Cosmology with the Dark Energy Survey

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Outline

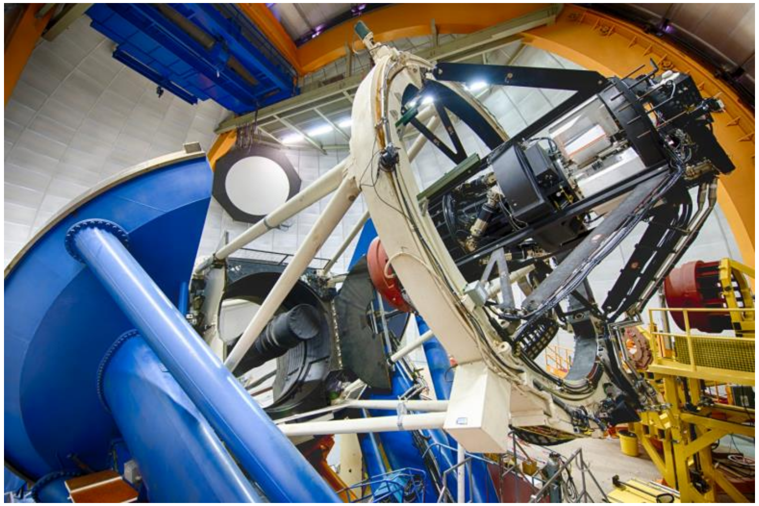
1. The Dark Energy Survey (DES) Project
2. Scientific Results
    1. *Supernovae*
    2. *Galaxy Clustering and Weak Gravitational Lensing*
    3. *Hubble Parameter*
3. Conclusions


The DES Project

The Dark Energy Survey

DARK ENERGY SURVEY

Optical/IR imaging survey with the Blanco 4m telescope at Cerro Tololo Inter-American Observatory(CTIO) in Chile with DECam (570 Mpx camera with 3 sq-deg FoV)



5000 sq-deg (1/8 of the sky) in grizY bands up to i_{AB} ~ 24th magnitude or z~1.5 (2500 sq-deg overlapping with SPT survey) +
30 sq-deg time-domain griz (SNe)

4 probes of dark energy: Supernovae Ia, Galaxy clustering and BAO, weak gravitational lensing, Galaxy clusters counts

NGC 1365

NGC 1365 (the Great Barred Spiral Galaxy) is a barred spiral galaxy about 56 million light-years away in the constellation Fornax. *(Credit: DECam, DES Collaboration)*

DARK ENERGY SURVEY

DES Collaboration

~500 scientists from
25 institutions in 7 countries
darkenergysurvey.org
Facebook.com/darkenergysurvey
Twitter: @theDESurvey

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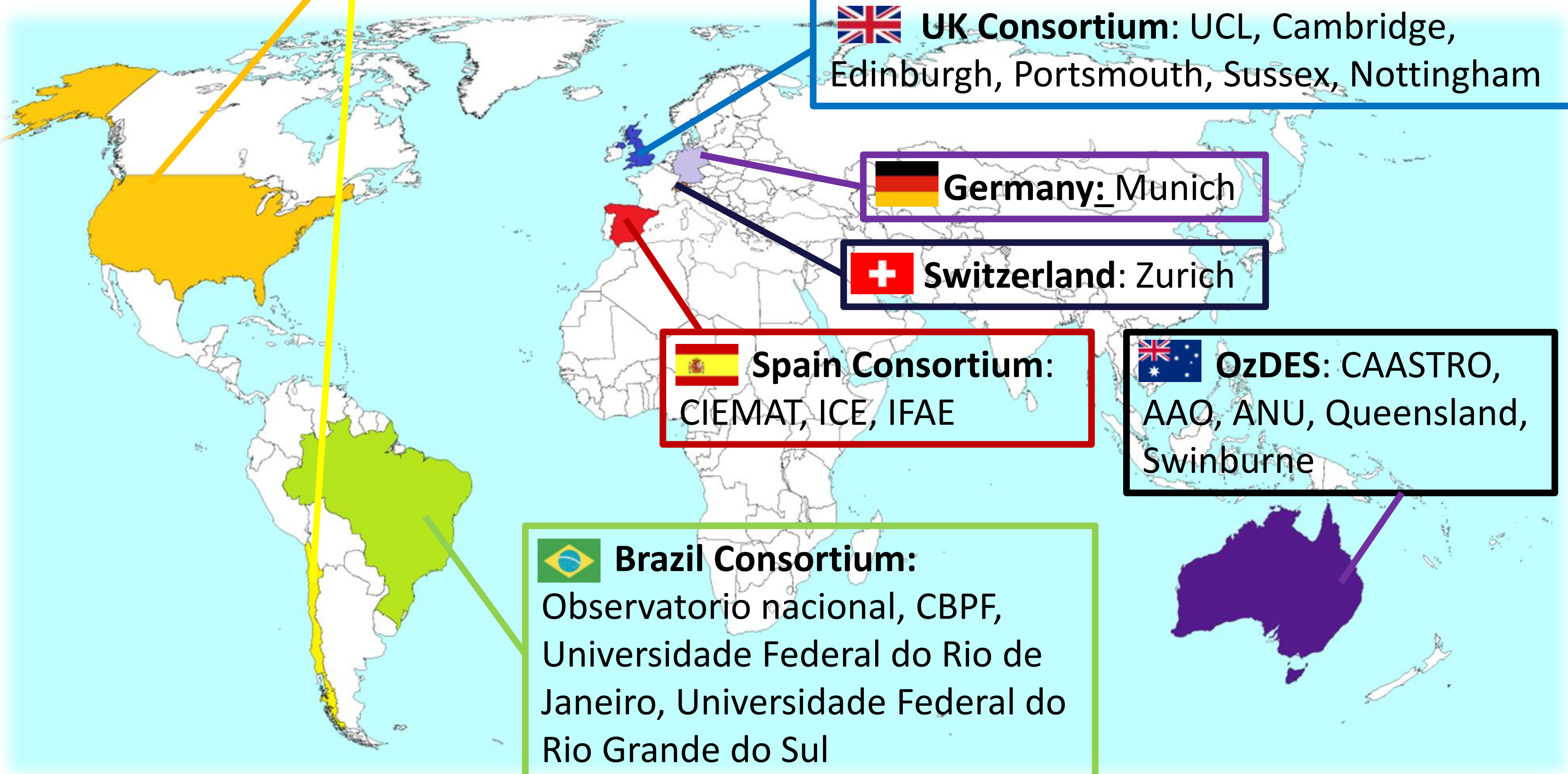
USA: Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of pennsylvania, Argonne National Laboratory, Ohio State University, Santa Cruz/SLAC Consortium, Texas A&M University , CTIO (in Chile)



UK Consortium: UCL, Cambridge, Edinburgh, Portsmouth, Sussex, Nottingham

Germany: Munich

Switzerland: Zurich

Spain Consortium: CIEMAT, ICE, IFAE

OzDES: CAASTRO, AAO, ANU, Queensland, Swinburne

Brazil Consortium: Observatorio nacional, CBPF, Universidade Federal do Rio de Janeiro, Universidade Federal do Rio Grande do Sul

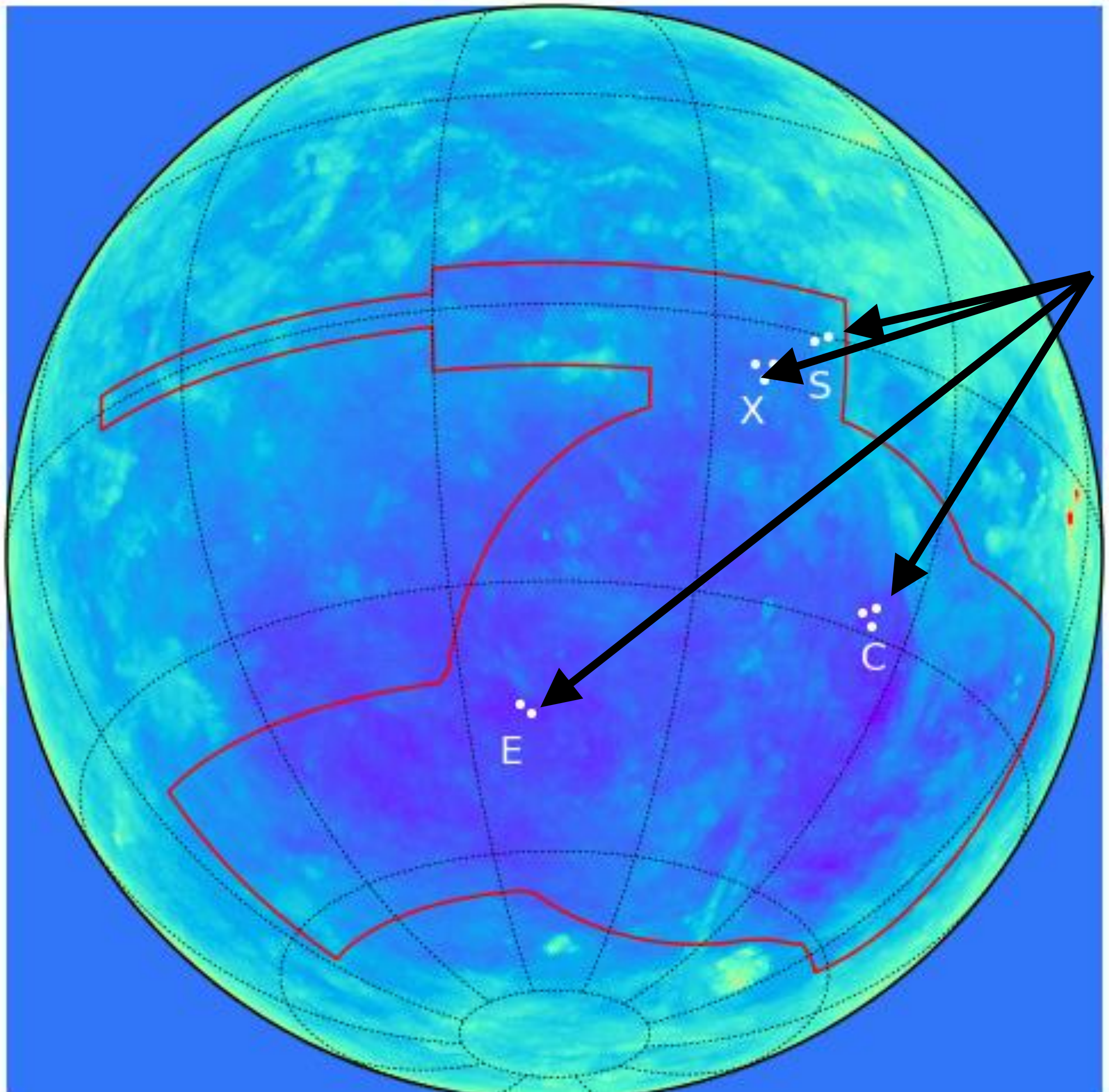
DES Survey Area

5000 square degrees, 1/8 of the sky

DARK ENERGY SURVEY

Footprint has been covered 900 seconds in each filter (g,r,i,z; 450 sec in Y) after 5.5 seasons.

