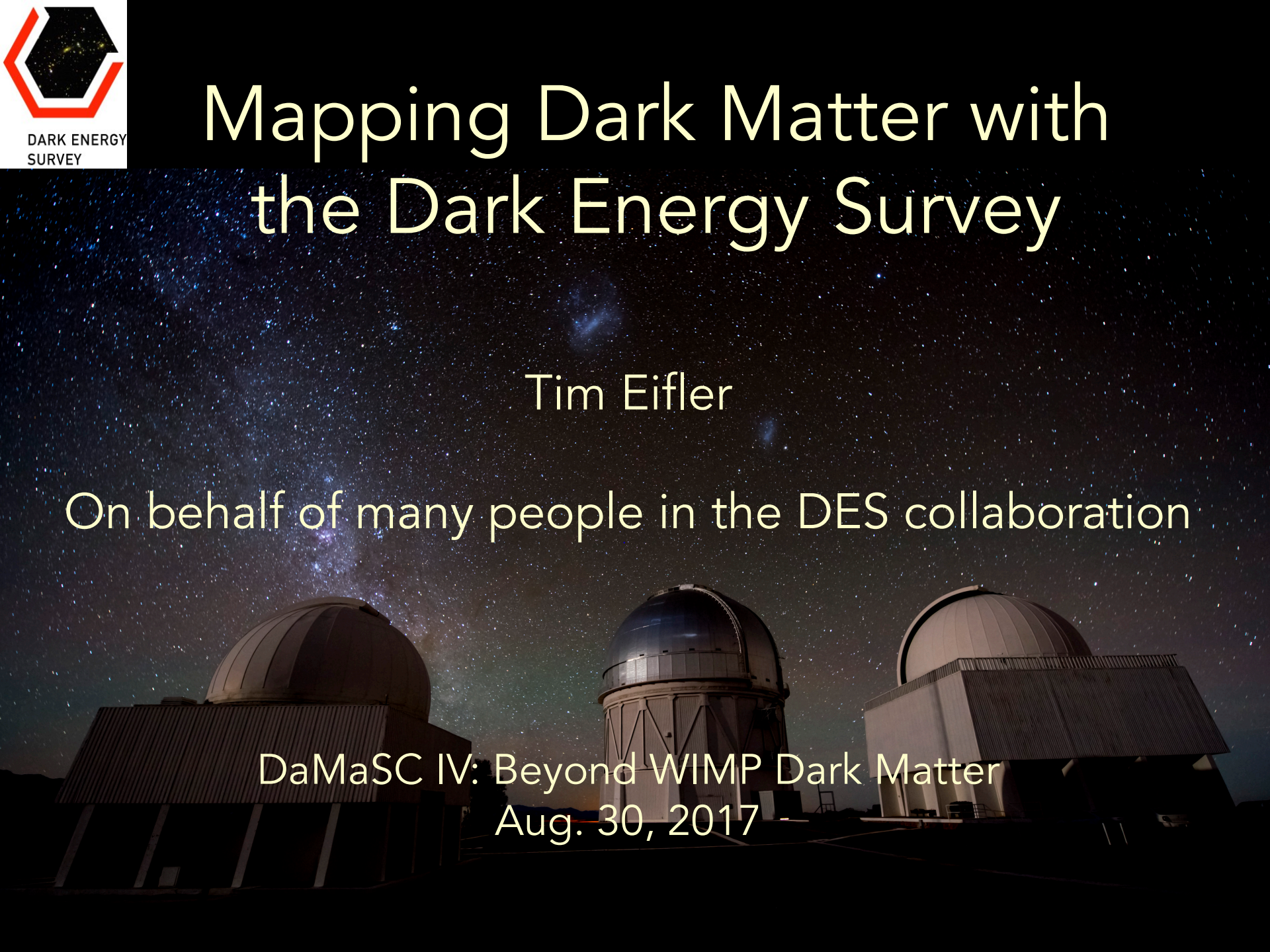


Mapping Dark Matter with the Dark Energy Survey

Tim Eifler

On behalf of many people in the DES collaboration

DaMaSC IV: Beyond WIMP Dark Matter
Aug. 30, 2017

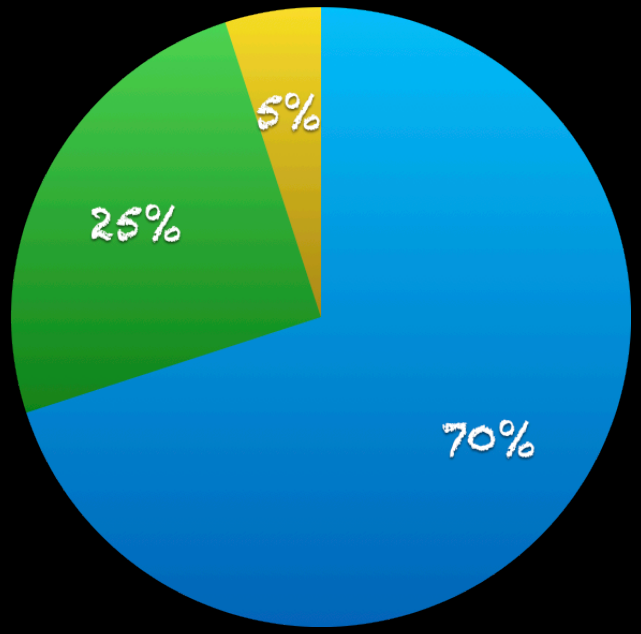
Disclaimer

DES has recently published Year 1 cosmology results

- DES collaboration 2017 (Multi-probe Cosmology Constraints)
- Krause, Eifler et al 2017 (Multi-probe Methodology)
- Zuntz, Sheldon et al 2017 (Shear Catalogs)
- Elvin-Poole, Crocce et al 2017 (Clustering Sample)
- Prat, Sanchez et al 2017 (Galaxy-Galaxy Lensing)
- more online, more to come

www.darkenergysurvey.org

The focus of these results is on cosmology and dark energy properties, but obviously one can't ignore dark matter



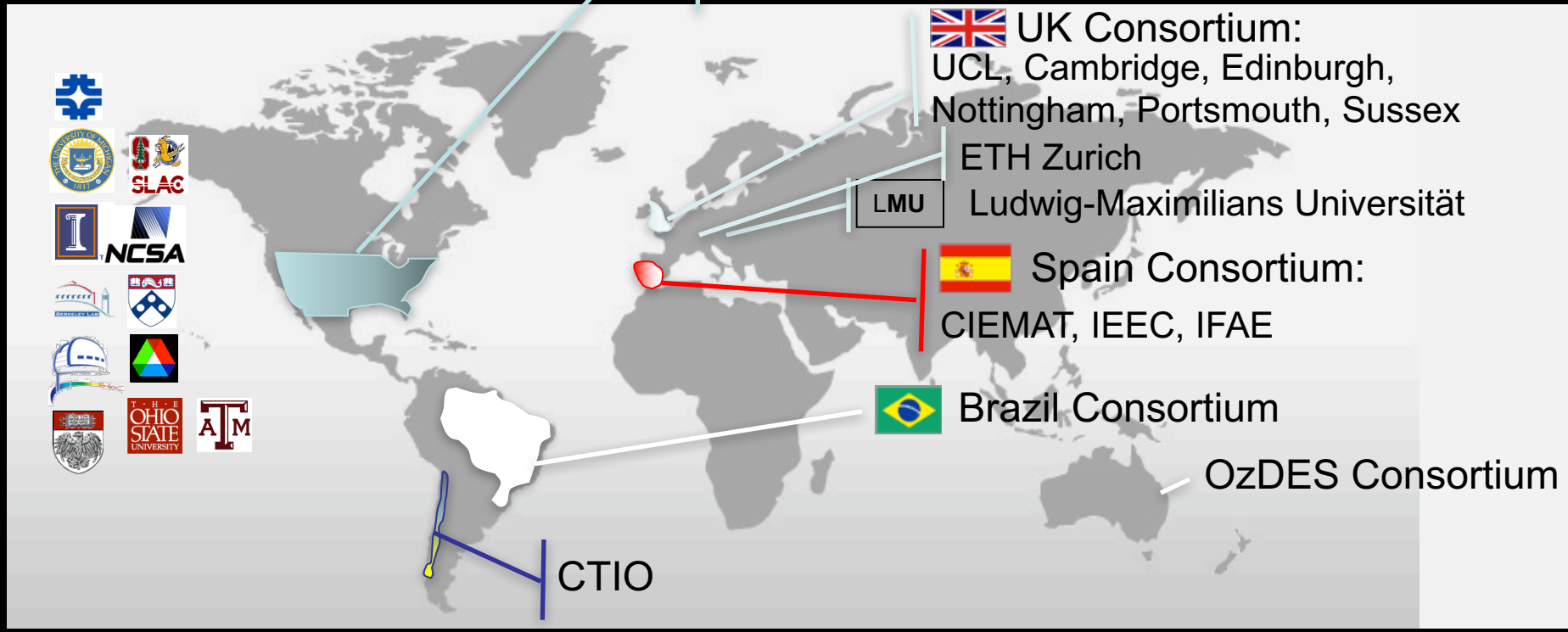
This talk:

