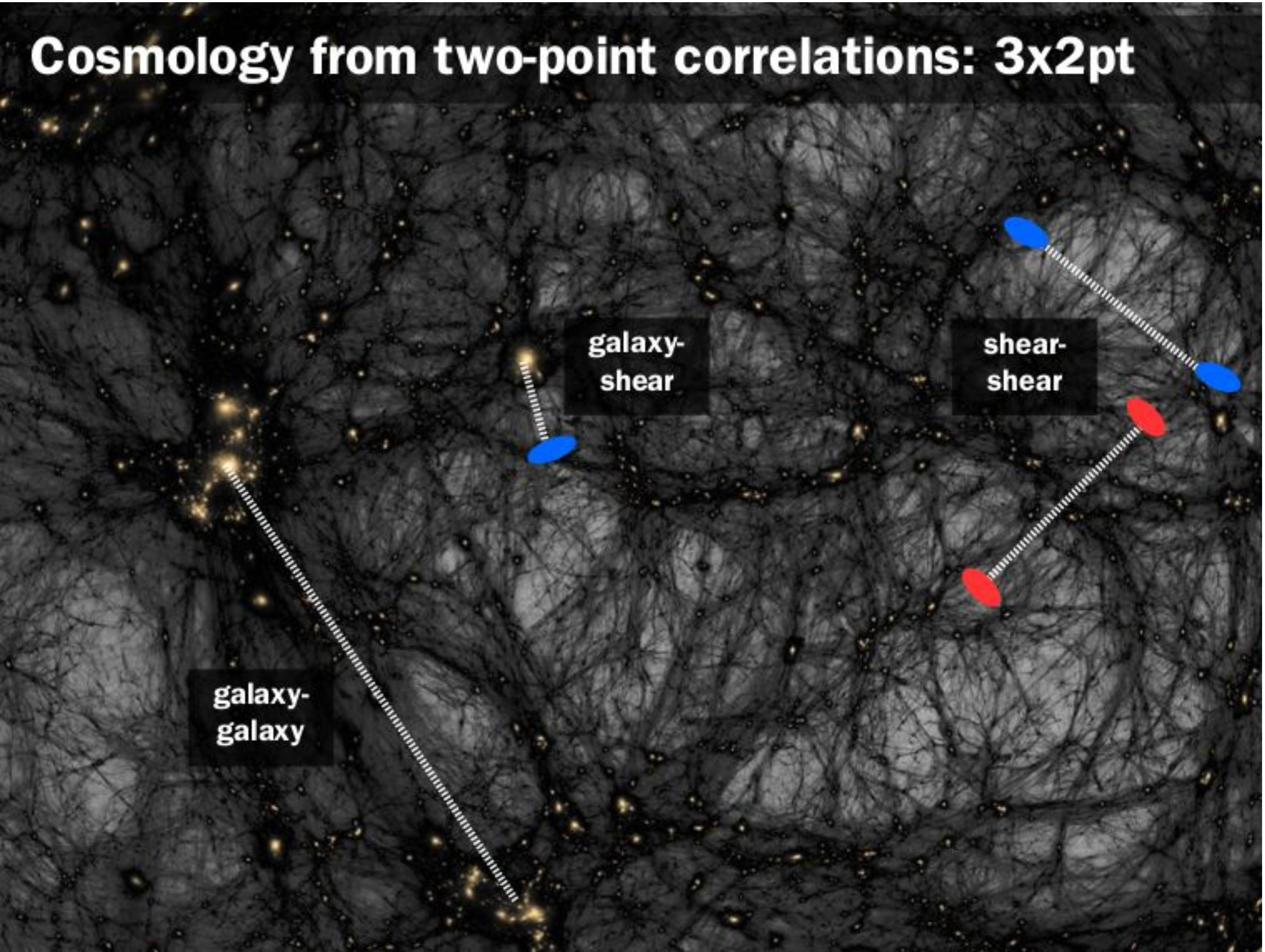
Blind analysis, an example

Do not show labels in plots.