Data taking is finished (09/01/2019)



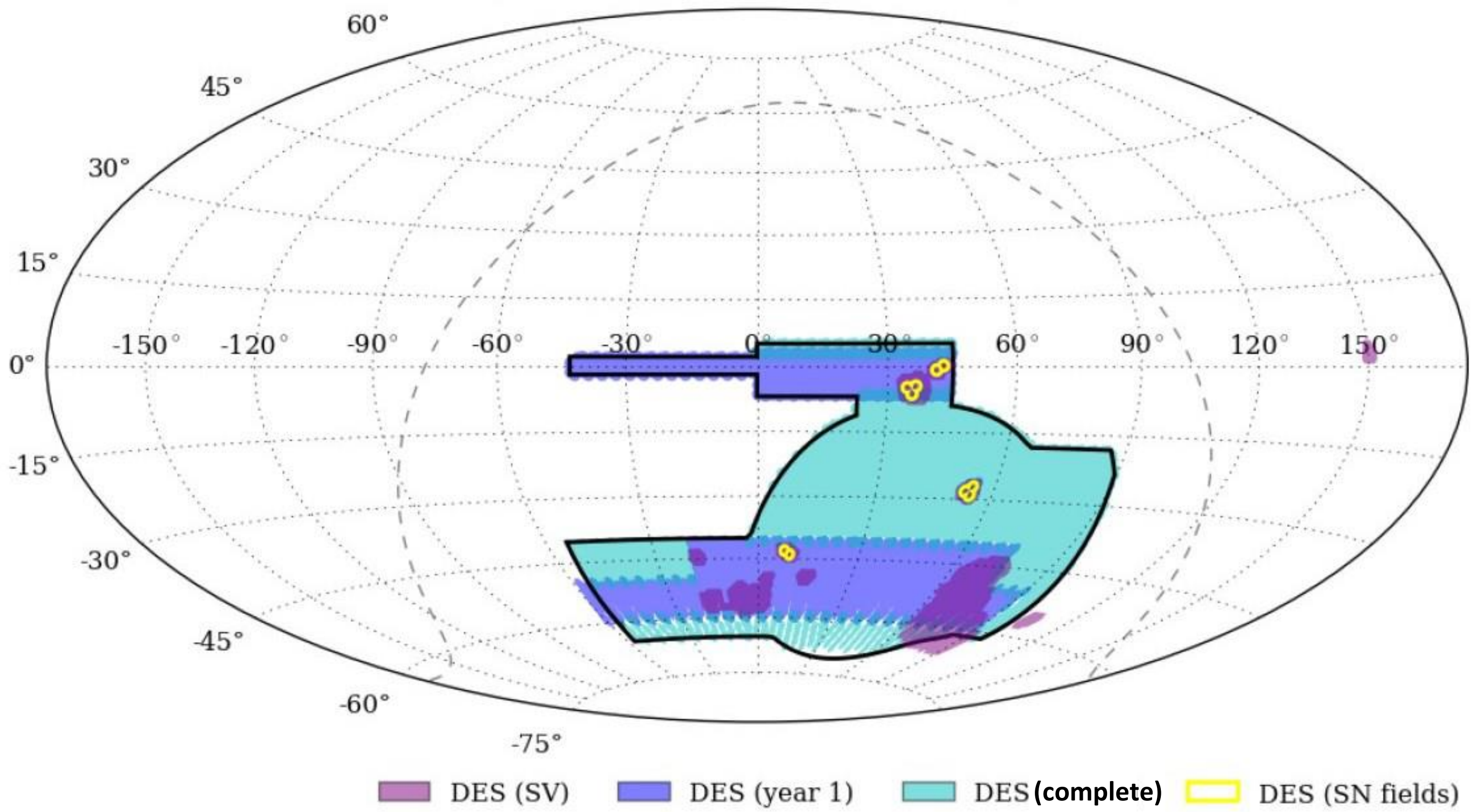
10 SN fields, each observed every ~6 nights: 2 Deep, 8 shallow

Data Sample

Year 1: half of the footprint, half of the depth → Current Results

Year 3: whole footprint, half of the Depth → In a few months

Year 5: whole footprint, full Depth → For 2021




Scientific Results

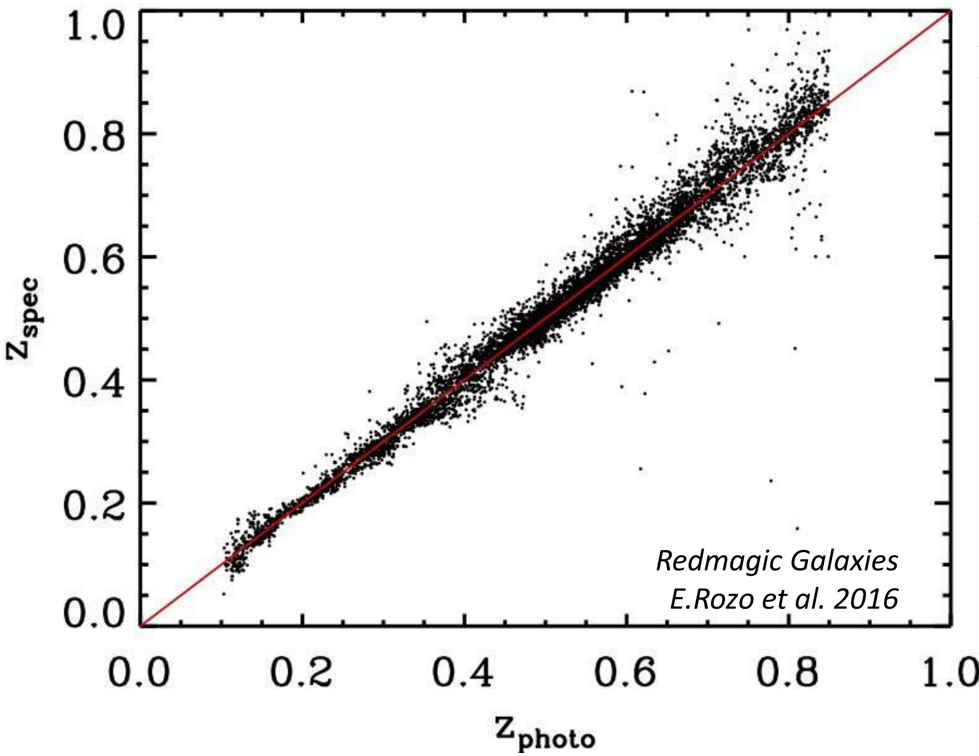
Photometric Redshift

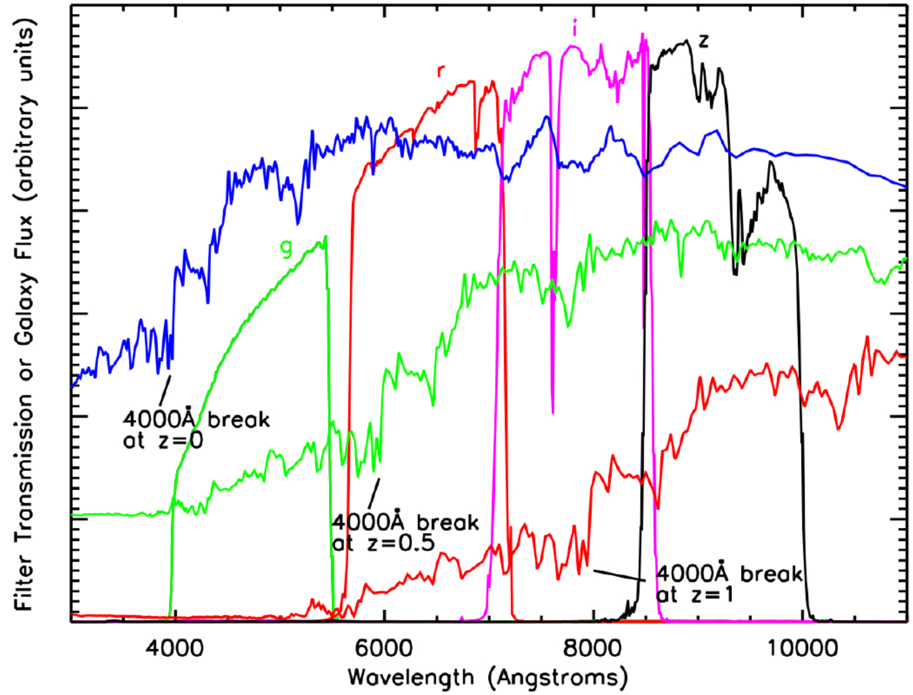
Measure the Galaxy redshift using images in different colors (g, r, i, z, Y filters).
Not very precise for each Galaxy, but millions of galaxies

DARK ENERGY SURVEY

Measure relative flux in each filter and combine them to obtain the redshift

Several methods: Fit to template spectra, use known spectra to train a P(z|g,r,I,z,Y) relation