1) Overview on DES Y1 cosmology results
2) Dark Matter projects/ideas (ongoing, future)

Dark Energy Survey Collaboration

~400 scientists;
US support from
DOE & NSF

Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Lab, Ohio State University, Santa-Cruz/SLAC/Stanford, Texas A&M



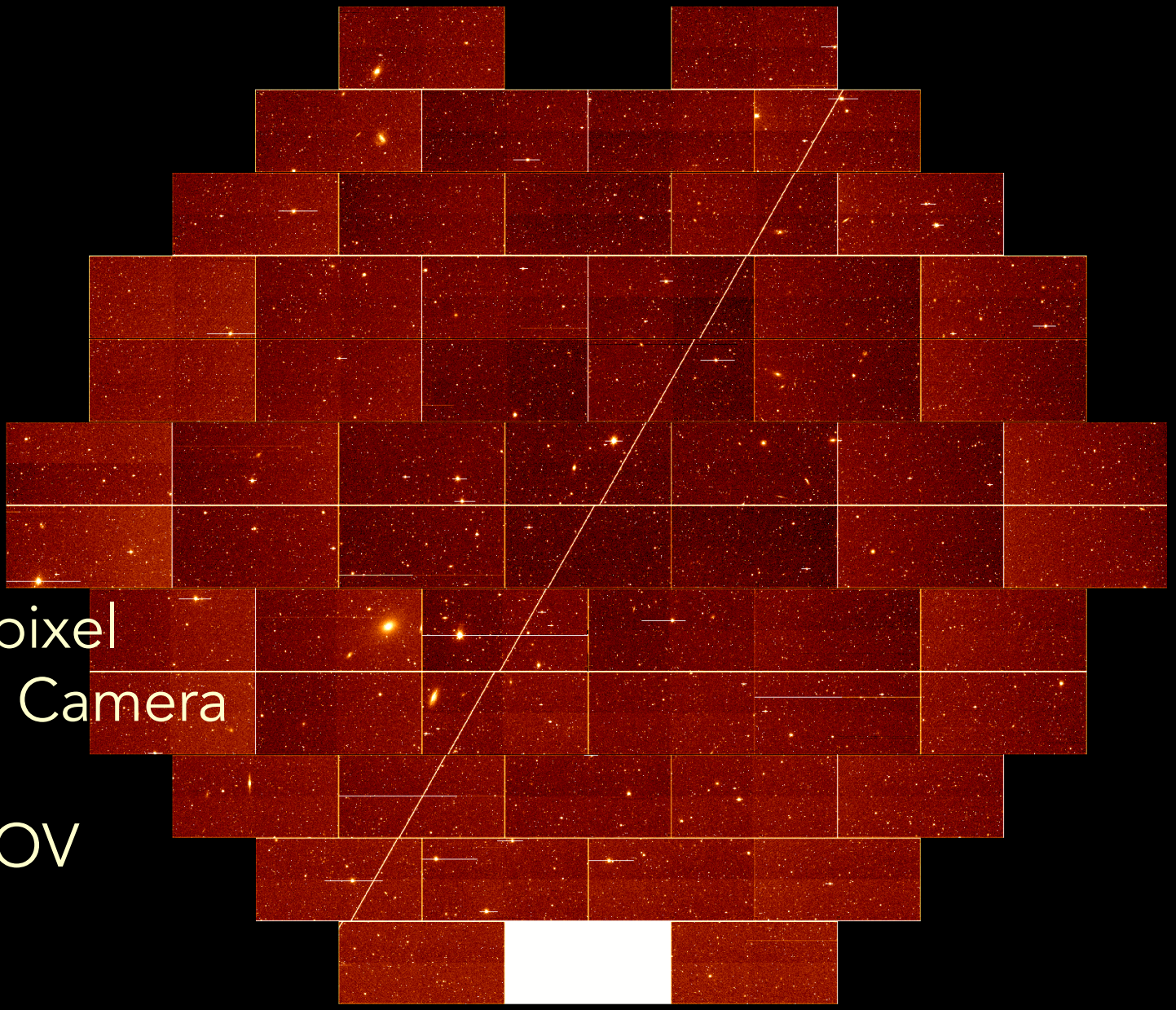
Dark Energy Survey Collaboration

DARK ENERGY SURVEY

Raw DECam Image

570-Million pixel Dark Energy Camera

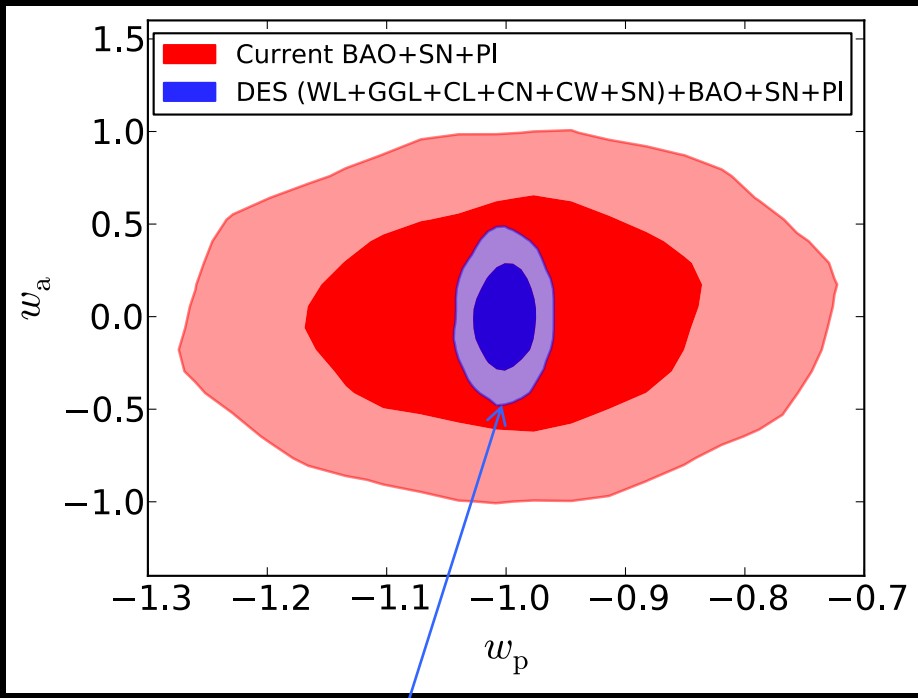
3 sq. deg. FOV



DES Cosmology Probes

- Galaxy Clusters
  - Tens of thousands of clusters to z~1
- Weak Lensing
  - Shape measurements of ~200 million galaxies
- Galaxy Clustering
  - ~300 million galaxies to z ~ 1
- Supernovae
  - 3000 well-sampled SNe Ia to z ~1
- Strong Lensing
  - ~30 QSO lens time delays
  - Arcs with multiple source redshifts
- Cross-correlations
  - Galaxies, WL x CMB lensing