Apply random shifts to galaxy shear parameters.



Cosmological results with weak lensing and galaxy clustering

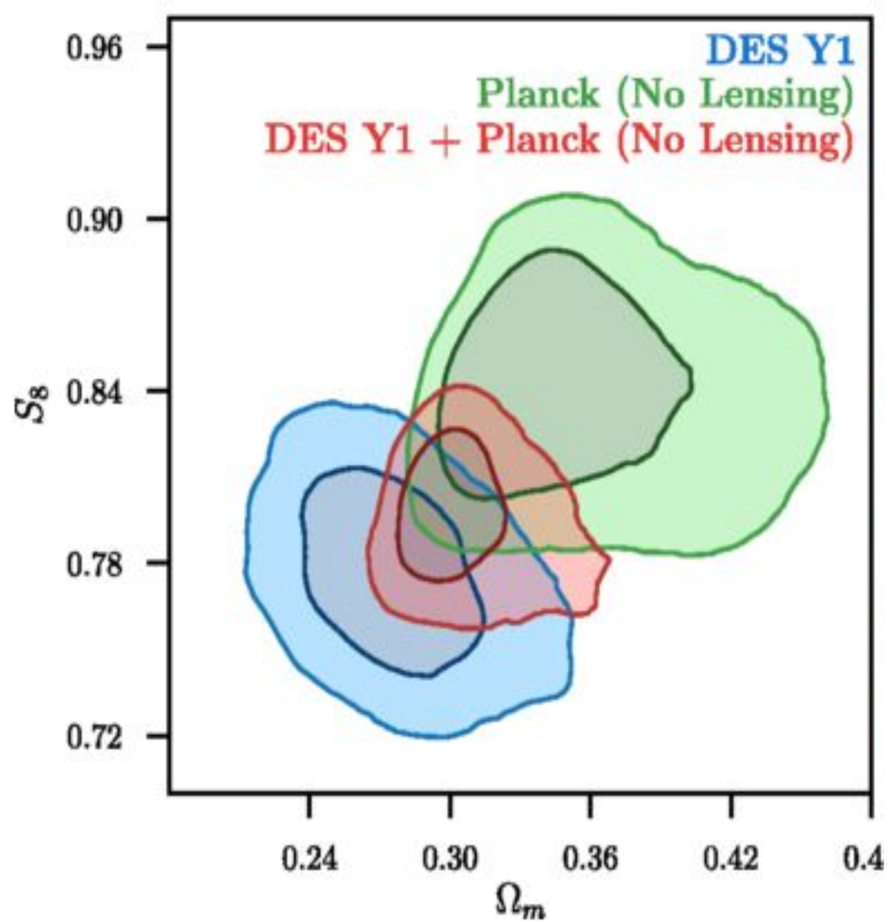


Consistency of evolved structures with CMB

DES and CMB constraints matter density and S_8 with equal strength

Difference in central values in same direction as results from other lensing experiments. Is S_8 low?