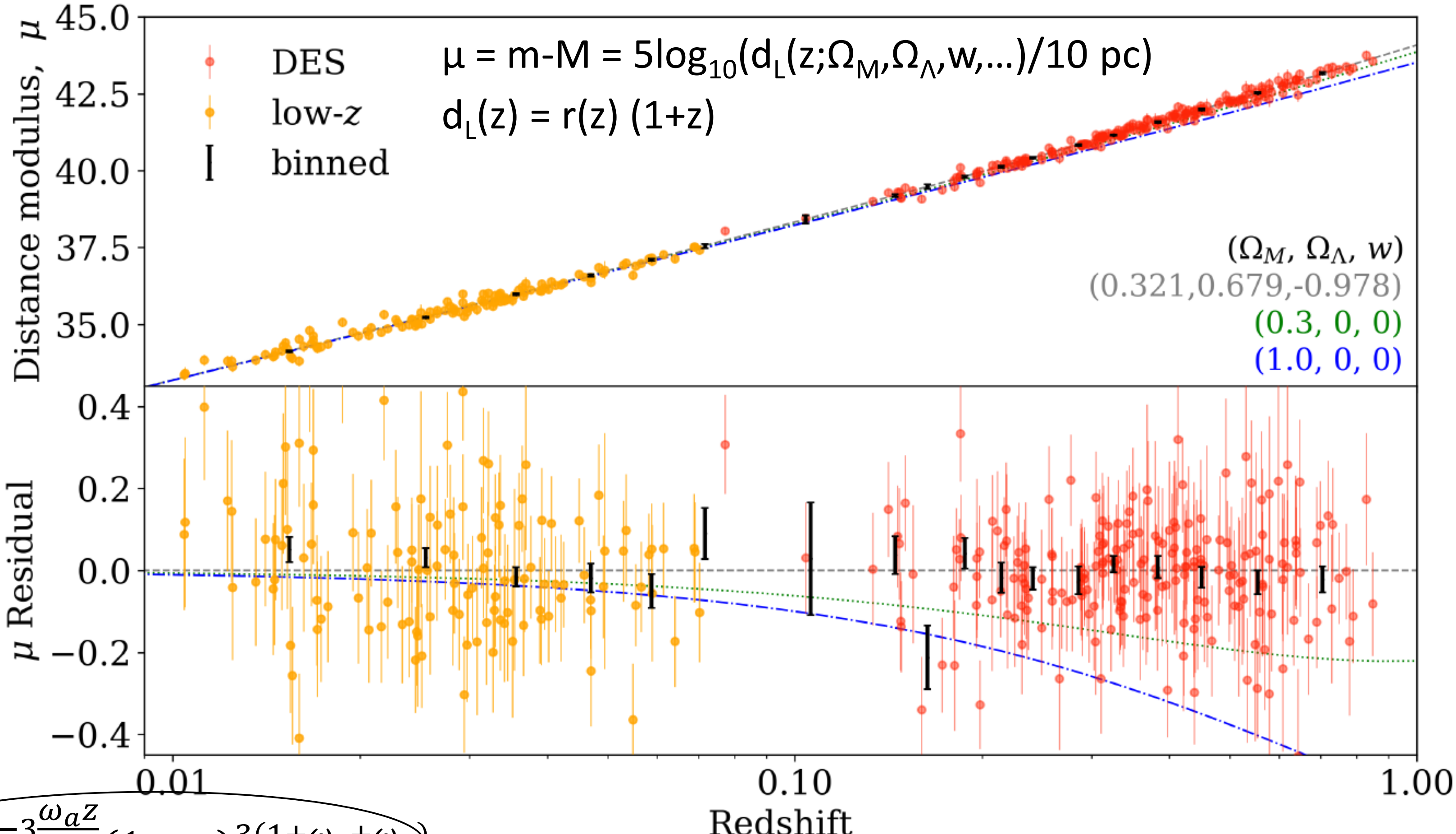
Redshift relative precision σ(z) < 0.1
Selected subsamples can have much better resolution

Challenge: spectroscopic training sets and calibration data not complete to the depth of DES

DARK ENERGY SURV

Supernovae Ia

Hubble diagram with supernovae from the Y3 sample, that have spectroscopic redshift and identification. Supernovae Ia are standarizable candles



$$\Omega_{DE} e^{-3\frac{\omega_a z}{1+z}}(1+z)^{3(1+\omega_0+\omega_a)}$$

$$r(z) = \frac{c}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_\Lambda + \Omega_k(1+z')^2 + \Omega_M(1+z')^3 + \Omega_r(1+z')^4}}$$

Supernovae Ia

Hubble diagram with supernovae from the Y3 sample, that have spectroscopic redshift and identification

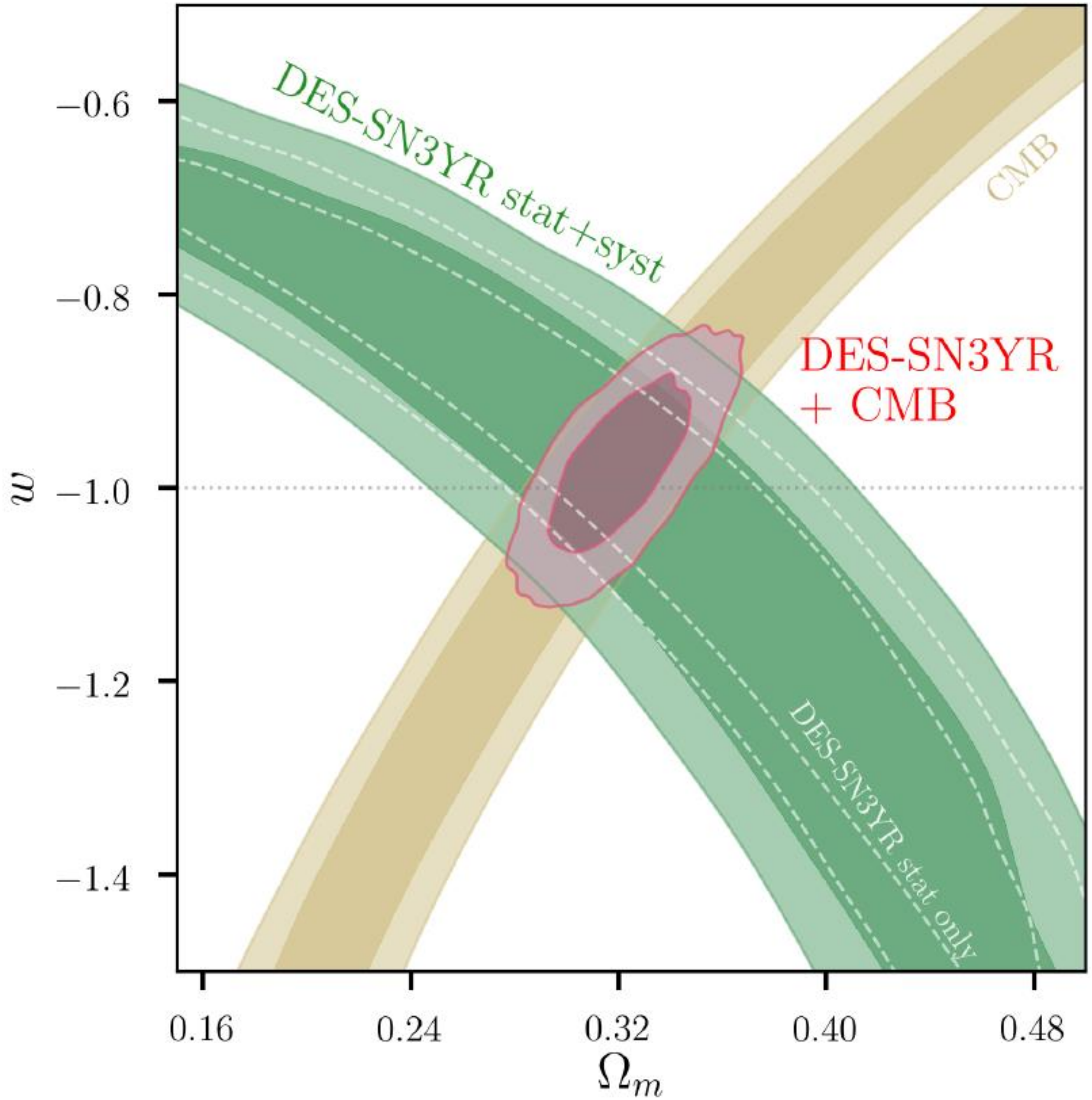
DARK ENERGY SURVEY

Results are compatible with the dark energy being the cosmological constant

For these results, a total of 207 spectroscopically confirmed SNe have been used, combined with 122 at low redshift from previous experiments

This is a 10% of the total number of supernovae that have been discovered in DES

Results will significantly improve in the near future with the full sample



Galaxy Clustering and Weak Lensing

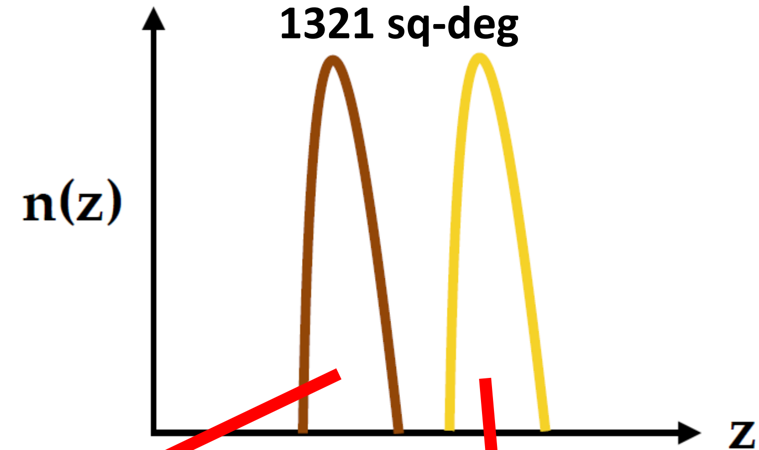
The measurements of positions and shapes of the galaxies can be combined to obtain the maximum information about cosmological parameters

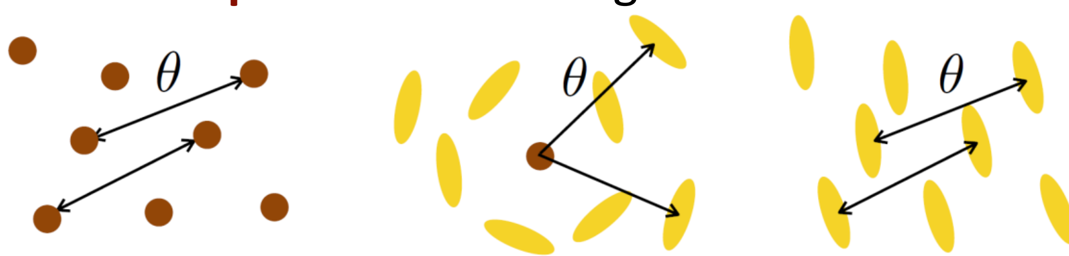
DARK ENERGY SURVEY

2 samples of galaxies: **"lenses"** and **"sources"**

Combine the auto and cross-correlation of

1. **positions** of the lens galaxies
2. **shapes** of the source galaxies





Galaxy clustering | Galaxy-galaxy lensing | Cosmic shear

LENSES:

redMaGiC galaxy selection: Large, red and bright galaxies.