$$w(a) = w_0 + w_a(1 - a(t))$$



DES Y5 forecast

T. Eifler, E. Krause

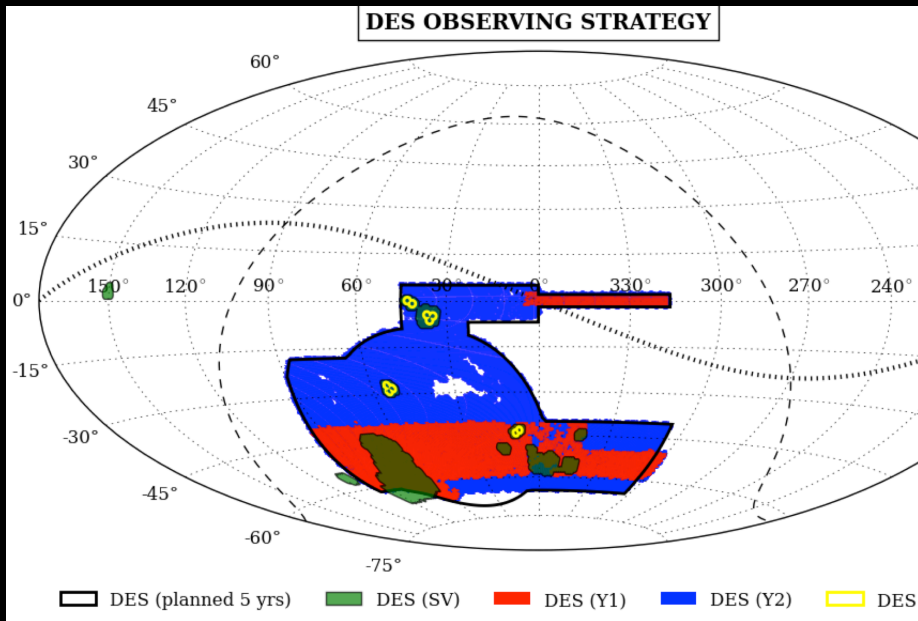
DES Survey Progress

SV (150 sqdeg, full depth)
science done, catalogs public

Y1 (1321 sqdeg, 40% depth)
data processed, cosmology results

Y3 (5000 sqdeg, 50% depth)
data processed, vetting catalogs

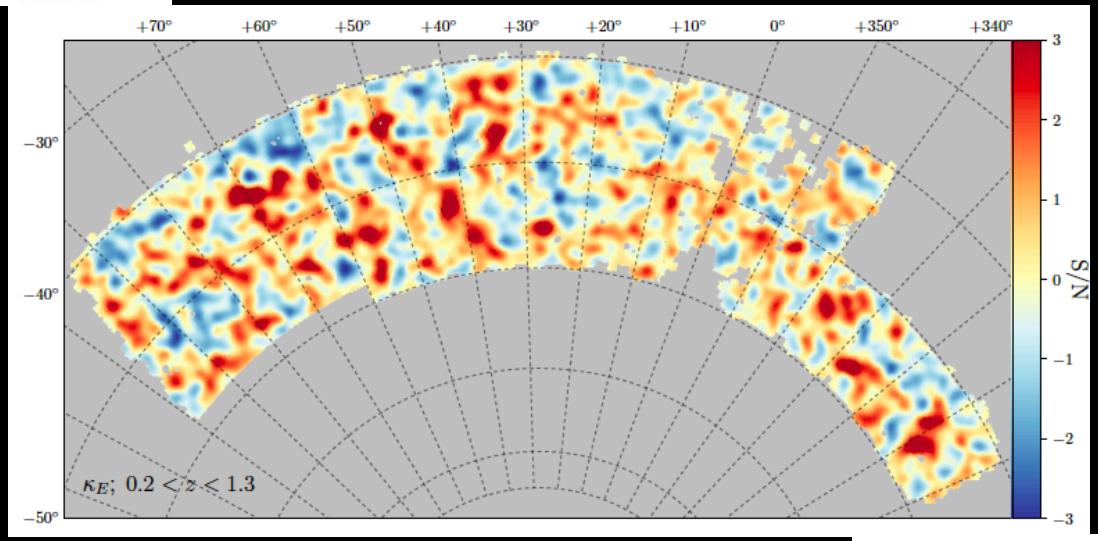
Y5 observations ongoing



	Area	Exposure time (s) (per visit for SNe) Specified median PSF FWHM (arcsec)					Dithering	Cadence
	(deg²)	g	r	i	z	Y		
Wide	5000	10x90 - 10x90 0.9"	10x90 - 10x90 0.9"	10x90 - 10x90 0.9"	10x90 - 10x90 0.9"	10x45 - 10x45 -	10 fully interlaced tilings	10 tilings over 5 years
SN Shallow	24	1x175 -	1x150 -	1x200 -	2x200 -	-	Minimal dithers	Seeing >1.1" or 7 days since last observed
SN Deep	6	3x200 -	3x400 -	5x360 -	10x330 -			

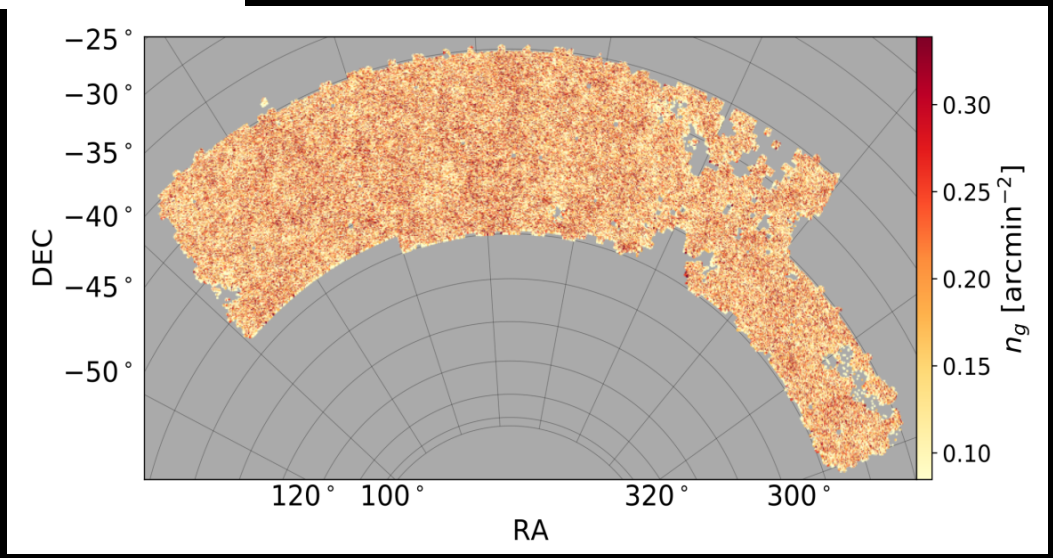
Major El Nino affected Year 3

DES Year 1 Galaxy Samples

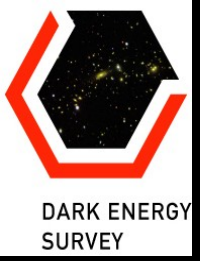


- 26 million source galaxies
- 4 redshift bins
- Sources for cosmic shear & galaxy-galaxy lensing

- 660,000 redMaGiC galaxies with excellent photo-z's
- Measure angular clustering in 5 redshift bins
- Use as lenses for galaxy-galaxy lensing