Good bayes factor - blinded criterion with no evidence for inconsistency



Key result: DES + geometry + CMB yields consistent, tightest constraints

- consistent constraints from geometric probes + DES

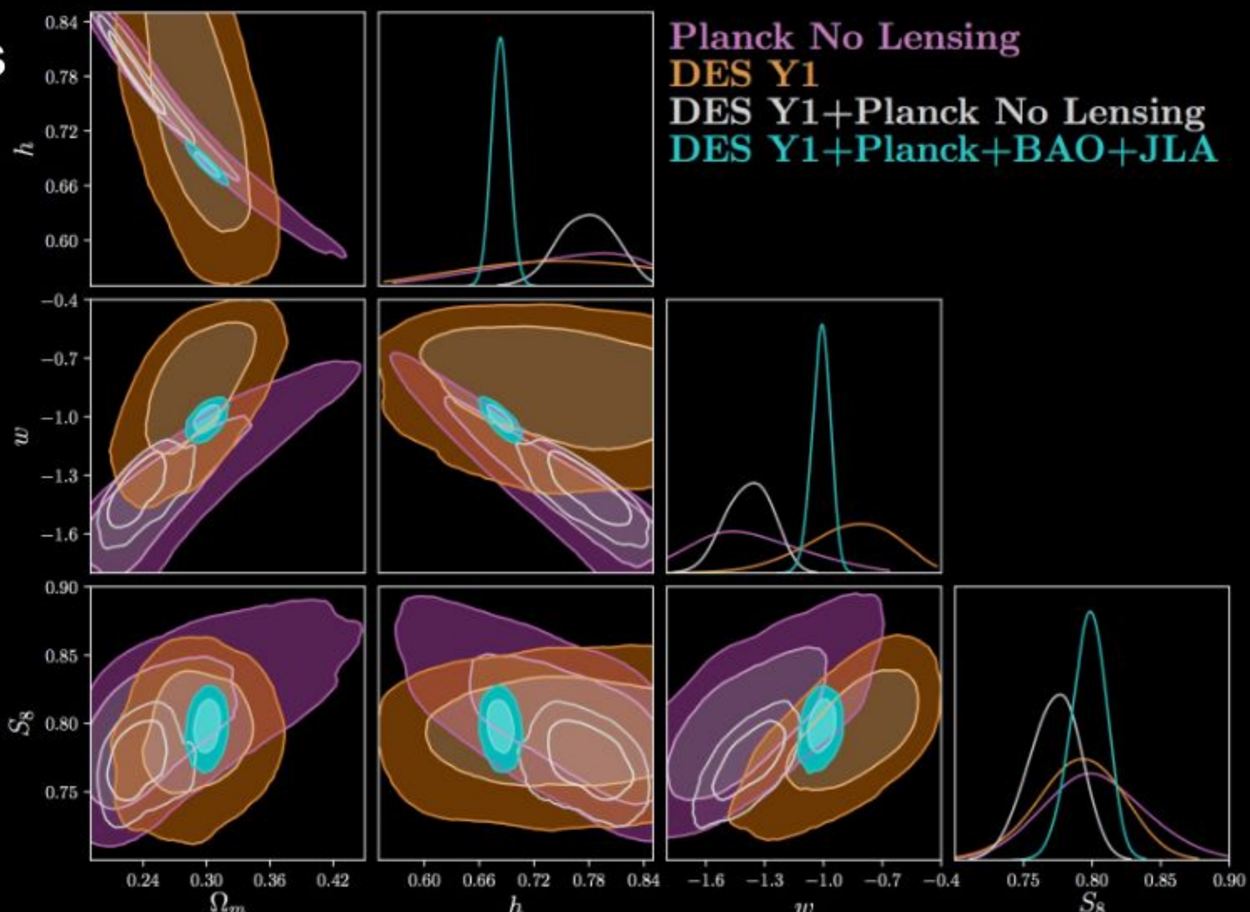
- most precise measurements in ΛCDM:

$$\Omega_m = 0.301^{+0.006}_{-0.008}$$

$$S_8 = 0.799^{+0.014}_{-0.009}$$

- no evidence for w≠-1 in any combination

$$w = -1.00^{+0.04}_{-0.05}$$



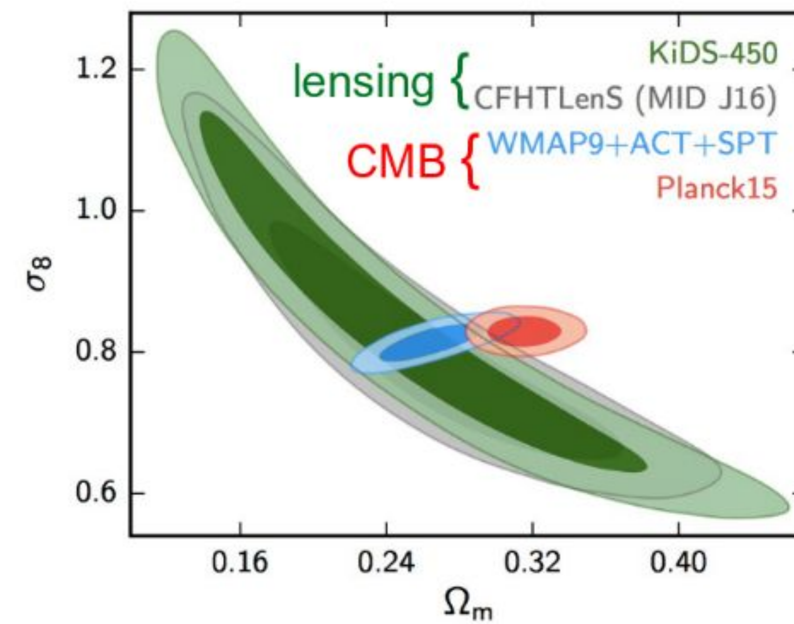
Recent tensions in data?

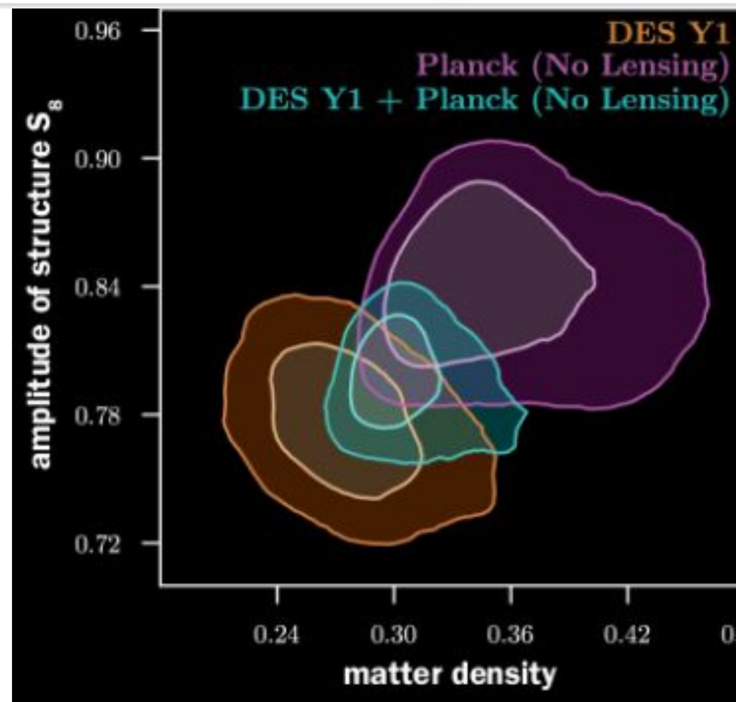
- cosmic shear: recent studies have claimed 2-3σ offset from Planck CMB in Ω_m-σ_8

  A non-issue?

  A crack in ΛCDM?