Easily identifiable, strongly clustered, having small photometric-redshift errors and massive

6.6×10^5 galaxies with $\sigma_z/(1 + z) = 0.017$

SOURCES:

Remove stars and images within 30 pixels of the edge of a CCD. High quality: S/N > 10 all exposures and all bands

We need to measure the ***redshift and MAINLY, THE SHAPE*** of all these galaxies

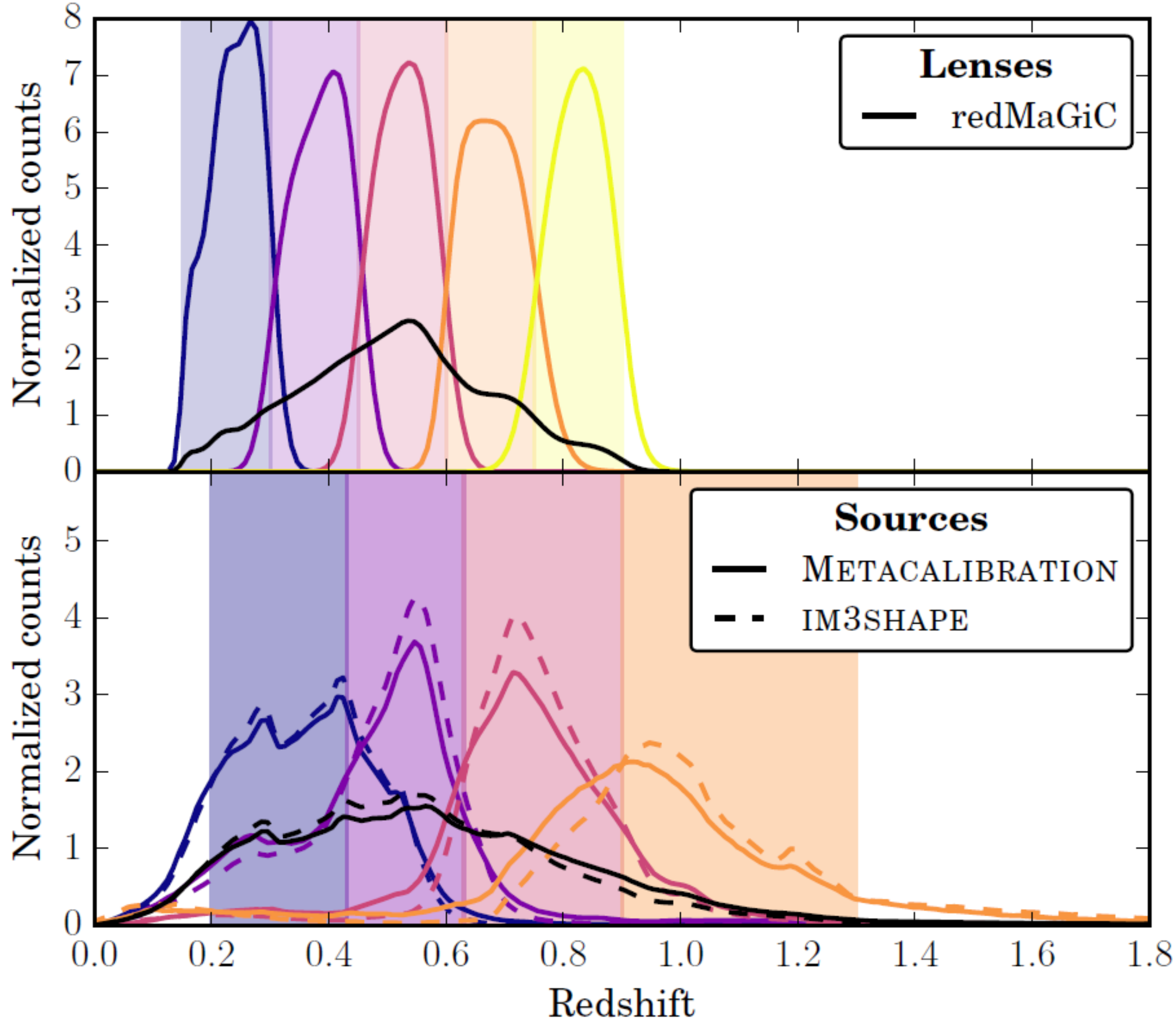
26 million galaxies

Galaxy Clustering and Weak Lensing

The disribution of galaxies in space contains a lot of information about cosmological parameters. Source sample.

Redshift distributions for lenses and sources in the cosmology análisis

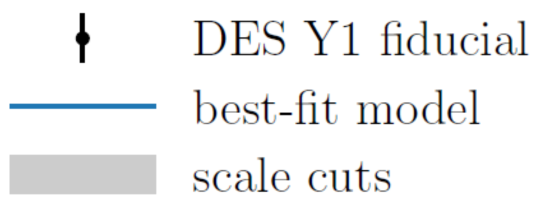
Validation of these distributions is done with spectroscopic Galaxy samples and galaxy cross-correlation functions between different redshihft bins



Galaxy Clustering and Weak Lensing

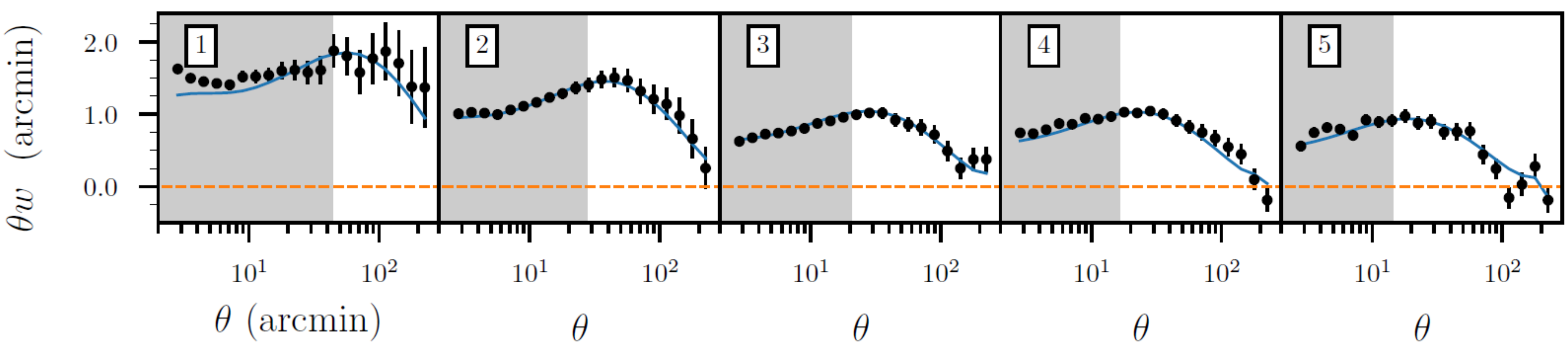
Galaxy Clustering data vectors

DARK ENERGY SURVEY



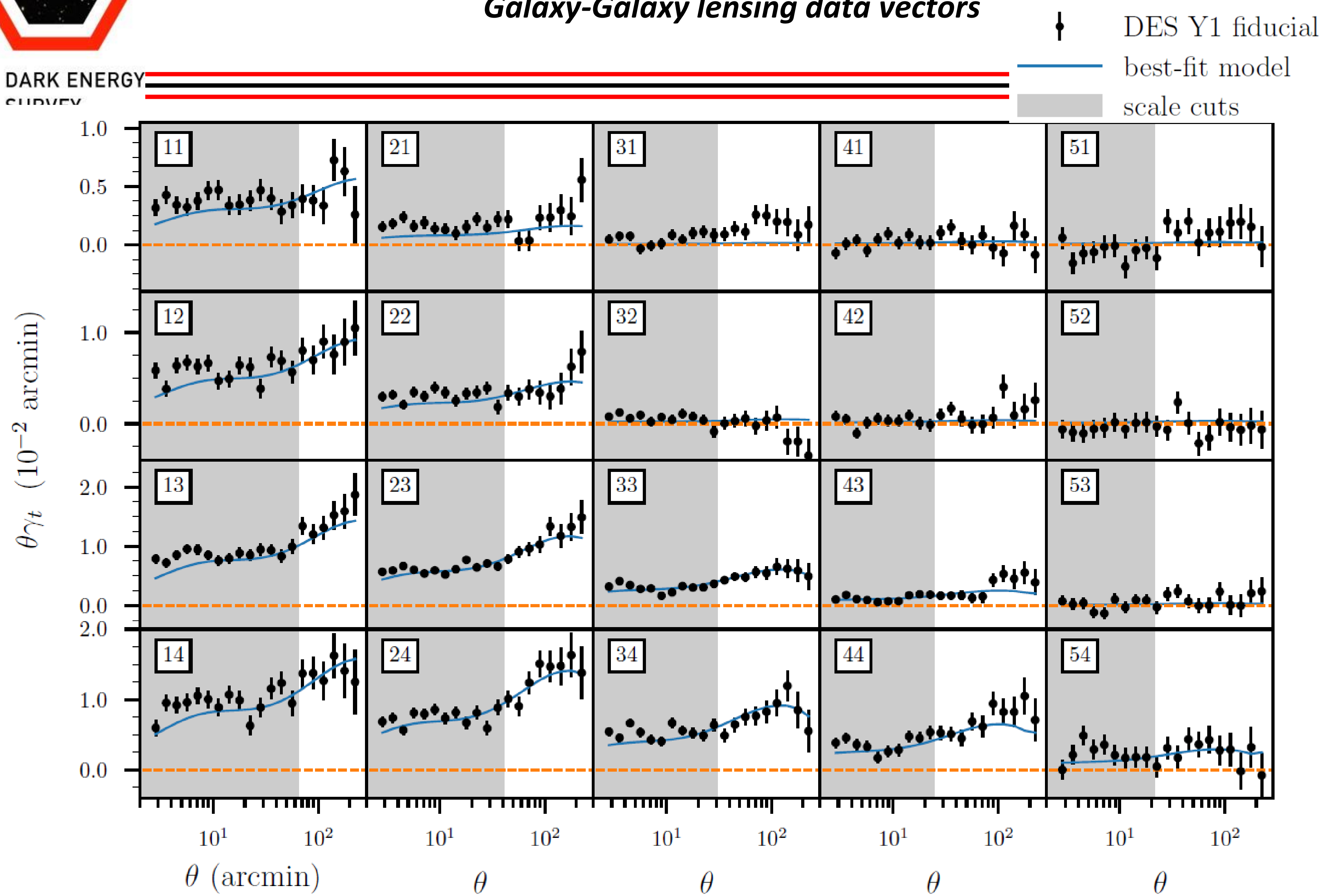
Angular correlation functions for 5 redshift bins

Scales in grey are not used for cosmology (non-linearities, scale dependent bias, baryonic effects...)