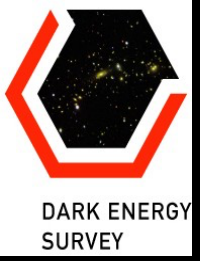


First Year of Data: ~1800 sq. deg. Analyzed 1321 s.d. after cuts



DES Year 1 Cosmology Analysis

- Compare & consistently combine three 2-point correlation function measurements:
  - Angular clustering: autocorrelation of 660,000 luminous red galaxies with excellent photo-z's, in 5 redshift bins
  - Cosmic shear weak lensing: shear-shear correlation functions from 26 million galaxy shapes in 4 redshift bins
  - Galaxy-galaxy lensing: correlate red galaxy positions (foreground lenses) with source galaxy shear



Dark Energy Survey Year 1 Results: Multi-Probe Cosmology: Methodology & Results

E. Krause, T. Eifler, et al. 1706.09359
DES Collaboration (Abbott et al.)

Multi-Probe Methodology

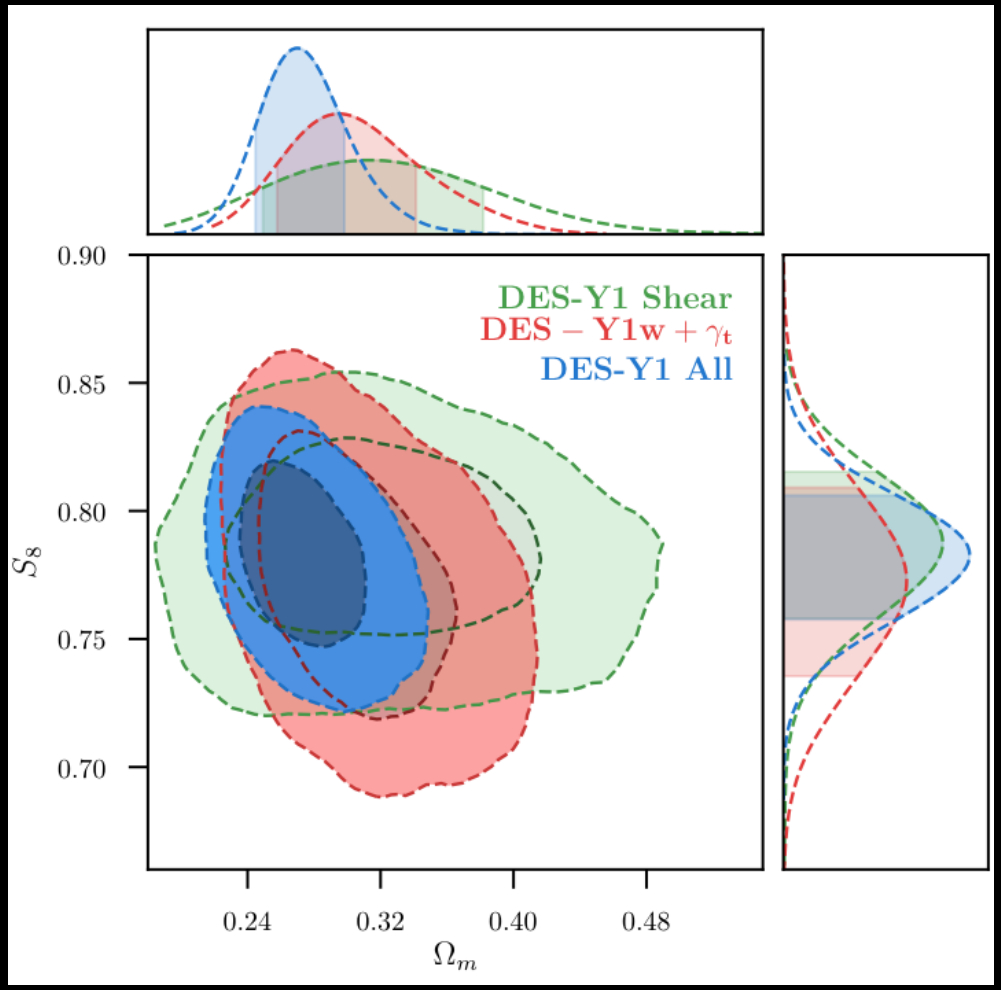
from data vector **D** to parameters **p**

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

- model data vector, incl. relevant systematics
  - implementation details should not contribute to error budget
  - are the systematics parameterizations sufficient for DES-Y1?
- covariance for ~450 data points
- sampler - don't get the last step wrong...

methods paper: validate model + implementation, covariance, sampling

Multi-Probe Constraints: LCDM



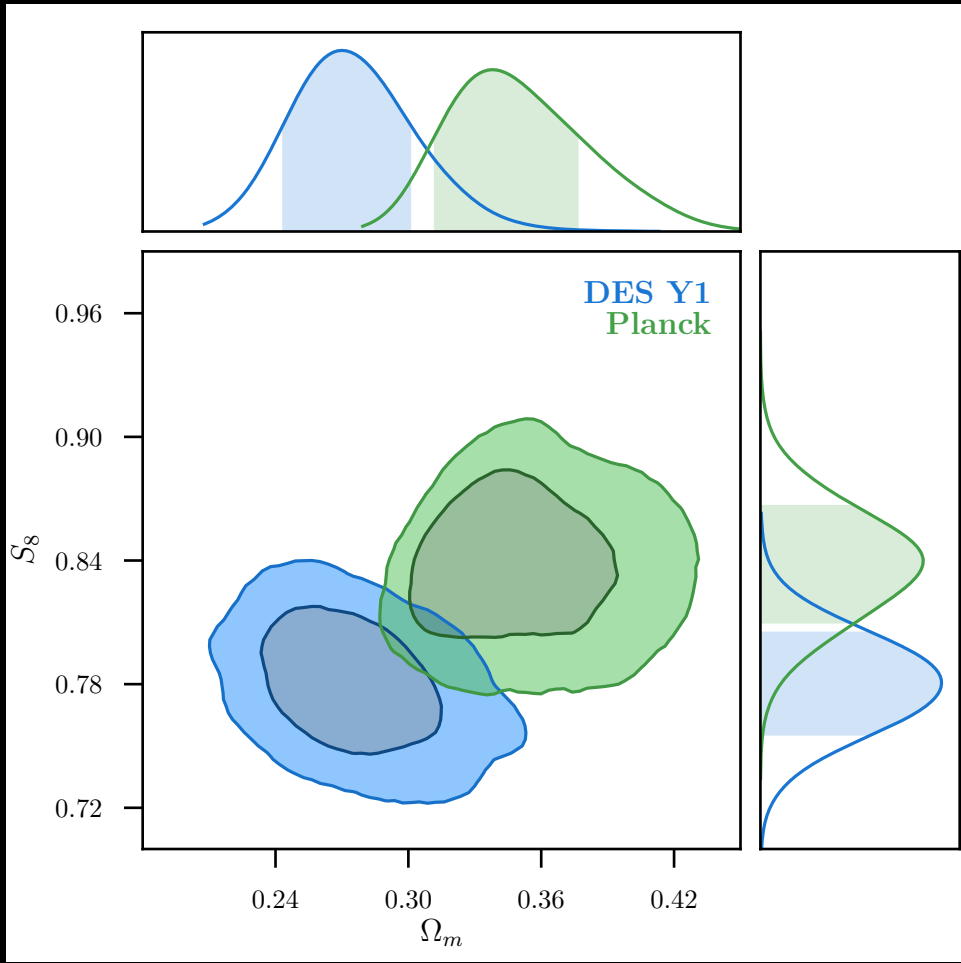
- DES-Y1 Multi-Probe: clear increase in constraining power
- marginalized 4 cosmology parameters, 10 clustering nuisance parameters, and 10 lensing nuisance parameters
- consistent (R = 2.8) cosmology constraints from weak lensing and clustering in configuration space
- joint analysis constraints on astrophysics (intrinsic alignment of galaxies)