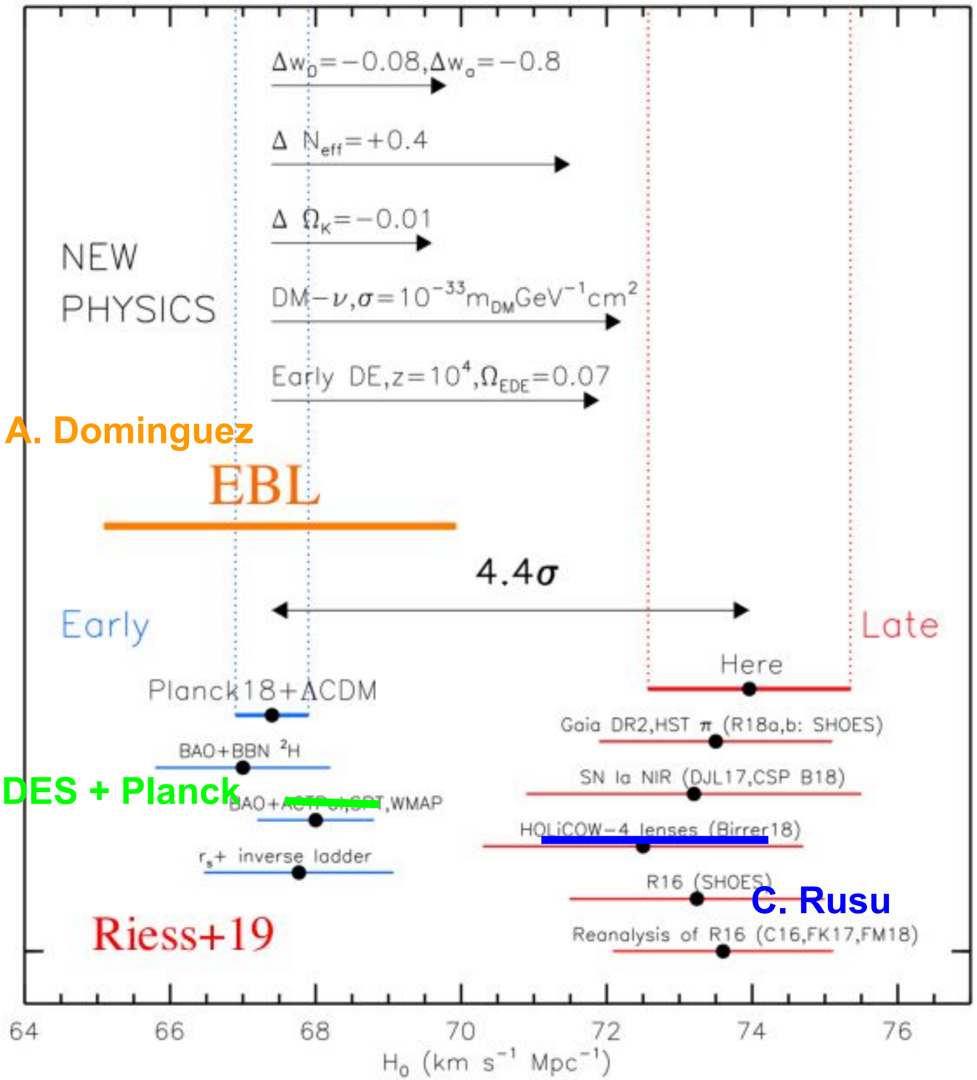
  A systematic error?

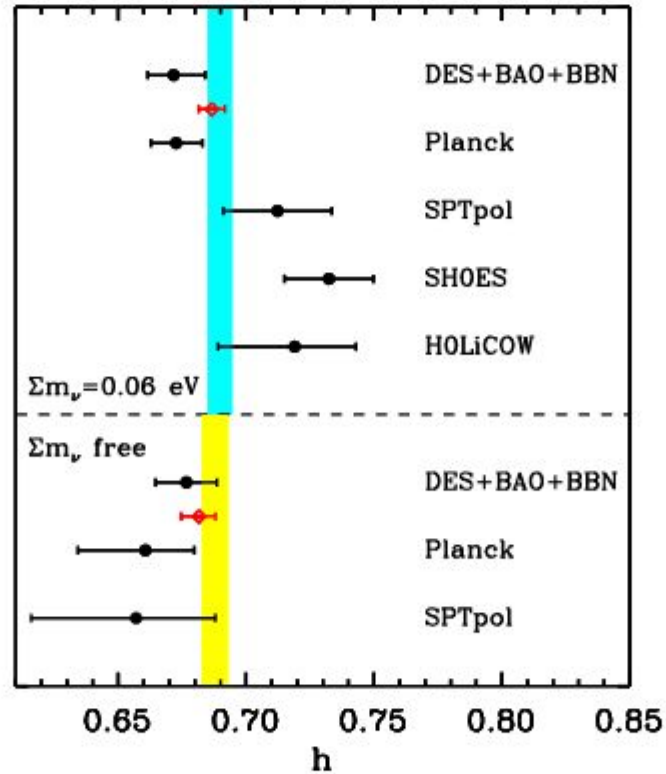




Recent tensions in data?