Galaxy Clustering and Weak Lensing

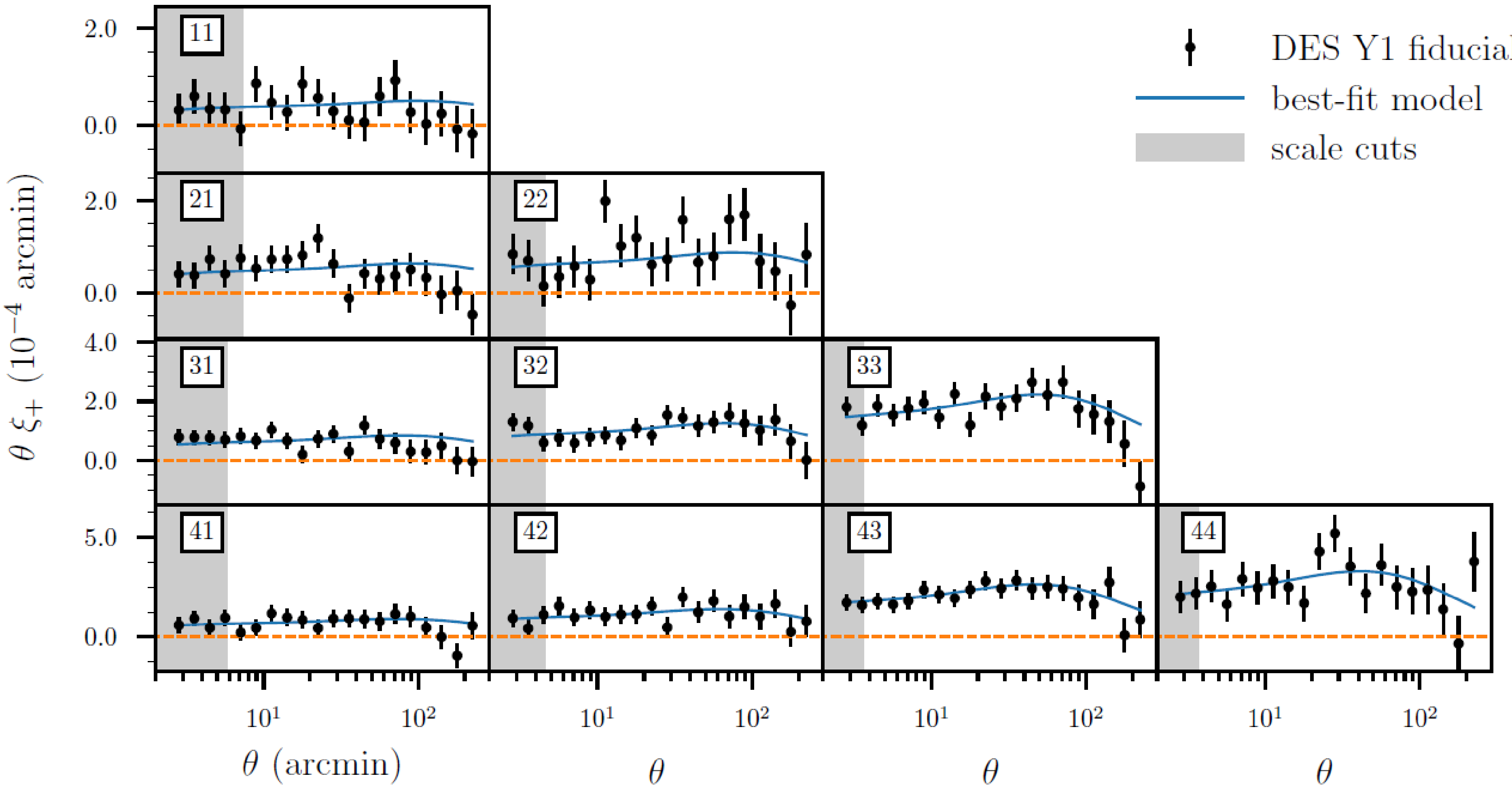
Galaxy-Galaxy lensing data vectors



Galaxy Clustering and Weak Lensing

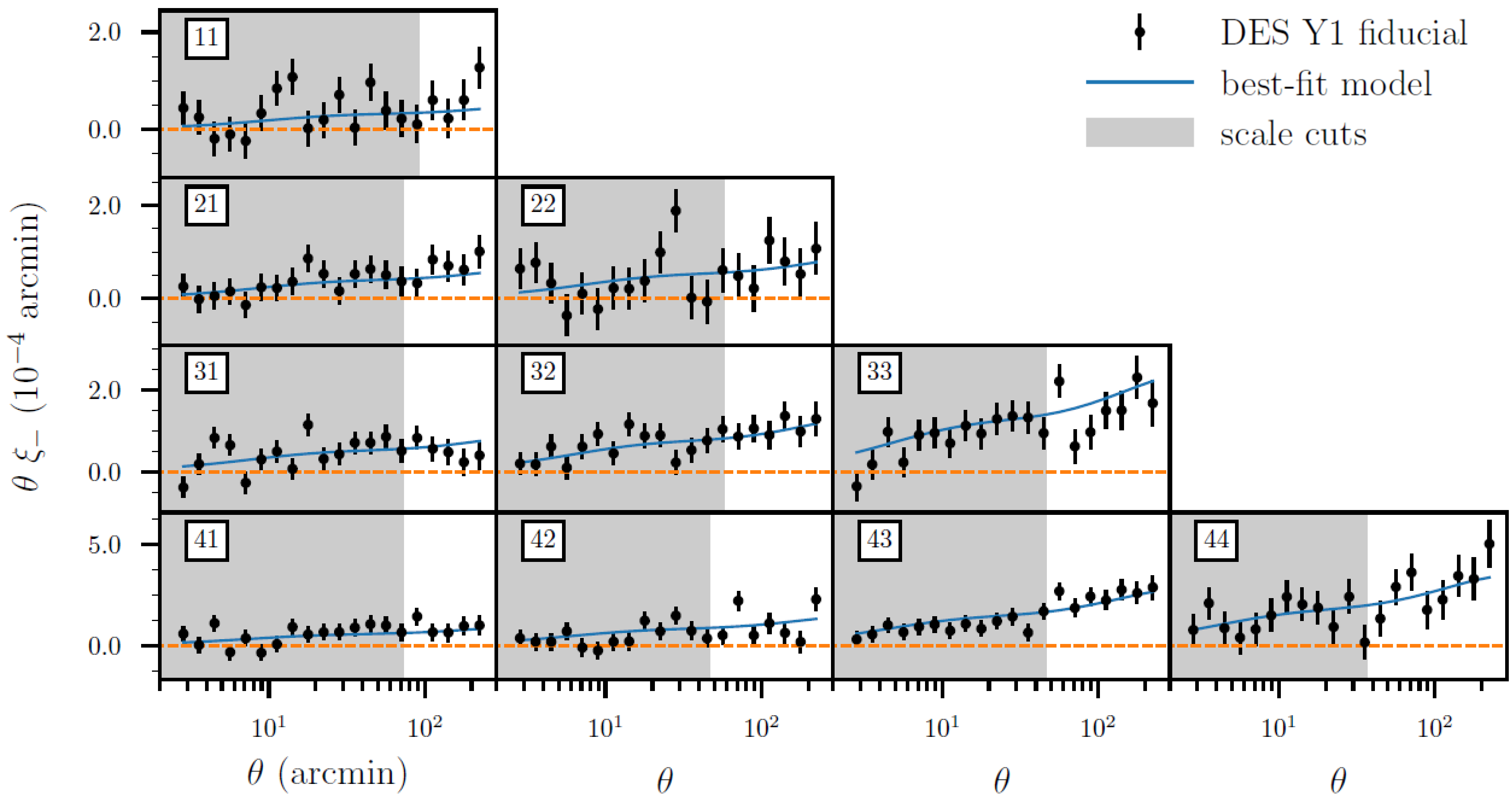
Cosmic shear data vectors

DARK ENERGY SURVEY



Galaxy Clustering and Weak Lensing

Cosmic shear data vectors



Galaxy Clustering and Weak Lensing

Huge effort to accurately determine the covariance matrix among different cosmological probes. Use theory, simulations and data

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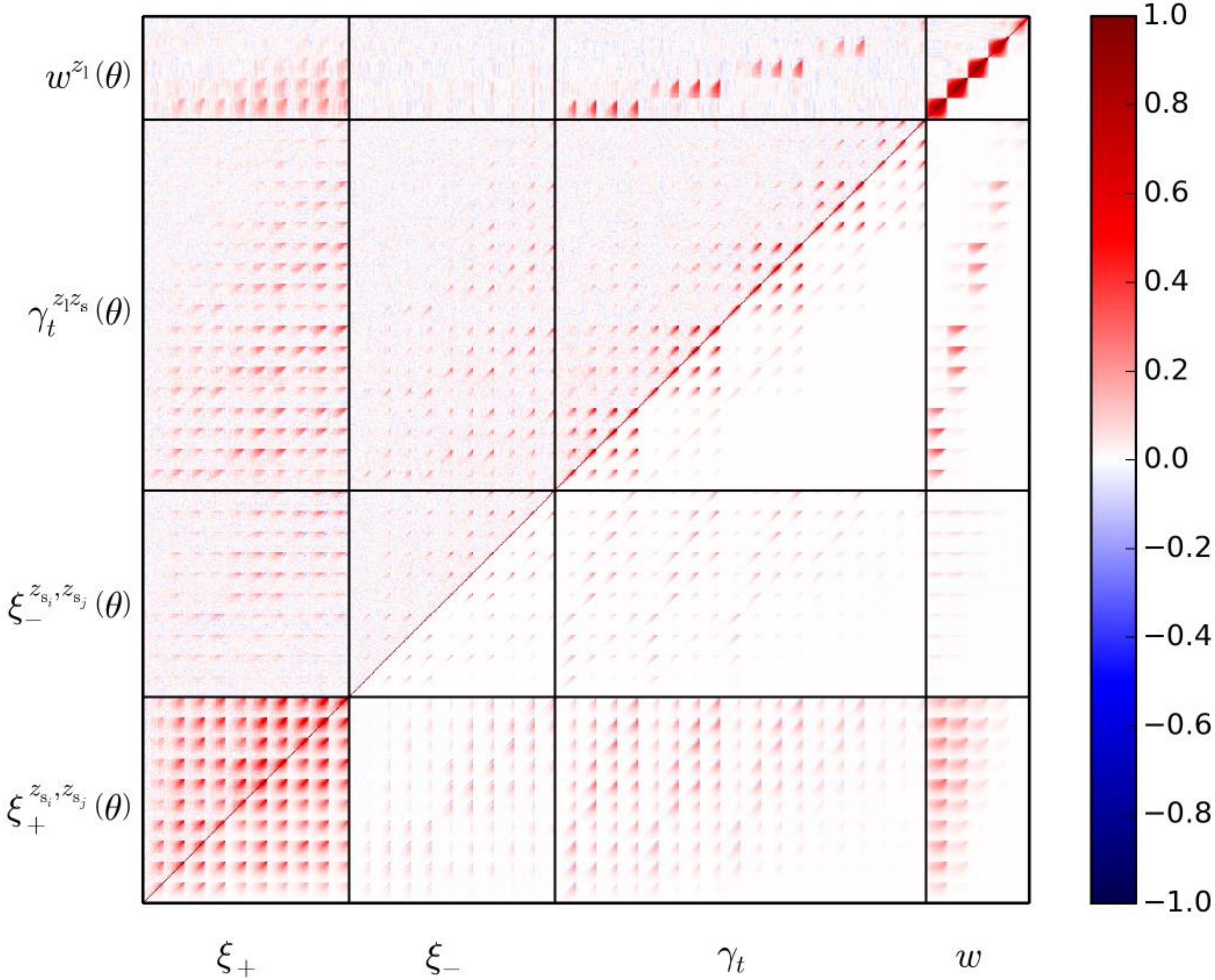