$$A_{\rm IA} = 0.50^{+0.32}_{-0.38} \quad (95\%\,{\rm CL})$$

DES Collaboration 2017

Comparison of DES 3x2 with Planck CMB: low-z vs high-z in ΛCDM

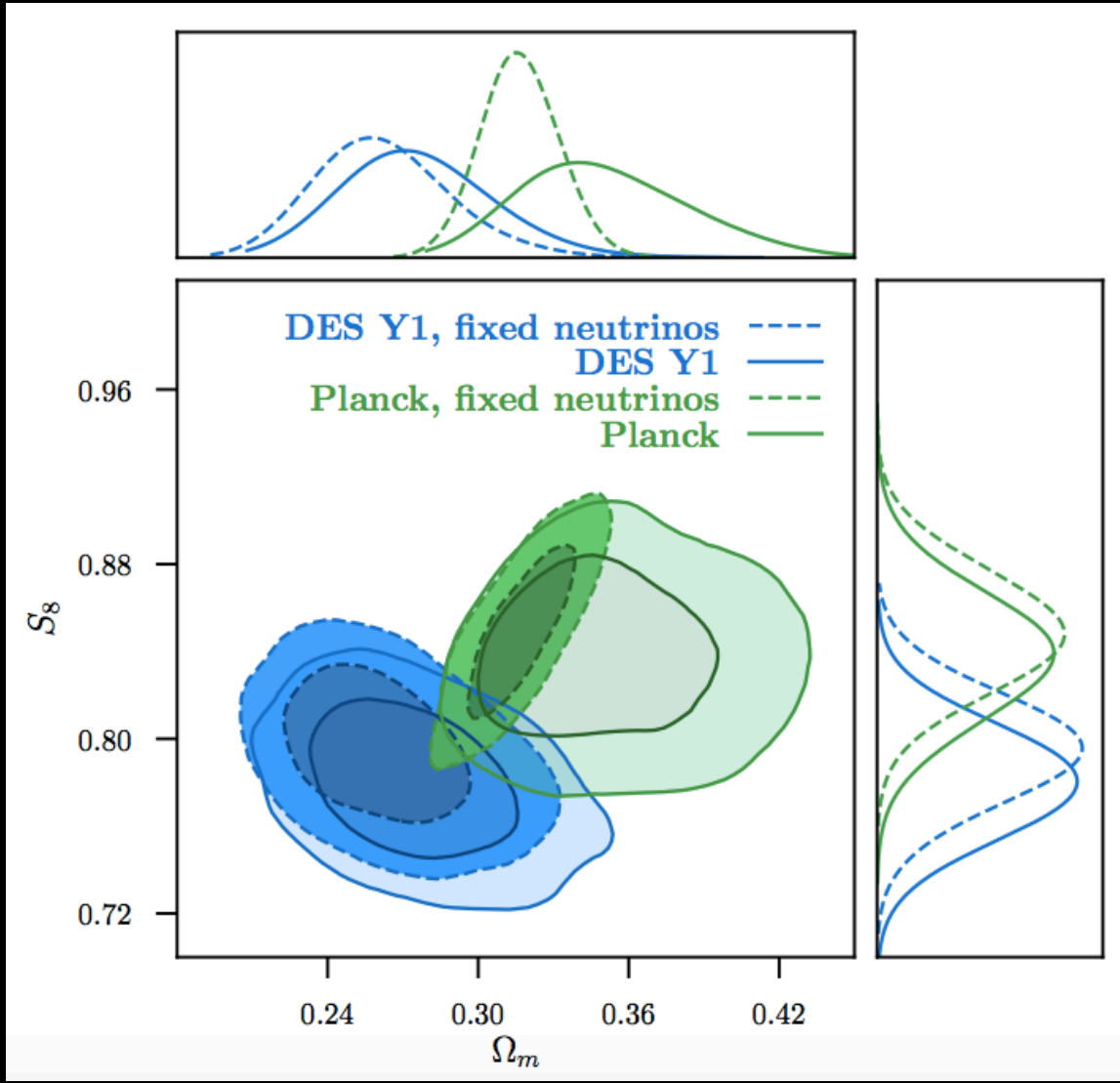
- DES and Planck (here without CMB lensing) constrain S_8 and Ω_m with comparable strength
- Differ in central values by >1σ, in same direction as for KIDS
- Bayes factor R = 4.2 indicates consistency in ΛCDM



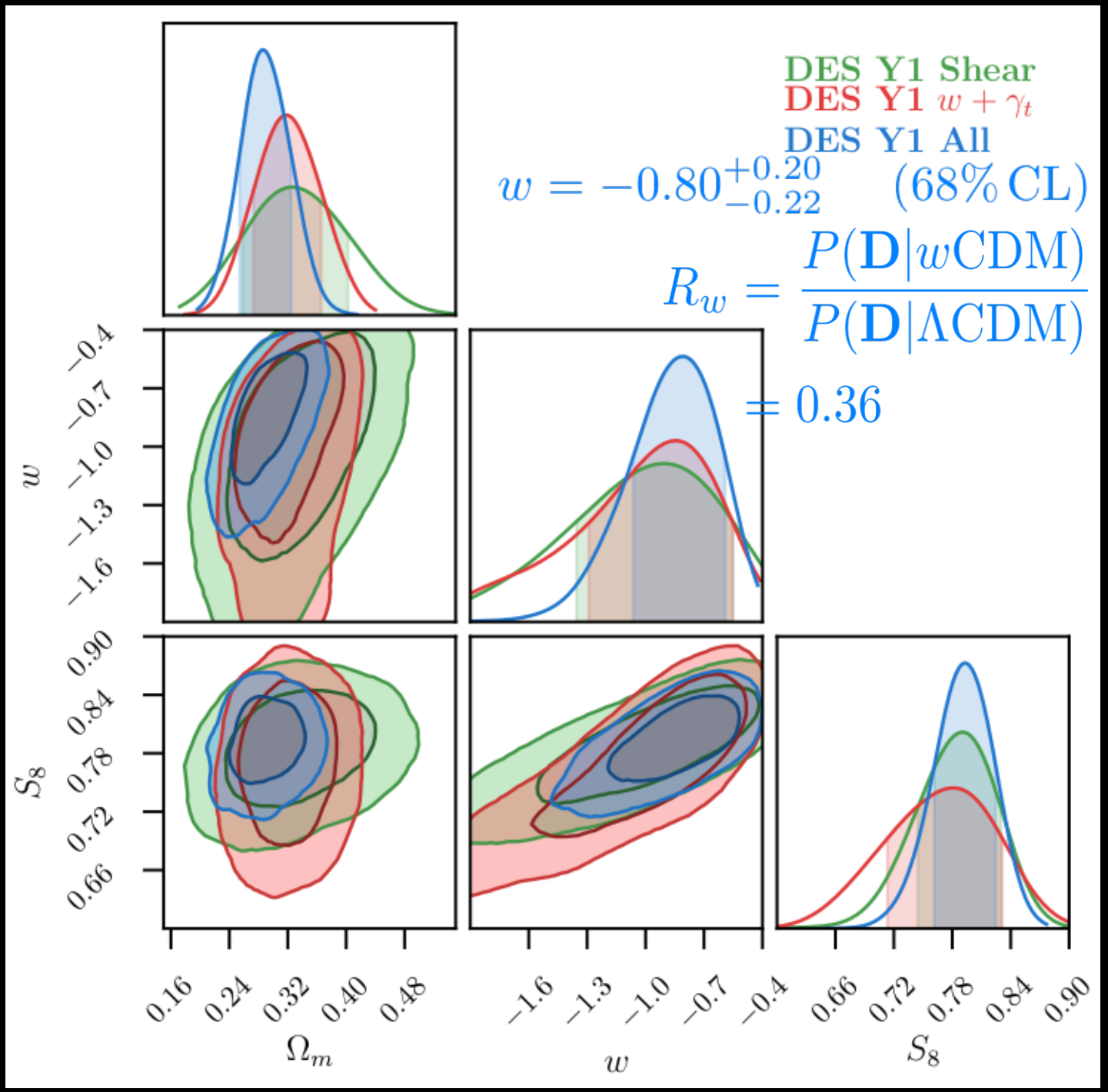
What if we fix neutrino mass?