Local expansion rate measured differently at local Universe than at younger age

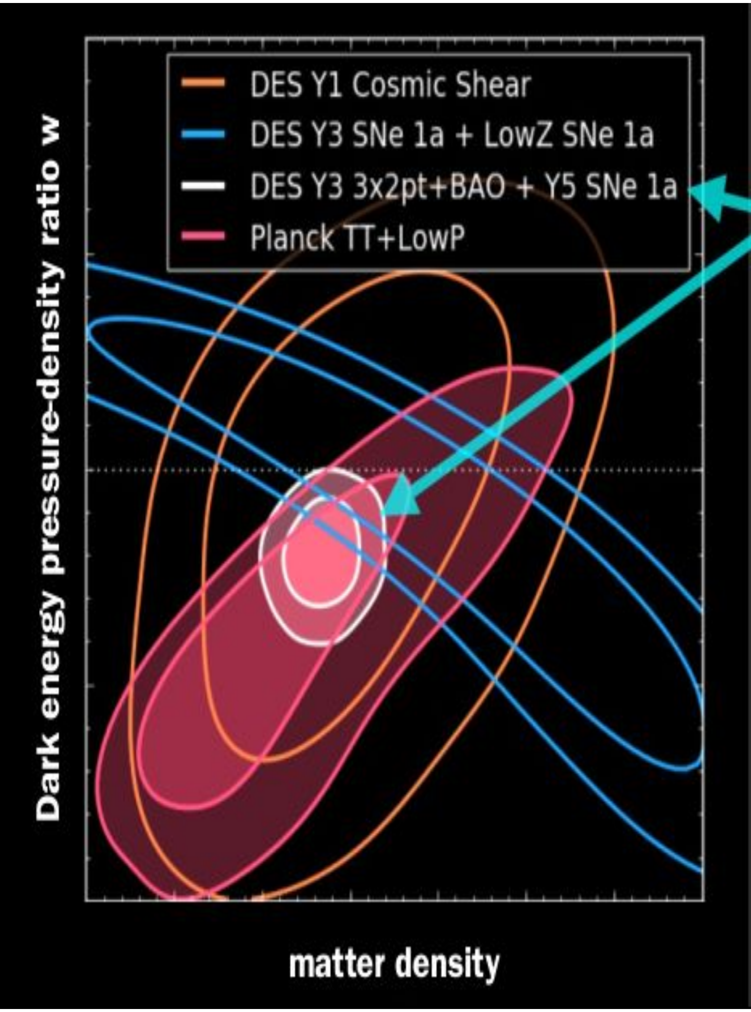




Possibilities

- Systematic effect
- Early dark energy
- Dark radiation
- Dark matter with stronger early interaction with matter or radiation than thought

Future perspectives



Projection based on expected statistical and analysis improvements - not data!

(contour position is artificial)

Figure: Michael Troxel

Release	Year	Statistical power
DES Y1	2017	35M galaxies, i~22.5 1,321 sq. deg, 6/sq. arcmin <z>~0.6
DES Y3	2019	93M galaxies, i~22.5 4,100 sq. deg, 6/sq. arcmin <z>~0.6
DES Y6	2021	200M galaxies, i~23.5 5,000 sq. deg, 11/sq. arcmin <z>~0.8
LSST Y1	~2023	1200M galaxies, i~24 18,000 sq. deg, 18/sq. arcmin <z>~1.0