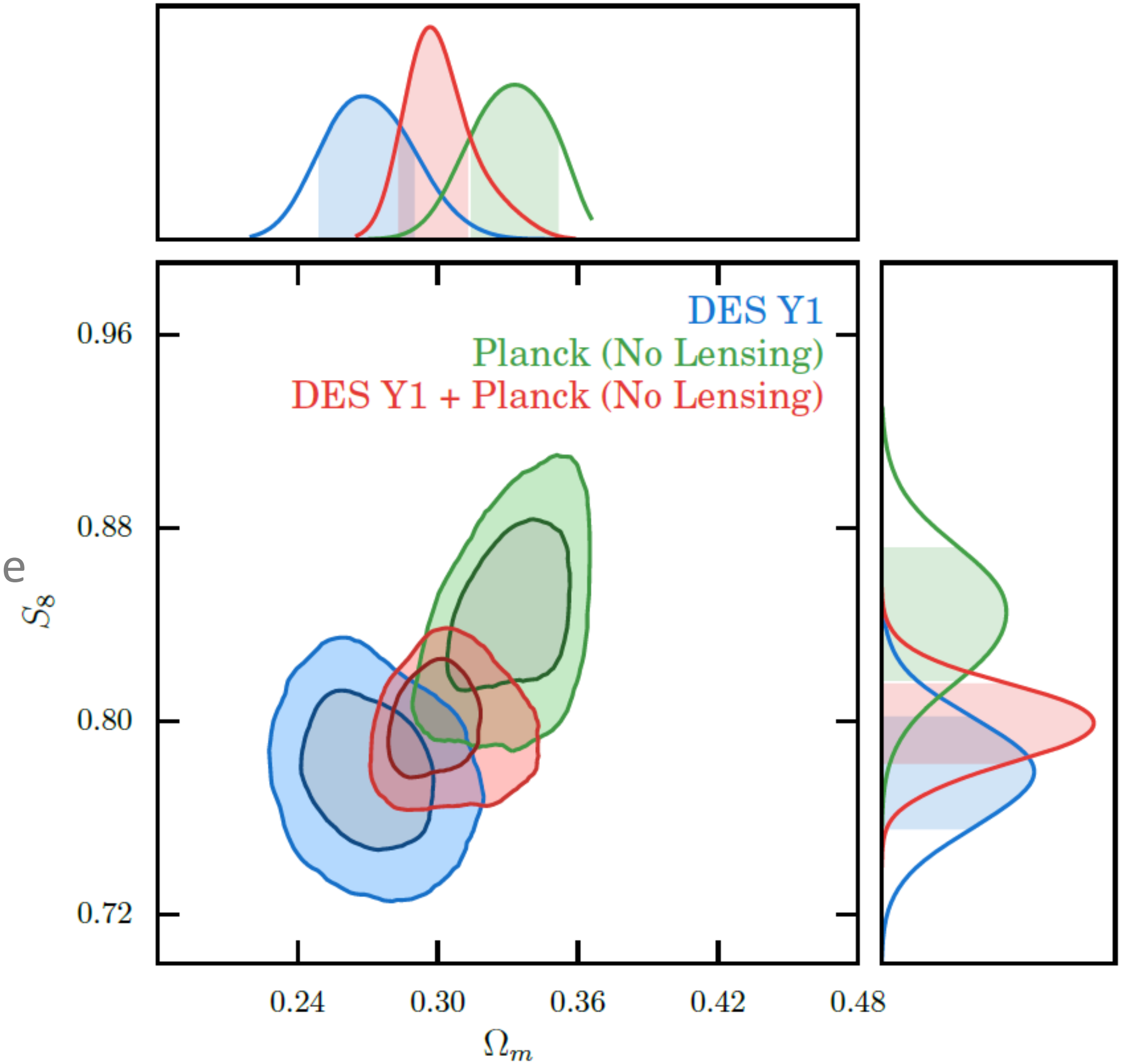
Galaxy Clustering and Weak Lensing

Results of the combined análisis. First time ever that these combination is done in a single galaxy survey

$S_8 = \sigma_8 (\Omega_m / 0.3)^{½}$ 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.

- **Ω_m** : fraction of matter in the total matter-energy of the universe now.

- First measurement in late universe with **precisión comparable to CMB**.



Galaxy Clustering and Weak Lensing

Late universe and early universe cosmological parameters are statistically compatible. ΛCDM is a good description of the Universe

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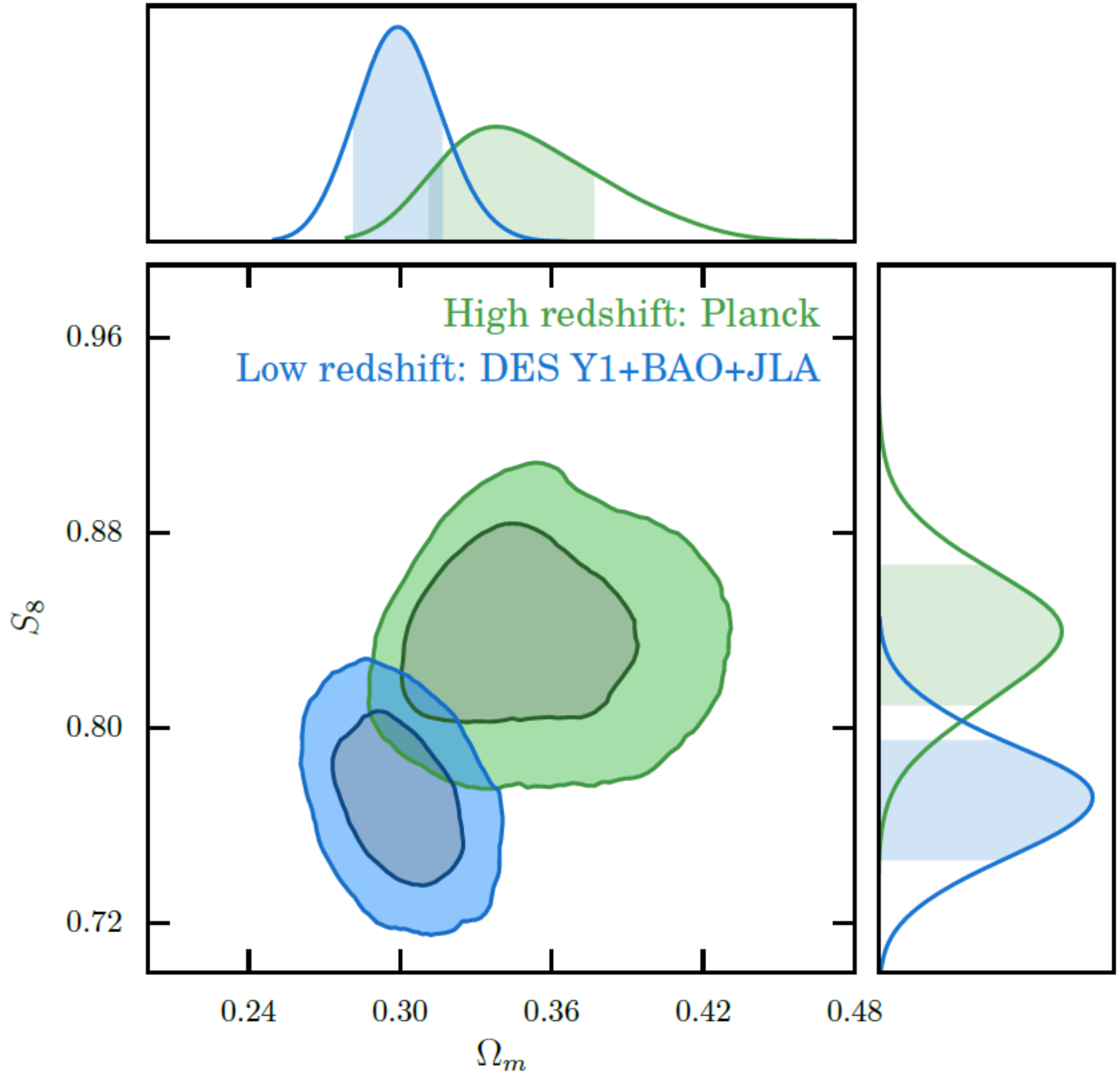
Combination of all the late universe experiments compared to CMB results from Planck sattellite

Results are statistically compatible

DES contours will shrink by a factor of at least 2 in a few months, when the análisis of the Y3 sample is finished



Combining all results:

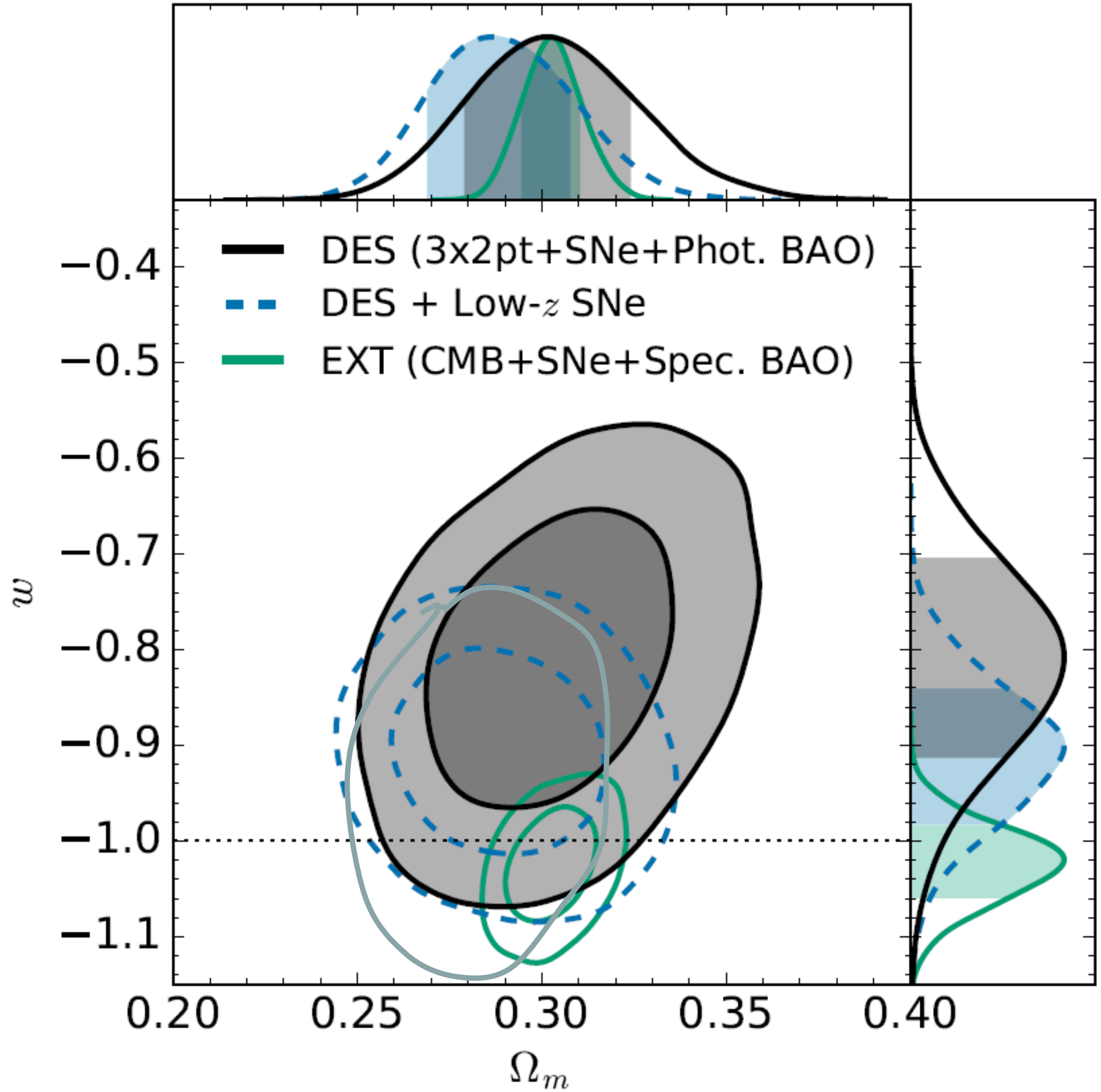
clustering + weak lensing + supernovae

DARK ENERGY SURVEY

DES only results are of a precisión comparable to the combination of all the previous cosmology projects combined

And are still going to improve by a large factor

[Results are compatible with the dark energy being the cosmological constant]



Extended models: beyond ΛCDM

We have also explored some extensions of ΛCDM.

Time varying EoS for the dark energy

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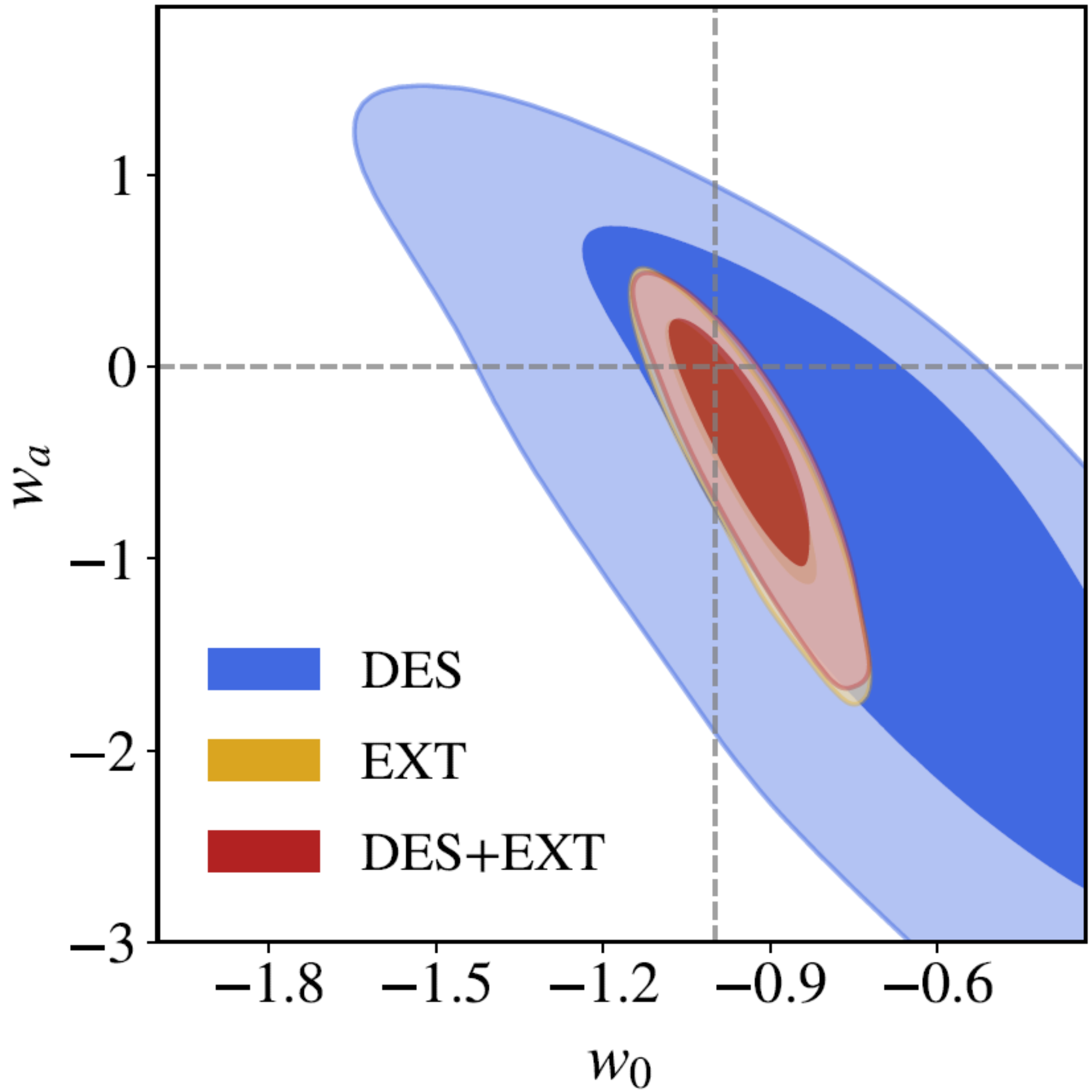
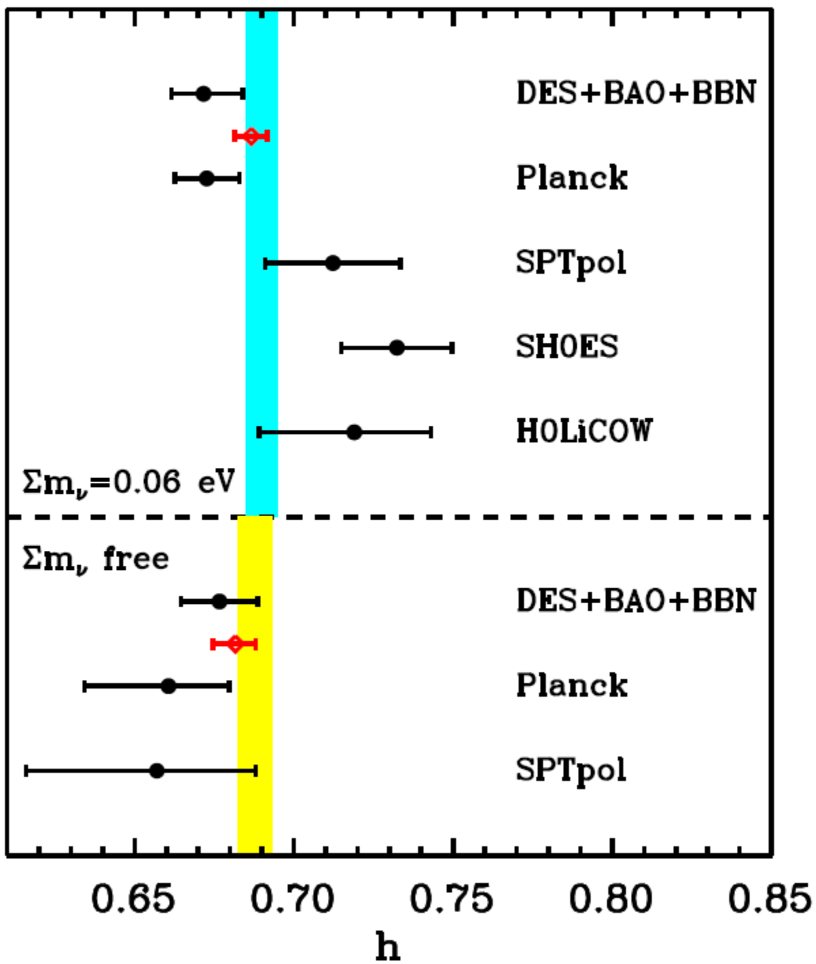
No evolution of the EoS parameters for the dark energy is observed with the 3x2pt analysis