- Hold neutrino mass at 0.06 eV (lower limit from oscillation experiments)
- DES 3x2 still consistent with Planck in LCDM

$S_8 = 0.797 \pm 0.022$	DES Y1
$= 0.801 \pm 0.032$	KiDS+GAMA [62]
$= 0.742 \pm 0.035$	KiDS+2dFLenS+BOSS



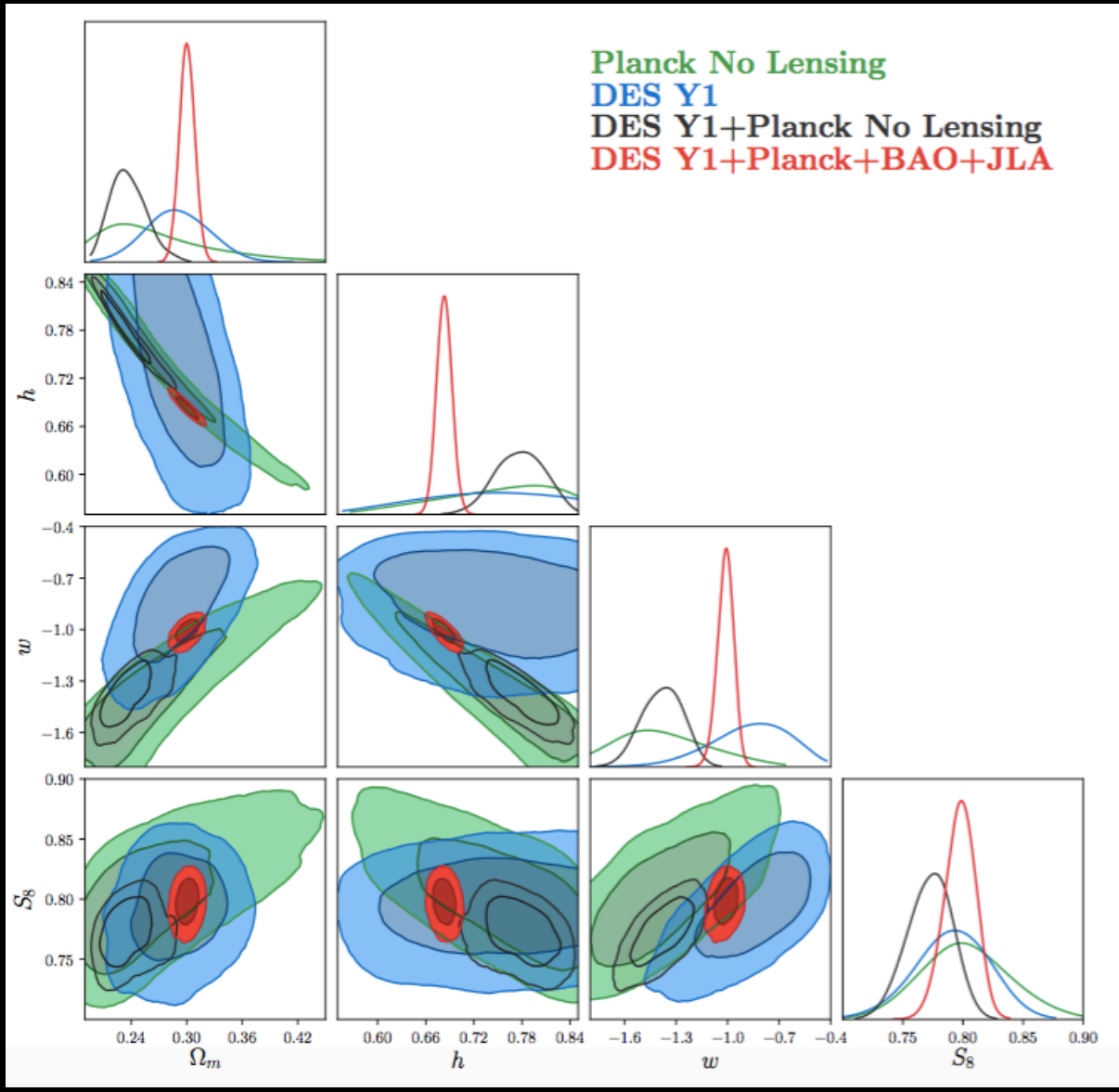
DARK ENERGY SURVEY

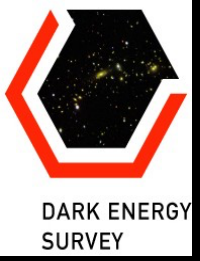


Combine multiple data sets: wCDM

- DES 3x2 consistent with Planck (now including CMB lensing)+BAO+JLA in wCDM
- Combine to achieve very stringent parameter constraints:

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

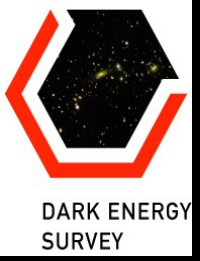




The Future

- Y3 analysis is ongoing, 1300 deg^2 increased to 5000 deg^2 and slight increase in depth
- Inclusion of galaxy clusters and SN information
- Model extensions to modified gravity, time-dependent eos
- Inclusion of SPT CMB Lensing ongoing
- ACT MOU, and eBOSS MOU exists for further extensions
- Please let me know if you have ideas to test DM scenarios, external collaborator status us easy to get

Some ideas... ->



Dark Energy Survey Year 1 Results:
Galaxy-Galaxy Lensing

Judit Prat, Carles Sánchez, et al.
(DES Collaboration)

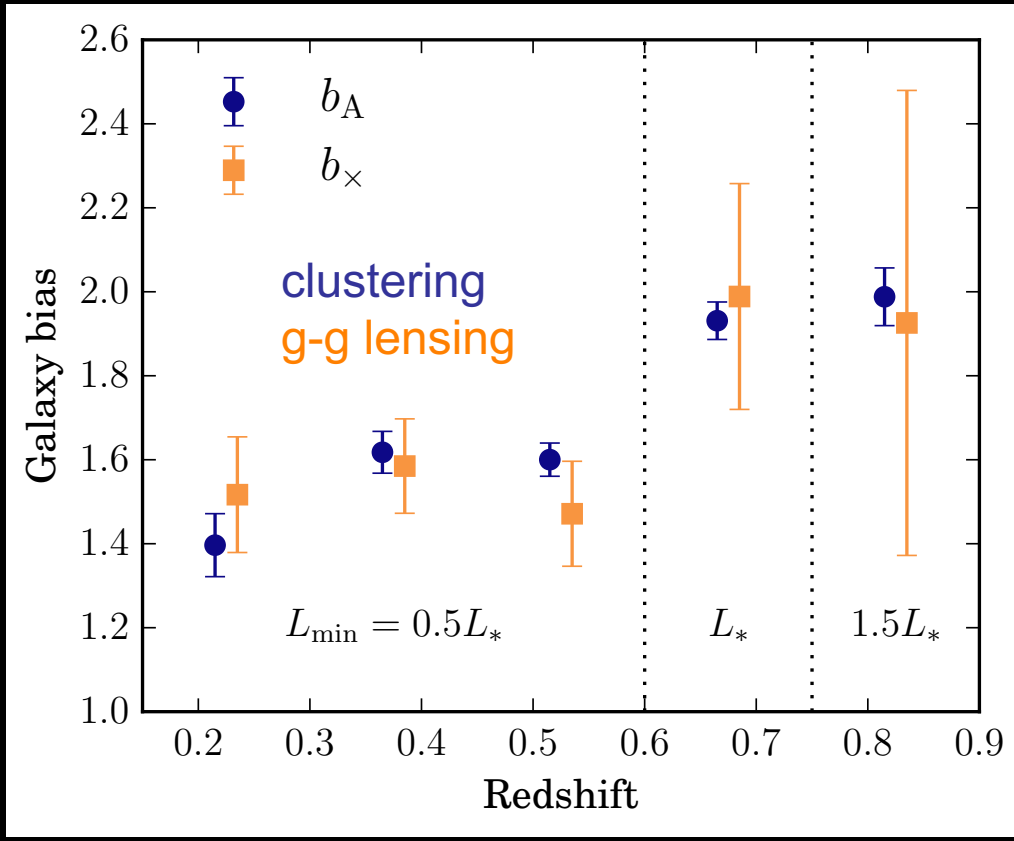
redMaGiC galaxy bias

DES Y1 cosmology analysis assumes the identical linear bias for galaxy clustering and galaxy-galaxy lensing