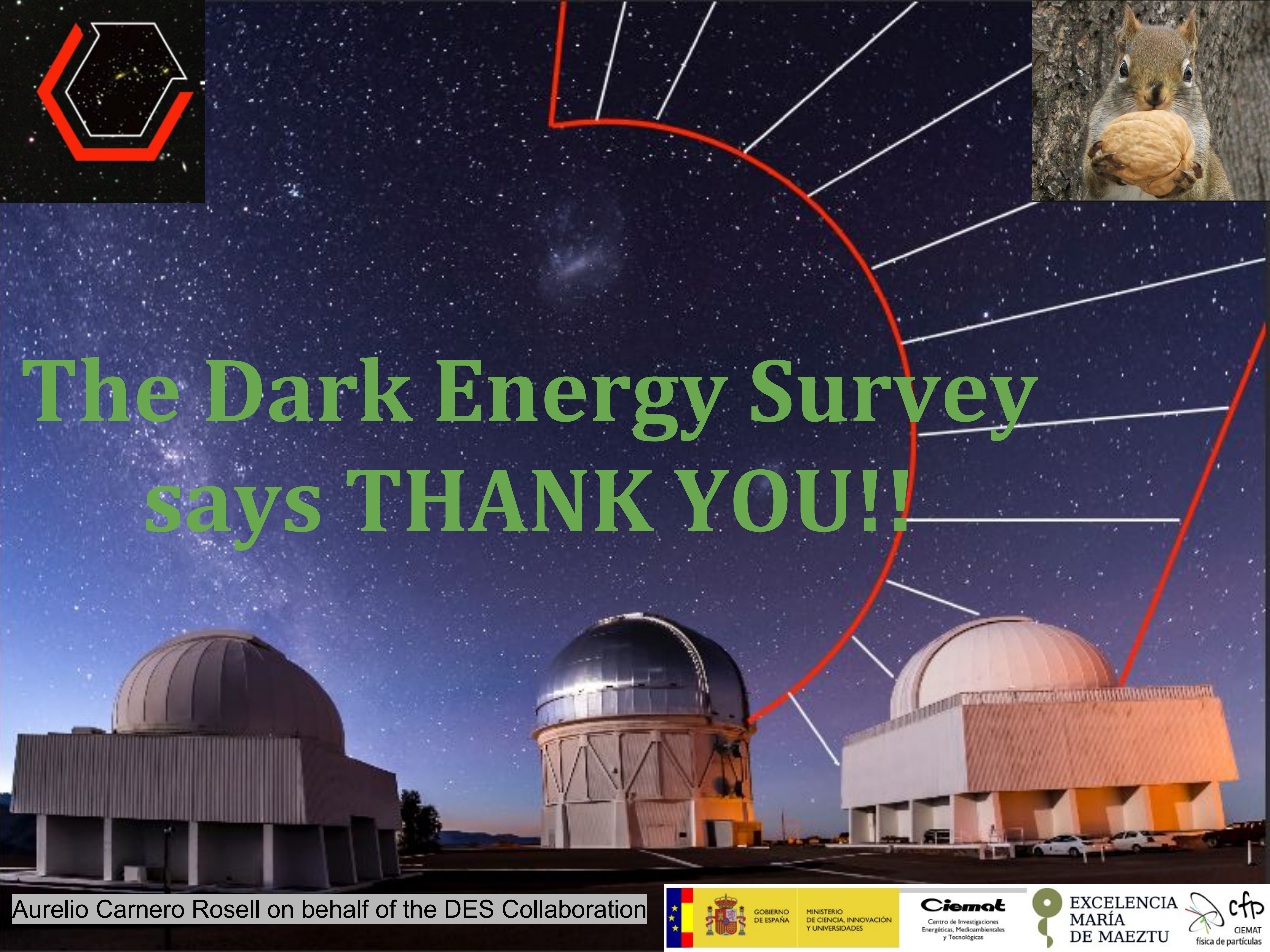
Wrapping up

DES have, for the first time, combine multiple probes coming from the same data, paving the methodology for the future. With 1 year data only:

- In combination with external probes, **reach a 4% uncertainty in DE**. At this level, we confirm the Lambda Cold Dark Matter model.
- **We demonstrate the multiprobe analysis**, reaching a precision similar to CMB.
- Plus other interesting science!

Are we close to a change of paradigm in cosmology? Are we ready for that? Are we seeing tensions in the data?

Cosmology is exciting!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says THANK YOU!!
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