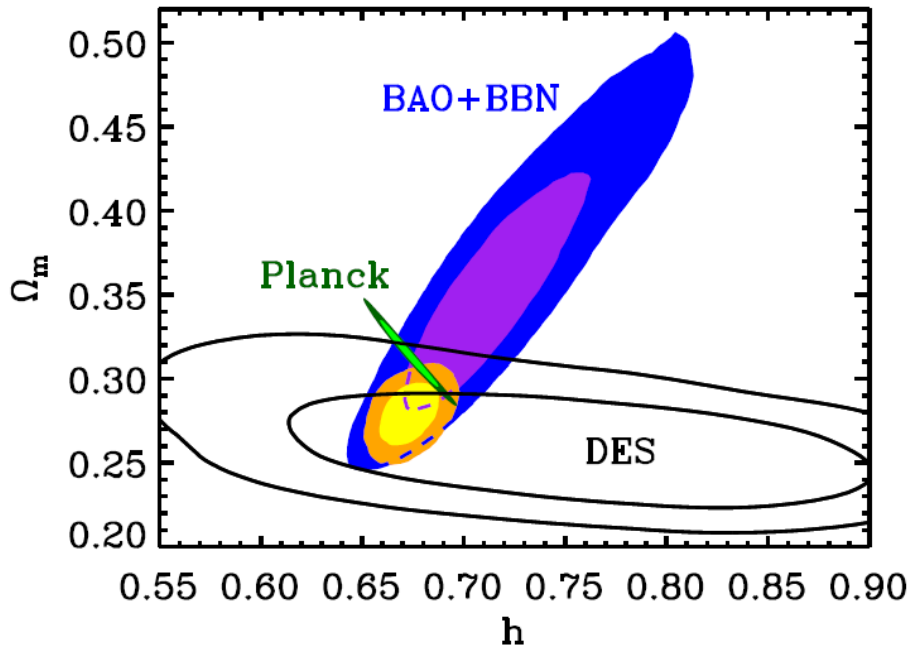
These measurements are completely independent of the supernovae results



Other results:

H_0 with clustering, BAO and D/H





Determination of the Hubble parameter from DES-3x2pt+BAO (no DES) + BBN (no DES)

Independent of all the previous measurements

Result compatible with Planck measurement

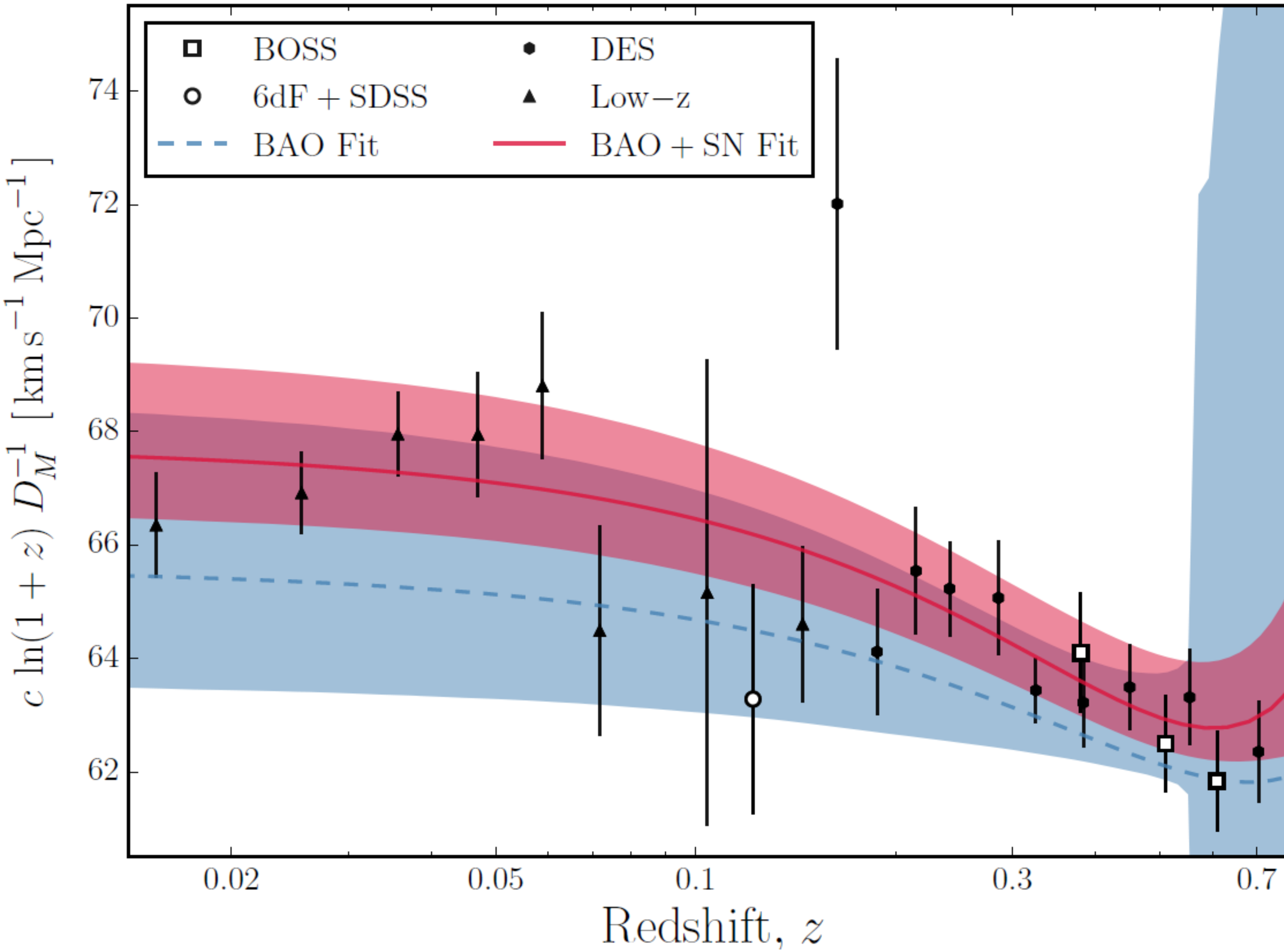
Other results:

H_0 with inverse distance ladder

Extrapolate backwards the distances measurements from supernovae

Including BAO measurements from other experiments

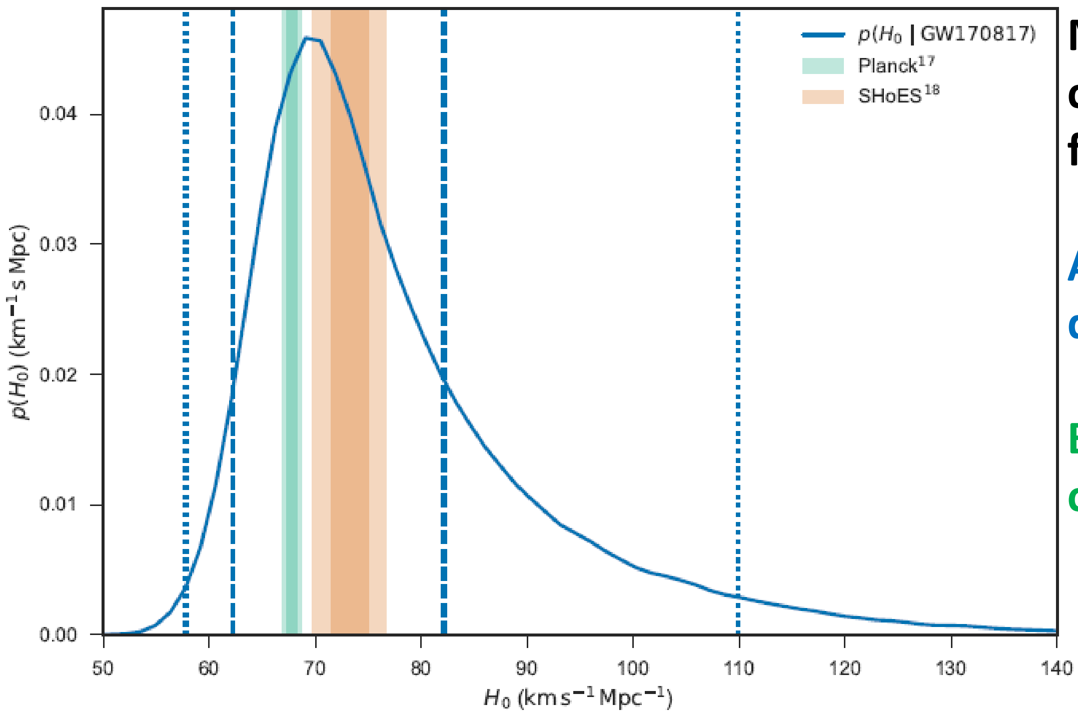
Results compatible with Planck measurement



DARK ENERGY SURVEY

Other results:

H_0 with gravitational waves



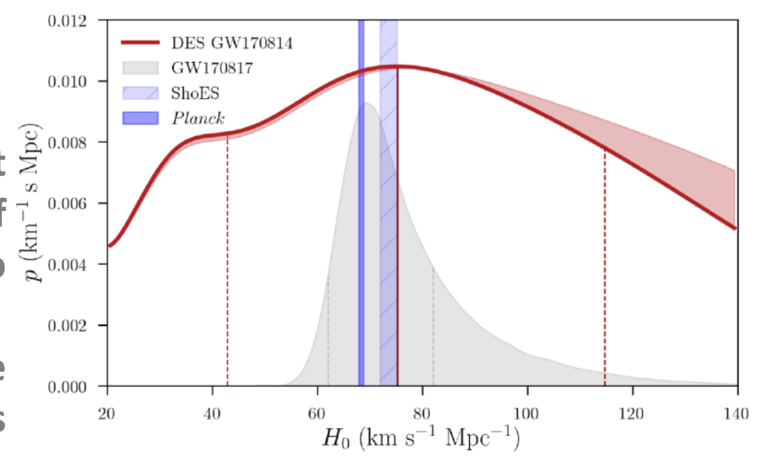
Measure redshift for Neutron star collisions from DES and distance from LIGO-VIRGO

Accurate and independent determination of H_0

Best measurement with ~50 NS-NS collisions

Measure redshifts for every galaxy that is candidate to host black hole collision and determine the statistical distribution of redshift for the distance determined with LIGO-Virgo

Can be a competitive measurement of H0 with black hole collisions



Conclusions

DES has provided a wide set of results from its Y1 data set:

- Measurement of the anisotropies in the matter distribution now using WL and LSS, **compatible with ΛCDM**.
- Several measurements of the Hubble parameter that are independent of other probes
- Y3 spectroscopic SNe results are competitive with previous surveys and **in agreement with ΛCDM**.
- DES Data Release 1, including Y1-Y3 catalogs, is publicly available at: *https://des.ncsa.illinois.edu/releases/dr1*

Much improved results to come in a few months for the Y3 data sample. Stay tuned!