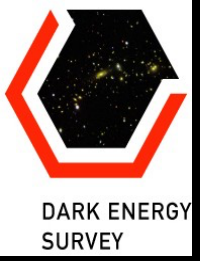
At fixed cosmology, measure galaxy bias separately for both probes.

(exclude small scales)

Find no evidence of r≠1



Idea 1: Explore galaxy bias as a function of scale, redshift, galaxy sample

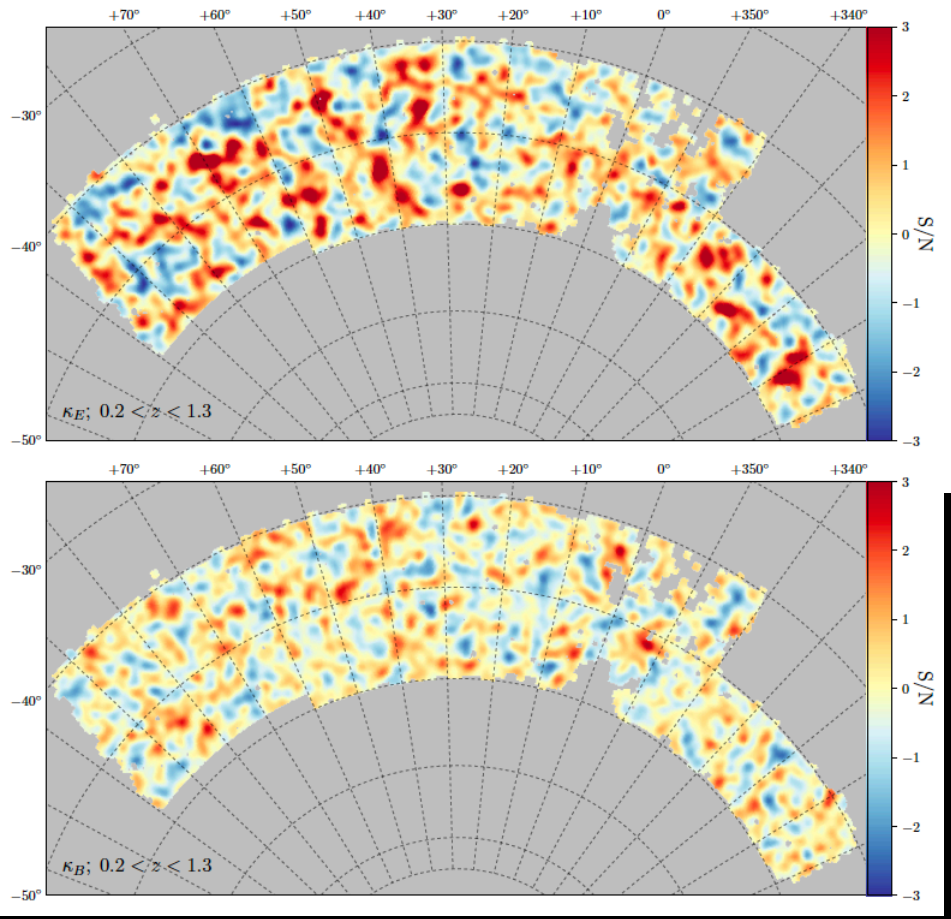


Dark Energy Survey Year 1 Results: Weak Lensing Mass Map

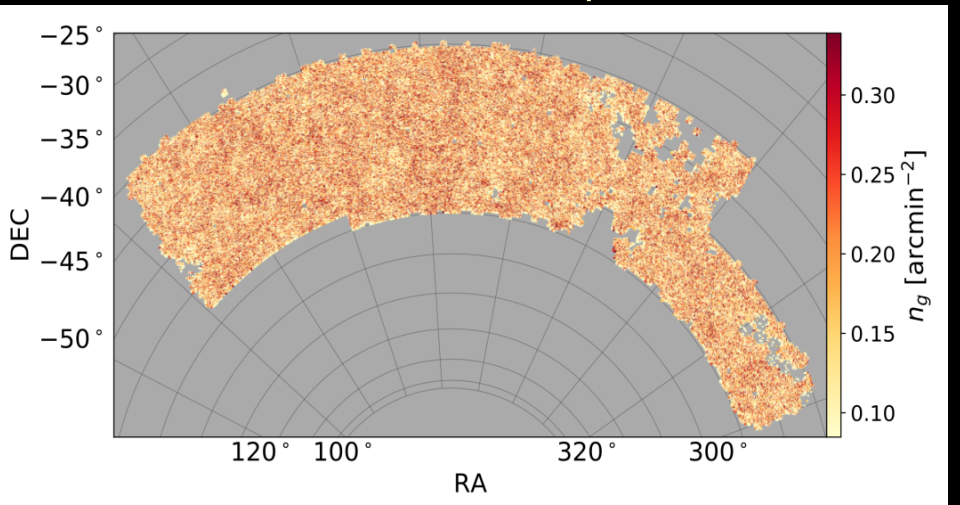
Chihway Chang et al 2017
(DES Collaboration)

Matter Maps

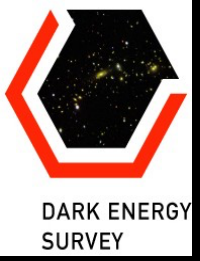
(Dark) Matter Map from metcalibration catalog



Galaxy density map from redMaGiC sample



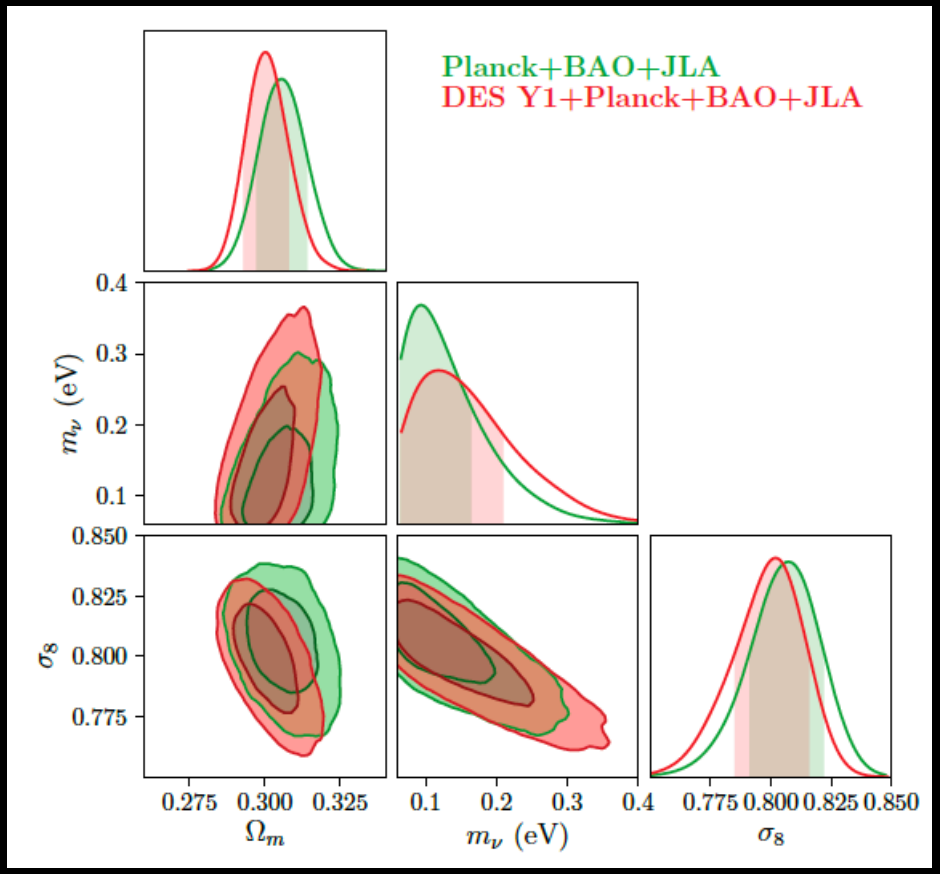
Idea 2: Compare galaxy density and (dark) matter maps for different tracers



Dark Energy Survey Year 1 Results: Massive Neutrinos

The DES collaborations 2017

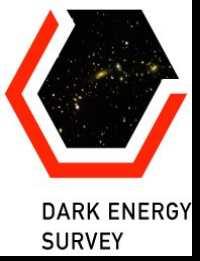
Massive Neutrinos



DES clustering amplitude is lower compared to LCDM prediction from Planck

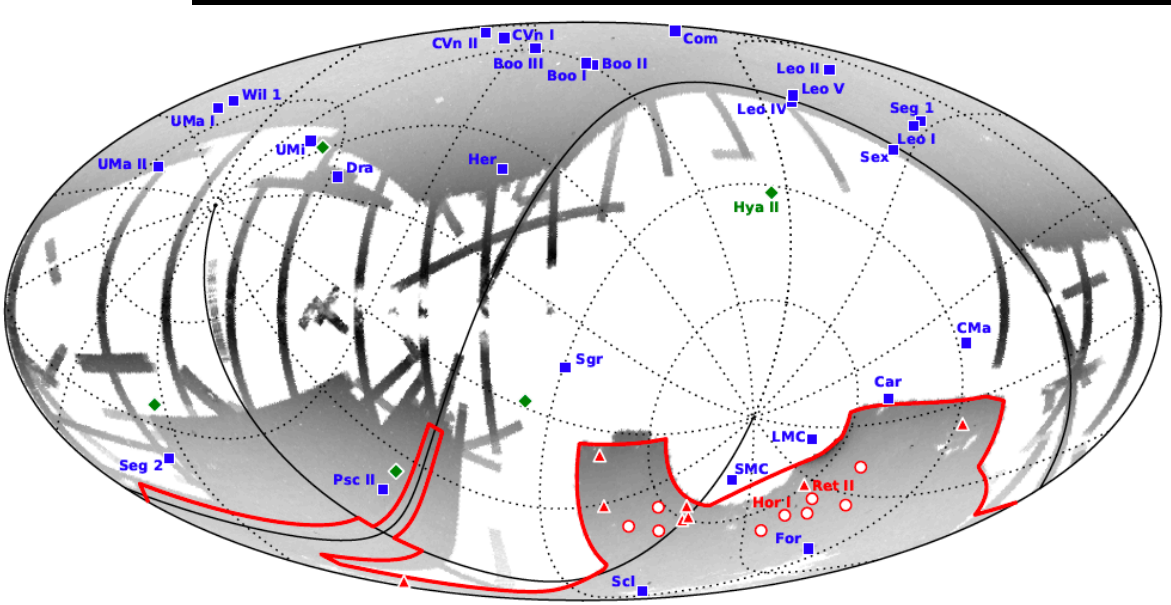
- decrease S_8
- decrease Ω_m
- inecrease sum of neutrino mass
- assume different dark matter species/properties

Idea 3: Implement your dark matter model (interactions, scale/redshift dependence, particle mass, and rerun the analysis, evtl including bi/trispectrum measurements)



Dark Energy Survey Dwarf Galaxies
Nearby dark matter laboratories
Substructure “Problem”

Dwarf Galaxies



8 new dwarf galaxies detected in DES Y1 data

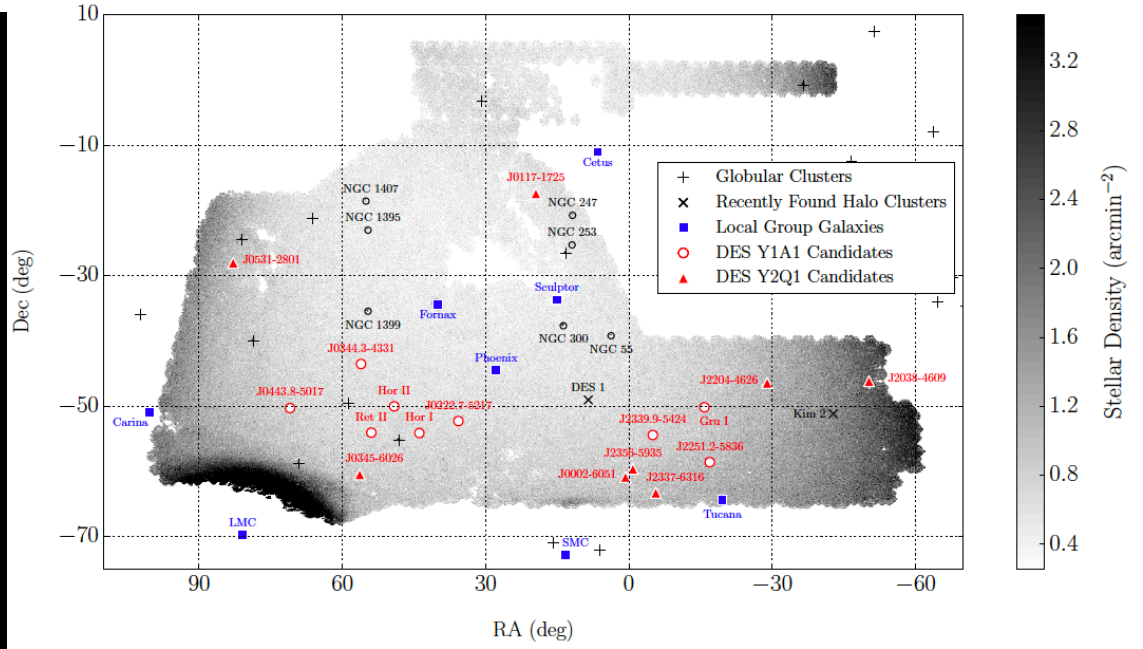
Several more candidates in Y2

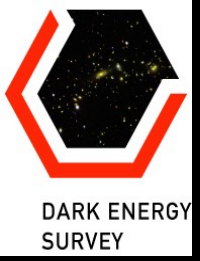
More expected as survey depth increases Y3-5

Ideal laboratories for DM annihilation studies

- Albert et al '17
- Bechtol et al '15
- Drlica-Wagner et al '15

Milky Way Halo models: e.g., Horiuchi et al '15





Summary

- Y3 analysis is ongoing, factor 4 increase in area, 1.2 in depth
- Year 5 observing is ongoing and analysis will happen next year
- Even more increase in constraining power will come from new methods to combine cosmological probes (clusters!, SN, CMB lensing)

- Think about how to test predictions of YOUR favorite DM model with DES data (happy to help with the implementation)